TRIAL & RE-TRIAL

THE EVOLUTION OF IRRIGATION MODERNISATION IN NWFP, PAKISTAN

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The Evolution of Irrigation Modernisation in NWFP, Pakistan

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AOSM	Adjustable Orifice Semi Module (a modified APM)
APM	Adjustable Proportional Module (Crump's Orifice outlet)
ASCE	American Society of Civil Engineers
AVIO	Automated (hydraulic) flow and discharge regulator for orifices
AVIS	Automated (hydraulic) flow and discharge regulator for open channels
AWB	Area Water Board
CBIO	Crop Based Irrigation Operations (project)
CCA	Culturable Command Area
CDA	Canal and Drainage Act of 1873
CIDA	Canadian International Development Agency
CRBC	Chasma Right Bank Canal system
CROPWAT	FAO computer programme for calculation of crop water requirements
CSU	Colorado State University
CV	Coefficient of Variation
DCL	Deputy Collector (Office of Revenue Department linked to Irrigation)
DIPHE	Department of Irrigation and Public Health and Environment
DoA	Department of Agriculture
DPR	Delivery Performance Ratio
DPS	Designed Physical System
DUFLOW	Hydraulic simulation programme developed by IHE
ETc	Evapotranspiration coefficient for particular crop
ETo	Reference crop Evapotranspiration
FAO	Food and Agricultural Organisation of the United Nations
FO	Farmer Organisation(s) (management organisation for secondary level)
FPP	Final Project Plan
FSD	Full Supply Delivery
FSL	Full Supply Level
FSQ	Full Supply Discharge
GCA	Gross Command Area
GoP	Government of Pakistan
HYV	High Yielding Variety
IBIS	Indus Basin Irrigation System
IBP	Indus Basin Project
ICID	International Commission for Irrigation and Drainage
ID	Irrigation Department (officially DIPHE)
IIMI	International Irrigation Management Institute (now IWMI)
IMIS	Irrigation Management Information System
IMT	Irrigation Management Transfer
IWAA	Indus Water Apportionment Act
IWMI	International Water Management Institute
IWT	Indus Water Treaty

Kc	Crop coefficient, for calculation of ETc
KIF	Kharif Intensity Factor
KRC	Kabul River Canal system
LCC	Lower Chenab Canal system
LSC	Lower Swat Canal system
LJC	Lower Jhelum Canal system
MAF	Million Acre Foot (equals to 1.23 cubic kilometres)
MIS	Management Information System
MMH	Minimum Modular Head
NDP	National Drainage Programme
NWFP	North West Frontier Province
OFWMP	On-Farm Water Management Project
O&M	Operation and Maintenance
PC-1	Project Content (Formal project document containing project definition and budget)
PCC	Project Coordination Committee
PHLC	Pehur High Level Canal (system or project)
PIDA	Provincial Irrigation & Drainage Authority
PIM	Participative Irrigation Management
PU	Public Utility
PWD	Public Works Department
RD	Reduced Distance (distance from head, or intake of canal, usually in feet)
RIF	Rabi Intensity Factor
RWS	Relative Water Supply
SCARP	Salinity Control and Reclamation Project
SIAP /ADC	Swabi Irrigated Agriculture Project /Agricultural Development Component
SIC	Hydraulic simulation programme developed by CEMAGREF
SSC	Swabi SCARP Consultants
SDO	Sub-Divisional Officer (office of ID)
SE	Superintending Officer (office of ID)
SYM	Sheikh Yousaf Minor
ToR	Terms of Reference
TVA	Tennessee Valley Authority
UBDC	Upper Bari Doab Canal
USBR	United States Bureau of Reclamation
USC	Upper Swat Canal system
WAMA	Water Management Project and Department at Agricultural University of Peshawar
WAPDA	Water and Power Development Authority
WUA	Water Users Association(s) (management organisation for tertiary level)
XEN	Executive Officer (office of ID)

GLOSSARY

Abiana	Irrigation Water Fee, charged on irrigated and matured crop
Acre	Imperial measure equalling 0.4 hectares
Amir Parwas	'Defenders of the rich', notion for colonial officers that preferred to administer through the use of 'local customs' with cooperation and favouring of local chieftains and elites.
Branch Canal	Large off-taking canal from main canal (i.e. > 100 cusecs)
Chak	Tertiary Unit
Chakbandi	Process at start of 20th century to define the size and boundaries of tertiary units and subsequently the delivery rate through the outlet.
Colaba	19th century pipe outlet of unitary orifice area
Cusec	Imperial measure, 'cubic feet per second', equalling 28.3 l/s
Distributary	Secondary level canal
Gur	Home processed sugarcane (i.e. dried malasse)
Gharib Parwas	'Protectors of the poor', notion for those colonial officers that preferred to administer through justice and equitable laws.
H-Register	Register for monitoring of the hydraulic head (H) over each outlet.
Kacha	Informal or Non-proper (i.e. kacha road = dirt road)
Kharif	Summer and monsoon season (i.e. May - September)
Khel	Extended family unit within the tribal entity of Pukhtoon Culture
Irrigation Duty	Measure of Delivery Rate defined as acres per cusec per growing season
Lambardar	Village water fee collector (assistant to Patwari)
Minor Canal	Small Distributary Canal (i.e. > 50 cusecs)
Mogha	Outlet structure
Nakka	Farm Inlet structure
Normal Supply	Full Supply Level or Discharge
Nullah	Natural drainage channel, stream bed.
Outlet	Water control structure that regulates the water supply from secondary canal to tertiary unit
Patwari	Office of the Revenue Department responsible for field assessment of water fees and crops.
Pucca	Formal or 'proper' (i.e. Pucca Road = Metal Road)
Pucca Nakka	OFWM pre-fabricated farm inlet structure. Consisting of a small division box in the watercourse, with on two to three sides an inclined concrete slab with a hole. Attached by chain is a concrete lid, that fits exactly into the hole in the inclined slabs.
Rabi	Winter and cold season (i.e. October - April)
Rajbula	Anglo-Hindi term in use during 19th century for secondary canal; usually reserved for those canals that were still in private property of water users.
Regime	Canal which in regime, has reached a balance between scoring and silting.
Tatils	(Or Tatiling) Rotation among outlet structures within a distributary canal
Tocavi	Loans that were provided by the colonial administration during the 19th century for agricultural development by water users.
Warabandi	Water allocation and distribution roster. Defines each water user's irrigation turn with an accuracy of minutes within a tertiary unit, based on the land holding. Usually each plot or owner receives one irrigation turn per week.
Water Allowance	Water Delivery Rate at the outlet or canal head. Usually defined in cusecs per 1000 acres.
Zilladar	Office of Revenue Department. Supervisor of Patwari and Assistant to Deputy Collector.

ACKNOWLEDGEMENTS

"Trial & Re-Trial"stands as much for the subject of irrigation modernisation, as for the process of completing this thesis. Gaining understanding of the realities and dynamics of water management in the field is an iterative process of observing, questioning and explaining the practices one encounters, until the moment inevitably comes that a new insight, a stance remark or a loose end pups up, and urges you to go through the process again. The same holds of course for the writing of the thesis itself, which goes through various drafts. The first was nearly always fun and exciting to do, while the latter seemed at times a tedious process to endure. In both cases, however, each completion of re-trial cycle is a satisfying stage to reach.

Although the writing of this thesis has been an individual, and sometimes lonely, enterprise, going through the iterative cycles of research and writing has been far from being a lone exercise.

First of all, this research has greatly benefited from my alliance with the Water Management project (WAMA) – a bilateral cooperation project between the Irrigation and Water Engineering group of Wageningen University and the Water Management Department of the Agricultural Universtiy of NWFP, Peshawar, funded by the Dutch Government. My first acquaintance and positive experience with WAMA and water management in NWFP, I gained during an MSc-research conducted together with Flip Wester in the traditional Kabul River Canal system around Peshawar in 1993. In 1995 I was enabled to join WAMA as a research assistance, thanks to funding by KLV. During this period I have been involved in setting up and conducting a research programme in the Lower Swat Canal system, together with the staff and students from WAMA. In March 1996 I obtained an AIO-position with the Irrigation and Water Engineering group in Wageningen. After a spell of six month in Wageningen I returned to Peshawar to join WAMA again till August 1998. Through this alliance with WAMA, and the trust, urging and guidance Hammond Murray-Rust put in me and in the staff of WAMA to go out there into the fields and canals to observe, feel, learn and investigate, I have been able to gain a wealth of experience and insights in both the water management dynamics in NWFP, as in the conducting of field research.

The joint research capacity of WAMA provided a unique opportunity to gain insight in the water management situation in the Peshawar Vale, the issues the irrigation department and water users were coping with in their day to day management strategies, as well as the great flux of change that was propagated by the various modernisation and development projects. It is thanks to the contribution of all the participants in these research programmes and the opportunity to direct two of them in the cases of this research, that has enabled me to take here the wider perspective of the irrigation modernisation programme in NWFP, integrating much of the material and insights gathered collectively at WAMA, in addition to the analysis of historical material, project documentation, design material, literature and the own field interviews and experience.

Many thanks are therefore due to staff of WAMA, which have rendered my experience in Peshawar very pleasant through their great hospitality, and have enabled to collect a wealth of information through the fruits of collaboration: Sultan Muhammed, Riaz Ahmed, Niaz Muhammed, Shakirullah, Siar and Muslehuddin as the committed field staff; Jamal Khan, Zubair Khan, Tahi Sarwar, Nisar Ahmad, Guldaraz, Javaid Tariq, Tahir Shah, Jehangir Khan and Arbab

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During the second phase of writing, discussions with colleagues and my supervisor have helped me to get through this difficult and challenging stage. Thanks are due to Linden Vincent which urged me through three drafts of the thesis in five months, to sharpen up the text. Furthermore discussion held with colleagues have often proved to be of value and stimulating. In particular I like to thank: Flip Wester, Margreet Zwarteveen, Alex Bolding, Wim Kloezen, Joost Oorthuizen and Bert de Jager.

I also want to thank the secretaries of our group, Trudy Freriks and Gerda de Fauw, who were always willing to grant a helping hand in handling administrative and office affairs, and avert imminent crises such as getting the final draft out of the printer.

Furthermore I want to express here my appreciation of our small library at the “Nieuwlanden”, which turned out to hold, against all odds, such jewels of British irrigation engineering as Crump’s 1922 paper on moduling of irrigation channels, en de Gruyter’s personal and annotated copy of Buckley’s 1920 Irrigation Pocket Book.

From January to June 2002 I spent in Wageningen to give a final spur to the completion of this thesis. I have nearly abused the great hospitality and patience of my dear friends, Flip Wester and Houkje Berger, and Ans Knaap and Piet, Pieter and Aafke van den Boom, who have been so generous to provide me with a home in Wageningen during this period of work and stress. Your company and friendship have been invaluable to me during this period!

Flip Wester deserves furthermore my permanent gratitude, by haven taken care of all the affairs that needed to be taken care of to get this thesis through printing, and which I could not take care of myself here from Rome.

I like to thank my father, Henk van Halsema, for editing the Dutch summary. After several years of writing all professional documents in English, the Dutch summary suddenly turned out to be daunting task.

Finally, I want to thank my wife, Esther Wiegers, for her unfaltering support throughout the work on this thesis, be it in Peshawar, Wageningen or Rome. At last, we can be by ourselves again!

Rome, July 2002

CHAPTER ONE

IRRIGATION SYSTEMS & CONCEPTS OF IRRIGATION MODERNISATION

A CONCEPTUAL INTRODUCTION TO THE THESIS

1.1 INTRODUCTION

Pakistan, with its 14 million hectares under large scale irrigation, has not been deprived of the critical analyses on its irrigation system performance, nor from numerous attempts to tackle them over the years. As Pakistan is still facing a large increase in population and the potentials for irrigation expansion are limited, national as well as international policy makers and donors acknowledge that there is a pressing need for intensification of irrigation production through better performance of the existing systems. The cause of poor performance is seen by many as lying in the age of its systems, as a large part of them still date from British colonial times. Pakistani irrigation has been typified asa textbook example – albeit an impressive one – of old-fashioned, rigid and restricted irrigation that no longer suites the flexible needs of modern agricultural production (*cf*. Plusquellec *et al*; 1994). As a response, different attempts have and are being made to improve the performance of the large scale irrigation systems, particularly in the North West Frontier Province (NWFP), through an irrigation modernisation programme.

This study examines the attempts undertaken over the past twenty years in the NWFP to develop and introduce 'modern' irrigation water delivery services in large scale government run irrigation systems. The general objective of the modernisation is to attain higher degrees of productivity and efficiency in water use to meet the demands of an ever increasing population (120 million with an annual growth rate of 2.60 per cent), in a country where large scale irrigation accounts for 67 percent of the total agricultural, and 78 percent of the irrigated, area.

To acquaint the reader with some of the transformations in NWFP, I first take you on a canal safari through two of the systems that are studied in this thesis. By travelling through the scenery of large scale canal irrigation systems that are being subjected to a transformation to fulfill the needs of our modern times, after 100 and 80 years of intensive use, we can reflect on the concerns, dilemmas and paradoxes confronted in the development of modern irrigation, and which form the subject of this thesis.

A Canal Safari

Standing on the Malakand Pass facing south on a bright and sunny day, one has a beautiful view of the green plains of the Peshawar vale. Closing off one's mind to the deafening noises of the intense traffic, the thousands of green fields covering the vale provide a serene picture of a pleasant and fruitful landscape. The eye is immediately caught by the ash gray stream of water that appears out of the mountain reach underneath your feet and gently cascades down into the vale. At each drop the turbulent water stream is caught in the glistering light of the sun, producing white bands that intersect the gray line cutting through the landscape. This is a man made stream that diverts the waters from the Swat river into the Peshawar vale, and has made it possible to transform the arid waste land of the plains into a green, populated and productive rural area. This stone pitched channel of the Upper Swat Canal irrigation system is a monument of hydraulic engineering to the use of irrigation by the British colonial state as a means, not only to transform a landscape, but to give shape to an administrable rural community. This irrigation system was specifically built in 1914 to induce the wandering tribes of Pashtoon warriors and pastoralists to settle into the quiet and peaceful lives of agriculturalists. That 80 years later the green glow of the vale and the glistening foam of the water still catch the eye, seems an attestation of the benefits that irrigation can bring to society, as well as of the skills of engineers to realise such a transformation.

Driving back to Peshawar, we have an excellent opportunity to cut across this agricultural plain to take a closer look at the canal irrigation system that has sustained this impressive transformation over such an extended period. Many of the roads cutting across the vale are placed on the embankments alongside the irrigation canals, while the numerous potholes and buffalo carts force us to take a leisurely pace and a good look around.

Turning right at the bifurcation at the end of the stone pitched channel at Dargai, we take the canal road heading west along the Abazai branch of the Upper Swat Canal system. After a short while our pace is suddenly brought to a virtual halt, not by the usual vagaries that accompany rural travel, but by the frantic activity of construction. Workers are busy cementing the sides of the canal, while others are painstakingly taking out bridges and drop structures of high quality masonry work that still stand firm after all those years. At yet another location, we can see what will come in place of the khaki yellow of the natural stones and the deep red of the bricks. Rusted wires protrude out of concrete encases, and the old chutes within which the water used to be contained over a drop are replaced by steep slopes on which rows of concrete blocks are placed, as a blunted and inclined fakir bed, to break the force of the water. What is going on here? The serenity of our green and fruitful landscape is disrupted. Will our contemplation on the benefits of irrigation turn out to be misguided? Or did we simply take a wrong turn in our voyage?

With the anxiety of a disillusioned tourist we make inquiries about the purpose of all these construction activities. Quickly we are reassured. Irrigation is still considered beneficial, but these new times ask for new water delivery services, and most of all, the growing demands for water and food require that ever higher degrees of efficiency and productivity are attained in irrigation. The Upper Swat Canal system is simply being remodelled to accommodate these new demands on irrigation made by present day society.

We continue our journey and turn left to take a road heading southwards along one of the minor distributary canals taking off from the Abazai branch. With awakened curiosity we peruse the remodelling activities going on here. Pre-fabricated concrete canal sections of parabolic shape are being laid out and cemented together, and concrete slabs are put together to form an outlet to divert the water to the multiple water users of one tertiary unit. Bright blue billboards draw our attention to the dates and other specifications on which the water users have been organised to form an association, and completed the improvements of their watercourses with the assistance of a project and the Swiss government. All seems well geared towards accommodating the new increases in water flows and establishment of the higher efficiency and productivity of water use.

Driving on towards Peshawar we pass the town of Mardan and enter the command area of the Lower Swat Canal system – another old British irrigation system that has been remodelled a few years earlier to enable the delivery of water according to the criteria of our time. Struck by the monotony of the endless cultivation of sugarcane, we halt at the tail end of a small minor distributary to take a closer look. One of the first things we take a look at, is one of the enormous drainage canals that cut four to five metres deep through the terrain to dispose of drainage effluent. Two drainage pipes appear on the right bank of the canal at a depth of three metres that both discharge an abundant flow of water. Slightly amazed by such apparent abundance of water, we stroll on to the minor itself. At the tail we encounter an unusual situation; just downstream of the last outlet structure the neatly lined watercourse has been cut on its right bank, where part of the irrigation water is flowing out of the watercourse. Following the course of this ‘water loss’ through a earthen ditch, we find that the water is diverted straight into a surface drain. Pursuing our way upstream along the minor, we see that all outlets are gated; a new phenomenon in Pakistan. The gates, however, are completely encased, and not even the spindle is visible. It is thus difficult to determine how far the gates are opened, nor can we discern any measuring devices for up- and downstream water levels and gate openings, with which the flow through the outlet can be determined and regulated. It actually looks as if the gates are hardly ever adjusted, but are simply set at a fixed opening; an observation that is confirmed at another outlet that is closed, not by means of the gate but by closing off the opening with earth filled bags.

Bewildered by the apparent affluence of water we encountered in an area where water was traditionally valued as a scarce and valuable resource, we pensively head back to the car. We ask ourselves what a modern water delivery service should entail in the present day. That an increase in water supply can be instrumental in increasing agricultural production, we can appreciate. But surely, the ever increasing demands on water on the wider scale of the river basin and the nation would also demand for some sparing and efficient use of such a finite resource? Besides, what are all these gates on the outlets for when they are not used, and drainage is used as a means to regulate water use to match crop water requirements?

Back on the road to Peshawar we cross one of the large distributary canals of the Lower Swat Canal, when we spot a number of big concrete structures littered around the canal banks. From the green and black scribbles that cover these larger than man structures, it is clear that they have lain here for quite a while, and are used as public notice boards or out-lets of political propaganda. Closer inspection reveals that these are indeed outlets, yet those intended for the regulation of irrigation water. These massive pre-fabricated concrete structures, that were introduced to hold regulation gates, never got installed and instead now adorn the landscape. The old original outlets are indeed still in place, where the canal water level fills them up to the brim, delivering substantially more water than they were originally intended for.

Not quite sure of what to think of this salient detail of irrigation remodelling, we take the back road to Peshawar. As we pass the sub-divisional office of the Irrigation Department, our mouths slip ajar in astonishment: on a field the size of a cricket ground near one hundred of the pre-fabricated outlet structures stand neatly side by side, row by row, as headstones in a western style graveyard. In sharp contrast with our morning impressions, this seems to be an attestation of how the development of modern irrigation can turn into another white elephant. With burgeoning wariness we ponder over what we have seen happening in the transformation of these canal systems.

Water abundance in a place of traditional scarcity; water delivery mediated by drainage and not flexible delivery now possible through scientific management; experiments in gated water control that have not been widely installed; replacing masonry with concrete; and from agency control to new associations. These are some of the concerns, paradoxes and dilemmas of irrigation modernisation explored in this thesis.

1.2 IRRIGATION AS A PRODUCT OF SCIENTIFIC ENDEAVOURS

As irrigation is as old as human civilisation, and has known enough ups (the pyramids of Egypt) and downs (the downfall of the Mesopotamian civilisation) in its distant past to draw lessons from, one wonders why the modernisation of irrigation services should still be a relevant subject. How difficult can it be, at the end of the day, to water a plant? The watering of plants is, however, strange as it might sound, not the primary concern of large scale government-run irrigation systems.[1] Although it is the obvious purpose an irrigation system should serve, the main objective in large scale (government run) irrigation systems is to manage the water delivery in its allocation, scheduling and distribution in such a manner, that it provides the possibility to all the water users to water their plants in a fair, adequate and sustained form, without depleting the resource. This has often proven to be an insurmountable task.

The publications on irrigation and water management (this new addition included) are strewn with examples of problems in delivering irrigation water in the right quantities, at the right time, at the right location. In large scale irrigation the ‘tail-end problem’, where huge tracks of agricultural land at the bottom of the receiving end are in a dire state of dilapidation, drought and poverty, has become notorious to the extent that it is almost regarded as endemic. The problems associated with delivering irrigation water in the right quantities, at the right time, and at the right location are thus as old as the road to Rome, and were subjected to a range of analyses in the course of the last two centuries.

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1 For those who already exclaim: typical! No, I do not mean this as an obvious symptom of bureaucratic incompetency.

The 19th and the first half of the 20th century can be characterised as the era of large scale irrigation development under auspices of the state. Spurred by the discourse of scientific and technological positivism and advances in hydraulic engineering, irrigation became a state enterprise, not only as a provider of infrastructure and resources, but also as a means to disclose and plan new territorial and administrative realms of the state (*cf.* Gilmartin; 1994 & 1995, Hedrick; 1988). The development of irrigation by the British colonial state during this period still stands as a prime forerunner, with the Indus-basin as an example of impressive engineering grandeur. Contemporary developments took place in the USA with the development of the West (*cf.* Reisner; 1986, and Worster; 1985), irrigation development in Dutch colonial Indonesia (*cf.* Hofstede, ter & van Santbrink; 1979), and in the south of France and French colonial Africa. Great strides were made during this era in advancing hydraulic science and -engineering, with the primary focus on containing and technically controlling the water flows, and their divisions/distribution, in the expanded network of centrally managed irrigation channels.

From roughly 1950 to 1980, the attention span of the irrigation sector was broadened by the understanding of agro-meteorology and principles of 'watering the plants'.[2] Thanks to Penman's method for the determination of evapotranspiration values on the basis of climatological data – a fruit of his contribution to the warfare at the African front during WWII – the crop water requirements farmers should meet to maximise their yields, became a scientific field that could provide more exactitude in determining how much water was needed when and where. Further impetus was provided by the advances made in understanding photosynthesis and plant breeding, that were fuelled in their development by the Rockefeller and Ford Foundations and the establishment of the CGIAR organisation. In the early 1970s this field took a great flight within the realm of irrigation development with the creation of the CROPWAT model under the auspices of the FAO. Coupled to a model of yield response to water, the meeting of crop water requirements throughout the year and throughout the irrigation command area, with ever increasing accuracy, became the new vogue in the development of large scale irrigation. The irrigation sector focussed mainly on two issues: (i) the assessment and prediction of crop water requirements, and the devising of water scheduling and distribution methods and principles with which those requirements could be matched in water delivery; (ii) the devising of hydraulic control principles and structures with which the required variations in water delivery could be controlled accurately. The challenge it laid itself herein, was to attain ever increasing degrees of efficiency (in water use) and efficacy (in productivity) (*cf.* below). These developments in the irrigation sector naturally engaged into a symbiosis with the Green Revolution of the time, where the newly introduced HYV (high yielding varieties) required timely and adequate supplies of water.

Related to these developments in plant-soil-water relationship was the subsequent increased attention for the water management practices at the tertiary level. Henceforth the farmers' water management practices were studied and reflected against the potential optimums derived from

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[2] Strictly speaking, this was of course not an entirely new field of scientific enterprise, and certainly not as far as irrigation was concerned. The water requirements of crops, and the issue of water use efficiency at the farm and field level, were always taken into account, and deliberated upon, in some form in the development of irrigation (see chapter two). This era is, however, characterised by the new scientific developments in this field, that provided a new impetus to the thinking on what constitutes a 'good' irrigation water delivery service.

the scientific models. Benefits were soon seen to lie in the development of on-farm and tertiary level water management development to raise productivity, by adapting the timing, adequacy and efficiency of the tertiary and on-farm irrigation scheduling and application. (*cf*. Levine; 1977, Wickham; 1985, Chambers; 1988)

During the 1980s the attention span of the irrigation sector further broadened into the realms of water management. It became increasingly clear during this decade that the developments in the previous era, though instrumental in increasing understanding in the relationship between soil, water and plant, the yield response to water, and its requirements for water delivery, did not resolve the traditional problems of water distribution that large scale irrigation systems had to cope with. Notwithstanding the enabling role irrigation had played in bringing about the Green Revolution, this same revolution seemed regularly, in one of those fine contradictions of life, to exacerbate the 'tail-end problem', as those that managed to hook on to the bandwagon of progress increased their water use (and production) at the deprivation of others. The time was ripe to seek improvements in irrigation by addressing management issues, rather than jumping straight into technical amelioration. Realisation that improvements at the tertiary level were also significantly hampered by problems of water management at the main system level, was a logical next step to take (*cf.* Bottrall; 1981a & b, Chambers; 1988).

One developed stream of management thinking was closely linked to the performance framework that emerged in business management during the seventies. With the development of (quantitative) water delivery performance assessment, an initial attempt was made to further improve water scheduling and delivery. Simultaneously, its early applications in existing irrigation systems demonstrated convincingly how many irrigation practices (in delivery and use) tended to fall short of the defined (agricultural) optimums of the CROPWAT models. By monitoring of performance and setting of delivery targets, it was attempted to redirect the operational management of centrally managed irrigation systems to focus on their (technical) water control; on the timeliness, adequacy, reliability and equity of water distribution. The first conclusions that were rapidly drawn with this new approach were that in many irrigation systems the management agency lacked the adequate information to act on for controlling the water delivery and distribution.

Parallel to the development of performance based irrigation management, there has been a growing body of critics who assert that in reality, the management of irrigation water delivery and use tends to induce pursuit of objectives not accounted for in the defined optimums, or even run counter to them (*cf*. Wade; 1982, Chambers; 1988, Zaag, van der; 1992, Mollinga; 1998). Increasingly this has led to the realisation that the management of irrigation is dependent on the objectives and capacities of the involved and affected people. This has spurred a rich body of research on actual water management practices, in both centrally and farmer managed irrigation systems, with special attention to the structuring role of politics and culture on water management tasks and functions of water allocation, distribution, maintenance and conflict resolution. Notable contributions in this field have been: Wade (1982) on corruption in government run irrigation systems; Geertz (1980)[3] on Balinese religion and its role in water allocation and distribution; and the contributions of Coward (1980) and Uphoff (1986) from the Cornell University's programme on the social and organisational aspects of water management.

This increased attention to the water management practices as performed by the water users (including government agencies personnel), has had its impact on thinking about management reform in large scale irrigation systems that are run by government agencies. It became clear that these large scale systems are intrinsically prone to a friction between the desires and requirements of water management of the individual users and those of the central agency and policy. During the past decade one possible approach to tackling this phenomena has been developed through the promotion of decentralising water management in large scale systems. Drawing from the lessons learned from farmer managed irrigation systems, this approach centres around the withdrawal of government agencies from water management responsibilities at the lower and middle levels of the irrigation system, and their turnover to organisations of water users. As a new approach to the tackling of some of the irrigation problems, it has mainly focussed on the complexities of organising the new water management structures that would have to follow such a policy of decentralisation (see chapter eight).

1.3 IRRIGATION AS SYSTEMS

The general objective to pursue in (large scale) irrigation systems as defined at the end of the opening paragraph of section 1.2 is still valid for today's aims in irrigation design and development.[4] Simultaneously, it is too general an objective to provide concrete design criteria with which engineers can work. In order to design an irrigation system, the principles of water allocation, scheduling and distribution, as well as the requirements or demands of water use, will have to be specified in order to make deliberate and conscious choices on the water conveyance and distribution technology to be applied, and the water control principles and strategies to be adopted. Since the 1970s and the onset of the CROPWAT model, there has been a marked tendency in irrigation engineering to conduct these specifications according to the criteria of meeting crop water requirements and the enabling of yield maximisation. The purpose of serving the optimal 'watering of plants' is thus brought back to the front through a hind door, as an expression of the scientific optimal principles of watering plants.

When the distribution and delivery of irrigation water is differentiated into the different processes it covers, however, questions arise on the issues at stake. The output of the process of water distribution and delivery is solemnly concerned with the mode of water availability at the farm level. As this output becomes one of the many resources of another process (i.e. that of transforming crop seedlings (input) into crop production (output)) it is not a process that is

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3 Strictly speaking this anthropological contribution of Geertz already dates from the 1960s (see literature), but it is telling it got revived attention in 1980 as an example of the importance of social and cultural factors in shaping irrigation water management.

4 Particularly since it provides enough room to accommodate the present day concerns with social and environmental sustainability, even when considered on the larger scale of the basin or in relation to other uses of water.

linearly related to the goal of food security. Instead, water becomes an item that is exchanged from one process to another, and from one process owner *cum* manager to another, thereby changing from object to subject of transformation.

The allocation, scheduling and distribution mechanisms tend to be mostly defined in technical parameters of rate, duration and frequency of water supply, as output targets to be reached in the design and operation of the water conveyance process. As this defining of parameters and targets is mostly done by irrigation engineers for an optimum water supply, the question arises how well this serves the system operators and cultivators. According to the scientific logic of engineers it serves them well, when measured to the stick of water use efficiency, crop water requirements, and productivity. However, operators and farmers tend to apply logic that is steered with multiple concerns and perceptions.

With the introduction of the CROPWAT model the irrigation sector got more attuned to the need to control more accurately the distribution and delivery of water to meet crop water requirements. While with the focus on water management it learned to appreciate that other processes and the pursuit of different objectives can prevent attainment of such control. The awareness that irrigation water management is not purely a technical field, but constitutes a complex of processes in a 'sociotechnical system' (*cf.* Vincent; 1995 & 2001, Mollinga; 1998) where various people with different objectives and strategies interact with the water delivery system, has increasingly created a dilemma for the irrigation sector to cope with. What does this 'humanising' of water management entail for the design and development of irrigation systems? How can and should one cope with the human management factor in the engineering of, what is essentially, a physical process and technical core system? Can we translate human and management objectives and strategies in concrete design criteria which engineers can cope with?

Representation of the users in the development phase through an adequate assessment of their social needs (in terms of strategic farming requirements and livelihood strategies), however, is less often attained due to the lack of adequate conceptual tools. Levine (1977) already listed this shortcoming as:

I. *"Our knowledge of the interrelationships between water and plant growth far exceeds our knowledge of the inter-relations between water and the human element in delivery and utilization: in other words, irrigation engineers face the same social problems, as say, veterinary surgeons.*

II. The efficiency concepts used in irrigation system design tend to under-stress the human component as a factor in water use crop production.

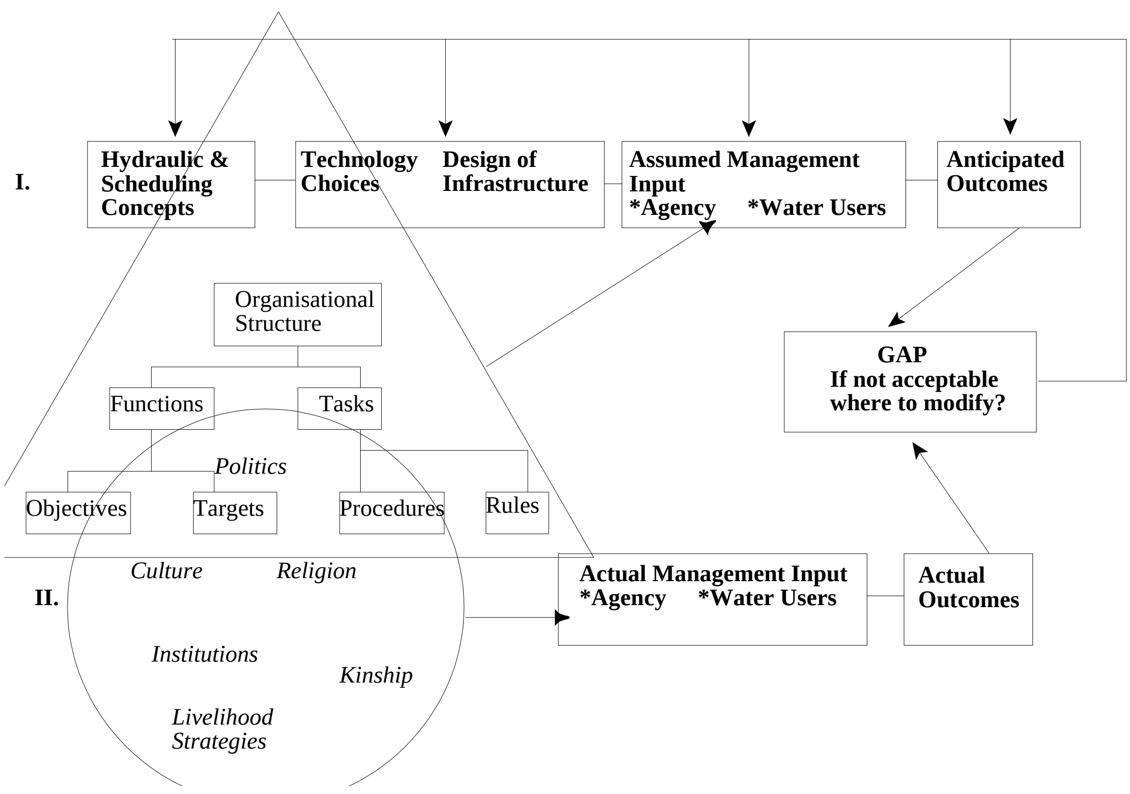
III. Irrigation systems, on the one hand, and the farmers they serve, on the other, have criteria of optimal efficiencies of water use which may not coincide. When they are far apart there is friction between the system and the farmers and/or between the farmers.

IV. Within the resources available to the farmers and to the system, the operational optima for both parties can be brought closer together by effective liaison, e.g. feedback and response mechanisms.

V. As a result of (1) to (4) above, it is usually better for the irrigation engineer to 'recognise' probabilities initially and strive, through reasonable acceptable change, towards possibilities." (Levine; 1977:37)

The design and development of irrigation systems (almost irrespective of whether it concerns a new systems or the remodelling or modernising of an existing system) tend to be treated as a two phased process (see fig. 1.1): (I) the design and creation of an irrigation system with its intended use and effects; (II) the actual use of the irrigation systems that generates a specific irrigation and water management practice. In the design and construction interventions in large scale irrigation much attention is usually given to phase I, which is covered by a specific intervention and development project (usually with foreign financial and consultancy assistance). The intrinsic pitfall of such an approach is to fall back into a compartmentalisation and separation according to (scientific) specialisation. In the first place, this often leads to a time, money and attention barrier between the phases I and II. The specialists of the corps of engineers and policy makers attempt to define and create an optimum solution within the defined socio-physical constraints, after which the outcome (i.e. the new or renovated system) is handed over to the real life situation of the operation agency and water users, with a quick dissemination through training in operation and management procedures. More often than not, policy makers define in a first stage the criteria and characteristics of the 'anticipated outcomes'; generally in broader terms like intensification of agricultural land use, higher water user efficiencies and (more recently) privatisation of services and economic viability. In a second stage, a corps of engineers focuses on composing an infrastructure of a certain 'hydraulic and scheduling concept' and 'technological features' as an answer on the interpreted characterisation of the anticipated outcomes. In a third stage, an appropriate management structure is assumed and designed, often as a means to make sure that the chosen technology and designed infrastructure can lead to the anticipated outcomes. The management structure then usually contains the operation and

Fig. 1.1: Traditional Structure of the Design & Implementation Process in Irrigation Interventions



maintenance requirements to achieve the assumed optima, in an attempt to reach a formal structure within the complexity of the social and cultural environment (pictured as a simplified triangulation of the wider circle).

Nowadays the recognition of the shaping of irrigation water management by social (or human) factors has become much larger and apparent, due to the increased attention to water management issues. A lot of examples and insights have been gathered over the last two decades on the 'distortion' of the water management processes by social processes, that has impeded the attainment of the scientific optima in reality. The development of a congruent concept, for application in irrigation development and management, of how these social factors shape water management is, however, still at its early stages and subject to debate.

Irrigation Concepts and the Understanding of Irrigation Systems

The linchpin of water management in large scale irrigation is to establish the allocation, scheduling and distribution as effective control mechanisms on the water conveyance and delivery process. From an engineering viewpoint this is a technical matter of water control. However, management wise, human factors play a crucial role in executing these feed-back and feed-forward control mechanisms, providing each executor the opportunity to evaluate the decision to execute control not only according to the predetermined technical criteria and targets, but also according to other added criteria and values derived from his/her personal experience or environment.

The issue of control is, that it presupposes the existence of a desirable state to which the process (in this case of water conveyance and delivery) and system can be re-directed, when confronted with disturbances or deviations stemming from its environment or internal in its processing. In other words, irrigation schemes and their processes of water conveyance and delivery need to be regarded as *systems*:

> *"As long as a system is a unitary whole, a disturbance will be followed by the attainment of a new stationary state, due to the interactions within the system. The system is self-regulating. If, however, the system is split up into independent causal chains, regulability* [i.e. control] *disappears. The partial processes will go on irrespective of each other."* (Bertalanffy; 1968:70)

In order to be manageable (i.e. exert a degree of control and a sense of direction) irrigation water delivery should thus be a *system* as defined by Bertalanffy. Even though the great difficulty of irrigation 'systems' to perform well, and above all to keep up their performance levels in the face of changes in their environment, raises serious doubts on whether irrigation 'systems' can be regarded as true *systems* at all.

The question thus arises what type of system irrigation schemes should be regarded as, if they are to be considered as a unitary whole, and what could their 'stationary state' or emergent properties then entail? An obvious answer to the latter would seem: to deliver the water in such a manner that it provides the possibility to all water users to water their plants in a fair, adequate and sustained form, without depleting the resource. In this the individual tendency of water users to water their plants as they deem fit irrespective of the system's requirements, is contained in order to avoid that "the system is split up into independent causal chains". As to the method in which a system can retain its stationary state or emergent property, Bertalanffy distinguishes four principles of 'dynamic teleology' (i.e. principles of directing processes) with which systems can be typified:

- Direction of events towards a final state which can be expressed as if the present behaviour were dependent on that final state. Every system which attains a time-independent condition behaves like this.

- Directiveness based upon structure, meaning that an arrangement of structures leads the process in such way that a certain result is achieved. [mechanistic goal seeking with the principle of feedback]

- Equifinality -- the fact that the same final state can be reached from different initial conditions and in different ways. [open systems, that progress to and maintain a steady state]

- True finality or purposiveness, meaning that the actual behaviour is determined by the foresight of the goal. True purposiveness is characteristic of human behaviour, and it is connected with the evolution of the symbolism of language and concepts. (Bertalanffy; 1968:78-79)

For irrigation systems the question arises how the principle of directiveness, in trying to impose a structure of water control, compares to that of the principle of equifinality? One could argue that the steady state of equifinality represents the goal and purposiveness seeking of an open system. But what would than be the principal difference between the two? It seems primarily to lie in the principle of control that can be attained: the process and matter is controllable by means of the simple feed-back mechanism in closed systems, while the control can not be ascertained in the complexity of processes in open systems.

As has been argued above, it is dubious whether the conveyance and delivery of irrigation water is a 'stable' enough process to acquire any form of stationary state to which the control mechanisms can direct the process. The very phrasing of what constitutes a 'fair, adequate and sustained' water conveyance and delivery process already highlights this issue, as it contains generic wordings that are susceptible to multiple interpretations and the modernity of science and policy. For irrigation systems to be *systems*, we thus need to make an analytical approximation as the one Bertalanffy introduced for living organisms: "[...] *the definition of the state of the organism as steady state is valid only in first approximation, insofar we envisage shorter periods of time in an adult, as we do, for example, in investigating metabolism. If we take the total life cycle, the process is not stationary but only quasi-stationary, subject to changes slow enough to abstract from them for certain research purposes* [...]" (Bertalanffy; 1968:122).

Unfortunately, from an engineering point of view, irrigation systems are not purely natural-physical systems for which a quasi-stationary state can be defined on the basis of the latest scientific paradigm only. The act of water management consists also of human or sociological systems, in which the equifinal state of the system will be susceptible to the purposiveness people attach to the system. As the application of systems theory to socio-human systems shows (*cf.* the Soft Systems Methodology developed by Peter Checkland, Checkland; 1981, Wilson; 1990, Checkland & Scholes; 1990 and Checkland & Howell; 1998), humans frequently change their values and assessment of what should be the desirable state and purpose of a system. They thus often embody an internal flux of change by questioning what the purpose of the system should be, or how the system should work. The issue of reaching a temporal quasi-stationary state becomes thereby a topic of dynamic teleology itself in the maintenance of the system. This dynamic nature, however, also permits it that a system develops in progressive stages of stationary state. The fortunate trouble with human systems is, as Checkland puts it:

> *"Any situation in which human beings try to act together will be complex simply because individuals are autonomous. Shared perceptions – essential for corporate* [or organised] *action – will have to be established, negotiated, arranged, tested in a complex social process.* [...] *facts and logic will never supply a full description of human action."* (Checkland; 1989:277)

Such human systems tend to be less tangible than natural or designed physical systems, but are clearly characterised in that they *"consist of a number of activities linked together as a result of some principle of coherency"* and which are *"more or less consciously ordered in wholes as a result of some underlying purpose or mission"* (Checkland; 1981:111)

Irrigation systems, can then be regarded as hybrid systems, in which designed physical systems (DPS) and human systems occupy a prominent and interrelated role. The infrastructure and its technological composition are a central designed physical system that provides the means to establish a particular irrigation water delivery service. It is, however, the human systems that add and manage the purpose of the DPS; in its design, as well as in its use. In the end it will always be the human systems that give and sustain purpose to irrigation by trying to direct the system into a particular quasi-stationary state, through their execution of the allocation, scheduling and distribution mechanisms.

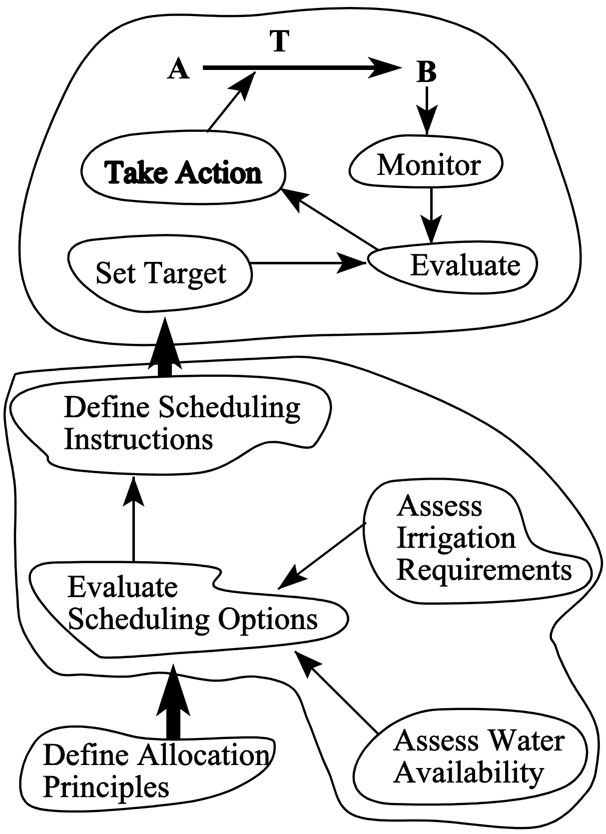
The designed physical system of the irrigation network through which the water conveyance and delivery is given shape, pertains to the classical domain of hydraulic and civil engineering. As a DPS, these systems are characterised by the fact that they are human-made systems to serve a specific purpose. Their development through the application of empirical and scientific knowledge of the natural and physical elements determines their level of complexity. The scope of such systems is delimited by the reductionist character of the applied knowledge, which is based on reducing the natural surroundings to empirical, refutable and predictable relations. To be designable, or engineerable, a problem, and the system to cope with that problem, needs to be structural: "[...] *the engineer's problem is a structural one: there is a gap to be bridged between the desired future state and the present state; how to bridge it is the problem"* (Checkland; 1981:139, emphasis in the original). The processes engineers deal with need to be structurally directive in order for engineering and its products to be meaningful. If not, their products would be susceptible to chance rather than design and purpose (i.e. present state + engineering –> future state A, B, C or ?), or bear little relevance as the present state is not changed by engineering, or leads to a future state anyway, independent of the engineered system.

Irrigation as Conceptual Constructs

In irrigation design and engineering the need to structure the irrigation problems and the process of water conveyance and delivery, has increasingly led to a dilemma in which design engineers have to assume and prescribe a particular use and management of the irrigation water delivery system. These are inevitable steps that have to be undertaken to make irrigation engineerable, and be able to provide enough conveyance capacity in the canal network to irrigate the planned-for command area and crops; and to provide for a water regulation and division capacity with which the water can be distributed and delivered in a timely and adequate manner. With the advent of the CROPWAT model in the irrigation science, the irrigation water management problems became increasingly universalised into a structural problem of being able to meet crop water requirements in the right amount at the right timing. This tendency was further reinforced by the policy discourse that water is becoming increasingly a scarce resource that needs to be managed with more care and efficiency (*cf*. Wester; 2002). 'Scientifically' modern irrigation became increasingly defined as the capacity to save water in the conveyance process, and deliver it in the right quantities and timings for the optimisation of crop production (see next section).

In the design and development of 'modern' irrigation the operational plan, with its specifications of how to manage and deliver the water, became the means to give shape to what should constitute a 'modern' irrigation water delivery service. The need to schedule and control the water delivery in better accordance with the crop water requirements, became a means to structure the irrigation water management. In the process, the irrigation water delivery became defined as a controllable natural-physical process that could be monitored and manipulated according to measurable and scientific performance criteria. Figure 1.2 presents a simplified model of what such a structuring of the water management could entail. The water distribution in the canal network is ideally to be controlled through a classic feed-back mechanism, in which the water delivery output "B" is maintained near its target value for the duration of each scheduling cycle. The scheduling is then usually regarded as a feed-forward water distribution mechanism to set the water delivery targets for each subsequent schedule cycle. The scheduling is then to be conducted as a means to distribute the water and meet the crop or irrigation requirements to different degrees of accuracy, depending on the scheduling principle adopted (*cf.*

Fig. 1.2: Feedback and Scheduling Structures for Water Management



Clemmens; 1987a&b). The scheduling options are then constrained by the water allocation principles and rules that govern the water distribution in any given situation, the water availability, and the hydraulic capacity of the irrigation system to regulate and control the water flow. With the adoption of general performance criteria such as the Relative Water Supply (RWS) and Delivery Performance Ratio (DPR)[5], the process of water allocation, scheduling and distribution can then be monitored and optimised by setting ever more stringent performance targets.

The operational plans thus usually contain a conception of the irrigation system that seeks to direct the water conveyance and delivery in terms of the natural-physical model. In its application in water management, however, it requires considerable amounts of monitoring, information processing and structural target management, that require more skill and change management of operation staff and water users than is usually acknowledged. Moreover, it presupposes a commitment of staff and water users to target management as well a managerial capacity to control both staff and water users in their execution of, and participation in, the water distribution and delivery to the operational targets. This often turns out to be difficult to attain in large scale irrigation systems, particularly when attempted through centrally managed structures.

Management as Human Systems: A conceptual dilemma of purposes v targets

What the above described 'engineering' conceptions of irrigation water management often fail to realise is, that the scheduling and distribution of irrigation water are not merely processes of scientific and numerical models. The daily conducts of scheduling and distribution are often contested and negotiated practices in which operating staff and water users alike put forward claims and objectives that are derived from socio-political values and processes, or simply from customary practices. Irrigation systems, and in particular large scale open canal systems, are extremely open systems, in which every discontented or other thinking individual, or groups of individuals, can easily interfere on his/her own behalf in the core process of water conveyance and delivery. Thus the emergence and maintenance of a consentient equifinal state of water delivery is an elaborative social process.

The question thus arises, how can one reach a consent and accommodation on what the steady state of the water conveyance and delivery process should be in irrigation, when considered as a system of equifinality, so that effective control mechanisms (of technical water control as of managerial scheduling and distribution) can be established?

The engineering response has initially been to try to devise technological packages that attempt to close the system of water conveyance and delivery, in an attempt to make it a controllable natural-physical process; i.e. closed pipe systems and automated water control concepts. True closure, however, can never be reached in irrigation, as in the management of the allocation, scheduling and distribution human evaluation will always take place, as well as in the personal water demand and use behaviour. Moreover, an alternative strategy is in most cases

[5] RWS is defined as: net irrigation water supply plus effective rainfall, divided by crop water requirements; and the DPR as: actual delivery irrigation rate divided by the targeted irrigation delivery rate.

available for discontented users by tapping the aquifer as an additional resource. The management of groundwater, is extremely difficult to close as a controllable natural-physical system.

If technical closure and control is not feasible in irrigation, or at least a feeble enterprise, one will thus have to seek a management response to the issue of water control. It is, however, clear that(irrigation) water management control mechanisms such as allocation, scheduling and distribution are hybrid systems' components that structure the human interaction with the designed physical (or 'hard') system. Irrigation clearly has a classic 'hard-systems' (Checkland; 1981) component, which constitutes the engineerable part of the equation; but it also has a clear soft-systems component in its water management domain. Both come together in an interrelated form in the control mechanisms, where the hard-system shapes and structures the soft-system, and *vice versa*.

According to Checkland *et al* management and organisations cannot be regarded as goal seeking machines with which human activities can be managed *cum* structured by the setting of appropriate goals and targets and monitored according to predefined performance criteria, as the management concepts of Simon and Drucker suggested in the 1970s (*cf.* Checkland & Scholes; 1990, Checkland & Howell; 1998). But rather, people will primarily react upon their past experiences and evaluate current activities and decisions against past experiences of relations and interactions with others. The setting of formal structures and goals in management does thus not provide any guarantees of their effectiveness in controlling the system. In the field of irrigation one also encounters examples to illustrate this: Wade (1982) and van der Zaag (1992) provide good examples of how individuals, or groups of individuals, act in the controlling of the water delivery process on the basis of principles and criteria other than those defined in the formal management structure and scientific optimum. Another ironic example, is the general decline in irrigation and water sector funding during the 1990s, that followed on the surge of management and performance assessment studies conducted during the 1980s that led to the inevitable conclusion that the universal scientific norms of good performance were hardly ever attained in practice.

The challenge is thus to find a means to reach a consent and accommodation on the desired (equifinal) state of the system of water delivery. The possibilities to force a consent, however, are restricted, as the users and partakers in the system are usually not part of one (formal) structure and institution wherein consent can be elaborated. In any case, the consent and accommodation will have to be elaborated on the basis of the multiple prevailing conceptions and views among the actors involved of what the (equifinal state of the) system should be; particularly among those that have a (potential) role to play in establishing the control mechanisms. Where these views contradict or bite, the following issue arises: can one elaborate a consent – which will always remain unlikely or hazardous in the extreme open systems of irrigation water management – or does one need to accommodate the differences in an amended concept, and redefine the equifinal state of the system to be established?

The recent increased tendency to promote decentralisation and participation in water management is a potentially promising development. It could provide the means to elaborate a consent and accommodation of different concepts of the water conveyance and delivery process. To what extent the developments in this direction might indeed fulfill their promises, however, remains to be seen. Until now, the primary attention seems to be given to formally structured water users' organisations according to western style examples, with the objective to elaborate a consent of the technical and scientific principles of operation and management, rather than leaving room to accommodate different and new conceptions of water management.

If irrigation water management is to be regarded as a system, in which the processes of water conveyance and delivery are ordered, managed and controlled in such a manner that an equifinal state of water delivery service can be established with which the system can be characterised, we thus need to regard it as a sociotechnical system of extreme open nature. The equifinal state of the water delivery service will then have to emerge out of the interaction of the social (management) system on the designed physical system through the control mechanisms of water allocation, scheduling and distribution. The challenge lies in finding and maintaining an accommodation in the principles and strategies for the control mechanisms, that are both technical feasible and socially purposeful. The latter is by definition contextually dependent, and will be governed by the appreciations the stakeholders have of the system, the way it should work, the problems it should tackle, and ultimately, the purpose it should serve. In order to be meaningful, the design and engineering of irrigation systems will have to serve the purposes of its users.

The design and development of irrigation system can thus not be solely reduced to a structural problem of a natural-physical system that is defined in scientifically 'objective' problems and targets, but needs to be regarded in its social environment from which the stakeholders derive their appreciations of what the system should look like and the purpose(s) it should serve. The designed-physical system constituted by the irrigation network, is a sub-system than can, and needs to, be defined in engineering terms when the wider socialtechnical system of water management has been conceptualised by accommodating the prevailing appreciations among its stakeholders. That is, if irrigation engineering is to be meaningful, in the sense that it is to provide the means to transform a water conveyance and delivery process to a predetermined equifinal state that is regarded purposeful; rather than become a vehicle for potential transformations with possible outcomes A, B, C, or any unanticipated X.

As described below, the engineering concepts for the design and development of irrigation systems make anticipations or assumptions of the water management sub-system, and its role and function in the wider sociotechnical system. This tends, however, to be done from a scientific appreciation of how the irrigation system should work and function. The tendency is to produce a conceptualisation of the irrigation system to be developed that contains a structured operation and management plan, in which the allocation, scheduling and distribution mechanisms are 'designed' as simplified monitoring, targeting and regulation processes. In practice, however, the social environment in which the system has to function often produces substantially different appreciations of the system and its control mechanisms for the water conveyance and delivery process. As has been frequently documented over the last two decades, this can easily lead to situations in which stakeholders act differently in the control mechanisms, or in their own discretion, than anticipated. The sense of control and directive teleology can then be easily lost, with the danger that the deprivation of part of the stakeholders from the delivery service will lead to a 'degradation' of the system into a chain of causal reactions, that bears more similarities with an environment, than with a system. The design and development of irrigation, in its wider sense of a sociotechnical system, should thus also be a social process, in which prior to the engineering of the designed physical system, a consent is elaborated and maintained on the conceptualisation of that system, which seeks to accommodate the appreciations of the stakeholders.

Irrigation Modernisation: In search of appreciations and the concepts they entail

From Checkland *et al* it follows to review the design and modernisation of irrigation system, on how the reaching of a consent and accommodation of differing concepts and views among stakeholders is handled, and the effect this has on being able to effectuate the control mechanisms for the water conveyance and delivery process in practice. This is particularly so in those cases, as the ones treated in this thesis, where one seeks to 'modernise' existing irrigation systems by transforming the water conveyance and delivery process into a new service that meets other (and supposedly better) criteria and principles of water supply/demand. The mediation of the appreciations held by the stakeholders in the conceptualisation of the system will be important to establish a consent on how the system should be controlled in its daily operation. As Checkland *et al* argue, the appreciations people hold of their situation, the system and the purposes it should serve, are primarily and foremost determined by their past experiences, and evaluations of their relations with others, in their attempts to achieve their purposes (*cf*. Checkland & Scholes; 1990, Checkland & Howell; 1998). In irrigation, the appreciations through past experiences can then be expected to shape the (strategic) behaviour of the stakeholders in the activities they undertake (or for that matter, chose not to undertake) in executing the control mechanisms of water allocation, scheduling and distribution.

For the analysis of the design and modernisation of irrigation a review of the conceptualisations of the irrigation systems to be established will be made. The hard-soft systems dichotomy would in the first instance suggest that the engineering concepts concentrate on composing the designed physical sub-systems (i.e. the irrigation network and its technological and hydraulic configuration) in which regulation of the water conveyance and delivery process is enabled. While the conceptualisations of the stakeholders, as appreciations based on their past experiences, will be instrumental in structuring the operational management in its execution of the control mechanisms. Of particular interest is then to see whether, and to what extent, the appreciations of the stakeholders are accommodated in the engineering concept applied in the development of the system. Also whether this is then achieved through the elaboration of a consent by means of concept mediation, or primarily through conceptually assumptive accommodation. Operational water management is then selected as a focus point in which the appreciations of the system will collide in the establishment of the water control mechanisms, and either reach a consent or accommodation into a new appreciation of the system and its control mechanisms, or fail to establish control on the water conveyance and delivery process.

The approach chosen, is to try to explicate the appreciations of the stakeholders in conceptualisations of the(sociotechnical) irrigation system to be established. Here the control mechanisms of water allocation, scheduling and distribution interact as social domains of negotiation, contestation and organisation on the regulation of the water conveyance and delivery process in the designed physical system of the irrigation network. For the engineering and policy appreciations this is largely done by conceptualising the design and operational plans of the modernisation projects studied. The conceptualisation is carried out on the two interrelated elements of the system:

(i) conceptualisation of the designed physical sub-system and the regulation concept for the water conveyance and delivery process. The focus is directed to the design assumptions and choices made in the elaboration of the design as an appreciation of the water conveyance and delivery process the designers and policy makers seek to establish.

(ii) conceptualisation of the water management plans, as an appreciation of how the control mechanisms of water allocation, scheduling and distribution should be structured to control the conveyance and delivery process. Focus is directed to the principles and criteria with which the human activities are to be structured and managed in the execution of the operational tasks. For both elements, attention is further given to the attempts made to establish both elements in practice; in the capacity to realise the designed physical sub-system as envisaged in the design, as the method of change management adopted to embed the assumed principles and strategies of water control and management in institutional and organisation management processes.

The appreciations of , what could be called, the 'system owners'[6], the operation agency and water users, are conceptualised on the basis of their past and present water management practices. Emphasis is given to the principles and criteria that have been developed over time and adopted in the water management practices of allocation, scheduling and distribution, and the regulation of the water conveyance and delivery process this has resulted in. The difficulties experienced in establishing and maintaining the management and regulation of the water conveyance and delivery process, as well as the abilities to adapt the system to dynamic changes in its agricultural and social environment, are taken as important elements that will shape the appreciations towards the system requirements.

The conceptualisations are not presented through conceptual modelling, but by analytical descriptions that capture the context, history and practices encountered in the design, implementation and management of the irrigation systems studied. This is purposefully done, as the composing of conceptual models almost inevitably tend to produce two pitfalls that need to be avoided: (i) in expressing simplified models of complex sociotechnical processes and systems there is a danger that the analyst's appreciation of the situation will come too much to the forefront in his/her attempt to capture the situation and others' appreciations in simplified notions; (ii) the danger that people forget that conceptual models are concepts, rather than models of processes that can actually be reproduced to structure, plan and manage the processes in practice.

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[6] 'System owners' is used by Checkland *et al* to indicate those persons or organisations that are in the position to stop or alter the process and system functions. In extreme open systems such as irrigation one can of course not really talk of ownership in these terms. The design engineers, government agencies and financiers are also in a position to influence or alter the system. The operation agency and water users, however, are the ones who will have to deal with the system from day to day and give shape to and maintain its dynamic teleology.

1.4 IRRIGATION DESIGN AS A CONCEPTUALLY STRUCTURED PROCESS

1.4.1 Modernisation v Rehabilitation

A general definition of what the modernisation of irrigation entails is given by FAO (1996):

> *"A process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes combined with institutional reform, with the objective to improve resource utilization (labour, water, economic, environmental) and water delivery service to farmers."* (Quoted in: Burt; 1999:15)

In other words; contemporary modernisation seeks to improve the water conveyance and delivery process, by converting it into a service to water users and improve its efficacy, while increasing the efficiency with which it uses its resources. The definition acknowledges also that this will require alterations in the designed physical system, as well as in the social management structures. In principle, the definition also leaves room to regard modernisation as a relative process of transforming situation A into B, in which ‘modernisation’ is achieved as long as situation B is able to attain higher resource use efficiency and/or water delivery efficacy than situation A. In principle this thus also leaves open the opportunity to regard modernisation as a long term process of successive stages of improvements (i.e. from A to B to C to D).

In our era of globalization, however, there is also unmistakably a trend discernable in which modernisation is regarded more in absolute terms of ‘modernity’, as new technologies and water management arrangements around the world set standards of what is achievable in terms of efficiency and efficacy in irrigation systems. These are standards against which the current state and progressive stages of development get, if not measured, at least reflected against. As the development and modernisation of irrigation has increasingly become an international affair, with the involvement of external and international consultancy firms and multinational donor agencies, these ‘modern’ standards increasingly shape the engineering and policy appreciations and conceptions of the state the systems should be modernised to. With the increasing notion that water is becoming a scarce resource among international policy makers and the irrigation sector at large, the urge is increased to opt for modernisation strategies and objectives that conform to high standards of efficiency and efficacy. By opting to pursue such ‘externalised’ objectives, the conceptualisation of the system is also likely to be ‘externalised’, as concepts of the technological designed physical sub-system and the management and control principles are imported as the required means to attain the pursued standards. How this will coincide or collide with the appreciations of the stakeholders in the establishment of the control mechanisms in the day to day practice, will then become evident from the degree to which the set standards of efficiency and efficacy are indeed attained in practice.

Rehabilitation in irrigation is, by definition, a conceptualisation failure. Rehabilitation is a process that belongs to conservationists that seek to conserve a painting, an archeological site, or a species. Rehabilitation seeks to reduce (in terms of simplification, not in normative value) a system to the first dynamic teleology principle of Bertalanffy in which it attains a time independent state/condition. It has no place, or role, in a sociotechnical system as irrigation water management, where the appreciations of the stakeholders of the system and the purpose(s) it should serve will always change, and be adjusted, on the basis of the past and recent experiences they have had with the system. Trying to conserve the purpose(s), objectives and criteria of the past for water management through rehabilitations, is thus a futile attempt to disregard the experiences people have had with the system. The experiences with 'rehabilitation' in irrigation, where the systems seemingly quickly enter a systematic cycle of rehabilitation, degradation and re-rehabilitation, as the problems in water management and distribution tend ro reoccur quickly, can then be regarded as a strong attestation of the systemic failure to appreciate the role of human agency in water management.

1.4.2 Engineering Concepts of (Modern) Irrigation:

The design and development of the designed physical sub-system is, as argued above, a typical engineering subject. In order to be engineerable the 'problems' of irrigation water delivery have to be structured and objectified so that the water conveyance and delivery process can be defined (i.e. conceptualised) as a natural physical process for which a physical-technological network can be composed, so that the process can be regulated (i.e. controlled) according to specified criteria and objectives. As this structuring and conceptualising of the designed physical sub-system (and process of water regulation) is conducted by means of the scientific paradigms used to define the natural physical process, it is useful to contemplate how this leads to general conceptualisations of the irrigation system that structure the design and modernisation process.

During the 19th century and the first half of the 20th, the development of the scientific fields involved in irrigation (i.e. agronomy, hydrology and hydraulics), as the field of irrigation itself, took a great flight as empirical knowledge and practical experience were accumulated throughout the world. The field of hydraulic and irrigation engineering was driven by these developments, although initially through strong conceptual 'schools' (i.e. American, British, Dutch and French) among the nations that invested strongly in the development and expansion of their irrigated agriculture. All initially developed their own conceptions and objectives on the regulation of the water conveyance and delivery process, based on the particular problems they encountered. These conceptions that got materialised in the 'national' hydraulic structures that were developed, as the Constant Head Orifice, Open Flume, Romeijn and Module a Masque.(*cf.* Horst;1998) Unfortunately, no comprehensive monograph yet has been produced that provides a comparative overview of the development of these national engineering schools and concepts and their mutual exchange of knowledge and ideas in the scientific fields, as attested by the widespread use of the Manning/Strickler equation, and in the field of water control and distribution, as attested by the Crump-deGruyter outlet as a Dutch modification of a British structure.

After WWII the internationalisation or globalization of the field of irrigation development took flight with the collapse of the colonial era, the rise of the multinational development corporations and aid, and the further development and dispersion of scientific knowledge. The scientific knowledge base and the engineering conceptions of irrigation became increasingly shared in the international organisations as the World Bank, ADB, knowledge centres as the FAO and ICID, and academic journals and conferences. The problem analysis and aims for the scientific fields and the irrigation and water sector as whole, became increasingly generalised, as seeking greater knowledge and understanding of how the natural physical processes of water conveyance and delivery and irrigated agriculture work, so that better designed physical systems can be developed to manipulate and regulate those processes.

Since the 1960s the general objective of irrigation modernisation can be defined as:

> To realise a water delivery service that provides the opportunities and means to meet varying crop- and irrigation water requirements that stimulates efficiency in water use and increased productivity.

The main issue from an engineering point of view, and in terms of 'conceptualisation' of irrigation, is: how to control the variation in flows through the irrigation system (i.e. the physical-technological network) in an adequate and timely manner that meets the above objective. That is, control in both the technical sense of water control concepts, as in the managerial sense of operating and managing strategies and procedures. (As had been argued above, both control issues are heavily interrelated, and should be regarded as the two sides of the same coin.)

Basically two distinct approaches can be discerned that have developed over time as to how give shape to this control of flow variability and the response mechanism to match water supply and delivery to actual water use and requirements:

The CROPWAT Philosophy & its Concepts of Modernity

This approach was developed in the 1970s in response to the new means that became available to accurately assess and predict the crop water requirements and yield response with the CROPWAT model. This opened-up the way to scientifically define the variability of crop water requirements, and hence the requirements of flow variation in the irrigation system with which the water supply service would have to respond. This 'triggered' the new performance evaluation paradigm with which irrigation systems are to be assessed henceforth, and which define "good" and "modern" irrigation in terms of efficiency, adequacy, timeliness and productivity of primarily water supply and use. A paradigm that is also heavily influenced by the Green Revolution and its demands towards irrigation.

These developments have had their marked influence on irrigation engineering and its conceptualisation of new and 'modern' water delivery services. Henceforth, irrigation systems were evaluated in terms of their capacity to meet the crop water requirements not only adequately, but also efficiently, without providing constraints on productivity. Quickly the problems of irrigation became defined in terms of the difficulty to vary the water supply in a controlled manner both timely and adequately. A problem that was particularly acute in the manually operated up-stream controlled canal systems, that represented the majority of large-scale government run irrigation systems in the world.

The response-mechanism that evolved to control the flow variability in these systems according the new performance demands, was primarily based on the new scientific insight and tools provided by the CROPWAT model. The application of this model provide the opportunity and means to define irrigation and water management as a *hard system* (*cf.* Checkland; 1981) and a scientific enterprise. The problems were thus defined in *hard systems* and engineering and scientific terms as: if we are able to assess and predict the actual crop water requirements in advance, we can devise a technological response with which we can vary and control the water supply in an accurate and timely manner from the water source to the crops in the fields.

The engineering and scientific challenges in the conceptualisation of 'modern' irrigation were seen as improving the accuracy of both the assessment and prediction of actual crop water requirements, and that of the control of flow variability in the irrigation network (in degree of variation as in frequency and timeliness). The goal was defined as: providing water to the crops in the fields 'just enough and just in time'. The emphasis was thus put on the accuracy and effectiveness of 'scheduling' the water delivery in accordance with crop water requirements.

Scheduling became seen as the central task and control mechanism of water management and operation at the system level. The CROPWAT approach enabled the sector to define scheduling as a technical and scientific field, that dealt with numbers and figures (i.e. mm of water requirements and rates (l/s) of water supply) that had to be matched and accounted, effectively pushing the human, or *soft*, element to the background. Even where farmers or WUA are expected to place their requests or demands for water delivery to the operation agency this characterisation essentially holds. Not only are the requests to be made in the technical scheduling parameters of rate, duration and frequency, in order to enable the scheduling to be conducted. They are also expected to be related to the actual crop water requirements as the fulfilment of those requests tends to be based on the availability of water and the predicted or permitted crop and irrigation water requirements. Scheduling became thus an information gathering and processing activity (or 'sub-system') in a technical sense, putting huge demands on the monitoring capacity of operation agencies in the fields of: water availability; flow conditions in the system; cropping patterns; climate conditions and water requirements. This is particularly so in those systems were one sought to conduct the scheduling and operation centrally controlled at the main system level. Through such technical scheduling it was attempted to enter the management domain of the water users and redefine its purpose and process in the scientific paradigm of CROPWAT.

The rapid advancements in computer technology that marked the 1980s gave a new impetus to these types of concepts and schedules, as it provided the opportunity to computerise the information gathering and processing and even of the scheduling itself. With the development of specific Irrigation Management Information Systems the hope revived that higher level of accuracies in both the assessment as prediction of changes in water requirements could be made that would allow further improvements in the 'just enough and just in time' delivery of water.

Varying the water supply 'just enough and just in time' in response to assessed and monitored requirements or collected demands, turned out to be a difficult and burden-full task when one sought to control this centrally through 'arranged' scheduling. Further improvements to the 'just enough and just in time' principle were, in response, sought through decentralisation of the scheduling to the secondary level of the system, that provided more space for decision making at the tertiary level by means of the so called 'demand-based' schedules. Such decentralisation of scheduling became feasible by developing further water control concepts and technology that would create a buffer in the canal system with which permitted changes in water withdrawal could be temporarily met.

The establishment of such arranged or demand-based irrigation schedules through manual and centralised operation of the system, often proved difficult to achieve in practice. These difficulties were centred around the following issues:

(i) The considerable data gathering and information processing that is required to conduct these schedules, is always dependent on the quality and quantity of the weakest data link. In transforming the management agencies for adoption of such scheduling methods, problems tend to emerge in realising the required data collection and information processing capacity. This demands considerable investments in measuring devices and methods, training in data collection and information management, and the management of data collection and target control. In the west, these problems have been addressed by increasingly investing in automated and remote data collection and water control, and developments in monitoring and simulation models and information systems.

(ii) The reluctancy to allow for operational losses at the secondary level, as has been long common practice in the western USA. In the absence of allowing for operational losses, the failure to reach the scheduling targets in actual water delivery immediately results in the emergence of a head-tail end problem. This severely undermines the whole water management effort, as the scheduling and delivery of water becomes unreliable and untrustworthy. As a consequence, water tends to become contested and field operators come under pressure to deviate from the schedule in order to provide reliability and adequacy on the individual level. In contrast, experiences in the western USA indicate that the allowance for operational losses provide the management organisation with the opportunity and time to invest in a gradual upgrading of the system to reduce the losses.

(iii) The advantages of the arranged and demand-based scheduling methods are strongly based on the benefits they can bring to the individual water user in terms of providing the opportunity to receive water in accordance with her/his owns scheduling plans. These advantages can best be realised when the arrangements/demands can be made at the individual level. This is largely dependent on capitalising on the advantages of scale, as occurred in the west, where individual water users take-off directly from the secondary canal and comprise the scheduling unit. In the context of small-holders where the tertiary unit comprises multiple users, the scheduling is essentially conducted at the intermediate level of the secondary canal by field operators. The potential benefits for the individual water user are then subjugated to the practical limitations the scheduler has to face in amalgamating all individual requests and objectives into a workable schedule. Scheduling as a control mechanism is then essentially withdrawn form the (centralised) process management, as the deliberations and decisions to compose and adjust the schedule are made by the field operator on a nearly daily basis. The task of water scheduling and distributing becomes then more of a mediation process to accommodate the objectives and requests of the water users with the water delivery limits and targets imposed by the official schedule of the main system operation. The level of success tends then to be primarily dependent on two ‘soft’ or managerial elements: the personal capacity and skill of the field operator to conduct the scheduling as a mediation process; and the degree to which the bureaucratic culture of the management organisation provides enough room and regulation for the field operator to conduct this mediation at her/his discretion. Rather than focussing on target management, human relationship management becomes a central element of the process; from the part of water users towards the field operator to secure their good relationship and good service, and from the field operator towards the central management to secure her/his room for manoeuvre and muster enough support and appreciation for the problems and needs (s)he has to face in her/his daily scheduling and distribution work. (*cf*. Zaag, van der; 1992)[7]

Aspects of these elements mean that the actual effectuated operation of the system and regulation of the water distribution do not correspond with the official scheduling plans and methods. As is then often revealed by performance assessments that call for tightening up of the control through more persistent focus on target management. The persistent difficulties in establishing good performance levels with such varied scheduling methods in centrally managed and manually operated systems has, however, led to a growing body of critics that has argued to dispel these concepts and concentrate on either 'structured' concepts (i.e, simplified rotational and proportional distribution) or change to concepts of flexibility. (*cf*. Shanon; 1986 & 1992, Albinson; 1993, Horst; 1998, Plusquelec *et al*; 1994)

The Managerial Flexibility Philosophy & it's Concepts of Modernity

From the 1980s onwards, a shift in the conceptualisation of 'modern' irrigation began that concentrated on reversing the response mechanism with which to control the flow variability in irrigation systems in order to match it to variations in water requirements *cum* demands. Instead of trying to match the variations in advance – through predictions and feed-forward control mechanisms that require a complex of monitoring, planning and control sub-systems with the risks to end up with a system that supplies water 'just not enough and just not in time' – this new approach tried to match the water delivery in response to actually occurring variation by means of feed-back control. The technological 'trick' and challenge that enables this reversal in response mechanism, is to create enough buffer or storage capacity in the water supply system that can accommodate the variations in water withdrawal from the system. The challenge lies therein to create enough capacity for timely response (i.e. rapidly) to increases in withdrawal, and enough storage 'room' for decreasing withdrawals, while being able to adjust the source supply in response accordingly.

With the need for advanced planning and control of flow variation thus gone, or at least considerably reduced, such storage-based systems can provide larger degrees of freedom for the regulation of the flow through the outlets; thus providing *flexibility* of water use. Providing this managerial flexibility at the delivery point (i.e. outlets and even farm-outlets) has become the goal in itself in these new concepts for modern irrigation. By providing such freedom of decision at the tertiary (or even quaternary farm) level within certain limitations (usually on maximum rate and seasonal allocated volume) the scheduling is basically relocated to the water users' management domain, wherein (s)he can accommodate other criteria and objectives than the ones stemming merely from the CROPWAT paradigm. Additionally, the flexibility allows for developments, such as changes in cropping patterns or even irrigation application methods, to be undertaken without being restricted by the limitations of the centrally arranged schedules.

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7 The work of van der Zaag provides an excellent study of the work conducted, and relationships maintained by a field operator in his duties as scheduler and distributor, providing a rich picture of these dynamics. It is also still one of the rare works that gives attention to this aspect of water management. For a more recent study that handles the same issue in a case of Peru, see Vos (2002).

The premise behind this philosophy of providing for 'managerial flexibility' is, that water users provided with such a flexible delivery service make responsible use of it. The idea is, that flexibility in service provides no restrictions to (and hence no excuse for not) optimising the efficiency and efficacy (i.e. productivity) of water use, and that its freedom and quality should act as a stimulus. Implicitly, the water users are thus still expected to pursue the optimisation of water use according to the CROPWAT principles, and certainly not abuse the relative abundance of water supply available in the main system for 'over'-withdrawals and inefficiency. In order to curb the latter, it is often proposed to price the water service fees volumetrically at such a level that it becomes economically attractively (i.e. stimulating, if not necessary) for water users to economise their water use and force themselves to pursue efficiency. These proposals are usually coupled with the suggestion to meter the water delivery and charge for actual volumetric use.

There are in essence two distinctive water control concepts that have been developed over the last decades, for the provision of managerial flexibility in irrigation water management: concepts based on in-line storage; and those based on off-line storage. The advances in hydraulic engineering in the field of irrigation have primarily been made in technological developments for the control of varied supply and the regulation of buffer storage, through refinements in the hydraulics of unsteady flow conditions.

The principle of in-line storage in open channels, and the developments made for this control principle, is strongly based on the understanding and application of the hydraulics of unsteady-flow.[8] This has changed the operational control principles with which to control the water delivery, from concentrating on water levels and discharges, to that of controlling water levels and volumes. Rather than having to anticipate the discharge levels in new steady-state flow conditions for the expected water requirements, the operational strategy is shifted towards refilling the subtracted volumes of water adequately and timely through an operational and hydraulic feed-back cycle. The developments made in the field of hydraulics and irrigation engineering to realise this shift, have concentrated on new hydraulic structures such as downstream controlled water regulators, level-top canals, hydraulic and electro-mechanical automation of control structures, and remote monitoring and water control facilities. The application of these requires a sound knowledge of the hydraulic principles of unsteady-state flow conditions, and skills in electro-mechanical and computer automation for remote and/or local control. (*cf*. Plusquellec *et al*; 1994, Burt; 1982 & 1987, Goussard; 1993)

The principle of off-line storage, with the creation and regulation of storage reservoirs at the head and/or the secondary or tertiary level of the system, provides the opportunity to control and regulate the flow variations closer to the source of demand, and thus variation, that allows for hydraulic and operational decentralisation and flexibility in management. The technologically easiest solution is to connect the storage facilities to a buried pipe network, with which the farms are connected to a reservoir, and may use the irrigation water as on a tap system. Though requiring some investment, it is the technically and hydraulically simplest form to provide for optimum scheduling and management flexibility in irrigation. (*cf*. Merriam; 1987 a, b & c,

[8] As opposed to the hydraulics of steady-flow conditions that have governed the hydraulic- and irrigation engineering for the last century through the applications of formulae as Manning, Strickler, Kuttler and Lacey/Kennedy.

Bentum, van & Smout; 1993)

The developments in in-line storage control have spurred the combination with volumetric control at the main system with buried pipe networks from the secondary to quaternary level, as a means to economise on the investment costs for storage facilities. The application of these control principles are, however, subjected to two important conditions: (i) they are not suitable for conditions of water with high silt load, as the flow velocities in the storage facilities (off- or in-line) will frequently be too low to prevent sedimentation; (ii) the available volume of water must be related to the actual water requirements to provide for the flexibility in scheduling and management, or additional resources as groundwater must be available to supplement the shortages.

1.5 IRRIGATION MODERNISATION IN NWFP, PAKISTAN

The favourable position of NWFP in terms of water availability for allocation in irrigation has enabled the Provincial Government to pursue a modernisation programme for some of the aging irrigation systems. As far as irrigation water is concerned, this programme encompasses three basic elements of change:

- an increase in overall delivery capacity;
- the provision of significantly greater water control infrastructure that has the potential to enable a closer match between water supplies and crop water requirements; and
- the improvement of the drainage capacity in the command area through the provision of a network of open channels and tile drains.

Since the start of this modernisation programme in 1980 four irrigation systems have been remodelled or newly constructed through four irrigation projects, that have attempted to introduce and establish a water conveyance and delivery service that would better meet the crop- and irrigation requirements than the traditional so called ‘protective’ irrigation systems. These are:

- the Lower Swat Canal (LSC) that was originally commissioned in 1885, and was remodelled through Mardan-SCARP project from 1980 to 1992;
- the Chasma Right Bank Canal (CRBC), which is a new canal that is currently still under construction (although the first two stages have been completed in 1992 and 1998);
- the Upper Swat Canal (USC) that was originally commissioned in 1914, and was remodelled through Swabi-SCARP project from 1992 to 1999;
- the Pehur High Level Canal (PHLC) system, which is a new canal linking up to USC that is about to be completed, for which design started in 1995, and construction in 1998/9.

Although the basic objectives and criteria for the modernisation and development of these irrigation system were the same, the actual design concepts and outcomes have been substantially different for all four, leading to irrigation systems with different hydraulic behaviour and different control strategies and mechanisms in their operational plans. The central issue of this modernisation process has been to come to terms with what should constitute a modern irrigation water delivery service within the context of NWFP. The issue was thus to come to a conceptualisation of the irrigation system wherein the DPS is technically capable of regulating the water conveyance and delivery process in accordance with the crop water requirements, and is operable through control and management arrangements that are feasible in the social context of common practices and strategies of the operation agency and water users.

The remodelling of the LSC under Mardan-SCARP can be regarded as the initiation of the modernisation programme in NWFP. From the onset of the project, the objectives for the remodelling were set to convert the water conveyance and delivery service into a 'demand-based' service, in which the water delivery could be varied so that crop water requirements and water users' demands could be met. The project team, consisting of foreign and national consultancy firms and the Water and Power Development Authority (WAPDA), were charged with the design and construction of the remodelling of LSC. The modernisation objectives were translated into an irrigation concept and design that sought to deliver and manage the irrigation water supply according to arranged scheduling principles; at first with the objectives to meet the varying crop water requirements, and in later stages to meet demands placed by water users. To enable this substantial transformation of the water management principles in LSC, the irrigation network was enlarged and equipped with numerous water control structures to enable the regulation of the varied water delivery. The main strain of the water delivery regulation was to be regulated through manually operated gates at cross regulators in the distributary canals and on each and every outlet structure. This required an enormous change from the Irrigation Department (ID) and water users to adapt their water scheduling and distribution practices to the principles of monitoring and target management embedded in the design concept.

The remodelling of LSC through Mardan-SCARP as a first attempt to modernise irrigation in NWFP was selected as one of the prominent cases for this research. It was the only one out of the four modernisation projects that was already 'completed' at the start of the research. This provided the excellent opportunity not only to address the design and implementation process itself. Also it allowed the investigation of the way the ID and water users had responded to the changes, by effectuating changes in their water management practices and strategies as expressions of their interpretations of what modern 'crop-based' irrigation could effectively entail in the context of NWFP. This was an important opportunity, particularly since the effects of Mardan-SCARP on the water management practices of the ID and water users were hardly documented, despite the fact that they could contain valuable lessons for the other modernisation projects underway. Also, the approach of Mardan-SCARP had provoked a conflict with implications for the other modernisation projects undertaken in the province, which is studied in this analysis.

In CRBC an attempt has been made to introduce 'crop-based irrigation operations' through the Crop Based Irrigation Operations (CBIO) project after completion of stage I of CRBC. The context in which this was attempted is somewhat peculiar, in that the Chasma canal of stage I was already built and configured, although only with temporary pipe outlets at the secondary level. The objective of the CBIO project was to identify and test an operational plan for crop-based irrigation with which the water conveyance and delivery process could be regulated so as to match the actual crop water requirements at the tertiary level. In the broader realms of the modernisation programme in NWFP, the CBIO project represents a second attempt to come to a conceptualisation of a 'productive' water delivery service with which the crop water requirements could be met. Initiated after the completion of Mardan-SCARP, the CBIO project was well aware of the sensitivity of its task in light of the objections brought forward by the ID against the former. The issue was addressed by seeking to clarify the conception of '*crop*-based' as opposed to '*demand*-based' irrigation, in which the operation agencies could retain a central role and control in varying the water supply in anticipation of the variations in crop water requirements.

The CRBC and CBIO are only a minor case in this study, presented in chapter six. As the case lies to the extreme south of NWFP, and was well documented by the progress and final reports of the CBIO project, the material presented is based on secondary sources. The case is treated, however, as it represents an important stage in the irrigation modernisation programme of NWFP in its attempt to come to terms with a viable and workable conception of 'productive' irrigation. Central in the analysis of this case lies the way in which the controlled variation of water supply throughout the main system level, in order to match the varying crop water requirements, has dominated the conception of what 'crop-based' irrigation should constitute, while the operation agencies 'failed' to appreciate its need and feasibility.

With the remodelling of the USC through Swabi-SCARP, which followed upon completion of Mardan-SCARP, the irrigation modernisation programme in NWFP was seemingly suspended, or at least conducted with less ambitions towards establishing crop responsive irrigation operations. After the confrontational experience in Mardan-SCARP, Swabi-SCARP seemingly sought to calm the atmosphere with the remodelling of USC, by opting for less changes in the water distribution technology and scheduling and distribution mechanisms for the time being. This was an important strategy as the same ID-circle was involved in Swabi-SCARP as the one that put forward its objections in Mardan-SCARP and was coming to grips with the newly remodelled LSC. Tellingly also, another consultancy consortium was involved in Swabi- than in Mardan-SCARP.

The design process of Swabi-SCARP had already been completed at the start of the research period, and the construction work proceeded throughout it. This provided the opportunity to review the conception of the 'revamped' proportional distribution system, and its implementation in the field. The central issue in the analysis is presented in chapter seven. It centres around the critical issues inherent to the proportional distribution concept, of establishing the hydraulic capacity to distribute the water proportionally over the range of seasonal water supply variations, and establish the operation and maintenance capacity to control and maintain those conditions. The latter is reflected against the general deterioration of the proportional distribution capacity in the traditional system that has taken place over the last five decades, and the dynamics in water management practices that has led to, and resulted from, this process. Two case studies are presented on the implementation that were conducted shortly after construction, that enabled verification whether the design assumptions on the hydraulic capacity for proportional distribution were attained in reality.

In the last case of PHLC, the modernisation attempts for irrigation in NWFP were reinvigorated with a turnabout in the conception of modern irrigation water delivery service. Making use of the excellent opportunities provided by having Tarbela reservoir as the water supply source (as opposed to the river intakes in the other three cases), PHLC system was designed for automated downstream water control, with which an optimal flexible water delivery service can be established for both arranged, and on-demand, water scheduling and distribution principles. The choice for automated downstream control was justified as the best solution to control the precariousness of water flow and variations at the confluence where the PHLC canal is to link with a major branch canal of the USC system, to alleviate the water shortages at the latter's tail end. The choice for automated downstream control was further elaborated upon in devising a concept for the water conveyance and delivery in PHLC/USC, with further proposals to provide for a closed pipe on-demand water delivery system in the newly to develop command area of PHLC. Within the modernisation attempts undertaken in NWFP, the PHLC project stands out as last attempt to conceive a modern concept of irrigation, in which the controlled variation of water supply to meet variations in crop water requirements and demands is sought by technological closure of the water conveyance and delivery system.

The PHLC case is presented in chapter seven, together with Swabi-SCARP, as both projects are interlinked and will constitute an integrated system in the future. As the construction of PHLC only started after completion of the research, the treatment of the case is limited to review of the design decisions made.

1.6 THE RESEARCH APPROACH AND METHODOLOGY

The subject of this research – the attempts undertaken to modernise irrigation in NWFP, Pakistan – has been handled with a set of general, and common day, questions in mind. These are questions that arise from the premise and popular belief that the design, development and establishment of irrigation systems, as products of concerted efforts of engineering and development cooperation, should be capable of improving the conditions in water management and irrigated agriculture. These are considered to be the general objectives of such development undertakings, that raise the expectations and belief (within the general public, as well as within the people and organisations that are involved and affected) that these objectives can be realised through engineering and concerted development.

The expectations that people put forward are the products of their appreciation of the situation. These need to be accommodated in directing the engineering and development activities into a concerted process of conceptualisation of an irrigation system, as a sociotechnical system that can address the perceived problems, and fulfill the purposes, of water conveyance and delivery process. The focus of the analysis is thereby directed to the process in which the projects of irrigation modernisation in NWFP have coped with the handling of the different appreciations of what the irrigation system should be capable of, and how it should function, in their attempts to come to a concerted conceptualisation and implementation of the system to be established. The aim was to explore what dilemmas the irrigation modernisation projects faced in NWFP in reaching an accommodation in the conceptualisation, implementation and establishment of the system.

Research Objectives & Questions:

In order to provide answers on these issues, the following objectives were formulated for this research:

- To interpret the policy objectives for irrigation modernisation in NWFP, Pakistan;
- To come to a conceptualisation of modern(ised) irrigation in the design and implementation process, and an evaluation of design approaches adopted in NWFP;
- To understand how the 'concepts of irrigation' can be related to feasible operations of the system through a correlation of the system's technological configuration and the control mechanisms of water allocation, scheduling and distribution in the management interfaces and structure of the wider sociotechnical system;
- To study the attention given to the system's users in the design initiatives of irrigation modernisation in NWFP, and the assumptions made about their needs, objectives and strategies in the daily operation of the new to establish system.

An important focus of the research was to study the interpretation of the policy objectives for the irrigation modernisation programme in NWFP into concrete design criteria, and its conceptualisation of modern(ised) irrigation within the design process. As well as, how this design process and policy interpretation has evolved and changed in the course of 15 years with the involvement of different consultants among the different projects. The central theme of the research was the conceptualisation of the irrigation system within the design and implementation process by the different actors and stakeholders involved, and to understand how the technological configuration was related to (operational) management of the system as an appreciation of a feasible irrigation process. The main question formulated for the research was:

> *What factors have led to changes in the conceptualisation of 'modern' irrigation, the choice and utilisation of irrigation technology and the potential involvement of users in the design, operation and maintenance of the systems, in the evolution of the process of large-scale irrigation system modernisation in NWFP, since 1980?*

In studying the design process in the different projects (i.e. LSC, CRBC, USC and PHLC), the process of conceptualising the irrigation system will be compared in its different elements.

The stark differences between the designed irrigation concepts adopted in the modernisation programme in NWFP form a leading thread of the research and thesis. The different outcomes of the design process are appealing, as they must primarily be a result of the changes in designers' view point or policy shifts, as the socio-economic context of the water users and the socio-political context of the irrigation agencies do not differ starkly.[9] Of research interest becomes thus how these differences relate to the users' practices, requirements, capacities and strategies. The resulting differences in designed irrigation concepts, suggested that different interpretations have been made on what constitutes a 'good' and 'modern' irrigation water delivery, and on what is the appropriate and feasible method of involving users (agency and farmers alike) in irrigation water management, and on the establishment of the desired control mechanisms.

The research approach thus concentrated on working out the conceptualisation of irrigation that were produced by the different projects in their interrelation of the managerial control mechanisms, technological configuration and the water conveyance and delivery process. Besides an elaboration of the technical design and its subsequent possible and intended water conveyance and delivery process, and its principles and options for the water allocation, scheduling and distribution mechanisms, an elaboration is made of the management requirements that were made explicitly and implicitly in the conceptualisation of the systems in the design.

To gain insight in the objectives, preferences, capacities and strategies of the users towards 'modern' irrigation (i.e. their appreciations of the current situation and future requirements), the irrigation water management practices, past and present, of the irrigation agency and water users are studied and analysed. A historical analysis is made of the development and establishment of the 'protective' irrigation water delivery system during British colonial time, and the changes and adaptations it underwent to the start of the modernisation initiative in NWFP. This historical analysis concentrates on two issues: (i) the elaboration of the concept of 'protective' irrigation, and (ii) the difficulties and problems both operation agencies and water users faced in the day to day water management practices and the strategies they adapted to tackle those problems.

To gain insight in how the users were represented in the design processes, two approaches were followed: reconstruction of discussions, deliberations, and conflicts that took place during the design and implementation phases; and comparison of the assumptions made during the design about cropping and irrigation strategies with current day practices and strategies. Of particular interest is how the different cases used assumptions of 'good irrigation practices' and irrigation water requirements to structure the water scheduling and distribution mechanisms. These assumed and designed characteristics of the water delivery service are reflected against the irrigation practices, in which the irrigation requirements and methods are evaluated in the field.

Throughout the thesis and the cases, the analysis concentrates on the water control mechanisms in operation, as interfaces where the different appreciations of the irrigation concept from the stakeholders (designers, operation agency, water users, etc.) collide, and the processes that eventually determine the equifinal state the system can reach. At the end, it is hoped, that this analysis can contribute to the answer of the following question: With more appreciation of the past experiences and the different conceptions of the system, can the current state in irrigation

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9 The areas covered by the systems studied are adjacent to each other, characterised by the Peshawar Vale culture of settled Pathans and outside tenants, while the irrigation agencies have a common tradition since they exist from the creation of the Irrigation Departments in 1917. An exception is the Topi area in PHLC, where no canal irrigation tradition exists. The context in CRBC is also slightly different, as it primarily deals with the creation of a new irrigation system.

water management be changed into a conceptualisation and actions that accommodate better the different views of operating agency and water users?

Research Execution:

The field research for this thesis was carried out from 1995 to 1998 in affiliation with the Water Management project (WAMA) – a collaboration between the Irrigation and Water Engineering group of Wageningen University and the Department of Water Management of the Agricultural University of Peshawar, NWFP. From July 1995 to March 1996 I was affiliated to WAMA as a research assistant, and returned after a six months interval in Wageningen, to finalise the research proposal, to further conduct the field research and participate in the research programme of WAMA from October 1996 till August 1998. During this period WAMA set up a set of research programmes throughout the irrigation systems surrounding Peshawar, in which staff of the Water Management Department as well as its BSc and MSc students were able to conduct research into various aspects of irrigation water management. To ensure continuity of data collection, field and research staff were also employed for these research programmes. In addition MSc students from Wageningen joint from time to time to conduct their research within these programmes.

In the research programme conducted in the Lower Swat Canal different types of data and information have been collected for different parts of the system and with varying intensity over an extended period. Databases were compiled with monitoring data from the ID (water levels and cropping patterns for the entire system) for years prior, during and after Mardan-SCARP, as well as a drainage database (water tables, hydraulic conductivities and drainage plans) on the basis of data from WAPDA. For the assessment of the general impact of Mardan-SCARP these databases were used and analysed and supplemented with data obtained from surveys and questionnaires conducted for the purpose. The main stage of research, however, has been conducted on few selected research sites, of which the Sheikh Yousaf Minor comprised the major one. Sheikh Yousaf has been monitored by WAMA for 24 consecutive months on a daily basis, in which the water levels of all the outlets and the gate operations have been measured, as well as the cropping patterns in its command area. In addition, various studies have been undertaken into the established water management practices at the tertiary level, and the strategies and rules adopted by the water users in their day to day irrigation and water management activities.

In the case of Upper Swat Canal and Swabi-SCARP project, WAMA was contracted on request of the Irrigation Department and through financing of the ADB to conduct a hydraulic performance evaluation of the first remodelled distributary canal system – Kalpani distributary and its minors – before commissioning. This task was conducted over a five months intensive measurement period from January to June 1997, in which the system was measured, monitored and calibrated. The work was carried out by a field team, consisting of eight members plus supporting staff. The findings and reporting of the study were presented and extensively discussed with Irrigation Department, the Swabi-SCARP project and the provincial WAPDA and Planning and Development departments.

The research in Upper Swat Canal was followed up by a MSc-student from IHE in Delft with support from WAMA from July 1998 to April 1999, on the Jalala distributary shortly after completion of its remodelling by Swabi-SCARP. This enabled me to verify whether better results were obtained than in the case of Kalpani distributary, after modifications were made by Swabi-SCARP on some of the outlet structures used and the procedures of implementation. (See chapter seven)

In addition to these two research programmes, material has been collected on the designs and the operational manuals and other project and policy documents form the cases treated in this thesis as well as discussions held with ID and project staff. Further, use has been made of data collected in other research programmes conducted by WAMA, notably on the water management practices in the traditional Kabul River Canal, in which I worked as part of my MSc in 1993.

1.7 THE OUTLINE OF THE THESIS

The next chapter presents a historical analysis of the development of the large canal irrigation systems in the Indus basin during British colonial time. The analysis focuses on how the concept of 'protective' irrigation was developed and refined over time by the irrigation authorities. This was a continuous attempt to further improve their control over water conveyance and distribution, until in the 1920s the concept of self-acting proportionality introduced by E. S. Crump was widely applied throughout the Indus basin. It is argued in this chapter that, contrary to the widespread belief, the British colonial authorities never managed to implement a truly proportional and equitable water distribution system in their 'protective' irrigation systems, not even after Crump had developed the technical means to do so. The chapter ends with a conceptualisation of the self-acting proportionality of 'Crump canals' that became the paradigm of irrigation in the 1930s. Special emphasis is given to the hydraulic configuration of these canals and the Open Flume and Adjustable Proportional Model outlets, and the sensitivity of these canals to disruptions of their hydraulic configurations that will upset their capacity for proportional distribution.

Chapter three treats the era after independence of Pakistan till the start of the modernisation programme in NWFP around 1980. This chapter focuses on the changing scene of irrigation management and development in the Indus basin, that has resulted from substantial changes in its institutional and political context. These changes were initiated by the rapid and dramatic effects of partition, that threatened the viability of Pakistan's Indus Basin Irrigation System (IBIS) as the allocation, scheduling and distribution of the Indus waters became internationally contested between the newly independent states of Pakistan and India. It is argued in chapter three, that the institutional change linked arms with the internationalisation of irrigation and water development, wherein multilateral donor agencies, WAPDA and international consultancy firms negotiate and determine the course and content of the developments. The steady degradation of the water delivery services since the 1950s can partly be explained as a process that could thrive in the context of institutional and policy changes. This sets the scene for the modernisation programme of NWFP, demonstrated throughout the case studies, outlined already in section 1.5, which are presented in Chapters four to seven. Chapter eight deals, as an epilogue to the modernisation programme, with the institutional reform programme for the irrigation sector in Pakistan, that was initiated in 1994 and finally got underway in 1999/2000. Seemingly this would represent an important shift in the policy and intervention approaches to tackle the problems of water management in Pakistan, that would come as a welcome change to the technological interventions reviewed in this thesis. Finally, some general conclusions are drawn in chapter nine on the function of engineering and designed physical systems in the wider hybrid system of irrigation water management. To effectuate a process of change and innovation, there is still a need to come to grips with the issues of management in irrigation, as socialtechnical processes that interact with the technological DPS in the establishment of the equifinal properties of the system. The systems framework adopted in this thesis can be useful to analyse these interrelations, and as means to make the appreciations and conceptions of the system explicit, so that a process of accommodation can be initiated as part of the process of change management. There is, however, still a clear need for an appropriation of a *management* framework in the water sector, for which a more concerted and collective initiative will have to take place, than could be provided with this thesis.

CHAPTER TWO

DEVELOPMENT OF THE PROTECTIVE IRRIGATION CONCEPT

THE FAILURE OF IRRIGATION INSTITUTIONS & TECHNOLOGIES TO ACHIEVE EQUITABLE WATER DISTRIBUTION IN THE INDUS BASIN

2.1 INTRODUCTION[10]

The development of canal irrigation in the Indus river basin under British colonial rule has been characterised by a prolonged struggle of irrigation engineers and policy makers to get the process right. From the first British endeavour in irrigation onwards, two features of canal irrigation became immediately evident that have since driven the process of irrigation development in the basin: (i) irrigation could be an immensely profitable undertaking that creates wealth, prosperity, productivity and political-economic stability; and (ii) it was a precarious undertaking that required continuous fine-tuning of technical and managerial issues in order to create and maintain the conditions for such profitability. As with any state enterprise requiring huge investments and prolonged commitment, the colonial Authorities quickly defined a set of general parameters or performance criteria to gauge the success of irrigation, and justify each undertaking. However, it were the practicalities on the ground that really determined the conditions of irrigation in each scheme, and which became the domains of the Irrigation Authorities[11] in which they were accountable to 'fine tune' technical water delivery control in the face of sanctioned privilege and pragmatic local action.

The interests of the colonial state in pursuing canal irrigation to expand and consolidate its rule over its dominions on the Sub-Continent are well argued elsewhere (*cf*. Whitcombe; 1983,

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[10] Sections 2.1 to 2.5 of this chapter are largely a reproduction of an earlier paper by Halsema, van & Vincent; 2001. Section 2.6 is based on an earlier paper by Halsema, van & Murray-Rust; 1999.

[11] During the 19th century the Irrigation Authorities were still a specialised branch within the Public Works Department; it was only at the turn of the 20th century that gradually the 'independent' Irrigation Departments were established in the different Provinces. Throughout this chapter the term 'Irrigation Authorities' will be used to indicate the cadre of professional irrigation engineers that were responsible for the construction and management of the irrigation systems.

Stone; 1984). These included the political-economic advantages of developing a lucrative Revenue-base, settling of unruly and wandering tribes in administrable agricultural communities, and protection against famine. However, while these advantages have played a crucial role in driving these irrigation development efforts, such accounts tend to over-emphasise the state's objectives in shaping the irrigation and agricultural conditions on the ground.[12] This chapter disputes the view that the colonial state and its Irrigation Authorities exerted enough control to realise the stated objectives on the ground, especially for irrigation policies from the last quarter of the 19th century onwards. On the one hand, the irrigation policies were driven by the political discourse of a benevolent state, that should modernise society by imposing new systems of justice, fairness and equity. For irrigation this discourse was defined in terms of providing protection against famine, creating an efficient and equitable water distribution system where each cultivator would receive his/her fair share of water, and extend its beneficial service ever further (*cf*. Famine Commission; 1881, 1885 and 1898).[13] On the other hand, however, the pursuit of this 'benevolent discourse' was impeded by an intrinsic dilemma of the colonial state. The approach to rule efficiently and effectively by means of a relatively low administrative presence raised an inherent contradiction. The administrative discourse of 'scientific empire' that propagated the coalescence of administrative rule with local traditional customs, rules and rights, "*linking Administrators and Indian elites together in a common political structure*" (Gilmartin; 1994: 1128), contradicted the declared purpose of the 'benevolent state' - to promote and impose a 'fair and equitable' political-economic system. Within the colonial administration there were supporters on both sides - known as the *amir parwas* (defenders of the rich) and the *gharib parwas* (protectors of the poor), respectively - contesting for primacy in local and policy affairs. (cf. Allen; 2000).

Gilmartin's (1994) treatise is one of the first and only accounts that treats the development of canal irrigation in light of this intrinsic dichotomy of colonial rule; coined by him as the dichotomy between the discourses of 'scientific empire' and 'imperial science'. He asserts that this dichotomy created a split along institutional lines, embodying a paradigm conflict between civil administrators and irrigation engineers; the former favouring administrative efficacy and the latter promoting scientific efficiency. This, however, seems too polar and rudimentary an analysis, that fails to take into account the Irrigation Authorities' own interests in, and responsibilities for, administration. Gilmartin shows how developments in engineering and hydraulic science, that evolved around 'universal values' of efficiency and equity, started to undermine the values of 'custom' and 'privilege' that governed the administrative rule of the 'scientific empire'. However, it remains difficult to assert whether this indeed evolved to an externalised conflict of paradigms between the different branches of colonial authorities, or whether it was as much an internal dilemma for the Irrigation Authorities to accommodate

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[12] Stone is more sensitive to the limitations of the Irrigation Authorities' ability to control the conditions on the ground than Whitcombe, and provides some interesting examples.

[13] It is interesting to note that the imposition and extension of the Revenue-system was considered part of this benevolent discourse among contemporary administrators; arguing that a fair and uniform Revenue assessment system freed the cultivators form excessive and whimsical tributes they had heretofore to pay to their local despotic rulers, enabling them thus to become 'modern' profitable cultivators whose property rights were recognised by the state (cf. Allen; 2000).

conflicting interests.

This chapter studies and critiques this 'paradigm conflict' in development of canal irrigation in the Indus-basin. This is done by taking the Irrigation Authorities' perspective, to show that the features and benefits of the irrigation systems were primarily determined by the ability of irrigation engineers to control technical and managerial issues on the ground. In doing so, it argues that irrigation engineers were as much part of the colonial administration as their civil colleagues, and that it was convenient for early irrigation development to fall back on the 'science of empire' discourse and methodology of civil administration for their administration of 19th century irrigation. The formulation and institutionalisation of the Canal & Drainage Act of 1873 was instrumental for appeasement of the contradictory requirements of technical efficiency and administrative efficacy. It formalised the discretionary powers of canal officers to accommodate the polemics of this dichotomy, which only grew into larger and more pressing contradictions with the progress of irrigation science.

The chapter ends with a hydraulic analysis of Crump's concept of self-acting proportionality. By using the hydraulic flexibility ratio introduced by Crump, an analysis is provided of the hydraulic configuration of the outlets that is needed to achieve the self-acting proportionality. This analysis provides insight on the sensitivity of the hydraulic configurations to disturbances that lead to deviations in proportionality and problems in water distribution. Section 2.7 then treats the operational rules that have been derived from the hydraulic concept for day to day operation of the irrigation systems that have been adopted by the irrigation authorities throughout the Indus-basin.

2.2 PARAMETERS FOR IRRIGATION DEVELOPMENT IN THE INDUS BASIN

Like Rome, the vast irrigation infrastructure of 13.6 million ha left behind by the British on the Sub-Continent was not built in one day. It took the colonial authorities the best part of a century to get going after their first endeavour in canal irrigation with the rehabilitation of the Western Jumna Canal in 1820. Considering that the British were new to irrigation, and that the hydraulic and engineering sciences were then in their infancy, this is no surprise. In fact, the impressive rate of irrigation development in the first half of the 20th century attest to the contribution of the colonial Irrigation Authorities in the fields of hydraulics and irrigation-engineering.[14]

The irrigation developments in the 19th century were characterised by a trial and error approach – in which valuable experiences were gained through numerous successes and set-backs – that served to define and develop a congruent and effective irrigation policy, management and technology. From the outset, policy debates were governed by economic concerns of the colonial state - triggered especially by three specific enquiry committees (Famine Commissions of 1880-85 and 1898, and the Indian Irrigation Commission of 1901-03). While some early experiences had shown clear benefits (both financially as politically) for the state

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[14] The rate of development becomes even more impressive, when one considers that the majority of the irrigation works conducted after the independence of Pakistan in 1947 as part of the Indus Basin Project, were implementations of blue-prints designed in the 1930s (Michel; 1967).

from irrigation development, other experiences warned of high financial burdens. The most prominent warning came from the financially disastrous, and short-lived experience, of irrigation developed by private companies with state guarantee (*cf.* Stone; 1984). By acknowledging the technical difficulties of irrigation engineering in sustaining and controlling a secure water supply, the committees always acknowledged and promoted a prominent role for irrigation engineers in the development and administration of irrigation. However, the benefits of irrigation for the state were clearly defined to hinge on the rate of up-take of irrigated agriculture by local communities. This adoption was crucial for creating direct and indirect benefits; the former through expansion of the revenue-base and direct taxation of higher valued irrigated agricultural produce; the latter by providing a secure agricultural production in times of drought.

As the irrigation endeavours were financed through loans, the productivity of the state's enterprises was monitored through the remuneration yielded by each system, measured on direct tax returns against the investment and operating costs plus 4 to 6 per cent interest (Mollinga; 1998). This productivity criterion proved difficult to meet in areas where agriculture already existed (either rain-fed or through well irrigation) and where greater or more secure production required huge investments in infrastructure to supply canal water (such as the Deccan in the United Provinces and the Bombay Agency, where most of the 19th century works were concentrated). Other criteria were thus sought to justify the huge investments and continued commitment of the state to irrigation development. The recurrence of dramatic droughts provided the excellent 'excuse' to emphasise the indirect benefits of canals that secured the production of staple food and prevented general distress among the populace. Irrigation as a protection against famine became justifiable when the stringent criteria of 'productive' remuneration could not be met, but a system could protect a large area against the devastations of drought. An area was considered adequately protected when 42.5 percent of it could be supplied with irrigation water; either from wells or canals (Stone; 1984). Special funds were set aside over different periods by the colonial state for the development of such 'protective irrigation systems' (Mollinga; 1998), although eventually the 'protective irrigation systems' amounted only to a mere 16 percent of the total area developed with canal irrigation under colonial rule. This is mainly because the colonial state in later years concentrated its irrigation developments in the much more favourable conditions of the Indus-basin, where huge tracks of crown-waste land could be converted into the granaries of the Raj, by means of the so-called 'colony irrigation systems', that yielded impressive levels of remuneration of up to 45 percent (*cf.* Michel; 1967).

Whether, irrigation under development was financially 'productive' or 'protective', the parameters set forth by the state to gauge its success, and on which the Irrigation Authorities were held accountable, were standard. They were directly linked to the area that could be served by a system and the intensity of irrigated cultivation it could sustain:

- *Water Allowance*: the ratio between the available water quantity and the serviced Culturable Command Area (CCA); expressed in [cusecs/ 1000 acres].

- *Kharif and Rabi Intensity Factors*: percentage of CCA that was deemed feasible to be irrigated under full standing crop in the respective season; expressed in [%].

- *Irrigation Duty*: the amount of acres of a particular crop or cropping pattern that could be adequately irrigated and brought to maturity with one cusec; expressed in [acres/cusec].

These three interrelated parameters were not only important as irrigation performance indicators for post-implementation evaluation. They were also crucial in design of a system to decide on the feasibility of a particular alignment of main canal and the command area it could serve, and whether its expected remuneration would be 'productive' or 'protective'. The *Water Allowance*, by definition, would provide an indication of the relative water supply that could be provided by each system, given its water delivery capacity and command area at different levels of the system; i.e. system, distributary or tertiary. The *Kharif* and *Rabi Intensity Factors* were used to define the percentage of the command area that could be fully irrigated in each season given the particular water allowance. Theoretically, these parameters were important to determine the command area of each system, as they would determine how far the relative water scarcity might be stretched. Given the hydrological and agronomic conditions of Northern-India, where both the crop water requirements and river discharges are at their lowest during the *Rabi* season, the *Rabi Intensity Factor* (RIF) was generally decisive in defining the command area. The maximum permissible command area was thus determined by: available river flow during the *Rabi* season, the *Irrigation Duty* of the *Rabi* crops, and the target RIF. As a general rule, the *Kharif Intensity Factor* (KIF) would then be determined by the maxim that one cusec of water during *Kharif* could irrigate half the area it could irrigate during *Rabi* (Buckley; 1920, Famine Commission; 1885). The *Irrigation Duty* was basically a parameter used to express the crop water- and irrigation requirements, and as such would determine which *Intensity Factor* was achievable given a particular water allowance. The *Irrigation Duties* were empirically determined for a range of crops, and collected from a wide range of agricultural and geographical settings.[15] The fairly high degree of variation in specific crop duties, gave a scientific expression of the variable factors that influence the irrigation requirements - such as crop type, climatic and soil conditions, and conveyance and application efficiencies (*cf.* Buckley; 1920, Leliavsky; 1957).

The early irrigation engineers of British India learned the hard way, that planning and designing of irrigation systems is one thing; but that their implementation and the actual control of water distribution and use, is quite another. The actual rationing of canal water and its planned distribution over the command area proved an extremely tedious and cumbersome undertaking in the absence of adequate water control structures and limited management capacity. By default, rather than anything else, the endeavours of the early design and construction engineers of the Public Works Department were primarily limited to the construction, extension and continuous maintenance of the main canals (their headworks, alignment and capacity). In essence, these early British systems were no more than sophisticated man-made river diversions, rather than controlled water distribution systems, that diverted the waters from their natural river beds, to be 'picked-up' and used by farmers on their land. Crucially, the development of the distribution network and command area, that largely determined the afore-mentioned parameters, were left

[15] This included data from various countries (among which the USA, Italy, Egypt and Spain) that were partially collected by British irrigation officials during study trips. These data show that the different values adopted in Northern-India were comparable to those in the different regions of the USA. (Buckley; 1920)

to the farming communities, who could simply apply for an irrigation right and then had to build their own supply canals and 'hook them up' to the government main or branch canal. Since this connection consisted of nothing more than a simple open-cut, there was virtually no control on water being taken by each farmer or village channel. This process was somewhat regulated by the considerable financial needs to build a channel and invest in irrigated agriculture, thus initially limiting irrigation to those that could afford it.[16] As a consequence, the early development of irrigated command areas tended to be limited to a narrow strip along the government main and branch canals. Only a few were willing and able to bear the financial burden, at considerable risks, to construct and maintain the relatively large and long *Rajbulas* required to develop command areas further away from the government supply channels.[17] Once 'hooked-up' to the government supply system, rights to water use were established and claimed on the basis of investments made:

> "[...] *in some cases prescriptive rights in the water courses constructed by individuals in the early days of the canal have given rise to a certain amount of inconvenience, because, although the water pertained to the Government, the channel in which it was carried from the distributaries to the Villages belonged to the individual who had originally the enterprise to make it, and he consequently charged a further rate on all lands irrigated."* (Capt Ottley, Famine Commission; 1885:460)

The area to be irrigated, and the amount of water to be used, were thus in practice primarily determined by the capacity of the local community, or resourceful individuals, to invest in, and make use of, irrigation (for whom, for reasons described by Capt. Ottley, there was a clear preference to apply for, and invest in, one's own water course or *Rajbula* whenever possible). However, the 'narrow' limits of command area development would naturally lead to relatively low efficiencies of water use, that would push farmers to increase their cropping intensities beyond the policy targets. That, under these circumstances, the majority of well-tracts, that were considered protected against famine, also hooked-up to the irrigation systems, is not surprising. The practically commandable area proved much smaller that the potential when left entirely dependent on the financial and entrepreneurial participation of the local communities, putting considerable stress on the Irrigation Authorities to prove the success of their systems in these areas. Secondly, it were the well-owners and users that were most likely to possess the financial means to invest in canal irrigation.[18] Although the absorption of well-irrigated land into

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[16] Farmers could apply for a *Tukavi*, or government loan, to help finance the construction of a canal. But it seems that these loans were not very popular among farmers and not exactly eagerly taken up (Famine Commission; 1885:450).

[17] *Rajbula* is the Anglo-Hindi term for a distributary canal. From the accounts of the Famine Commission and Irrigation papers it seems, however, that this term was mainly used by irrigation officials to indicate farmer- or village-owned canals; and that the term distributary was mainly reserved for those canals that were gradually taken over by government and remodelled according to engineering principles. (*cf*. Famine Commission; 1885, Kennedy; 1882, 1898, 1905) The risks for farmers to built their own *Rajbulas* were considerable, consisting of the troubles of siltation, that could render a wrongly or poorly build canal useless in a matter of months, or otherwise require large financial and/or labour investments in order to maintain it.

[18] Stone (1984) gives a nice account on the economic rationale for well-irrigators to hook-up to canal irrigation;

(continued...)

canal-irrigated land would initially have given little financial profit for the state - since well-irrigation land revenues were equally assessed as irrigable land - the Irrigation Authorities would certainly have an interest in adding those revenues to the overall remunerativeness of their systems.[19]

The Irrigation Authorities could arguably have tried to control the initial development of irrigation by imposing strict rules on the size and course of community canals allowed to hook-up, and the area thereby permitted to be irrigated. But, it was equally in their own interest to work in collaboration with local communities to meet the targets of their systems and promote the rapid development of command area and irrigation intensities to figure in the general statistics. However, the limits of growth were fairly quickly reached in a contracted command area. 'Uncontrolled' intensification of irrigation eventually led to serious water distribution problems as head-end users started to take ever larger quantities of water and expand and intensify cropping at the cost of tail-end users. The situation clearly required further extension of control by the Irrigation Authorities. This started with the reforms enacted in the Canal and Drainage Act of 1873.

2.3 FORMAL LAWS AND CONTINGENT MANAGEMENT

> *"In truth, the full benefit of the engineering skill and knowledge can never be applied to the construction and maintenance of the works unless the engineers are constantly watching their operation and have an intimate acquaintance with all their peculiarities and the precise wants which they are to supply. Not only is professional knowledge necessary to secure the best management, but a complete practical knowledge of the details of management is necessary to secure the most satisfactory application of professional skill to the works. To know best the design and construct the works, the engineer must know how they are used; and to know how best to use the work, the managing officers must have engineering knowledge. The conclusion seems unavoidable, that the engineer should have the management of irrigation.* [...] *I dispute the position that, under a reasonable system, professional engineers would be one with less capable of dealing justly with established right to water supply than the district revenue officers, or less careful of the interests of the community and of the public revenue dependent on the efficiency of the irrigation, or less able to command respect and co-operation from the people of the country in which the works lie.* [...] *As to questions of laws, rights, and customs, so far as these really affect the management of irrigation, I can conceive no reason why they should not be as well understood by a specially trained class of engineers as by the revenue officers."* (Strachey, quoted in Famine Commission; 1885:443)

(...continued)

arguing that the latter was much more profitable.

[19] The early revenue system that assessed the tax rate on the basis of potential land use charged an 'enhanced land revenue' rate on the basis if land was irrigable from a given source (well or canal), irrespective of whether it actually was irrigated or not. Eventually this assessment system caused problems to the Irrigation Authorities themselves, as farmers claimed water on the basis that their entire landholding was taxed as irrigable, even through irrigation was intended for only 42.5 percent of the landholding (*cf.* Famine Commission; 1885). The problem was solved by reforming the revenue system by charging "irrigation service fees" through the occupier's rate (or *Abiana*), which was assessed on actually irrigated crops brought to maturity.

Not only could these words of Richard Strachey be an appropriate prologue to the Canal & Drainage Act of 1873 enacted in northern British-India, and which is still upheld in present day Pakistan; in a political sense they are its prologue. Strachey, as the first Inspector-General of Irrigation (1866-69), later member of the Council of India (1869-71, 1879-89), and president of the first Famine Commission (1878-80), was instrumental in the promotion of the Irrigation Authorities' role in managing irrigation affairs and its formalisation and institutionalisation through the Canal & Drainage Act of 1873. With the Act, the irrigation engineers, through the office of Canal Officers, were put at the centre stage of irrigation development and management, by empowering them to shape and take control of regulation of water distribution by both technical as administrative means. With the enactment, irrigation affairs were essentially relegated to a separate juridical domain, to be administered by the 1st and 2nd class Magistrates, embedded within the duties of the Canal Officers.[20] These extraordinary arrangements were necessary in the view of irrigation professionals like Strachey. Effective water control by irrigation professionals required that the deficit in technical water control could be offset by their control of administrative and judicial issues, to safeguard the interests and requirements of irrigation. As Strachey successfully argued, the latter demanded professional knowledge of the technical complexities that rendered water control feasible and sustainable.

With the Act the water regulation capacity of the Irrigation Authorities was extended on three important fronts:

- *Rajbulas*: In order to stimulate command area development, the village or private ownership of supply channels was restricted to those water courses within the tertiary units - the maximum length of which was limited by law to two miles. The existing *Rajbulas* were gradually taken over by government and remodelled according to engineering principles to distribute water among the different water courses. In all new developments, the distributary canal network would henceforth be built and completed by the government before irrigation water was supplied.

- *Outlets*: The management domains of the Irrigation Authorities and water users were clearly defined and split. Henceforth, the outlet was defined by law as the delivery point where government water was delivered to the community. The outlet itself was defined as government property; all regulation of water upstream and through the outlet became thus exclusively the management domain of the Irrigation Authorities.

- *Tatiling*: In order to regulate water distribution and secure water delivery to the extremities of the command area, Canal Officers were empowered to close off temporarily the water supply to tertiary units, to implement rotation schedules (known

[20] Even today, the Canal & Drainage Act of 1873 is still upheld in Pakistan, and still forms a separate juridical domain, in which the Civil Law and Courts have no jurisdiction: *"Civil Court has no jurisdiction under this Act being a special enabling Act dealing with the use and control for public purposes of the water, as explained in the preamble, except as provided under Section 68 only, with a view to find that the provisions made in the section to be followed are properly acted upon."* (Nasir, 1993:3)

as *Tatils*). Section 32 of the Act contained provisions for Canal Officers to regulate water flow through outlets as they deemed fit.

Through these increases in managerial control the Irrigation Authorities could seek the optimisation of command area development and tighten their grip on performance parameters. By taking over the distributary network the water supply could be physically extended over a larger (and particularly broader) area, while the development of tertiary command area by local communities would be stimulated by the reduced costs of developing a conveyance network.[21] By appropriating the outlets, the number and size of water courses, and hence tertiary command areas, could be actively regulated. While with the implementation of *Tatils* the even distribution of water, and hence irrigation intensities, could be ensured. In short, active management of the performance parameters was enabled and promoted.

Although the management capabilities were thus greatly enhanced to control the parameters of irrigation, the actual regulation on the ground was severely hampered by the technical inabilities to control silt and discharges. The high concentrations of silt suspended in, and carried forward by, the river water taken in by the irrigation systems tended to result in 'unstable' canals, causing many troubles for the irrigation engineers, that required continuous attention and maintenance. The main trouble of 'unstable' canals was that their hydraulic capacities changed over time, either by silting up or scouring (or both at different sections of the canal), that immediately affected its carrying capacity, and hence its ability to deliver and distribute water.[22] These 'unstable' channels would effectively have varying *Water Allowances*, as a consequence of which the Irrigation Authorities could not fix the irrigation parameters in their operational management, but instead had to continuously adapt them to the new and changing capacities of the canals. This situation was further exacerbated by the inability of the Irrigation Authorities to effectively control the discharges through the outlets. Considerable improvements were first made in this regard by disallowing the open-cut 'outlets' and replacing them by standard sized *Colabas*[23]. However, their discharge would frequently vary either as a consequence of changing water levels in the supply canal due to scouring or silting, or by 'excessive' silt clearing in the water course by water users so as to increase the hydraulic head. As a result the irrigation

[21] It was not uncommon practice of the Irrigation Authorities to further stimulate the up-take of irrigation by applying reduced "development" *Abiana* revenue rates during the first years of use in a newly developed system. (RCAI; 1927)

[22] The problems associated with siltation in irrigation canals were very severe in the irrigation canals of the Indus-basin. It still remains today a problematic field, which in hydraulic analysis can only be coped with through empirical formulae. The two most known in the field of irrigation are both products of British irrigation engineers; i.e. Kennedy (1885) and Lacey (1929). When irrigation canals are in 'regime' they have reached a natural balance, in which the amount of scouring and sitlation that takes place is about the same, and its hydraulic features remains stable. The problem is, that this is a very fragile balance which is easily disturbed, and dependent on the discharge run through the canal, and the type and amount of silt carried in suspension in the water.

[23] The *Colaba* consisted of a simple pipe or barrel outlet. A *Colaba* was defined in a standard size of a single pipe with a diameter of six inches, or a multiple of the standard. In order to regulate the flow to be supplied to a *Chak*, the irrigation engineer would consider a specific ratio between the 'outlet orifice area' and the command area of the *Chak*; since no water levels or working heads were taken into account, the actual discharge through such an outlet remained an unknown and neglected quantity. (Mahbub & Gulhati; 1951).

systems remained highly dynamic in their features and their abilities to sustain increasing irrigation intensities and further expansion. *Tatiling* was basically the essential management response to regain water control on the ground, and try to repair the water distribution conditions that were undermined by siltation and/or over-drawing outlets.[24] However, this always remained an immensely cumbersome management tool that was susceptible to tensions, corruption and hassle that undermined its effectiveness:

> "[...] *for on outlets we have no power of control, and any attempt to introduce* [tatils] *always has resulted, and will always result, in the upper channels and owners who are willing to pay for the privilege, getting far more than their proper share.* [...] *The attempt to enforce tatils on minors by locked gates is invariably useless as the key must necessarily remain with Patwaris, or other equally untrustworthy subordinates; moreover keys have been made up by the village blacksmith before now."* (Kennedy; 1898:37)

Due to this inherent lack of technical water control it was thus impossible to formulate a water allocation procedure within the Canal & Drainage Act. Since the rate of water delivery at the outlet could not be controlled, let alone guaranteed, the Irrigation Authorities could not be committed to a formal allocation. By default, the water distribution and definition of 'proper' shares had to be conducted through application of policy targets for the irrigation parameters and the benevolent philosophy of 'equity' and 'fairness'. However, these parameters were directly dependent on the rate of water supply that could not be effectively controlled. Thus these had to be managed by secondary means such as the size of outlets and permissible command area, while the irrigation duty and intensity could be applied as indicators to decide whether proper and fair distribution was reached. The juridical framework and penal code of the Act were carefully framed around this requirement. It granted both substantial discretionary powers to the Canal Officers to decide what constitutes a 'fair and square' water distribution, and also all means to take corrective measures by changing outlets and command areas or implementing rotational schedules.

There can be little doubt that the philosophy of a 'fair', 'proper' and efficient water distribution was nurtured under the irrigation professionals of British-India.[25] They sought ever increasing and more accurate control of water distribution in their irrigation systems so as to optimise the command area expansion and irrigation intensification. These contradictory objectives were the crucial elements to reach remuneration and politically secure further developments in irrigation. In practical management affairs, however, the inherent contradiction between expansion and intensification, inevitably led to dilemmas. Increasing irrigation intensities could be seen to indicate over-delivery of irrigation water, which would infringe upon the potentials to expand the command area. However, they were simultaneously indications of the desirable increased

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[24] Siltation and over-drawing tend to go hand-in-hand, as siltation in a canal section leads to higher hydraulic heads at the outlets, causing them to draw-off more water than before, while the amount of water carried by the canal itself is reduced due to the siltation; the resulting skewed water distribution is thus inherently exacerbated.

[25] This is attested by the language used in the contemporary professional documents, and the numerous expressed concerns in spreading water 'fairly' and promote its efficient use. (*cf*. Famine Commission; 1881, 1885, 1898, Kennedy; 1882, 1883, 1898, 1905, Sharma; 1932 etc.)

water use efficiency that permitted water users to expand their irrigation. Moreover, it often proved difficult to enforce reductions in either water delivery or culturable command area, when exact water deliveries were not yet known and controlled, or canal capacities kept changing. Besides, the curbing of command area, even at the tertiary unit level, went against the grain of irrigation policy that was clearly targeted at extending irrigation to as large an area as possible through an irrigation intensity of 42.5 percent in average years, but allowing higher intensities (and thus increased revenue) in wet or good years. It was clearly intended that regulation of irrigation was to be conducted by restricting the water supply, and not the command area, so that the water users would have an incentive to increase water use efficiency through increasing their intensities. The problem of siltation also tended to aid the Irrigation Authorities in this regard, as it forced efficiency upon water users who tried to maintain the same levels of irrigation intensity with less capacity in the distributary canal due to siltation; thus effectively freeing up water in the main system for water short areas or further expansion (*cf*. Sharma; 1932, Jesson; 1940).

In this dynamic process of continuously trying to stabilise the irrigation canals, the test of 'fair' and 'proper' water distribution seems mainly to have consisted of securing a reasonable water delivery to the tail-end areas. These areas became increasingly deprived of irrigation water due to siltation and the 'growth policy' of extending culturable command area and intensifying cultivation. The only means available to ensure this, were thus by indirectly imposing higher water use efficiencies, by reducing the water supply through *Tatiling* and reducing the water allowances at the canal heads. These actions resulted in a steady increase in irrigation duties over the years, reflecting increases in water use efficiency: *"It is interesting to note that duties increase as irrigation develops, and as experience, both on the part of cultivators and on the part of the irrigation officers, leads to improvements."* (Buckley; 1920:409) As data from the Upper Bari Doab Canal and Lower Chenab Canal indicate, these increases could be quite substantial. In the former, increases in *Kharif* duty went from 60 to 125 acres and in *Rabi* duty from 65 to 240 acres over 75 years; while in the latter *Kharif* duty went from 65 to 110 acres, and in *Rabi* duty from 65 to 200 acres over 50 years (Leliavsky; 1957:516).

2.4 GAINING HYDRAULIC CONTROL

> *"Each outlet is merely a small masonry culvert or barrel under the bank* [i.e. a Colaba], *with orifice sections so proportioned as to give the required discharge for the known area of land on each watercourse. As, however, the head or fall through the outlet is necessarily unknown, only a mere guess can in the first place be made as to the outlet dimensions. These are, however, built on a rough estimate of the probable requirements, and the distributary opened; and after a few years' experience and crop measurements, those outlets which have then done too much area per annum are cut down on a rough-and-ready calculation, and those which have not done enough are enlarged. This sort of thing goes on every few years, or rather, it should go on were every official in charge full of energy, and keen on taking up this troublesome and thankless work; but as a matter of fact it is often found that ten or twenty years may elapse and the final state be but little better than the first; for it must be remembered that local conditions, and levels in the distributary itself are always more or less unstable; the state of the watercourses varies much at different seasons; and finally, rainfall and demand are potent factors in*

all those irrigation statistics forming the basis of such readjustments." (Kennedy; 1906:5)

The above quote of Kennedy on the troubles of controlling and distributing the water within the distributaries provides a telling picture of the dynamics of irrigation development during the 19th century and how this was shaped by the lack of discharge control at the outlets, and hence the distributaries. By the end of the 19th century, however, important break-throughs in hydraulic science finally enabled the Irrigation Authorities to further extend their water control and seek more accuracy in water distribution. Paramount among these was Kennedy's critical velocity formula of 1885, which tackled the problems caused by siltation; henceforth irrigation canals could be designed and built (or remodelled) according to their stable 'regime' dimensions. The possible 'fixation' of hydraulic properties thus provided the means to consciously manipulate these hydraulic properties for the establishment of a particular water distribution - and subsequent avoidance of the costly and time consuming maintenance activities of de-silting and channel training. Also crucially, the ability to fix the discharge capacities of the canals (i.e. stabilise their water allowance) created the potential to accurately plan and manage the water distribution from head to tail by seeking discharge control at the outlets. Not surprisingly, the period from 1895 to 1922 was subsequently characterised by a frantic search for a suitable outlet through which discharges could be accurately, but simply, controlled and by which a congruent method of water distribution could be implemented.[26] The objectives of this search were simple and straightforward: to replace the pipe or barrel outlets (which afforded little water control as they are dependent on both up- and down-stream water levels, and as a consequence susceptible to manipulations by water users on the down-stream water level) with new outlet devices that were less sensitive to water levels and manipulations by water users. The newly created possibilities to take active, and accurate, control of discharges, from the intake of a system up to the outlets, drastically changed the outlook of the Irrigation Authorities on water management. The relative water supply at the outlets could henceforth be fixed in relation to the command area it served, enabling the Irrigation Authorities to take a stronger hold on the parameters of irrigation development. The cumbersome and frustrating practice of *Tatiling* could be relegated as an old-fashioned water management practice to be used as 'emergency' operations only (*cf*. Kennedy; 1882, 1898, 1905). As to the appropriate water distribution method to be implemented, two schools of thought emerged within the cadre of professional irrigation engineers. These differed radically in the principle of discharge regulation at the outlets that they propagated: (i) fixed constant discharge and (ii) proportional distribution of flow fluctuations.

The Module and its Constant Supply Rate

Kennedy was one of the engineers that pursued the development of the module outlet, and who placed great value on the measurability and reliability of water deliveries. Numerous fascinating

[26] Mahbub & Gulhati (1951) give an excellent overview of the developments in outlets structures in India, and their hydraulic principles. Bolding, Mollinga and van Straaten (1995) give an interesting account on the search for the module in connection with attempts to introduce volumetric water distribution and charging in the Bombay Agency.

structures were developed and tested during this period, aiming to produce an outlet structure that would supply a constant discharge to the tertiary unit, independent of the flow variation in the parent channel and the downstream water conditions in the tertiary water course. The motivation behind this impossible quest, was the promise of eliminating the variability in water supply and distribution, and ultimately the mechanisation (i.e. automatisation) of irrigation water delivery according to an efficient plan of distribution. Apart from the hydraulic limitations of pipe or barrel outlets, the problems of skewed water distribution were also attributed to the whimsical utilisation of irrigation water by water users. Correction of the water distribution would require an enforcement of further water use efficiency; and *vice versa*, the enforcement of water use efficiency would enable the correction of water distribution. The sizing of an effective outlet structure in relation to the command area it served was clearly the lynchpin in the realisation of these objectives. In their search for an effective module outlet, Kennedy and his colleagues aimed to provide an accurately defined and delimited constant discharge through each outlet. The outlet would be self-acting (i.e. automatic) since the Irrigation Authorities had no capacity to regulate the thousands of outlets under their command. Such a module promised big advantages in the enforcement of water use efficiency, as it would not only limit the use of water to a pre-defined maximum. It would also enable the conscious sizing of the outlet to the command area of the tertiary unit, thus deliberately fixing its relative water supply or water allowance. A reliable but limited supply would then induce water users to greater efficiency if they wanted to maximise their production. Furthermore it provided the potential to introduce volumetric charging for water in the future. This was regarded as another advantage that would incite water users to increase further their water use efficiencies.

Although Kennedy and his colleagues managed to produce a number of outlets that delivered a reasonably constant discharge over a relatively wide range of water conditions, the module and its conception of water distribution did not become the new paradigm of water management in British-India. The numerous empirical trials (many of them in the Punjab) had brought a few problems to the front:

- The outlets were fairly expensive due to their incorporation of complicated and fragile mechanical devices that, additionally, proved susceptible to manipulation by water users;

- The poor level of silt-induction of many of these structures immediately barred them from practical use, as they disturbed the fragile regime balance of the canals unacceptably;

- Crucially, they did not solve the problem of skewed water distribution adequately, since the inherent fluctuations in water supply (characteristic of run-of-the- river systems) would get concentrated in the tail ends of the canals.

This failure to introduce the module as the working solution blunted the high degree of optimism in a technological resolution of the problems in water distribution and efficiency. Nevertheless, an alternative approach was soon developed.

Self-Acting Proportionality

In the search for an appropriate outlet, the hydraulic jump had appeared as a condition of water flow that effectively barred the influence of downstream water flow conditions from interfering with water control measures taken upstream. Furthermore, this condition of semi-modularity proved to be easily containable and manipulable (in the sense of design). In 1922 Crump introduced two new outlets that took advantage of this semi-modularity: the Open Flume and the Adjustable Proportional Module (APM)[27]. Being an experienced engineer with responsibilities in operation and maintenance, Crump understood the problems and difficulties of controlling the water distribution throughout a canal system. Though his objectives and motivation were much the same as those of Kennedy and his colleagues, he understood that he had to deal with *"two independent difficulties, the requirements of which are in direct opposition"* (Crump; 1922:3):

- The fluctuations in supply levels that are intrinsic to run of the river systems; the effects of which can be mitigated by proportional outlets;

- The gradually rising and falling of (full supply) water levels due to silting, respectively scouring of the canal bed as a consequence of changing, or settling, regime; for which the installation of rigid modules can ensure that the supply to tertiary units remains close to the allocated discharges.

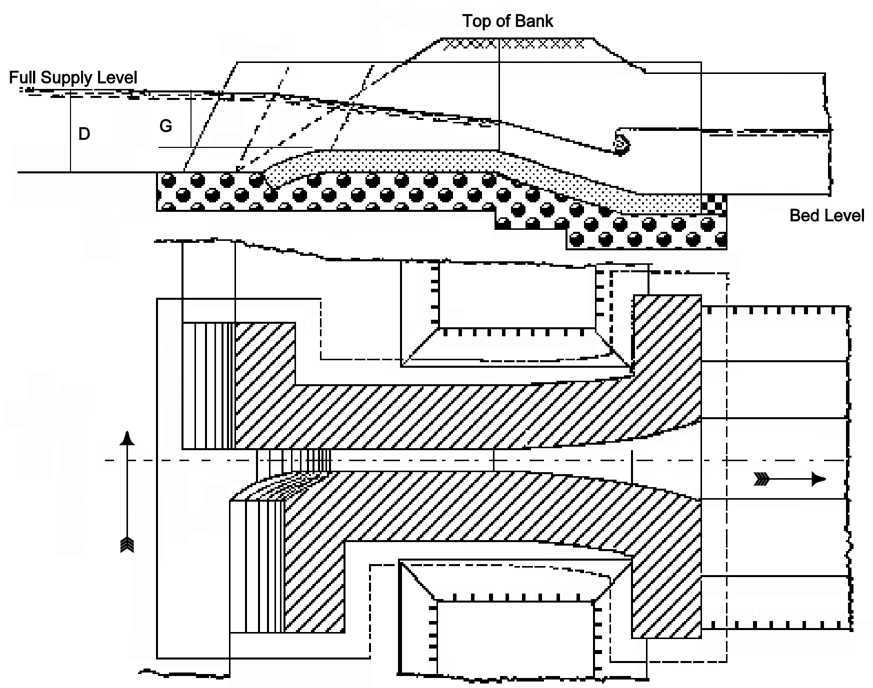
The challenge was thus to evolve a design in which the required rigidity would be kept to a minimum so to ensure an overall proportional distribution along the distributary (whether of shortages or surpluses), in order to guarantee that the tail reaches would get their fair share of water. In Crump's view it was essential to maintain proportionality not only within one distributary, but also within the whole system; not only for the mitigation of diurnal fluctuations, but also for the accommodation of different supply levels between the *Kharif* and *Rabi* seasons.The Open Flume and APM introduced by Crump are basically similar outlet structures (see fig. 2.1 and 2.2, respectively). They are remarkable simple masonry devices that can be built in situ, and consist of a narrow throat with a sloping sill; in case of the APM a rounded roof-block is placed on top of the throat to create an orifice. Both structures are supposed to work

[27] Strictly speaking the annotation of 'module' by Crump for his APM outlet is wrong, since it is dependable on the upstream water level conditions. However, Crump choose this annotation to indicate that the APM was relatively insensitive to small changes in upstream water level.

under a hydraulic jump, by which there is a simple stage-discharge relationship, in which the discharge is determined by the upstream water level and the width of the throat, and in case of the APM also the height of the orifice. Crump's hydraulic concept of self-acting proportionality is as follows: in a regime channel, there is a stable discharge at the head of the canal that yields a full supply level (FSL) (and depth) through the channel. By placing the APM and Open Flume outlets at an exact hydraulically specified depth, the allocated discharge can be cast in bricks for each outlet by setting the width and height according to the stage-discharge relationship. Once thus built, a 'Crump canal' would be self-acting in its water distribution between flow fluctuations of 70 to 120 percent of full supply (or design) discharge. Within this range, the Open Flumes deliver (when installed correctly) the exact proportion of their design discharge as on which the distributary is operated, while the APM function proportionally for small fluctuations around full supply, while delivering closer to design discharge under large fluctuations (*cf.* section 2.7 for exact details on the hydraulics of Crump's and Kennedy's water control concepts).

The latter was specifically intended to mitigate the effects of siltation in the head reaches of distributaries.[28] By limiting the operation of the distributary canals to within the reasonable and practicable range of 70 to 120 percent of full supply, a controlled and equitable water distribution was thus secured from head to tail, without the need of regulating or rotating flows at the outlets. Crump's proposal for remodelling canals on the basis of proportional water distribution with the application of Open Flume and APM outlets were taken up immediately for widespread

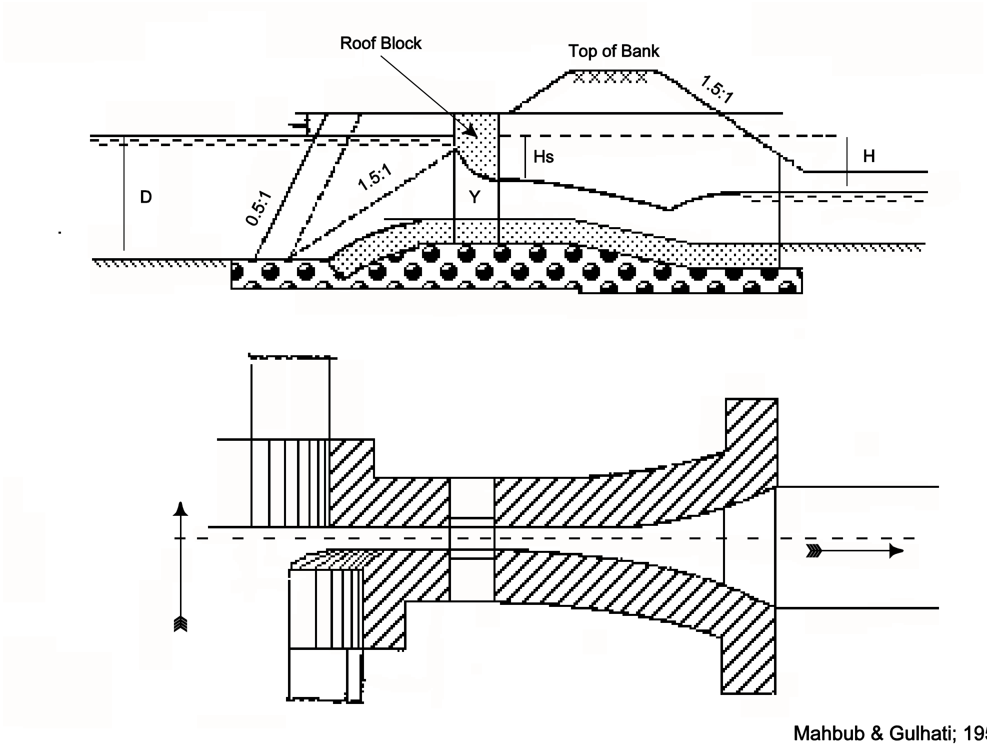
Fig. 2.1: Open Flume Outlet



Mahbub & Gulhati; 1951:69

[28] In addition, the APM had the advantage that in case of unexpectedly severe siltation (or scouring) it could be simply re-adjusted by loosening the roof-block, and re-installing and fixing it with a mortar key to its adjusted depth.

Fig, 2.2: The APM Outlet



Mahbub & Gulhati; 1951:79

implementation, covering 67 percent of all outlets in the Punjab by 1944, while 31 percent remained of the barrel type (see table 2.1). Besides the clearly demonstrated advantages of proportional distribution in self-acting canals, the proposed outlets had two more appealing features. Firstly, they were both remarkably simple devices, that could be constructed at relatively low cost and were relatively robust (i.e. tampering of their discharge regulation required physical damage). Secondly, they both possessed a very small Minimum Modular Head (MMH) – i.e. the minimum hydraulic head that is required to secure the semi-modular functioning of the structure – which made them suitable for widespread application in the relatively flat command areas of Punjab and Sindh.

This hydraulic concept, together with the design approaches of regime theory, thus provided the appropriate means for the 'fixation' and regulation of water distribution up to the tertiary level. The delicate balance of this hydraulic concept of self-acting proportionality comprises, however, three fragile components of potential disturbance:

- The sizing of outlets should meticulously reflect the allocated discharges of the tertiary unit. Any deviations or alterations in size immediately affect the proportionality of the canal and its subsequent tail delivery capacity. Authorised alterations of outlets require an accommodation of the changes in a new hydraulic balance between normal or full supply level and outlet settings.

- The proportionality of the canal is sensitive to the hydraulic settings of the outlets, particularly in the case of APM. The effective working head of the outlets should reflect the proportional settings, as any deviations or alterations will delimit the working range of supply variations, or alternatively affect the tail-end supplies.

- The hydraulic balance of the self-acting proportionality hinges on the correct definition of the normal or full supply water level and corresponding discharge, since all outlet settings are determined in relation to this water level. Any inaccuracies or changes in this water level-discharge relationship immediately jeopardises the proportional functioning of the canal.

Table 2.1: Number of Outlets of Various Types in the Punjab in 1944

Name of Canal System	Pipe or Barrel	Open Flume	Adjustable Orifice Semi Module	Harvey	Kennedy Gauge Outlet	Scratchley	Bend	Gibb's	Pipe cum Open Flume	Pipe cum OSM	Open Cut	Total
Upper Chenab	2,008	340	414	3	23	---	---	---	1	---	---	2,789
Lower Chenab	509	1,503	3,420	23	52	---	---	68	---	---	---	5,575
Upper Jhelum	3	368	347	---	---	---	---	---	---	---	---	718
Lower Jhelum	731	1,832	1,233	---	---	35	6	2	---	---	---	3,839
Lower Bari Doab	69	1,873	1,034	---	16	---	---	---	---	47	---	3,039
Western Jumna	1,781	1,031	1,259	60	2	---	---	---	---	---	11	4,144
Sirhind	257	539	1,641	3	3	---	---	---	---	---	---	2,443
Upper Bari Doab	1,640	1,413	1,113	30	11	---	---	4	---	---	---	4,211
Derajat	4,019	672	240	16	---	---	---	---	---	---	235	5,182
Ferozepore	699	850	1,617	---	---	14	---	---	---	---	2	3,182
Pakpattan & Mailsi	1,001	1,048	1,433	---	---	---	---	---	5	3	---	3,490
Haveli	96	987	1,438	---	---	---	---	---	---	---	---	2,521
Total	12,813	12,456	15,189	135	107	49	6	74	6	50	248	41,133
Percentage	31	30	37									100

(Mahbub & Gulhati; 1951:3)

2.5 CUSTOM OR CONTROL IN WATER DELIVERIES

With this ability to fix the water allowances of each canal by carefully maintaining its regime balance, and by controlling the discharges through the outlets, the Irrigation Authorities could finally exert technical control of the water distribution in their systems. This was a major turning point, in that henceforth the water distribution and parameters of irrigation could be accurately planned and implemented, instead of managing irrigation mainly by 'corrective' operations. The technical rationing of irrigation water could now be based and implemented on the regime carrying capacity of each canal (i.e. its water allowance) and the command area it served. To do this, the Irrigation Authorities were required to extend their administrative control further, and formalise the discharges through the outlets as well as the command areas of each tertiary unit or *Chak*. Subsequent remodelling of canals was undertaken frequently between 1890 and 1947. In remodelling, the allocation of water, in terms of relative water supply per unit of command area, had first to be conducted and formalised administratively before it could be implemented technically through specific hydraulic configurations of the canal and its outlets. This process became known as *Chakbandi* (lit. fixing of tertiary unit).

The principal aim of these remodelling endeavours was to rationalise the water distribution in ways allowing the Irrigation Authorities to control and conduct the water distribution in an orderly and planned manner, such as to secure a 'fair' and 'proper' distribution for head- and tail-end areas alike. To achieve the latter, abolition of the malfunctioning *Tatiling* was regarded a first priority. The new aim was to ration the water distribution in such a manner, that each canal would be able to supply all its outlets continuously with its regime water allowance, and that rotational water supply would be confined to the main system (i.e. rotating water between minors and branches/distributaries) in times of water shortage. (Kennedy, 1882, 1898, 1905) The latter was easier to oversee and implement by the limited staff of the Irrigation Authorities, as it confined the active regulation of water to a limited number of gates and places in the system.

As a first prerequisite, the Irrigation Authorities needed to fix both the size of the *Chak*'s command area as well as the rate of water supply through each outlet; i.e. the water had to be formally allocated in terms of a particular water allowance defined at the outlet. In practice, this meant that the remodelling of canals required a large number of re-definitions of the water distribution and re-alignments of the conveyance network. In this, in general the number of outlets and *Chaks* would be reduced through amalgamation of existing ones, and outlets would be downsized according to the newly defined rationed rate of supply. As a consequence of this new water distribution policy, the command areas of existing canals and systems had to be fixed in relation to their regime water allowances. This forfeited any future extension of command area as long as no extra water could be made available in the main system. Any growth in irrigation was henceforth limited to the intensification of the irrigated area within the tertiary units by increasing the water use efficiency or irrigation duty, which would permit more area to be irrigated by the same water allowance. In a successful remodelling, the result would thus be that:

> *"Most of the increase in the irrigation is at the tail of the distributary. The irrigation of the outlets in the head reach has not fallen because they had too much water before and wasted it in excessive waterings. Now they are getting the authorised supply and use water economically for the same area."* (Sharma; 1932:99)

The interference of the Irrigation Authorities in the water supply at the tertiary unit through *Chakbandi* in order to ration and rationalise it, was resisted, particularly from those standing to lose from it. The issue of 'established rights' to irrigation (water) was fiercely propounded by those concerned, in an attempt to salvage their favourable water supply conditions. To them, the sudden, and seemingly arbitrary, rationing of water supply and command area for the sake of efficiency represented a repudiation of the irrigation rights they had enjoyed so far, and of the considerable investments they had made to establish those rights.[29] In this ensuing conflict with the Irrigation Authorities, the influential landowners drew on the support of the *amir parwas* in the civil administration, as attested by the words of the Multan Commissioner Merk:

> *"From the point of view of a professional commercial department the cardinal maxim is to make the best use of the volume of water available. [But] it is quite another thing to introduce [rules] suddenly, arbitrarily, without compensation and without regard to established rights and interests that have been possessed and enjoyed for generations... The people have rights to which they are entitled under the law, if they are entitled to anything..."* (Merk (1908), quoted in Gilmartin; 1994:1141)

Seemingly, the administrative policy of coalescence was at stake, that made use of local and traditional institutions that were based on acknowledged notions of 'custom' and 'genealogical' leadership. A policy that tended to allocate 'privileged' and 'customary' rights to local elites as 'compensation' for governing their local communities in line with the interests of the colonial state or other services rendered. (*cf*. Gilmartin; 1994, Stone; 1984, Ali; 1988) The new 'efficiency water allocations' in irrigation, when conducted along the principle of equality, threatened to undermine the practice of 'privilege'. However, the Irrigation Authorities themselves were also heavily dependent on local and traditional community organisations for the water management at the tertiary level. Although the equity principle was imbedded in the *Warabandi*[30] time share allocation of irrigation turns as formalised in the Canal & Drainage Act of 1873, a formal *Warabandi* schedule tended only to be implemented when disputes arose within *Chaks* and were brought in front of the Irrigation Authorities for settlement. Thus as a result, by 1939 hardly half of all tertiary units in government systems had a formal *Warabandi* schedule drawn-up by the Irrigation Authorities (Gilmartin; 1994). Generally, the Irrigation Authorities chose not to intervene at the tertiary level unless strictly necessary, since they had hardly the means to get

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29 Even though most of the *Rajbulas* were already taken over by the Irrigation Authorities by the time they started to implement the *Chakbandi*, the conveyance network of water courses within the *Chak* always remained the property of the water users, which they had to build and maintain by their own financial means.

30 The formal *Warabandi* schedule is regulated by sections 67 and 68 of the Canal & Drainage Act of 1873. It provides for a time share allocation of the water delivered through the outlet, that defines the time and duration of each irrigation turn within a tertiary unit. It explicitly refrains from providing any guarantees or specifications on the quantity of water to be supplied through the outlet. Commonly, but not necessarily, the *Warabandi* is based on a seven day rotation, in which the 168 hours of continuous water supply are divided (up to the minutes) over all landowners proportionally to their landholding. (cf. Nasir; 1993, Malhotra; 1982)

actively involved at that level. (Ali; 1988, Stone; 1984) While it was clear that the Irrigation Authorities had to intervene in order to regulate water distribution and improve its efficacy and efficiency, there was technically no need to impose equity in water allocation among all water users. The political and administrative interests to continue with differentiation of 'privileged' or 'customary' rights could still be accommodated within the new technical requirements of water distribution, by formally granting different water allowances to different outlets/tertiary units. The rate of relative water supply could thus still be differentiated, as long as the total of rates of outlets granted along one canal did not exceed its regime capacity. What had to be conceded, however, was the equity concept of proportionality: this had to be limited to the even distribution of excesses and shortages of canal water supply over the outlets along the canal, in *pro rata* of their allocated discharges.

As far as the Irrigation Authorities were concerned, the critical boundaries within which differentiation of water allocation could be applied were clearly delineated by the regime capacity of the canals and their ability to supply all authorised outlets continuously without recourse to the malfunctioning *Tatiling*. Inevitably, this meant imposing higher water use efficiencies in head-reaches by down-sizing some outlets and rationing their frequently excessive water supplies.[31] The biggest problem, however, in the eyes of civil administrators and agriculturalists, was that allocation of water by rationing outlet sizes and command areas would seem arbitrary; particularly since a number of re-allocations and re-adjustments would inevitably take place in the course of ten to twenty years.[32] But it has been this specific requirement to accommodate the 'politically' differentiated water allocations that has impeded the Irrigation Authorities in defining a clear allocation policy in terms of a sanctioned water rate at the outlet. Not withstanding their technical ability to accurately fix and specify the sanctioned water allowances at the outlets, the Canal & Drainage Act was never revised to provide any procedures to conduct this allocation, nor to provide any guarantees to water users on the rate of water supply. Instead, it was simply left to the discretion of the canal officers to decide on each allocation and 'formalise' it in terms of outlet dimensions, full supply discharge and irrigable command area through (a simple) annotation in the Outlet- and Irrigation Registers. This could be revised by the same officers whenever they deemed it necessary. No doubt this was seen as a prudent solution for the juridical dilemma in which under the requirements of technical efficiency and limited supply it was inevitable that the 'privileged' water allocation to some *Chaks* could only be granted through deprivation of others. But the water distribution had to be literally cast in bricks. Thus the Irrigation Authorities had to take control over the water allocation, by compiling a delicate hydraulic configuration in which the stable regime water

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31 Particularly in the early remodelling endeavours, there was ample room for rationing down head-end outlets, since most of the *colaba* or barrel outlets tended to be relatively so large, that their water users could take water as and when they pleased (*cf.* Mahbub & Gulhati; 1951).

32 These frequent re-adjustments and remodellings were primarily the consequence of two factors: (i) it often proved difficult to strike the regime balance of a canal, and hence its stable water allowance, straight away with the limited empirical formula of Kennedy; (ii) until the massive implementation of Crump's outlets after 1922, most remodellings were done by using *colabas* or barrel outlets on which the Irrigation Authorities could not accurately control the discharges. It was thus only after Crump, that they were finally able to produce stable canals with accurate hydraulic configurations in which the elements of the water allocation could be settled. (*cf.* Mahbub & Gulhati; 1951, Kennedy; 1898, 1905, 1906, Sharma; 1932, Jesson; 1940)

allowance of a canal would be divided-up over all its outlets, in such a manner that all of them would receive their sanctioned discharge on the basis of continuous supply. But as to allocation of sanctioned outlet discharges, they could still take the 'customary' or 'privileged' water rights into secondary consideration to differentiate between the *Chaks* of one canal.

As a result, the remodelling of canals according to the technical requirements of regime and controlled water distribution could still frequently result in highly differentiated water allocations. Not only between the different systems or distributary canals of one system - as could be expected from having to settle into their natural regime discharges[33] – but also among the outlets of one canal. Since most of the old British systems in the Indus-basin were never again officially remodelled after 1947, the majority of those allocations are still upheld officially today.[34] At system level, the eventual balance that could be struck between regime discharge capacity and culturable command area finally resulted in large differences in relative water supply, ranging from 0.28 to 1.37 l/s/ha (4.01 - 19.95 cusecs/1000 acres) for 44 systems in present day Pakistan (Jurriens et. al.; 1996). Within canal systems, the same degree of variation and differentiation could be found in water allowances at the head of the distributaries (see table 2.2), leading to considerable differences in relative water supply for different areas in the system. It becomes apparent that equity, in terms of equal water allowances, was certainly not a rule in water allocation for the Irrigation Authorities, even though it might have been their philosophical ideal, as shown by the large variation in official water allowances among outlets of one canal (see table 2.2). After Crump's hydraulic control concept, there was certainly no longer a technical excuse to justify such differentiations in water allocations, by which some *Chaks* were clearly more privileged than others. Moreover, the differences in allocation were often substantial. They represent the difference between irrigating only part of a command area or nearly all of it, or growing water consuming cash crops as sugarcane and rice or not.

With the new colony canals – where huge tracts of crown waste land were converted into productive and profitable agricultural land – a great new means to apply the 'political favouritism' of the *amir parwas* became available, that would effectively ease the pressure put upon water allocation: the allotment of prime agricultural land. Instead of having to appease the 'political favouritism' by generous water allocations, this could be done by granting extra land with water rights under favourable financial terms, or simply as compensation for services rendered to the state (*cf*. Buckley; 1920, Ali; 1988, Stone; 1984, and Whitcombe; 1983). It was thus in these colony or settlement schemes - the latter serving specific political objectives - that the Irrigation Authorities were in the position to bring their water control and distribution concept to fruition. This was particularly so in schemes developed after 1922, when they had all the technical means to specify and control the water distribution accurately, and even started to develop the tertiary units themselves in well delineated blocks before settlement. They could simply plan and set the water allowances of all the outlets before any land and accompanying

33 Although canals whose regime would settle to give high water allowances could arguably have been reduced by further expanding those canals, or making water available for further expansion in the main system, and thus might in some cases also be considered a reflection of privileged allocations.

34 It is not uncommon that the design dimensions and water allocations of the outlets are still based on the design sheets of the latest British remodelling, that generally took place between 1930 and 1947, and consisted of fitting in the Crump outlets.

water rights were granted! Under such favourable circumstances it was of course fairly easy and straightforward to just simply apply the proportional equity principle, and set the water allowances equally for all outlets along a canal in order to meet the policy targets for command area, irrigation intensity, and remuneration.

The Lower Swat Canal in the North West Frontier Province (NWFP) provides an example of such a successful implementation of the proportional equity principle in a settlement scheme. Although this was already commissioned in 1885, the official water allocation that was implemented during the remodelling according to Crump's hydraulic concept in 1933, 1941 and 1944 of the different distributaries of its Charsadda sub-division, resulted in a remarkably uniform water allocation with an average water allowance of 0.36 l/s/ha and a coefficient of variation of only 4.9 (min. 0.26; max. 0.46; n=258) (GoNWFP/PID; 1988). Meeting these targets, however, did not always prove any easier. This was attested by Mr. Walker in 1927 (Secretary of Irrigation for NWFP), when he had to defend the poor performance of the costly Upper Swat Canal system that was facing problems still familiar today in newly developed systems. Thirteen years after its commissioning, still only half of its command area was developed and actually irrigated, by which the system was forced to be run on excessively low irrigation duties and considerable waste, since all canals had to be run on design capacity to guarantee an orderly water distribution. As the consequence of which, those that did make use of the abundant irrigation water had little notion of the intended rationing of water supply as contained in the official allocations. As to the reasons for the occurrence of this situation, Mr. Walker stated the chronic lack of tenants and *"the general apathy of land-owners towards their estates"* (RCAI; 1927:99).[35]

[35] Mr. Walker's refraining from mentioning landowners as part of the problem suggests that nearly 100,000 acres of irrigable land had been granted to (large) landowners that were not in the capacity of cultivating their landholding. As Stone (1984) and Whitcombe (1983) argue, settlement schemes such as the Upper Swat Canal were highly appropriate for the appeasement of local Chieftains and the honouring of military services rendered by indigenous recruits; as it seems from this case, the level of 'honouring' or 'appeasement' could be somewhat lavish. To ameliorate the situation, Walker was even disposed to provide further lavish 'incentives' as granting *Tocavi* loans, reduced *Abiana* fees, and even free crops (i.e. no *abiana* charges) for areas under first time irrigation (RCAI; 1927).

Table 2.2: Variations in Officially Authorised Water Allowances at Canal Head and at the Outlets for different irrigation systems in Punjab and NWFP. (After Bandaragodda & Rehman;1995)

Canal	**Sample Size**	**Water Allowance in [l/s/ha]**			**Coeff. Of Variation**
At Distributary Head	(n)	Minimum	Maximum	Average	[%]
Lower Chenab Canal a)	03	0.19	0.32	0.24	29
Fordwah Branch Canal * b)	16	0.33	1.03	0.54	32
Fordwah Branch Canal b)	06	0.26	0.42	0.31	18
Kabul River Canal 1913 c)	05	0.44	1.64	1.02	45
KRC 1949 d)	05	0.31	0.83	0.58	32
KRC 1994 e)	05	0.38	0.92	0.64	31
At the Outlet					
Lower Chenab Canal					
Mananwala a)	74	0.13	0.52	0.15	35
Karkan a)	47	0.17	0.30	0.20	08
Pir Mahal a)	47	0.20	0.84	0.27	58
Junejwala a)	19	0.14	0.28	0.21	13
Fordwah Branch Canal					
Azim * a)	75	0.38	0.67	0.44	14
Fordwah a)	87	0.24	0.55	0.26	14
Kabul River Canal ('94)					
Hazarkhani f)	48	0.41	0.98	0.63	13
Kurvi f)	32	0.13	0.94	0.66	24
Pabbi f)	11	0.15	0.79	0.42	44
Jamrao Canal					
Bareji (1984) g)	23	0.08	0.45	0.20	34
Nara Canal					
Heran (1932) g)	24	0.17	0.39	0.27	20
Rohri Canal					
Dhero Naro (1932) g)	25	0.18	0.34	0.23	16

a) Bandaragodda & Rehman;1995, b) Kuper; 1997, c) GoNWFP;??, d) GoNWFP; 1952, e) GoNWFP/PID; 1994a, f) GoNWFP/PID;1994b, g) Lashari & Murray-Rust; 2000. * Non-Perennial Canal

2.6 THE HYDRAULIC CONFIGURATION OF SELF-ACTING PROPORTIONALITY

> *"An irrigation system in its parts comprises a very delicate machine, and these several parts constantly require adjustment and overhauling; to deprive the machine of these adjustments can only spell immediate loss of efficiency and in a very short time disaster."* (Gee (1914) quoted in Gilmartin; 1994:1138)

In order to gain and maintain the hydraulic control on water delivery and distribution that Kennedy, Crump and their colleagues were seeking with the development of new outlet structures, they had to gain insight in the hydraulic configuration and properties of the irrigation canals and their structures. This became particularly important as the quest for hydraulic control was geared towards self-acting outlets that would 'automatically' regulate the water distribution without the need for human intervention or regulation. In such cases the outlets have to be hydraulically configured so as to function (i.e. self-act) conform the water distribution objectives and design criteria. If not, this will inevitably lead to water delivery and distribution problems in the tails of the distributary canals, for which no 'easy' or straightforward solution would be at hand as: (i) the dreaded *tatiling* would only provide a mitigation of the problem that represented a malfunctioning practice the abolishment of which formed one of the prime objectives for the innovations of self-acting distribution; (ii) the re-configuration of the canals through re-design and remodelling required large amounts of time, money and attention, and furthermore re-opened the issue of water allocation.

To quantify the distribution pattern he was seeking, and to determine the exact degree of proportionality he needed to and could achieve, Crump (1922) defined the hydraulic ratio of flexibility:

$$f = \frac{dq/q}{dQ/Q} \qquad (1)$$

In which f is the flexibility [-], q the off-take discharge and, Q the parent channel discharge at the off-take. When f reaches unity, and thus the relative change in off-taking discharge equals the relative change in parent channel discharge, proportionality is secured.

In order to make the hydraulic flexibility easily applicable it is desirable to relate it to water levels instead of discharges, especially since the latter were difficult and cumbersome to determine in Crump's time. For an open non-regulated channel the discharge can then be related to the water level as:

$$Q = C * d^{n} \qquad (2)$$

In which Q is the parent channel discharge, C a co-efficient of discharge, d the water depth, and n index of d.

Similarly, the discharge relation of an outlet can be described as:

$$q = C * h^{m} \qquad (3)$$

In which q is outlet discharge, h the working head over the outlet, and m the index of h. Substituting (2) and (3) in (1), it thus follows that:

$$f = \frac{m}{n} * \frac{a}{h} \qquad (4)$$

From the application of either Manning or Chezy formula for open channel flow, it follows that the index n equals 5/3 for non-regulated conditions (Crump, 1922; Mahbub & Gulhati, 1951; and Albinson, 1993). For any overflow weir type structure under free flow conditions, such as the Open Flume introduced by Crump (see fig. 2.1), it follows that the index m equals to 3/2. Substituting these values in equation (4) yields thus the flexibility function for a weir type off-take in non-regulated channels:

$$f = \frac{9}{10} * \frac{d}{h} \qquad (5)$$

The flexibility of a weir type off-take is thus determined by the water level over the crest (h), and will reach exact proportionality when the crest is set at 0.9d below the canal water level, and flexibility equals unity.

For an orifice type of outlet under free flow conditions (i.e. semi-modular), such as the Adjustable Proportional Module (APM) introduced by Crump (see fig. 2.2), it follows that the index m equals 1/2, thus yielding a flexibility function of:

$$f = \frac{3}{10} * \frac{d}{h} \qquad (6)$$

In this case the flexibility is thus determined by the head over the orifice, and will reach exact proportionality when h equals 0.3d below the canal water level.

Both equations (5) and (6) can be re-expressed in ratio's to design levels, so as to facilitate the comparison of flexibility values under different levels of supply. For weir type off-takes it follows:

$$f = \frac{9}{10} * \frac{D}{D - cw} \qquad (7)$$

Where D [-] is the parent channel water depth expressed as the ratio of the design water depth, and cw [-] is the crest height of the weir off-take expressed as the ratio of the design water depth.

Likewise, for an orifice type off-take:

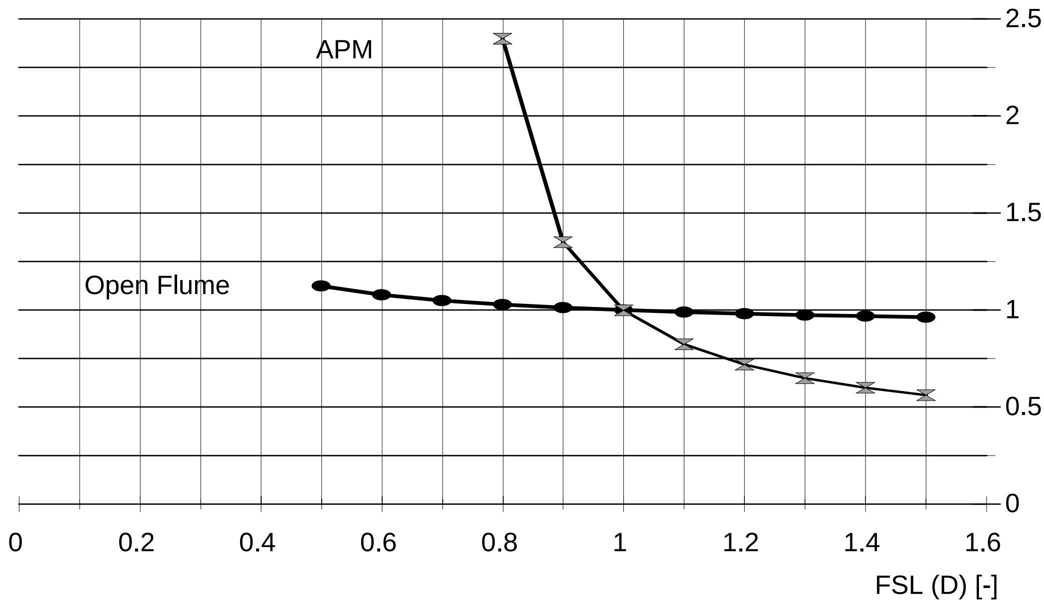
$$f = \frac{3}{10} * \frac{D}{D - co} \qquad (8)$$

Where *co* [-] is the height of the orifice above the bed level expressed as the ratio of the design water depth.[36]

The hydraulic flexibility thus makes it very clear that the degree of proportionality is highly dependent on the relative water depths over the off-take structures, as well as on the sensitiveness of the structure to changes in that water level. As such, the hydraulic flexibility is not a static characteristic, but will vary with the working range of water levels to which the outlet is subjected. Figure 2.3 presents the relation of the hydraulic flexibility for both Open Flume and APM under different levels of water supply. Both structures have been dimensioned so that a hydraulic flexibility of unity is attained for design conditions. From fig. 2.3 it becomes immediately clear that the weir type structure functions under near proportionality (*f* equalling unity) for a wide range of supply levels. The orifice structure, on the other hand, tends to become hyper-proportional (*f* > 1) when supply falls below design level, thus aggravating the shortages for the off-take; while it becomes rigid or sub-proportional (*f* < 1) when supply exceeds design level, thus increasing the excess water further down the parent channel.

In terms of realising a proportional distribution pattern, the Open Flume thus seems to be a remarkably appropriate and simple device. Crump realised, however, that their use was not always feasible, particularly in the head reaches of the canals. The relative large water depths

Fig. 2.3: Hydraulic Flexibility (*f*) for Open Flume and APM Outlets [-]



[36] Note: The point of measure for the orifice height is dependent on the type of orifice structure considered and depends on the value used in the discharge co-efficient: for the APM it is the soffit of the orifice (i.e. the roof-block); for the Neyrpic it is the centre of the orifice.

at the head of the canals would not always permit the installation of Open Flumes at their optimal depth of 0.9*D*, or result in too narrow throat widths. Moreover, the proportionality of the Open Flume would make it susceptible to the vacillations in discharges caused by settlement of regime. The effects of which, according to Crump, are amplified in the head-reaches of the canals. (*cf.* Crump; 1922)

Although Kennedy had realised a breakthrough with his formulation of the regime theory and critical velocity formula and design charts, one should bear in mind that these were far from perfect. The whole issue of regime behaviour of open channels was, and continues to be, an empirical approach to reach a natural state of balance. Kennedy's formula, and all subsequent refinements that have been made by Lacey (1929), Blench (1957), van Rijn (1984) and others, in principle remain an approximation of the natural process, derived from an accurately compiled data set. Blench (1957) neatly summarizes this aspect as *"all Lacey channels are regime channels, but not all regime channels are Lacey channels"*. The problem remains that the regime behaviour is very much dependent on the site specific nature of the silt and its temporal characteristics. So though Kennedy had set a new standard, the realisation of regime in canals remained a difficult and often problematic issue that required especially site specific empirical knowledge and experience.[37] The detailed accounts of Sharma (1932) and Jesson (1940) on the difficulties they encountered in establishing regime in the distributaries of the Lower Jhelum Canal between 1927 and 1938, are a telling tale of this less than perfect nature of regime theory.

Crump thus displayed a grave concern for unsettled regime and its effects on the water distribution throughout the canal. According to him this was a feature that particularly manifested itself in the head reaches of channels; in developing a regime slope the bed-level of the channel would gradually pivot around its tail, till it reached its regime balance. A process which according to him could be helped by splitting up the channel in a number of reaches with the help of semi-modular control weirs, providing thus a number of pivot points for the canal bed. Giving the impression that the canal beds would tend to pivot upwards, rather than downwards[38], his selection of APM outlets for those head-end reaches would be very appropriate to make sure that the tail reaches would not be deprived of their share of water. A scouring of the bed would equally secure the tail-end deliveries, be it at the cost of the shares of the head-end outlets. Although it is questionable to what extend Crump was aware of this latter implication, since he treated flexibility as a static characteristic, it could be relatively easy remedied by adjusting the setting of the roof block to the new prevailing conditions.[39]

The principal aim, however, remained to secure the flow deliveries towards the tail-ends of the canals, for which a proportional distribution had to be secured. In order to ascertain the level of proportionality in a canal with a number of outlet structures, it thus becomes desirable to determine the cumulative effect of the individual off-take characteristics on the on-going parent channel discharge. For this purpose Crump defined the flexibility *F* of the parent channel as:

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[37] Interestingly, it later appeared that the data set on which Kennedy had based his formula, was not quite as appropriate as he had thought, since it contained channels with different grades of sediment, and some of his channels might even have had inerodible beds (Blench; 1957).

[38] No verifications of these regime responses to the installation of control weirs have been found.

[39] The 'adujustability' of the roof-block in the APM, consisted of the loosening of the roof-block, readjusting, and refit it with a masonry key (i.e. cement), and was thus in no sense a mechanism for flow variability.

$$F = \frac{dQ/Q}{dQo/Qo} \qquad (9)$$

Where *Qo* is the normal supply of the parent channel at its head.

From (1) and (9), the flexibility of the off-take structure with respect to the head of the parent channel can be derived as:

$$f.F = \frac{dq/q}{dQo/Qo} \qquad (10)$$

The change in discharges flowing through this configuration can be determined as: F.Q at of the off-take structure; f.q through the off-take structure; and as F.Q + f.F.q upstream of the off-take. A fractional change dQ/Q upstream of the off-take structure will thus result in a flexibility:

$$F + \Delta F = \frac{F(Q + fq)}{Q + q} \qquad (11)$$

If now, the normal supplies of the channel, in the parent channel downstream the off-take and through the off-take, are expressed as fractions *k* of the head supply Qo as follows:

$$Q = k.Qo$$

$$Q + q = (k + \Delta k).Qo$$

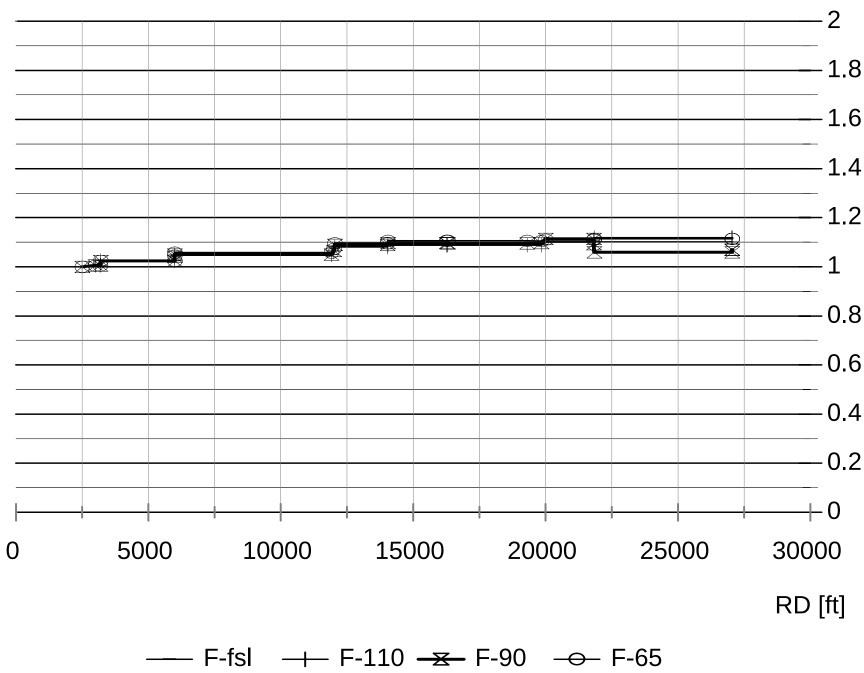
The fractional change up-stream the off-take can be rewritten as:

$$F + \Delta F = F.\frac{(1 + f\frac{\Delta k}{k})}{(1 + \frac{\Delta k}{k})} \qquad (12)$$

As any channel head can be considered to posses a flexibility of unity before it reaches its first off-take structure, the channel flexibility can be determined off-take by off-take.

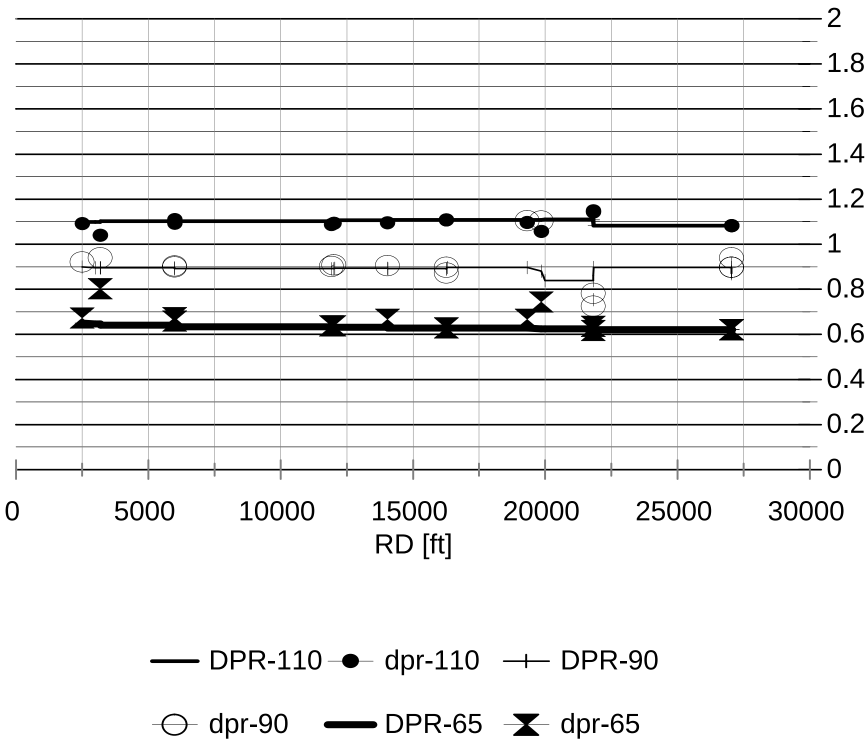
These ratios of hydraulic flexibility thus provide the means to consciously choose a hydraulic configuration for a canal, and determine its water distribution behaviour under different levels of supply. For the dilemma that Crump faced — having to provide for rigid outlets in head reaches while seeking proportionality[40] — it provides the means to determine how much the proportionality will be off-set by each non-proportional outlet that has to be put in. A flexibility analysis then shows, that a canal configuration possesses a degree of resilience to accommodate different water distribution structures. The smaller the ratio of off-taking discharge to on-going discharge is, the smaller its impact will be on the canal flexibility and subsequent tail-end delivery capacity. The 'flatter' the flexibility characteristic of the 'deviant' off-take is, the less sensitive it will be to changes in supply level. The confinement of the use of the APM in head-end reaches thus made Crump's proposal extremely feasible in the attainment of a proportional distribution over the length of the channel. A carefully configured channel, in which the Open Flume and APM outlets would be set at their proportional setting for normal or Full Supply Discharge (FSD) conditions, would thus yield a self-acting channel that could distribute its water according to the design ratios of outlet discharge. As is shown by figs. 2.4 and 2.5, a configuration of $f = 1.0$ results in such a proportional distribution for a wide range of supply levels (0.65 - 1.10 FSQ), thus securing the tail-end reaches of their fair share of water under varying conditions of supply. As a consequence, the rotational practice of *tatiling* could be discarded as long as the variations in supply would not exceed the proportional limits of the configuration. Figure 2.4 shows that the channel itself remains near proportional over its entire length, as the flexibility F remains close to unity. Figure 2.5 shows the same result in terms of

Fig. 2.4: Hydraulic Flexibility (*F*) for Crump Canal (*f* = 1.0) [-]



[40] Not quite realising that the APM possessed such a wide flexibility range (see fig. 2.3) Crump was under the impression that he had designed a rigid module with a flexibility less than unity, although fig. 2.3 clearly shows that it also can work under hyper-proportional (*f* larger than unity) conditions.

Fig. 2.5: Delivery Performance Ratio for Crump Canal (*f* = 1.0) for Canal Deliveries (DPR) and Outlet Deliveries (dpr) [-]



discharges.

The flow distribution pattern is shown here in terms of the Delivery Performance Ratio (DPR), defined as: the actual discharge divided by the design discharge. In the presented figures DPR (in capitals) is used for the characterisation of the discharges in the parent channel, while dpr is used for the discharges through the off-takes. The near horizontal lines of discharge behaviour reflect the near proportionality that is attained in the channel, by distributing the excess or shortage of normal supply equally over all the outlet structures.

In contrast, Kennedy's attempts to develop a rigid module, would have resulted in a diametrically opposed water distribution pattern, which is reflected in figs. 2.6 and 2.7. Where thanks to the self-acting rigidity of the outlet structures (f << 1.0) the discharge through the outlet remains remarkably constant under different levels of supply (fig. 2.7), but the parent channel itself becomes extremely hyper-proportional (F >> 1.0, fig. 2.6), thus making the tail-end reach extremely vulnerable to any form of supply variation. Although this configuration might provide advantages in delivering a nearly constant supply to the tertiary units, it puts an enormous burden on the operating agency, in that it will have to secure a minimum of flow variation at the head of each canal.

Fig. 2.6: Hydraulic Flexibility (*F*) for Kennedy Canal (*f* << 1.0) [-]

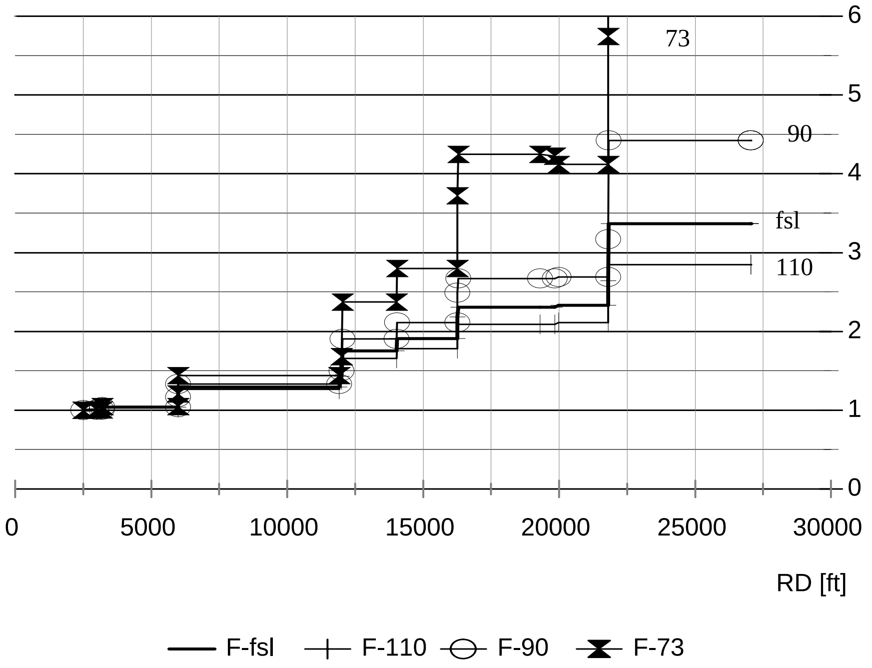
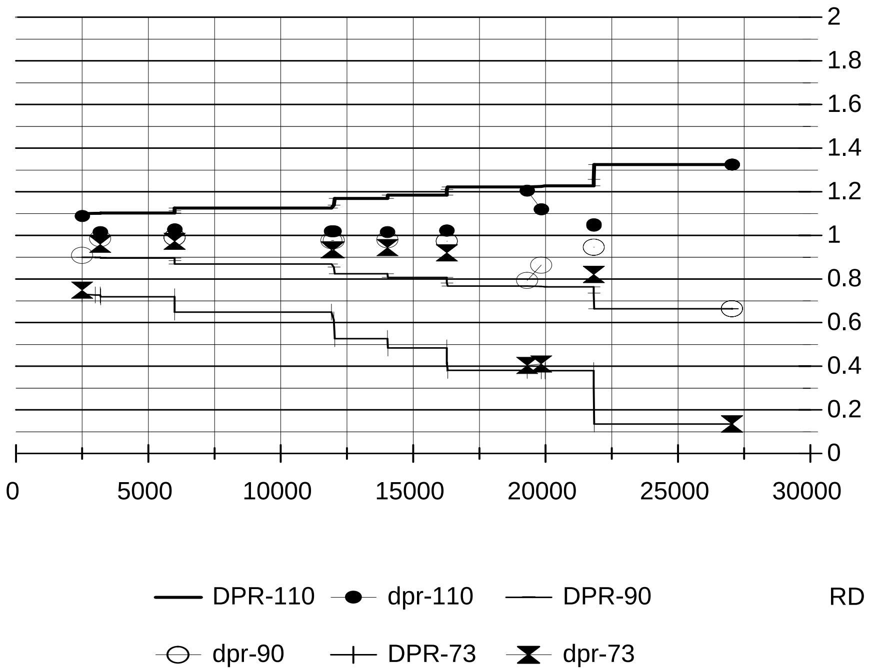


Fig. 2.7: Delivery Performance Ratio for Kennedy Canal (*f* << 1.0) for Canal Deliveries (DPR) and Outlet Deliveries (dpr) [-]



The fragility of the hydraulic configuration and its sensitiveness to the dynamics of unsettled regime, were experienced to the fullest by Sharma and Jesson in their attempts to 'fixate' the Lower Jhelum Canal system between 1927 and 1938. Although they meticulously implemented Crump's, as well as the regime theory's, design criteria, they faced immediate and paramount problems of siltation that completely undermined the water distribution in their channels (Sharma; 1932, Jesson; 1940). Careful observations led Sharma eventually to conclude that Crump's APM was a significant contributor to the problem, in that it did not take its fair share of silt from the parent channel and thus inevitably led to siltation of the downstream reaches. He solved this problem by modifying the design of the APM — and to a minor extent that of the Open Flume – so that its silt induction capacity was substantially increased. This single, but most important, modification to Crump's design criteria led to the lowering of the crest of the APM from the proposed 0.6 *D* to 0.8 *D*, and minor changes in the approach curvatures of the outlet (Sharma; 1940). In addition, the name of the outlet was changed into the more appropriate Adjustable Orifice Semi-Module (AOSM).[41]

The implementation of this new irrigation paradigm has been widespread and prolonged. The majority of the Indus Basin Irrigation canal systems have been remodelled during the 1930s and 1940s according to this concept. Even after independence, the Open Flume and APM/AOSM remained the standard outlet to be implemented according to the configuration settings as defined by Crump, and continued to be so well into the 1970s. As such Crump's notions on water distribution have had a huge impact on the development of the Indus Basin Irrigation system, in which they not only characteristically shaped the physical and hydraulic lay-out of the infrastructure, but also that of the management mode of operation.

2.7 THE MODUS OPERANDI FOR SELF-ACTING PROPORTIONALITY

With the gradual completion of the *Chakbandi* and the implementation of proportional water distribution, the operational requirements for water management had steadily increased. The principal objective to take control of the water distribution within the canal network in order to secure the water deliveries to the tail-end reaches, introduced the irrigation departments to the need to take operational control with more precision and more frequency. However, from the outset there has been an awareness that this increase in operational control had to be achieved within the limited capacities of the departments. Like all other realms of the public administration, the irrigation departments were set-up to serve a large as possible area with a minimum of staff, in which the capacity of the administration was limited by the availability of highly trained and specialised officers. The emphasis that was put on the self-acting nature of new developments in irrigation technology, reflect this managerial objective of minimizing the requirements for active control mechanisms.

Although some operational procedures were in place prior to the implementation of Crump's

[41] The seemingly long time it took Sharma and Jesson to solve the problems of the LJC system, is not only related to the problems of silt induction of the outlets. They basically faced the same problem at the distributary intakes, which took a long time to adequately solve. (Sharma; 1932 & 1940, Jesson; 1940)

self-acting proportional canals, the further developments of procedures and control mechanisms were closely associated with the hydraulic characteristics of these Crump canals. The operational procedures and objectives that evolved over the years, can be divided over two different types of control mechanisms: delivery planning and, feed-back control.

The crux of protective irrigation is the division of water over a large area, while limiting its use to a specific part of that area. By definition water is scarce, and its delivery, and use, needs to be restricted. As a consequence, the planning of that delivery needs to be governed by the availability of water for irrigation, rather than by the demand for it. This yields the opportunity to conduct this planning in a pre-determined and pre-fixed manner, in which the operational targets for the canals are fixed for a prolonged time to direct the day-to-day feed-back operations.

The process of *Chakbandi* has clearly been a crucial attempt by the irrigation departments to settle and formalize this planning of water delivery. The mechanism adopted in Northern-India was to restrict, primarily and principally, the delivery, by fixing the rate of water delivery through each outlet. A principal that amounted to a fixed water allocation for each tertiary unit. Although the cultivators were formally left free to decide upon their use of that restricted water delivery — that is, within the realms of the *Warabandi* — the fixed water allocations were 'translated' by the irrigation departments into feasible agricultural practices by way of the *Kharif* and *Rabi* Intensity Factors and crop water duties. As has been argued before, it profed to be impossible to conduct this planning according to a fixed set of rules and criteria; the allocation of water turned out to be not merely an issue of scientific efficiency, but of political interests as well. As to the principles that have been adopted in the politics of differentiation in water allocation, one can only guess and speculate as long as accurate research material on this issue remains absent. It seems likely, however, that the used expressions of KIF/RIF and irrigation duty, provided ample opportunities for affected land owners to enter into debate with the irrigation departments about the appropriate rate of delivery for their established irrigation practices; as the adopted irrigation duty, which reflected the conveyance and application efficiencies, would yield a specified rate of delivery for a determined cropping pattern and intensity.

How ever the negotiations and decisions on the rate of delivery were conducted and made, in the end they resulted in a significant differentiation between different *Chaks* and distributaries of one canal system. At some point or the other — particularly prior to remodelling — the rates of delivery had to be fixed, as it was an essential requirement for the technical strategy that was adopted. With the 'Crump canals' the distribution of water was to a large extent cast in bricks, in which the irrigation departments simply could not afford to keep on changing or adjusting the rate of delivery.

The day-to-day operations of the canal systems were mainly concerned with feed-back control mechanisms for stabilising the water distribution within the working range of self-acting proportionality, and the monitoring of its working. The central measure of control has always been the water level, which could be quickly and easily monitored, in relation to the Full Supply Level (FSL) targets. The water delivery, and its division over the secondary branch or minor canals, was governed by delivering a specific FSL target at each canal head.

- In times of enough water availability, FSL represented the operational target that had to be controlled at each division point in the system. Gate keepers at these division points could then simply engage into a feed-back cycle, in which the intake structure would be manipulated on the water level of the head gauge, just downstream of the intake.

- In times of less water availability, but enough to secure the lower limits of proportionality, the system could be operated on a percentage of FSL. The lower limit of the operational target was set at 75 percent of FSL. A value that was set on two grounds: (i) below 75 percent of FSL the proportionality of the canals could no longer be secured, since the APM/AOSM outlets would start to function in a hyper-proportional mode ($f < 1.0$), or start to operate as Open Flumes (i.e. water levels would fall below the roof-block) and draw significantly more than their proportional share; (ii) prolonged operations of canals below 75 percent of FSL could severely upset the regime balance of the canal. The gate keepers could then operate the same feed-back control mechanism as under normal supply, but to a new target level as specified by the canal officers.

- During shortages of water availability, when the lower limit of 75 percent FSL could not be reached, water would be delivered in rotation over the main system. The canal system would be split up in two or more sections, in which each section would receive in turn a water supply of FSL for the duration of eight days. The length of the rotation turn has been decided on the grounds that it would enable the supply of a full *Warabandi* turn (of seven days), allowing for one day of lead time to fill the channels.

These are the basic principles for operating the water delivery in the protective irrigation systems of the Indus Basin, and they are still common rules for the majority of systems which do not basically differ in their objectives and infrastructure from the 'state of the art' systems of 1930-1947. Although these rules cover the principles of water delivery that is driven by dividing the available water proportionally over its irrigation network, they provide no control over, and guarantee for, the actual working of that proportionality. This requires additional measures and procedures that are aimed at controlling the processes that might jeopardise the self-acting features of the hydraulic characteristics in the canals. A number of measures and procedures have been devised for this purpose, that together were meant to check the threats of siltation and outlet tampering.

The feed-back control based on FSL is, though very functional, quite susceptible to semantic errors; the control mechanism functions on the implication that the FSL reading of the head gauge reflects a full supply discharge delivery. In normal situations this correlation would be attained, provided that an accurate calibration of the head gauge had taken place. Any siltation or scouring that might occur on the canal bed, or even on the embankments for that matter, would result in an immediate error in discharge delivery as the target water level would no longer correspond to the design discharge of the canal. The monitoring of the tail gauge, more specifically the ratio between head and tail gauge, was the procedure that was devised to detect the occurrence of such problems. By configuring the tail reaches of canals such that the tail gauge would give a reading of 1.0 ft for design capacity, the proportional working of the canal could be easily monitored by its reading.

Though an effective measure for the detection of deviations in proportionality, the tail gauge reading would not provide any information as to the causes of deviation — i.e. wether by siltation or outlet tampering. An additional procedure was thus devised by Jesson (1940), who proposed to keep up a so called H-register. The H-register contained monthly measurements of the hydraulic heads (H) over de crest of each outlet when the head of the canal was supplied with FSL (or FSD).[42]In case of any detections of deviations in proportionality, the H-register could be consulted to determine at which point(s) in the canal the problem was caused. A closer inspection would then reveal wether the deviations in off-taking discharge were caused by changes in water levels due to silting/scouring or due to tampering of the outlets. Once the causes were thus detected, appropriate maintenance activities for the restoration of the self-acting proportionality of the canal could be devised and carried out.[43] Jesson devised this register specifically to tackle the problems he was facing with Sharma in remodelling the Lower Jhelum Canal into a self-acting 'Crump canal' between 1927 and 1938. He proposed to take the H-register up as a formal register in his contribution to the Punjab Engineering Congress of 1940 (*cf*. Jesson; 1940), well after the other registers were already in use. As such, it can be regarded as a final refinement of the concept of self-acting proportional distribution.

The principal objective of all these operational and monitoring procedures was thus to keep the self-acting proportionality of the canals running as intended. Feed-back to secure a stable output of proportional distribution was the sole and principle *modus operandi* of the system. It was designed, adequately and efficiently, to produce, and reproduce, a service output that was pre-defined and pre-determined on the basis of available resources. As such it could remain the same for a prolonged time, as it did not require, nor incorporated, any means for adapting its service output to changing circumstances. The latter could only be addressed by remodelling and re-configuring the distributary canals, in which the re-allocation of water and restoring of the self-acting proportionality could be carried out in light of the new balances of 'favouritism' and water availability and demand. The Outlet and Irrigation Registers were important tools in this, as they could be used as a double-edged sword: (i) to establish new practised norms of efficiency from those *Chaks* that achieved higher irrigation intensities than that of the policy norms; and (ii) cut back the water allowances, as the targeted irrigation intensities could be achieved with the new higher efficiencies.

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42 Under this condition, all measured and registered H-values should reflect their design values for normal, or 'proper', conditions.

43 One might think that a cunning misdemeanor would have been to only increase the width of an outlet in order to increase its discharge and leave its hydraulic head untouched. Although this might have stunned canal officers for a bit, the up-keep of the Outlet Register — which stated the full dimensions of each outlet — once a year, would have provided eventually for the required control. The only truly cunning manipulation is to leave the dimensions of an APM/AOSM outlet unchanged, but increase its discharge by aerating the orifice with the aid of a plastic hose.

2.8 DISCUSSION & CONCLUSIONS

This analysis of the historical trajectory of irrigation development in the Indus-basin by the British colonial (irrigation) authorities lays bare the roots of some of the most pressing problems of water control and distribution that Pakistan is still coping with in the present day. Skewed water distribution was a natural consequence of the limited technical control available in the early days to accurately regulate the water distribution in the system, and of the policy to spread water thinly over as large an area as possible. The problems of regime, and the inaccuracy of the open cut and barrel outlets, inevitably led to a differentiated water distribution that was as much shaped by the physical and technical constraints encountered in each case, as by the socio-economic opportunism of the early water users. With the formulation of the Canal & Drainage Act of 1873, substantial discretionary powers were granted to the canal officers to intervene in the water distribution as a means to strike a balance between the water delivered and the area irrigated.

With the advances in hydraulic science – most significantly those in regime theory and the ability to contain the hydraulic jump in simple and accurate outlet structures such as the Open Flume and APM, it became increasingly possible to take more accurate control of water distribution and the parameters of irrigation like water allowances and cropping intensities. With each of the subsequent numerous remodellings they undertook, the irrigation authorities were able to re-adjust the water allocation and distribution in their canals according to criteria that best suited the technical, political and economic interests of that moment – and trim any excesses in differentiation that had emerged. That at times this led to clashes between administrators and engineers was inevitable, since the interests of the former had to be subservient to the latter. As nicely reflected in Strachey's words, is was important to keep the control of water distribution, and the allocation of irrigation and water rights, in the hands of the irrigation authorities. In the end not so much to be able to impose equity, as to broker the allocation of 'customary' and 'privileged' water rights with the technical limitations of efficiency and efficacy.

Gilmartin (1994) argues that this conflict evolved into an institutional paradigm struggle between administrators and engineers. However, the failure to develop any clear water allocation rules and procedures within the Canal & Drainage Act, after the technical means were available to implement them, implies otherwise. Rather, it seems to indicate that in order to prevent the threatening conflict of paradigms – between or within the different branches of the colonial administration – it was better to forfeit the formulation of a clear water allocation policy. The formal differentiation in water allocations granted during the remodellings and implementation of Crump's water control concept during the 1930s and 1940s attest to this. It shows that the irrigation authorities were perfectly able – as argued by Strachey – to appease both the political interests of 'privilege' and the needs of technical efficiency.

The various outlets developed and used by the irrigation authorities, such as the *colabas*, modules and flumes, represent an evolving spectrum of attempts to design self-acting hydraulic structures that could provide equitable and effective local water distribution, consistent with both the flow regime in the distributaries (fluctuations and silt load) and restricted local management capacity. However, the necessity to allow local privilege – and ironically the ease with which this could be built into points in the system, provided overall canal regime was kept – meant that other necessary institutional reforms did not take place.

The concept of protective irrigation through application of self-acting proportionality was thus not fully developed at the time of Pakistan's independence in 1947. Great strides were made between 1885 and 1947 on the technical side in hydraulic science and irrigation engineering. However, the management system to regulate the allocation of water and monitor and control the distribution of water was not fully developed into an unambiguous management concept. That technically the concept of self-acting proportionality was completed and became the new paradigm, is attested by its widespread implementation throughout the 1930s and 1940s through numerous remodellings of existing systems and rapid expansion of the Indus basin system. The further refinement and amendment of the management rules and procedures, and the eventual resolution of the dilemma between administrative privilege and technical efficiency, was perhaps just a matter of time. The continuous technical refinement through remodellings, and monitoring innovations as the H-Register introduced by Jesson, were bound to result in ever pressing needs for such reforms and settlement of the water allocation paradox. The history of events with WWII and the dramatic acceleration of independence and partition in its aftermath, however, were not very conducive for such reforms. With independence Pakistan thus inherited the vast irrigation infrastructure of the Indus-basin and the technical capability to divert and distribute the water proportionally. However, the management and judicial structures were not yet fully developed and geared towards an unambiguous control of the water allocation, monitoring and maintenance of this irrigation concept of 'self-acting proportionality' that lay embedded in the infrastructure.

CHAPTER THREE

THE NATION & THE BASIN

EXPANSION OF THE INDUS BASIN SYSTEM AND THE DIMINISHING ROLE OF THE ID IN IRRIGATION DEVELOPMENT

3.1 INTRODUCTION

The partition of British colonial India and the independence of Pakistan and India not only represent the end of the era of geo-political colonialism, but also marked a change in the institutional setting of irrigation development of the Indus basin. This chapter deals with the first three decades of the independent state of Pakistan and the policies it adopted and implemented to further develop the IBIS. This overview of the recent history of irrigation development in Pakistan is provided here as further background information to the setting of the irrigation modernisation undertaken in NWFP from 1980 onwards.

This chapter begins with an overview of the programmes that were adopted and implemented in the IBIS after independence to further expand and intensify the irrigation. The first and biggest of these, was the Indus Basin Project. This was set up and funded under the auspices of the newly created World Bank, and directed at salvaging the IBIS from the negative effects of partition, in which the eastern tributaries to the Indus were allocated to India. With it, the policies and programmes were directed towards the integration of the IBIS as a system, and towards the improvement of its efficacy and efficiency. For the first time the irrigation department no longer played the central role in the development and implementation of irrigation, but was relegated to the operation and maintenance of the canal systems. The overview presents, how the development analysis and objectives, as well as the programmes, for the IBIS were conducted by the newly created federal authority of WAPDA, policy makers and multilateral agencies. Section 3.3 looks at the impact the diminishing role of the irrigation department has had on the operation and maintenance of irrigation. It is argued, that the externalisation and internationalisation of the irrigation design and development in the IBIS has restricted the dynamic management of the irrigation department with which it used to seek improvements in water delivery, and be able to periodically regulate the issue of water allocation. It is argued that the reduced role of the ID has been conducive for its fossilisation in which the irrigation systems gradually degraded, steadily losing their capacity for proportional distribution. The two major national programmes to further improve the IBIS, the SCARP-tubewell and On Farm Water Management, have, on closer analysis, not led to a solution of these problems associated with degradation, but rather provided the ID with an indemnification for its lost capacity to provide tail-end areas with their fair share of water.

In section 3.4 it is argued how the increasing relative scarcity of water within the IBIS since the independence of Pakistan, has increased the importance of the *Warabandi* as a central institution for water management at the tertiary level. As a *de facto* water allocation and distribution mechanism, it plays a central role in the water management strategies water users adopt, and the arrangements they make with each other to optimise it. In section 3.5 a short problem analysis is presented, that emerged within the irrigation sector of Pakistan towards the end of the 1970s, and have initiated the modernisation programmes conducted in NWFP.

3.2 INDEPENDENCE: EXPANSION AND INTENSIFICATION OF THE IBIS

3.2.1 Partition and the Indus Water Treaty[44]

Apart from the enormous political and social upheaval caused by the mass migration of millions of people, the Partition of 1947, and its division of the Punjab between the newly independent states of Pakistan and India, introduced a sharp fault line through the Indus basin and its network of interdependent irrigation systems. The new established border line cut right through two important watersheds — that of the Sutlej and the Ravi — as well as through two major irrigation systems. The Upper Bari Doab Canal (UBDC) had been cut through right across its branches, leaving the tail portions to Pakistan; while the head works at Ferozepore had been awarded to India, one of its off-taking channels (the Dipalpur) was awarded to Pakistan. On the first of April 1948 this arbitrary and political fault line erupted, when India cut-off the water supplies to the tail ends of UBDC, as well as to the Dipalpur canal, depriving thus five percent of Pakistan's sown area of irrigation water.[45] Thus the first 'formal' opportunity was taken by India to assert — in all practical manners and political rhetoric — its upstream riparian property rights of the three eastern rivers of the Punjab; i.e. that of the Sutlej, Beas and Ravi.

Faced by this immediate threat to its agricultural productivity, Pakistan instantly despatched a ministerial delegation to Delhi for negotiations on the allocation and distribution of the waters of the eastern Indus basin. These negotiations resulted, on the 4th of May 1948, in the Inter Dominion Agreement. The agreement upheld India's property rights to the eastern rivers, but allowed Pakistan the use of a share, against payment, until the time that India had found the

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44 This section is largely based on Michel (1967): *The Indus Rivers*; *A Study of the Effects of Partition*. Michel provides an excellent account on the developments of IBIS during the 1930s and the settlement of the Indus Water Treaty and its IBP.

45 The first of April 1948 coincided with the expiring of the 'Standstill Agreement', which provided, among other things, that the pre-Partition allocation of water in the Indus-Basin Irrigation System would be maintained.

resources to usurp the total available flows. Although this agreement alleviated the immediate and urgent problems of Pakistan, it unambiguously showed its temporal character, by explicitly stating that it simply served to allow Pakistan the time to tap alternative sources for its irrigation requirements.

Not surprisingly, the Inter-Dominion Agreement was followed by a period of frantic activities in irrigation developments at both sides of the border. In the years following, Pakistan built three link canals (i.e. Marala-Ravi, Bombanwala-Ravi-Bedian-Dialpur, and Balloki-Suleimanke) to secure the water supply to its parts of the UBDC and Sutlej Valley Project. The expansion was necessarily confined to the Indus itself at Kalabakh, Taunsa and Gudu, primarily to settle contingents of the huge amount of refugees. On the other side of the border, India pursued its intentions quickly with the construction of the Bhakra dam and Nangal barrage on the Sutlej, the Harike barrage and Rajasthan canal, and the Ravi-Beas link canal. These activities would even at minimum supplies nearly triple the amount of water being used for irrigation in the Indian portion of the Indus basin, as compared with the pre-Partition period.

Further negotiations between Pakistan and India on the allocations of the Indus basin water resources continued after 1948, and eventually were conducted under the auspices of the World Bank from 1952 to 1960, when they finally culminated into the Indus Waters Treaty (IWT). Although the World Bank entered the negotiations with the intention of securing the integrated water management of the Indus basin, this proved early on to be a politically unfeasible track, in which neither party was willing to submit its critical water resources to the control of the other. The Indus Waters Treaty — the first of its kind in surpassing national boundaries — thus finally defined the strict division of the Indus basin and its waters between Pakistan and India. Basically, the treaty formalized India's initial stake of 1948, by allocating the entire flows of the eastern rivers (Sutlej, Beas and Ravi) to India, and those of the western rivers (Indus, Jehlum and Chenab) to Pakistan. The allocation, based on monitored estimates of the total available flows, amounted to 27.13 km^3 (22 MAF) of water per year for India, and 119.6 km^3 (97 MAF) to Pakistan.

Although the treaty, in terms of volume, seemed not unfavourable to Pakistan, Pakistan nevertheless stretched the negotiations to a lengthy eight years in order to secure the necessary financial and natural resources it required to develop its re-structured Indus Basin Irrigation System (IBIS). Unlike India, Pakistan's whole irrigation future was dependent on the detailed outcomes of the IWT, and so quite naturally it sought to guarantee not only its established irrigation capacity, but also that of its future potential. Both aspects played an important role in the lengthy, and often technically elaborate, negotiations. At the heart of the matter lay the amount of compensation that Pakistan would be entitled to — to be provided partly by India, but most substantially by a set of Western Governments in an arrangement set up by the World Bank — in order to substitute its loss in water resources. Pakistan pushed its case to the limits of the negotiations, by arguing that a mere by-passing of its intakes from the eastern rivers with supply channels from its 'own' western rivers, would infringe on its future potential for irrigation development, and would thus amount not to a replacement of lost resources but to an unacceptable trade-off with its future.[46] At stake were the possibilities for Pakistan to develop storage facilities in the western Indus basin; facilities that were crucial to bridge the periods of late *Kharif* - early *Rabi* and late *Rabi* - early *Kharif,* when the water was relatively scarce and threatened to hamper Pakistan's developments in irrigated agriculture. Apart from the mere water allocation arrangements it defined, the IWT became for Pakistan increasingly important for the financial aid arrangements it entailed. The World Bank had early on in the negotiations managed to establish a Development Fund that would finance all the infrastructure projects that were deemed necessary for the implementation of the treaty. The issue of providing for storage facilities for Pakistan became thus contested by all parties, since this would substantially increase the required funds. By 1960 finally a settlement was reached by limiting the compensation charges to India to a fixed amount of US $173.8 million, and setting the funds available to Pakistan at US $838 million. The final agreement provided for a storage dam on the Jehlum river at Mangla with a live capacity of 5.86 km^3 (4.75 MAF) and a non-specified facility for an additional 5.18 km^3 (4.2 MAF) storage on the Indus.

The irrigation works set out in the Indus Basin Project (IBP), and financed by the treaty's Development Fund, were urgently implemented in order to meet the time frame of the treaty, which stipulated that India would continue to provide Pakistan with a specified amount of water from its eastern rivers until April 1st 1970. The works that were intended to offset the water lost to India amounted to the construction or remodelling of six barrages and the construction of six link canals with capacities ranging from 283 to 566 m^3/s (10,000 to 20,000 cusecs) (see fig. 3.1). While the construction of these works proceeded successfully with the help of numerous foreign consultancies, the matter of the storage facility on the Indus was further worked out and taken up by the newly created Water and Power Development Authority (WAPDA) of Pakistan. By 1964 the World Bank and funding members of the Development Fund, conceded to the mounting costs and revised estimates of WAPDA, by raising the fund to US $1.9 billion. The storage facility on the Indus, however, was to be further investigated by a World Bank study group, before it would be finally admitted to the IBP. In 1967 the study group concluded positively on the construction of the Tarbela dam, with an estimated cost of US $775 million. Although the live storage capacity of 11.47 km^3 (9.3 MAF) exceeded the 5.86 km^3 (4.75 MAF) required under the treaty's agreement, all funds that remained available after completion of the Mangla dam and the six barrages and link canals were made available for the construction of Tarbela, as had been agreed in 1964. (Lieftinck et. al.; 1968)

With the commissioning of Tarbela dam in 1975, Pakistan had thus its re-structured IBIS in place with enough capacity and capabilities to serve future required irrigation expansions. The two storage facilities and set of link canals now enabled a fully integrated water management of the western Indus basin, in which the waters of the Indus could be allocated and re-directed among all irrigation systems of the country. The waters of the Indus basin would thus be

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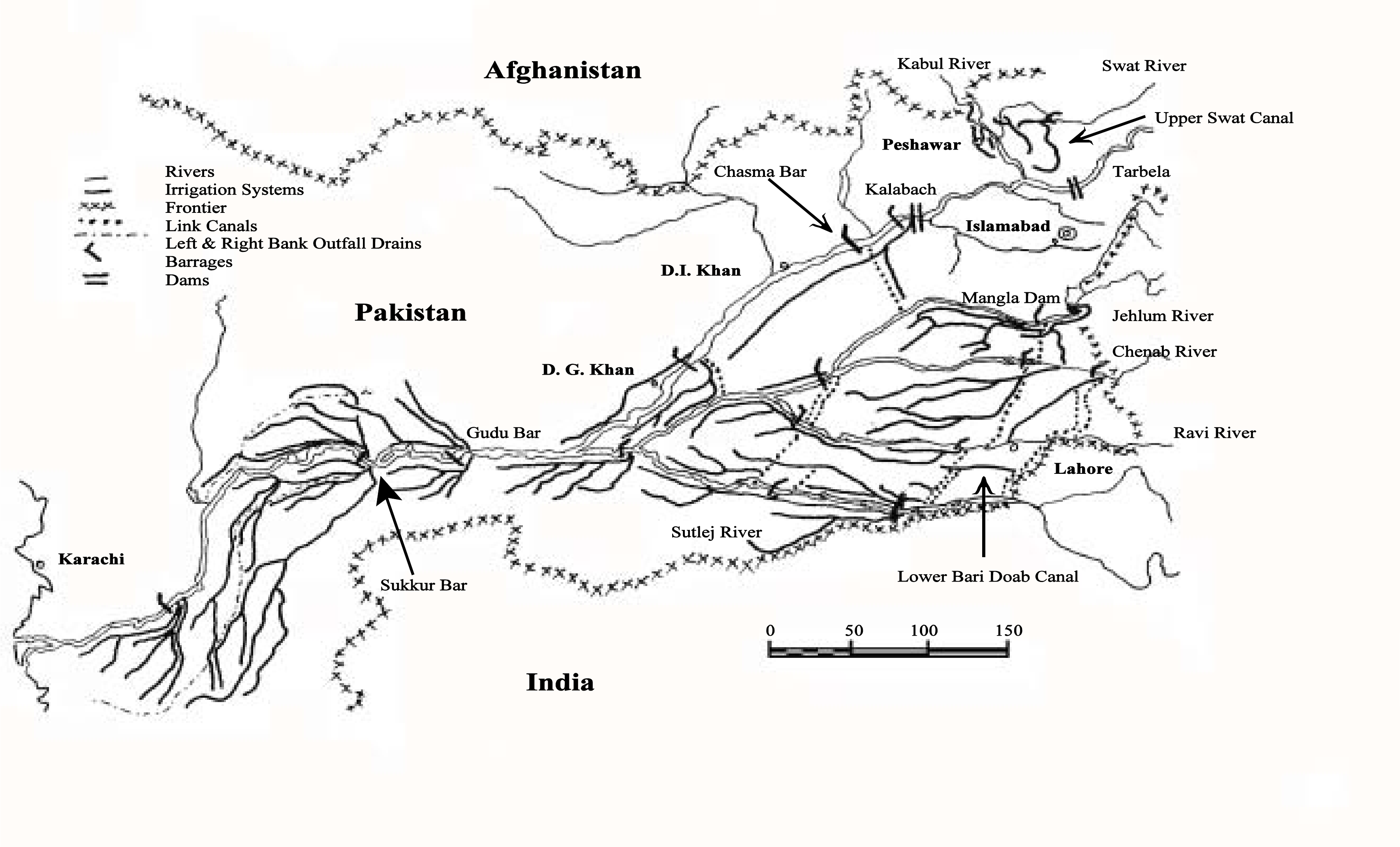
[46] The formulation of the Indus Waters Treaty, and its negotiations, hinged as far as Pakistan was concerned, on the very definition and implications of the wordings *"Pakistan shall* [...]*accomplish the replacement, from the Western Rivers and other sources, of water supplies for irrigation canals in Pakistan which, on 15 August 1947, were dependent on water supplies form the Eastern Rivers."* (Article IV of the Indus Waters Treaty, Michel; 1967:563)

Fig. 3.1: The Indus Basin Irrigation System and the Existing & Proposed Dams, Barrages and Link Canals



managed on a central level by WAPDA, which from then on allocated and distributed the water to each system and each Province.

3.2.2 Improving Efficiencies and Intensifying Production

With the settlement of the Indus Water Treaty and its accompanying Indus Basin Project, Pakistan had secured the water resources and delivery capacity for its existing irrigation systems. Right from the start, even during the extended negotiations over the IBP and its implementation, the policy of irrigation expansion that had fed the exponential irrigation developments of the 1930s in Sindh and Punjab were continued by the newly independent Nation of Pakistan. Not in the least, to provide a settlement and feeding policy for the millions of new Pakistani citizens that had arrived from what was now independent India. The new growth in irrigated command area of the IBIS has been achieved rapidly and formidably; from 8 million ha (20 million acres) at the time of independence to 13.8 million ha (34.5 million acres) by the end of the 1980s. The majority of this was achieved by building new irrigation systems based on blue-prints developed by the Punjab and Sindh Irrigation Departments during the 1930s – as were the majority of the IBP works of link-canals and barrages, including Mangla dam. (*cf.* Michel; 1967)

Although the completion of Tarbela dam had considerably increased the available potential for irrigation, the further growth in irrigation was hampered by two factors: (i) all the 'easy' and economically feasible sights for expansion were more or less utilised with the developments of the Sukkur, Gundu and Taunsa barrages on the Indus and their associated canals (see fig. 3.1); (ii) increase of the irrigation intensities in the existing systems was severely hampered by the huge problems of water logging and salinisation. Nevertheless, the World Bank Study Group (i.e. the Lieftinck commission) supported the construction of Tarbela dam, since it recognized the need of Pakistan to substantially increase its agricultural production in order to sustain its large and rapidly growing population. Reviewing Pakistan's available resources for agricultural development, the Lieftinck commission set the long term development aims for the irrigation sector in Pakistan to increase its irrigation intensities to 150 percent. A target which, in its view, could only be feasibly achieved by further extending the Salinity Control And Reclamation Project (SCARP), that was initiated by WAPDA in the late 1950s, over a considerable part of the irrigated command area of Punjab.(Lieftinck et.al.; 1968)

SCARP Tubewell Programme

The SCARP programme, consisting of the installation of a network of public tubewells to lower the groundwater table and provide additional irrigation water, started in 1960 with the objective to reclaim 0.5 million ha (1.25 million acres) of waterlogged area in the Rechna Doab (i.e. the area between the Chenab and Ravi rivers). This use of tubewells as a means to tackle the problems of waterlogging and salinity – which by 1950 had affected over 2 million ha (5 million acres) of irrigated land, with an estimated growth of 29,000 ha per annum (72,500 acres) (S. Johnson; 1982) – was considered feasible by both the Lieftinck commission as the Revelle commission[47]. This approach had namely two potential benefits to offer that made it attractive in the context of Punjab: (i) it was an effective and easy way to lower the water table in a very flat terrain that lies a thousand km from the sea[48]; (ii) it provided additional irrigation water for conjunctive use in an area where the canal water allowances were low (i.e. in the order of 0.35 l/s/ha). The use of tubewells in fresh groundwater areas as an additional source of irrigation water was considered important by the Lieftinck commission to make use of the extra storage capacity created with the Tarbela and Mangla dams on the Indus. The extra water made available was not enough to provide year round increases in water delivery since *"the withdrawal capacity of the canal system already equalled or exceeded the combined natural mean flows of the river system in all months except June, July and August"* (World Bank; 1996:102). By supplementing the newly created surface storage capacity with groundwater extraction in the water scarce months, its use could be maximised to benefit an area as large as possible in establishing cropping intensities of 150 percent. The Lieftinck commission therefore thought it prudent to recommend that nearly 50 percent of public expenditures on irrigation and drainage should be committed to the installation of public tubewells (op.cit.). With the positive recommendations of the Lieftinck and Revelle commissions, and the securing of foreign loans, up to US $ 650 million was committed to the SCARP programme during the 1960s-70s. By 1986 12,500 public tubewells had been installed covering a command area of 10 million ha (25 million acres). (Lieftinck; 1969, Traxler & Ruttan; 1986)

By the late 1970s it became apparent that the agricultural targets set by the Lieftinck commission, as well as the drainage objectives, were not achieved by the implementation of the SCARP tubewell programmes, which suffered numerous problems in their implementation. Although initially promising, the widespread implementation of tubewells proved to be a costly affair in operation and maintenance, that could not be sustained over large areas of the programme (*cf*. chapter eight). Though the SCARP programmes have had their impact in alleviating some of the relative water shortages and enabled the increase of the irrigation intensities, in general they fall short of the projected productivity and intensity targets. By 1982 it was estimated that only 57 percent of the public tubewells in the Punjab were still operated (S. Johnson; 1982). Those still in use, moreover, were often subdued to erratic operation due to load shedding (i.e. power cuts) or maintenance problems (*cf.* S. Johnson, 1982, R. Johnson, 1989, Traxler & Ruttan; 1986; Merrey; 1986b). These increasingly poor results of the public tubewell programme has eventually lead the World Bank to change its policy in the 1990s and to grant loans for programmes that seek to privatise (i.e. hand-over to water users) these electric tubewells once installed by the SCARP programme (*cf*. World Bank; 1997).

The use of private tubewells as a 'mere' supplementation of irrigation water through conjunctive use of canal and groundwater has, on the other hand, proved to be quite a success. Recognised by the Lieftinck commission as an important potential for the establishment of the 150 percent cropping intensities, it recommended that the private development of tubewells

47 The Revelle commission was a panel of experts headed by Roger Revelle, that was sent by President Kennedy of the USA in 1961 to Pakistan to specifically address the problems of waterlogging and salinity.

48 The application of drainage canals would inevitably result in large and deep cut channels, as is the case with Indus Left & Right bank drain outfalls that are currently under construction in Sindh, as part of the National Drainage Programme I (see chapter eight).

should be stimulated by government policies (mainly through import relaxation on equipment) (*cf*. Lieftinck et.al.; 1968 & 1969). In the relative watershort areas, especially Punjab and Sindh, the developments in private tubewells took such a flight that by 1990 an estimated 225,000 private tubewells were in use (World Bank; 1996).

On-Farm Water Management Programme

While the construction work of the IBP was still under way, the problem analysis and attention span for the IBIS shifted towards the tertiary level with the large research programme conducted by the Colorado State University (CSU) on water management at the tertiary level. This programme, funded by USAID, ran from 1968 to 1974, and has been paramount in bringing tertiary level water management to the forefront of problem analysis and policy formulation. One of its major findings, that has had a profound impact on the irrigation sector investment and development policies in Pakistan from 1975 to 1990, was that the conveyance losses at the tertiary level amounted to 40 - 45 percent. The results of the CSU study clearly indicated that vast improvements in water use efficiency and productivity could be attained by improving the water conveyance and distribution conditions at the tertiary level, and improving the irrigation application methods and crop management on-farm. A comprehensive programme was subsequently set-up to tackle these tertiary level water management issues, consisting of watercourse lining, installation of division boxes, precision land levelling and provision of extension services for irrigated agriculture.

USAID provided for a follow-up to the CSU study by funding the first On-Farm Water Management pilot programme (OFWM) from 1976 to 1981. As the tertiary level did not belong to the traditional domain of the ID, and the intention was to incorporate extension services for irrigated agriculture, the OFWM programme was set-up within the Department of Agriculture (DoA). The programme was structured around the three issues identified by the CSU study. In order to effectively deliver its services of watercourse improvement, precision land levelling and extension, OFWM was to set-up officially registered Water Users Associations (WUA). The precision land levelling and extension components have not been very successful (*cf*. World Bank; 1996), and are not treated here any further. From the start, the OFWM programme concentrated its efforts on the improvement of the tertiary level water conveyance and distribution.

The improvements of the water conveyance and distribution were concentrated on three issues: (i) providing water course lining for the first stretch of the watercourse (10 to 30 percent of the length); (ii) installing concrete division boxes throughout the tertiary unit (i.e. the so called *pucca nakka* that consist of inclined concrete tabs with a circular hole that can be closed off with fitting concrete lid); (iii) stimulating and organising the watercourse maintenance and de-silting. The watercourse lining and installation of *pucca nakkas* were heavily subsidised by OFWM, in which the water users were only required to provide a contribution in the form of labour equalling to approximately twenty percent of the costs. OFWM provided for the technical assistance and materials. Additional requirements were that the water users would establish a formally registered WUA, and clean and repair the unlined sections of the watercourse. The OFWM pilot programme proved quite a success in so far that it renovated 1,300 watercourses of the projected 1,500 in its five year time span. In 1980 the OFWM programme was taken over for funding by the World Bank on request from the government of Pakistan. During the 1980s and early 1990s the work of OFWM was continued and extended, with the result that by the mid 1990s a further 25,000 watercourses (nearly a quarter of the total of 107,000 watercourses in Pakistan) were renovated (op.cit.).

The OFWM programme proved in the end to be primarily concerned with the lining of watercourses and the meeting of its renovation targets. This is also reflected in the viability of the numerous WUA that have been formally set-up and registered to conduct these renovations. The vast majority of these have ceased to function as soon as the watercourse renovation was completed. As to the savings in water losses achieved, no unambiguous figures are provided, although estimations indicate that lining of watercourses as conducted by OFWM result in a 10 to 15 percent reduction of the conveyance losses. These figures are mainly affected by the standard practice to line the first 10 to 30 percent of the watercourse section, irrespective of where the actual highest conveyance losses would occur. (op.cit.)

The latest OFWM programmes have taken stock of some of these deficiencies of the past, by changing some of their procedures and requirements. The water users are now required to contribute 20 to 25 percent of the capital costs in cash, in addition to their labour contributions. It is also no longer intended to line the first section of the watercourse as a standard procedure, but to actually adapt the renovation plan to those sections of the watercourse that have the highest conveyance losses. As to the viability and functions of the WUA, there is as of yet no clear indication of how OFWM should contribute to the establishment of WUA and FO as water management organisations that purchase their water from the public irrigation utilities as proposed under the PIDA act (*cf*. chapter eight).

The Indus Water Apportionment Accord

As had become evident during the height of irrigation development in the 1930s, the water of the Indus river was increasingly taken up by the expansion of the irrigated command area. By the time of the development of the Sutlej Valley Project in Punjab and the Sukkur barrage in Sindh (see fig. 3.1) the allocation of the waters of the Indus over the different provinces had become an issue needing attending at the basin level. During this period Sindh in particular aired concerns about the brazenness with which the Punjab and its Irrigation Department were making use of the riparian rights to develop irrigation on a vast and rapid scale. (*cf.* Michel; 1967)

After independence, and with the further commitment of the Indus waters through the IBP, the allocation of the available water among the four provinces and their existing and future irrigation systems became an increasingly prominent issue to be addressed at the national and basin level. The creation of WAPDA as a national and basin level organisation with operation and management responsibilities for the IBIS – as opposed to the provincial level organisation of the ID – was pursued with this need in mind (see section below). With the completion of the storage facilities that created an extra water availability of 17.73 km^3 (14.55 MAF) (i.e. the combined live storage capacity of Tarbela and Mangla dam and Chasma barrage), the question of who would be permitted to make use of this water became a prominent inter provincial political issue. Each of the provinces contested their shares of the Indus waters in an attempt to secure their irrigation and agricultural developments for the future. In the absence of a water allocation settlement, each of the provinces was trying to push forward their irrigation development projects as a means to state their claims on the waters of the Indus.[49] The four irrigation projects of NWFP treated in the forthcoming chapters, are all the result of this political strategy:

Mardan- & Swabi-SCARP, Chasma Right Bank Canal and Pehur High Level Canal, were all conceived in the 1970s-80s with the clear objective of increasing NWFP's share of water use, which up to then was relatively low. In contrast to the other provinces, NWFP still had an 'easy potential' available for increasing its irrigated command area and water use. Fearing to lose some of the abundant water flowing through its territory to the structurally water short provinces of Punjab and Sindh, these projects served to state NWFP's claim on a share of the Indus waters.

By 1991 a settlement on the allocation of the Indus waters was finally reached and enacted through the Indus Water Apportionment Act. The act allocates each province a specified share of surface water (in MAF), which they are entitled to in present and future use. NWFP's share is relatively generous to the extent that it still has potential left for future expansion or intensification of its irrigated command area.

3.2.3 The Changing Role of the ID in Irrigation Development

With the independence of Pakistan the management institutions for irrigation were effectively taken over by the new government. The Irrigation Departments continued to exist as they were set up by the British, performing their management functions as before. The newly established government of Pakistan had not only taken over the physical irrigation infrastructure, but as well the concept of protective irrigation by which these systems should be run.

The crisis with India over the waters of the Ravi and Sutlej rivers and the ensuing negotiations on the IWT had placed the issue of water resource management firmly on the irrigation agenda of Pakistan. The IWT and its Indus Basin Project (IBP) made the control, allocation and distribution of the water resources of the Indus Basin a management priority for Pakistan. The formulation of a policy and procedure to cope with the provisions of securing a water delivery to its numerous irrigation systems, was urgently needed. The newly created relative water scarcity of water resources required a tightly and accurately controlled allocation and distribution policy at the central level of the Basin; a requirement that superceded the traditional management domain of the ID.[50] In 1958, during the full swing of the negotiations on the IWT and IBP, a specific and new management institution was created in the form of the Water and Power Development Authority (WAPDA), to deal with this crucial issue. As a primary management function WAPDA would specialise in the central monitoring and coordinating of the allocation

[49] A strategy that was based upon the reasoning that it would be highly unlikely that established irrigation systems and command areas would be given up, or abandoned, for the sake of an equitable allocation.

[50] Previous arrangements on the allocation of water resources, as those required by the implementation of the Sutlej River Project, had been carried out by a specially created irrigation committee that mediated the demands of the individual provinces. This committee, however, lacked the means and structure for the detailed regulation of water distribution that was required under the IBP. (Michel; 1967)

and distribution of the water resources of the Indus Basin for Pakistan, so that the irrigation requirements of each system could be attuned in a national water distribution plan.

The role allocated to WAPDA, however, went much further than the mere management and allocation of the water resources at national level. The realisation of the allocation and re-distribution of the Indus Basin water resources required major developments in infrastructure to provide for the necessary control options. These requirements were taken care of with the formulation and implementation of the IBP. To ensure the necessary coordination of the numerous works that were provided for in the IBP, WAPDA obtained also the executive control on all the design and construction works in irrigation. Henceforth, every major work in irrigation engineering — from barrages and intakes to the construction or rehabilitation of canals — would be carried out by WAPDA. As such, it became an organisation that could effectively plan and control any future developments in irrigation, in which it could enter into direct negotiations with donor agencies as the representative of the Government of Pakistan in all matters pertaining to power and irrigation.

The creation and development of WAPDA as a new and major institution in water management has had a major impact on the management role of the ID. Its immediate effect has been that it caused a brain drain on the ID during the 1960s. The majority of the top class civil engineers were drawn to WAPDA when it became the sole agency that was able to attract funds and projects for the development of irrigation works. The colossal IBP, as well as the SCARP programmes (I - IV), were the raisins in the porridge during the start of this new era of developments in the Indus Basin, that provided numerous opportunities for qualified engineers to seek employment in the attractive positions of design and construction supervision.

With the course of time, the monopoly of WAPDA in the design and construction of irrigation works started to infringe upon the responsibilities of the ID. It could have been argued that the IBP was primarily concerned with the development of the means (i.e. barrages and link-canals) that were required to perform WAPDA's main function (i.e. managing the water resource base). However, WAPDA's increasing involvement in projects that are purely and merely concerned with irrigation reduced the ID to an agency that is responsible for the overseeing of the day to day operations of 'WAPDA's Indus Basin Irrigation System'. This has interrupted an important tradition in irrigation management where the design and operation of irrigation systems has been synchronised because both activities were carried out by irrigation engineers that had extensive practical experience and responsibilities in both aspects (as Crump, Kennedy, Jesson and Sharma). The new arrangement of responsibilities between WAPDA and the ID has taken out the incentive that marked the heydays of the ID during the first decades of the 20th century, when the numerous inventions in irrigation technology and canal improvements were all geared at improving the operation of water distribution for the ID. Since the creation of WAPDA the ID's role has been delimited to the mere maintenance of the systems as they have them, or as they get them from WAPDA. Their power to determine the course of future irrigation developments is limited as *"... its* [the ID's] *present role in development can be compared to that of the House of Lords, having power to recommend changes and to delay actions, but not to overrule a basic scheme."* (Michel; 1967:357).

3.3 THE SALIENT FEATURES OF DETERIORATION

There can be no doubt on anybody's mind that the huge investments that have been made in the development of the protective irrigation schemes in the Indus-basin, have had a tremendous impact on the economic en rural development of Pakistan. The vast tracks of barren and desert like land that have been turned into agricultural production grounds is one of the major features that have made it possible to accommodate the huge increase in population from 37 million to 140 million that Pakistan underwent since independence. The mere live length of the irrigation infrastructure, with all of the British canal systems still running after 100 years of operation[51], is another remarkable feature of productive investment that is in stark contrast with the present day common infrastructure live length of 30 to 50 years. At the same time, it are also these features that have put the protective irrigation in present day Pakistan under stress. The huge population growth (still at a staggering 2.7 percent) keeps building up the pressure to increase the crop intensities and production beyond the original protective targets; while the age of the infrastructure increases the burden for operation and maintenance.

In spite of the increasing demands that have been made on the productive capacities of the irrigation systems in Pakistan, the hydraulic capacities and operational supply philosophy under which the systems have to operate remained basically the same as those defined in the protective irrigation concept during colonial time. Even the huge investments made under the IBP (including those for the Mangla and Tarbela reservoirs) have been primarily employed to replace the lost supplies to existing protective schemes, or to expand irrigation with new canal systems that were designed according to the same protective concept. An assessment of the level of performance of the irrigation service that is provided by these systems should therefore be conducted against the criteria of the original protective irrigation concept that shaped both the infrastructure and the management of these systems.

The objectives and targets for the operational management of these systems are thus defined by the operation and maintenance of the 'self-acting' Crump canals (*cf.* section 2.6). The operational objective is therein defined as delivering a continuous irrigation water delivery to the tertiary units, in which each unit is delivered its allocated rate or a proportional (*pro rato*) share of its allocated rate whenever the inflow to the canal, and system, deviates from its design or full supply discharge. The hydraulic properties of 'self-acting' Crump canals then dictate, that the targets for canal operation are to run the canals at, or near, their full supply levels, but never below 75% of FSL; targets for which the 'self-acting' proportionality of water distribution is assured by the hydraulic properties of the canal.

On the basis of these criteria, the performance assessment of the main system operations, should therefore concentrate on two parameters: (i) the ability of the ID to operate the canals within the water level targets; (ii) the capacity to establish and maintain a 'self-acting' proportional water distribution among the tertiary units when the canals are operated within their range of operational targets.

[51] The majority of which have only undergone one major rehabilitation program during the 1930s - 40s.

3.3.1 Water Level Operations

The primary and principal task for canal operations in Pakistan is thus to run the canals at, or close to, their full supply levels on a continuous basis throughout the irrigation season. In order to achieve this, the ID is supposed to aim for a steady state operation of the canal systems in which it tries to minimize the intake of discharge and water level fluctuations that can be caused by fluctuations in the water supply from the river. The normal operational procedure is thus to set the gates of the division structures (i.e. the intake structures of the canals) so that each canal receives its FSL target under FSL conditions, and concentrate further operational activities on the regulation of the river intake structure in order to limit the intake of discharge fluctuations into the system. Once the steady state conditions are reached, the operational requirements of the system are kept to an absolute minimum and basically reduced to monitoring of the water level targets. The actual discharge and water level targets on which the systems are operated tend to be the same as those that were defined during the design, or latest re-modelling, of the systems. For the Kabul River Canal (KRC) system, for instance, all the operational targets are still derived from the longitudinal design sheets from the last time the system was re-modelled – for the different distributary canals these design sheets go back from the newest of 1976 to the oldest of 1933. In other words, the canal operations are determined by the design targets, which are kept essentially the same for a prolonged time, independent of the agricultural changes that might have occurred since the completion of the last design intervention.

As a general rule, the ID tries to run their canals at the defined full supply levels for the better part of the irrigation season, particularly at the heads. In most instances, one will find that these head-end targets are reasonably well met, providing there is enough water available to meet the design intake of the main canal. However, deviations from full supply deliveries are implemented in response to either a shortage of water, or to excessive rainfall. The former frequently occurs in the Punjab, for which the ID has to fall back on a rotational schedule at the distributary level. Canals are then supplied with water on a rotational roster of first (FSL), second (partly FSL) and third (hardly any supply) priority basis (*cf*. Kuper, 1997). The latter is frequently practised as a damage control measure; after heavy or prolonged rains (say 40 mm or more) the delivery to the canals is shut down in order to avoid overtopping or damages to the canal.

Figures 3.2 - 3.5 present the water deliveries to the head of the canals (distributary, branches and minors) of the Lower Swat Canal (LSC) system for 1975[52]. The water deliveries are presented as the canal head gauge expressed as a ratio of its design target. Essentially all canals should therefore run at the ratio of unity when the operation targets would have been met. The first thing the data clearly show, is the ID's response to rainfall: during the winter rains in March (when the crop water requirements are also still low) and the monsoon rains in August the canals have been frequently (nearly) closed down in order to avoid damages to crops and canals. At the beginning of the irrigation season in February the intake of water in the main canal falls short of its design target, but thanks to the rainfall the rotational schedule initiated by the ID is

[52] This was before the LSC was modernized through the Mardan-SCARP in the 1980s (*cf.* chapters 4 & 5), and it was still a protective irrigation scheme.

interrupted. During the *Kharif* season (from May to April) the operational target of FSL is more

Fig. 3.2 Water Deliveries in Lower Swat Canal for 1975
Canal Head Gauge Readings (Ratio of FSL Target) [-]

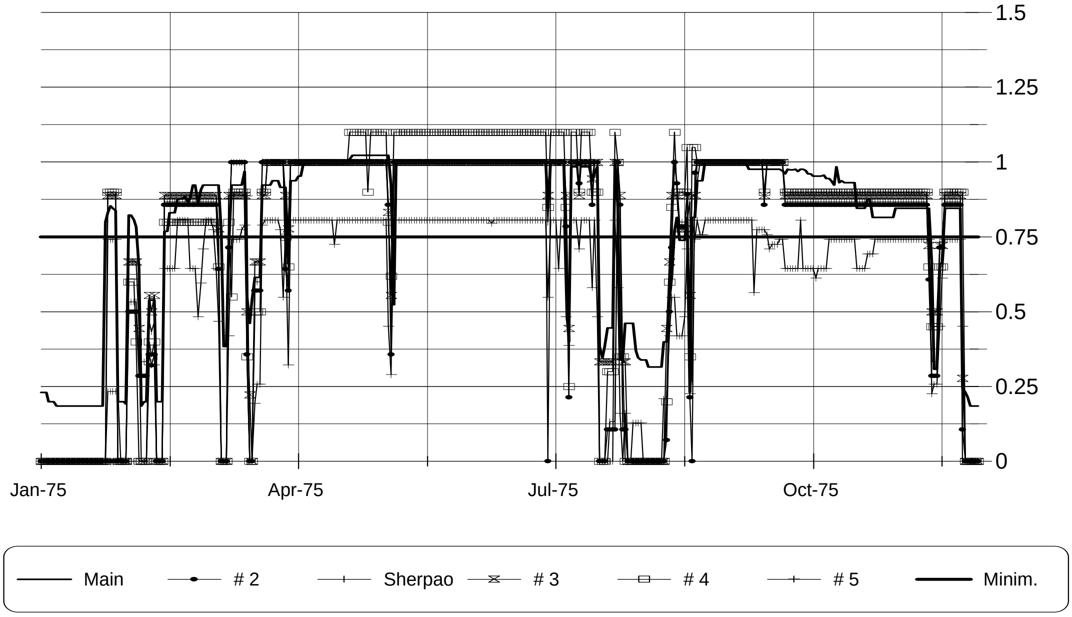


Fig. 3.3: Water Deliveries in Lower Swat Canal for 1975 (cont.)
Canal Head Gauge Readings (Ratio of FSL Target) [-]

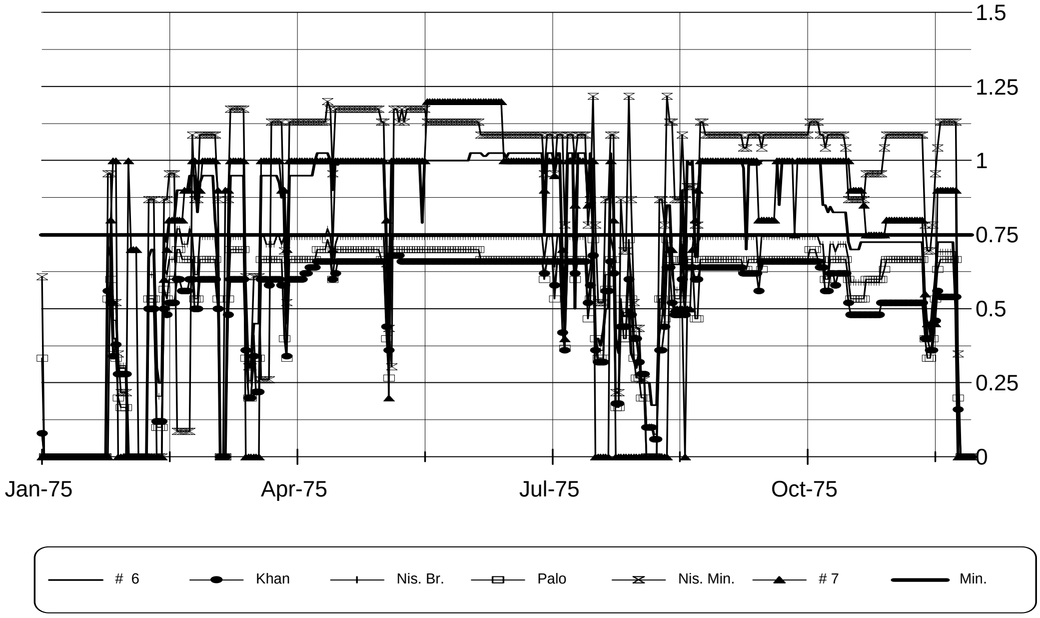
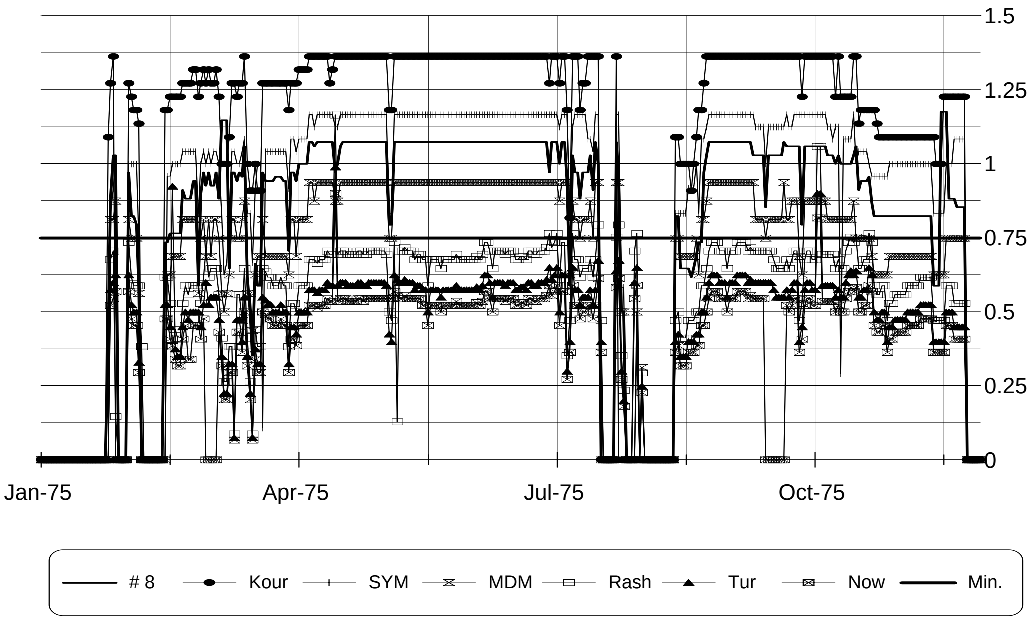
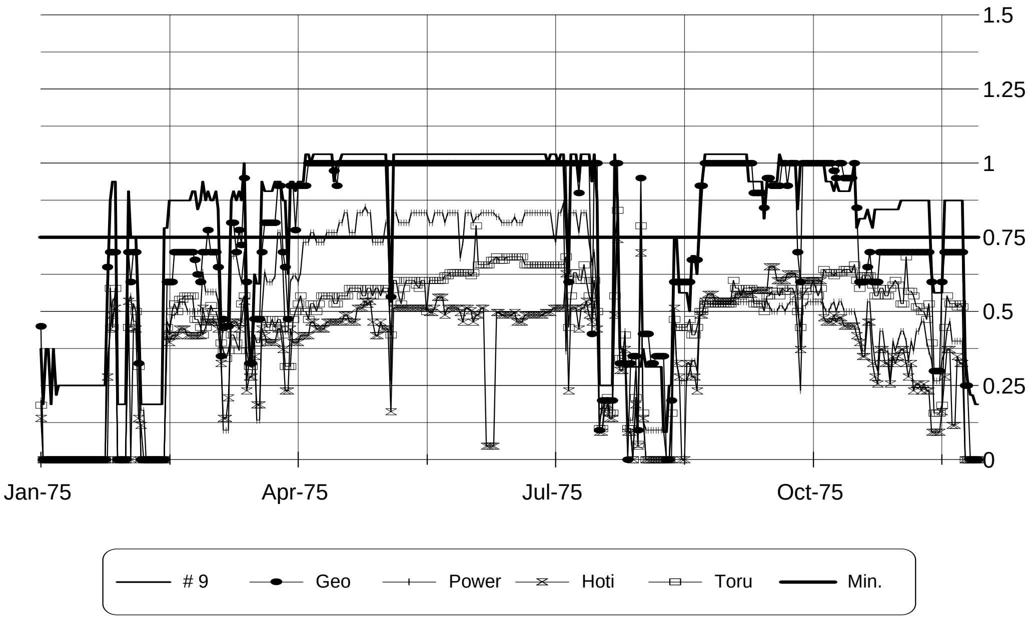


Fig. 3.4: Water Deliveries in Lower Swat Canal for 1975 (cont.)
Canal Head Gauge Readings (Ratio of FSL Target) [-]



or less reached for 11 out of 23 canals (which include all the major canals). Seven canals –

Fig. 3.5: Water Deliveries in Lower Swat Canal for 1975 (cont.)
Canal Head Gauge Readings (Ratio of FSL Target) [-]



Rashakai, Turlandi and Nowshera minors of Distributary # 8; Hoti and Toru Minors of Distributary # 9; and Palosa minor of distributary # 6 – show a clear and classical tail-end problem obtaining well below the minimum allowable target of 75 percent of FSL (*cf.* fig. 4.2). Two canals (Kourakh branch and distributary # 4) receive structurally too much, while three canals (Maho Dheri, distributary # 5 and Power House) receive about 80 percent of their target. Another common operational strategy that can be identified from this data is the tendency of the ID to lower the supplies at the end of the season (November/December) to about 75 - 80 percent of FSL, as the supplies in the river are getting lower as well as the crop water requirements reach their minimum around 2 mm per day. It must be noted that this data taken from the official Gauge Register of the ID is most probably somewhat optimistic; the data suggests a remarkably stable steady state flow which in reality proves not to be quite so stable. Nevertheless, the data provide a clear indication of the operational intentions of the ID and their efforts to supply the canal heads with their full supply targets.

The issue of tail-end gauges, however, is a completely different matter. With a well functioning Crump canal, the tail gauges should reflect the same ratio of target fulfilment as those under which the specific head gauges are operated (i.e. one foot water depth, under ideal conditions and configuration). The official registration of tail-end gauges, unfortunately, tends to merely reflect the official targets rather than the true field values. They thus frequently yield situations in which the official tail gauge values possess coefficients of variation that are miraculously lower than their head-end gauge. As an indicator for performance, the officially recorded tail gauges thus provide little meaning.

3.3.2 Dilapidation of the Hydraulic Profile

Once the canals are supplied at the head with their full or designed water supplies, the hydraulic property of ‘self-acting’ proportionality should be able to assure a proportional water distribution among the outlets of a canal so that each tertiary unit receives its targeted water supply. Although this requires no active operational water control measures, the ID bears the operational responsibility to maintain the hydraulic profile of the canals according to the designed proportionality criteria, to ensure that these targets of water delivery are met. An evaluation of the water delivery performance should then concentrate on the capacity of distributing the delivered head-end discharge proportionally over the outlets of a canal.

The most straightforward measure – if one has discharge measurements to its disposal – of water delivery performance is then to evaluate the Delivery Performance Ratio (DPR) of water supply among each outlet of the canal. This ratio evaluates the actual delivered discharge through the outlet against its design value, thus yielding a value of unity for excellent performance.[53] In the case of Crump canals, the DPR evaluation should thus yield a horizontal

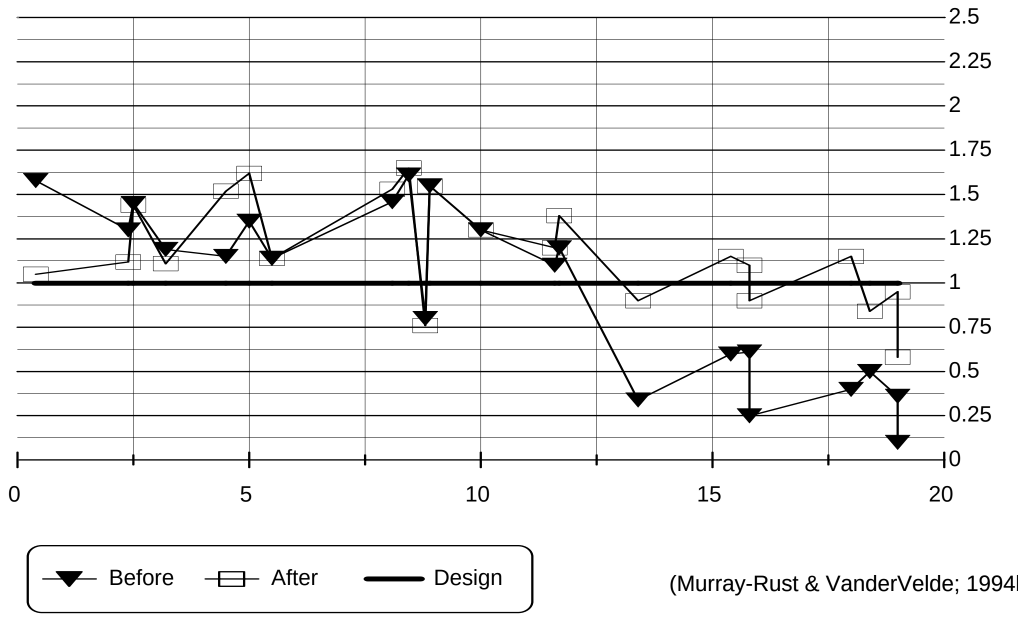
[53] Strictly speaking the DPR is defined as the ratio of actual water delivery against the targeted delivery rate (*cf.* Murray-Rust & Snellen; 1993). For the self-acting proportionality this would strictly mean that the targeted delivery rate would be proportional to the supply rate of the parent channel – i.e. when the distributary is run at 80 percent of full supply discharge, the targeted supply rate for the outlets would be 80 percent of design discharge. However, by adopting the design discharge as the target delivery independent of the supply level of (continued...)

line among the outlets of one canal; i.e. all outlets should be running at the same DPR as under which the intake of the canal is running (DPR of unity when FSL is delivered at the head, or a DPR of 0.8 when the canal is running at 80 percent of its design discharge, etc.).

Figures 3.6 and 3.7 present the DPR for two canals (Lagar and Pir Mahal distributaries) of the Lower Chenab Canal (LCC), as have been presented by Murray-Rust and VanderVelde (1994b). Both cases present a typical head-tail end problem of water distribution, in which the head-end outlets tend to run at a DPR substantially more than unity, while the tail-end outlets run at a DPR substantially below unity. This situation is commonly encountered in the present day operations of protective irrigation systems in Pakistan, be it in different degrees of severeness. (*cf.* Bandaragoda & Saeed-ur-Rehman; 1995, Bhutta & VanderVelde; 1992, Kuper & Kijne; 1992, Kuper; 1997, Visser *et al*; 1998, Ahmad; 1999, Babar; 1999, Murray-Rust *et al*; 2000, Lashari & Murray-Rust; 2000) In general, the DPR evaluation will quantitatively confirm the impression that although the canals are nearly supplied with their design, or target, discharges, the tail-end outlets are more often structurally deprived of their fair share of water supply.

Interestingly, the DPR evaluation of distributary canals of LCC has been conducted by Murray-Rust and VanderVelde to determine the impact of maintenance activities on the improvement of the proportional water distribution. For this purpose figs. 3.6 & 3.7 present the outlet DPR before and after a targeted desilting programme was carried out by the ID in order to restore the hydraulic profile of the channels. In the case of Lagar distributary the data shows

Fig. 3.6: Water Distribution Performance in Lagar Distributary
Outlet DPR Before and After Canal Desilting [-]



(Murray-Rust & VanderVelde; 1994b)

[53] (...continued)
the distributary, one can easily compare the performances of one canal for its different supply levels.

Fig. 3.7: Water Distribution Performance in Pir Mahal Distributary Outlet DPR Before and After Canal Desilting [-]

(Murray-Rust & VanderVelde; 1994b)

a dramatic improvement in the water delivery performance after the desilting had been conducted, bringing back the DPR of tail-end outlets to a value close to the targeted unity. In the case of Pir Mahal distributary, the achieved improvements are much less successful. In the latter case, the analysis indicates that the problems in achieving a proportional water distribution are caused by a distortion of the hydraulic profile due to alterations in the hydraulic settings of the outlet structures themselves, rather than by a problem of siltation. (Murray-Rust & VanderVelde; 1994b)

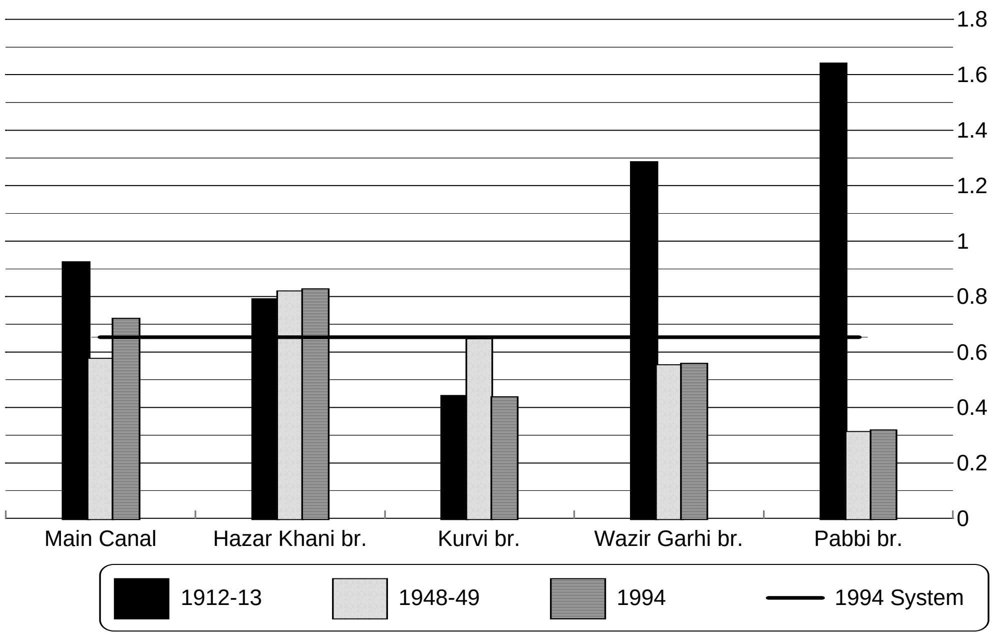
In any of these assessments of water delivery performance, a further analysis will always have to be conducted in order to determine the precise cause(s) of the identified (and quantified) deviations in proportionality. In terms of the maintenance of the hydraulic profile of the canal it is always important to distinguish between two structural deterioration processes: (i) alterations in regime properties through siltation and/or scouring of the channel; (ii) alterations in the hydraulic configurations of the outlet through tampering and/or changing of outlet dimensions. Moreover, one should be aware of a third and more temporal process of operational interference, in which the total or partial closure of outlet structures by water users lead to a deviation of proportionality at the tail-end. Although this is not a deterioration of the hydraulic profile, it leads to a deviation of proportionality in times of excess water supply (i.e. when ETc is very low) that can cause severe problems for tail-end tertiary units when they do not have access to adequate drainage facilities.

The water allocation provides a crucial function in that, in principal, it should provide for the design – or reference – values of the canal and outlet discharges on which the hydraulic profile for the 'self-acting' proportionality should be based. All the canal measures – FSL, the canal and the outlet dimensions – should be derived from the allocated discharges along each point of the canal or system. One would thus expect, that such a vital aspect would have been secured in a well defined management procedure. As has been explained in the foregoing, this has, however, never occurred.

In the previous chapter it has been argued why the ID never managed to implement an uniform procedure of water allocation. It is, however, evident that not only was the water allocation not carried out along equitable division principles – which on itself has no immediate consequences for the derivation and controlling of the required hydraulic profile – the allocations were furthermore subjected to changes over time. The latter, of course, having great consequences on the controlling of the hydraulic profile, as it implies that after each change in water allocation the hydraulic profile should be construed anew by finding the proper balance between new FSL and outlet(s) dimensions.

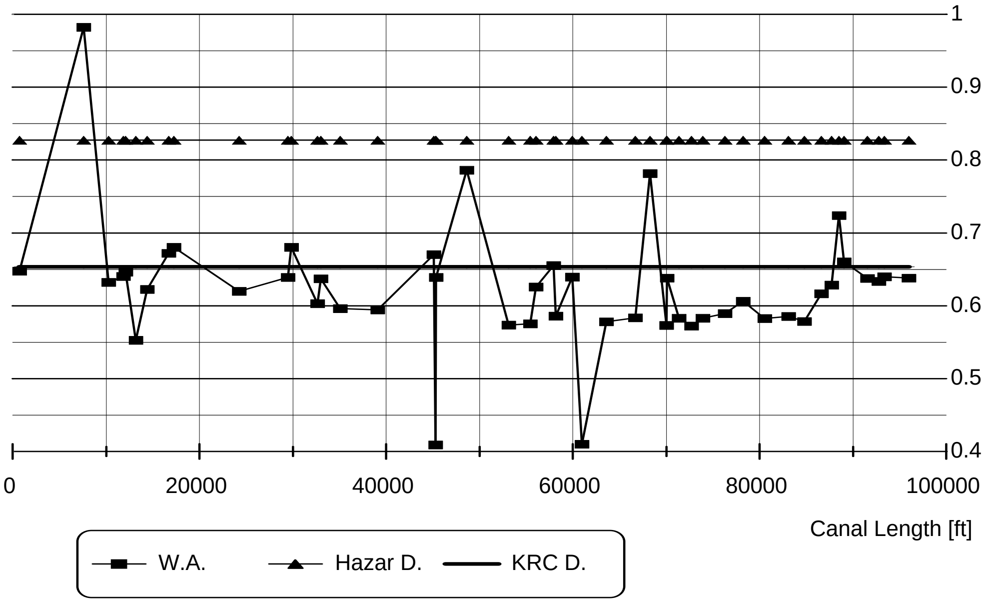
Figures 3.8 - 3.11 provide an overview of the water allocations for the KRC. Figure 3.8 presents the water allowances for the main canal[54] and the four distributary canals of the KRC for three different years. The first thing that becomes apparent, is that there are stark differences in water allocation between the different distributary canals of the same system, in which their allocated shares deviates substantially from the average water allocation for the system (defined as the full supply intake at the system head divided over the total culturable command area). Although the allocations belong clearly to a protective scheme, the 'level of protectiveness' differs starkly for the different channels varying from a meagre 0.4 l/s/ha (5 cusecs/1000 acres) to a reasonable 0.8 l/s/ha (10 cusecs/1000 acres). The extreme high values of water allowance – in terms of protective irrigation – for the Wazir Garhi and Pabbi branches for the year 1912-13 are partly explained by the fact that the command areas of these channels were still under

Fig. 3.8: Historic Water Allowances at Canal Head in Kabul River Canal System [l/s/ha]



[54] For the main canal, the water allowance is defined for the water that has been allocated to supply the tertiary units that take-off directly from the main canal (i.e. the water that is used to supply the distributaries is excluded from this figure).

Fig. 3.9: Official Water Allowances at Outlets [l/s/ha]
Hazar Khani Branch, Kabul River Canal System



development at that time; in 1948-49 the total CCA of these channels had been extended fourfold. The changes in allocation for the other canals, however, can not be explained in these terms.

Whit regard to the water allocation towards the tertiary units within one distributary canal, similar stark differences in the values of the official water allowance appear. Figures 3.9 - 3.11 present the officially registered water allowances for all the outlets of the Hazar Khani, Kurvi and Pabbi branches of the KRC, as can be found in the present day Outlet Register. The extreme small tertiary units are not presented in the graphs, as they tend to have extreme high water allowances due to the misfit between the small command area and minimum required size of outlet structure. The presented differences in water allowances must thus be the result of deliberate allocation decisions. That equity is not a primary objective of water allocation and distribution is clearly reflected in this data. The stark differences in water allowances that can be encountered among the outlets of one canal emphasize Gilmartin's (1994) thesis that 'the level of protectiveness' for which irrigation water is being supplied differs for every tertiary unit, and is mainly the result of the allocation 'agreements' that have been reached between the ID and the local communities.

3.3.3 Operational Management as a Rule Abiding Mechanism

As has been argued in the previous paragraph, the daily operation by the ID of the protective irrigation systems is primarily governed by the efforts to meet the FSL targets at the head of the canals. The meeting of this target constitutes by far the most important rule through which the ID conducts its management activities. This is, by itself, not surprising, since the design water

Fig. 3.10: Official Water Allowances at Outlets [l/s/a]
Kurvi Minor, Kabul River Canal System

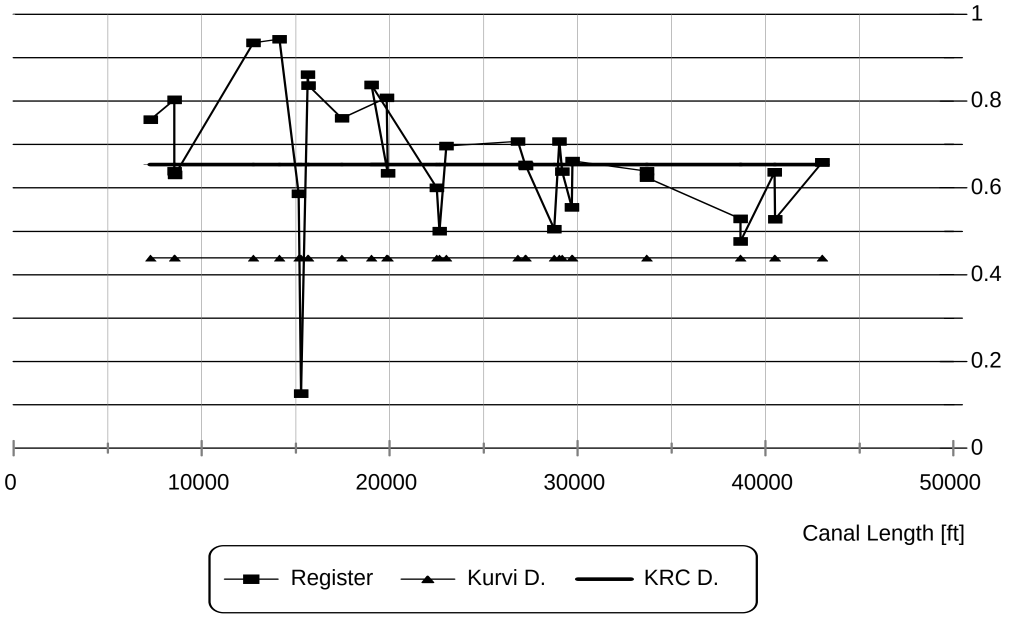
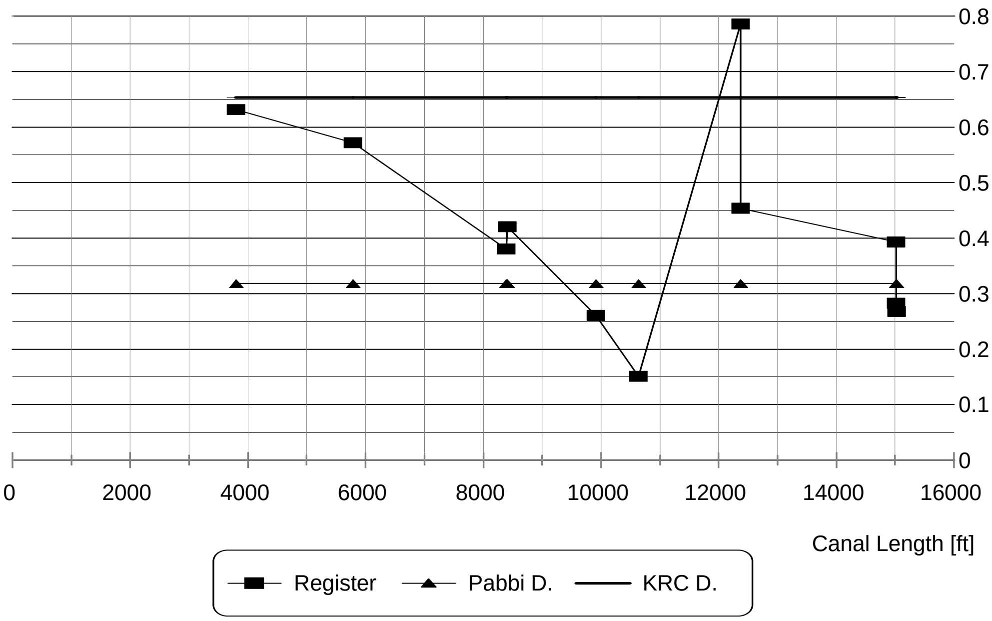


Fig. 3.11: Official Water Allowances at Outlets [l/s/ha]
Pabbi Minor, Kabul River Canal System



levels comprised one of the principle operational targets of the concept of protective irrigation. However, there is more to the operation and controlling of the 'self-acting' proportionality than meeting FSL targets alone. The crux of managing the protective irrigation in the field according to its design concept has always been to control the water allocation, the dimensions of the hydraulic structures and the canal profile in order to maintain a specific hydraulic profile, in which the FSL operation would 'automatically' lead to the desired distribution of water. The former is very much a prerequisite for the latter to function as intended.

That the FSL operation continues to be implemented in the current day operations of the protective irrigation systems, is largely due to the well defined and relatively simple procedures in which this operational task has been translated. From the very beginning, the operational procedures have been defined in a clear set of rules that stipulate that the canals should be operated in principle at FSL, that deviations from this target could be tolerated as long as the minimum target of 75 percent of FSL could be reached, and otherwise a rotational schedule on the main systems should be implemented. A set of rules that have been incorporated in the daily management by the design and upkeep of the Gauge Registers, that provide the management tool to monitor the actual canal operations and enables the ID to enter into a simple feed-back cycle to reach its operational targets. This operational procedure has thus been effectively institutionalized within the ID, even to the extent that the present day Gauge Registers are still drawn from the central government printing offices and have the same format as the ones introduced in the 1930s.

The issue of maintaining the required hydraulic profile of each canal by controlling the water allocation, hydraulic structures and sedimentation processes have never been translated in such well defined procedures, as those for attaining an FSL operation. Although the concept of protective irrigation has implicitly always attached enormous significance to these prerequisites of 'self-acting' proportionality, the ID never managed to define a clear set of rules by which a procedure could be established.

Controlling the Hydraulic Profile: According to the Concept...

In order to run the 'self-acting' Crump canals as intended, a primary management function is to control the hydraulic profile of the canals according to their proportional settings so as to ensure that the prerequisites of the 'self-acting' water distribution are met for the operation of the system on water levels. This management function was partially given shape by Jesson (1940) with the use of the Gauge and H-Registers in unison as operation and monitoring tools (see section 2.7) Used together, these tools could identify any deviation of proportionality in water distribution. Not only as an identification of whether deviations were taking place in a canal (through the Gauge Register), but also where along the canal the deviation was caused (through the H-Register). On-site inspection would then be required to determine whether the deviation was caused by problems in the regime of the channel, or due to illegal alterations (i.e. tampering) of the outlet structures.

The Gauge and H-Registers were thus designed to shape a routine activity of monitoring the water delivery as a first step of a feed-back control mechanism of evaluating the actual water delivery status against its operational targets. In order to exert control, a second step is required that defines the procedure that should be followed in adjusting the encountered water delivery situation, once deviations are identified through monitoring, to meet operational targets. As has been explained above, this was done for the operational procedures for delivering full supply *level* by defining a set of rules that specified three ‘tolerable’ classes of water level operation. For the control of the hydraulic profile, however, this second step of adjusting the process of water delivery, in case of occurring deviations from operational targets, has not been formally defined. Implicitly, this control procedure is governed by the hydraulic principles of ‘self-acting’ proportionality; i.e. the hydraulic principles determine how the physical parameters of the canal dimension and outlet structures should be ‘set’ and controlled in each particular situation in relation to the steady state water levels of the normal supply, which on its turn is defined by the water allocations. In essence, the rules for controlling the hydraulic profile are thus defined in the hydraulic principles that need to be applied in each particular situation. However, this covers only the technical side of the control mechanism.

From a management point of view, the control of the hydraulic profile entails an elaborate procedure, as it basically implies that the control can only be effectuated by implementing an (partial) overhaul of the canal infrastructure. Once a deviation from the operational targets has been monitored, there are no simple operational procedures available to the management with which to solve the problem. In terms of operation, the only option available is to implement the *tatiling*; an option that is dreaded by farmers and ID staff alike, and moreover provides no solution but just a mere mitigation of the problem. The restoration of the hydraulic profile requires a physical adjustment of the canal and its structures, that tend to be a time, labour and cost intensive procedure that usually can only be implemented during the annual closure of the system, providing that there are enough funds available to do so. Exerting control on the hydraulic profile, thus basically requires the management to engage in a considerable maintenance activity that requires careful planning and has to be submitted for (financial) approval to the central provincial government. As such there are no explicit rules that can be followed to engage the control of the hydraulic profile once defects have been detected through the routine monitoring. Instead the control function becomes part of the maintenance procedures that have to be financed by the central exchequer and thus tend to get approved by the central authorities on a case by case basis.

Management-wise, the arrangements for the controlling of the hydraulic profile are thus rather peculiar. On the one hand, the canal officers of the ID have all the powers that are required to exert this control endorsed by the Canal & Drainage Act: they can close the canals and outlets when they deem necessary, levy hefty penalties on water users for the tampering with outlets, modify outlets, and even (re)define the water allocations and normal supply conditions of the channels. But on the other hand, they are dependent on the financial means that they are granted by the exchequer, in response to their requests, for the extent they will be able to implement the required control measures.

...And According to Practice

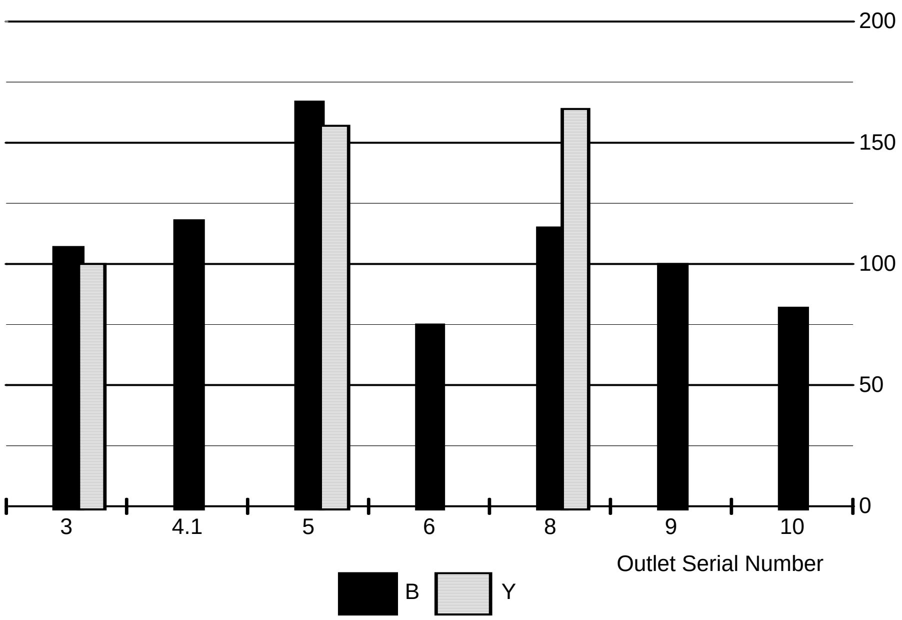
In the present day situation in Pakistan, the H-registers are seemingly not maintained as a routine monitoring tool by the ID. The extreme difficulties in getting hold of an up-kept H-Register – not WAMA, IWMI Pakistan nor I have ever been able to get one – however, raises doubts on whether this tool is actually used by the ID in its daily operation and maintenance activities. Since this register was devised by Jesson as an O&M tool at a relatively late stage – he proposed to take it up as a formal register in his contribution to the Punjab Engineering Congress of 1940 (*cf.* Jesson; 1940) – the question arises whether its use ever got institutionalised within the ID at all. Neither do the tail gauge entries in the official Gauge Register always reflect the conditions that are prevailing in the field. Effectively, the whole control mechanism for the maintenance of the hydraulic profile is no longer part of the operational routine. This loss of an important control mechanism might be regarded as indicative of the current loss of commitment to the objectives of proportional water distribution in protective irrigation. It certainly has made the administration of the current state of affairs – in which the deterioration of the proportionality characteristic has become an endemic feature – more easy. The occurrence of this deterioration can only be indicated, at best, in general terms of non-realisation of the tail gauge targets. As to where the causes of this deterioration may lie (i.e. problems of regime or outlet dimensions) no management information is maintained. It will hardly require a lengthy exposition to explain that in the structural absence of such information it has become rather difficult to take the appropriate corrective measure of control in a timely and adequately manner. Contrarily, the absence of this information gathering fortifies the personalised character of the allocation and distribution of water, in which the discretional powers of the canal officers are further strengthened, and the process of accountability can no longer be based on this important information. For that matter, any process of performance assessment has been made much more difficult. With the data of the H-Register it would have been fairly simple, for instance, to conduct a structural hydraulic flexibility analysis once a month for the assessment of the water distribution performance to all the outlets.

This is not to say that maintenance is no longer carried out. Rather, it is carried out as a task in its own right, instead of being a closely linked support service for the control of the hydraulic profile. Maintenance is increasingly being regarded as a routine measure to get rid of the siltation in the canals, maintain or repair canal linings to reduce the conveyance losses, and to maintain the (mainly gated) structures in working conditions. Canal officers thus tend to follow standard procedures in the preparation of the maintenance schedules: the canal profile has to be maintained ever X years, so every year Y metres of canal have to be cleaned and trimmed; the gates of the structures need to be painted every X years, so Y gates get painted every year, etc. (GoNWFP; 1992). These maintenance schedules are on their turn then submitted, in standard formats and according to prefixed time schedules, for funding to the central authority at the provincial level (i.e. the office of the Secretary of Irrigation). The Secretary then disperses the available funds over the requests, after which the canal officers schedule the maintenance activities according to priorities and available funding. In this manner maintenance has been reduced to a routine procedure, with a clear set of rules and guidelines that every officer in the bureaucracy can follow. While in the original concept, where maintenance was supposed to be intertwined with the control of the hydraulic profile, maintenance was primarily intended as a corrective measure, rather than a routine procedure. Which of course is a rather awkward principle for a bureaucratic organisation, as the submitting of the maintenance schedules then becomes synonymous to the reporting of problems to one's superiors; equalling to a statement that one has not been able to meet the operational targets.

The structural neglect of this crucial control mechanism in the daily management of the systems has thus led in many instances to a general deterioration of the hydraulic properties of the canals. The price that had to be paid – mainly by the tail-end water users – has been the gradual, but structural, loss of proportional water distribution. Even though desilting remains to be carried out from time to time by the ID as part of their general maintenance activities, its impact on restoring the hydraulic properties for proportional distribution cannot be targeted, let alone measured, with the information and procedures that are currently used by the ID. And as the figures from the targeted desilting in LCC show, siltation is only one of the processes that need to be controlled; as the data from Pir Mahal distributary suggests (*cf.* fig. 3.7) the dimensions and hydraulic settings of the outlet structures also require a tight control. Figures 3.12 and 3.13 present the actual outlet dimensions compared to their officially registered values for a set of sample outlets from the Pabbi and Hazar Khani branch canals of KRC. Although the figures only present information on the outlet dimensions and not on the hydraulic settings – which can even further offset the proportional properties of the canal – they provide a clear indication of a loss of hydraulic control in which the 'self-acting' proportionality can no longer be attained. In the case of the KRC, where most canals and outlets are running for 25 to 60 years[55], it is clear that an overhaul of the canals is long overdue if one wishes to keep running the system according to the objectives and procedures of protective irrigation.

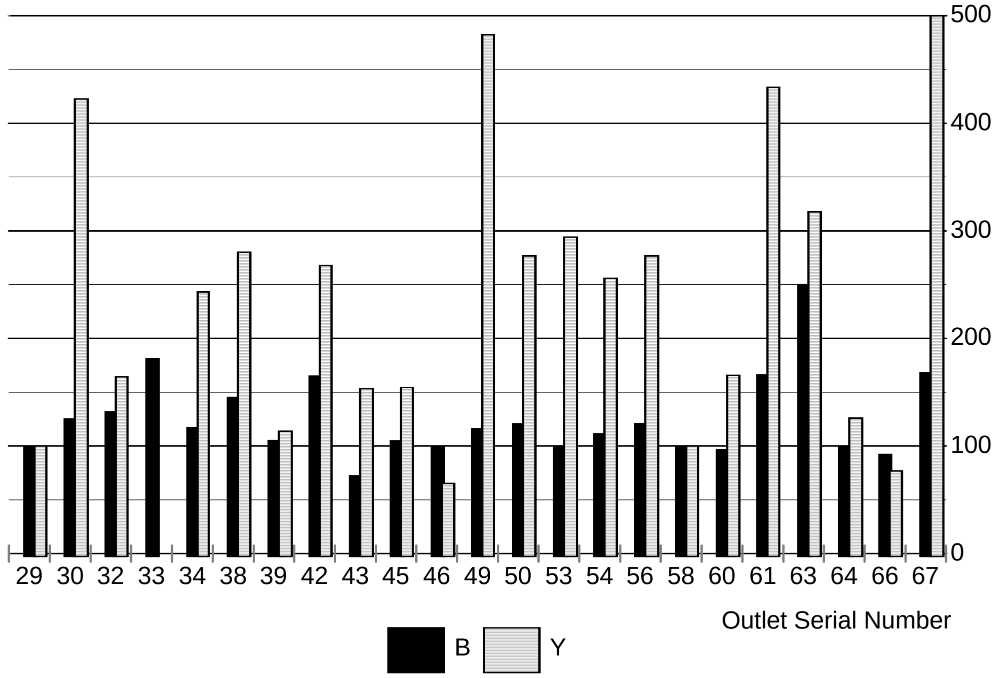
An important issue in the inadequacy of maintenance of the hydraulic profile has been the near absence of remodelling and rehabilitation activities as a routine activity of the ID's O&M and irrigation development activities. The days when Jesson and Sharma could 'tinker' for ten years on one distributary canal, in order to get its hydraulic configuration and water distribution properties just right (*cf.* Jesson; 1940, and Sharma; 1932), are long since gone. As has been

Fig. 3.12: Actual Outlet Dimensions of Pabbi Minor
Outlet Dimensions as Percentage of Design Value



55 Which by no means is exceptionally long for the canal systems of the Indus Basin. Many of the canals from the Sindh and Punjab are also still operated with such aging infrastructure.

Fig. 3.13: Actual Outlet Dimensions of Hazarkhani Branch
Outlet Dimensions as Percentage of Design Value



argued above, the newly independent state of Pakistan had other and more pressing concerns to attend to by protecting its IBIS from the adverse effects of partition. Although the share of public investment in agriculture and irrigation were relatively high during the first two decades of independence – around 30 percent for the period 1955-60, and about 46 percent during 1960-70 – the vast majority of these investments were committed to the work of WAPDA in the IBP. After completion of the IBP this share declined rapidly to the present level of about 17 percent. The annual O&M budget allocations for the provincial irrigation departments similarly declined over the years to the extent that even not all routine maintenance budgets can be met. An important factor in the latter has been, that during the 1980s the collected revenues as a percentage of O&M costs has declined from 53% to 38%. (Bandaragoda; 1999, *cf.* chapter eight)

Seen in light of the above, the relevance for the upkeep of the H-Register has as good as vanished, when the ID is not provided with the means and capacity to address the problems of hydraulic configuration and water distribution the register is meant to identify.

3.3.4 How to get away with a deteriorated water delivery

The gradual decline in water control and ensuing classical head tail end problems in water delivery service have resulted, naturally, in many water management problems. In many instances it has seriously affected the capacity of the ID to deliver the services as defined by the concept of protective irrigation. The inherently relative scarce water supply has been frequently and considerably infringed upon for a large and growing number of tailenders. The intrinsic nature of a protective service induces low tolerance levels for errors in water supply, as a failure to deliver the restricted quantity tends to have an immediate and substantial negative impact on the agricultural productivity of the affected water users. The question then naturally rises how the ID can get away with such a gradual deterioration in its water delivery service. A question that needs to be explored in two aspects of water management: the process of management accountability and, the process of acquiring alternative sources of water supply.

The institutional setup for water management of protective irrigation, as defined by the CDA and the task and functions of the ID, restrict the opportunities for water users to engage in an accountability process on the service they are provided with. Once water users are deprived of their 'protective rate' of water supply at the tertiary unit, there is very little they can do. They can file a complaint with the canal officers for more water. However, the canal officers can then decide, as part of their discretional powers provided by the CDA, if they will grant the complaint or not. A decision that can be made entirely circumstantially: since the water allocation is not embedded in a clear cut procedure, it provides little legal possibilities to establish a specific claim on water supply. Additionally the canal officers can always 'formalise' a shortfall in supply as an unfortunate but necessary consequence of having to deal with a general shortage of water or 'technical' problems as provided for under section 32 of the Act. The process of accountability is further complicated by the fact that the service of water supply is defined – in its concept as in its institutional setup – as a relative service: a shortfall in water supply can only be contested as erroneous if the shortfall is disproportional to that of the other tertiary units along the canal; or on a higher level, to that of other canals in the system. Conducting accountability thus requires knowledge of the state of water delivery throughout the distributary canal and system – information which is typically gathered and kept by the canal officers of the ID.

When a complaint is ruled upon unfavourably by the canal officers, the affected water users have an option to appeal. The appeal, however, has to be submitted to the first class magistrate canal officers (i.e. SE or his superiors) of the same irrigation circle to which the initial complaint was filed. The appeal can thereupon be dealt with in the same circumstantial manner as the complaint itself, be it that it is ruled upon by a superior officer. The process of accountability has thus, to all means and pruposes, been made an internal management affair.

There is, however, one notable exception when it comes to the quaternary and individual level of irrigation where the water supply service is defined by the *Warabandi*. The allocated time share can not only be contested by a water user through the filing of a complaint with the canal officers, but moreover it can be submitted for appeal to the Civil Courts. This inclusion of a third party ruling, provided by the CDA, is made possible by the explicitly and unambiguously defined procedure for the drawing up of the *Warabandi* roster. Although the procedure can be lengthy and costly it is commonly applied[56], as it provides (in principle) an opportunity for water users to acquire a justly and accounted for time share. In terms of securing an appropriate water delivery service – that is to say, within the constraints of the protective irrigation concept – this accountability procedure only provides the opportunity to a part of that service; i.e. the time

[56] That it can be a lengthy and costly (in legal costs) procedure is illustrated by a number of cases that went all the way up to the Supreme Court and could take up to twenty years to be resolved. In such cases it is not so much the procedure of drawing up a *Warabandi* that is contested, but more often the prerequisites as which land belongs to the irrigated command area and not; can this field legally apply for extra orchard or land reclamation time allocation, etc. (Halsema, van and Wester; 1994).

share allocation. The very important aspect of accounting for the rate of water supply at the outlet, which after all also determinates the adequacy of the water supply service, remains the sole decision domain of the ID, as the provisions of the CDA explicitly exclude the Civil Courts (or any other third party) from interfering with the water distribution. (*cf.* Nasir; 1993)

The authoritarian like powers of the ID in the decision and accountability procedures of water distribution do, of course, facilitate the normalization of a disproportional water distribution practice. That is not to say that the ID can be completely indifferent to the problems and complaints of the affected water users in the management of these affairs. Mounting pressures from prolonged and accumulated complaints can lead to tedious appeal procedures or 'social unrest' in the field that eventually may mark the affected areas as problem-prone, which might affect in the end the very career opportunities for the responsible canal officers. However, it provides the ID with the means and opportunities to settle the water distribution problems in accordance with the particular technical, financial and social circumstances of each case.

Instead of, or in addition to, trying to oblige the ID to restore the proportional water distribution by holding it accountable to the objectives and 'spirit' of the protective irrigation concepts, a remedial strategy is to tap the groundwater by means of tubewells. This strategy has been widely adopted in the Indus Basin, both privately and publically.

Since public tubewells have been frequently implemented in the tail end areas of the command areas, where the water logging and salinity problems were mostly concentrated, they have often served to compensate for the losses in canal water supply. As such these programmes have often served to indemnify the ID from having to restore the proportional water delivery capacities of their canals, thus effectively undermining the emergence of an accountability process. Not that these programmes have effectively eradicated the water management problems of these area, since particularly in the Punjab and Sindh ground water has to be used in conjunction with the canal water due to its saline qualities (*cf.* Murray-Rust & VanderVelde; 1994a). However, in many instances it has certainly alleviated the pressure to provide for more irrigation water (*cf.* Halsema, van & Wester; 1994, Wahaj; 2001).

3.3.5 The Dynamics of Warabandi

> *"Herve Plusquellec has pointed out that we have ignored another important aspect of water management for groundwater control: the antiquated waribundi rotation system at the watercourse level. This system, which has been in effect for over a century, undoubtedly results in localized waterlogging as well as inequitable distribution of water below the moghas."* (Ahmad & Kutcher; 1992:94)

The problem of *Warabandi*, as highlighted in the above quote, is that it seemingly does not square with the conceptions of 'modern' and 'adequate' irrigation water delivery services that have been developed and refined on the basis of the scientific insights of crop water requirements and yield response to water. The formal rigidity of the *Warabandi* roster, where every water user is provided with a fixed turn (i.e. at a fixed timing), of fixed duration and – under theoretical ideal delivery performance – of a fixed rate and volume, is in clear defiance of the knowledge that actual crop water requirements vary starkly over time. It can thus logically be inferred, that *Warabandi* must be an ineffective and inefficient water distribution method that hampers production – when argued from the objective of optimising water management and crop production per unit of land.

In the water management context of the IBIS, however, the *Warabandi* should primarily be regarded in its institutional capacity to regulate the water management at the tertiary level within the constraints imposed by the irrigation system. As so often, the formal and theoretical rules and procedures turns then out to be not quite so rigid in practice, when the institution is subjected to the dynamics of the strategies that water users apply in their daily water management activities.

The historical development of the *Warabandi* as a mechanism for water management at the tertiary level, provides already a picture of its strategic application. It was taken up as a formal roster for the regulation of the water distribution at the tertiary level with the formulation of the Canal & Drainage Act in 1873. As Gilmartin (1994) shows, however, *Warabandi* was an indigenous water distribution method that was in use in northern-British-India, particularly among multiple owners of one well.[57] It has thus been adopted in the Canal & Drainage Act, where formal rules have been set for the allocation of the time-share of water delivered through the outlet in proportion to the landholding (*cf.* chapter two, Malhotra; 1982, Nasir; 1993). At first, however, the uptake of *Warabandi* in the Canal & Drainage Act was primarily a judicial provision for the settlement of water conflicts for when they arose, and as they arose. Meaning, that formal *Warabandi* rosters would only be drawn-up after a conflict would be brought before the irrigation authorities for resolution (*cf.* Ali; 1988, Gilmartin; 1994). As stated, by 1939 only an estimated half of all tertiary units had a formal *Warabandi* drawn-up by the irrigation department (Gilmartin; 1994). Since independence this situation has changed, in the sense that nowadays nearly all tertiary units have a formal *Warabandi* roster drawn-up by the irrigation department (*cf.* Bandaragoda & Rehman; 1995).

Apart from a mere element of time, the increase in formal *Warabandi* rosters also coincides with the intensification of the irrigated agriculture and the mounting pressure on the water resources. With the rapid increase in population since independence, the number of water users have increased manifold through fragmentation of landholdings. This has led to an increase of the relative water scarcity, wherein the smaller landholding decreases the flexibility to adapt the cropping intensities to water shortages at the individual level as people quicker reach the limited acreage of (economically) sustainable agriculture.[58] Not only does increase in relative water scarcity tend to initially lead to increases in water conflicts, the formal *Warabandi* rosters, once drawn-up, clearly tend to be applied more strictly in times of water scarcity (*cf.* Halsema, van & Wester; 1994, Bandaragoda & Rehman; 1995, Wahaj; 2001). The importance of the *Warabandi* lies thereby primarily as a mechanism to regulate the water distribution at times of water scarcity through its proportional time share allocation. It may thus be ancient and rooted in indigenous practices, its institutional role to prevent and settle conflicts in water distribution has only grown and become more prominent with the passage of time when demand for water, as its relative scarcity, have only grown.

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57 Gilmartin's has been the only references I have encountered to accounts of the origins of *Warabandi* that pre-date the Canal & Drainage Act.

58 For (very) large landowners, as can still be found in Sindh and parts of Punjab, and to a lesser extend in NWFP, this is of course not an issue. They face, however, a different 'dilemma' in that they have to patronage their tenants and labourers, that usually form their political constituency.

One thus tends to see that at times of severest water scarcity (i.e. during peak water requirements), the *Warabandi* roster for canal water is applied more strictly. During periods of less scarcity, however, adaptations to the scheduling roster are readily and frequently made to accommodate more convenient and effective application timings and quantities. The most commonly applied among these, is to exchange a *Warabandi* turn to lower the frequency of irrigation to a fortnight or three weeks; i.e. turns are pooled among water users to lower the irrigation frequency and increase the application volume. A practice that increases the ability to refill the root-zone of deep rooting crops with one irrigation turn, and allows cultivators to practice pre-sowing irrigation and fill their soils to field capacity (*cf*. Beeker; 1993, Halsema, van & Wester; 1994). During times of relative abundance, mainly restricted to the December, water users will restrict their irrigation applications (both in volume as in frequency), and alteration to the *Warabandi* are focussed on restricting night time irrigation – providing that adequate drainage opportunities are available.[59]

The exchanges of *Warabandi* turns between water users of one tertiary unit, and sometimes even between water users of different tertiary units, are usually, as far as canal water is concerned, not so much governed by the principles of trade, but by the social principles of kinship relations. Preference is usually given to enter in exchange arrangements first with family members (usually brothers), then the *khel*[60] or extended family, and the tribe, before engaging outsiders. As such these arrangements represent rarely economic trades, but are primarily kinship arrangements to improve the irrigation schedules for both parties (or, in modern economic parlance, to create a win-win situation). The arrangement can be ad-hoc or on a more structural basis. As a general rule, however, the scarcer the water situation, the more stringent the arrangements are made. Meaning that, in times of water scarcity irrigation turns will usually have to be returned by the next *Warabandi* cycle, while in times of relative abundance turns can be granted or taken as part of investing in, and maintaining, ones kinship relations. (Halsema, van & Wester; 1994, Leeuwen, van; 1997)

A different matter is the more structural arrangements that are made in the form of a *kacha Warabandi* (i.e. unofficial) that is used instead of the *pucca Warabandi* (i.e. official), even though the latter exists. It is not unusual to encounter such situation, particularly when the *pucca Warabandi* dates back to the time when the ancestors were the owners of the land and holders of the water rights and turns. In such situations, the *kacha Warabandi* in use can often lead to disproportional time share allocations, in differentiation of what an updated *pucca Warabandi* would yield. There are various reasons for such differentiations to occur. The most obvious and common is that part of the command area has been taken out of production – be it through expansion of the village or the road network, or by abandoning waterlogged and saline land. The time share of which, is then added to the remaining part of the holding. Other reasons are: differentiations can be made in the non-registered inheritance arrangements of land and water rights; old extra time share allocations for land reclamation and orchards are still in place;

[59] In NWFP such drainage opportunities are usually available in the form of natural *Nullahs* as in the case of the Kabul River Canal System (*cf.* Halsema, van & Wester; 1994, Leeuwen, van; 1997). In regions as the Punjab, where *Nullahs* are much less frequent, there is tendency for water users to take waterlogged and saline areas out of command and use them for 'drainage areas' (*cf.* Wahaj; 2001).

[60] The *khel* is the extended family unit with the tribal unit of Pokhtoon culture.

tenants receive a disproportional time share from their landowners and official water right holders. (*cf.* Bandaragoda & Rehman; 1995, Wahaj; 2001, Merrey; 1986a,b,c) The *kacha Warabandi* is then the means to regulate the water distribution schedule and adapt the outdated *pucca Warabandi* to the present socio-environmental conditions in the tertiary unit. As long as serious conflicts do not arise, that are brought before the irrigation department for settlement by members of the tertiary unit, the *kacha Warabandi* can continue to govern the day to day water management arrangements within the *Chak*. When conflicts do arise, a solution or settlement will first be tried to be reached within the local community with the help of village elders. If required, the *Zilladar* can be engaged to help set-up a new *kacha Warabandi*. The incentive to settle the issue within the community is great, because it allows it to apply its own equity principles rather than those formalised in the Canal & Drainage Act, and the drawing up of a *pucca Warabandi* is costly and lengthily matter, not in the least because the actual landholding will have to be officially registered in the land-registry. (*cf*. Halsema, van & Wester; 1994, Bandaragoda & Rehman; 1995, Leeuwen, van; 1997)

The matter is quite different for private tubewells. There where groundwater is extracted through private entrepreneurship, water is usually sold in cash or kind transactions. The extra water is then purchased for conjunctive or supplementary use to canal water. The quality of the water (i.e. its salinity content) is then often a determinant factor in the market and whether it is used for supplementary or conjunctive use. (*cf.* Strosser; 1997)

3.4 THE NEED TO RESPOND TO CROP WATER REQUIREMENTS

Despite the numerous improvements that had been carried out during the 1960s and 1970s to the IBIS in order to enhance its performance – mainly through the installation of tubewells through the SCARP and the lining of watercourses through the OFWM projects – there remained a sense that the system was still underachieving. The gains achieved by these initiatives were, after all, mainly confined to increasing the command area (either through expansion or reclamation) and increasing the cropping intensities. The overall productivity, in terms of yield per acreage, remained at a dismally low level, particularly when compared to international standards.[61] These low yields became a recurring problem that was mentioned in every major document (research or policy) produced on irrigation in Pakistan, linking it to ever increasing concerns on how Pakistan was to meet its growing food requirements.

In the second half of the 1970s there was a marked shift in the analysis of the irrigation problems of Pakistan, in that increasingly the traditional protective irrigation systems were being regarded as ‘antiquated’ systems that placed too much restriction on agricultural production. This view was supported by recent developments in the irrigation sector as a whole. After the development of the CROPWAT model in the first half of the 1970s and the mounting successes

[61] It must be noted, however, that although the average yield statistics that are used in national and international policy documents dealing with Pakistan are always very low in comparison to the international standards, it is not very clear where these figures come from, or how old they are. Figures from specific cases obtained through research projects always tend to provide higher than the national average figures, which raises some questions about the accuracy and reliability of the national averages used.

with the introduction of High Yielding Varieties during the Green Revolution, more and more emphasis was placed on the need to increase the delivery efficiencies and closely match the irrigation supplies with crop water requirements. The inherent low supply levels and rigid rotation schedules of the protective irrigation systems were thus starting to be regarded as impediments to the further development and 'greening' of the agricultural production in the Indus Basin.

Studies into the performance of irrigation systems of the Indus basin were henceforth increasingly being conducted along these lines of determining delivery and application efficiencies and the ability to meet crop water requirements. The very low yields were coming to be seen as almost endemic to the protective systems; where the per design shortage of water was further being aggravated by huge losses in the conveyance of water in the main and tertiary system, and the *Warabandi* rotation resulted in a structural mismatch between water supply and crop water requirement.

With continuing concerns about the level of productivity that was being attained in the IBIS, the need to match the supplies more closely with crop water requirements became gradually recognised at the policy level. In 1979 WAPDA stated the problem of mismatch between supplies and requirements as being caused by: (i) inadequate water supplies throughout the year; (ii) limitations of the design canal capacities. In 1988 the National Commission on Agriculture, from the Ministry of Food and Agriculture, attributed the low productivity to: (i) the chronic inequity affecting the tail enders; (ii) shortages during critical periods of the crop growth cycle. This led it to recommend the development of macro-level water management plans for the distribution of irrigation water supplies more in line with crop water requirements. At the same time, however, the Commission cautioned its recommendation with adding that such crop-based initiatives should be started initially only on a pilot scale. A similar recommendation was made during the finalising of the Water Sector Investment Plan for Pakistan in 1990, when Kirmani concluded that: *"More water can be made available for productive use by changing the historic withdrawal pattern to a crop needs pattern, by ensuring equitable distribution and by conjunctive use of surface and groundwater storage."* (Kirmani (1990), quoted in: Bandaragoda; 1998: 5). (Bandaragoda & Badruddin; 1992, Bandaragoda; 1998)

Although the need to transform the existing systems into a more productive form of irrigation got thus more acknowledged at the policy level, a cautious strategy was adopted. At the heart of policy there remained a sense that water was inherently scarce within the IBIS, delimiting the scope for productive modernisation. After all, on the level of the Indus basin, the situation prevailed that there was simply not enough water readily available to enlarge the water allocations for the different canals. This stance inhibited the formulation of a policy to tackle the paradox of restoring equity – caused to a considerable degree by head-enders that try to meet their crop water requirements – and simultaneously better match supply with demand. The ensuing strategy was thus to limit any initiatives for productive irrigation to those circumstances where the potentials for raising supplies to match potential crop water requirements arose. The intention being to gradually utilise the extra water made available within the IBIS – through increased storage capacity by the IBP and future savings through reduction of losses – to match supplies more closely with requirements, on a case by case basis.

The international donors reacted on this strategy by each formulating one project that would explore the introduction of productive irrigation as a pilot case; the World Bank through the remodelling of the LSC with Mardan-SCARP, and the Asian Development Bank with the development of the new CRBC. Both thus took up the initiative the moment the opportunity arose, at a time when there was no policy to address this modernisation in any of its technical or institutional issues. Presumably the pilot projects were to define the issues and prepare the grounds for the formulation of policies.

It is important to note that this tentative strategy for further development of the IBIS has been formulated in line with the leading paradigm of irrigation development at the time; it is based on the discourse that the enhancement of productivity should be sought through maximizing the crop yield per acre – a view firmly established by the successes of the Green Revolution. The alternative discourse, that of seeking yield maximization per unit of water, has not been fully considered as an alternative development strategy. Even though this might have been an appropriate alternative for Pakistan (that would follow upon the traditional philosophy of protective irrigation), where water remains scarcer than land, and has been studied and propagated by some scientists (notably Shanan (1986 & 1992), Narayanamurthy (1993 a & b) and Perry (1993)), it has nevertheless not been taken up for the case of Pakistan by either scientists, policy makers or donors. Undoubtedly, an important consideration in the chosen strategy has been its long term implications for the water control facilities in the IBIS. The matching of supplies with crop water requirements would inevitably lead to necessary future increases in storage capacity within the IBIS. This prospect has always featured high on WAPDA's 'wish list' ever since the completion of the Lieftinck (1968) report, and is argued fiercely in the recurrent discussions on the desirability to build Kalabakh Dam.

3.5 DISCUSSION & CONCLUSIONS

The era of independence marked the externalisation of the design and development of irrigation in Pakistan. The enormous effort and investment that was put into the IBP as part of the nation building effort, unwittingly disrupted the continuous search for seeking further improvements and innovations in the delivery and use of irrigation water. With the IBP, the financial, conceptual, institutional and policy resources were 'distracted' for 25 years towards the realisation of the grand 'vision' of creating the largest integrated irrigation system in the world. In this vision, the creation of a technical control and regulation capacity of the water resources at the national basin level stood central, together with the establishment of WAPDA as the federal authority that would allocate, regulate and generally manage the national water resources. This vision was strongly fed by the technological positivism that marked the era, in which the faith in technology, and designed physical systems in general, was nearly unbounded.

With the IBP, the system boundaries, and analysis, were set at the national/basin level, with as central process the acquisition, regulation and conveyance of the national water resources. The central problem and solution in this analysis was primarily defined as a technical one, as having to secure adequate water resources for maintaining and expanding the irrigated command area in the Indus-basin. Water scarcity had become the central problem and delimiting factor for irrigation; initiated by the explosive growth of run-of-the-river canal systems in Punjab and

Sindh during the 1920s -30s, and aggravated by the effects of partition. The objectives and purpose of the IBP were thereby set to capture enough water through storage facilities, and create a national conveyance network, with which the existing and future irrigation systems could be supplied with adequate amounts of water at the right time.

The sub-systems of the canal networks and the irrigated agriculture were in principle left untouched during these first years of securing the water resources – or so it seemed. Irrigation and water management in the canal systems were meant to continue as before (i.e. as developed and established during the numerous 'Crump remodellings' of the 1930s-40s), under the daily auspices of the Irrigation Departments. The new canal systems built during this period as part of the expansion policy, were only physically new. Conceptually they were all 'Crump canals', the majority of which were even designed during the 1930s-40s. The success of this national irrigation policy has mainly been achieved thanks to two factors: (i) the substantial expansion of the irrigated command area from 8 million ha in 1947 to nearly 14 million ha by the end of the 1970s; (ii) the intensification of cultivation to substantial higher intensities than originally envisaged in the designs. Both were achievable thanks to the increased capacity to capture and convey water at the basin level as a result of the IBP.

The SCARP-tubewell programme was a technical initiative that sought to find a technical solution to the problems of water-logging and salinity that increasingly emerged. It was conceived and introduced as a promising alternative to horizontal drainage. The latter was deemed too costly to be borne by the new nation alongside the IBP. Moreover, the former seemed promising by enabling the conjunctive use of surface and ground water, that would allow for further intensification of cultivation.

With the increasing demands for water, the importance of the (formal) *Warabandi* as a water distribution mechanism in times of water scarcity grew, as is reflected in the widespread rise of formally drawn up *Warabandi* rosters since independence. The strength of the *Warabandi* as the central institution in the regulation of day to day water management at the tertiary level, lies in its unambiguous allocation through proportional time-shares. With the *Warabandi* slip (i.e. the water right statement) every water user has a clear claim on 'her/his' water. It is on the basis of this clear-cut claim that water users can engage in negotiations and arrangements with each other, striking balances between the 'willingness to pay' (i.e. acquire someone's turn) and 'willingness to accept' (i.e. foregoing one's own turn) – although hardly ever in economic payments as far as canal water is concerned. The multiple deviations that do occur in practice when the water availability permits, show that the water users, in general, possess a great deal of ingenuity and determination to optimise and 'flexibilise' the *Warabandi* to their irrigation requirements and strategies.

With the passage of time, however, the constraints of the IBIS increasingly came to the forefront. Notwithstanding the successes in expanding and intensifying the command area, problems of water scarcity, distribution and stagnating productivity within the canal systems became increasingly evident by the mid 1970s. Studies on water management practices within the canal systems – spurred by the restricted opportunities for further expansion of the command area – divulged problems of disproportional water distribution at the main, secondary, and tertiary level. In case of the latter, high conveyance losses, water scarcity and the rigidity of rotation were presented as the main constraints to increased productivity.

Before independence, canal remodelling and 'tinkering', in combination with the *Chakbandi* process, formed effective substitutes for the control mechanisms of allocation and maintenance. These periodic re-configurations of canals served to strike new balances in water allocation and distribution, and adapt the irrigation system to the changes in the socio-economic and physical environment. They formed the dynamic control mechanism with which periodically new equifinal states for the system could be defined and established, as a process of seeking continuous improvements and innovation. With the post-independence change in institutional setting, however, the ID lost this primary control mechanism to manage, develop and improve the irrigation systems. In essence, it became institutionally reduced from managers and developers of irrigation systems to administrators of the government inventory of irrigation infrastructure.

This institutional degradation was not only a consequence of the shift in responsibilities in the task of design and development of irrigation, but was also further aggravated by the ensuing competition for personnel. With the creation of WAPDA as the principal counterpart to the foreign consultancy firms in the design and construction of the irrigation facilities in the IBIS, the irrigation department lost one of its principal roles as innovators and developers of irrigation with which it had made its name. The immediate effect was that bright managers and innovators such as the Sharma's, Jesson's, Crump's, Kennedy's, and Lacey's of the past, where drawn to WAPDA, as it quickly became the place to be for civil engineers that were interested in design and construction. In the course of time, this led to a complete externalisation of the design process. The designers (foreign and domestic) possessed little or no operation and management experience, while the staff of the ID no longer possessed the experience, or the opportunity, to engage in design and development.

The increasingly evident deterioration of the canal systems into structurally disproportional water distribution systems is the striking phenomenon of these post-independence developments. That is to say, of the aggravated disproportionality that evolved into structural tail-end problems. With the increasing evidence produced from the mid 1970s onwards, two developments took place: (i) the myth of equitable proportionality in water allocation and distribution of the 'Crump-concept' became propagated as the design target and standard of the 'good past age', rather than the conceptual ideal it once was; (ii) the ID quickly became stigmatised for being incapable of maintaining those standards and principles for equitable water allocation and distribution.

This mythologisation and stigmatisation was not only based on a false ideal, but also on the false premise that the judicial and managerial rules and procedures were geared towards the maintenance of this ideal. As was argued in this and the previous chapter, neither of these assumptions can be sustained. In the absence of any formal and specific commitment to a water allocation and distribution principle, the water users were, and continue to be, deprived of an essential means to engage the ID in any accountability process. Rather, they were thrown back on the strategy of their forefathers, to engage in individual and discretionary negotiations with Canal Officers to come to arrangements on the appropriate size of the outlet and command area.

The problem is thereby not so much the occurrence of disproportionality as such, which has always been inherent to irrigation in the Indus-basin, but the gradual and steady degradation of the hydraulic properties of the canals. As the ID no longer had the means to strike new water allocation and distribution balances through hydraulic re-configurations and remodellings of entire canals, any changes agreed by discretion, are by default at the deprivation of the tail.

The enormous increase in the pressure on, and competition for, irrigation water – illustrated by the growth in population from approximately 60 million in 1947 to 140 million at present – has strained the irrigation systems in the basin by demanding ever larger quantities of water. The pressure has found its natural and traditional accommodation in the discretionary water allocation and distribution provisions of the Canal & Drainage Act and the management procedures. In these arrangements the ID has tried to accommodate the irrigation systems to the changing environment by formally or informally granting adjustments to the three primary parameters of irrigation; i.e. Water Allowance, Cropping Intensity and Irrigation Duty. By the end of the 1970s it was already clear that in the majority of the irrigation systems a complete overhaul and revision of the water allocation and distribution arrangements was long overdue. As in the times of Kennedy and Crump, there was an urgent need for a *Chakbandi* process, in which a new congruent balance can be struck between the water availability, allocation, delivery and use. As has become evident from the fate of Crump's irrigation concept, this is, however, not only a matter of technical intervention to gain physical control on the regulation of the water resources. Such an overhaul of the irrigation system clearly needed to be accompanied by a revision of the Canal & Drainage Act and O&M procedures, in which a clear and specific water allocation policy is embedded. This latter is a prerequisite for the institutionalisation of clear and specific O&M targets and control mechanisms that are specifically geared towards the operation and maintenance of the irrigation concept. The discretionary powers of the Canal Officers clearly needed to be curbed and subjected to a process of accountability, in which the maintenance and improvement of the overall irrigation concept and water delivery service are the primary concern, rather than the 'pressing' needs of individuals and localised developments.

The institutional and technical developments that have taken place since independence, have not contributed to the reform of the water management sector. The irrigation programmes that were initiated concentrated on technical interventions to increase the capability to physically capture and regulate the conveyance of irrigation water throughout the IBIS. These interventions did not involve any conceptualisations of irrigation water management or water delivery service. They 'simply' sought to establish the IBIS as a basin level system, in which the inherent water shortage would be alleviated by increasing the water acquisition and conveyance capacity and efficiency. In the face of institutional competition with WAPDA, the ID not only stagnated, but its O&M capacity deteriorated. The SCARP-tubewell and OFWM programmes have led in this institutional environment to antonymous side effects. The relative increase in water availability these programmes yielded have, on the one hand stimulated the discretionary 're-adjustments' to the water allocation and distribution, while they simultaneously served to indemnify the ID from the poor distribution within the canal systems by mitigating its effects. As such, these programmes became poor surrogates for the remodellings of yesteryear. At the same time, the high O&M costs for the tubewells strained the budgets of the irrigation departments further, at the cost of regular maintenance.

Towards the end of the 1970s, however, the stagnating growth in irrigated agriculture gave impetus to a changed approach in irrigation development for the IBIS. Clearly new concepts of irrigation water delivery were needed, both technically and managerial. It was no longer a sole matter of reducing the water scarcity, but of seeking higher productivity and efficiency in water delivery and use, through innovation and modernisation of the water delivery systems. With the decision set to seek to establish a form of 'productive' irrigation within the IBIS, by opting for concepts of crop- or demand-based irrigation, the policy makers, donor agencies, WAPDA and consultants entered straight into the management domain of the ID. This phase of modernisation provided thus the opportunity to re-address, 50 years after the implementation of Crump's concept, the issue of water allocation and distribution, by striking a new congruence between water availability and use. From the success and shortcomings of the implementation of Crump's concept it is evident that such a conceptualisation for modernisation needs to be internalised and institutionalised within the ID. Not only in the realms of technical and hydraulic water control and its operational targets, but also in the realms of water management, in which the allocation, scheduling and maintenance procedures are specifically and explicitly geared towards the O&M of the concept. How the modernisation initiatives have fared in this challenge, is the topic of the following chapters.

CHAPTER FOUR

DESIGN & CONCEPTUALISATION OF A RESPONSIVE WATER DELIVERY SERVICE

THE CASE OF MARDAN-SCARP

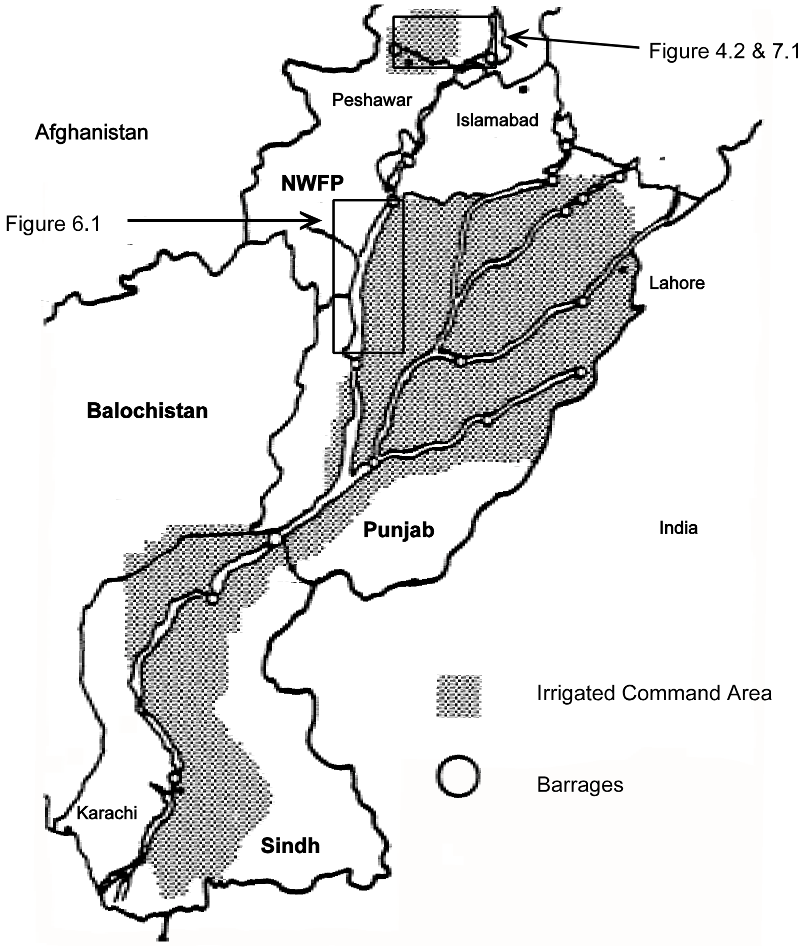
4.1 INTRODUCTION

The previous chapter shows that the extensive and long running ‘protective’ irrigation systems of the Indus Basin were increasingly running into problems. By the 1980s the moment had come to readdress the developments in irrigation by exploring the possibilities to depart from the traditional protective mode of water delivery and aim, instead, for a more ‘productive’ mode of water delivery more in response to the actual crop water requirements. The North Western Frontier Province (NWFP) provided excellent opportunities to commence this innovation, as it had a relative surplus of water available to meet future crop water requirements.

The development of the new Chasma Right Bank Canal (CRBC) and the modernisation of the existing Lower Swat Canal (LSC) by the Mardan-SCARP project (see fig 4.1), both initiated at the late 1970s, were the first interventions in the Indus Basin that explicitly sought to establish such a new mode of water delivery and distribution. For the first time, these projects aimed at establishing a new irrigation concept in which the operation and management of water delivery would be specifically geared at responding to the crop requirements. Both projects, though different in scope and detail, were meant to introduce, for Pakistan, new technologies in infrastructure and new operational procedures that would enable the management of varying flows in response to changing crop water requirements. At the time of their inception these projects seemed to exemplify a new phase in the development of the Indus Basin, in which a modernisation of the irrigation sector would be initiated by coordinated efforts in adapting the irrigation policy, management and technology to meet the requirements for increasing productivity.

This chapter will treat this first phase of irrigation modernisation in Pakistan by scrutinising the conception, design and implementation of the Mardan-SCARP project. Firstly it will treat the process of conceiving a new concept of modern irrigation for Pakistan, and the objectives and assumptions set and made in choosing for crop-based irrigation. The modernisation of LSC by

Fig. 4.1: Project Locations within IBIS



Mardan-SCARP is then treated in some detail. First in how the notion of crop-based irrigation has been translated into a detailed design in which particular choices have been made on water control and operational management, and its development into a new system. Section 4.4 details how the modernised LSC should be operated and managed, according to the Mardan-SCARP O&M manual. The central issue here is the way in which the project conceived new water scheduling and distribution mechanisms, expecting thereby the water users and the ID to radically transform their water management practices, without giving adequate attention to a process of change management to realise such a transformation. Section 4.5 treats the ensuing conflict between the Mardan-SCARP project and the ID, in which the choice of outlet, and the issue of water scheduling in response to water requirements *cum* demands became contested. The section ends with the subsequent pilot project that was undertaken to address the operational management issue, but which failed to settle the conflict as it focussed primarily on demonstrating the advantages of demand-based irrigation, rather than on testing and working out practical operational procedures for the new canal system. The final section (4.6) concludes by showing the eventual repudiation by the ID of the demand-based irrigation concept and the O&M proposals of the project.

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4.2 THE LOWER SWAT CANAL & ITS IRRIGATION PROBLEMS

4.2.1 100 Years of Irrigation in the Lower Swat Canal

The Lower Swat Canal, positioned in the Peshawar Vale covering the plain between Charsadda and Mardan (see fig 4.2), was the first irrigation canal in NWFP to be built by the British. When is was commissioned in 1885, it had no particular features that discerned it from the other systems built in the Indus Basin. It was built as a typical run of the river protective irrigation system that served a modest command area of 60,000 ha (149,105 acres GCA) by taking its water from the Swat River at Munda. In contrast to the Punjab, it crossed a terrain which had a relatively steep slope and was cut by a number of natural drains. The distributaries and minors thus featured relatively more drop and cross structures. In terms of water availability and distribution, however, the LSC was just a common system of its time, providing relatively scarce water through *Warabandi* rotation. The irrigation duties by which it was operated did not differ significantly from any of the other systems in India (see table 4.1).

In 1935 the LSC, like most of the other systems around that time, was remodelled according to Crump's water control concept. In addition to the new APM and Open Flume outlets, a movable control weir was constructed across the Swat river at Munda headworks in order to secure the intake during low flows. Henceforth, the irrigation water could be supplied to the 60,000 ha on a continuous basis by the ID by operating 25 water control points (mainly at the heads of the distributaries and minors) and monitoring 95 gauges.

After commissioning in 1885 the command area was relatively quickly developed, establishing irrigation intensities of 70 percent annually during the first ten years and settling around 120 percent for the next fifty years after full development of the command area with the completion of Kalpani distributary[62] in 1897 (see fig. 4.2). With a relatively modest capital cost of Rs 28 per irrigable acre, the LSC thus became quickly an 'administratively productive' system, yielding a good 11 percent net revenue on capital outlay between 1913 and 1918 (Buckley, 1920). By the time of *moduling* the LSC canals along Crump's water control concept in 1935, irrigation became fully developed, marked by a shift in cultivation practice in that henceforth the *Kharif* cropping intensity would exceed that of the *Rabi* season (see fig 4.3); an indication that more high value perennial crops – such as sugarcane and orchards – were being cultivated.[63]

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[62] Although Kalpani distributary is hydraulically part of the LSC system as it takes-off from distributary # 9 (i.e. tail main canal), is was not taken up in the modernisation conducted by Mardan-SCARP as it is administratively part of the Swabi sub-division of the Irrigation Department that is responsible for the O&M of the Upper Swat Canal. Kalpani was therefore modernised/remodelled as part of the Swabi-SCARP project, that made substantially different design choices than Mardan-SCARP. Both Kalpani and Swabi-SCARP are reviewed in detail in chapter seven.

[63] The increase in perennial crops has a marked effect on the statistics of irrigation intensities, since these crops are counted only once, during the *Kharif* season, and subsequently lead to an undervaluation of the *Rabi* intensities.

Fig. 4.2: Mardan-SCARP and Lower Swat Canal Project Area

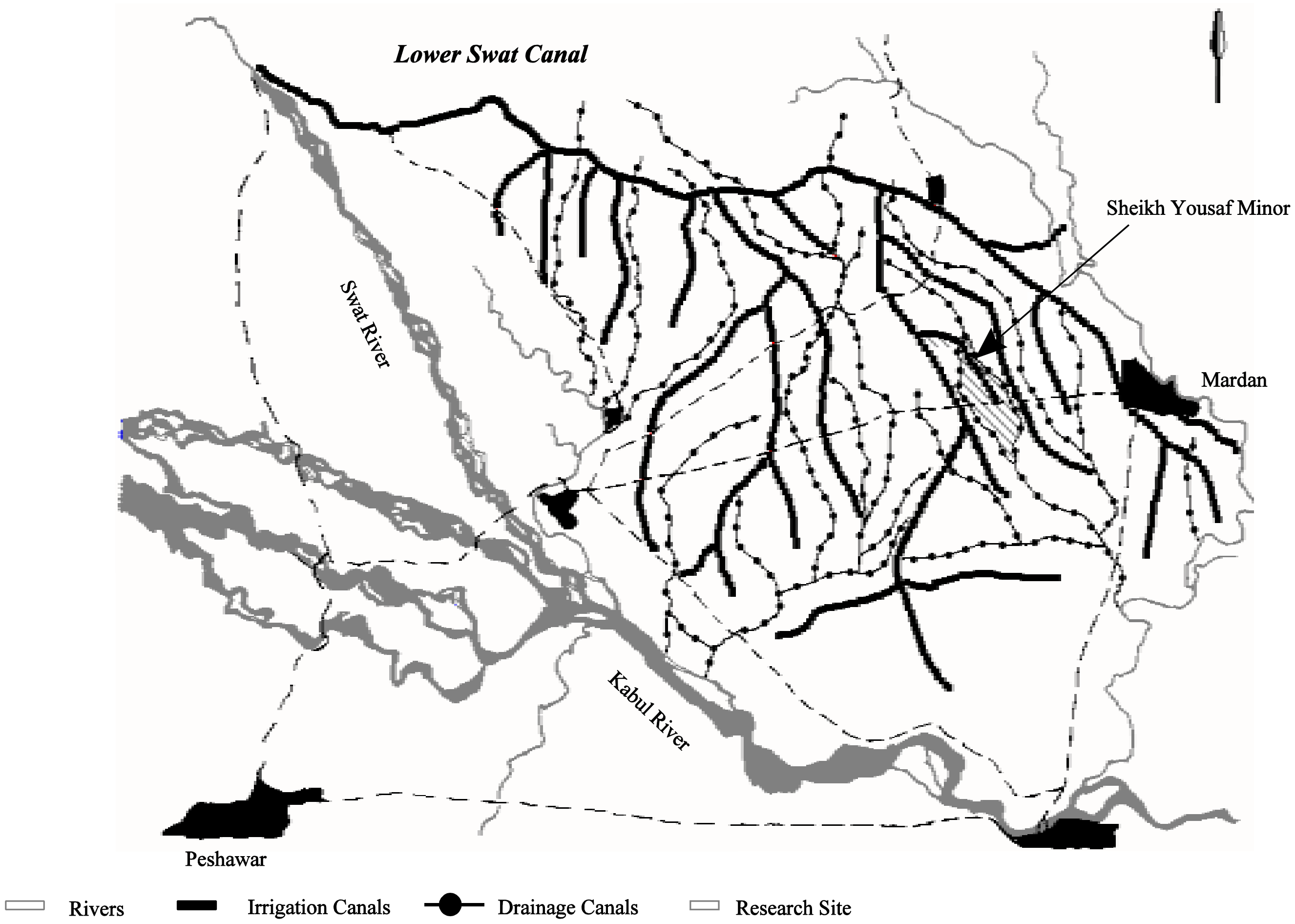


Fig. 4.2: Mardan-SCARP and Lower Swat Canal Project Area

Table 4.1: Irrigation Duties in Indian Canals 1913 - 1918 [acres/cusec]

	Rabi					*Kharif*				
	13/14	14/15	15/16	16/17	17/18	13	14	15	16	17
United Provinces										
Betwa Canal	286	154	214	121	133	68	12	21	45	23
Ken Canal	44	113	116	129	136	57	40	56	51	41
Upper Ganges C.	206	262	215	183	202	146	115	126	125	156
Lower Ganges C.	254	209	225	214	183	130	117	99	88	127
Agra Canal	215	213	184	136	121	165	139	103	163	149
Eastern Jumna C.	226	199	225	210	194	125	127	116	140	125
Rohilkund Canals	150	116	126	148	151	129	106	123	87	120
North-West Frontier P.										
Lower Swat River C.	194	239	222	196	223	118	120	117	133	130
Kabul River C.	98	106	101	83	266	80	101	80	93	99
Punjab										
Western Jumna Canal	158	135	186	150	155	110	107	82	120	108
Sirhind Canal	202	165	222	183	158	94	120	99	92	87
Upper Bari Doab C.	219	240	263	285	267	110	113	83	117	132
Lower Bari Doab C.	163	65	119	149	105	25	76	45	79	87
Upper Chenab C.	52	32	102	72	90	61	48	51	97	86
Lower Chenab C.	236	190	230	230	197	73	74	73	79	95
Upper Jehlum C.				110	106				72	61
Lower Jehlum C.	166	181	179	216	179	81	80	67	89	91
Bombay										
Nira Canal	225	176	94	102	89	197	179	186	170	95

(Buckley; 1920)

4.2.2 Problem Definitions and Objectives for Modernising LSC

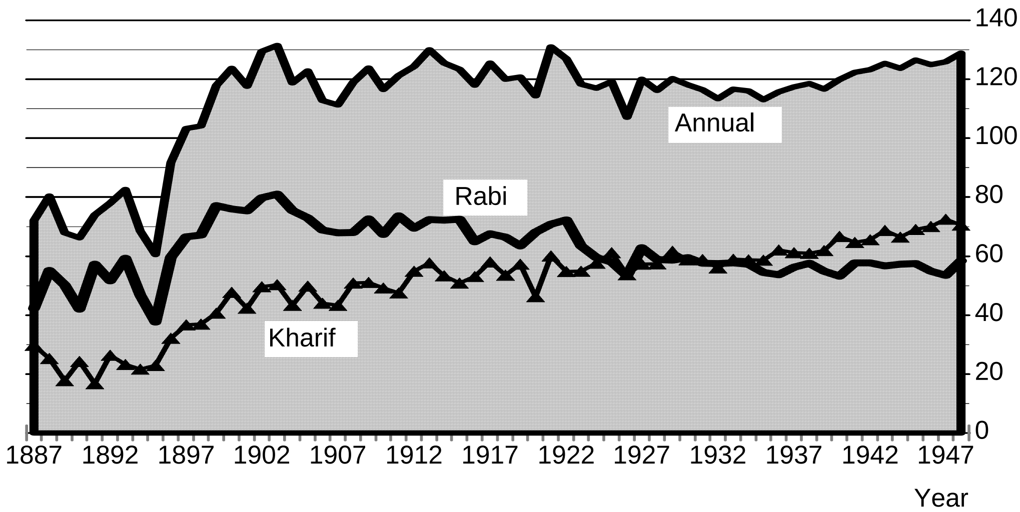
The formulation of the Mardan-SCARP project took five years, from 1977 to 1982, to cover the different planning stages reflected in the Project Planning Report (1977), the Staff Appraisal Report (1979), Final Project Plan (1981), and finally the mandatory PC-1 (1982). The project had been set up as a multilateral aid project jointly funded by the International Development Agency (of the World Bank), the Canadian International Development Agency and the Government of Pakistan. The project was implemented jointly by WAPDA and the Government of NWFP, with the aid of Harza/Nespak Consultants and the Canadian Drainage Team.

The problem analysis in the early stage of Mardan-SCARP was fairly straightforward and concentrated on the ailments of an aging system. From 1935 onwards the irrigation intensities in the LSC had been steadily rising to a level of 150 percent (see fig.4.3) according to official statistics, even though the water intake for irrigation remained at its 1935 design capacity of 28.4 m^3/s (1000 cusecs)[64], or 0.53 l/s/ha. Water had thus been getting gradually scarcer by the year. Particularly the tail-end areas of the distributaries were increasingly affected by water shortages.

As in other areas of the IBIS, the LSC was increasingly facing problems with the double menace of water logging and salinity in its command area as a result of a rising water table during a near century of continuous irrigation supply. Even though the LSC possessed relatively good natural drainage facilities when compared to systems in Punjab and Sindh, about half of its command area was assessed as being affected by water logging or salinity by 1980.

The 'traditional' SCARP method to tackle such problems through the massive installation of deep tube-wells to lower the water table and provide for additional irrigation water had come, by the late 1970s, under discussion for its disappointing effectiveness and high operation and maintenance costs. By making use of the opportunity to use extra river water, the Mardan-SCARP project intended from the outset to seek a solution by developing an integrated irrigation and drainage system. The water logging and salinity menace was to be tackled through the implementation of a surface and sub-surface drainage system designed to maintain the water table at sustainable levels, while the irrigation system was to be modified to meet the crop water and salt leaching requirements in order to reach a sustainable salt balance in the root zone. As

Fig. 4.3: Historic Cropping Intensities for Lower Swat Canal (1887 - 1947) [%]



(PWD/IB;1952)

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64 The official design capacity of LSC in 1935 was 700 cusecs. However, the officially authorised discharge was raised to 830 cusecs, and could be exceeded temporarily during the season to 1000 cusecs whenever river flows aloud.

the latter element implied that future irrigation deliveries would have to anticipate, and respond to, cropping patterns, the objective to transform the LSC into an 'agriculturally productive' system, by supplying irrigation water in response to actual requirements, was added at an early stage of the project. It was felt, that with the considerable investment to be made with Mardan-SCARP, the LSC should be gradually transformed into a demand-based system without further large investments in the near future.

The Mardan-SCARP design and implementation team – consisting of WAPDA, Harza/Nespak and the Canadian Drainage Team – were thus entrusted with the task to remodel the LSC system according to the following three main modernisation objectives:

- To raise the water delivery capacity of the system to the extent that it would be able to meet the future crop water and salt leaching requirements;
- To provide for drainage facilities that would maintain the water-table at productive sustainable levels and furthermore allow for reclamation of water logged and saline soils;
- Provide for irrigation facilities that would allow the irrigation operations to be gradually transformed into a 'modern' demand-based responsive water delivery service.

Since the first two objectives provided fairly straightforward technical guidelines for the design, the project team concentrated from an early stage on the extensive design and construction work to be done. Although the third objective has a number of implications for the structuring and organisation of operational management, the project team seems to have regarded it mainly as a technical design issue. In the end, Mardan-SCARP met the objectives by technically refurbishing the LSC system so that demand-based irrigation would be technically possible in future, seemingly assuming that the gradual transformation of operations would be carried out after the implementation of the design by management specialists. In the next paragraph the conversion of these objectives into a concrete design for Mardan-SCARP will be presented, in order of complexity and difficulty of resolution.

4.3 INFRASTRUCTURAL DEVELOPMENT: WATER DELIVERY & CONTROL CONCEPTS

4.3.1 The Drainage Network

The major part of the Mardan-SCARP project comprised of the design and construction of the drainage system, and constituted a technical innovation for Pakistan in that for the first time an irrigation system became fully integrated with a sub-surface and surface drainage network. As the use of sub-surface drainage technology was relatively new to Pakistan, the project team gave a lot of attention to determine the physical design parameters through extensive surveying of the project area and determination of the hydrological water balance. Basing the drainage requirements on the 1 in 5 wet year, the design cropping pattern determined by the project and assuming that crop water requirements would be fully met by irrigation, the project defined the following design criteria/parameters:

- A design water table depth of 1.07 m (3.5 ft);
- A drain centre depth for sub-surface drains of 1.98 to 2.13 m (6.5 - 7.0 ft);
- A design drainage coefficient of 3 mm/day.

Besides being determined as the economically optimal depth, the drain centre depth of 6.5 ft would also ensure that during periods of no recharge the water table would fall sufficiently low to prevent salinisation of the root-zone through capillary rise in the predominantly loamy soils. In order to maintain a sustainable salt balance below 1400 ppm at the bottom of the root-zone, the leaching requirement was determined to amount to 165 mm/year (6.5 inches/year). The hydrological water balance, however, determined that this leaching requirement would be amply met during an average year when the annual ground water recharge – culminating from effective rainfall and irrigation applications – would amount to 335 mm/year (13.2 inches/year). (Harza-Nespak; 1984)

Based on these design parameters, the ensuing drain spacing amounted to 80 - 140 m (260 - 460 ft) depending on the specific soil conditions. Making use of PVC drain materials, a gravel envelop and mechanical installation, the cost for construction of the sub-surface drainage alone was budgeted for US $1,250 per ha (US $500 per acre) (in 1984 value), when commissioned in contracts of 10,000 ha (25,000 acres) to take advantage of economies of scale. The construction of the sub-surface drainage system was carried out in two phases; the first one covering of 10,676 ha (26,689 acres) CCA was carried out from 1982 to 1986, while the second one covered another 23,607 ha (59,018 acres) of CCA and was completed in 1992.

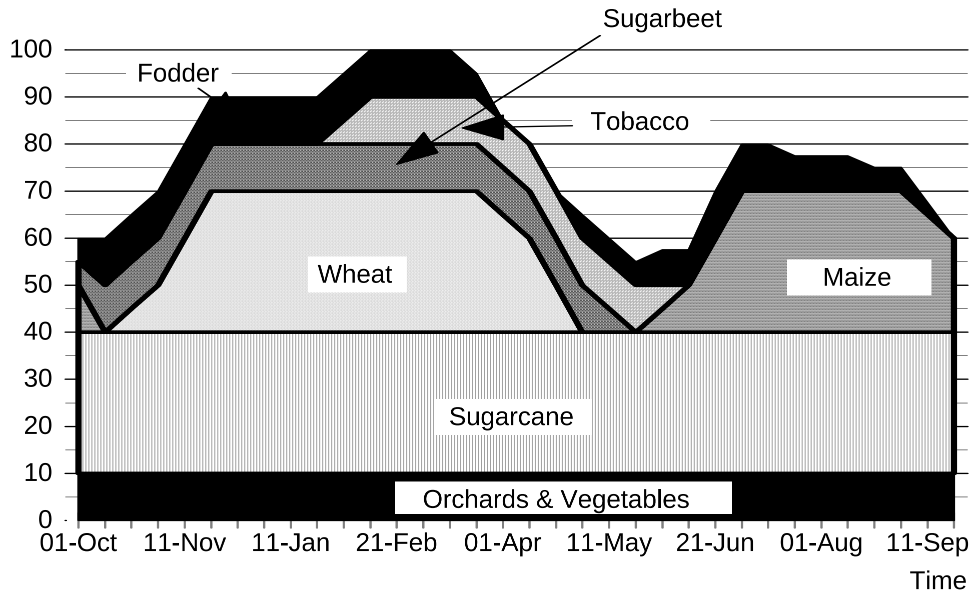
In addition to the sub-surface drainage, the surface drainage was completely remodelled to accommodate the sub-surface drainage flows and additional surface drainage. In total some 480 km (300 miles) of surface drains – the majority already existing – were re-dimensioned by the project to divert the drainage water of the LSC back into the Indus Basin through the Swat and Kabul rivers. The secondary surface drains were dimensioned to accommodate the surface runoff of a 1 in 5 year 6 hour rain storm of 50 mm (2.0 inches) with a maximum intensity of 23 mm/hour (0.9 inches/hour). However, in order to collect the sub-surface drainage outflow, disposed of at a tertiary collector depth of 2.4 - 2.7 m (8 - 9 ft), the secondary surface drains had to be deepened to around 3.4 m (11 ft) below surface. This latter design criterion proved in most cases to provide for ample discharge capacity. Besides collecting the sub-surface drainage water, surface drain outlets were constructed every 450 m (1,500 ft) along the secondary surface collector drains in order to provide for tertiary surface drainage opportunities. After completion of the drainage works, Mardan-SCARP had thus created a rather unique situation for Pakistan, in which 50 percent of the CCA was provided with an adequate sub-surface drainage system that could accommodate 3 mm/day, and every tertiary unit bordered to a secondary surface collector drain into which it could dispose any quantities of surface drainage water it wanted.

4.3.2 The Irrigation Network and its Water Delivery Capacity

The design and development of the irrigation system proved to be considerable less straightforward than that of the drainage system. From the on-set – as explicitly formulated in the Final Project Plan (FPP) – the objective was set to transform the LSC in a *demand-based* irrigation system. A notion that clearly captured the intention to transform the LSC into an 'agriculturally productive' system in which the crop water requirements could be met by varying the irrigation water supplies according to crop needs. However, as a design objective it was still a broad and general guideline – particularly if considered when it was formulated[65] –, leaving the project team to define the degree and method of water supply variation, and congruent water control technology, for which the system should be designed. As a consequence the project team was thus entrusted with defining, through its design, the methods and procedures of operational management by which the system should be used (defining new roles and tasks for the Irrigation Department as well as farmers) – rather than being guided by explicit design criteria stemming from well-defined operation methods and procedures by which the system was planned to be used. Mardan-SCARP was thus set-up in such a way, that the project team had to make a number of critical decisions in its design of the irrigation system that would have far reaching implications for the institutional set-up of the future water management arrangements.

With the need to establish concrete design criteria, the project structured the design of the irrigation system around the objective of having to meet crop water requirements. As a first step (as part of formulating the FPP) it set out to determine the required capacity of the system. For

Fig. 4.4: Design Cropping Pattern for Mardan-SCARP [%]



(Harza-Nespak; 1984)

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[65] One should take into account that the classification of clearly defined types and methods of irrigation delivery scheduling (such as limited rate demand, arranged, limited rate arranged, fixed duration arranged, etc.) were only formulated by the ASCE in 1987 (Clemmens, 1987a & b).

this purpose, and subsequent design criteria, it defined a design cropping pattern with an annual cropping intensity of 180 percent (see fig. 4.4). The design cropping pattern implies thus an increase in agricultural production by raising the projected cropping intensity from 150 to 180 percent, with a modest increase in perennial and cash crops; setting sugarcane at 30, tobacco and sugarbeet at 10 and orchard and vegetable at 5 percent.[66] Combining this design cropping pattern with the average climatological data for the project area, the expected crop water requirements and their temporal variation were determined and used for the definition of subsequent design criteria.

Using the crop water requirements of the design cropping pattern as water delivery targets for the remodelled irrigation system, the following design criteria and parameters were defined:

- Irrigation application efficiency of 75 percent;
- Water course conveyance efficiency (after remodelling) of 80 percent;
- Effective rainfall determined using USBR method;
- Water delivery capacity criteria

Command Area (CCA) [acres]	Delivery Rate [cusecs/1000 acres]	Delivery Capacity (QT) [cusecs]
<100	Separate Outlet not provided	
100 - 200	19 (1.34 l/s/ha)	QT= 0.019(CCA)
200 - 10,000	19 - 11	QT= 0.040(CCA)^0.86
> 10,000	11 (0.78 l/s/ha)	QT= 0.011(CCA)

- Canal delivery conveyance losses of 283 l/s per 93 thousand square metres of wetted perimeter (10 cusecs per million square feet), or Q(L) = 0.13 (Q(T) 0.5) * L, in which Q(L) is the seepage loss in cusecs, Q(T) the capacity at tail of reach in cusecs, and L length of reach in canal miles.
- Be able to control variations in water supply accurately, so that the calculated variations in irrigation requirements can be met (see fig. 4.5).

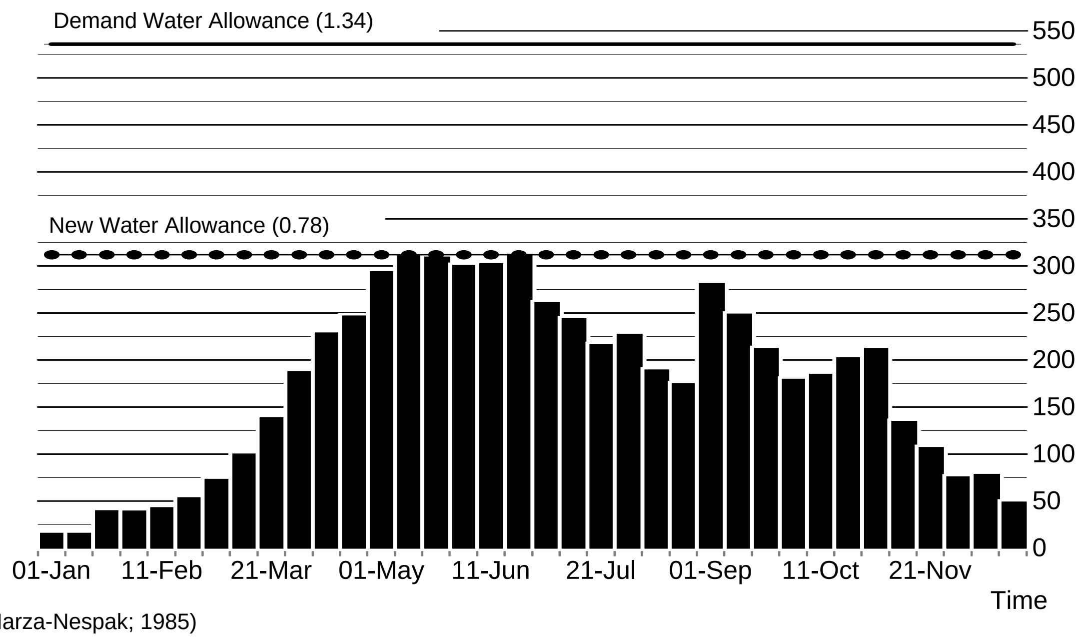
The water delivery capacity at the water course head was thus set at 1.34 l/s/ha (19 cusecs/1000 acres) for command areas ranging between 40 - 80 ha (100 - 200 acres), in order to meet the expected crop water requirements. Although the peak water requirements of the design cropping pattern were determined to amount to 0.78 l/s/ha (11 cusecs/1000 acres), the design team recognised that in practice the realised cropping patterns could be different than the one assumed for design. By setting the maximum delivery capacity at 1.34 l/s/ha, the design provided for the flexibility for farmers to diverge from the design cropping pattern and still be able to meet their

[66] However, if one takes into account that the official cropping statistics are undervaluing the actual realised cropping intensities because perennial crops are only accounted for once a year, the design cropping pattern would represent an official cropping intensity of only 155 percent. In terms of cropping intensities this would thus hardly represent a significant rise in productivity. This has been acknowledged in the Final Project Plan, where it is stated that the planned for cropping intensity of 180 percent is not significantly higher than the pre-project realised 175 percent (Harza-Nespak, 1981). However, in later documents only the official statistics of 150 percent are mentioned, thus giving the incorrect impression that the project was aiming for a 30 percent increase in cropping intensity.

peak crop water requirements. That is to say, the value of 1.34 l/s/ha is based on the trade-off, that it would allow for the full irrigation of all crops, except sugarcane which would have a 10 - 20 percent water shortage during the month of June. The overall capacity of the system, however, is based on the design cropping pattern, and thus a tertiary unit delivery capacity of 0.78 l/s/ha, expecting thus that, on average, the realised crop water requirements would not exceed that of the design cropping pattern. An expectation that was defended explicitly in the project documents by arguing that the objective was mainly to raise the crop yields, rather than enhancing the cultivation of cash crops.

This relative over-dimensioning of the canal capacities at the lower levels of the secondary and the tertiary system was done with the clear intention of establishing a form of demand-based water delivery service. This is common practice in order to avoid that the capacity of the system will act as a constraint on the freedom of the water users to demand *cum* request for the water delivery they require to meet their crop water requirements, and as such will curb the *managerial flexibility* that demand-based systems seek to provide. This is, however, only intended to be made use of to temporarily meet higher than ‘normal’ and localised peak water requirements, as the main system capacity can not provide such higher than ‘normal’ peak water requirements when they would occur on a large scale and simultaneously. The premise being, that it is realistic to assume that farmers in the course of time may diverge from the assumed/designed cropping pattern and thereby exceed the anticipated peak water requirements. The system is hence designed to cope with this, as long as this does not occur on a massive scale and/or the higher peak demands are staggered over time. As long as these conditions are met, farmers are thus free to choose their cropping pattern and intensity (as has been common practice in the Indus-basin where crop localisation was never practised, unlike in India (*cf.* Mollinga; 1998)). The lower capacity at the main system (i.e. that of 0.78 l/s/ha compared to 1.34 l/s/ha) is supposed to work as a constraint on the massive exceedance of the ‘normal’ anticipated peak water requirements.

Fig. 4.5: Mardan-SCARP Irrigation Requirements at Water Course Head for 400 ha (10-day periods) [l/s]



(Harza-Nespak; 1985)

Whether this constraint will be effective, depends on the extent to which the peak water requirements of the assumed/design cropping pattern reflects the actual realised average peak water requirements, and on whether the actual delivery capacity of the main system is indeed limited to a restricted supply.

The capacity of the LSC was therefore enhanced to carry a maximum design discharge of 54.9 m^3/s (1940 cusecs). A delivery rate with which it would be able to meet the determined peak irrigation water requirements of 0.78 l/s/ha during the five 10 day periods in May and June (*cf.* fig. 4.5). Of these 54.9 m^3/s, 7.3 m^3/s (or 13 percent) were expected to be lost through seepage in the main distributary system up to the tertiary unit. In order to accommodate this new delivery capacity, the intake of the LSC was doubled by adding a new intake structure at Munda, parallel and in addition to the old intake structure. The carrying capacity of the 35 km (22 miles) of main canal, 112 km (70 miles) of branch canals and 133 km (83 miles) of minor canals were increased by deepening and widening of the existing canal infrastructure. The remodelling of these canals was done through the application of the Manning equation for open channels, using a maximum velocity criterion and empirically determined roughness coefficients. The use of Lacey's regime equation was discarded because the remodelling had to make use of the existing bed slopes.[67] The roughness coefficients were determined on a number of measurements taken for this purpose at the LSC and USC.

4.3.3 Water Control Concepts & Facilities

In order to be able to meet the variations in crop water requirements in a precise and adequate manner the design had to provide for more water control options. The anticipated operation of varying delivery schedules required an active control of discharges – as opposed to a control of merely water levels – at different levels of the system. Even though the project was always aimed at a gradual transformation of the system's operation, the intention has been for the design to prepare the LSC for the highest level of envisaged water control – i.e. the one that would be required for the last stage of water control. Envisioning a highly responsive (48 hrs) demand-based irrigation water supply system, the design thus sought to maximize the water control options.

First, a crucial, but obvious, change in water control had to be made at the pivot of water management: the outlet. Provisions had to be made at this delivery point to actively regulate the discharge in order to meet varying crop water requirements *cq.* demands. At the time of formulation of the FPP, however, the project proposed to introduce these flow regulation gates for outlets at a later stage. Anticipating a gradual transformation of canal operations, the FPP came up with an outlet design that consisted of a 'gated APM" (see fig. 4.6). Initially, it was proposed, the pre-fabricated outlets would be installed as 'original' APM with the roof-block fixed in place. While at a later stage, the fixed roof-blocks would be replaced at relatively low cost with a movable regulation gate enabling the active control and regulation of varying

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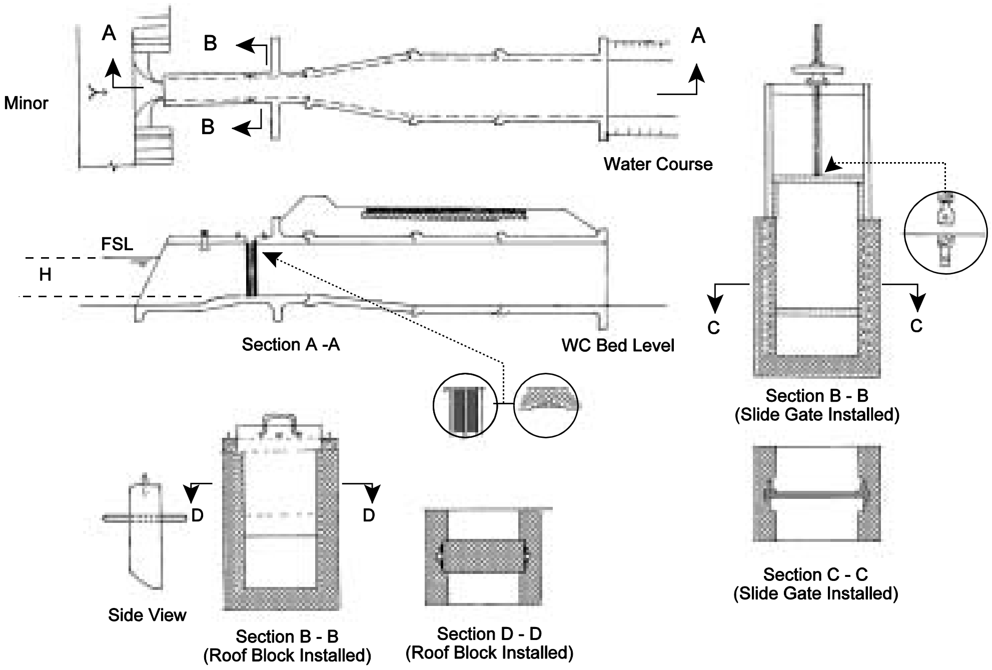
[67] According to the design team the use of Lacey's regime equation would lead to substantial flatter and wider canals due to the increased capacity; features which were deemed undesirable for the remodelling of existing canals.

Fig. 4.6: Gated APM Outlet; Mardan-SCARP design as presented in FPP

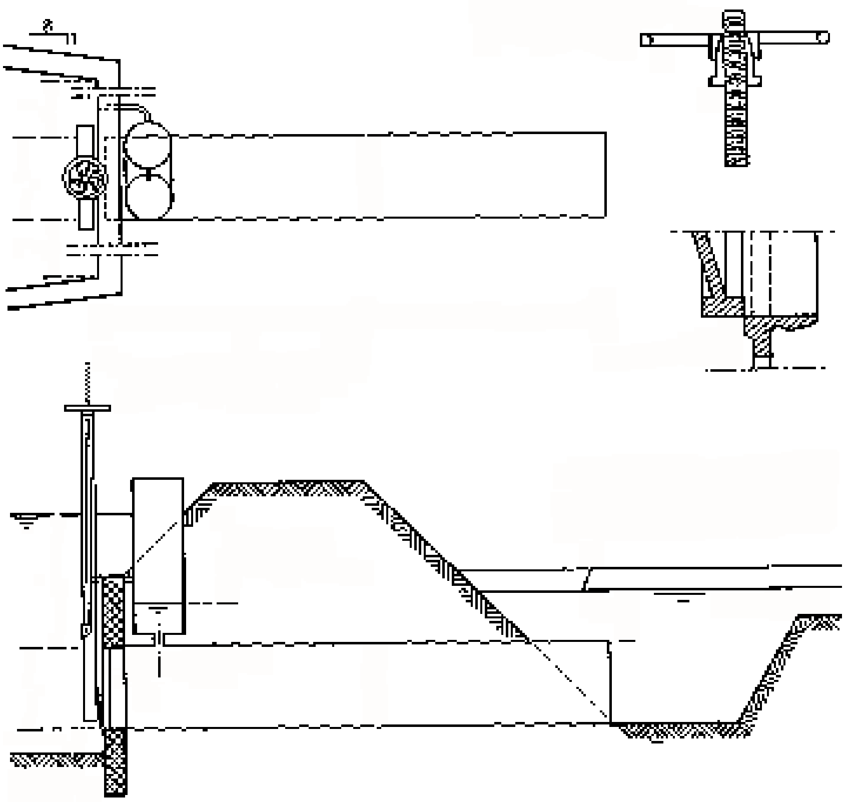


(Harza-Nespak; 1981)

discharges. Basically, the design proposed to transform the 'traditional' APM at a later stage into Crump-deGruyter outlets, be it with a straight edged gate instead of the rounded off gate of the original Crump-deGruyter (*cf.* De Gruyter; 1926, 1927a&b, Bos; 1976). However, during the design phase of Mardan-SCARP, this proposal was dropped for non-documented reasons, and replaced by another outlet design.

The initially proposed 'modified' or 'regulable APM' outlet was replaced during the detailed design of the LSC with the American-type Metergate outlet. Although it is not clear why this important design decision was made at this stage of the project, nor how it was reached (Bandaragoda, 1998), it represented an accelerated introduction of 'modern' canal operations. The introduction of the Metergate outlet (see fig. 4.7) implied an immediate switch to controlled discharge operations at the 520 outlets of the LSC. The hydraulic conditions of the Metergate outlet, which operates under submerged conditions, would require that the Irrigation Department take immediate active control over an additional 520 water control and regulation points. The loss of hydraulic jump at the outlet would no longer permit for the gradual transition of operations as planned, in which the first phase would have allowed for the replication of the passive proportional water distribution (Harza-Nespak, 1981). Perhaps the choice for the Metergate was born out of the requirement to adjust the delivery rate accurately and frequently when the canal operations would be conducted in response to demands placed 96 and 48 hours in advance. This was suggested for the third and fourth operational transition phases in the operation and maintenance manual produced by the project, in which also the Metergate was introduced as the chosen outlet. Although the Metergate has a proven record for such conditions in the US achieving discharge measurement accuracies of 3 to 6 percent, the Crump-deGruyter

Fig. 4.7: Metergate Outlet



(Bos; 1976)

outlet would have performed just as well with proven accuracies of 3 percent while retaining the hydraulic jump (Bos, 1976). Moreover, the Crump-deGruyter has the added advantage it is basically a modified APM outlet on which the roof block is made regulable by transforming it into a sliding gate.

For the design of the water control structures of the main and distributary system, it was decided that the variations in water delivery would have to be achieved by:

- operating the main system under steady-state hydraulic conditions;
- matching the varying water requirements *cum* demands by varying the intake of water at the headworks at Munda accordingly – i.e. no water storage facilities would be provided for in the main system.

In order to make it possible to control the flow variations throughout the system under the above conditions, the design aimed to provide for control and regulation facilities of discharges, as well as water levels, at all the major distribution points. Obviously, all head-regulators of distributaries and minors were therefore to be supplied with discharge regulation gates; for which the project chose the classic undershot sliding gate, which can also operate under submerged conditions.

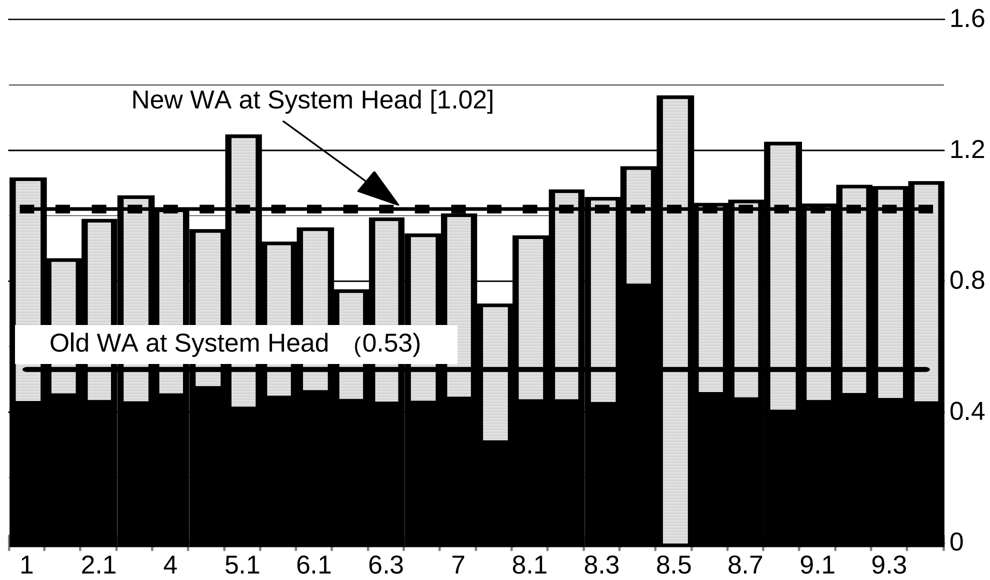
In order to control, and possibly regulate, the water levels (and hydraulic heads over off-take structures) the design sought to make maximum use of the potentials provided by the 221 drop-structures in the system. As these structures had to be remodelled in any case to accommodate the new discharge capacities, it made sense to optimise them simultaneously for the purpose of water level control. The design came up with two types of drop/control structures. The big drop structures in the large distributaries (No 6, Nisatta Branch, No 8 and 9) were fitted with one or two radial undershot gates fitted on top of rectangular inclined drops, which due to the available drop could operate under free-flow conditions. The remaining drop-structures (i.e. the majority) were designed and constructed as rectangular inclined and vertical-check drops, depending on the size of flow and the height of drop. For the control and regulation of water levels, the design proposed that these drop-structures would be fitted out with vertical undershot sliding gates at a future stage, when the third and fourth phase of demand-based operations would come into effect. Consequently, these structures do not possess the ideal hydraulic features to function as overflow cross-regulators during the period they have to be used without gates and as they have been constructed. The overflow section is deliberately kept small to the size of the future gate(s), operating under a small head to allow for future undershot operations. Naturally, the 'temporal' overflow weirs are neither sharp or broad crested, so that they are also not very suitable for discharge measurement.

In addition to the discharge and water level regulators for the delivery of irrigation water, the design also provided for the construction of wasteways at every head and tail section of distributary and minor canals. Although these wasteways could have been taken up in the design as an integral and crucial part of the water control strategy, this has not been the case. According to the design criteria in the FPP, *"Canal wasteway structures serve two major purposes: (1) disposal of excess water reaching the canal and (2) dewatering of a section of canal for routine maintenance or emergency repair of a damaged section of canal"* (Harza-Nespak; 1981:iv-24). Basically they were thus treated as ordinary drainage and emergency features for the protection of the canal infrastructure. A notion that is supported by the fact that these wasteways have never been built. The initial design, however, proposed that each head reach of a distributary or minor canal would be fitted with a side-channel spillway and a gated turnout; the latter to be equipped with a manually operated vertical slide gate. The type of wasteway structure to be fitted at the tail reach of the distributary and minor canals, was not further specified other than that it would be a "simple" structure that would allow the diversion of water into the surface drainage system.

Besides the crucial water control structures needed for operation, the design also included the necessary conveyance structures such as siphons and aqueducts and transportation facilities as roads and bridges, which had all to be remodelled in order to accommodate the new increased design capacities of the channels.

The preliminary design presented in the FPP expected that the total remodelling of the irrigation infrastructure of LSC, comprising of remodelling approximately 945 structures and earthwork of 2.3 million m^3 (3.0 million yd^3), would be completed in six years without interrupting the supply of irrigation water to the fields. Due to a conflict on the desirability of installing Metergate outlets, however, the actual construction of the irrigation works took much

Fig. 4.8: Mardan-SCARP Design Water Allowance at Distributary Head [l/s/ha]



(Harza-Nespak; 1985)

longer, and was finally completed in slightly modified form in 1994. Except for the outlets and wasteways, the design has been implemented according to the detailed design, as described above. As a result, the carrying capacity of the LSC canals was more or less doubled as when compared with the situation prior to the project (see fig 4.8).[68]

4.4 TRANSFORMING OPERATION & MANAGEMENT: CONCEPTS OF DESIRABLE PRACTICES

> *"An effective operation and maintenance program for an irrigation and drainage project is imperative for its success and the realization of the maximum long-term benefits from the constructed or rehabilitated project. No matter how well constructed, an irrigation or drainage system fulfills its* ***intended function*** *only when* ***properly*** *operated and maintained.* [...] [The manual's] ***function is to outline and discuss the necessary operation and maintenance procedures which must be followed if the project is to function as intended and continue to function satisfactorily*** *over its designed life span."* (Mardan-SCARP Operation and Maintenance Manual, emphasis added, Harza-Nespak; 1985: 1)

[68] The new water allowances as based on the design capacities of the canals are slightly different due to the differences in command area, which results in different maximum capacities as in accordance with the design capacity criteria presented in section 4.3.2.

4.4.1 Organisational Structuring for the Management of Demand-Based Irrigation

These introductory remarks to the Operation and Maintenance manual give an impression of the ways of thinking adopted in the design and construction of the remodelling of LSC by the Mardan-SCARP project. They convey the message – almost unconsciously, as if it is the most natural way of modernising irrigation – that the project has painstakingly devised a modern irrigation system that fulfills the highest standards of the field and now, in order to work properly, will have to be put to use in accordance with those standards. It makes clear that the approach adopted for modernisation was to introduce new externally available technology and concepts, and subsequently train the users in their water management practices for their correct application. The O&M manual produced by Mardan-SCARP was clearly intended for this latter purpose, and as such provides us with a picture of what kind of irrigation system the project team had in mind when they designed the system. As it tries to spell out the new O&M procedures that it expects the ID and water users to adopt to make effective use, as intended, of the new irrigation facilities, it reveals some of the crucial design assumptions that have been made. It also reveals the high expectations the project has placed in the capacity and willingness of ID and water users to adapt their water management practices to its design. As such, the O&M manual epitomises the adopted design strategy and project set-up of Mardan-SCARP, which has been primarily governed by seeking an ‘optimal’ technical solution and facility for the creation of demand-based irrigation, rather than customise the facilities for O&M procedures that have been planned and developed in advance (or alongside the design) in conjunction with ID and water users.

Targets and Objectives for Institutional Change

Realising that the shift towards demand-based irrigation requires quite a change in water management practices from both ID and water users, and in accordance with the proposals of the FPP, the O&M manual describes four operational phases that gradually increase the responsiveness of water delivery and ultimately lead to the intended demand-based operations. In defiance of the recommendations of the FPP, the first phase for operations starts already immediately with controlled variations of water deliveries, requiring thus the ID to immediately change their system’s operation from the moment of commissioning. The four phases of operation, as described in the O&M manual, are:

- *Centrally Determined Scheduling* This operational phase, as an introduction to demand-based and crop water requirements sensitive operations, foresaw that the ID would adjust the supply rates in accordance with the mean crop water requirements. Based on the design cropping pattern and the mean climatological data for Mardan, the O&M manual calculated the mean crop water requirements and subsequently tabulated the ensuing water indents at water course and canal heads for each ten day period. The manual proposed that the ID would follow these calculated and tabulated water indents as a first acquaintance with the concept of controlled variations in water supply. The imposition of these supply variations would, according to the manual, simultaneously provide the water users with a learning phase in which they could get acquainted with the concept of crop water requirements.

- *Centrally Determined Crop-Based Scheduling* This second phase proposed that the ID would adjust the variations in water delivery in accordance with the actual crop water requirements. Instead of the tabulated water indents of the O&M manual, the ID was then supposed to determine the water indents 'freshly', by calculating the actual crop water requirements on the basis of up to date recorded cropping patterns and monitored climatic conditions. For water users this phase constituted, according to the manual, a period of continued refinement of their knowledge and application of crop water requirements in their water management practices.

- *Arranged-Demand Scheduling* In this third phase of irrigation operation, the water users were supposed to play an active role in scheduling water deliveries, by placing their irrigation demands – expressed as a specific rate (discharge) – through their Water Users Associations (WUA) 96 hours in advance with the ID. The ID was then supposed to accumulate all the demands and prepare the water indents for canal and water course heads, and vary the water supply accordingly. The manual does not, however, specify whether the water users would be restricted to place their demands on specific days (i.e. resulting in fixed scheduling cycles of four days), or whether they would be free to place demands, or changes therein, whenever they like as long as it is 96 hours in advance (i.e. possibly resulting in daily scheduling and flow variations).

- *Arranged-Demand Responsive Scheduling* This fourth and final stage of irrigation operation, which presumably constitutes the intended function of the remodelled LSC as envisioned by the designers, is basically the same as the previous phase with the difference that the time required for placing an irrigation demand in advance has been reduced to 48 hours.

These four phases for the operation and water management of the modernised LSC contain two distinct conceptualisations of how the varying water requirements should be met by controlling flow variations in the delivery system in a planned and controlled manner. Both concepts contain assumptions on, and prescriptions for, the way the ID and water users should structure and execute their operation and water management, to make progressively optimal use of the new system. These concepts are centred around the issue of gaining information on the (crop) water requirements, and to vary and control the water supply in the system to match those requirements as efficiently and accurately as possible. For both issues, each of the proposed phases is geared towards gradually improving the efficiency and accuracy with which the varying water requirements can be matched with supply.

The four phases of operation and the two conceptualisations of irrigation they are based on are reviewed below on the assumptions they contain on the 'desired' behaviour of the ID and water users in operation and water management, and how the operation and water management should be changed and structured to realise the objectives imbedded in the concepts and the design. The first two operational phases represent the initial stage for 'gradual' change of operation and management, and are structured by the concept of '*centrally crop-based scheduling*'. Phases III & IV represent an other stage for changing operation and management, which is structured by the concept of '*arranged demand-based scheduling*'.

Structuring Operation & Management: for Crop-Based Irrigation...

The first phase for operation was intended to represent a 'crude' form of crop-based irrigation operations, to be adopted in the first year after commissioning. Initially, during the conception of Mardan-SCARP, this phase was intended to require only minor changes in operation and management from both ID and water users. With the gated APM outlet, initially proposed in the FPP, the intention was to install this outlet during this first phase with a fixed roof block (i.e. as an original Crump APM) (*cf.* Harza-Nespak; 1981). This initial proposal thus did not foresee the ID having to regulate the flow (variations) at the outlets during the initial stage of operation after commissioning. The first phase of crop-based operations were thus meant to be simplified as follows:

The crop water requirements were to be predetermined for the first year of operation on the basis of the design cropping pattern and the mean climatological data for Mardan, resulting in equal relative water requirements for all outlets. The main system could then be operated with a crude variation in supply, that would more or less match the requirements. The idea basically was, that the system could be operated at different levels of supply (say four or five) that would crudely follow the variation in crop water requirements. At the secondary level, these supply levels would then be distributed 'automatically' over the outlets through the self-acting proportionality of the APM. At the tertiary level, the water users could simply adhere to *Warabandi* as they were used to. The only effective change proposed, was thus for the ID to start varying the supply in the main system in crude steps.

Although this is seemingly a nice proposal that would allow the ID to get acquainted with the new hydraulic configuration of the system and the planning and controlling of flow variations, it was hydraulically unfeasible. Due to the over-dimensioning of the lower levels of the canal system up to 1.34 l/s/ha, which was required for the future demand-based operations, the APM outlets would not function proportionally (i.e. around an *f* value of unity (*cf.* section 2.7)) to distribute the variations in supply. This becomes immediately evident from fig. 4.9, which gives the new design capacity or FSL for Sheikh Yousaf Minor, the crop water requirements of the design cropping pattern, and the 70 percent FSL minimum threshold value[69] below which APM outlets should not be operated. As the figure clearly indicates, only two operational supply levels would be hydraulically feasible to meet the variation in crop water requirements. The initial proposals of the FPP thereby contained a hydraulic contradiction that had to be solved by the Mardan-SCARP project team in its design and implementation for LSC.[70]

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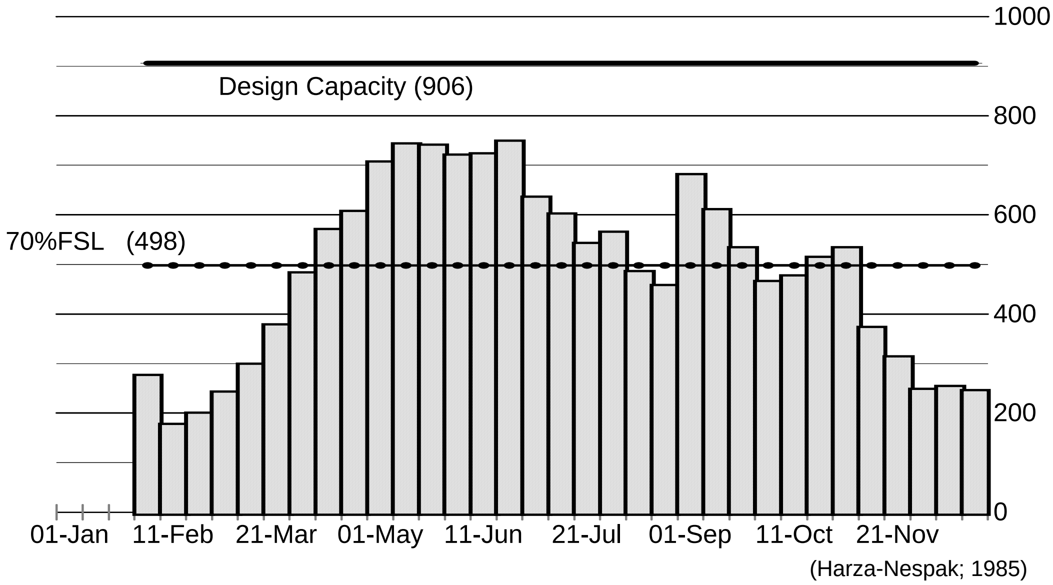
[69] 70 percent FSL is equalled here to 55 percent FSQ, on the basis of the Q-H relationship for open channel flow, in which Q is related to H^5/3 (see chapter two).

[70] The hydraulic contradiction was created by proposing both the use of APM outlets and creating the over capacity for demand-based operations at the lower levels of the system (*cf.* Harza-Nespak; 1981). An option to

(continued...)

Fig. 4.9: O&M Manual Water Delivery Targets for Sheikh Yuousaf Minor (10-day periods) [l/s]



This hydraulic contradiction on water control for the first operational phase was thus resolved by the design team by choosing an entirely different outlet structure: the Metergate. With this gated outlet, the discharge could be regulated and controlled over the entire range of crop water requirements. Furthermore it enabled the precise matching of water requirements *cum* demands with the possibility to optimise the water delivery in its efficiency and efficacy in all operational phases.

As a consequence, the first operational phase for the first year after commissioning already required drastic changes from the ID in its operation and control of water supply. The water control and regulation points that the ID would have to operate would be increased by more than 2000 percent (from a mere 25 to nearly 600). Moreover, a fundamental change in the operation of these water control points was expected from the ID, in that in addition to mere feed-back control these structures would also have to be operated through feed-forward control in order to implement the scheduled variations in water delivery. As the schedules and variation in supply would have to be effected and controlled in discharges and volumes, the ID was expected to gather data and process information on hydraulic heads, gate openings, discharges and volumes on an unprecedented scale. The only simplification left over for this first phase of operation was that the ID would not yet have to conduct the scheduling and water delivery planning. This was predetermined in water delivery targets on the basis of the design cropping pattern, and the

(...continued)

solve this problem could have been to lower the FSL operational level for the initial stages, so that the use of APM would become hydraulically feasible and effective; i.e. the strategy adopted by Swabi-SCARP which is treated in chapter seven. Since the APM functions under a wide range of hydraulic flexibility in response to water level variations (see section 2.7), a proper hydraulic configuration for initial self-acting proportionality would also have required the use of Open Flumes at the lower levels of the system as in Swabi-SCARP.

variations in supply to be implemented and controlled would be uniform for the whole system. The efficiency and efficacy targets for the controlled variation of supply were, however, immediately set high by proposing to vary the supply with a high frequency of thirty-three 10-day scheduling periods in a year.[71]

In the second phase of operation, the ID would have to take control over the crop-based scheduling procedures, in order to adjust the water delivery schedules to the actually occurring crop water requirements, rather than using those of the predetermined design cropping pattern. The goal here was to further improve the efficiency and efficacy of the crop-based water delivery service, and to further increase the scheduling and water control and delivery capacity of the ID. This would imply two important changes from the ID:

(i) It would have to collect up to date data of the actual cropping patterns of all the 520 tertiary units, and convert this data into crop and irrigation (adding for losses) water requirements through the application of CROPWAT calculations – for which the method and procedures were specified in the O&M manual. This represents a marked shift for the collection of cropping pattern data as performed by, and institutionalised in, the ID hitherto, in which the *Patwaris* collect those data for the purpose of revenue assessment. The timeliness and accuracy requirements for using cropping pattern data as an input for the crop-based scheduling, demand a radical change from the traditional task and procedures with which the *Patwaris* conduct their work. The O&M manual provides no clear proposal for effecting this.[72]

(ii) The scheduling of water supply variations in response to actual crop water requirements could result in a large differentiation of supply variations over different localities in the irrigation system, when the actual cropping pattern diverges over the command area. This requires the ID to differentiate in its scheduling and water delivery accordingly. Although this forms one of the prime purposes and objectives of crop-base irrigation operations, it represents a marked shift in thinking and acting for the ID staff.

For the water users of LSC this initial stage of crop-based irrigation was meant to represent a learning stage to acquaint themselves with, and sensitise their water management practices to, matching irrigation applications with crop water requirements as embedded in the CROPWAT paradigm. In essence they would still remain at the receiving end of the water supply service,

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[71] This choice reflects the influence of the CROPWAT paradigm, and its objectives embedded in the irrigation concepts to meet crop water requirements as precisely and accurately as possible. Although the 'assumed' water requirements for Mardan-SCARP vary with a steep curvature (see fig. 4.9) it would still have been an option to suggest a 'learning' schedule consisting of eight delivery periods, instead of the proposed 33. This would, however, imply that the system would be operated with losses, either operational or applicational, at either the secondary or tertiary level, which clearly goes against the embedded objectives of crop-based and demand-based irrigation.

The thirty-three 10-day delivery periods in a year are derived from incorporating the annual closure of the system during the month of January.

[72] There are three aspects to this collection of cropping pattern data which are not well accounted for in the O&M manual in light of traditional practices of the ID: (i) the data would have to be collected at the start of each growing season, as quickly and early as possible, for the entire command area requiring much larger capacity for data collection and processing; (ii) the frequency of data collection would have to be increased, as the traditional *Rabi*/*Kharif* data do not provide adequate information on the water requirements during the transition periods between the seasons (i.e. April-May and October); (iii) the issue of accuracy of the data collection in relation to its use for revenue assessment.

receiving varying water supply rates that would supposedly match their crop water requirements. At the tertiary level, the water users were supposed (according to the proposals contained in the O&M manual) to continue distributing and applying the high and frequently varying delivery rates according to the traditional *Warabandi* schedule.

The O&M manual does not clarify how the water users were supposed to deal with the low water flows during the *Rabi* season, which would only amount to 0.2 to 0.3 of the peak flows in their *Warabandi* practices. These substantial lower flows would inevitably result in much higher relative conveyance losses, and require increases in the duration of application to make irrigation practical, which upset the strict implementation of the *Warabandi* schedule. Neither does the manual make any allowances for the refusal of water at the outlet (not even for the demand-based stages), as water is supposed to continue to be delivered continuously for 24 hours.

The latter supply criteria is a consequence of having no storage facilities in the main system. Permitting higher supply rates during *Rabi* to facilitate the application of the *Warabandi,* would result in operational losses that would undermine the efficiency and efficacy objectives of the modernisation. Alternatively, rotational supply schedules could have been devised, either as low requirement *tatils* at the secondary level or at the main system level. Such 'tradtional' operational procedures were, however, not considered in the O&M manual.

A curious, but easy to repair, mis-alignment in the proposed operational procedures for the first two phases of the transformation of water management in LSC, relates to the proposed 10 day scheduling cycle. The proposal to vary the irrigation water delivery in accordance with (average, and later actual) crop water requirements every 10 days, does not align with the proposal to retain the 7 day *Warabandi* distribution schedule at the tertiary units during these same operational phases.

A logical alignment of these main and tertiary level scheduling cycles would be to shorten the main system scheduling to a cycle of 8 days. This was the normal practice for main system rotation scheduling, allowing thus one day for the new flow settings to stabilise. To further stimulate steady-state flow conditions, one could even contemplate to split up the system in two scheduling divisions that are scheduled four days after each other, to minimise the flow rate changes in the main system.

...and for Demand-Based Irrigation

The second stage for modernising operation and management in LSC intended to further improve the efficacy and efficiency of varying the water delivery in accordance with the actual variations of (crop) water requirements. The potential mismatch between delivery and actual requirements were to be minimised by increasing the frequency and consequently decreasing the scale of flow variations (i.e. targeting the actual requirements more accurately in their variation). This would allow for changes in water delivery to be effectuated on 96 hours advance notice (phase three) and later even on 48 hours notice (phase four). The principle and mechanism for the scheduling of the flow variations were, however, to be changed into a demand system.

Instead of having the ID conduct and control the scheduling centrally on the basis of crop water requirement calculations from data of actual cropping patterns and climatological conditions as in stage one, the water users were to be permitted to conduct their own water scheduling at the tertiary level, and place their demands for variations in supply directly to the ID. Operating staff from the ID would then collect those demands and dispatch them to the central office for the system-wide scheduling and transformation into operational orders for the flow regulation and water control points in the system. The ID was thus still supposed to retain the overall control over the overall scheduling and water distribution in the system, by being permitted to decide whether or not it could fulfil the water demands of the water users. It was thus never the intention of the design team to grant the water users any control over the outlet and water distribution, not even to the extent of permitting closing down the outlet.[73]

In placing their water demands *cum* requests the water users were thus expected by the authors of the O&M manual to adhere to the principle of meeting their actual crop water requirements as accurately as possible:

> *"Daily evaporation records should be published, and the Irrigation Department and Extension Service as well as the OFWM Directorate should cooperatively initiate a program of irrigation scheduling among farmers. This program would correlate evaporation pan data with crop consumptive use and will greatly assist in the education of farmers to good irrigation practices. It will assist them in ordering water in accordance with crop demands."* (Harza-Nespak; 1985:47-48)

The water demands/requests, to be placed in specific rates of flow (i.e. cusecs [l/s]) at the outlet, were thus seemingly expected to be computed by the water users through application of the CROPWAT principle.

The water management principles at the tertiary level were expected to change fundamentally during this stage of 'demand-based' operation, in which the *Warabandi* was no longer to be practised, as water users were supposed to fine tune their irrigation practices to their crop water requirements by ordering variations in outlet supply every four to two days. The *Warabandi* was to be replaced by a tertiary unit 'water scheduler', termed *'common irrigator'* by the O&M manual (see next section), which was to be appointed by the water users through their newly formed WUA.

An issue which is not well accounted for in the O&M manual is, on which principles the tertiary unit irrigation scheduling should be conducted, and how this should be related to the water allocation rights as specified under section 68 of the Canal and Drainage Act (that provides a proportional time share of the water delivered through the outlet to landholder of the *chak*). In cases of diverse cropping patterns, in which different water users are supposed to meet different crop water requirements under a continuous flow, the *common irrigator* will inevitably have to revert to variations in the duration of the scheduled irrigation turns – particularly since the O&M manual stipulates that each water user is supposed to receive the full outlet flow. The juridical

[73] For this reason I have chosen to use the notion "*arranged*" in my classification of the four operational phases. Strictly speaking the notion "*demand-based*" schedules is reserved by the ASCE classification (*cf.* Clemmens; 1987a&b) for schedules in which water users are granted some freedom in adjusting the water supply themselves in one ore more of its three parameters of rate, frequency and duration. The scheduling mechanism as proposed here, is more based on placing "*requests*", rather than "*demands*", for changes in water supply that have to be "*arranged*" (i.e. agreed upon) between ID and water users. The use of the notion "*demand-based*" by Mardan-SCARP is to be considered rather unfortunate, as it fed the ensuing confusion and trepidation of the ID.

issue of the water allocation rights should not pose a problem as long as all demands can be met, but raises the question whether the allocation principles of section 68 should be attained as a basic right in times of scarcity or not. Practical rules should nevertheless be in place with which the *common irrigator* can deal with the multiple demands of the water users of the tertiary unit, that allow him/her to delimit the individual's requests in frequency as in volume. No deliberations were made on this issue in the O&M manual, that treats the *chak* as a unitary entity to be represented by the *common irrigator*, rather than an entity containing multiple users with possibly multiple irrigation and cropping strategies.

4.4.2 Reorganisation Requirements for Responsive Water Management

In order to realise the above described changes in operation and water management practices both ID and water users would have to effectuate some significant changes in the tasks, procedures and organisation of their operation and management activities to produce the 'desired' institutional changes. The O&M manual provides some specifications on the kind of changes Mardan-SCARP would have liked to see effectuated after the commissioning of the remodelled LSC, by the ID as well as by the water users. Although neither of these parties were full participants in the design and implementation of Mardan-SCARP or its formulation of the manual, the expectations of the project team were initially high towards the feasibility of achieving these changes: *"A reasonable time for changing to the demand system would appear to be five years from the time that the system is remodelled and measuring gates are installed."* (Op.cit.:28) (i.e. implementation of the third operation phase).

Reorganisation Plans: for the Irrigation Department...

The task of irrigation water delivery scheduling was supposed to become a central task and control mechanism in the ID's operation and maintenance of the new LSC system. As stipulated in the O&M manual, Mardan-SCARP suggested to give shape to this crucial task by creating a new office of *'Water Dispatcher'* within the Mardan Irrigation Circle and the implementation of some form of Irrigation Management Information System (IMIS). This *Water Dispatcher*, suggested to work alongside the Executive Engineer (the canal officer responsible for the O&M of the LSC system), would thus be responsible for executing the water scheduling for the entire system and define the discharge targets and operation instructions for all the flow regulation points. A task which would change in nature according to the stages of operation.

The scheduling of the first stage of crop-based operations would require a lot of data collection and information processing to conduct the up to date computations of the actual crop water requirements throughout the command area. Apart from having to structure and control the timely and accurate collection of all the data, it requires a management information system for the timely processing and disbursement of the required information. This was acknowledged in the manual by suggesting that the *Water Dispatcher* should be equipped with a personal computer to facilitate his/her task; no more and no less. No further deliberations are made for effectuating the change within the ID to institutionalise such an IMIS, except that the ID staff would require some in-house training on operation, scheduling, water control and data collection.

This lies in sharp contrast to other developments in the field, where the development and implementation of IMIS were often regarded as irrigation management improvement programmes in themselves. In such programmes primary attention would be given to the training of Agency and WUA staff in the collection, processing and use of data and information.

Furthermore, the *Water Dispatcher* would be required to monitor the operational status of the system, on the basis of discharge data from all the flow diversion and regulation points (including all outlets). Data which (s)he would receive on a daily basis from the *Gauge Readers*.

In the second stage of arranged-demand scheduling the information processing would change again, to a system in which the *Water Dispatcher* would ‘simply’ receive the water requests/demands from the *Gauge Readers*, rather than compute the delivery targets him/herself. Presumably, the IMIS of the first stage would be kept in place so as to enable this officer and his/her superiors to check on whether the placed demands for water conform to the actual calculated crop water requirements. This information can then be used in the decision on whether or not to grant the water request/demands in the system scheduling.[74]

The *Gauge Readers* were proposed to perform the actual operation of the system by manning the gates and becoming the executors of the feed-back and feed-forward scheduling and water control on the canals. To be upgraded in their functions from government scale 5 to 9, the *Gauge Readers* (although Gate Keepers might have been a more appropriate nomination) were envisioned to interpret a pivotal role in the operation of the system, by having to embody the service point where water passes from the ID to the water users. Right after commissioning (i.e. during the first phase of operation) these *Gauge Readers* would bear the responsibility to regulate the flow through all the gated outlet structures in addition to that of the canal head regulators.[75]

To facilitate their duties, Mardan-SCARP would equip all outlets and flow regulation and control structures with calibrated gauges. For outlet regulation, the gates of the Metergate outlets would be locked, and be operated exclusively by *Gauge Readers*. The tasks of these operators – that traditionally consisted of the monitoring of a few head and tail gauges and the execution of operational orders on a limited number of canal head regulators for usually not more than a dozen times per year – would thus change tremendously right from the moment of commissioning. From the first day they would be expected to daily collect discharge data on all outlets and canal flow division structures (i.e. head regulators), as well as water level readings of the cross-regulators and tail gauges of the system under their command; in other words, they were to provide all the monitoring input data on water distribution for the *Water Dispatcher* and his/her IMIS. Furthermore, they would have to implement the flow variations in water supply and distribution according to the orders issued by the *Water Dispatcher* and his/her superiors with an initial frequency of every 10 days. The latter requires considerable hydraulic skills in

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74 This is a common procedure for arranged-type schedules that make use of IMIS. It allows schedulers to apply priority scheduling in times of water scarcity, on the basis of, for example, crop water consumption classes.

75 The O&M manual is not clear on the quantity of *Gauge Readers* that would be needed to operate the new system according to its proposals. At one point it suggest to appoint one *Gauge Reader* for a hydraulic system unit of approximately 2000 ha (5000 acres), which would add up to 28 *Gauge Readers* for the whole of LSC, whereas elsewhere it suggests to appoint 15 *Gauge Readers*. The first suggestion seems, however, to be in line with the normal standards for such type of operation.

order to control the water fluctuations in the canal system; particularly since the water supply schedules are based on steady-state water control. Needless to say, dealing with and controlling such relatively high and frequent flow variations in the canal system, comprises fundamentally new requirements when compared to their traditional skills and practices. This was acknowledged by Mardan-SCARP by their proposal to substantially upgrade their functions within the ID. However, this acknowledgement was simultaneously undermined by proposing that the ID could impart the required skills through house training of these staff.[76]

In terms of the formal 'hard-systems' structuring of the operation and water management for LSC, the job-description of the *Gauge Reader* would seem rather straightforward and de-socialised; almost as if the *Gauge Reader* would be expected to act as a technical sub-process of the IMIS and scheduling processes by collecting and following instructions of dry technical data and parameters. However, in the second stage of arranged-demand operations particularly, the *Gauge Reader* was bound to become an agent in the scheduling and distribution process, with the difficult task of having to act as a 'negotiator' between the central scheduling (i.e. *Water Dispatcher*) and the water users with the task of elaborating a consent on the matching of demands/request with scheduled deliveries. Morever (s)he will bear the responsibility, if not formally at least informally in the eyes of water users, to maintain the water distribution along the secondary canal adequately, reliably and equitably. As has been increasingly documented over the years, secondary canal operators responsible for active (i.e. not self-regulating) water distribution are prone to conduct the actual water deliveries according to their own discretionary allocation and scheduling principles, particularly when the formal and centrally conducted scheduling does not meet water users' wishes and expectations (*cf.* Booth; 1977, Bottrall; 1981,Zaag, van der; 1992). This raises the issue that operation and management proposals of Mardan-SCARP can be perceived as a threat by the canal officers of the ID, as embedding an unwanted encroachment of their discretionary powers by subordinate staff that traditionally form part of one of the lowest layers of the administration's hierarchy.[77]

Although the cropping pattern data are traditionally collected by the *Patwaris* for the revenue assessment, no suggestions were made to re-organise their tasks so that they comply with the requirements of the crop-based irrigation scheduling. It is thus not clear whether, or in what form, the tasks and functions of the *Patwaris* and *Zilladars* (the former's superior) would play a role in the operation and management of the system; nor if the traditional method of revenue assessment and collection would be upheld.

The tasks and duties for the canal officers remained basically the same according to the proposals of the O&M manual, be it that they would have to supervise the work of the Water Dispatcher and the Gauge Readers in their new tasks responding to crop water requirements and water users' request in their scheduling and delivery. However, the manual provided no new

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[76] Another issue in this regard is, that it might be impossible to skip four Government grades at a time within the bureaucratic structure and rules of the administration. Which would have meant, that the existing staff of Gauge Readers would have to be replaced and augmented with people that are permitted to occupy grade nine positions.

[77] In the traditional system of self-acting proportionality the flow through the outlet can, as explained, not be regulated. As a consequence water users who want to increase their water supply with formal or informal sanction from the ID, had to engage in elaborate negotiations with the canal officers (usually XEN and/or SE or even their superiors).

rules and procedures by which the canal officers could execute this supervision. Further, the manual proposed that an extra unit would be added to the ID to take care of the maintenance of the drainage system, comprising of two extra XEN (one for drainage and one for the mechanical office), each supplied with two junior engineers and four sub-engineers. No further significant changes were proposed by the manual for the ID, while the project expected the ID to implement those changes when taking over. No project component was defined for transforming the management procedures, nor did the manual foresee any further incentives (like equipment, or training programmes) for the ID to implement the required changes.

...and for the Water Users' Water Management Practices

The water users were supposed to learn to schedule their irrigation applications in accordance with their actual crop water requirements. During the first stage of crop-based operations, the OFWM programme and the agricultural extension service of the Department of Agriculture (DoA) were expected to train the water users in this element. Within the tertiary unit, the *Warabandi* would remain to be applicable, be it that the supply rate would be varied by the ID in accordance with the crop water requirement of the unit.

For the implementation of the second stage of arranged-demand operations, however, the tertiary level water management practices would have to change significantly. Most drastically, the *Warabandi* would have to cease to exist as a central institution to make room for the managerial flexibility of allowing changes in water delivery to be requested on a four - two day notice. It is virtually impossible for the ID, and generally for irrigation systems of such a scale as LSC, to deal with all the potentially diverse water requirements and requests of the numerous small individual farmers and water users. Thus some practical organisational structure would have to be created that could function as an intermediate managerial structure and domain between the ID and the individual water users. The obvious and most common way to do this, is to establish formal Water Users Associations (WUA) at all the tertiary units. Such WUA could then organise their water scheduling and requests at the tertiary level, permitting the ID to treat them as unitary entities.

The task of setting up and bring into existence the 520 WUA in LSC was delegated by the O&M manual to the OFWM section of the DoA, that was involved in Mardan-SCARP for the remodelling of the water courses and the on-farm land levelling. This thus put considerably higher demands on the work of OFWM, which had developed an effective *modus operandi* in which the WUA created for the purpose of watercourse remodelling ceased to exist the moment the work was completed (*cf*. chapters three and eight). For the second stage of demand-based operation the WUA, however, would have to take an active role in the tertiary level water management.

To act as an intermediary between the WUA and the *Gauge Reader*, it was further proposed that each WUA would appoint a representative:

> *"The Chairman, or some designated representative of a WUA should collect the water orders from the water users on the watercourse. He would serve as a water order coordinator and might be called a 'Common Irrigator' as is the case in some countries.* [...] *The Common Irrigator should be reimbursed for his services and his wages should*

be paid by the WUA from fees levied on the members." (Harza-Nespak; 1985:30-31)

As has been argued in the earlier paragraph, the function of the *Common Irrigator* was bound to entail rather more than merely 'collect the water orders' from the individual members. To come to a practical organisation of all the individual requests and requirements, (s)he would have to act as a tertiary unit scheduler, in replacement, or also not unlikely, emulation of the *Warabandi*.

4.4.3 Issues of Control

For Water Distribution & Allocation

Mardan-SCARP decided to dimension all the outlets to a maximum relative delivery capacity of 1.34 l/s/ha to meet the potential peak water requirements during demand-based operations. The main system's relative capacity, however, is supposedly delimited to 0.78 l/s/ha. This raises the issue on how an equitable and fair water distribution should be controlled in the system, and prevent astute water users *cum* tertiary units from appropriating the in-built extra capacity at the cost of tail-enders, as has been the ingrained practice since yesteryear.

Supposedly it is the responsibility of the *Water Dispatcher* and his/her superiors to guard the fair distribution of water during peak water requirements periods by putting limitations on the maximum rate and/or volume of water supply that can be granted during this time. The O&M manual, however, only contains sparse guidelines for the procedures and principles in such events:

- in case the total water requirements *cum* demands/requests exceed the total available flow, the *Water Despatcher* should *"apportion the available water in accordance to the cultural command area"* (Harza-Nespak; 1985:51);

- *"In the event the crop irrigation requirements exceeds the design capacity of the channel, due to a larger than normal acreage of high water use crops, it will be the responsibility of the Irrigation Department and the WUA to guide the farmers in their cropping patterns so that peak demand does not exceed design capacity."* (Op.cit.:25)

In order to delimit and prevent the occurrence of such contingencies, it is suggested that the ID and WUA guide (i.e. convince) the farmers to restrain themselves from growing crops that result in larger than anticipated peak water requirements. In the absence of any control mechanisms to impose such restrictions on cropping patterns, this guidance is euphemistically described as: *"The situation is not expected to occur often but if it does it will only take a season or so for the farmers to adjust their cropping patterns according to the capacity of the irrigation system."* (Ibid)

This might work while this phenomenon is restricted to the tertiary level and its relative capacity of around 1.34 l/s/ha. On the secondary level of minor and distributary canals, however, where the design capacity is supposed to be restricted to 0.78 l/s/ha, the restriction of water requirements becomes a matter of agreement, if not enforcement, between several tertiary units *cum* WUA. The question thus arises what measures the ID should (be able to) apply to reach a consent on the restriction of cropping patterns at the secondary and main system levels; and whether practical restrictions on the maximum rate and volume to be granted during peak water requirements are required. This in turn raises the question on how such restrictions should be backed by, and imbedded in, the water allocation rights and rules to be adopted in a modernised LSC. In the absence of such arrangements, one can only hope that the assumed design cropping pattern on which the system capacity has been based indeed turns out to reflect the irrigation and cropping objectives of the water users of LSC in the face of increased water availability.

Hydraulic Limitations for Water Control

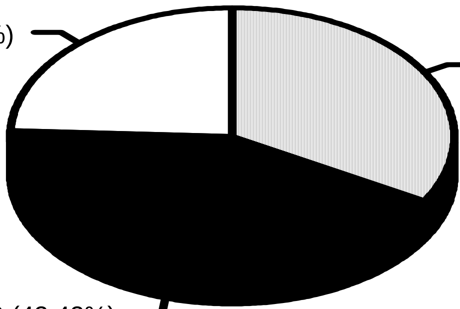
When considered against the intended methods of operation, the designed and constructed infrastructure for LSC possesses two important limitations for effective water control: in handling silt-loaded water, and in containing unsteady-state flow conditions.

Although the project team acknowledged the fact that the water of the Swat River is heavily loaded with silt, it decided to use the Manning equation (with maximum velocity criteria and empirically determined roughness coefficients) for the remodelling of the channels. However, in order to avoid siltation of the channels, a minimum velocity criteria should have been determined to define the lower limits of canal operation – like the clearly defined 70 percent lower limit of yesteryear. As a consequence the operational procedures set out in the O&M manual do not take into account operational limits in order to avoid siltation, but simply allow the scheduling to freely follow the crop water requirements. The resulting water delivery schedules, as proposed by the manual for the first phase of operation, thus anticipate a high degree of flow variation in response to changing crop water requirements, in which the water supply in the channels would vary between 20 and 85 percent of the design capacity (*cf.* fig 4.9)[78]. When taken over a full year of irrigation supply (comprising of 33 delivery periods), the main canal of LSC would have to run between 81 and 100 percent of its design capacity for a mere 24 percent of time, while for 33 percent of the time it would have to run below the traditional lower limit of 70 percent of FSL (i.e. 55 percent of FSQ) (*cf.* fig 4.10). No efforts were made to determine the lower limits of 'regime operation', nor practical experiences have been gained with running channels at such low supply levels for such a prolonged time under these silt conditions (i.e. below 40 percent of FSQ for 21 percent of time). It is thus questionable whether the remodelled LSC could be operated sustainably according to the proposed schedules; particularly since the presence of the numerous check-structures would significantly lower the flow velocities under low supply.

Since the intention has always been that the remodelled LSC would be operated under steady-state flow conditions, while managing a variation in water delivery without storage facilities, it would be essential to operate the system in accordance with its intrinsic lead-time in order to

[78] The fact that the proposed water delivery rate does not reach the 100 percent of design capacity of the distributary channel is a consequence of over-dimensioning distrubutary channels that supply a command area smaller than 4000 ha (10,000 acres), allowing for a maximum water allowance of 1.34 l/s/ha (19 cusecs per 1000 acres) while the main canal capacity and proposed schedule is based on the assumed design cropping pattern that requires a water allowance of only 0.78 l/s/ha (11 cusecs per 1000 acres).

Fig. 4.10: Mardan-SCARP Main Canal Water Delivery Rate
Percentage of time canal is run at different ratios of FSQ



(Harza-Nespak; 1985)

avoid unsteady-state conditions. This is to say, the delivery scheduling should take into account the time the system needs to settle a flow variation into a new steady-state flow, and that its scheduling cycle should always exceed this lead-time.[79] However, with the formulation of the operational procedures in the O & M manual, the limitations imposed by the intrinsic lead-time have not been taken into account, nor have they been determined. Though the numerous drop structures in the system would aid the stabilisation of the water flow, this hydraulic advantage has been significantly neutralised by the submerged outlets that magnify the sensitivity of the system to changes originating from the outlets and tertiary units. Thus it is questionable whether the proposed 96 and 48 hours demand response delivery of phase III and IV would be operationally feasible under steady-state conditions; particularly when the cross-regulators would also be fitted with gates, as proposed, increasing further the points in the system from which destabilising flow variations could originate.

[79] Apart from the mere length of the canal system, the lead-time is also significantly affected by the hydraulic configuration of the canal system. The latter being paramount in defining how the flow variations will be propagated throughout the system, and how sensitive the system will be to propagations of flow variations as a result of flow changes made within the system.

4.5 IMPLEMENTATION: (UN)CONFIRMING DESIGN ASSUMPTIONS

The design for the remodelling of LSC and its anticipated mode of operation, as described in the previous paragraph, were produced and formulated in the draft version of the O & M manual in 1985 by the Mardan-SCARP Project team. Set against the initial design objectives for Mardan-SCARP, the design could be little else than approved by the Project Coordination Committee (PCC) and Donors (World Bank and CIDA), as it met all three of the objectives by: (i) doubling the discharge capacity of the system; (ii) providing adequate drainage facilities; (iii) setting out a specific path for changing into demand-based responsive irrigation water management. As a result, the project went ahead with the implementation of the infrastructural works as stipulated by the design presented in the draft O & M manual of 1985.

During the course of design implementation, however, the Mardan-SCARP project soon enough ran into increasing opposition from the part of the ID against the installation of the proposed Metergate outlets. Though it has proven difficult to reconstruct this clash in opinions in all its details and procedures, the main issues are now analysed. The ensuing dispute between the project and the ID sealed the fate of the impact that the modernisation attempt of LSC could have. In order to fully appreciate how this conflict between designers and operators could arise, it is necessary to explain the institutional set-up of the Mardan-SCARP project and the formal roles allotted therein to the different parties in the conflict.

The Mardan-SCARP project did not differ significantly in its set-up from any other SCARP or major irrigation project conducted in Pakistan since the initiation of the IBP. As was common practice, a leading role at centre stage was allocated to WAPDA and the consultants, who together comprised the project team that had the task to design and oversee and manage the construction of the remodelling of LSC. In order to provide the project team with an adequate mandate to manage the construction work, the ID's water management responsibilities over the canal system were temporarily suspended and handed over to WAPDA for the duration of the construction period.[80] These management responsibilities were to be handed back formally to the ID when the latter would accept and resume the operation responsibilities of the system after commissioning – to take place officially one year after completion of the construction work.

The formal role granted to the ID in the execution of the Mardan-SCARP project was limited to a membership on the PCC, and the execution of the conversion of water courses into minors according to criteria and specifications set forth in the design.[81] Acting as the representative of the Government of NWFP, the PCC was set-up at the secretariat level, with the participation of the Departments of Irrigation and Agriculture, WAPDA's General Manager (North), headed by the Chief Secretary Planning & Development. Further participation was granted to the Commissioner and Deputy Commissioners of the Civil Administration from the project area.

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[80] Not all management responsibilities were handed over to WAPDA. The ID retained the responsibility over fee collection, all matters pertaining to the tertiary unit, and administration of the Canal & Drainage Act. All matters pertaining to the operation and maintenance of canals and outlets, however, were subjected to WAPDA.

[81] The design criteria adopted specified that the discharge capacity of new outlets should not exceed 141.5 l/s (5 cusecs). In those cases that the existing tertiary unit had a CCA larger than 105 ha (263 acres), the command area would therefore have to be split up, converting thus the original outlet and main water course into a small supply minor to the newly defined units.

From the composition it becomes already clear that the forum of the PCC was not created to deal with the nitty gritty details of design criteria, nor to partake in the tedious process of iterating design decisions. Rather, it was set-up to monitor the progress of the Mardan-SCARP project on behalf of the Government of NWFP against the objectives set forth in the Project Planning, FPP and (most of all) PC-1 documents – on the basis of which the loan agreement was made – and to facilitate the implementation process by directing the activities of the different agencies involved[82] and endorsing the timely dispersion of funds. As mentioned, the PCC had little choice other than to approve the design against the broader project objectives and proceed with its implementation. Subsequently, it mainly focussed its activities on the demanding task of supervising the numerous contracts and implementation activities. (*Cf.* Bandaragoda et. al.; 1994, Bandaragoda; 1998).

All seemed to go well as far as the installation of the drainage facilities and increase in canal capacity were concerned. These were two of the main project activities that encompassed the majority of the construction work (particularly at the beginning), and that were directly related to clear cut objectives. However, things went less well with the operational management component. Even though the project team had made an attempt to clarify the operational issues for Mardan-SCARP in its O&M manual, this remained a project element that continued to foster ambiguities among the different parties involved. To settle this issue, the donor agencies proposed to work out a workable solution by means of an operational management pilot project. As becomes apparent from the donor review missions, however, the project continued to struggle with the paramount issue of operation.

In the summer of 1988 the Donor agencies, during one of their review missions, suggested to tackle the operational issues through the set-up of a specific Operation & Maintenance project component for which a separate PC-1should be submitted by the autumn of that same year. At the time it was suggested that this O&M component would follow the procedures set forth in the draft manual, and seek to further specify and try these through a pilot project in which WAPDA, together with the consultants, would provide the required expertise and training of the line Agencies. However, this project component never materialised as such, as even the called for PC-1 was never submitted.

In the next review mission of February 1989 no reference is made to the PC-1 requested by the previous mission. Instead this mission suggested that a new pilot area[83] would be selected along distributary No. 8, comprising about 300 acres, recommending "[...] *that pending the construction of the head regulator, WAPDA, Irrigation Department, Agriculture Department (Extension and On-Farm Water Management) and Consultants will formulate a plan for demand irrigation trials in the pilot area, which would comprise a plan of action and a program for training of Irrigation and Agriculture Extension personnel and farmers in determining crop water requirements and irrigation scheduling and system operation.*" (Bandaragoda et. al.;

82 This is primarily related to the coordination of implementation activities, where the Agricultural Department is involved through OFWM in land-levelling and water course remodelling, the ID in the conversion of water courses into minors, and WAPDA in overseeing the contracts for canal remodelling and drainage installation.

83 Seemingly the intentions initially were to start a pilot scheme in the head-reach of the system along distributary No. 3. One of the few reasons mentioned why this plan has not been followed-up, is that the selected area would not be representative in its social-cultural and landholding structures. (Bandaragoda, et. al; 1994, EDC; 1991)

1994:24)

In October 1989 the review mission stated that it was not pleased with the progress booked so far with the pilot scheme along distributary No. 8. It recommended that the pilot scheme be extended to the 300 acres as originally envisaged and that the demand irrigation specialist returns to provide further assistance. Furthermore it revised the objectives for the pilot scheme, downgrading significantly its role for the Mardan-SCARP project as a whole: *"It was agreed that the pilot scheme will not directly benefit this project, but that its results if positive could benefit future projects."* (World Bank/CIDA review mission, Oct 25 - Nov 2, 1989; quoted in: ibid)

May 1990: ID, WAPDA and Consultants were requested by a review mission to complete the pilot scheme and to expand it "expeditiously" to the 240 acres still to be covered and to keep the Donors informed of their progress.

During the review mission of July 1991 the ID requests the Donors to suspend the installation of the Metergate outlets. The mission agrees, on condition that the pre-fabricated outlets will be stored by the ID for future use when it is ready to resume demand-based operation of the system.

In October 1991 the 'wind-up' mission of the Donors concludes that *"Now that more than 90% of the project works have been completed, serious attention should be given by the Irrigation Department to ensuring satisfactory O & M of all completed work* [...]*"*. Without referring further to any implications of demand-based irrigation, the mission urges the ID to "vigorously" pursue the implementation of the 1985 draft manual, adding to it that the *"Irrigation Department is to ensure equitable distribution of water among the users."* (World Bank/CIDA review mission, Oct 15 - 24, 1991; quoted in: op.cit:25)

From these Donors's review missions it becomes blatantly clear that something went wrong during the implementation phase of Mardan-SCARP while the project attempted to develop new operational procedures. One gets the impression that the Donors gradually gave up on their intentions for, and expectations towards, the development of demand-based irrigation operations for LSC. The events during two crucial stages of the implementation phase shed some light on how the problems around operation haven been brought to the surface and basically remained unsolved: the pilot scheme, and the early operational experiences with the first remodelled canal.

Though marred by some initial hiccups, the pilot scheme for the determination of, and training in, demand-based operational procedures finally got under way in 1989 under instigations of the Donors at the newly selected site along distributary No. 8. Focussing on the need to explore the implications of demand-based irrigation, the project and Donors made a rather peculiar decision at this stage by opting for the implementation of a small (24 ha (60 acres)) demand-based pilot scheme that would deliver water to the farm through a low-pressure buried pipe system. With the aid of the internationally acclaimed specialist and advocate of such 'flexible' delivery systems, this 'demonstration' scheme, that departed completely form the original project design, was installed at one tertiary unit. Consisting of a level-top feeder water course, that takes its water from distributary No. 8, the system was designed to deliver three 28.3 l/s (1 cusec) streams over a piped network supplying the farm outlet valves (Merriam; 1991). With a design delivery capacity exceeding 2.5 times the one adopted by the project design (i.e 3.5 v 1.34 l/s/ha (50 v 19 cusecs/1000 acres)), the pilot scheme intended to demonstrate the benefits of a flexible demand-based irrigation system where farmers could optimize their irrigation practices by irrigating when and as long as they wished with a limited delivery rate of 56.6 l/s (2 cusecs). Though the incorporated water delivery flexibility of the pipe system was designed to allow for the water users to eventually operate the irrigation scheduling and delivery, the pilot scheme was initially meant to be used as a 'training ground' for the personnel of the line agencies and farmers in matching irrigation water deliveries and applications with crop water requirements. For the latter purpose, personnel of the ID were to operate the farm outlet valves in response to farmers' requests, while the personnel of OFWM and Agricultural Extension could concentrate on determining the optimum irrigation applications on an 'example farm'.

Notwithstanding the frequent urges of the Donor missions towards the project and ID to extend their demand-based operation trials to the remaining 96 ha (240 acres) of the initially selected pilot area of 120 ha (300 acres), no further activities were undertaken in the operations pilot scheme. It is also not clear what the intentions of the Donor missions were for these remaining 96 ha (240 acres). Although reference has been made for the extension of the low pressure pipe systems with a further 12 ha (30 acres), the remaining 84 ha (210 acres) were supposedly to be operated with the Mardan-SCARP irrigation facilities. It is, however, difficult to foresee how scheduling and delivery procedures can be effectively tried and practised on such a small scale (which hardly exceeds one tertiary unit), and how these practices should be related to the vastly different ones obtained with the buried pipe system. The eventual 'downgrading' of the piped pilot scheme by the donors, to a general experimental site that might provide lessons for future projects instead of preparing operational procedures for Mardan-SCARP, therefore seems to have come as a logical consequence.[84] As far as the lessons provided by the pilot scheme are concerned, the involved line agencies all eagerly agree that the system provides optimum irrigation facilities for the implementation of demand-based irrigation, but that the high required capital costs prohibit its replication on a large scale in the current circumstances.[85]

By 1990 the canal remodelling had proceeded to such an extent that the first distributary canals were being completed according to the design specifications of the 1985 O&M manual; i.e. featuring a double discharge capacity, Metergate outlets, and cross-regulators. The time was thus approaching to gradually hand back the operation and maintenance responsibilities to the ID. In 1990, distributary No. 3 was one of the first canals to be entirely completed and which presented itself for handing over. However, in the absence of clear and agreed upon operational procedures for the newly remodelled LSC – the O&M manual, after all, had never passed the status of Draft version – this proved to become a problematic issue. The completion of distributary No. 3 thus created a deadlock situation, in which WAPDA opined that its role and responsibilities were clearly ended with the completion of the design and construction work, while the ID refused to assume operational responsibilities in the absence of a formal operational

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[84] This conclusion of events around the pilot trials seems essentially preceded by the review mission of February 1989. It's stated objective (see above) for the pilot area on distributary # 8 indicates already a shift in focus from operational trials towards establishing a learning ground and training programme for the application of the CROPWAT paradigm in on-farm and tertiary level water management, rather than on testing and refining the operation and scheduling procedures for the secondary and main levels.

[85] Apart from the high capital costs required, further objections could be raised from technical considerations that would follow from a large scale implementation and which have not been worked out so far; such as how to provide for enough storage capacity within the main system under regime conditions.

plan and the means and funds to implement such a plan. As a consequence, distributary No. 3 was basically left to operate by itself and its water users. In the absence of any ID personnel or water users organisation to take and conduct an effective water control on the distributary level, the water distribution along the outlets of the canal ran quickly out of hand. Since all the outlet gates were installed without locks, the head-end water users were quick to take full advantage of the situation by operating their own outlets to take water to such an extent that they could refrain from night time irrigation. As a consequence the tail-end outlets only received adequate amounts of water during the night time. The ID was subsequently quick to use this anarchic water management situation as a vindication of its objections against the Metergate outlet, and to step in to enforce its water control by fixing all the outlet gates into a fixed position. (*cf.* EDC; 1991)

Following this 'uncontrolled experiment' with the new water control structures provided by Mardan-SCARP, the ID thus requested the donors for the suspension of the installation of the Metergate outlets, which was subsequently granted in July 1991. The Metergate outlet thus became effectively the (technical) focal point of the objections and discontent of the ID against/with the design and proposed operations of Mardan-SCARP. Regarded as the materialisation of the demand-based water delivery concept, the experiences at distributary No. 3 had effectively shown that the situation in the LSC system was not yet ready to effectively implement such demand-based operations. 'One could clearly not entrust the water users with responsible behaviour in the distribution of water, and the ID should therefore regain the full control over the outlet so that it would be able to ensure an equitable distribution along the distributaries and the system at large'. After July 1991, the ID was allowed to do just that, when it resorted to the installation of gated AOSM outlets instead of the Metergates. The ID thus subsequently implemented the outlet of the original design as presented in the FPP, be it with a modification of the gate-structure, which was completely encased and required a special operation key so as to thwart any tampering in water distribution by water users.

4.6 THE ID'S REPUDIATION OF THE DEMAND-BASED CONCEPT

From the events described above it becomes clear that the outlet structure became the focal point of the ensuing conflict between the ID and Mardan-SCARP project on the implications of the 'demand-based' irrigation design on the manageability of the system. Although the outlet is a rather logical focal point, as it performs a pivotal role in water control and operational procedures, the technicalities of design seem to have overshadowed the operational issues in the playing out of the conflict. The issue of who was to exert control at the distributary level and through which procedures, however, lay at the heart of the conflict, while the technicalities of outlet design were effectively used to stall a process of change that was increasingly regarded as unfeasible and unwanted.

The draft O&M manual of 1985 and the set-up of the Mardan-SCARP project resulted in two interrelated problems in shaping new operational procedures for the LSC system that nurtured to a significant extent the ensuing conflict between the ID and the project. First of all, the O&M manual, and the project at large, dramatically failed to provide a clear cut operational plan by creating much ambiguity about ‘modern irrigation water management’ through its injudicious use of notions as ‘demand-based’ irrigation and ‘flexibility’ in confusion with ‘crop-based’ irrigation and ‘arranged scheduling’. Secondly, the ID was compelled to defend its institutional interests as the project set-up had essentially reduced its role to becoming a target for change, instead of a participant in designing and effectuating change.

Although Mardan-SCARP never intended to transform the LSC into a truly demand system, but rather designed it for arranged scheduling operations in which the water delivery could be varied according to crop water requirements (i.e. ‘crop-based’ irrigation), the insistent stressing in the manual on having to respond to farmers’ demands in the operation of the outlets constituted a threat to the traditional jurisdiction of the ID. In failing to provide a clear distinction between crop-based arranged scheduling, where the control and decisional powers over water distribution remain entirely with the agency, and that of a demand-based delivery system, where some of the control and decisional powers on the rate, frequency and duration are devolved to water users, the project allowed this to become a main concern for the ID. This concern was further aggravated by the minimal staff deployment proposed by the manual, in which only one water dispatcher would be added to the ID staff while 15 of its filed staff members would be trained and upgraded for the operation of more than 500 gates in response to farmers’ demands. With the proposed transformation of operational management for LSC, the core issue of water control was at stake. The crucial question of according to whose discretion would the water delivery and distribution be conducted in future, was left for implicit interpretation. By focussing mainly on the need to meet crop water requirements, the project allowed this crucial issue to be blurred into the background. The first reaction of the ID in response to the proposals presented in the O&M manual was to try to buttress its presence and control at the distributary level, by arguing that it would require at least one operator for every 3 - 4 gates if it was to implement any form of ‘demand-based’ irrigation operation (EDC; 1991). Not surprisingly, such an over-kill of operational staff was unacceptable to the Government of NWFP, who would have had to foot the bill.

The implementation of the Mardan-SCARP design was thus quickly hampered by an emerging dispute on how the operational management of the remodelled LSC should be given shape. It became evident at an early stage that the proposals contained in the O&M manual for the shaping of operational management were not deemed feasible and desirable by the ID. However, the project continued with its planned schedule for implementation of the physical works in the belief that it would be able to amend the operational procedures adequately before the time of commissioning.

Evidently, the outlet played a crucial role in this whole episode of the project, as it quickly became the object that embodied all the operational issues at stake. Something the project never seems to have fully grasped; or in any event at too late a stage. The choice for the Metergate outlet was a crucial one, that polemicised the issues of devising an adequate level of water control and appropriate operational procedures; not only for the ID, but for the project as well. The Metergate outlet undermined to a substantial degree the initial project intention to gradually transform the operational management of LSC in phases of increasing water control and water delivery accuracy.

Having failed to substantially increase its staff, based on the recognition that it would be required to drastically modify its operational procedures and practices, the ID started to question the feasibility of the operational procedures of the O&M manual and the very necessity of installing the Metergate itself. With the benefit of hindsight it is clear that at this crucial junction the project made a capital mistake, gravely misjudging the situation and issues at stake. It could have tried to appease some of the implicit and explicit concerns raised by the ID by elaborating on the concrete scheduling and delivery tasks for the operation of the future system. After all there were enough reasonable objections (hydraulic and institutional) that could be raised against the Metergate outlet and the system's as well as the ID's capacity to control highly and frequently varying water flows in response to changing requirements/demands. Instead the project seemed to have opted for a 'head to head' defence of its outlet and recipe for operational management. The only line of defence it could take for the justification of its choice for the Metergate outlet, was in terms of the water control that would be required to implement the 'demand-based' irrigation of operational phases three and four, and the enormous benefits such 'demand-based' irrigation operations would bring to the project area. So, instead, and in defiance, of being originally earmarked as a mid to long term management objective for LSC, 'demand-based' irrigation operations was suddenly pushed to the forefront as a major issue that required immediate attention and clarification. After all, the 'preposterous' suggestion of the ID that it would require one operator for every 3-4 gates clearly showed that this concept of how a 'modern' and responsive irrigation system could be operated still needed a lot of clarification and education.

By 1989 this need for clarification and education was officially acknowledged by the project donors, who subsequently called for a pilot scheme to be developed in which water management procedures could be tried and tested, and in which operational staff and water users could be trained accordingly. But the decision to opt for the small scale buried-pipe system in order to explore the implications and procedures of demand-based irrigation, simply defies any understanding from the part of this researcher. It is, however, certain, that by opting for the buried-pipe system – instead of 'simply' trying to implement and elaborate the four phases of operation as presented in the O&M manual along one distributary canal (if need be, with different types of outlets) – the project and donors gave space for action by the ID. The results and experiences obtained with the buried-pipe system easily captured the hearts and minds of every sceptical canal officer into acknowledging the huge benefits demand-based irrigation could offer. However, the considerable cost of its installation and its complete departure from the Mardan-SCARP design and its system capacity effectively prohibited its replication for the whole of LSC, and thereby that of the implementation of 'demand-based' irrigation operations in the system. The project thus 'lost' the justification for its choice of the Metergate outlet and with that its recipe of responsive outlet operation by the ID to the requirements/demands of the water users.

The first water management experiences obtained at distributary No.3 under the new conditions created by Mardan-SCARP served to further seal the fate of 'demand-based' irrigation operations for LSC in the minds of the ID. The short lived experience of anarchic water management clearly showed that the canals and outlets of Mardan-SCARP did not provide the hydraulic benefits of the buried-pipe system, where every user could be easily supplied with the water (s)he wanted or needed. If anything, the resulting skewed water distribution had clearly shown that there was a need for the ID to step in and resume its firm control over water in order to oversee and guarantee its just distribution. The latter was precisely what the ID was subsequently allowed to do when it was granted the permission by the donors to suspend the further installation of Metergate outlets and replace them with their own gated AOSM.

4.7 DISCUSSION & CONCLUSIONS

The pre-fabricated Metergate outlet structures scattered around the embankments of distibutary # 6 and stored in the back yard of the ID, as we encountered at the end of our canal safari in chapter one, epitomise the conflict that ensued in Mardan-SCARP on the appreciation and conceptualisation of what should constitute a 'modern' irrigation system. The repudiation of these alien technological products form the caricature of the externalised design process that took place in Mardan-SCARP. Although seemingly a technical dispute, the outlet conflict embodied the essence of the transformation that was sought to be effectuated with the modernisation of LSC. Namely, to regulate the water delivery in response to the varying crop water requirements *cum* water demands.

The set-up of the project, with WAPDA and consultants coming in to conduct the design and remodelling of the LSC, has from the start hampered the process of conceptual accommodation between ID, water users and the designers and constructors of the remodelled system. The set-up essentially conformed to the one presented in fig. 1.1, in which the development process is compartmentalised into the stages of inception, design, construction and operational guidelines. The conceptualisation of demand-based irrigation produced by the Mardan-SCARP design, was essentially fed by contemporary engineering concepts of modernity. As such, it primarily consisted of a technological package for a designed physical system that technically enabled the regulation of water delivery in response to varying demands. The two primary shortcomings in the project set-up were:

- The project team was set to work with too general a terms of reference, in terms of the objectives and characteristics for the modernisation of LSC. As a consequence, the designers had to make decisions and assumptions in the specification of the irrigation concept that had far reaching consequences on the operational management. The final design became thereby too prescribing on the water management objectives and strategies to be adopted by the ID and water users, without being founded on consultation and agreement.

- There was no specific and substantial project component for the elaboration, implementation and institutionalisation of the transformation of the water management procedures and practices of ID and water users. In the end there was hardly any means and space available to conduct a process of operational change management. This element was relegated too easily to in house training and extension.

Rather than developing and accommodating a concept of the to be established system with the

ID and water users, and on the basis of their practices, concerns, strategies and objectives, the Mardan-SCARP design led to an imposition of a 'modern' technological concept to which the primary actors responsible for operation and management would have to conform.

Within the institutional set-up this has led to a further aggravation of the degradation and frustration of the ID. With Mardan-SCARP it was yet again made clear, that the ID was no longer acknowledged as managers and developers of irrigation, who can develop and innovate the irrigation systems on the basis of experienced problems and shortcomings. The modernisation of LSC became thereby more of an attempt to replace an old system with a new one, rather than an attempt to develop a new equifinal state and control mechanisms to adapt the existing system to its changed environment.

The ensuing conflict and deadlock on whether the Mardan-SCARP design was functional and appropriate for the institutional and natural-physical environment of LSC, or not, was not only a matter of political obtuseness. The externalised process and import of the concept for the modernisation of the system, led to a failure to properly address some of the paramount concerns and issues that have governed the daily practices of water management.

Sediment and canal operation strategies for regime maintenance, has been discarded too lightly as an old-fashioned hydraulic and operational paradigm that would be incompatible with the modern requirements of controlled variability. While this has been one of the major issues that have shaped the operational rules, procedures and experiences of the ID. Ironically, WAPDA also did not take this issue serious in the case of Mardan-SCARP, while it has shown no reservations whatsoever to bring sedimentation and regime maintenance forward as one of the primary concerns of operational management, when it had to bear the O&M responsibilities itself in the case of Chasma Right Bank Canal (*cf.* chapter six). Apart from the regime considerations, the technical controllability of the extreme flow variations for crop/demand based operations remained questionable in the hydraulic configuration of the remodelled LSC, in the absence of an unsteady flow and hydraulic sensitivity analysis.

At the level of main system operation, the organising, processing and regulating the demands and arrangements for varying water deliveries was too much regarded as a 'simple' matter of balancing the numbers of water availability and requirements in the computer of the water dispatcher, and dividing them as operational discharge targets throughout the system. Instead of producing a congruent plan for transforming the monitoring, feed-back control, scheduling and hydraulic discharge control capacities of the ID. At the tertiary level, the institutional strength and functionality of the *Warabandi* was discarded, without providing any concrete alternative for the water users to conduct their tertiary water management arrangements. The misalignment of the 10-day scheduling cycle with the 7-day *Warabandi* roster, is in this respect exemplary of the focus on the tertiary unit as an unified entity of water requirements *cum* demands. No provisions were made for how the Gauge Readers and Common Irrigators would have to come to an accommodation of the diverging individual water requests and requirements into a practical and 'implementable' schedule. Thereby negating the prospect, that the scheduling and water distribution processes would be centred around these middle level operators, as being the most deterministic for the individual water user, rather than at the central level of the Water Dispatcher with which the Canal Officers could keep control over the system.

The choice for the Metergate outlet had far reaching implications that effectively impeded the gradual and stepwise transformation of the operational management processes and control mechanisms. These consequences, and the ensuing conflict it ignited, effectively inhibited the option to initiate an appropriation process to search and develop operational alternatives to the ones presented in the O&M manual and the customary practices. The buried-pipe pilot exercise has neither been very conducive in this regard, as it primarily served a theoretical issue in its attempts to put up a defence for the inherent advantages the concept of demand-based irrigation has to offer, rather than trying to develop concrete operational alternatives. In the continued absence of any concrete provisions for operational management, the functionality of the remodelling of LSC remained to emerge out of the adaptations that the ID and the water users would make in their water management practices in order to establish a new equifinal state of water delivery service.

CHAPTER FIVE

ADAPTING WATER MANAGEMENT STRATEGIES IN THE NEWLY REMODELLED LOWER SWAT CANAL

OLD HABITS & NEW OPPORTUNITIES

"The irrigator, the owner of the water right, knows only one test of the efficiency of the canal management – does he have an ample supply of water whenever needed by his crops? The success of an irrigation enterprise depends on the success with which this test is answered; that is, upon the system of distribution of water under the canal." (Widstoe, quoted in Mahbub & Gulhati; 1951:4)

5.1 INTRODUCTION

With the commissioning of the LSC in 1994, Mardan-SCARP had come to an abrupt end. The physical works in drainage and irrigation had been completed, while the project failed to define and implement a new operational procedure with the participation and consent of the ID. A situation had thus arisen, in which the physical and environmental constraints (i.e. water scarcity, water logging, potentially limited water control) that had governed the irrigation practices heretofore were substantially changed by the project, while no new management procedures were yet established to take optimal advantage of the newly created opportunities. Although a general increase in irrigation performance was to be expected due to the general alleviation of the physical and environmental constraints, it remained to be seen to what extent this would also induce changes in the irrigation practices of both the ID and water users. By comparing the post commissioning performance of LSC with that realised prior to the project, an assessment can be made of the impact of the improved drainage and water availability, as well as of the extent of changes in water management practices. To this end a research programme was set-up within WAMA to gain insight in the current water management practices in Lower Swat Canal, and to assess the impact of Mardan-SCARP in changing those practices and the overall performance of the system. This chapter is based on the research results obtained at WAMA during a two and half years study of LSC from mid 1995 till the end of 1997.

The chapter starts with the assessment of the general impact of Mardan-SCARP on the operational practices of the ID at the main system level, and on changing cropping strategies and improved agricultural production. While Mardan-SCARP had little impact on changing the operational procedures and strategies with which irrigation water is delivered and controlled, as the traditional rules of FSL operation were quickly reinstated, the increased capacity and drainage facilities of LSC have markedly improved the irrigation conditions for water users.

Section 5.3 provides a more detailed picture on how the increased water supply is controlled and distributed at the secondary level, by focussing on the Sheikh Yousaf Minor. It becomes clear that a marked turn-around has taken place in LSC, in which it has been transformed from a water scarce system into a system of relative water abundance. For the ID as for the water users this has made the control of excess water one of the prime objectives of operation and management: for the former by concentrating on reacting in its main system operation to rainfall; for the latter by refusing canal water when crop water requirements are low. The relative abundance of water has resulted in a clear increased tolerance from the part of the ID towards water users' interventions in the minor.

Section 5.4 focuses on how the abundant water supply and the control of excess water have changed the water management practices of water users at the tertiary level, and in section 5.5 what impact this has had on the use of *Warabandi* as a water allocation and distribution mechanism originally devised to deal with water scarce conditions. To establish how irrigation and drainage have been integrated in the daily water management practices, a detailed study was conducted on two drainage units of Sheikh Yousaf Minor during the second half of 1996.

The conclusions review the established operation and management practices in the newly remodelled LSC, and the current water management practices and strategies of both ID and water users are discussed in light of the initial concepts and objectives of Mardan-SCARP. The integration of irrigation and drainage in the daily water management practices, combined with the informally established division of water supply and drainage tasks between ID and water users, have clearly taken away the incentives for a tight control of supply variations and matching crop water requirements with water supply at the main system level. Questions are, however, raised on the sustainability of the current water management practices, and on the relevant issues in the conceptualisation of irrigation for future developments.

5.2 THE 'NEW RICHNESS' OF FULL SUPPLY OPERATION

The failure of Mardan-SCARP to institutionalise new water scheduling and delivery procedures within the ID, meant that the latter had, at the time of commissioning, little choice than to resort to the old practices and procedures of operation. This situation is illustrated *in extremis* by the fact that the ID still uses the 1930s gauge register format to administer the water distribution in LSC. The problems surrounding the implementation of the water management pilot scheme had prevented the conversion of any of the water scheduling and delivery ideas and options as vented in the O&M manual into concrete procedures and methods. The office of water dispatcher was never created, nor was any information system set up to collect and process any data and information on discharges and water requirements. The required discharge calibration curves of the new control structures and canal head-gauges were not even available at the time of commissioning. In short, none of the water management procedures of the ID had been adapted at the time of commissioning to the new water control options of the LSC.

Reinstating FSL Operations at the Main System Level

Resuming full responsibility for operation and maintenance of the LSC, the ID reverted to the 'normal' practice of Full Supply Delivery (FSD). As it was anyway unable to control discharges in the absence of updated calibration curves, the practice of monitoring and managing head and tail water levels was resumed, thus making use of the same paper register formats as used prior to Mardan-SCARP. With no means and procedures available to assess the water requirements and match supply accordingly, the water distribution had to be supply driven. Applying the old operational procedures for the main system level, the water distribution at the secondary level had to be managed accordingly. The ID imposed the old water distribution procedures by setting all the outlet gates, both of Metergate Outlets as of the gated flumes, in fixed positions and only regulated the inflow into the head of the distributary canals. In short, the ID resorted to operate the remodelled LSC as before, be it on a higher level of water supply.

Water delivery at the main system was thus resumed as before the project, with the aim of delivering a stable delivery around FSL. When comparing the water levels at main system level for the years 1975, 1985 and 1995 (*cf.* fig. 5.1) no significant differences in operation can be discerned; FSL operation is aimed at throughout the year, while the regulation of water delivery is primarily governed by reacting to rainfall and a general reduction of supply towards the end of the irrigation season. The operational target remained thus to run the system at or near full capacity whenever the river flows at Munda permit, with three exceptions to the rule:

- In times of rainfall the ID has to react by closing down or drastically reducing supply in order to protect their canals and avoid overtopping;

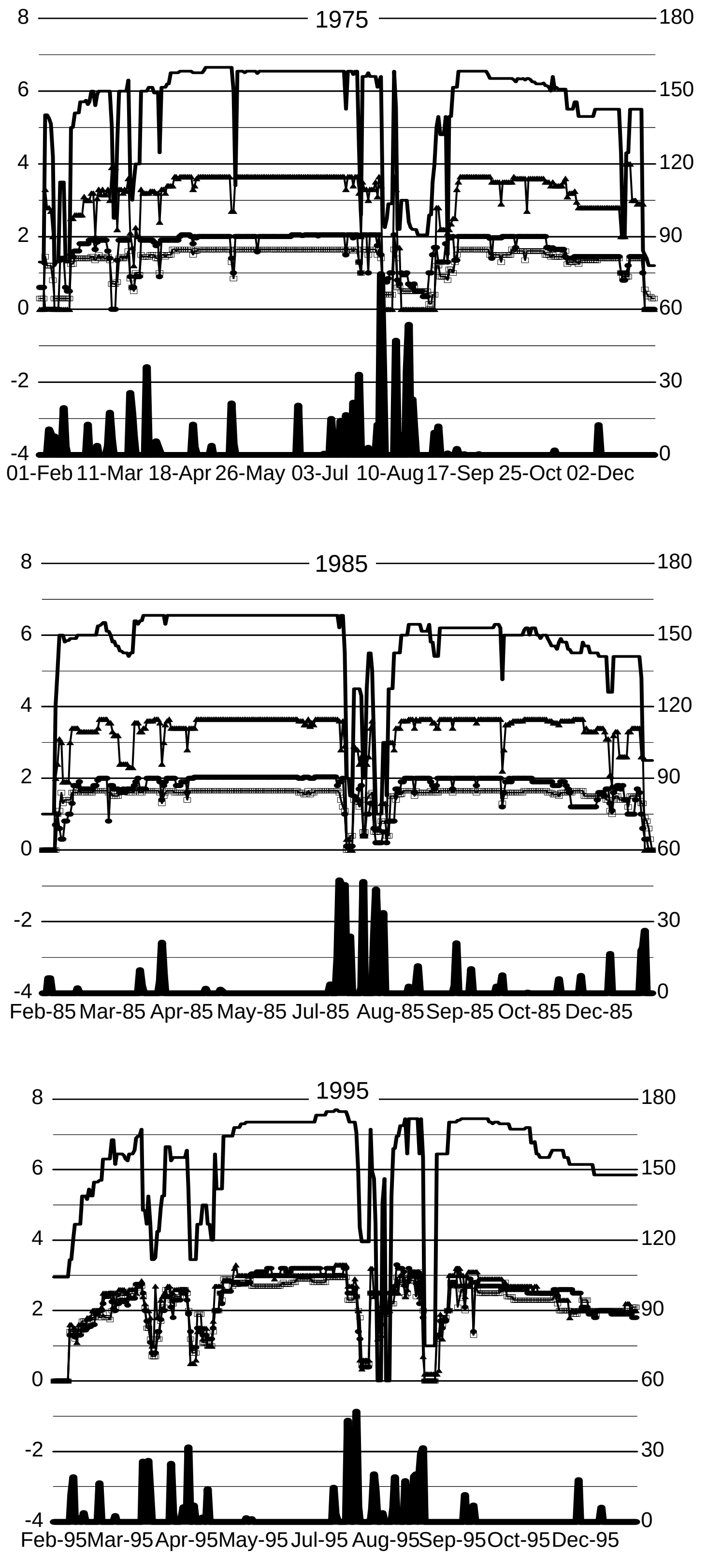
- At the end of the irrigation season the water requirements become very low due to very low evapotranspiration, permitting lower levels of supply that coincide with declining river discharges;

- In times of water shortages when FSL can no longer be sustained, a rotation schedule at main system may be applied.

The first two occur annually, while the third occurs occasionally at the start of the irrigation season. Even in the latter occasion, which occurred in March 1997, the ID resorted simply to the old operational rules and procedures, by implementing the rotational schedule among the Charsadda and Mardan divisions of LSC. This amounts to an eight day rotation schedule, permitting thus the completion of one seven day *Warabandi* schedule, in which the water supply is rotated between Charsadda (distributaries 1 till 6) and Mardan division (distributaries 7 till 9).

Fig. 5.1: FSL Operations in LSC Main Canal

Head Gauge Readings [ft], Rain [mm] (right-hand scale)



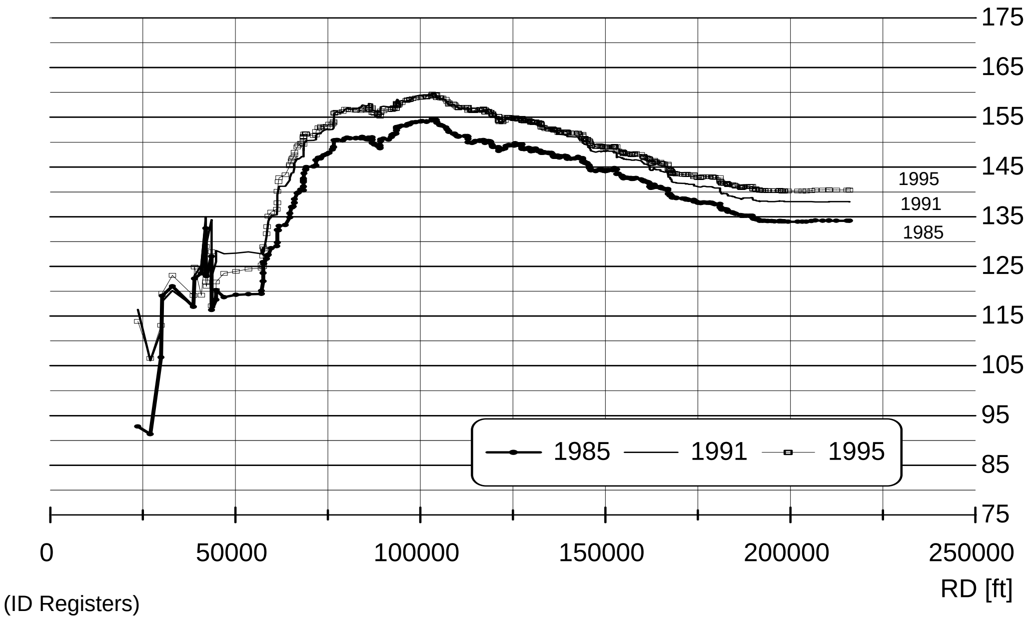
Although at the time of commissioning the ID had thus little choice than to resort to its old supply driven water delivery method of minimum interference and regulation, the favourable conditions provided by Mardan-SCARP of adequate drainage facilities and generous water supply levels also made this a viable option. Even though the full capacity of the system was nearly doubled by the project, the river Swat in general supplies enough to enable a full supply delivery, while the newly installed drainage facilities effectively dispose of any excess water that might reach the command area.

General Impact of Increased Supply and Drainage

The increased delivery capacity and newly constructed drainage facilities greatly improved the irrigation conditions at the tertiary level. Two of the major production constraints that prevailed prior to Mardan-SCARP – i.e. those of water shortage and water logging – were thus effectively eliminated after commissioning. Both improvements could be expected to have a positive impact on the agricultural production within LSC.

Based on the official statistics of the ID, a slight, but significant, increase in cropping intensities can indeed be discerned. Figure 5.2 presents the cumulative cropping intensities set against the relative distance from the intake at Munda, for the years 1985, 1991 and 1995. These years represent three stages of the project: 1985 prior to the improvements; 1991 when nearly all the drainage works were completed, but work on increasing the delivery capacity had not yet begun; and 1995 the second year after commissioning. In the first instance, primarily the drainage seems to have had an impact on increasing cropping intensities by reclaiming water logged areas of the command area that were previously left out of production. The impact of these has been variable over the system, leading to larger increases in cropping intensities in those areas that were the most affected by water logging. By contrast, the impact of the increased

Fig. 5.2: Cumulative Cropping Intensities in Lower Swat Canal (Except Kalpani)



delivery capacity would seem rather small, restricted to a mere 2 - 3 percent increase in overall cropping intensity towards the tail of the system. However, as with that of the drainage works, the impact of increased delivery capacity varies per distributary canal, over a range from no significant change to an increase up to 10 percent; the latter mainly occurring at the tail-end areas of the system. The combined impact of both improvements, though positive, does not seem to eradicate the traditional head-tail differences, leaving the tail-end areas lagging behind about 30 percent in cropping intensity.

Taken overall, the impact of Mardan-SCARP on the productivity in LSC would thus seem a little disappointing with regard to the scale of improvements undertaken. However, the scope for increases in cropping intensities was limited in the first place, as expressed in the initial project objective to raise the cropping intensity for LSC from 175 to180 percent (*cf.* note 66). Moreover the above figures represent the performance realised according to the official ID statistics, which tend to undervalue the realised productivity by about 20 percent, as is confirmed by the data collected in the field and presented in table 5.1 below. This also explains the relatively low impact of the increase in delivery capacity; with true cropping intensities as high as 180 percent there is little scope left for further intensification, particularly when mainly perennial crops are grown.

Table 5.1: Cropping Intensities in LSC after Mardan-SCARP (at selected watercourses)

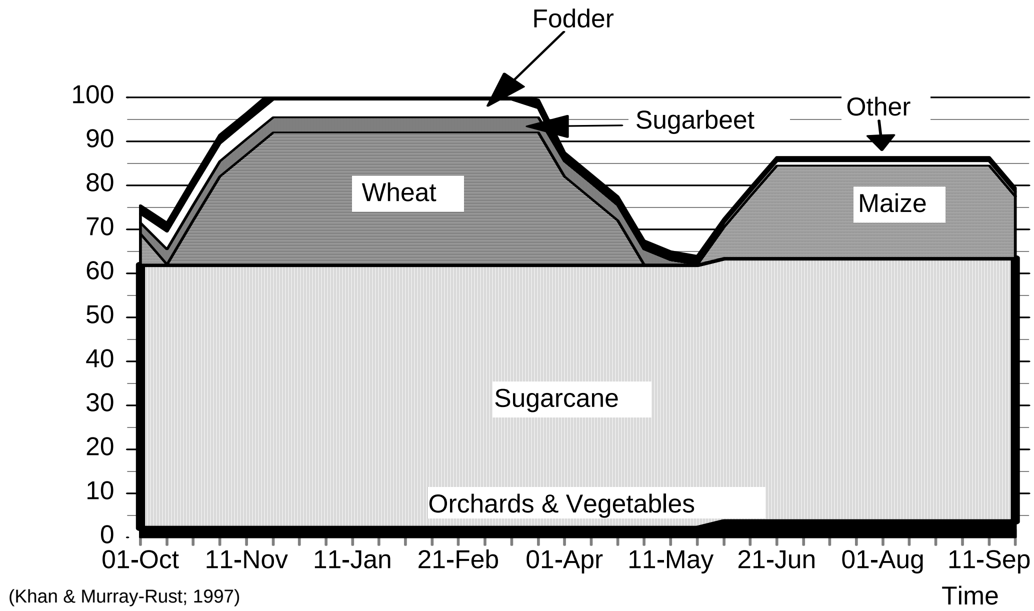
Location	Sample Size	Kharif Season	Rabi Season	Annual
Head	30	94	88	182
Middle	30	93	96	189
Tail	30	62	88	150
Overall	90	85	93	178

(Source: Khan *et al*; 1997)

In order to assess the impact of the Mardan-SCARP improvements on the irrigation performance in LSC, one thus has to take into consideration the cropping pattern. Here the changes effectuated after commissioning of the system have been much more profound, exceeding the assumptions made during design. Although the delivery capacity for LSC was determined on the assumption that water users would continue to grow a variety of crops (i.e. sugarcane, maize and wheat, *cf.* fig. 4.4), in reality farmers were quick to exploit the improved irrigation conditions to their maximum benefit. In the case of LSC this meant a huge increase in the area cultivated with sugarcane, as is shown in fig. 5.3. Stimulated by favourable economic conditions – in which the input requirements and costs for sugarcane are relatively low, while the marketing conditions for the produce are good, either through sugar refineries in the area or through home processing of *Gur* for the local and Afghan markets – the area cropped under sugarcane quickly rose to an average of 60 percent of the command area (*cf.* fig. 5.3). That the actual are cropped with the high water demanding cash crop sugarcane exceeded the design assumptions by 100 percent, thus accounts for how farmers responded to the extra water made available through Mardan-SCARP.

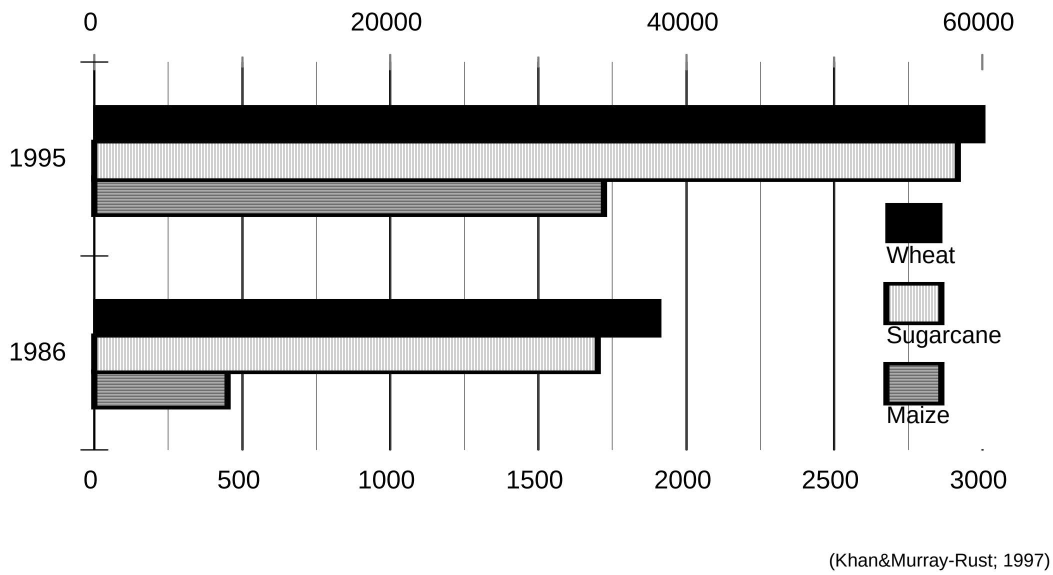
By removing the constraints of water shortage and water logging, the production conditions

Fig. 5.3: 1995 Average Cropping Pattern in Lower Swat Canal [% CCA]



were also improved to allow for a substantial increase in yields; which was after all one of the main objectives of Mardan-SCARP and the prime reason behind introducing demand-based irrigation. Although the yields of the three main crops may still fall considerably short of the potential maxima, there has been a clear impact in LSC, raising the established yields per hectare of maize, sugarcane and wheat in 1995 to 386 , 172 and 161 percent respectively of those established in 1986 (*cf.* fig. 5.4).

Fig. 5.4: Crop Yields Before & After Mardan-SCARP (sugarcane top-scale) [kg/ha]



The newly established increases in water delivery throughout the LSC system have also had a marked impact on the conjunctive use of groundwater in irrigation by means of tubewells. Before Mardan-SCARP both public as private tubewells were widely used for the dual purpose of augmenting irrigation water supply and combating the effects of waterlogging. After completion of Mardan-SCARP both constraints on irrigation were basically eliminated by the increases in water supply and the construction of an effective drainage network. As a consequence, expensive groundwater is hardly used anymore within the command area of LSC and the tubewells are no longer used, or even dismantled altogether.

5.3 THE DELIVERY OF ABUNDANCE AND CONTROL OF EXCESS

Although seemingly no drastic changes were effected after commissioning by the ID in the water control and delivery procedures for the main system, one would expect the mere increase in water availability to affect the water management strategies and practices at the secondary and tertiary level by creating a hitherto unknown level of flexibility in the regulation of water demand and supply. The room for manoeuvre thus created by the relative abundance of water supply was in effect further enhanced as a consequence of operating the system at design capacity rather than at the assumed crop-demand capacity. By building in this extra demand delivery capacity of 1.34 l/s/ha (19 cusecs per 1000 acres) at the secondary and tertiary levels of the canal system, the realised high RWS at secondary level came as a predictable consequence of implementation under the given management procedures. In order to gauge the effects of these changes in the dynamics of water management, and gain insight in the changes that have been effected in the field, the water management practices at Sheikh Yousaf Minor (SYM) were monitored for 24 months, and are presented below.

Sheikh Yousaf Minor

Sheikh Yousaf Minor is a typical medium sized minor of LSC, situated at three quarters along the system, taking off from distributary No 8 as the third minor (*cf.* fig. 4.2). With it length of 5,781 m (1867 ft) it supplies a Cultural Command Area of 856 ha (2140 acres), divided over 11 tertiary units. Of these 11 units, 9 units are supplied with water through the Metergate barrel outlet fitted with the ID enclosed gate structure, while the two tail-end units are served by a traditional tail-structure comprising of two Open Flumes. The fact that all upstream outlets are uniformly fitted with the Metergate structure according to the Mardan-SCARP design, is a consequence of the short lived intention of using SYM as a pilot case for the Crop-Based Irrigation Operations (CBIO) project (*cf.* Chapter Six).[86] SYM contains one other feature thanks

[86] After the initial experiences with the Metergate outlets in distributary No 3, the ID tried to convince the project team and donors to install gated flumes of their own design. For the CBIO project it was agreed, however, that the original Metergate outlets would be installed, be it with the ID gate, while in the remaining distributaries and minors, the installation of outlets was slowed down or suspended. As a consequence, one can still find a diversity of outlet structures in many of the other distributary canals, comprising of Metergates, gated flumes (continued...)

to this short lived intention, namely an escape structure at its tail through which the supply can be drained off into the surface drainage network.[87] As the command area of SYM had been classified as water logged, the whole command area was fitted out with a sub-surface drainage network in the second phase of the drainage works, disposing off its effluent water into the remodelled Narai and Kandar surface drains. The total command area of SYM is served by 18 drainage units, that were drawn on hydrological boundaries that do not coincide with tertiary unit boundaries of the water supply system. The CCA of the tertiary units varies from 17 ha (43 acres) to 157 ha (393), which is a common variation in the old systems of NWFP.

Although SYM benefited to some extent from being targeted for the CBIO project, this has had only small consequences for its infrastructure. Since the CBIO was in fact never implemented in LSC, SYM did not benefit in other potential areas, such as being fitted out with calibrated measuring structures/devices or the organisation of operational management. Like the rest of LSC, there are no formal WUA present among the tertiary units, and it is operated like the other canals by the normal ID staff. At the field level, SYM is operated by one gate keeper, a *Malik* and four *Patwaris*, and falls under the jurisdiction of the SDO of the Mardan division.

Water Delivery & Distribution at the Minor

Due to its medium sized command area, the design capacity of 906 l/s (32 cusecs) for SYM far exceeds the assumed water requirements of the design cropping pattern on which the capacity of the main system was determined (*cf.* fig. 4.9). However, since the ID opted to operate the LSC according to the old strategies by fixing the outlet gates in place and operating the canals around their FSQ, one would expect the deliveries to SYM to substantially exceed its delivery targets as defined by the O&M manual, as long as the main system would be able to provide enough water. On a first sight, this seems indeed to have been the case in SYM. Figure 5.5 presentsthe water deliveries at the head of SYM for July 1995 to August 1997, averaged out for the 10 day delivery periods.[88] Compared with the O&M manual delivery targets for SYM, based on the designed cropping pattern, it is clear that substantially more water is being delivered to SYM, making use of the extra demand-based capacity of 906 l/s (32 cusecs). However, when the O&M delivery targets are replaced by the actual crop water requirements – by substituting the designed cropping pattern with the average cropping pattern found in the field (*cf.* fig. 5.3) – a rather different picture emerges. The actual water deliveries then fulfil quite well the actual crop water requirements at the level of the minor, suggesting that the actual water deliveries comply with

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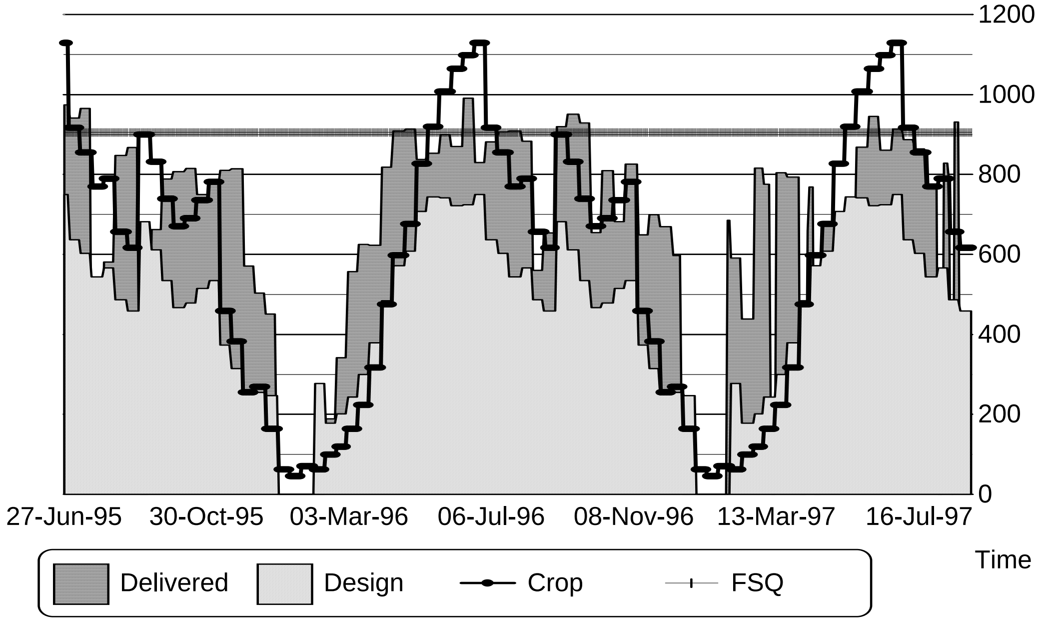
(...continued)
and even original old outlet structures in some cases. However, since 1997 the ID has resumed the installation of the original Metergate outlets with ID gates, gradually thus replacing the original old outlet structures.

87 Although the original design of Mardan-SCARP foresaw the implementation of escape structures at all the distributary canals, this has not been carried out consistently during implementation. As a consequence of which only a small minority of the canals actually do possess an escape structure.

88 The actual deliveries at the head of SYM are derived from own daily measurements of the head gauge, and calibration thereof on a range of discharge measurements taken during the research period. The design delivery targets are derived from the O&M manual, while the actual crop delivery targets are computed by substituting the assumed design cropping pattern with the actual average cropping pattern and applying the water demand calculations set forth in the O&M manual.

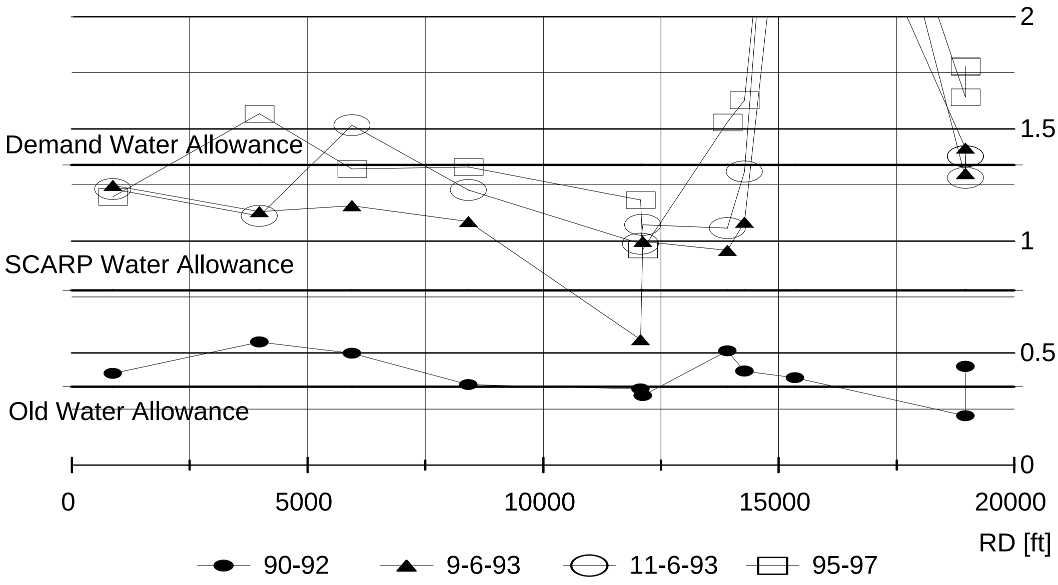
Fig. 5.5: Water Delivery at Sheikh Yousaf Minor Head July 1995 - Aug. 1996
(10-day periods) [l/s]



crop-based irrigation operations. The two exceptions where the actual deliveries exceed or fall short of the requirements are furthermore perfectly justifiable: (i) the relative water shortages occurring during the *Kharif* season are consistent with the design assumption that the demand-based water allowance of 1.34 l/s (19 cusecs per 1000 acres) would yield a 10 - 20 percent water shortage in the case of 'excessive' cultivation of sugarcane; (ii) the relative excess of water during the end and start of the irrigation season when the crop water requirements tends to be low, is explained by an adherence to the operational requirements of regime maintenance that stipulates that canals should not be run for extended periods below 75 percent of their full capacity.

When regarding the distribution among the outlets, the above picture is further strengthened, confirming the strategy of the ID to operate the system on the full or 'demand-based' capacity, rather than the lower intended system capacity for the assumed cropping pattern. Figure 5.6 presents the water delivery rates to the outlets of SYM when the minor is running at or near its design capacity. The first thing the figure makes clear, is that Mardan-SCARP has realised enormous benefits for the water users by nearly trebling the water delivery to the tertiary units. The fact that all the outlets are provided with a delivery rate that lies near the 'demand-allowance' of 1.34 l/s (19 cuesecs/1000 acres) rather than the system's 'SCARP-allowance' of 0.78 l/s (11 cusecs/1000 acres) is a natural consequence of the ID strategy to fix all the outlet gates in place. After commissioning of the canal, the ID opted to fix the outlet gates into place, and by doing so, opted to fix them according to the traditional rules: i.e. at full supply capacity. In the case of SYM, this meant that once the Metergate outlets were installed according to the design criteria, the full supply capacity of each outlet would be determined by the size of the pre-fabricated barrel and/or the full capacity of the water course (whichever is the limiting factor). The fixing of the gate to its maximum opening then determines the maximum flow that can be

Fig. 5.6: FSL Delivery Rates at Sheikh Yousaf Minor Outlets
Befor & After Mardan-SCARP [l/s/ha]



(WMED; 1992, IIMI; 1993,

supplied without the risk of overtopping.

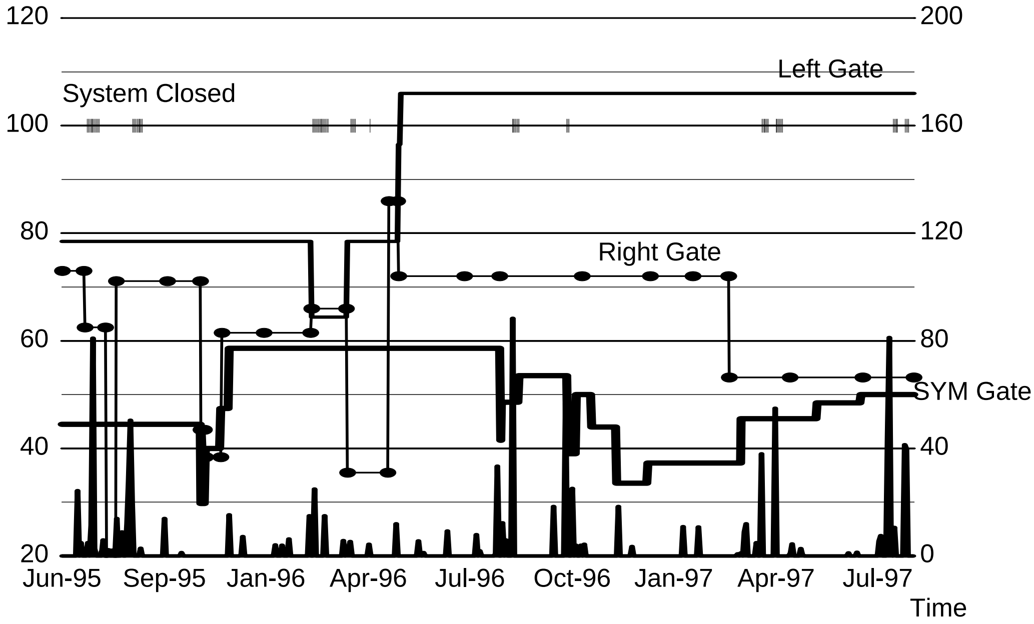
The diversity of water delivery rates among the SYM outlets can then be explained as a consequence of two factors: (i) those tertiary units that have a CCA larger than 80 ha (i.e. outlets 4, 5, 6 and tail right) are supposed to have per design a lower demand water allowance that ranges between 0.78 and 1.34 l/s/ha, depending on the size of their CCA; (ii) apart from the carrying capacity of the water courses, the delivery rate is determined by the size of the pre-fabricated barrel of the outlet, which can lead to 'misfits' between the actual size and the required design capacity. Table 5.2 lists the design capacities, actual size of the installed barrels and the actual delivery capacity for the outlets of SYM. From these data, it becomes clear that outlets 5 and 6, although receiving close to their demand water allowances, are receiving slightly less because of a relatively small barrel size, while for outlet 2 the opposite is the case and receives a bit more than it should. Outlet 9 is an exceptional case, that has a far too large barrel size, permitting it to withdraw much more water than it should. Outlet 1 is cut a little relatively to its design capacity, which can only be explained by either a too low gate setting, or a limited capacity of the water course. Both tail-end outlets receive generous delivery rates through their 'custom-made' open flumes, indicating that they are slightly over-dimensioned or that the tail water level in the minor is actually slightly higher than anticipated or that the outlets have been set slightly too low.

Table 5.2: Sheikh Yousaf Minor Outlet Design Capacity and Barrel Sizes

Outlet No.	Reduced Distance from Head [ft]	CCA [ha]	Design Capacity [l/s]	Installed Barrel Size (diameter) [inches]	Actual Delivery Capacity [l/s]
1	880	68	91	18	81
2	3981	44	59	12	69
3	5950	56	75	18	74
4	8418	157	193	24	209
5	12075	98	128	18	116
6	12125	134	168	18	129
7	13920	49	66	18	75
8	14280	35	47	12	57
9	15358	17	23	18	66
Tail Left	18967	53	71	na	87
Tail Right	18967	145	180	na	258

By fixing the outlet gates into place, the ID opted to operate the newly remodelled LSC system as a supply-based system – be it on demand-based water levels – in which the water supply is regulated at the main system level and in which farmers are forced to react to the received supply in their water management activities. Although Mardan-SCARP increased the potential for flow regulation manifold, by adding numerous control structures throughout the system, the ID clearly remained to concentrate its water control activities on the traditional points of the system; i.e. the intake structure and the head regulators of the distributary and minor canals. Figure 5.7 presents the gate movements at the cross-regulator in distributary No. 8 and the head-gate of SYM for the 24 months measurement period. It is clear that the radial gates of the cross-regulator in distributary No. 8 were hardly used for active water control, particularly since the left-bank gate never touched the water surface (except for a very brief and insignificant period in February 1996) and therefore never produced a water control effect. Over the 24 month period, the left hand gate was operated a mere three times (even though to no avail), while the right-bank gate was operated eleven times. Of the latter one, ten of the eleven operations were concentrated in the first 11 months of the measurement period. The head-regulator of SYM (a traditional control point) was operated slightly more with 15 gate movements in 24 months. Overall, the operation strategy of the ID is to set the right-bank radial gate at a steady depth with which it can feasiblely operate the flow variations up-stream of the control structure. Operations of the gate are limited to react to too low water levels in distributary No 8 that threaten the supply of SYM with its share of water. In contrast, the operation of the head-regulator of SYM follows the seasonal distribution pattern, in which the water supply is cut during the cold *Rabi* season and increased to FSQ during the hot *Kharif* season. The control of damage due to excessive rainfall which brings the risks of overtopping and bank erosion continued to be managed traditionally by

Fig. 5.7: Gate Operations at Sheikh Yousaf Minor & Distributary # 8
July 1995 - Aug. 1997, Rainfall [mm] (right-hand scale), Gate Opening [cm], System Closure

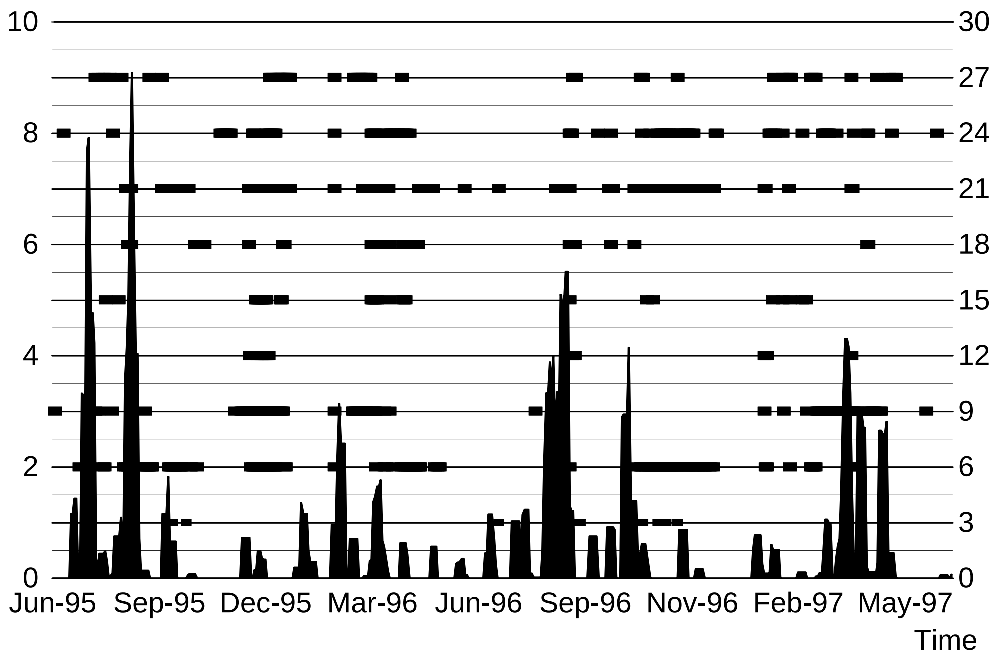


closing down the system at the intake; this was implemented eleven times over the measurement period.

Control of Excess: Water Users' Interventions in the Minor

Not withstanding the seasonal and damage control flow regulation to SYM, the supply based character of the water supply and the relative high water delivery rates to the tertiary units tend to result in a relative abundance of water at the head of the tertiary units. Water users would have to react to this in order to avoid damage to, or suffocation of, their crops (*cf.* next section). The traditional concern of trying to acquire additional water to supplement the scarce water supply has been effectively turned around in LSC into a concern of having to manage excess water without causing damage to crop or infrastructure. Although the rules regarding the management of secondary canal water have not been changed, the water users of SYM defy them on a regular basis in order to take effective control of the excess water they are supplied with. An effective and straight forward measure to do so, and which has been much applied in SYM is to refuse water supply by partially or completely closing down the outlet. Figure 5.8 clearly shows that refusal of water at the outlet has been a much applied water strategy in SYM over the measurement period for the first nine tertiary units that are served by a Metergate outlet. Although there is a considerable variation in the frequency with which this strategy is applied by water users of the different tertiary units (*cf.* table 5.3), it is an effective water control option that has been applied at all nine Metergate outlets. The fact that at some outlets this strategy is applied less often has to do with that some of them are less water abundant (i.e. No. 1, 5 and 6), and/or that the water users find it more convenient to apply an alternative strategy; namely that

Fig. 5.8: Water Refusal at Sheikh Yousaf Minor Outlets July 1995 - Aug. 1997
Days outlets were completely or partially closed;(outlet number [-]) Rain [mm] (right-hand)



of directing the received water flow entirely or partially into a surface drain (*cf.* next section). Since the gate structures of the outlets have been fixed in place by the ID, water users in SYM regulate the water refusal at the outlet by traditional means by partially or completely obstructing the flow through the outlet barrel by silt, bags, twigs and stones.[89]

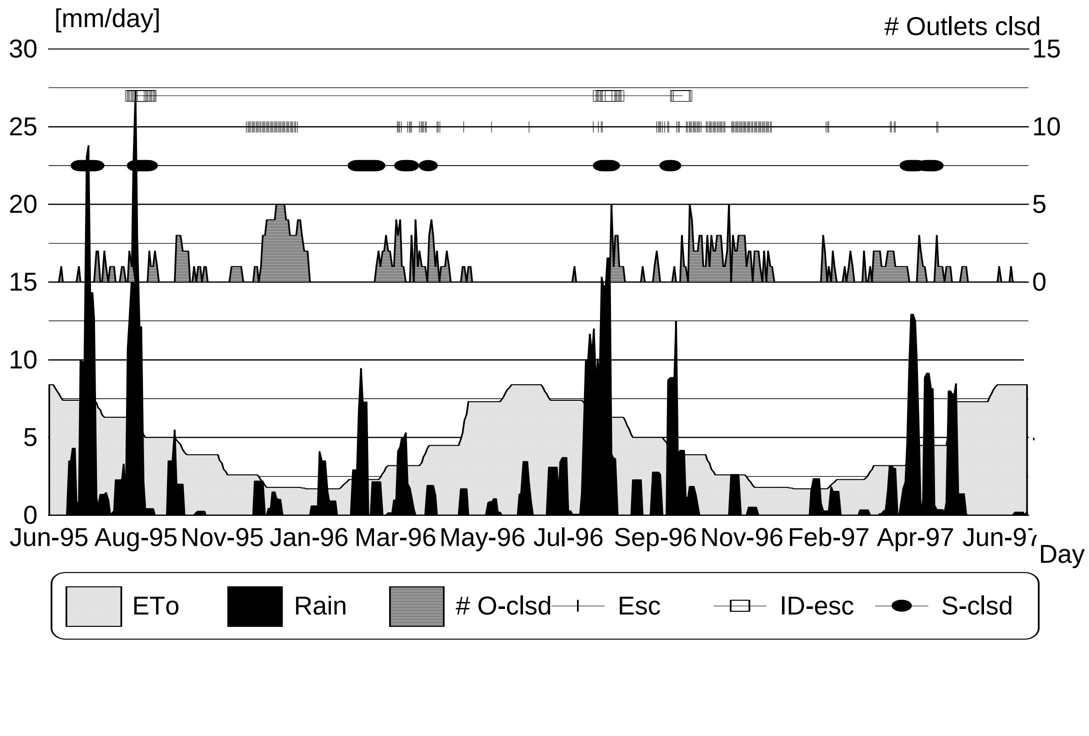
Under the traditional circumstances of 'protective' irrigation such frequent refusal of water at the outlet through interference of water users would inevitably and quickly lead to problems of overtopping and flooding at the tail-end of distributary canals, rendering this an unfeasible water management option – as is still largely the case in the Punjab (*cf.* Wahaj, 2001). In the case of SYM, however, this has become a feasible water management option after Mardan-SCARP, thanks to the availability of adequate drainage facilities at the tail of the canal that permit the effective disposal of excess water into the surface drainage network. Although this includes a *pucca* escape structure equipped with an undershot sliding gate, placed on the right-bank of the canal just up-stream of the tail-end structure, this facility is not used on a regular basis for the regulation of excess water. Over the 24 months measurement period this structure was only used three times (*cf.* figure 5.9) to dispose of the excess water reaching the tail. This is largely a

[89] Water refusal at the outlets was recorded on a daily basis during the measurement period. For each outlet the state of flow was recorded, in which total refusal was easily detectible. The occurrences of partial closure in order to cut the rate through the outlet, have been determined through an analysis of the recorded up- and down-stream water levels for each outlet. To determine the days of partial closure a line was fitted by eye through the main concentration of readings. All readings for down-stream water levels that are less than 75 percent value of the line are then identified and treated as instances of partial closure. While this method is not foolproof, the results are fully consistent with observed water users' behaviour: the days of partial closure are all associated with periods of high rainfall or of reduced evapotranspiration.

consequence of the failure of the ID to take operational control of this structure. As this is a formal gated structure, the operation of the escape falls formally under the operational responsibility of the ID. But, since the presence of operational staff along the canal is kept to an absolute minimum according to the supply-driven operation strategy, the ID has not been able to provide an adequate and timely operation of this structure. Consequently, the escape structure has become a crude regulation device that can, and is, operated by water users, but can only be opened completely by taking out the entire gate structure (including the gate casing). The use of the escape structure is thus limited to a binary regulation of open/closed, that limits its usefulness to those instances of total water refusal. During the measurement period, the use was thus limited to three instances when more than 100 mm of rain fall in the area and none of the water users were thus in need of any irrigation water. The escape structure is operated by water users around the tail-end area of the canal, who can respond immediately in instances of intense rainfall and numerous outlet closures (i.e. 5 and more), to avoid any damage due to overtopping. Generally they were quick to respond in such occasions, in which their actions tended to take effect one or two days before the system was shut down at the intake by the ID.

To increase the drainage opportunities at the tail of SYM, the water users of outlet No. 11 (tail-right) have ‘constructed’ a *kacha* escape structure by cutting the right-bank masonry wall of their water course, just down-stream of their open flume. This structure permits them to dispose off a substantial part of their water flow into the surface drain through a purpose-dug earthen canal that runs back under the Charsadda-Mardan road, linking up to the surface drain. This *kacha* escape permits them to adequately control the excess water reaching them, in a less cumbersome and more accurate manner than the *pucca* escape of the ID. By regulating the size of the escape opening with silt, bags and stones, they are able to adjust the drainage flow to adequate and desirable rates. As is depicted in fig. 5.9 this *kacha* escape is frequently utilized

Fig. 5.9: Water Refusal at Sheikh Yousaf Minor v Water Requirements
July 1995 - Aug. 1997; # of Outlets closed (right-hand scale) and
days escapes are open & system is closed



by the water users of tail-right. The figure also makes it immediately clear that the *kacha* escape is used in response to outlet closures upstream the minor that cause an increase in excess water at tail-right in times of intensive rainfall or low evapotranspiraton, and for themselves acts as an effective method of 'closing' down their own outlet.

Table 5.3: Frequency of Operational Management Activities at Sheikh Yousaf Minor, July 1995 - August 1997

Location	Frequency of Operation	Official Operator	Actual Operator	Remarks
Main Canal	11 [times]	ID	ID	Closure of main system after more than 70 mm of rainfall in one week
Cross-Regulator in Disty No. 8	Left: 3 (times) Right: 11 (times)	ID	ID	Mostly in response to low water levels
Head Gate SYM	15 (times)	ID	ID	To adjust water level in SYM to seasonal supply level
Outlets	(Days closed)	ID	Water Users	Outlets are closed or partially closed in response to rainfall or low evapotranspiration.
No. 1	19			
No. 2	135			
No. 3	100			
No. 4	14			
No. 5	31			
No. 6	21			
No. 7	109			
No. 8	94			
No. 9	61			
Pucca Escape	3 (times)	ID	Water Users	After very intense rainfall (>100 mm/week)
Kacha Escape	141 (days open)	None	Water Users	To control tail, and adjust flow for No. 11

5.4 WATER USE & REFUSAL[90] [91]

As has become clear from the analysis of Sheikh Yousaf Minor, the water management conditions have been significantly changed at the tertiary level. The realised turnabout in water availability at tertiary unit has, on the one hand, significantly increased the opportunities for water management by eliminating the stringent constraints of water scarcity, allowing a more

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90 The sections 5.4 and 5.5 are largely based on the paper: *Managing Excess Water: Drainage Strategies in Sheikh Yousaf Minor, Lower Swat Canal*, (Halsema, van 1997).

91 I want to thank Ronald Loeve for the collection of the discharge data within the tertiary units and the cropping data, which he collected as part of his MSc work and of which I make ample use of in this section. Many thanks are also due to WAPDA, who rehabilitated the groundwater observation wells and took the water table measurements.

flexible use of the irrigation water. On the other hand, it has brought a new set of constraints that need to be taken care of in order to avoid damage to cultivation and infrastructure. The water users of SYM were quick to take stock of these new conditions and adapt their water management practices and application of the *Warabandi* accordingly. The two predominant factors, allowing more flexible arrangements for water use and managing excess water, have been incorporated into the daily water management practices in such a manner that the management of irrigation and drainage water have become fully integrated at the tertiary level.

5.4.1 The Rate of Excess and its Temporal Variability

Managing excess water forms an integral part of water management activities in irrigation systems along with water acquisition, allocation and distribution activities and it merits special attention due to its intrinsic characteristics. For example, when excess water becomes a matter of drainage, it requires specific infrastructure that will enable the diversion of excess water outside the hydrological sub-unit of the irrigated area to avoid future waterlogging and salinity problems. The type of infrastructure and in particular the drainage opportunities it enables, will affect the type of water management activities and organisational requirements that prevail in any given unit.

The management of excess water is also heavily influenced by the rate of excess accumulation. In the 'classical' approach to drainage, the management of excess water is correlated in time with seasonal activities; drainage is then treated as a 'response' water management activity, eliminating temporary excesses of water primarily caused by rain. However, when the management of excess water is viewed in the context of other water management activities, an additional relationship becomes evident. The temporal change in the rate of excess accumulation of water is an important factor in shaping a water user's water management strategy for choosing between water acquisition, water distribution, drainage, and water refusal.

Field observations reveal that the transition from water distribution activities to drainage activities is not abrupt, but gradual. Whenever feasible, the first amount of excess water is used to increase flexibility in water distribution in the form of higher distribution losses, rather than an immediate shift to drainage. As excess water increases, the amount of distribution losses that pass through the sub-surface and surface drainage facilities also will gradually increase until the main activity becomes drainage instead of water distribution.

It is thus primarily the interaction between water diversion opportunities for distribution and drainage, derived from the physical infrastructure and the rate of excess water accumulation, that determine the character of water management by water users at any given time. Through the assessment of the rate at which excess water is increasing in relation to the available opportunities for water diversion, water users will decide to engage in individual or collective water management activities. Given the temporal character of excess water, it is no surprise that water management practices also change over time.

In order to give a detailed picture of the water management activities at the tertiary level, two of the 18 drainage units of SYM were selected for monitoring. Although the drainage units do not form an organisational unit for water management activities, they were nevertheless chosen as unit for analysis so that a water balance could be made for the period of measurement. The two units selected for monitoring are situated towards the tail of SYM (*cf.* fig. 5.10), and were selected because WAPDA had installed a network of water table wells that were rehabilitated and monitored during the measurement period.

Water Control Facilities at the Tertiary Level

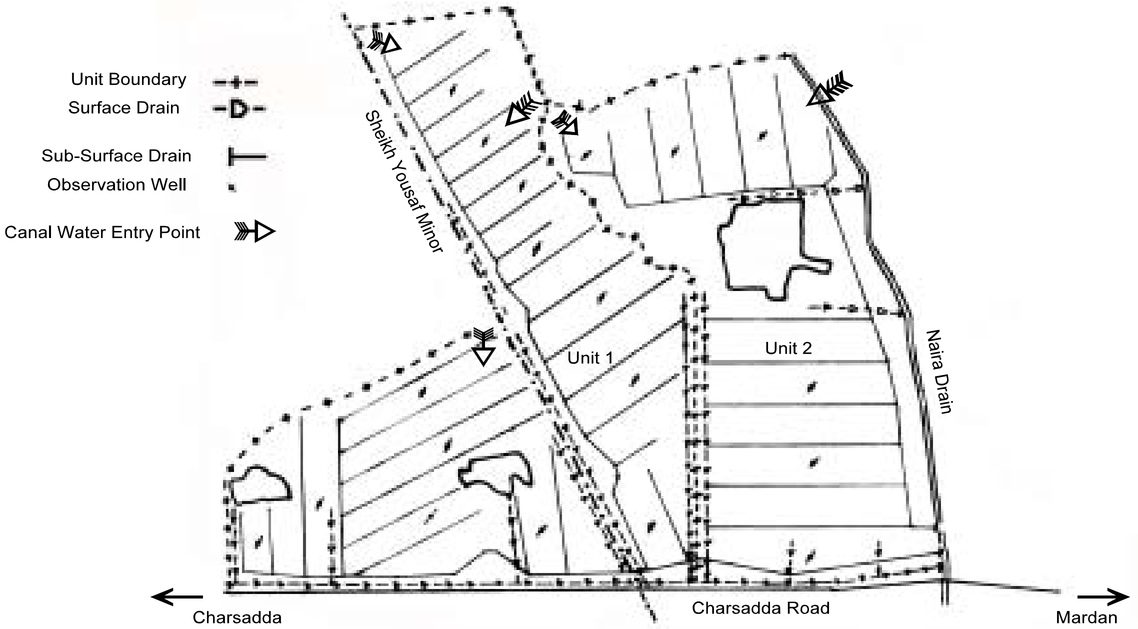
In addition to the sub-surface drains provided by Mardan-SCARP, every tertiary unit also possesses ample facilities for diverting excess water into open secondary drains through the surface drainage network. As each tertiary unit borders an open secondary drain, many parts of the watercourse network have been enhanced so that water can be drained off easily. In some cases there are small canals in which water is collected from different parts of the tertiary unit for disposal at a specific location on its border. Initially it is not always clear which channels are used for water distribution and which are used for drainage. However, field observations indicate that it is not very useful to attempt such a differentiation to these tertiary canals. Much more important is that every tertiary unit possesses a dense network of surface canals that can be used either for irrigation or drainage purposes, and that water can be readily disposed into thesecondary drainage network outside the unit through various points in the network (*cf.* fig. 5.10).

The sub-surface drainage network was designed to maintain the water table at 1.07 m (3.5 ft) below the surface. In order to achieve this target, the depth and spacing of the lateral quaternary drains were determined with a design drainage coefficient of 3.5 mm/day (*cf.* section 4.3.2). This provides water users with an automatic drainage facility that can effectively dispose excess water at a rate up to at least 3 mm/day, allowing them to over-irrigate their crops by the same rate without having to take any specific drainage measures.

The network of tertiary canals provides the water users with ample facilities and possibilities for diverting water anywhere inside the command area for irrigation purposes or outside the command area for drainage purposes. In each of the drainage units studied there are at least four locations in the tertiary canal network where water can be directly diverted into the secondary surface drainage network (*cf.* fig. 5.10). In addition to these ‘exit’ points, there are various locations where excess water can be diverted into an internal tertiary drain that leads to one of the ‘exit’ points. In drainage unit No. 1, for example, there are no less than four locations where either the entire flow of water, or a portion of it, can be diverted into the drain alongside the left bank of SYM. At two of these locations a *pucca nakka*, normally used for farmers’ irrigation inlets along the watercourse[92], has been installed in a lined section of the watercourse in order to facilitate the diversion of excess water into the drain. This adaptation of the *pucca nakka* as a drainage outlet in the watercourse network is frequently encountered in LSC, and it has been the first place were such use has been recorded. In addition to their use for drainage, many tertiary drainage channels can be and are used for delivering irrigation water via a shorter route

[92] The *pucca nakka* consists of a simple pre-fabricated concrete division box with two or more circular diversion wholes that are placed under an angle, and which can be very easily closed with a circular concrete lid. This device has been developed and introduced by OFWMP in the 1970s and has been its most successful product that is widely applied, and can even be purchased commercially at local workshops.

Fig. 5.10: Map of Selected Drainage Units in Sheikh Yousaf Minor



to farmers' fields than through the formal watercourse. An alternative, and frequently applied, management strategy for dealing with excess water is to refuse supply at the outlet, as discussed in the previous section.

Adapting Management Strategies to Relative Water Supply

The Relative Water Supply (RWS) at any given time is an important factor in the assessment of the need for and the nature of management of excess water. To determine the portion of the water supply that can be considered to be in excess, the net crop water requirements were subtracted form the available supply. A value is thereby obtained that can be expressed either as mm/day or l/s/ha, and which can also be expressed as a percentage of the available supply.

The quantum of excess water will always vary in time for three reasons: (i) seasonal and operational variation in water supply – which in this case is determined by the canal operations of the ID and the refusal of water by water users at the outlet ; (ii) variation in net crop water requirements over growing seasons and changes in cropping patterns; (iii) the rainfall. Plotting this rate over a given time frame for different locations will then provide an indication of where, when and to what extent water supply produces a need for integrating drainage with irrigation water management activities.

It is important to note that the rate or amount of excess water is determined against the net crop water requirements. Thus not all of the water expressed in the rate is truly in excess, as some of it is required for distribution and application losses. There is a preference, however, for expressing this rate against net crop water requirements, since the amount of water used to meet distribution and application losses may vary over time and form part of a water user's strategy for coping with excess water.

Assessing Excess Water Supply

Drainage units 1 and 2 are reasonably typical for the area, with representative cropping patterns that are dominated by sugarcane and irrigation supplies well above net crop water requirements for substantial part of the irrigation season. To determine the net crop water requirements a reference cropping pattern was developed comprising the five major crops and a correction factor. The composition of this cropping pattern was based on survey data obtained from the two drainage units and associated watercourse command areas; the data are presented in table 5.4. It proved difficult to assess the cropping pattern during the transition from *Kharif* to *Rabi* season from these data when sugarcane is being gradually harvested and either replaced by a wheat-maize-sugarbeet crop sequence or intercropped with other crops. However, since all crops are dry crops, the Kc values for the four main crop stages are very similar and of comparable value. By supplementing the July cropping pattern of unit 1 with the wheat in the same proportion as maize and adding a correction factor with a Kc value of 0.7 to bridge the gap between maize and wheat, an indicative net crop water requirement is obtained for the whole unit. The overall Kc values for the whole unit (including the non-agricultural area) thereby obtained, varies from 0.7 to 0.9 throughout the year, with its peak in the months of May and June. Actual water requirements were probably slightly lower, especially during *Rabi* when wheat is semi-dormant and during the ripening stages of most crops.[93]

Although unit 2 had a slightly different cropping pattern than unit 1 (i.e. somewhat less sugarcane and more maize), the same ETc values were used. The differences in ETc would be marginal and given the nature of the analysis, caution suggests setting crop water requirements slightly higher rather than too low.

Table 5.4: Cropping Patterns in Drainage Units 1 and 2 of Sheikh Yousaf Minor [%][94]

Crop	Unit 1 July 1996	Unit 2 July 1996	Unit 1 Nov. 1996	Unit 2 Nov. 1996	WC 7-A March ‘97	WC 5 March ‘97
Sugarcane	73.2	63.4	45.5	48.8	53.9	40.0
Wheat	-----	-----	07.1	15.2	25.3	31.9
Orchard	03.2	00.3	03.2	00.3	-----	00.5
Vegetable	01.9	02.6	-----	-----	-----	-----
Maize	10.9	17.7	-----	-----	-----	-----
Fallow	-----	-----	26.4	21.4	01.9	02.0
Other	-----	-----	07.6	01.7	04.0	03.2
Non-Ag	10.4	11.9	10.4	11.9	14.3	21.2

93 The applied ETo has been calculated with the Penmann-Monteith method using climatic data from the Mardan Sugarcane Research Institute, except for the windspeed and sunshine hours which have been taken from the mean climatological data for Peshawar as provided by the FAO.

94 Because November is in the period of transition from *Kharif* to *Rabi*, the cropping pattern data for *Rabi* were corrected with data obtained in March in the command areas of watercourses 5 and 7.

In figs. 5.11 and 5.12 the rate of canal water supply, rainfall and net crop water requirements are given in mm/day for both units 1 and 2 for the period September, 1996 through annual closure in December, 1996. Canal water supply rates are based on daily measurements at all the inflow points, for which a variety of measurement structures were used (Cut-throat and RBC Flumes, V-notch and rectangular weirs). As shown in these figures water was abundant during the period of measurement. Drainage unit 1 (*cf.* fig. 5.11) had a canal water supply that on average was four times the net crop water requirements, while unit 2 (*cf.* figure 5.12) received a less generous supply of just twice net crop water requirements. From the data depicted in these figures, the amount of excess water at any time can be derived by subtracting the net crop water requirements from the total amount of canal water supply plus rainfall. Figure 5.13 presents the amount of excess water for both units throughout the September - December, 1996 measurement period. Excess water is plotted as the average of the seven preceding days to adjust for short term peaks caused by rainfall and variability in canal discharge. As expected from the data shown in figs. 5.11 & 5.12, net excess water for unit 1 was two to three times the amount for unit 2. The sharp peaks of excess water during September and October are caused mainly by the monsoon rains; subsequently the level of supply and thus of excess decline until the end of November. The rise in excess in December results primarily from low net crop water requirements.

Fig. 5.11: Supply - Demand: Drainage Unit 1, Sheikh Yousaf Minor
Sep.-Dec. 1996 (rainfall right-hand scale) [mm/day]

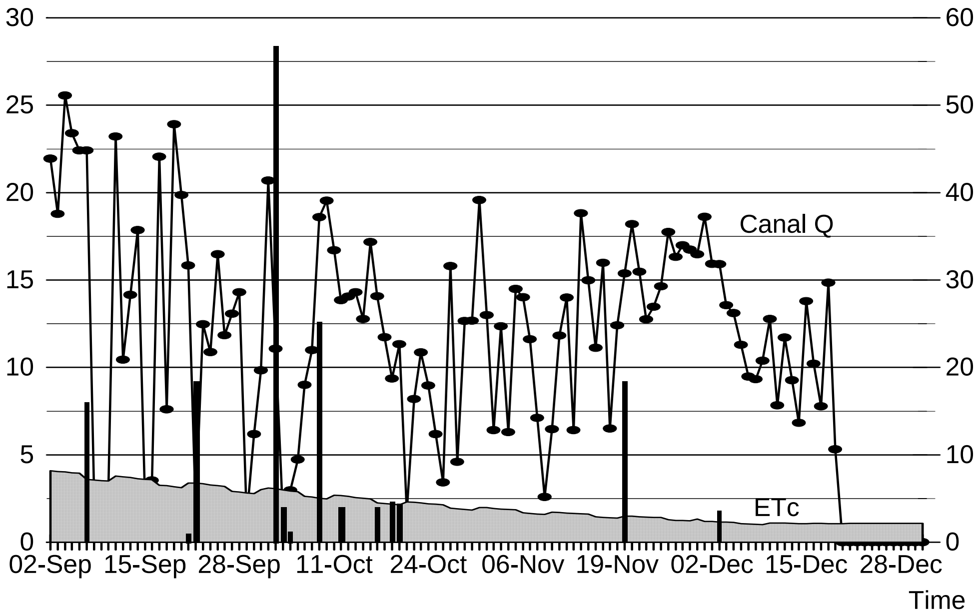


Fig. 5.12: Supply-Demand: Drainage Unit 2, Sheikh Yousaf Minor
Sep. - Dec. 1996 (rainfall right-hand scale) [mm/day]

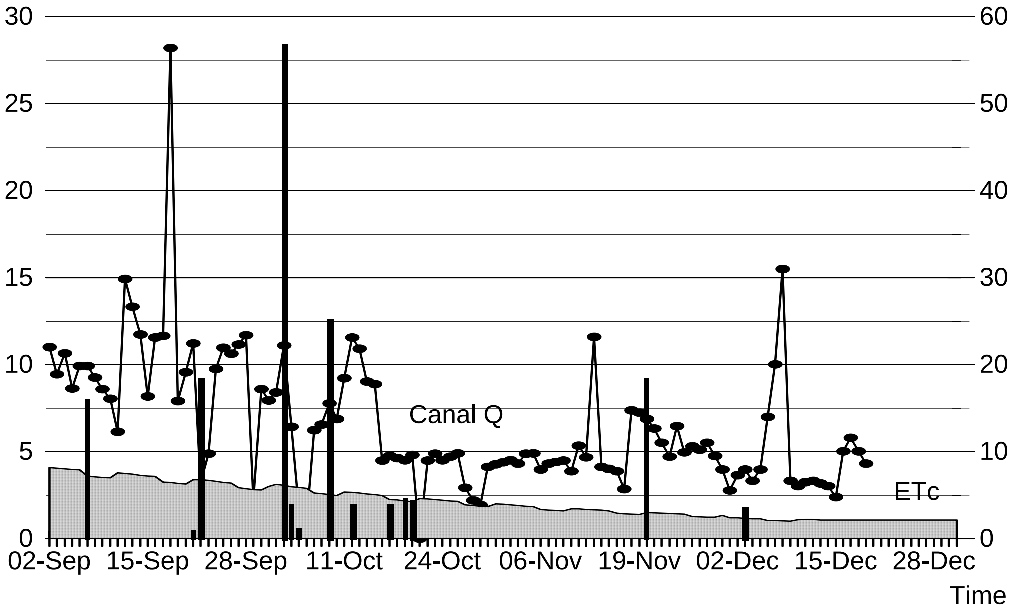
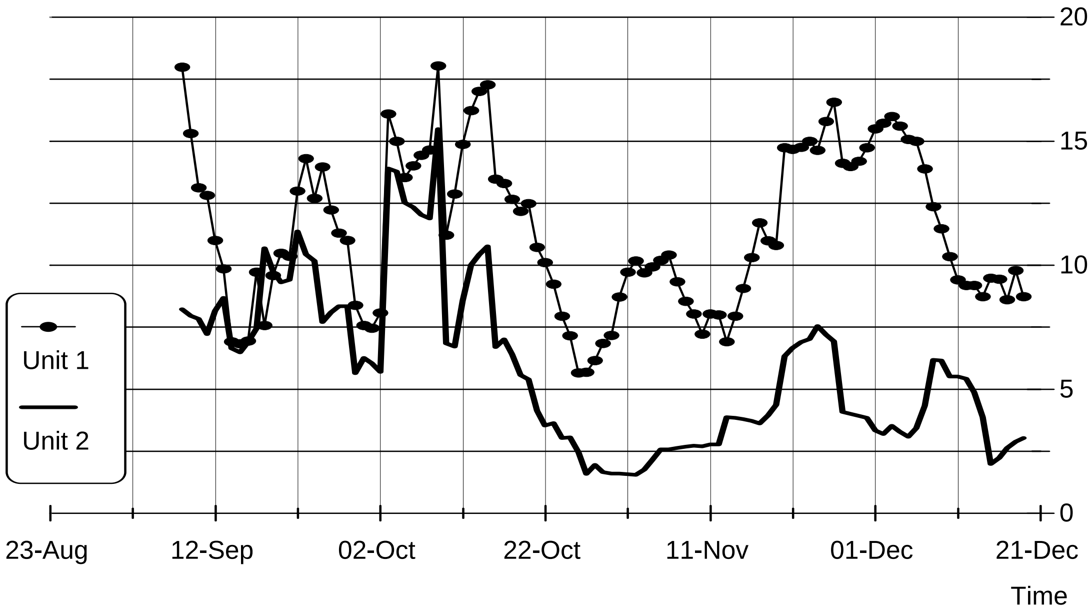


Fig. 5.13: Rate of Excess Water; Drainage Units 1 & 2, Sheikh Yousaf Minor
Sep. - Dec. 1996 (7-day avg.) [mm/day]



5.4.2 When & Where does Excess Water Become Drainage

From the above figures it becomes clear that the water supply in drainage units 1 & 2 were substantially in excess of the net crop water requirements during the end of *Kharif* and into early *Rabi* season. The amount of excess water varied from three to six times the amount needed to meet net crop water requirements. Assuming that water supplies were at least in this range during the hot summer months of May - July (an assumption that is corroborated with the data presented in figs. 5.5 & 5.6), irrigation water supply then also significantly exceeded the net crop water requirements during the summer. Other data appear to confirm this pattern (*cf.* figs. 5.16 and 5.17). In drainage unit 1 the full supply rate ranged between 17 - 20 mm/day (*cf.* fig. 5.11); a quantum well above the net crop water requirements that peaked at about 6 mm/day in late May - June - July, 1996 (*cf.* fig. 5.16). Even in drainage unit 2, about 45 percent of the full supply rate of 11 mm/day (*cf.* figs. 5.12 and 5.17) was in excess of the net crop water requirements for the period May - June - July, 1996. These findings are rather surprising insofar as water users in the study area said that these *Kharif* months continued to be a period of water shortage, no surface drainage occurs, and consequently the *Warabandi* is strictly implemented.

In order to assess the utilization of excess water during the May - July period, is was necessary to look at the performance of the sub-surface drainage system during those months. The average groundwater level below surface and the sub-surface drainage discharge are shown in figs. 5.14 and 5.15 for both drainage units for the entire year of April, 1996 to April, 1997. From these figures it becomes immediately evident that both sub-surface drainage networks were discharging throughout the entire measurement period, except during the month of January in the case of unit 2. It is also apparent that the rate of sub-surface drainage fluctuated in response to changes in the water table and with rainfall. The correlation coefficients between change in water table and the sub-surface drainage rate for units 1 and 2, were 0.90 and 0.91, respectively.

Interestingly, the rate of sub-surface drainage was on average 3 times as high in unit 1 as it was in unit 2, at 4.5 mm/day versus 1.5 mm/day (*cf.* figs. 5.14 and 5.15). However, part of the higher drainage discharge rate from unit 1 can be allocated to seepage losses originating from SYM itself, which flows across this drainage unit. The correlation coefficients between the amounts of excess water and the rates of sub-surface discharge and change in water table levels were much poorer for both units:

Unit 1: excess vs water table change: Corr. Coeff. = 0.12
excess vs sub-surface Q: Corr. Coeff. = 0.16

Unit 2: excess vs water table change: Corr. Coeff. = 0.38
excess vs sub-surface Q: Corr. Coeff. = 0.16

The absence of a good correlation between either water table rise or sub-surface drainage discharge and excess water indicates that large amounts of surplus water were diverted out of both hydrological sub-units through the surface drainage network during the months of September - December, 1996.

Fig. 5.14: Water Table & Sub-Surface Drainage Rate; Unit 1 Sheikh Yousaf Minor
April 1996 - April 1997 (drainage rate at righ-hand scale)

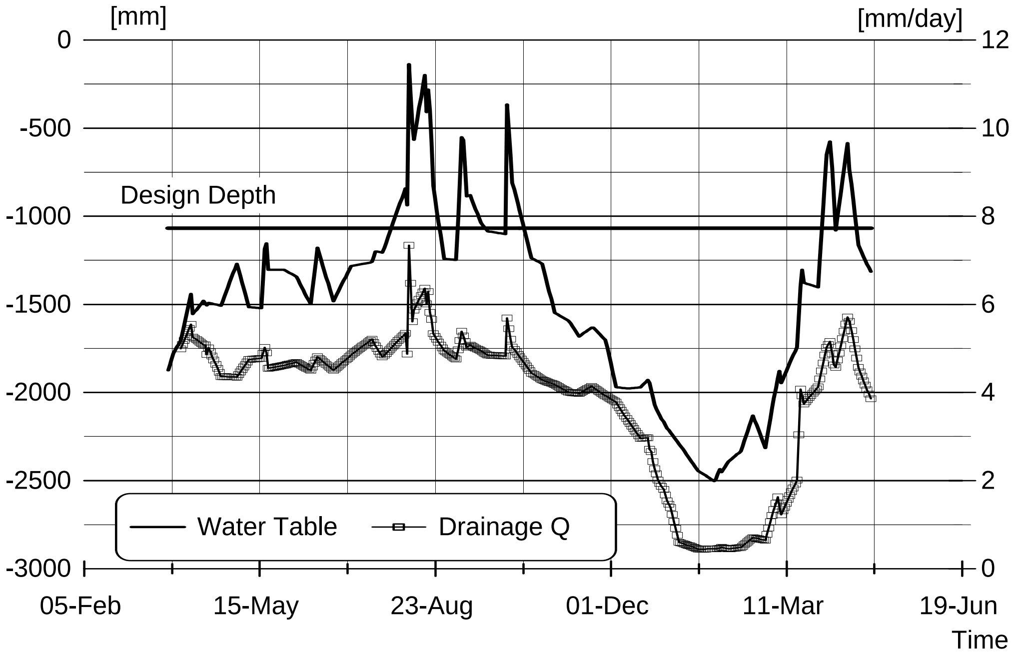
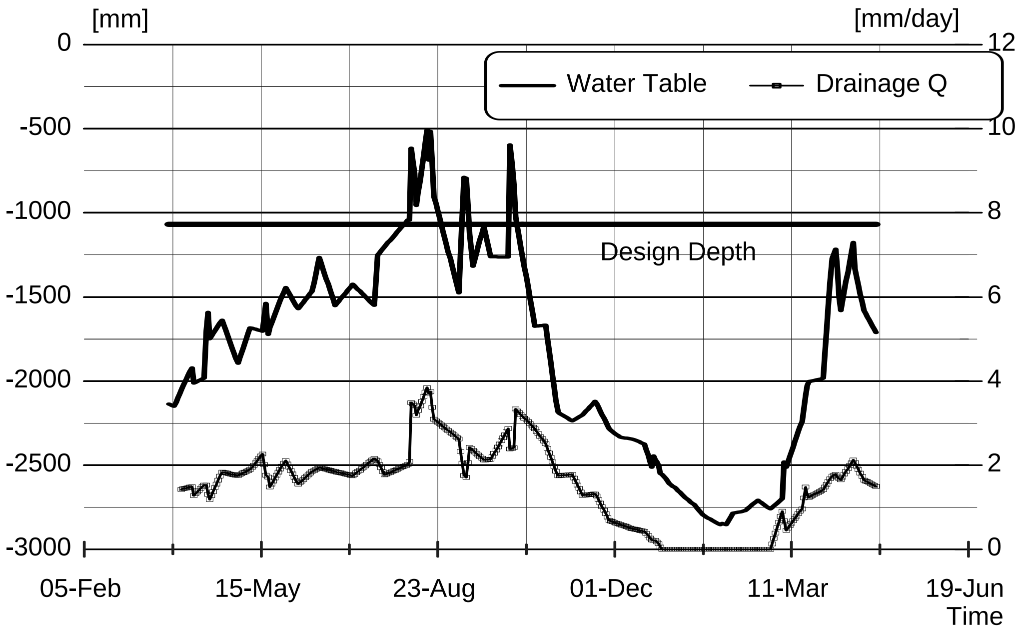


Fig. 5.15: Water Table & Sub-Surface Drainage Rate; Unit 2 Sheikh Yousaf Minor
April 1996 - April 1997 (drainage rate at right-hand scale)



Over-Irrigation & Sub-Surface Drainage

During the hot summer season of May to early July, when according to water users they still faced a shortage of water rather than an excess, two 'patterns' of excess water management could be distinguished. Despite the water users' claim, and the fact that hardly or no surface drainage occurred, the sub-surface data indicate that a substantial amount of excess water was flowing through the root zone during this period. In both drainage units, the groundwater table shows a rising trend from May into July, before the start of the monsoon in the last week of July, 1996 (*cf.* figs. 5.14 and 5.15). This is clear evidence of over irrigation, as the rise in water table can be attributed only to excess water flowing downward through an over-saturated root zone. Taking into account that the lateral sub-surface drains were laid at a depth between 1.98 to 2.13 m (6.5 - 7.0 ft) below the surface, it becomes clear that this process of water table recharge began from the time water users started to irrigate seriously in April, 1996.

Water users continue to perceive the pre-monsoon *Kharif* as a problematic period of relative water shortage, blaming the sub-surface drains for drying their soils. The data collected in drainage units 1 and 2, however, strongly indicate something else is happening. The discrepancy between the water users' perception and the collected data indicate a problem with the irrigation application methods used in SYM. Water users have not changed or adapted their irrigation application methods to the new situation, and continue to apply the full stream flow on their relatively small borders or borders/furrows. The nearly trebling of the stream flow as a consequence of Mardan-SCARP then induces a lower application efficiency at field level. This is further corroborated by the data, as the greater amount of over-irrigation occurring during this time at unit 1 is most likely caused by the higher discharge water users have to manage at field level, roughly 120 l/s (4.2 cusecs) compared to about half that amount in unit 2. Furthermore, the reduction of over-irrigation at the end of the *Kharif* season coincide with a reduction in the level of canal water supply, and thus tends to support this view. This tendency to over-irrigate, is furthermore enhanced by the traditional irrigation practice, stemming from the days that irrigation water was still relatively scarce, that one should make sure that with each application one's soil is filled to the brim, which means in practice that the soils are irrigated to above field capacity. With the sub-surface drainage network, the fields are drained to field capacity within a day, instead of the couple of days it used to take, feeding thus the perception that they are to blame of drying-out the soils.

The amount of excess water flowing through the soil can be quantified by expressing water table fluctuations as a rate of water supplement or extraction. For this purpose, water table fluctuations had to be converted into net water volumes, as the unit of water table mainly consists of solid soil and only a small fraction consists of pores that actually contain excess water. For a silty clays soil Kabat and Beekma give an effective porosity value *mu* = 0.04, thereby indicating that one metre of water table rise represents 40 mm of net water volume added (Kabat and Beekma, 1994: 405). By applying this relationship it was possible to quantify the amount of water that flowed in excess through the soil. For any given day, the excess was determined by the change in water table – a rise having a positive value, while a drop is quantified by a negative value – plus the rate of sub-surface drainage.

The results of this analysis to quantify the rate of over-irrigation are presented in figs. 5.16 and 5.17, for one year, from April, 1996 to April, 1997. To reduce the effect of daily variability and occasional rainfall events, the rate of over-irrigation has been calculated as a moving average of the previous 14 days. To facilitate easy comparison, the amount of over irrigation is plotted together with net crop water requirements; both expressed in mm/day. It is apparent from these figures that during the hot summer period (mid-May to late-July), excess water has been applied to the soil by means of irrigation, distribution losses, and substantial application losses. For unit 1 the amount of over-irrigation amounted to about 4 - 5 mm/day and for unit 2 about 2 mm/day against a peak net crop water requirement of 5.5 mm/day. The larger part of this excess water, around 80 percent, was diverted out of the hydrological sub-unit through the sub-surface drainage system. As a consequence, the water table rose immediately in response to rainfall.

In contrast to the hot summer period, the occurrence of heavy monsoon rain showers represented a period when the rate of excess water showed an acute and drastic rise. By comparing figs. 5.14 and 5.15 with figs. 5.16 and 5.17, it can be concluded that part of this acute excess water has been diverted through the soil. An already rising water table was immediately recharged by substantial amount of water, and the sub-surface drainage network responded to the rising water table by an increasing discharge rate which drained the water table in the course of a few days. The sub-surface drainage network, however, could accommodate only a portion of the acute excess caused by rainfall. Therefore, a substantial amount of excess water delivered through the irrigation system had to be managed through other means.

An immediate and logical water users' response observed in the field was to divert the entire watercourse flow into a surface drain. This strategy enabled the larger part of excess water to be removed immediately from the hydrological sub-unit. In cases of very intensive rainfall, a portion of excess water resulting from rain could also be disposed off through surface drainage by means of direct runoff from the fields. Water users implemented this latter strategy by opening their field bunds; a practice that is necessarily restricted to those fields bordering surface canals that are primarily used for drainage and lie below field level.

Fig. 5.16: Rate of Over Irrigation; Drainage Unit 1 Sheikh Yousaf Minor
April 1996 - April 1997 (14-day mov. avg.) [mm/day]

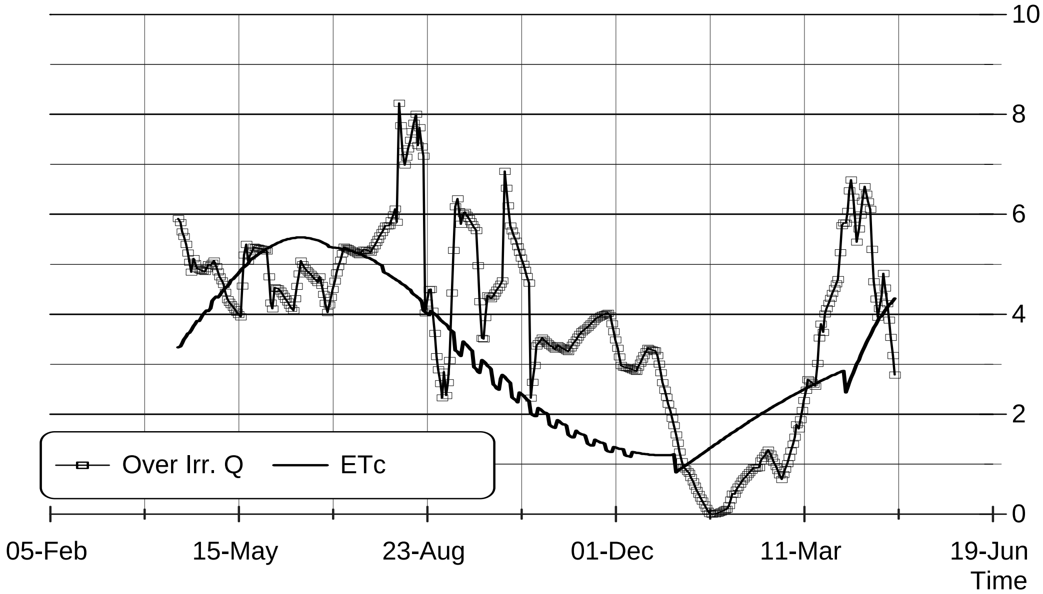
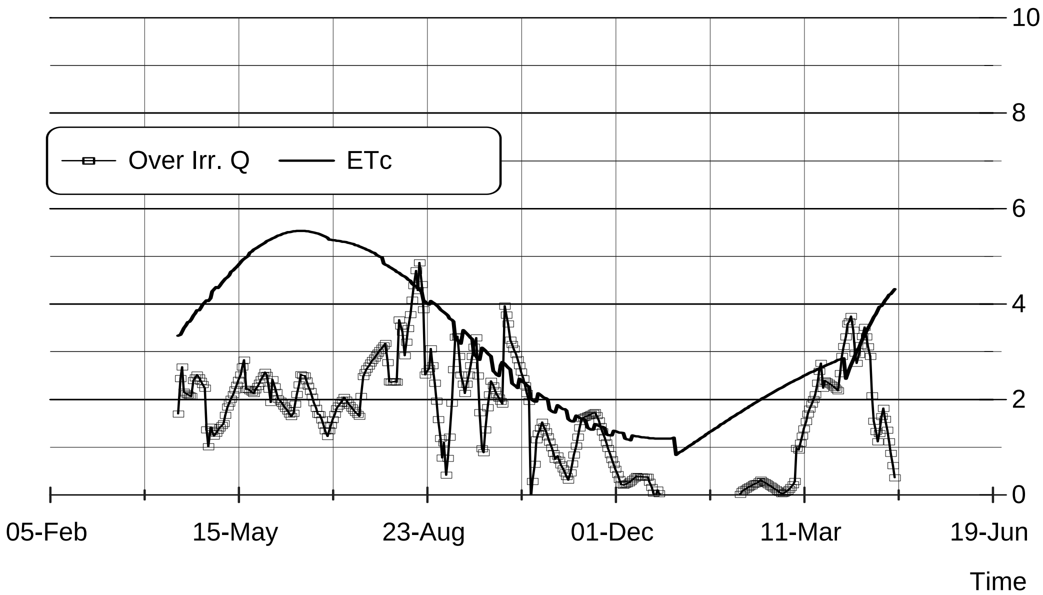


Fig. 5.17: Rate of Over Irrigation; Drainage Unit 2 Sheikh Yousaf Minor
April 1996 - April 1997 (14-day mov. avg.) [mm/day]



Surface-Drainage & Water Distribution

The amount of surface drainage that took place was determined by subtracting the amount of sub-surface drainage and the change in water table (in net volume) form the amount of excess water for any given period. Figures 5.18 and 5.19depict excess water and surface drainage as ratios of canal water supplies for units 1 and 2 for the period September - December, 1996 as a 7 day moving average. In both units, it becomes apparent that during the end of the monsoon rains in late September to early October, 75 - 100 percent of canal water supply was drained through surface drainage.[95]

When the rain is intensive and frequent, causing prolonged periods of excess water, water users in SYM command demonstrated a tendency to change their water management strategy. Instead of continuing to drain the entire irrigation supply through the surface drains, canal water was frequently refused by closing the outlet partially or fully to reduce the risk that full flowing surface drains will damage crops and houses (*cf.* previous section). In addition to reducing the quantity of excess water that water users have to manage, when timely applied, the practice of refusal also may enhance drainage from the fields; however, no observations have been made yet for this purpose.

Once the monsoon rains were over, the amount of excess water temporarily dropped because of lower canal supply levels, particularly in unit 2 (*cf.* figs. 5.11 and 5.12), and field preparations for the sowing of *Rabi* crops. From this point on, the water table continued to decline well below the design depth until about the beginning of March. This indicates that the amount of over-irrigation was reduced below the capacity of the sub-surface drainage network. However, from the beginning of *Rabi* until canal closure the amount of excess water actually increased again to about 90 percent of the supply, primarily because of lower net crop water requirements.

From figs. 5.18 and 5.19 it can be deducted that for a period of about 30 days (22 October to 21 November, 1996) more than 50 percent of the supply rate was used for irrigation, of which as much as 25 percent was in excess of net crop water requirements. From the end of November until canal closure the larger part of excess water – 80 to 90 percent – was drained through the surface drainage network; an amount as much as 75 percent of the water supplied. It is clear from these data that there is ample flexibility for water distribution within these units, even enabling water users to skip night time irrigation altogether during the month of December.

[95] In fact, the data suggest that as much as 125% of the water supplied has to be drained through the surface drainage network during heavy rainfall. Although this value may result partly from cumulative inaccuracies in water measurement, it is strongly indicative of run-off drainage due to a fully saturated soil.

Fig. 5.18: Excess Water & Surface Drainage v Supply; Unit 1 Sheikh Yousaf Minor
Sep. - Dec. 1996, Expressed as ratio to supply [-] (7-day mov. avg)

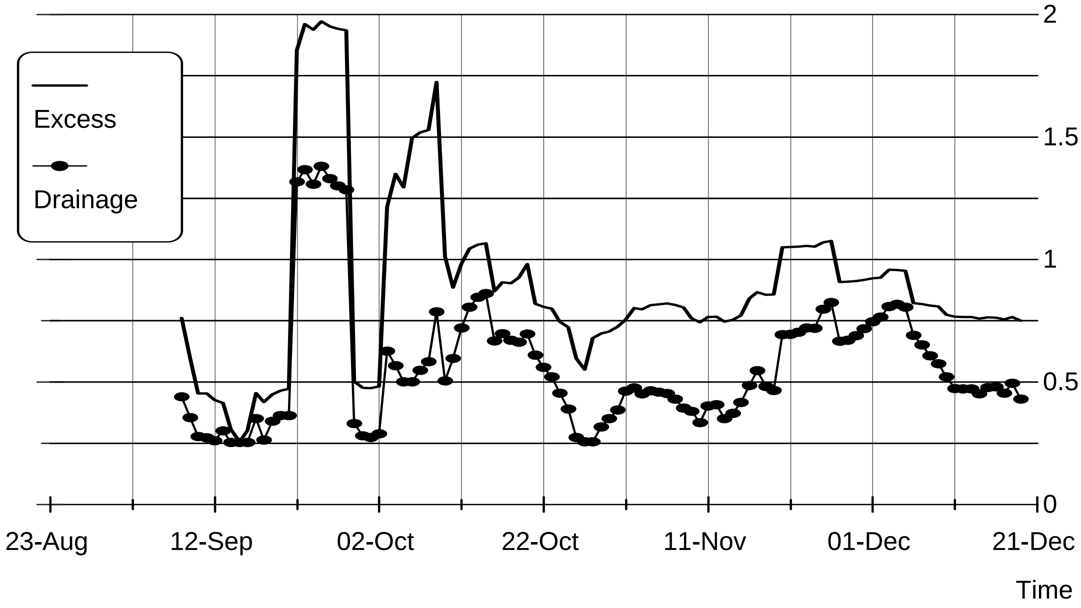
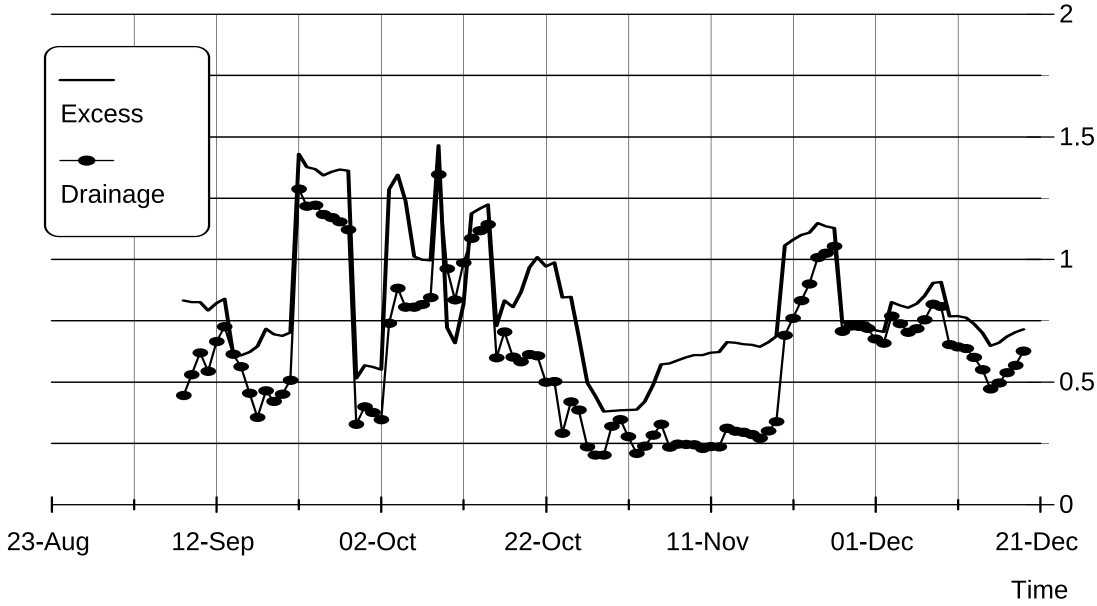


Fig. 5.19: Excess Water & Surface Drainage v Supply; Unit 2 Sheikh Yousaf Minor
Sep. - Dec. 1996, Expressed as ratio to supply [-] (7-day mov. avg.)



5.5 RE-ARRANGING THE RULES OF WARABANDI

In the foregoing sections it has been made clear that the dynamics of water management have been changed significantly for the water users of LSC, and those of SYM in particular, due to the changes in infrastructure and irrigation conditions effected by Mardan-SCARP. It should therefore come as no surprise that they have opted for a practical adaptation of the *Warabandi*, exploiting its potential flexibility in defiance of the formal rigidity that tends to be underscored in the professional literature.

Despite all the changes brought about by Mardan-SCARP the *Warabandi* remained unchanged for all the tertiary units of LSC.[96] This occurred to the extent that all the newly prepared *Patwari* maps of the command area are not used in practice by the *Patwaris*, as it proved more convenient to simply keep using the old pre-project maps while upholding the pre-project *Warabandi* rosters. Formally this also means that no changes in water management at the tertiary level have been endorsed by the ID, and that the water users of LSC are held accountable to the Canal & Drainage Act in exactly the same manner as before the project. For the water users this meant that they were ill prepared for the new water management conditions they faced after commissioning, and that they were basically forced to adapt their practices along the way until they would find a workable adaptation.

It is clear from the data presented above that the water users had to control excess water by integrating drainage into their irrigation water management practices. Notwithstanding the abrupt transition that took place with the commissioning of the remodelled canal system, the conditions turned out to be favourable in two important aspects for water user to transform their water management practices: (i) the drainage facilities are effective and provide many opportunities for water users to dispose of any quantities of excess water through either surface or sub-surface drainage, without causing immediate damage to others; (ii) due to the relative abundance of water, the management of the ID has relaxed as there is no need for tight operational control to address problems of water scarcity and distribution. The first condition permits a high degree of flexibility with which individuals can address water management needs, while the latter has been instrumental for the high degree of tolerance of the ID towards water refusal at the outlets.

The question thus arises how water users have coped with the abundant water supply and the need to control excess water, in the face of the opportunities available to them. Have the principles and strategies with which they conduct their water management for decades changed, or have the new requirements for excess water control and drainage, as well as the increased flexibility this provides, been accommodated in the structuring principles of the *Warabandi*? In other words; does the formal *Warabandi*, which was devised and used specifically to deal with relatively water scarce situations, still have practical significance in the conditions of LSC? Or has it informally ceased to be an institution with which water users shape their water management practices?

As discussed, one still finds the official pre-project *Warabandi* roster at the centre stage of the day to day water management practices in SYM. Evidently, the nature in which the *Warabandi*

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[96] Except for the one tertiary unit where the low-pressure buried pipe system was introduced as a pilot-project, where the *Warabandi* was abolished in order to experiment with 'demand-based' irrigation operations.

is used in the shaping of the post-commissioning water management practices, has changed starkly from the pre-project era. The function of the *Warabandi* as an institution for water management has clearly shifted; where it once clearly shaped the scheduling and minute-to-minute distribution of water in the *Chak,* it today predominantly serves as a water allocation principle to which the water users have to conform in their water management practices. Besides providing a 'reference' distribution schedule from which adaptations can be made, its paramount function is to define the allocated water share – defined as a time share of the total water course flow – of each individual water user in the tertiary unit. It is by providing an unambiguous and transparent definition of the allocated water share in a manner with which water users are well acquainted with, that the *Warabandi* can continue to serve as the principle means by which the arrangements of water management are made. Furthermore, the maintenance of the pre-project *Warabandi* roster provides two additional important advantages for the organisation of water management. It is well known among all the water users of one unit[97], and it provides a considerable degree of freedom for individual and ad-hoc collective action. The latter being highly valued by the Pathan (*cf.* Leeuwen, van; 1997 and chapter seven).

Sub-Classifications of Water & their Rules of Use

Although the water table data of drainage units 1 and 2 confirm that water supply is in excess of the water requirements during the hot summer months of May - July, water users in SYM still perceive this period as one of comparative scarcity. During this period the pre-project *Warabandi* roster is therefore maintained and implemented fairly strictly in eight of the eleven tertiary units.[98] Deviations from the water distribution roster are kept to a minimum during this period, and if it occurs through the sharing or lending of water turns between water users, the turns as a rule must be repaid within the next *Warabandi* turn. Even though this peak requirement period continues to be perceived as a relative water scarce period by the water users, the fact is that the official complaints about water theft or non-compliance with the *Warabandi* filed at the office of the Deputy Collector in Mardan have dropped from a pre-project average of 200 per year to a post-commissioning of 2 per year for SYM alone. This indicates a huge improvement of water availability that corroborates with the measurements conducted in drainage units 1 and 2.

During the monsoon rains the primary concern of water users in SYM is to manage the substantial amounts of excess water they receive. There are two ways in which they can control this excess water; depending on the situation, one or both are applied. As discussed, the first option is to utilize the surface drains to divert as much as the entire watercourse discharge from the command area. In addition to actively draining the surface flow, the canal water supply is also partially or fully refused at the outlet.

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[97] The distinction between well acquainted with, and well known, is used here to make the following distinction: well acquainted with is used to indicate that water users are familiar with *Warabandi* and know how it works; while well known is used to indicate that the specific content (in terms of time share defined turns) is known by the water users of one unit and that the knowledge is not only limited to ones own individual turn but also of the turns of one's fellow water users in the unit.

[98] Unit No. 9, with its over-sized outlet is an exceptional case, that due to its extremely high delivery rate can afford to deviate from the *Warabandi* even during these peak water requirement months. This exceptional case is not further treated here.

Manipulation of canal water supply at the outlet is done by individual water users who take the initiative based upon an assessment of the excess supply situation. Even though this is a logical and frequently used strategy during the monsoon season, water users in SYM continue to be reluctant to admit doing so; probably because it remains a serious breach of the Canal & Drainage Act. In contrast, however, all water users freely admit to re-opening closed outlets whenever they are in need of water during such periods of outlet closure. The general rule applied in SYM is that anyone who needs water, irrespective of their position in the *Warabandi* roster, is allowed to re-open a closed outlet.

During periods of perceived excess water when at least part of the supply is being diverted into the surface drains, there are ample opportunities to increase flexibility in water distribution at the tertiary level. Water that is flowing freely into surface drains is classified as ‘free’ water by the water users, which means that it can be used by anyone who needs it. Every shareholder, of course, also continues to retain a proprietary claim to the water during his/her respective *Warabandi* turn. The use of ‘free’ water is therefore subject to certain rules as well. Any water user using ‘free’ water is responsible for restoring the flow of water to a surface drain once (s)he is finished using it, or handing it over to another user in the command area. The right to claim use of ‘free’ water varies from location to location. Often the rule of ‘first-come, first-served’ is applied, and those who claim it later will have to wait until those who claimed it earlier are finished using it. In other cases, farmers located closer to the outlet of the watercourse are able to use their more favourable upstream position to stake a privileged claim.

Clearly, using ‘free’ water to irrigate outside of one’s own *Warabandi* turn carries some risk that it will be lost to others – particularly to the proprietor in whose turn one is irrigating – or of having to negotiate among multiple claims for use. One way water users are able to manage this risk is to ‘book’ or reserve ‘free’ water in advance with another shareholder who does not intend to (fully) utilize his/her *Warabandi* turn. In such an agreement, those who ‘book’ ‘free’ water only can be obligated to return it within the next *Warabandi* cycle (i.e. like the traditional exchanging of turns). However, such reciprocity typically is practised only during the period of the pre-monsoon *Kharif*. Water users whose scheduled *Warabandi* turn falls during the night, naturally, prefer to follow the strategy of ‘booking’ water in order to shift to, and secure, daytime irrigation.

Whether or not it is necessary to ‘book’ water depends strongly upon both the amount of excess water at the time and a local assessment of the relative availability of ‘free’ drainage water. For example, whenever the amount of ‘free’ or surface drainage water falls below 50 percent of the canal water supply (*cf.* figs. 5.18 and 5.19) there is still opportunity to irrigate outside of the *Warabandi* turn, but ‘booking’ may be essential to secure access to it. In contrast, when the amount of ‘free’ water reaches about 75 percent of canal supply, water is sufficiently abundant so that the risk of accessing it freely at any time is minimal and there is no real necessity to ‘book’ it in advance. During these periods night time irrigation is completely abandoned in SYM and no structured water distribution pattern can be discerned at the tertiary level.

Field data and observations clearly demonstrate that water management in SYM command is less a well organised activity involving groups of farmers acting together than it is a series of interventions undertaken by water users primarily on an individual and ad-hoc basis. To be sure, the existence of certain rules concerning the use of surplus water and the categorisation of surface drainage water as 'free' under certain conditions by water users does imply a wide degree of community agreement or consent. However, this should come as no surprise, as it is highly consistent with the traditions of tertiary level water management and highly compatible with the dynamics of *Warabandi*. The rules that have arisen in SYM to adapt the *Warabandi* to the new day-to-day requirements of water management also underscore this prevailing preference for individual action. It is on the basis of knowing each other's formal turns, that individual water users are able to classify water in their water course as being 'free', 'claimed' or 'booked, and that enables them to engage in face-to-face arrangements with their fellow water users. Consensus agreement among water users at the time of action also is required for the closure of watercourse outlets and the operation of the escape structures. However, this is typically achieved through informal rather than formal leadership.[99] Moreover, in the case of outlet closure, anyone is permitted to intervene to change the action, so long as the result does not damage another's property.

This prevalence of informal and ad-hoc arrangements, that enhance the individual's freedom for choice and action, in the newly emerged water management arrangements in SYM are of course largely supported by the conditions created after Mardan-SCARP. That a high relative water supply tends to favour informal and ad-hoc water management arrangements, has been known since Levine (1977) introduced the RWS parameter to explain the correlation. That the need for excess water control has not required any formal and organised arrangements, is largely thanks to the effective drainage system provided by Mardan-SCARP. The latter stands in sharp contrast to the conditions prevailing in Punjab and Sindh, where the refusal of excess water by some inevitably leads to the water logging problems of others, and requires formal regulation and arrangements to be effectively addressed (*cf*. Wahaj; 2001).

5.6 DISCUSSION & CONCLUSIONS

On Actual Water Management Practices

In our canal safari visit to the tail of Sheikh Yousaf Minor, it became immediately evident that the irrigation conditions in LSC were significantly changed as a result of the remodelling by Mardan-SCARP. Water was flowing everywhere: through the minor, outlets, watercourses, and even the tile and surface drains. Water had seemingly become so abundant that even at the tail outlet water users were in a position to refuse water and drain off substantial part of the delivered flow; an unusual sight in irrigation systems of the IBIS.

As a result of these changed conditions, in water availability and water control and management opportunities, new water management practices have emerged in LSC; if not so much on the main system level, certainly on the secondary- and tertiary level. Regarding the impact Mardan-SCARP has had so far, however, it is hard to resist the ironic remark –

[99] See van Leeuwen (1997) for an excellent treatise that specifically deals with the role of informal community leadership in water management in Pathan culture in NWFP.

particularly when one takes into consideration the project’s initial ambitious intentions – that according to Widstoe’s criteria of a successful irrigation enterprise quoted at the beginning of this chapter, Mardan-SCARP apparently has done well: water users of LSC certainly *did get an ample supply of water whenever needed by their crops.* It remains remarkable how both the ID and the water users have reacted to the new conditions and opportunities created by Mardan-SCARP. The former have incorporated the new supply levels with a minimum of changes in their operational practices. The latter have adapted their irrigation and water management practices in order to take hold of the newly created opportunities. Even though both responses were more or less predictable given the circumstances of commissioning, it remains remarkable how they managed to find relatively quickly a working mode of operation in which they not merely coexist but also synergise.

The data from Sheikh Yousaf Minor underscore the capacity of both the ID and water users to respond to the excess water conditions in such a manner that there is comparatively little risk of crop damage through excess water delivery. The remarkable thing about this whole process is that it is done without any communication between agency and water users, or, for that matter, among water users of different localities along the canal. It works, because there appears to be sufficient infrastructure available for either water users or ID to make logical and rational decisions about disposing of excess water. It is this combination of infrastructure and water availability that allows the ID to limit its own operational interventions to a minimum. It can feasibly tolerate a higher degree of water users’ intervention at the secondary level water management as long as this does not lead to an exacerbated skewed water distribution or flood damage.

In general, the water users of SYM command appear to have made good use of this increased tolerance of the ID, managing excess water throughout most of the year very effectively. They make full use of all available means, adapting their strategies to meet the excess water conditions they encounter. The lone exception to this general conclusion occurs during the three months or so of dry, hot summer weather. The variability of excess water throughout the irrigation season in conjunction with opportunities for drainage leads to three basic modes of water management:

- During the hot summer season water is still not perceived as being in excess; all excess water is drained passively, and perhaps unconsciously, by percolation from over-irrigated crops into and through the sub-surface drainage network.

- During times of perceived excess, especially from the onset of the monsoon rains until annual canal closure in winter, water is actively managed through the surface drainage network. This is done primarily through individualised action and is based on ‘classifying’ irrigation water as excess and diverting that portion of its flow into a surface drain. Because surface drainage facilities are available throughout each tertiary unit, this activity does not require group operation. Effective rules have been established concerning the user of surface drainage water within a tertiary unit which enhance the irrigation management options for individual water users. The result is that water users now have a higher degree of flexibility in water distribution for much of the year, even to the extent that night time irrigation can be abandoned completely during the start of the *Rabi* season.

- At times of heavy rainfall when excess water becomes an acute threat to crops and during time of low crop water requirements, the amount of excess water is reduced by manipulating the rate of canal water supply at the outlet. In practice this activity is undertaken by informal individual leaders who make an assessment of the need to reduce the canal water supply. Water management flexibility is ensured, however, by the practical rule that anyone in need of water at this time can increase canal supply conditions.

The only immediate scope available to improve the management of excess water in the command of SYM seems to lie in the apparent structural tendency of water users to over-irrigate their crops during the hot summer months.

In Relation to the Design Concepts of Mardan-SCARP

From the water management strategies that emerged in LSC after commissioning of Mardan-SCARP, it becomes apparent that the current practice of abundant FSL delivery is feasible thanks to the newly established drainage facilities and opportunities. In essence the water management strategy that emerged is based on 'letting' the water user match their crop water and irrigation requirements through regulation of the drainage effluent; rather than seek to control and regulate such a match at the secondary and primary levels of the irrigation network. This 'simplified' option for 'crop-based' water management was surprisingly not contemplated within Mardan-SCARP. There are two primary shortcomings in the process of conceptualisation that lay at the foundation of this:

(i) The project neglected to contemplate the role and function of drainage in water management and its interrelation with irrigation (i.e. no integrated approach was taken). Irrigation and drainage were predominantly regarded as two separate components and processes, each with their own 'technical' management and control objectives. This was further exacerbated by the fact that the design and implementation of the irrigation and drainage components were conducted by two separate project teams; the Canadian drainage team and the Harza-Nespak irrigation team.

(ii) The scale of conceptualisation: The boundaries of the system were set to coincide with the hydraulic boundaries of the LSC (except for the peculiar administrative boundary of Kalpani distributary). The basin level has not been regarded by Mardan-SCARP as a relevant system of integrated water management – as has become increasingly common nowadays. The ID, however, was quick to bring this forward as a justification for its established practice of abundant water supply. Reasoning that with the effective drainage system the excess water is made available again for re-use at the basin level, as it is all diverted back into the Kabul river which is a tributary to the Indus. An integrated conceptualisation at the basin-level would normally form part of WAPDA's responsibilities as manager and regulator of the IBIS. It's involvement in Mardan-SCARP, however, was primarily at the practical level with the provision of counterpart engineers for the design and construction supervision who tend to get quickly absorbed in the details of their daily work. Arguably, the integration of the management aspects of irrigation and drainage, and its conceptualisation on a wider hydrological system, should have been taken up at the stage of project definition, during the formulation of the final project plan and at the level of the provincial project coordination committee.

Given the circumstances of commissioning of Mardan-SCARP, and the failure to initiate a change process with ID and water users to transform their water management procedures along a well established plan and strategy imbedded in their appreciations of water management, the outcome that eventually emerged comes as no surprise.

At the tertiary level, the water users adapted their water management practices to take advantage of the opportunities provided by relative abundance of water and drainage facilities. Their adaptations of the *Warabandi* reveal a different appreciation of the concept of managerial flexibility than the one that is applied in the design (or engineering) concepts, and that was adopted in Mardan-SCARP. Where in the general concepts of ‘modern’ irrigation efficiency and flexibility are presented as reinforcing elements – when water users are enabled to get the rate of water supply at the timings and for the duration that best meet their requirements – the practices in LSC have exposed an opposite relationship. This is, however, less remarkable than it might seem. The management proposals of Mardan-SCARP might have provided for flexibility and efficiency at the outlet, but not necessarily for the individual water user. With the intervention of both the *Gauge Reader* and *Common Irrigator* in the scheduling and distribution of water, the actual flexibility for the individual water users would have to be subdued to the practicalities with which these intermediates would have to devise a workable schedule. The practices that actually emerged, in contrast, do provide an individual flexibility, thanks to the combination of relative water abundance and adequate drainage facilities.

Within the present context of post Mardan-SCARP, there are little incentives left for either the ID or water users to seek a tighter control over the water distribution within LSC, and improve the water use efficiency within the hydraulic boundaries of the system. The only prospect in the near future to induce another transformation of water management seems to lie in a significant rise of the water charges to provoke water users to seek water savings out of economic reasons. Which, given the record for price control over the last decades in the province seems unlikely to occur any time soon. Similarly, the prospects to induce the ID and water users in LSC to take a lead in the reforms and decentralisation of water management (*cf*. chapter eight) are considerably reduced with the transformation achieved with Mardan-SCARP. In the current context, where a good water delivery service is being realised with considerable managerial ease for both ID and water users, there is little incentive for change. The opportunity to establish some form of participative irrigation management in LSC by providing an institutional capacity building and managerial change process during the Mardan-SCARP project, was unfortunately missed.

The principle scope for further improvements lies now with the issue of over-irrigation, that might lead to a structural leaching of soil fertility and fertilizers, and thus act as an obstacle to productivity. This is, however, primarily an issue to be addressed through training and extension services, rather than a matter of irrigation modernisation or reform.

CHAPTER SIX

CROP-BASED IRRIGATION OPERATIONS: IN SEARCH OF A VIABLE ALTERNATIVE OF MODERN IRRIGATION

THE CROP-BASED IRRIGATION OPERATIONS PROJECT IN CHASMA RIGHT BANK CANAL

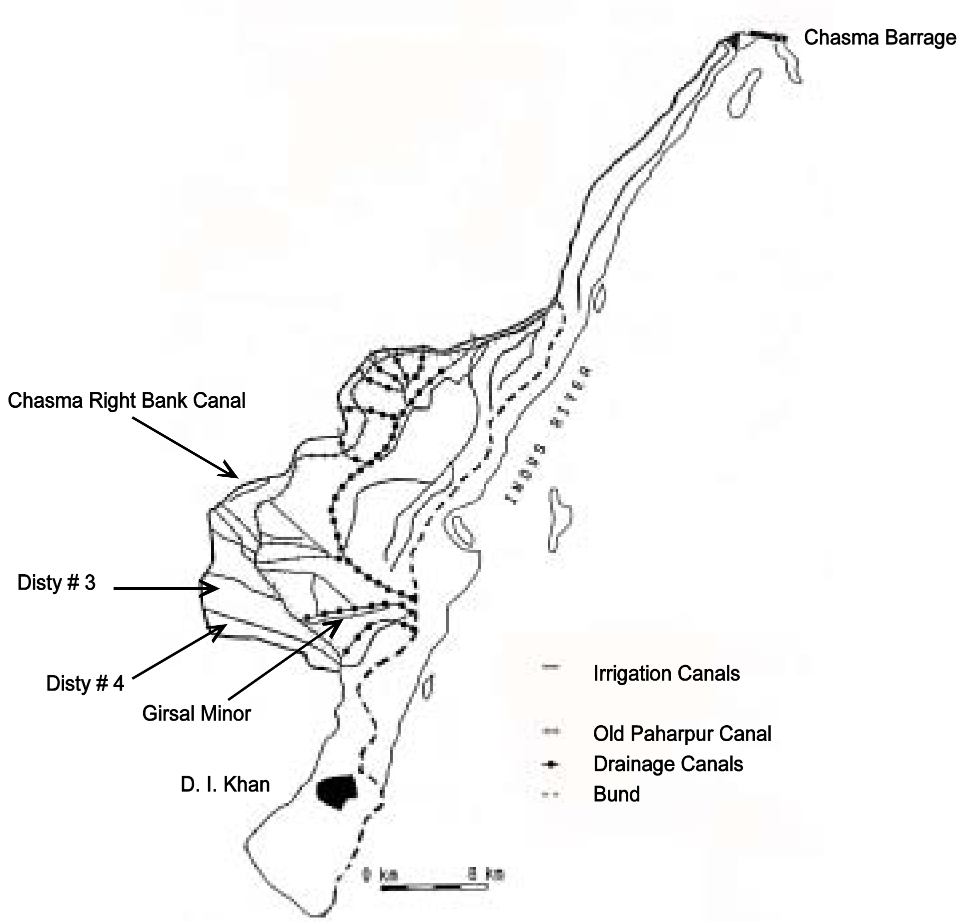
6.1 INTRODUCTION

The next attempt to introduce some form of crop-based irrigation operations as a path of modernisation of the IBIS was, despite the events in Mardan-SCARP, taken up for the development of Chasma Right Bank Canal. After the experiences in Mardan-SCARP the aim remained to find a viable alternative to realise 'productive' irrigation in Pakistan, wherein the water supply could be feasibly varied in accordance with the crop water requirements. For this purpose, a separate project component was initiated – the Crop-Based Irrigation Operations project (CBIO) – with the task to test and define operational procedures for Chasma Right Bank Canal, in which the crop water requirements could more or less be met. From the start, the intention was to come to a workable solution in the water management context of Pakistan, that would yield alternative operation and management procedures that would both be practical and feasible. To this end, the notion of 'crop-based' and 'modern' irrigation had to move away from that of 'demand-based' irrigation, that had caused so much contention in the case of Mardan-SCARP.

This second attempt to give shape to a concept of varied water supply in response to crop water requirements, is briefly presented in this chapter on the basis of the CBIO project results. In the scheme of irrigation developments undertaken in the IBIS, it represents an important stage in the attempts to define a concept of 'productive' irrigation that is workable within the context of the IBIS. The fact that a separate project component was specifically set up to address this issue, even be it in the form of 'mere' technical assistance project, would seem promising, given the events in Mardan-SCARP. In practice, however, the separateness of the project turned out to be one of the obstacles to success. The scope for transforming the operation and management of Chasma Right Bank Canal into a crop-based system were too much delimited by institutional and technical constraints imposed by operational practices of the line agencies and the already completed design and configuration of the canal system itself. The CBIO project in the end did not succeed to elaborate an integrated and congruent conceptualisation of crop-based irrigation, bud had to delimit its scope to a performance and feasibility study. Like in Mardan-SCARP, the attempts in Chasma Right Bank Canal were eventually bogged down by a technical discussion on the viability of controlling the flow variations in the main system, which the CBIO sought out to settle through hydraulic modelling.

Section 6.2 provides a description of the CBIO project and its objectives, and how it set out to define a concept of crop-based irrigation for Chasma. It is shown how the concept of the CBIO possesses remarkable similarities to the one devised by Mardan-SCARP for the first two stages of management transformation. In section 6.3 a description of the Chasma Right Bank Canal is given. Section 6.4 provides an overview of the operation and management realities the CBIO encountered in the field, and the constraints these practices imposed on the CBIO. Finally, the delimitated scope of the CBIO outcomes are discussed, with regard to its conception of crop-based irrigation, and its focus on the technical control of flow variability.

Fig. 6.1: Map of Chasma Right Bank Canal Stage I



6.2 SEGREGATING WATER MANAGEMENT FROM IRRIGATION DESIGN

6.2.1 The Need to Conceive a Crop-Based Irrigation Operation Concept

The disappointing experience of Mardan-SCARP in its attempt to introduce some form of crop-based or demand-based irrigation concept, had not gone unnoticed. The ensuing conflict around the outlet structures and the ID's repudiation of having to regulate flow variations frequently and at numerous locations, left the question unanswered on how to introduce a water delivery service that better met crop water requirements. The policy objective to improve the productivity and efficiency of Pakistan's irrigation systems was, however, still firmly in place; particularly with the multilateral donor agencies involved such as ADB and World Bank.

The immediate lesson that was drawn from the Mardan-SCARP experience, was the obvious one: it had failed to devise an appropriate technological and managerial package with which to introduce crop-based irrigation in the context of Pakistan, and was thus deemed non-replicable. The search for an appropriate concept and means to realise crop-based irrigation operations in Pakistan, had therefore to continue. This quest was taken up by the ADB when it commissioned the International Irrigation Management Institute (IIMI) in the autumn of 1991 to conduct the Crop Based Irrigation Operations (CBIO) project with the aim to introduce crop-based irrigation operations at the Chasma Right Bank Canal.

Through the CBIO project IIMI was asked to investigate, test and formulate a *"flexible operational management approach that could respond to crop water requirements"*. Acknowledging the similarities between Chasma and Mardan-SCARP – in developing a modern irrigation operation management that would be able to respond to changing crop water requirements – the ADB requested IIMI also to take up the case of Mardan-SCARP in the CBIO. This request was born out of the realisation that it could at least draw some further valuable lessons for the endeavours at Chasma, if maybe not quite provide a solution to the problems Mardan-SCARP was facing.[100] In the inception of the CBIO project it was namely already concluded that in Mardan-SCARP:

> "[The ADB Fact-Finding Mission and IIMI staff in December 1989] *noted the confusion resulting from apprehensions of those who tend to interpret the term 'demand-based irrigation' to mean complete freedom for farmers. The actual intent of the design changes appears rather to have been aimed at the general purpose of reducing the mismatch between water deliveries and crop water requirements."* (Garces & Bandaragoda; 1991:2)

IIMI's task was therefore also to resolve this ensuing confusion, and show through the CBIO project that crop-based irrigation did not entail 'complete freedom' (or anarchy in the view of some) for farmers, but could be a feasible option for Pakistan to achieve its increases in

[100] Throughout this chapter the term Chasma will be used to indicate the Chasma Right Bank Canal system or project, as the side by side use of the acronyms CRBC and CBIO might easily lead to confusion.

productivity and efficiency of irrigation.[101]

6.2.2 CBIO: In Search of a new Crop-Based Operation Method

The CBIO project was commissioned by the ADB as a Technical Assistance project, that should provide assistance in devising crop-based operational procedures for the Chasma canal system that was being developed by means of a loan agreement of the ADB. The specific objectives for the CBIO project were defined as:

I. *"Identify a flexible management approach for irrigation operations that respond to crop water requirements under prevailing supply constraints;*

II. *Increase understanding of crop-based irrigation operations by agency personnel and farmers, and identify training needs;*

III. *Field test and refine the management approach identified for crop-based irrigation operations; and*

IV. *Evaluate the benefits of crop-based irrigation operations and identify costs and opportunities for implementation on a wider scale."*

(Garces & Bandaragoda; 1991:14)

The CBIO project seemed thus specifically aimed at giving attention to the operation and management aspects of establishing a crop-based irrigation delivery service: a positive change after Mardan-SCARP, where the aspects of operation & management were only addressed by the O&M manual. The emphasis on operation & management, however, entailed at the same time a degree of ambiguity as it leads to a formal split of responsibilities. The main thrust of the Chasma project financed through the loan agreement was aimed at designing and developing the Chasma canal system, to be executed by WAPDA and its international consultants; while IIMI was brought in through a Technical Assistance project to get the operation & management right for realising crop-based irrigation. This raises questions on how the issue of devising concepts of water control for the planned and controlled variation of water delivery for crop-based operations could be addressed through such a compartmentalisation. This issue became immediately problematic, as the CBIO project had to conduct its work in the already completed stage I of Chasma, that, as it was quick to point out, was not really designed for crop-based irrigation (see below).

[101] Although the CBIO was initially requested to also conduct its work on Mardan-SCARP and to clear up the confusion that had ensued there during the implementation, IIMI quickly decided to concentrate its efforts on Chasma. Even though an agreement had been reached with the World Bank and the ID to use Sheikh Yousaf Minor as a pilot for the CBIO in Mardan-SCARP, IIMI thought that in light of the ensuing conflict between the ID and Mardan-SCARP project, it would not be conducive to conduct a pilot project for crop-based operations. It therefore decided during inception to limit its activities in Mardan-SCARP to study the events that led to the conflict and refusal of the Metergate outlets.

The objectives of the CBIO project also reflect this ambiguity of segregation, as they explicitly demand for the devising of operational plans and procedures, but refrain from addressing any technical elements of water control. As became quite evident from the early stages of the CBIO project, however, the context in which the project was defined and had to work in, played a major role in this as well. The conflict that had ensued in Mardan-SCARP around the outlet structure, was an example of how technological choices could easily lead to agitation of the ID. This had to be avoided for the transformation towards crop-based irrigation operations to stand any chances to succeed.

Defining a Crop-Based Irrigation Operation Strategy for Chasma

> "[...] *there is a continuum of options on how the irrigation service can be provided. The water delivery mode ranges from one where the user plays an entirely passive role, in which decisions are taken without his input (strict Rotation), to one where the user has complete control over the water delivery decision-making process (pure Demand). The concept of crop-based irrigation operations, while part of the continuum as indicated above, should* ***not*** *be defined in terms of the frequency, rate and time during which water is delivered to the field. Rather, it should be thought of as being a concept that places itself parallel to the Demand-driven side of the delivery options. The terminology emphasizes the need to seek a better match between the water requirements of the crops and the amount of water available for delivery. It does neither advocate nor encourages the idea that users should be able to satisfy, at all times, their individual needs. The core of crop-based irrigation operations lies in that the system needs to have a certain degree of design and managerial flexibility, and that users need to play a more active role in determining beforehand what their water needs might be."* (Garces-Restrepo et.al.; 1994:3-4, emphasis added)

It is difficult to foresee how one would be able to devise a concrete water control and operational strategy that is not defined in terms of the frequency, rate and duration of water supply. After all, it are precisely these three elements of the water delivery service that define the degree of managerial flexibility for water users in concrete terms, and provide the guidelines to define the scheduling mechanisms to plan the water delivery in advance to the expected requirements or processed demands, which on their turn produce concrete water delivery targets for the operation and water control. One would think that in order to make sure that the crop-based irrigation concept is not misunderstood – which was one of the prime reasons to start the CBIO project – is exactly why it should be defined in terms of frequency, rate and duration of water supply. This is a necessary step anyway in defining an operational plan, and it makes immediately evident which limitations/freedoms will be imposed on the end users, and at which specific level of the system. Of course, there is not one definition of crop-based irrigation in these terms; but that is exactly why it is necessary to make explicit choices on the kind of crop-based scheduling and operation one seeks to implement in any particular system when one wants to avoid confusion on the operational issues.

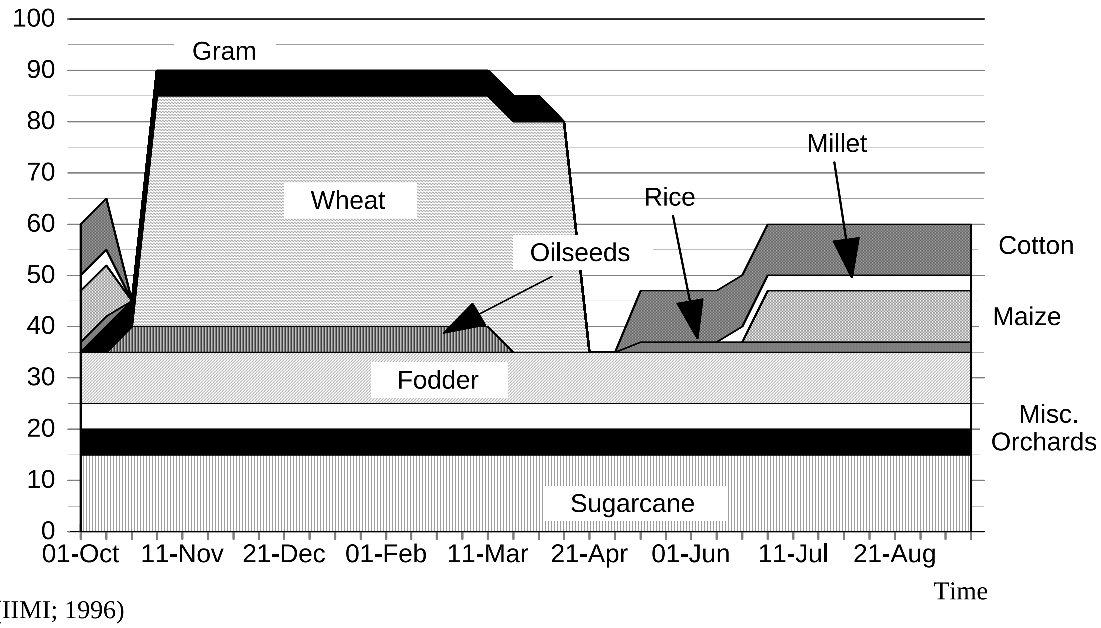
The CBIO project made an explicit choice not to define the operational plan for Chasma in terms of frequency, rate and duration of the water delivery service. However, from its start the project regarded the choices made in the design of Chasma, and the infrastructure as implemented in stage I, as constraints within which it had to operate. The scope for defining crop-based irrigation operations in terms of frequency, rate and duration might then seem too limited.

Like Mardan-SCARP, the CBIO project started its conceptualisation of crop-based irrigation operations from a literary interpretation of the notion. It simply took the design cropping pattern of Chasma (*cf.* fig. 6.2) to calculate the varying crop water requirements at the tertiary level, and used these to calculate the water indents/targets at the different levels of the system. Having taken a brief look at Mardan-SCARP and the ensuing row on its outlets, it is rather astonishing that the CBIO project also decided to translate these calculated crop water requirements into a 10-day scheduling frequency (*cf.* fig. 6.3). One can thus hardly avoid the impression, that the CBIO project simply took the first two operational phases as proposed in the O&M manual for Mardan-SCARP as a starting point for Chasma, notwithstanding the dilemmas this had created in the former.

Taking this proposition to 'simply' follow the crop water requirements in the water delivery schedules one step further than in Mardan-SCARP, the CBIO project set out to see whether such delivery schedules with highly varying water deliveries could be implemented in stage I of Chasma. To this purpose, the CBIO project decided to use a hydraulic simulation model for stage I of Chasma, with which it could run a number of water scheduling and delivery scenarios. The application of the model, was to serve a dual purpose: (i) to check whether controlled operation of varying water supply and crop-based scheduling was feasible with the infrastructure and hydraulic configuration provided by stage I; (ii) to define and test concrete operational procedures with which crop-based scheduling could be implemented. The model used by CBIO for these purposes was the Simulation of Irrigation Canals (SIC) developed by CEMAGREF. A model that had already been previously used by IIMI.

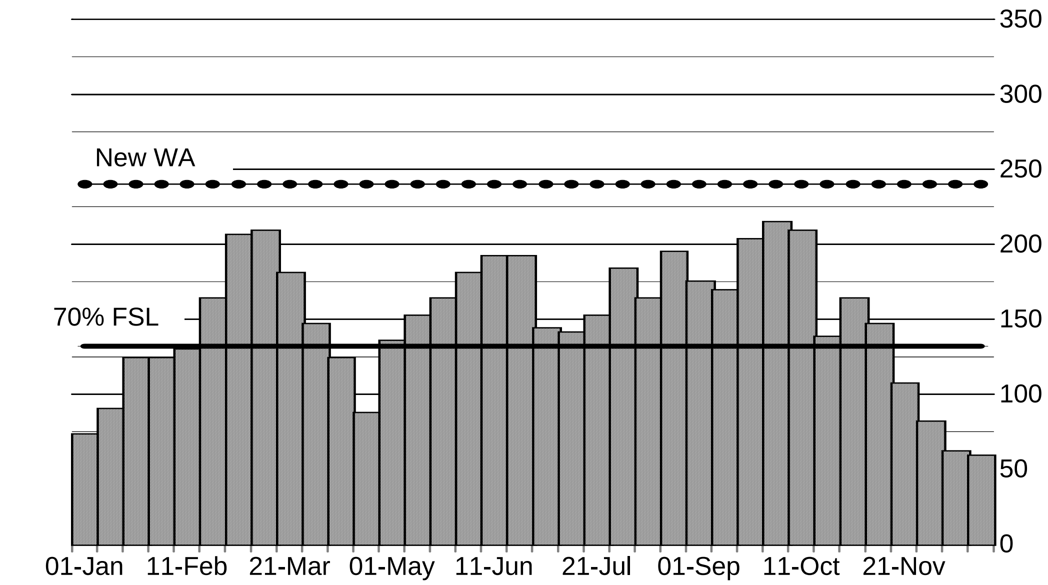
In order to be able to run the SIC model, the CBIO project had to concentrate a great part of

Fig. 6.2: Design Cropping Pattern Chasma Right Bank Canal [%]



(IIMI; 1996)

Fig. 6.3: Chasma Right Bank Canal Irrigation Requirements
At Watercourse Head for 400 ha (10-day periods) [l/s]



(Bandaragoda & Badrudin; 1992)

its ‘field activities’ on calibrating the model for Chasma stage I. To this end the main canal of stage I with all its water control structures and the distributaries # 3 and # 4 were selected for simulation in the model (*cf.* fig. 6.1). Apart from the calibration for the hydraulic modelling, 20 tertiary units were selected for intensive monitoring to gain insight in the present operation of stage I and in the dynamics governing the water supply and water requirements in Chasma. Of the 20 tertiary units, 8 were selected in each distributary # 3 and # 4, covering head-, middle- and tail-section, and an additional 4 in the Girsal Minor. The latter is a minor of the old Paharpur system, that is supplied by the tail of distributary # 3. The water supply, distribution and use were monitored in these supply channels and tertiary units for four consecutive seasons; namely *Rabi* ‘91/92, *Kharif* ‘92, *Rabi* ‘92/93 and *Kharif* ‘93.

6.3 CHASMA RIGHT BANK CANAL: DESIGN & MAIN FEATURES

With the completion of the Chasma Barrage on the Indus in 1982, as part of the IBP for the head regulation of the new Chasma-Jehlum Link Canal, Pakistan gained its third reservoir with a storage capacity of 0.6 km^3 (0.5 MAF). This new storage and water regulation facility provided the potential to further increase the IBIS with a new large-scale irrigation system on the right bank of the Indus. The Chasma Right Bank Canal was conceived and financed to make use of the extra water made available by the barrage and add another 230,675 ha (570,000 acres) to the Indus system. When construction of the first phase started in 1979, the design and water control concept for the main system did not differ substantially from the ones used in the Indus-basin up till then. This is reflected in the design discharge capacity of the main canal, which was set at 138 m^3/s (4,879 cusecs) and thus yields an average overall *Irrigation Duty* of 117 acres/cusec for the command area.[102] When this value is compared to those listed in table 4.1, it becomes clear that the relative water supply to be provided by this new system was a perfectly average one that is similar to those achieved in the older systems during the *Kharif* (*cf.* Lower Swat Canal, Lower and Upper Ganges Canal, Upper Bari Doab etc. in table 4.1).

The aim to also transform Chasma into a 'productive' irrigation system by way of crop-based irrigation operations was added to the project at a fairly late stage, when the construction of the first phase had already begun. The restrictions on the discharge capacity for the main canal and other parameters of the irrigation system were thus already set, defining general performance targets for the project that are more in line with the 'protective' systems, rather than the 'productive'. With the economic rate of return analysis conducted during the project inception phase to secure the financing, the project performance targets were defined as achieving Lieftinck's cropping intensity of 150 percent over the total CCA of 230,675 ha (570,000 acres). This meant that the total discharge capacity of the system would have to be spread out to an average *Water Allowance* of a mere 0.6 l/s/ha (8.5 cusecs/1000 acres); which is less than that of the traditional Kabul River Canal system. The late addition of the objective to make of Chasma a crop-based irrigation system, has led to a peculiar project set-up in which the design of the physical infrastructure has been seemingly separated from that of the operation and water control concept.

6.3.1 The Design & Construction of Chasma

Due to its large size and the fact that it is mainly a new irrigation system, the Chasma design and construction project has been split-up from the start into three stages of design and construction. The command area on the right bank of the Indus between the Chasma and Taunsa Barrages has been divided into three areas for the development of Chasma. In each consecutive stage, the main canal, distributaries, outlets and tertiary command areas were to be completed and developed before progressing into the next stage. Table 6.1 lists the main features of each stage.

Table 6.1 Main Features of Chasma Right Bank Canal Stages

	Stage I	***Stage II***	***Stage III***	***Total***
Length of Main Canal [km] (in thousand canal ft from head)	87.88 (0 -260)	40.56 (260-380)	157.17 (380-846)	285.6
No. of Distributaries	5 + (4 links)	8	36	53
CCA [ha]	57,605	35,547	135,523	230,675
Year of Completion	1987	1992	2002	

(Strosser & Garces; ??, www.aht-inter.com)

102 With the planned crop-based irrigation cropping pattern that foresaw a cropping intensity of 90 percent in *Rabi* and 60 percent in *Kharif*, the actually achieved *Irrigation Duty* was thus planned to fall down to a mere 70 acres/cusec during the *Kharif*.

Apart from the development of Chasma in three stages that are consecutively completed and brought under irrigation, it features one more peculiar feature: the command area of Stage III trespasses the Provincial border between NWFP and Punjab. The issue of water allocation and distribution is hereby burdened with Provincial politics that trespass the boundaries of the project and system, and are supposed to be regulated by the Indus Water Apportionment Act of 1991. Not surprisingly, the fact that Punjab's command area is entirely concentrated in the tail-end of the system that is currently still under construction and development in Stage III, while the majority of NWFP's command area is already developed and provided with irrigation water, complicates matters further.

The initial design for Chasma followed basically the traditional 'protective' water supply concept, by designing the canal network according to Regime criteria, minimizing the amount of control structures, and aiming for a water supply variation between 75 and 120 percent of FSL to be delivered through the traditional undershot slide gated head regulators at the secondary canals. One important deviation from the traditional design approach, is that no decisions were taken on the type of outlet structures to be used in Chasma; instead of settling this crucial issue before the construction and initiation of irrigation, the project went ahead by opting for the 19th century approach of using temporary pipe-outlets during the first years of irrigation development and settlement. The only exception, being the old Paharpur irrigation system that was absorbed in the Chasma command area of Stage I, and which has been connected through four link canals to the Chasma main canal. The old Paharpur irrigation system has been remodelled for the increased discharge capacity, while the remodelled outlet-structures remained the Open Flume and AOSM type.

This is quite a remarkable decision, as it forfeits the possibility to establish hydraulic control on secondary level water distribution that was made possible by the advances in hydraulic science at the start of the 20th century and thereafter. Particularly since the choice to revert back to the use of temporary outlets during the first years of irrigation development, was essentially the 19th century British approach with which it had encountered great difficulties in controlling the water distribution and command area development (both in terms of acreage as in cropping intensities). The painstakingly devised approach for the development of colony canals in the 1930s, in which all the tertiary units were layed-out and connected to well designed outlets that were configured to supply a particular equitable proportional share, was after all more than a mere fluke of 'modernity'. One of its main purposes was to gain finally some form of control on the allocation and distribution of water. (*cf.* chapter two)

The main canal is a contour channel that is run along a fairly flat slope along the highest feasible contour. The first 29.5 km (97000 ft) are unlined and designed to settle into its Regime dimensions for it FSQ of 138 m^3/s (4,880 cusecs). During Stage I WAPDA and consultants opted for the early 20th century method of constructing the main canal in over-dimension, in order to let it silt up to its Regime dimensions. This method has, in principle, the advantage that the planned siltation of the channel will produce a relatively water tight layer of silt that helps to reduce the seepage losses. The remaining length of the main canal is lined, using Manning's equation with a roughness coefficient value of 0.016.

In the first section of the main canal build during Stage I, there are two cross regulators at Km 29.5 and Km 77.5, and also include two escape structures where water can be spilled from the main canal back into the Indus. The main canal in Stage I feeds nine distributary canals, whose discharges can be regulated through traditional manually operated undershot sliding gates. The Takkarwah and Kot Hafiz distributaries, Kargarh Minor and Link Feeder # 4 feed the old Paharpur Canal Irrigation system, while the additional distributary was added to the original design to include some additional command area, and the distributaries # 1 till # 4 supply water to newly developed command area, as well as old command area of the Parharpur system (except for # 1, which only supplies newly developed command).

In the ‘new’ distributaries # 1 till # 4, as in the remaining newly to develop command area of Chasma in stages II and III, it was decided to use temporary pipe outlets during the first years of irrigation development. Normal pre-fabricated pipes with a diameter of 9 inches were used, invariably of the actual command area, that were installed at various depths, under various hydraulic downstream conditions (Garces *et al*;1992b). The distributaries were provided with purposefully built escape structures at their tail-ends, or with a connection to the old Paharpur canal that can function as such. The drop-structures in the distributaries were not purposefully configured to function as cross-regulators, but can act as such when stop-logs or barriers are placed on top of them.

6.3.2 The Institutional Setting of Chasma

The institutional set-up of the Chasma project has not been very conducive for the trial of a modernisation of irrigation management. In all, three line Agencies were involved in the project, while the CBIO project became almost an institution in itself. Due to its inter-provincial nature, WAPDA is to be responsible for the operation and maintenance of the main canal, even after completion of stage III. This is a unique situation for Pakistan, where WAPDA will retain the operation and maintenance responsibility of an irrigation canal even after the design and construction have been completed. However, since WAPDA bears the responsibility for administering the water allocation and distribution of the Indus Water Apportionment Act in the IBIS, it was agreed that it would take the O&M responsibility not only of Chasma Barrage, but also of the Chasma main canal itself. Equally unique, the O&M responsibilities of the Irrigation Department are confined to that of the secondary level; the distributaries and their minors. As in the case of Mardan-SCARP, the OFWM programme of the Agricultural Department was responsible for the development of the tertiary units; by constructing the water courses with the aid of WUA that were specifically set-up for that purpose, and the execution of the land levelling.

The CBIO project was added to Chasma as a fourth element at a late stage, when the design and construction of stage I was already completed, and WAPDA and ID had both commenced with operating the system in their own mode. The CBIO’s task to devise and field-test an innovative operational procedure, was thus further complicated by the need to coordinate and integrate the daily operational procedures of two line Agencies that heretofore have not cooperated closely, and whose relationship is characterised by an intense institutional and political competition. From an early stage, the CBIO project got caught in the middle of these institutions, and in the end did not manage to get the staff of both agencies to integrate, or closely cooperate, in their operational task, nor to participate collaboratively in the CBIO project itself (*cf*. Garces *et al*; 1992a & b, Garces; 1993). As a consequence, the CBIO project never really got to the stage of practically field testing a new operational procedure for Chasma, but had to delimit itself to a presentation of the analysis of the options for crop-based irrigation operations in Chasma, and a set of recommendations.

6.4 ASSESSING THE PROSPECTS: POTENTIAL OPTIONS v CONSTRAINED PRACTICES

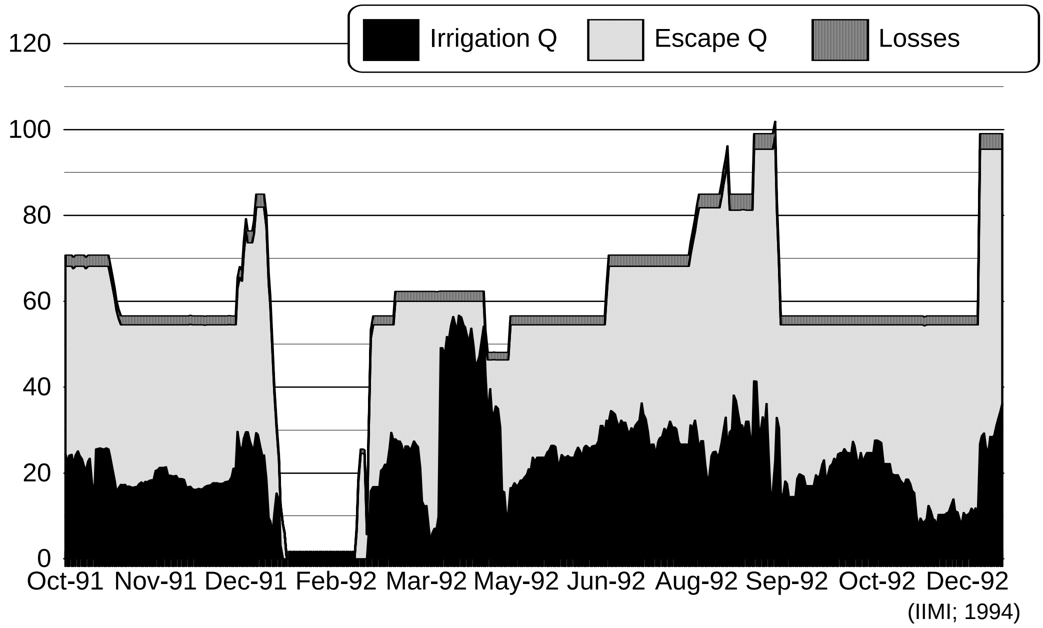
From the onset the CBIO project sought to define some form of crop-based operational plan that could be adopted in Chasma, irrespective of the major limitations in water control structures (which were regarded as design constraints to cope with), or the differing objectives of WAPDA and ID (which were expected as conservative resistance to change that the project would have to seek to overcome). From the onset the CBIO project already made a particular interpretation of crop-based irrigation operations, which it set out to try for Chasma. This interpretation was, as mentioned, based on the notion that irrigation water supplies should match as close as possible actual varying crop water requirements, and hence the irrigation water supply should be controlled according that variance on all three levels of the irrigation system. That the variation of water supply should be controlled on the three levels of the irrigation system with the objective to match as close as feasible the crop water requirements, raises questions on the suitability of the approach adopted by CBIO. Particularly, since this notion of controlling highly varying supplies at the main and secondary levels had failed in Mardan-SCARP, and it was acknowledged by the CBIO project from the start that Chasma was not really designed for such operations. Notwithstanding these considerable draw-backs, the project went ahead with its pursuit of trying to match the water deliveries in Chasma as close as possible to the actual varying crop water requirements. Not surprisingly, it quickly found out during the calibration of its model and the monitoring and research of actual water delivery and use practices, that the implementation of its notion of crop-based irrigation would run into a number of practical, hydraulic and institutional problems.

6.4.1 Hydraulic & Managerial Constraints at the Main System Level

In practice WAPDA was operating the releases from Chasma Barrage into Chasma main canal in a fixed supply mode, just like the ID in Mardan-SCARP, be it at substantial lower discharge levels than the design capacity (*cf*. fig. 6.4). It soon turned out, that WAPDA's primary operational objectives for the Chasma main canal were based on a number of specific hydraulic concerns:

- The unlined section of the main canal (i.e. the first 29.5 km) had a far bigger cross section that designed after construction. In particular, the bed level turned out to be more than 3 m (10 ft) lower than designed, causing excessive seepage in this 'in fill' section of the canal. A primary objective of WAPDA was thus to induce siltation in this head reach to gain height and reduce seepage. The first cross regulator at km 29.8 (98,000 ft) was operated to this end. In four years of operation, they have thus been able to raise the

Fig. 6.4: Water Releases into Chasma Right Bank Canal Oct. 1991 - Dec. 1992 [m³/s]
Irrigation, Escape and Loss Rates



bed level up to 2.4 m (8 ft).

- Due to the fairly low supply levels on which the canal was operated (i.e. 50 - 60 percent of FSQ, *cf.* fg. 4.34), WAPDA was facing some problems in establishing sufficient hydraulic heads over the off-takes. After the trial operations, the barrels of the four off-takes feeding the Paharpur system were already lowered to tackle this problem.[103] Notwithstanding this modification, the water at the tail cross-regulator (km 77.5 [257,000 ft]) has to be headed up 1 m (3 ft) to secure sufficient hydraulic head for an off-take 18 km (11 miles) upstream. This had reduced the flow velocity at the lined 'tail section' of stage I to such an extent, that siltation became a prime concern.

As becomes immediately clear from fig. 6.4, there was more than abundant water available in the main canal for WAPDA to supply all the distributaries of stage I with all the water they needed – or for that matter, could carry. The measurements and monitoring carried out by the CBIO project at the head-regulators of the four new distributaries (i.e. # 1 - # 4) soon confirmed that this was indeed what happened. The project came to the conclusion that the distributaries were supplied in a traditional manner, where the supply is tried to be kept around FSL during the *Kharif* season and around a lower level (i.e. 75 percent FSL) during the *Rabi*. It was evident that no attempts were undertaken (yet)[104] to regulate the supplies to the distributaries according to the

[103] Actually they built new off-take structures, but then at a lower level. Hence today, one can see two off-take structures at these locations, one of which is 'hanging high and dry' in the embankment.

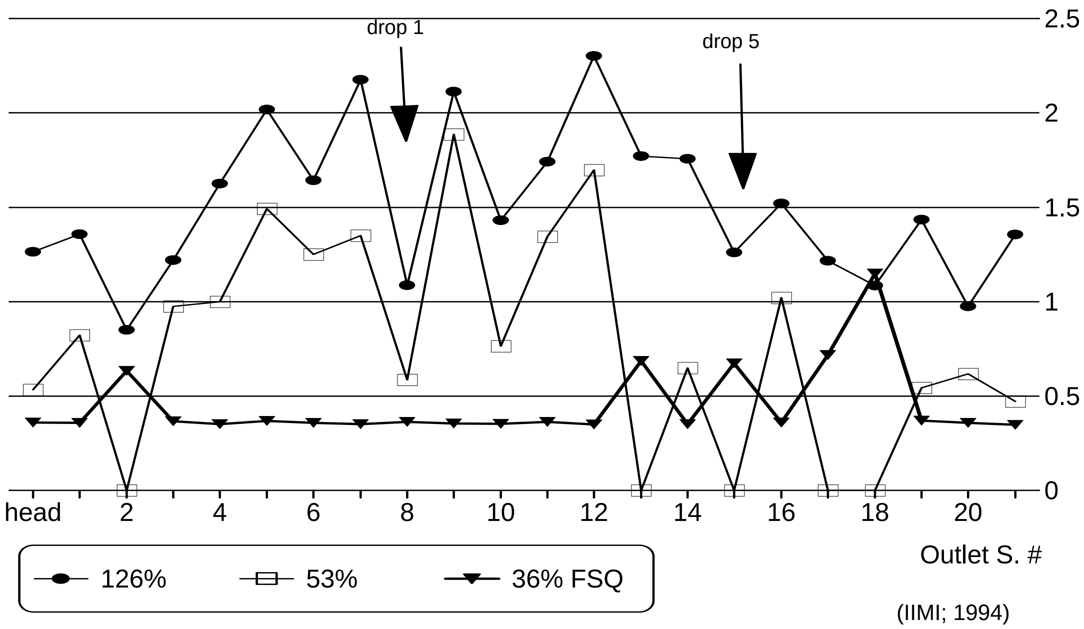
[104] This should, of course, come as no surprise, as the CBIO project was established in the first place to formulate and try out crop-based operation procedures for Chasma. Reading through the project's progress reports and (continued...)

crop water requirements. However, also a problematic issue became evident; namely that the distributaries were not merely supplied with their FSL during the *Kharif*, but with substantially more than their designed (and thus in principal allocated) FSQ. The actually delivered supply would range from 115 - 160 percent of FSQ for distributaries # 2 - # 4.[105]

6.4.2 Hydraulic Constraints & Management Strategies at the Secondary & Tertiary Level

At the distributary level itself, the state of water distribution and delivery was clearly governed by the hydraulic conditions of the temporary outlet structures. In the distributaries monitored by the CBIO project (# 3 and # 4), the conditions could be described – from a delivery point of view – as an absence of hydraulic control, in which even the discharges through the outlets were not

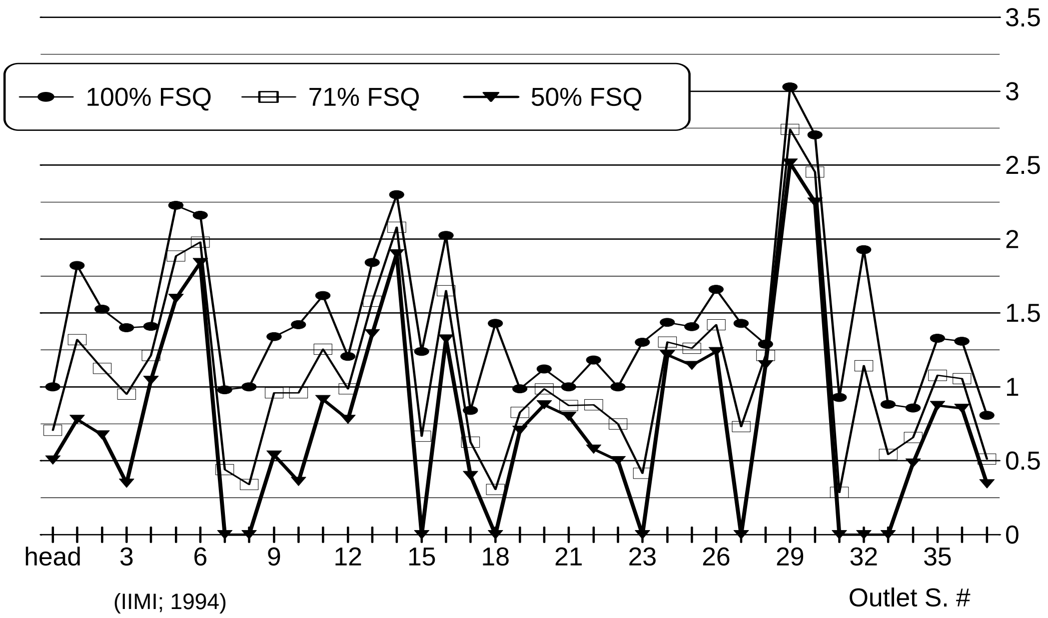
Fig. 6.5: Water Distribution Performance of Disty # 3; Chasma Right Bank Canal
Result of calibrated simulation for different supply leveles, DPR [-]
(With operation intervention for 36% FSQ)



[104] (...continued)
the three Volumes of the final report, one might think IIMI started to conduct the CBIO project more and more like a research project – in terms of performance assessment of, and feasibility study for, crop-based irrigation in Pakistan – rather than an implementation project as it was originally formulated. This seems partly a consequence of the numerous set-backs the project faced in getting collaborations with the ID and WAPDA of the ground. The shift towards research, however, is also partly admitted in guarded terms by IIMI when it states that is has somewhat underestimated the time, staff and budgetary requirements for such a project at the time of its inception (Garces; 1993:27). It must be noted in this regard, however, that the ADB was seeking a lot from a mere technical assistance project, which is always limited in its financial and time scope. The important issue of operational management would certainly be better served if was taken up as an integral part of the Chasma project. That this was not the case, but that it was delegated to a 'mere' TA project, is already remarkable in itself.

[105] Distributary # 1 received around 90 percent of FSQ. According to the CBIO this was due to two reasons: (i) the difficulties in providing sufficient hydraulic head at this off-take; (ii) the slow development of the command area.

Fig. 6.6: Water Distribution Performance Disty # 4, Chasma Right Bank Canal
Results of calibrated simulation for different supply levels, DPR [-]
(No operational interventions)

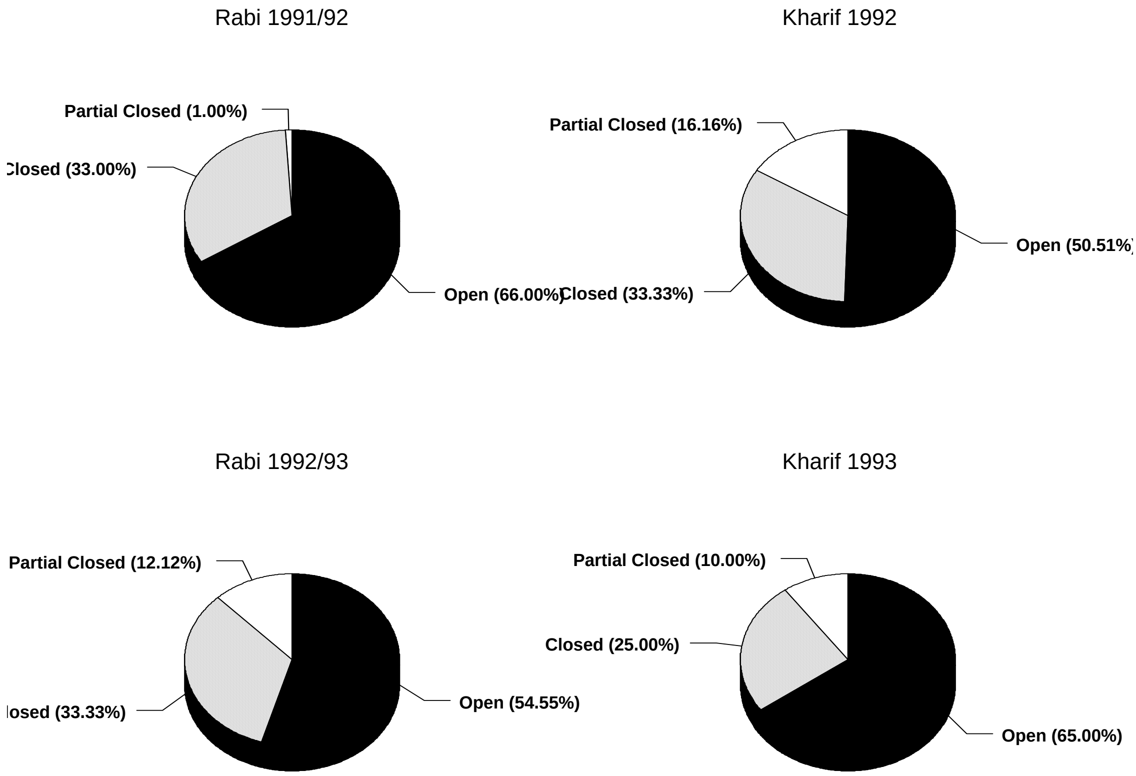


controlled. The causes hereof lie clearly in the indiscriminate use of the standard sized pipe barrel, irrespective of the tertiary command area, and the variety of hydraulic heads, and hence hydraulic flexibility, under which they function. The result is that nearly all the outlets of distributary # 3 and # 4 (*cf.* fig. 6.5 & 6.6) are able to draw off more than their design discharge. While 1/3 of them is even capable of drawing off in the range of 150 - 300 percent of design discharge.

Almost as by practical default, the water users in the newly developed area had to control their own water supplies at the outlet, by water refusal operations (i.e. closing down of the outlet). The project found that this water management strategy was indeed commonly and frequently applied in the distributaries monitored. Interestingly, a very peculiar and imaginative adaptation to the outlet structure evolved in the area to facilitate this operation. In the 'dispersion' box at the downstream side of the outlet, a simple pre-fabricated *Pucca Nakka* from OFWM is installed, with which the flow stream can be easily stopped by closing off the 'dispersion' box with the tight fitting pre-fabricated lid.

This water refusal strategy can work reasonably well in Chasma, as there are (unlike in Mardan-SCARP) very limited means to drain off the excess water at the tertiary level. Water users do thus need to take good care to avoid damages to crops and infrastructure from excessive water entering their tertiary unit. It is mainly due to the widespread and frequent refusal of water at the outlet (*cf.* fig. 6.7), in combination with generous supplies at the distributary head, that water still reached the secondary tails in adequate amounts.

Fig. 6.7: Water Refusal at Distributary # 3, Chasma Right Bank Canal
Rabi 91/92 - Kharif 1992, Percentage of Time Open/Closed



(IIMI; 1994)

These operational practices at the secondary level have had two significant impacts at the water course/tertiary level:

- Hardly any official *Warabandi* roster had been drawn-up in the newly developed command area of Chasma during the first five years of operation. Although there was a clear tendency to draw-up unofficial (i.e. *kacha*) *Warabandi* rosters under mutual consent; which provides the opportunity to deviate from the strict proportional time share allocation in order to accommodate differences in social status, water losses and soil types. However, in the day to day water management practices, most *Warabandis* were not strictly adhered to. Of the 20 water courses in distributary # 3, only 3 had no form of *Warabandi*, while the remaining 17 had all a *kacha Warabandi*; of the 36 water courses in distributary # 4 only 14 had a form of *Warabandi* drawn-up, two of which had an official *pucca Warabandi* administered by the ID.

- With the generous supply level at the distributary level, and practical ability to interfere on the water supply delivered through the outlet, water users in the new command area of distributaries # 3 and # 4 were quick to develop a marked preference for high water consuming cash crops, as rice and sugarcane. Although the overall cropping intensity did not differ significantly from that of the 'design cropping pattern', the area under rice cultivation was much larger than foreseen, while that of sugarcane was on the rise[106] (*cf.* Table 6.2).

Table 6.2: Established Cropping Patterns in Distributaries # 3 & # 4, CRBC.
Rabi 1992/1993, and *Kharif* 1993, compared to design values.

Crop	Distributary # 3 [%]	Distributary # 4 [%]	Design Crop Pattern [%]
Wheat	61.0	56.0	45.0
Gram / Pulses	16.5	12.5	5.0
Sugarcane	7.5	12.5	15.0
Fodder (Rabi)	7.5	5.5	10.0
Oilseeds	---	---	5.0
Orchards	---	1.0	5.0
Misc. (Vegetables)	0.5	0.5	5.0
Rabi Crop. Intensity	***93.0***	***88.0***	***90.0***
Rice	26.0	31.5	2.0
Sugarcane	9.0	13.5	15.0
Fodder (Kharif)	4.5	5.5	10.0
Maize	---	---	10.0
Millet	---	---	3.0
Cotton	---	0.5	10.0
Orchards	0.5	1.0	5.0
Misc. (Vegetables)	0.5	0.5	5.0
Kharif Crop. Intensity	***40.5***	***52.0***	***60.0***

(Garces-Restrepo et.al.; 1994b:84)

6.4.3 The Feasibility of Imposing Controlled Supply Variation

Based on the above described water management characteristics that had evolved in Chasma stage I during the first five years of operation, the CBIO project set out to devise a crop-based operational plan appropriate for Chasma. As mentioned, the primary aim it set itself, was to improve the regulation of water delivery in line with the actual requirements, by setting clear water delivery targets through crop water requirement calculations based on the design or actual cropping patterns (i.e. the proposed phases I & II of Mardan-SCARP). In this endeavour to formulate some form of responsive water delivery operations the CBIO project somehow could

[106] The intensity of sugarcane was initially hold back by the preferred crop rotation of rice and wheat. Though still under the design value, the cultivation of sugarcane was starting to rise.

not, or dared not, to raise the important issue of the temporary outlet structures and the adequacy of the hydraulic configuration of, and hence water control capabilities at, the secondary level. Even to the extent, that no references are made at all to this very important issue in the recommendations the project made in its final report (*cf.* Garces *et al*; 1994a).[107] As a result, the project had to concentrate itself in its recommendations on controlling supply variations at the heads of the distributaries and the main canal.

As part of its hydraulic simulation activities, the CBIO project had calibrated the head regulators of the distributaries. The general tendency to generously over supply the distributaries became quickly one of the major concerns the project tried to focus on in its operational recommendations. The CBIO's intentions in this regard were to induce a tighter control and regulation of the amount of water supplied to the distributaries. First of all to delimit the maximum supply to the 'allocated' design values, and secondly to regulate a variation in supply in response to variations in actual crop water requirements.

One of the concrete recommendations the CBIO made in order to facilitate the implementation of flow control and regulation at the distributary head, was a proposal to replace the traditional, and often inaccurate, head-gauges with proper flow measuring structures, as broad crested weir or flumes. The CBIO was, however, unable to start implementing the controlled supply at the distributary heads during the three years of the project. The flow measuring devices were never installed as part of the project, and actually never got past the stage of recommendations in the final report; nor were the calibration data generated by the project effectively utilized to implement a tight control of the water supplies at distributary heads. The latter has been attributed to the staffing problems the line agencies had in providing sufficient and adequately trained field staff, and to the lack of an adequate communication structure between WAPDA and ID, and between system managers and field operators. The suggestions made by CBIO to improve the operations of the distributary head-regulators during the course of the project were, however, also not very simple to implement under the given circumstances. From the start, CBIO has put the emphasis on having to respond to the varying crop water requirements, and to react to the water refusal operations of water users on their outlets, in a planned and systematic manner. This presupposes the existence and functioning of a communication and information gathering and processing structure, which was simply not there.

The accurate flow regulation and control at the secondary level was virtually impossible given the prevailing hydraulic configurations of the 'temporal' outlets. Nevertheless, the CBIO project has tried to show in its model that it was 'theoretically feasible' to supply the distributaries with the minimum crop-based water requirement of 36 percent of FSQ (*cf.* fig. 6.5). The practical feasibility of this simulated scenario is, however, very questionable, since the majority of off-takes were programmed at taking off a discharge equivalent to 36 percent of FSQ, to show that it was theoretically feasible to provide enough hydraulic head for the problematic outlets (i.e. # 2, 13, 15, 17 and 18) by heading up the water in the distributary by

[107] Of course, the outlet structure had become a sensitive issue, and it is understandable that the CBIO wanted to avoid raising a polemic issue as the one that governed Mardan-SCARP. It is, however, quite another thing not to raise it as an issue that needs to be addressed.

using stop-logs on the drop-structures. The recommendations eventually made by CBIO in its final report regarding the distributary system operations fall short of what could have been expected given the initial objectives of the project. However, by being unable to address the issue of the 'temporal' outlets and their hydraulic configurations, any recommendations in improved operations at the secondary level were necessarily to be delimited in scope.

Again, the primary aim of the recommendations was to induce an active regulation of the water delivery in accordance with the actual crop water requirements. The recommendations made centre around two propositions to introduce responsive operations of the distributary head-regulators:

- *"The PID could incorporate into their daily system monitoring activities the assessment of open/closure of outlets with the end-objective of deriving a method that will allow gatekeepers, based on the number of outlets closed in a particular distributary, to modify water deliveries."* (Garces *et al*; 1994a:x)

- *"This points to the need to formulate and develop a simple method that will allow the PID to calculate on a regular basis the seasonal crop demands that can be fed back into operational plans."* (Op.cit.:xi)

The first proposition would seem logical, following up on the widespread practice of water refusal operations by water users. Furthermore, it would entail a formalisation of the practice of some head-gate operators that already reacted to outlet closures on an individual basis, by diminishing the water supply during the night in periods of low demand. It is, however, questionable to what extend the practices of flexible refusal operations can be sustained, when the relative water supply at the distributary head is supposed to be delimited to its maximum design value of 0.6 l/s/ha – as was recommended by CBIO – while there are no proper means available (both in terms of operational procedures as in water control structures) to properly regulate the distribution among the outlets along the distributary. In the continued absence of hydraulic water control with the 'temporal' hydraulic configuration, the delivery of design discharges, let alone the delivery of lower 'crop-based' rates, becomes a near impossible task to perform equitably. Moreover, with a drop in relative water supply, the refusal operations at the outlets are bound to become less frequently applied as well. The loose discharge and water distribution control, coupled with the established preference for rice growing, risks to favour the development of serious tail-end problems, where the tail end will be perpetually short of water or only receive an adequate supply during the night, as was the case in the first weeks of trial operation in distributary # 3 of Mardan-SCARP.

The second proposition is dissapointing, in that in light of the objectives I & III formulated during the inception of the project, one would have hoped this to be a concrete output of the project, rather than a mere recommendation for future activities. The added suggestion that, *"A management information system (MIS) package will assist in tackling this type of problem."* (Garces *et al*; 1994a:xi) entails a guarded answer to the question as to why the CBIO was not able to provide some concrete operational and scheduling plans/procedures in the first place. The main thrust of the project activities were concentrated on the hydraulic simulations of the existing conditions in Chasma and on monitoring and analysing the established operational practices and irrigation performances at the three levels of the system. By avoiding the issue of the 'temporal' outlets, it never got to a stage were a decision was made on the principle of flow regulation and water delivery scheduling to be adopted at the secondary level, and that hence could have been tried out as a pilot on one of the distributaries. This impeded the project from developing a MIS itself, where attention could have been given to monitoring and scheduling procedures to be adopted by the ID.

With the hydraulic simulations in the SIC model, the CBIO tried to address some of the problems WAPDA was facing in the main canal, as well as trying to enable the control of varying flows in accordance with crop-based operations. A clear concern of WAPDA with regard to the latter, which the CBIO tried to address, was the problems it faced in running the canal at low flows. Initially, the minimal flow for the main canal, based on the lowest crop water requirements of the design cropping pattern, was defined as 40 m^3/s for the whole completed Chasma. Of these 40 m^3/s, 30 m^3/s would then have to be passed through past the tail of stage I. WAPDA has had clear reservations from the start as to the feasibility of operating the canal at such low levels. The simulations in the SIC model also clearly showed that it would be very difficult to operate the canal at such a low level, with the limited number of cross-regulators situated far apart. CBIO tried to address this particular issue – which it regarded as a basic principle of crop-based irrigation operations – by running a scenario for the main canal that featured one extra cross regulator to facilitate the control of the required hydraulic heads for the distributaries of stage I. This proved, however, to be not such a successful alternative, since the added cross regulator would create further low flow velocities in the main canal, and hence further increase the risks of siltation.[108] In the end, CBIO had to recommend that the initially planned minimum flow for the main canal be increased to 50 m^3/s, in order to facilitate distribution to the distributaries of stage I while retaining adequately high flow velocities throughout the main canal.

In the various simulations run through the hydraulic model of the main canal, concerns about its carrying capacity at full supply came to light. According to the simulations run at 85 percent (i.e. 105 m^3/s) of the intended full supply discharge – and verified with the measured hydraulic data set – the main canal would face capacity problems, as it started to infringe already on its recommended freeboard at its lined-unlined transition point (RD 120+000) and the lined tail of stage I. According to CBIO this problem is associated with the Manning roughness coefficient that was used for the design of the lined sections of Chasma, in which a standard text-book value of 0.016 was used. From the measurement and calibration of the hydraulic model, however, it turned out that the empirical value of this coefficient is closer to 0.022, which results in lower flow velocities and higher water levels than foreseen. (A similar issue arose in Swabi-SCARP,

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[108] The problem of low flow velocities in the main canal is directly related to the type of cross regulator, and type of water control, that has been adopted in Chasma and in the simulation scenario of CBIO. In Chasma, the undershot cross regulator is used, with the idea of heading up the water levels, and hence reduce the flow velocities, at times of low supply in order to secure enough hydraulic head for the off-takes. This particular problem relating to the issue of regime and siltation problems, can be better addressed by an other type of water control and cross-regulator. By using over flow long-crested weir type cross regulators, that are configured to maintain a specific water level at minimum flow, no ponding of water, and hence low flow velocities, are required to maintain sufficient hydraulic head.

where the designers used the same low Manning value, and hydraulic simulations and analysis of ACOP canal measurements resulted in the same empirical value of 0,022). Added with the siltation problems that were already arising at the tail of stage I, worries arose about whether the full capacity flow of 138 m^3/s could be carried by the canal.

6.5 DISCUSSION & CONCLUSIONS

The CBIO centred its efforts to propagate crop-based irrigation operations in Chasma on two related issues. It entered head-first into the ongoing 'modernisation debate' in NWFP in defence of the desirability to control a variable water supply in accordance with the variable crop water requirements. The notion of crop-based irrigation was strategically chosen to overcome the skepticism of the ID and WAPDA about varying and responsive water control in general, and demand-based operations in particular. The strategy applied by CBIO was thus to show that it was feasible to control supply variations required to closely match crop water requirements in a system like Chasma, and furthermore that it was possible to do this in a manner that retained the centralised control of canal operations. The use of the hydraulic simulation model served to show that such varied canal operations were indeed possible, in defiance of the entrenched convictions of the line agencies that, out of Regime considerations, canals in Pakistan should be run around their FSL and not below their 75 percent FSL threshold.

What does not seem to have been fully acknowledged by CBIO, however, is that the whole exercise of hydraulic modelling covers only part of the operational management requirements of any form of planned and controlled irrigation water delivery. Hydraulic modelling concentrates on only one, albeit an important, aspect of operational management: the operationalisation of the operational plan. In other words; defining the executable tasks and targets that operators will have to execute on the irrigation infrastructure in order to implement any particular water delivery. As such it forms an important means to define the interaction between technology and management. By means of calibrations and enhanced specific hydraulic understanding it shapes the operational management by defining the capabilities of hydraulic water control one can exert and the option it possesses to implement different water delivery schedules. However, in management terms, this is only part of the tasks. The planning process itself, as a directive control on the operational execution, is also an inherent part of operational management. In case of crop-based irrigation, it is exactly this planning that forms the main thrust of the feed-forward mechanism that is required to engage in a pro-active management for tuning water deliveries with anticipated requirements or arranged demands. Generally this planning entails more than a mere decision taken in the selection of an alternative out of a set of pre-defined options. Crucially, it entails a weighing of the available water against the anticipated requirements/requests, and a prioritisation of delivery in accordance with the allocation rules. As such it is a process that requires its own set of information, procedures, tasks and objectives and targets. Within the CBIO project this planning was conducted by the project itself. It subsumed a set of delivery strategies and targets – primarily based on the appreciation that the water delivery should match the crop water requirements of the designed or actual cropping pattern – to direct the operations within the hydraulic model. The required monitoring, information processing, scheduling and target setting would thus be conducted by the project itself (almost as a black box) in the continued absence of an appropriate MIS. For each set of operational strategies and delivery targets, the model would then come up with the required procedures and sequence of operation activities, that could then be used as instructions to the various operators within the canal network.

In a sense the CBIO project got carried away with the effort of using the hydraulic model as a means of identifying feasible options for the operational management of crop-based irrigation. The model requires a huge effort to calibrate and validate it to the field conditions, which in the end consumed a major part of the time and effort of the project. To be fair, this yielded quite an unique situation, in which all the major control structures were calibrated and provided with the necessary operational means as gauges and calibration curves/tables; a prerequisite for any form of tight operational water control. The CBIO project, however, failed to define and implement any procedures for the planning of crop based water deliveries that are required to direct the operationalisation of scheduling options by means of the hydraulic model. Adopting the assumptions of matching the crop water requirements, it proved that the new canal configuration at the main level was able to deliver reduced and varying rates at the distributary heads; be it with some difficulties and by raising the minimum target discharge. It did, however, not convince WAPDA or the ID for adapting their operational practices.

In the end, it seems that CBIO spent too much effort on trying to show that variations in water delivery could be implemented in Chasma for the sake of winning an argument, without carefully considering whether this was really necessary, or the most appropriate solution, to win the 'debate'. Given the institutional set-up, and taking into consideration the technical difficulties of the main canal of Chasma, it is questionable if indeed the main system itself has to be operated according to crop-based flow variation criteria. The hydraulic simulation results have made it clear that the traditional operational methods would ease the technical distribution problems of supplying all the off-takes, as well as facilitate the regime settlement of its head-reach, while reducing the risks of siltation in the lined reaches. This would seem to counter the whole intention of introducing some form of crop-based and responsive irrigation operation. This does, however, not impede the introduction of such operations at the lower levels of the system. It would enable to regard the main canal of Chasma more as a traditional link canal, that supplies the secondary sub-systems managed by the ID. The operational responsibilities could then be split according the traditional agencies' domains and the hydraulic units of the system. WAPDA would in such case, be able to administer the water distribution as it does currently for the whole IBIS, where daily intakes at the ID's systems are monitored and processed. Any amount of water carried in abundance through Chasma main canal could then be diverted back into the Indus at the various escape locations. By concentrating on a monitoring and information system, in which the water is accounted for, the Chasma diversion into the Indus can be taken into account of the downstream releases for Tunsa and Sukkur Barrages at Chasma.

The CBIO could then have concentrated itself straight away on delimiting the maximum delivery at the distributaries to the 'allocated' design discharges. These distributaries could then be operated by the ID on the same principle as for the intakes of their systems in the IBIS, where they have to indent their intake, and where the daily intake is measured and supplied to WAPDA. In a first phase of crop-based operations, attempts could then be made to vary the distributary flows crudely, say on a quarterly basis first. Since escape facilities are available at the distributaries, the spillage of operational losses are feasible. This is a feature that could have been used favourably in trying to devise as simple as possible operational procedures. A clear recommendation should have been made, and preferably tried out, by CBIO to choose a permanent outlet structure that facilitates and formalises the refusal operations by water users, which at the same time allows for a hydraulic control of the water distribution along the distributary at different supply levels. One can think of a Crump-deGruyter outlet structure with refusal gate, with which the operating agency can simply control the maximum supply by regulating the orifice at the desired discharge level; while water users can keep fine-tuning the supply by closing and re-opening the refusal gate.[109] Such outlets would then have to be configured with a hydraulic flexibility of $f << 1.0$, to aim for a $F >> 1.0$ at the distributary itself (*cf.* section 2.6).

Such an approach would simplify the operational requirements, allowing for a gradual fine-tuning of the supply to the requirements by aiming for a gradual decrease of the operational 'losses' at the tail. By simplifying the operational requirements to an easy 'setting' of discharges at the head regulator and the outlets, more emphasis can be given to monitoring and information gathering. An MIS system can then be slowly built-up, with the principal aim in a first phase to account for the water supplied and used, while concentrating in subsequent phases on devising scheduling procedures that are feasible and that aim at gradually minimizing the operational 'losses'.

After completion of the CBIO project the 'modernisation debate' is still going on in general terms of whether the close matching of the water supply to the crop water requirements at the main and secondary level is desirable and feasible. While still no concerted efforts have been made yet to simply try out a form of controlled flow variation at the secondary level, in which the ID can retain control of the scheduling and distribution arrangements. This is unfortunate. In the continued absence of any concrete trials that provide examples on how the rate, frequency and duration of the irrigation water delivery service can be regulated in order to come to a better service and a closer match between supply and requirements, the line agencies can continue to put forward their entrenched objections to change. While water users are left with little options than to try to capture advantages in water delivery service and flexible water management opportunities by incorporating drainage and water refusal strategies as water control mechanisms in their management of relative water abundance.

[109] Another solution might be to use a Neyrpic type of outlet structure, with which the supply level can be easily regulated by the number of compartments that are locked/un-locked, while water users can conduct their finetuning by simply closing and re-opening the unlocked compartments. It is, however, to be feared, that this type of outlet will not take its due share of silt, due to its relatively high setting. The Crump-deGruyter outlet, is basically a modified APM structure with a calibrated regulable roof-block, and like the APM, is known to take its due share of silt.

CHAPTER SEVEN

TRYING OUT NEW MODERNISATION STRATEGIES

BACK TO THE 1920s & INTO THE 21ST CENTURY: THE CASES OF SWABI-SCARP & PHLC

"It is clearly preferable to have a sub-optimal system that is seen to work, than to have a system with the potential for better performance which can not be made to work." (SSC; 1991b:9)

7.1 INTRODUCTION

The difficulties and draw-backs experienced with the attempts to introduce some form of crop-based irrigation in Mardan-SCARP and CRBC , left the question on how to modernise irrigation in Pakistan un-resolved and still open to debate. The question itself, however, was immediately raised again with the Swabi-SCARP and Pehur High Level Canal (PHLC) projects that foresaw new irrigation developments in the Peshawar Vale, making use of the water share still available to NWFP after the Indus Water Apportionment Act. Swabi-SCARP is a project similar to Mardan-SCARP, in that it entails the remodelling of the existing Upper Swat Canal system (USC) and the near doubling of its water delivery capacity, while PHLC consists of developing a new irrigation system making use of Tarbela reservoir, but linking its main canal to the USC. Both projects were also clearly aimed at providing some form of 'productive' irrigation with cropping intensities above 150 percent, in which the relatively high water availability provided the potential to match the irrigation water delivery with crop water requirements.

As to how to match the water delivery to the crop water requirements in a congruent water control and irrigation management concept, Mardan-SCARP and CRBC had failed so far to come-up with a tested and accepted 'solution' that could be adopted and refined in Swabi-SCARP and PHLC. If anything, Mardan-SCARP had clearly brought to the fore the controversies in varying water deliveries at the outlets and secondary level, and the objections of the ID to the notion of having to vary the water flow in response to farmers' needs or requests/demands. Both Swabi-SCARP and PHLC had thus to re-address this whole notion of controlled variation in water delivery in their designs, taking stock of the experiences and polemics of Mardan-SCARP and CRBC. Not in the least because both projects were to work on irrigation systems in which the Mardan-circle of the ID – the same circle that is responsible for the LSC remodelled under Mardan-SCARP – would bear the O&M responsibilities (*cf.* fig. 7.1).

In this chapter both Swabi-SCARP and PHLC are presented together, as after completion they will form a hydraulically interconnected system that will have to be operated in an integrated manner in order to optimise the water use of two sources. They are also treated here together as they represent two components of a second phase of irrigation modernisation interventions that were to re-try to conceive new water control and operational concepts that were suitable for the context in NWFP, taking into account the experiences of the previous attempts in Mardan-SCARP and CRBC. In terms of the water control concepts adopted by Swabi-SCARP and PHLC, however, they would seem a remarkable grouping, as they opted seemingly for diametrically opposed strategies: Swabi-SCARP opted for a rehabilitation of the proportional water distribution and Crump's water control concept; while PHLC opted for the automation of downstream water control and the flexible delivery of water through a low pressured pipe system up to the farm gate. This chapter takes up the story behind the first part of the canal safari in chapter one.

In the next section a brief description is provided of the Upper Swat Canal, and the problem analysis from which the modernisation objectives for USC and PHLC have been derived. Section 7.3 presents the conceptualisation of the self-acting proportionality by Swabi-SCARP, with an analysis of the considerations for technical water control and the operational control

Fig. 7.1: Map of Project Locations (Mardan & Swabi SCARP, and Pehur High Level Canal)

mechanisms. Section 7.4 provides the results of post-construction performance evaluations that have been conducted on two distributaries of Swabi-SCARP. The issue studied, was whether the newly remodelled canals performed proportionally, and whether the hydraulic configurations where conform the concept and the design. Section 7.5 gives a brief description of the automated downstream control concept of PHLC, in which issues of both technical and operational water control, are discussed. Finally some conclusions are drawn on the 'modernisation' attempts undertaken, and on the process of conceptualising new water control and delivery strategies.

7.2 THE UPPER SWAT CANAL AND ITS IRRIGATION PROBLEMS

7.2.1 General Features of Upper Swat Canal

When the Upper Swat Canal (USC) was commissioned in 1914 it represented the apotheosis of British irrigation engineering. It was build to command an area of 120,000 ha (300,000 acres) of crown waste land at the northern fringes of the Peshawar Vale, at the border of the British Indian Empire itself. The mountainous terrain, with its numerous ridges, and the numerous natural streams or *nullahs* that cut across the plain, formed natural obstacles to the conveyance line that required considerable engineering skills to overcome. Furthermore, the water intake of the system from the Swat river had to be situated north of a mountain range, for which a tunnel had to be build to convey the water to the command area on the plain south of the Malakand pass.[110] The costs for the construction of USC, that required numerous tunnels, aqueducts and siphons to defy the natural obstacles imposed by the terrain, were thus formidable. At a cost of Rs 66 per acre irrigable, it was the second most expensive irrigation system built by the British in 1920; more than twice the cost of Rs 28 per acre irrigable of LSC (Buckley; 1920).[111] That the construction of USC was nevertheless approved by the Colonial Authorities, is due to political reasons. The USC was developed as a political settlement area to induce the wandering and 'unruly' Pukhtoon tribes from the surrounding hills to settle into administrable agricultural live (*cf.* Stone; 1984, and Whitcombe; 1983)

The USC takes its water from the Swat River at the headworks situated at Amandara, north of the Malakand pass. The headworks include a regulator across the Swat river, to secure the intake of water during the *Rabi* season when river flows are low. From the intake the water is conveyed through a 6 km long contour canal before entering the 3 km long Benton tunnel through the Malakand range. At the exit of the tunnel a 20 MW power house was built by the British to try to recoup some of the investment costs through energy generation. After this first power station the water flow is split at the Malakand trifurcator, where 28 m^3/s (1000 cusecs) is diverted along a contour canal to the second 20 MW power generator at Dargai. The remaining

[110] The intake of USC at Amandara on the Swat River was thus formally located outside the British Indian Empire, at the confines of the kingdom of Swat. Winston Churchill was posted there during his first military service and spent quite some time guarding this Empire frontier, manning watch towers around Amandara.

[111] The Upper Jhelum Canal was the only canal that exceeded the costs per acre irrigable of the USC. The average unit cost of Rs 90,127 per mile of main canal of the USC, however, was never surpassed in other systems. (Buckley; 1920)

water flow is diverted downstream into the USC main stone pitched channel, or through the escape when the system is closed or requirements are particularly low. The stone pitched main channel continues its flow downstream over a number of small steps (i.e. falls), over which the water cascades down into the Vale. Before reaching the trifurcator at Dargai, the 28 m^3/s (1000 cusecs) used at the second power station are returned to the main canal. At Dargai (*cf.* fig. 7.2), the USC is split into two branches; Abazai and Machai (also at Dargai there is an escape structure into the Dargai *nullah*, which forms the third part of the trifurcator). The right bank Abazai branch is the smaller of the two and runs for approximately 18 km (60,000 ft), feeding 5 distributaries and 2 minors. The Abazai branch itself features 7 siphons and 17 falls. The larger left bank Machai branch runs for approximately 76 km (250,000 ft) and feeds 3 branch canals, 14 distributaries, 3 minors and 61 direct outlets. The canal itself features 5 siphons, 5 aqueducts, 6 tunnels and 20 falls to negotiate the natural drains and obstacles in the terrain. The stone pitched cascading main canal between the Benton tunnel and Dargai trifurcator, and the aqueducts, siphons and falls in high quality masonry work, are all impressive works of engineering and beauty. That all these works were still in proper order and use after 80 years, makes them all the more impressive.

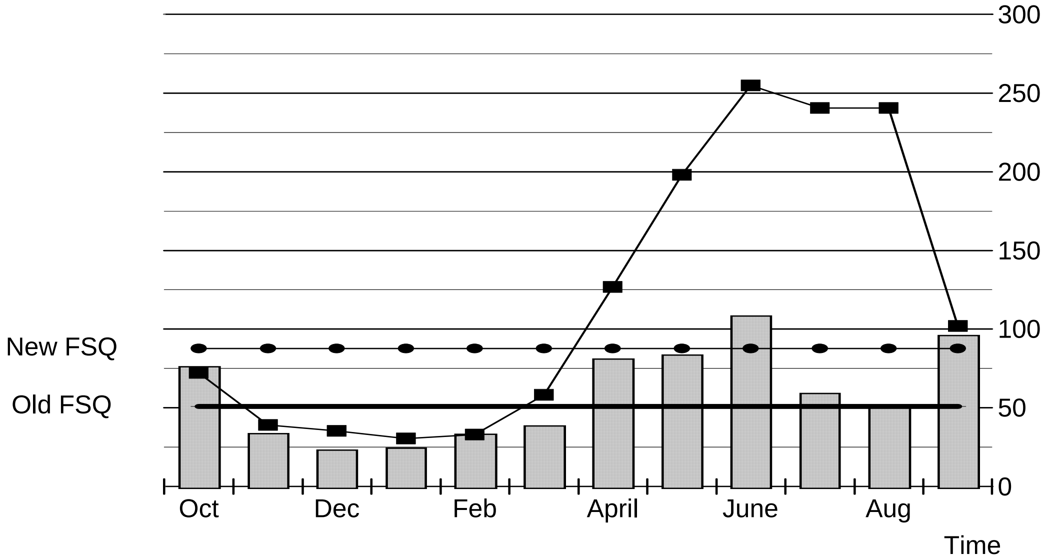
Apart from its impressive main canal works, the USC was a similar irrigation system as the LSC and other systems build in the Indus basin. With a FSQ of 51 m^3/s (1800 cusecs), it provided for a *Water Allowance* at the outlet of 0.35 l/s/ha (5 cusescs/1000 acres). After 1922, the Open Flumes and APM were installed, and in some canals modified Crump outlets featuring a ‘stilling box’ at the upstream end (i.e. in the parent canal), to provide for the self-acting proportional water control.

Fig. 7.2: Map of Upper Swat Canal System
(Research sites of Kalpani & Jalala distributaries indicated)

7.2.2 Problem Definition and Objectives for Modernising USC & PHLC

The original design of 1914 for USC foresaw a carrying capacity of 68 m^3/s (2400 cusecs) at the mainline canal. However, the construction of the Benton tunnel had yielded some minor problems, due to which its maximum capacity was restricted to 51 m^3/s (1800 cusecs) only. After commissioning the USC was thus chronically short of 17 m^3/s (600 cusecs), which has impeded the full development of its planned for command area and cropping intensities, particularly in its tail-end areas. The tail reaches of the Machai branch canal actually never ran at more than half their design discharge, depriving a good 40,000 ha (100,000 acres) of its intended *Water Allowance*. (SSC; 1992b) With the Swabi-SCARP/PHLC projects it was not only the intention to eradicate this chronic water shortage and tail-end problem by supplying the entire original command of USC with a new increased normal supply of 0.63 l/s/ha. It was also to provide the possibility to further expand the command area; 12,500 ha (31,250 acres) within the command of USC and 8,500 ha (21,250 acres) in the command of PHLC (Bozakov & Laycock; 1997). From the start it was clear that the Swat river at Amandara would not be able to provide enough water during the *Rabi* season to meet all these new increased requirements (*cf.* fig. 7.3). The PHLC would have to supplement the water supply substantially with water from Tarbela reservoir. From the onset, when the first plans for PHLC were made in 1971 during the construction of Tarbela, it has therefore been the intention to connect the PHLC to the Machai branch canal of USC at Km 73.7 (RD 242+000), to provide additional supply for the 32,000 ha (80,000 acres) of its chronically water short area (*cf.* fig. 7.2). For Swabi-SCARP it was thus important to conceive, from the start, a water control and operational plan for the USC main system in which both water supply sources (i.e Swat river and Tarbela reservoir) would be

Fig. 7.3: Water Availability & Requirement at Amandara Head Works
Avg. monthly discharge in Swat river at Amandara; monthly water requirements for USC & PHLC command [m^3/s]



(SSC; 1992a)

integrated. In order to do so, it needed to settle the question on how much water, and according to which criteria, could be supplied from PHLC to the tail of USC, and consequently how big the carrying capacity of the conveyance network upstream would have to be.

Water Supply Objectives and Criteria for Integration of USC & PHLC

With the Indus Water Apportionment Accord of 1991, it was decided that NWFP would receive an annual volume share of the water stored in Tarbela reservoir of 0.65 km^3 (0.53 MAF) for irrigation. The preliminary indications by the ID were that this volume should be used over the growing seasons as follows: 0.21 km^3 (0.17 MAF) in *Rabi* and 0.44 km^3 (0.36 MAF) in *Kharif*. These values thus represented the maximum volumes to be used by PHLC. The initial idea, as expressed in the feasibility study and ToR of Swabi-SCARP, for integrated management of USC and PHLC, was to transfer a fixed water supply of 9 m^3/s (320 cusecs) from USC at Machai branch km 73.7 (RD 242+000) downstream, and supplement any shortcomings with water from PHLC. However, from an early stage the Swabi-SCARP project team questioned this option, and set out to explore different options for the integrated use of both water sources, seeking maximisation of the water use and simplification of operational procedures. As can be derived from fig. 7.3, the main problem for USC has always been the low water availability at Amandara during the *Rabi* season. Typically the winter river discharges available for USC at Amandara drop down to 23 - 38 m^3/s (812 - 1340 cusecs), less than half its old full capacity of 51 m^3/s (1800 cusecs). These low winter flows form a limiting factor for the irrigation development in USC, as the proportional water control requires rotational water distribution to be applied at the main system level during the *Rabi* season. The development of PHLC thus provided the opportunity to alleviate these winter shortages in *Rabi* with additional supplies from Tarbela reservoir, which is full at the end of *Kharif* and the greater part of the *Rabi* season.[112]

The Swabi-SCARP project team explored two basic options for the integration of USC and PHLC. The first one consisted of 'transferring' the tail command area of 32,000 ha over to the PHLC, in the sense that the latter would fully supply the irrigation requirements of this area.[113] The USC would only have to supplement some shortages from Machai branch Km 73.7 (RD 242+000) during the periods of peak requirements in *Kharif*. The PHLC would then have to draw off from Tarbela reservoir at its foreseen maximum capacity of 28.3 m^3/s (1000 cusecs) during much of *Kharif*, including during the peak requirement month of June. In order to be able to draw this full capacity of 28.3 m^3/s (1000 cusecs) during June, the operational rules for Tarbela reservoir would have to be modified by guaranteeing a minimum water level in the reservoir that is 3 m (10 ft) higher than the current operational 'silt flushing' rule (*cf.* Note 112).[114] This option

[112] Tarbela reservoir is drawn down towards the start of *Kharif*, reaching its lowest level in June. During this month it is operated at its low level in order to flush as much silt as possible out of the reservoir with relatively high summer Indus discharges; it is then filled up quickly over the two months of monsoon in July and August.

[113] The delivery capacities for PHLC and USC were based on the calculated irrigation requirements and water delivery criteria adopted by Swabi-SCARP; these are treated in the section below.

[114] This analysis could be made by Swabi-SCARP prior to the initiation of PHLC project, since the PHLC was conceived already in 1971 during the construction of Tarbela itself. As a consequence, the intake tunnel from

(continued...)

had the advantage for Swabi-SCARP in that it would require a lower intake and carrying capacity for USC (79 m^3/s (2800 cusecs) instead of 88 m^3/s (3100 cusecs)) at its main canal, and considerably less capacity, and hence remodelling, of the Machai branch canal. Furthermore, the *Rabi* water shortages would be considerably alleviated by the virtual transfer of nearly one third of the command area to the PHLC. In the end, this option did not get approved by the government of NWFP, although it had the initial preference of the Swabi-SCARP project team. The main reason that it was not approved, was that PHLC should economise as much as possible on the water of Tarbela reservoir, which has a high economic value in terms of the power generated with it at Tarbela.

The second option explored by Swabi-SCARP consists in essence of a reversal of the supply criteria for PHLC. The USC would thus be remodelled for a maximum capacity of 88 m^3/s (3100 cusecs) supplying as much as possible its tail-end area below the confluence point at Machai branch Km 73.7 (RD 242+000), where PHLC would supplement any shortcomings in water supply. In this option, USC would then supply up to 21 m^3/s (748 cusecs) to the area downstream of the confluence point, while PHLC would be required to supplement this with up to 12 m^3/s (407 cusecs) during peak requirement periods (compared to the 19 m^3/s (657 cusecs) in the first option). This option got eventually approved, with the important addition, that PHLC would take over the complete supply of the areas downstream of the confluence during the for USC water short *Rabi* season, reducing substantially its need for rotation of water supply at the main level once PHLC is completed. (SSC; 1992a&b)

7.3 BACK TO THE BASICS: IMPROVING USC BY RE-APPLYING CRUMP'S SELF-ACTING PROPORTIONALITY

The Swabi-SCARP project, as initially defined in its feasibility study and Final Project Plan (FPP), bore remarkable similarities to that of Mardan-SCARP. In essence Swabi-SCARP was not merely conceived as a followup to Mardan-SCARP, but also as an extension of the remodelling and modernisation objectives to USC. WAPDA, and potentially its consultants for Mardan-SCARP, could thus 'roll on' to Swabi-SCARP after completion of Mardan and reapply as much was feasible the design and implementation procedures in USC. However, the polemics that had arisen around the outlet structure and the 'demand-based' irrigation concept of Mardan-SCARP during the early stages of implementation, made this scenario unfeasible. The water control and delivery concepts to be applied in Swabi-SCARP had clearly to be re-addressed, as even before the start of the project it had become evident that the Irrigation Department Circle of Mardan refused to accept the 'demand-based' operation concept of Mardan-SCARP (*cf.* chapter four). Swabi-SCARP had thus to start anew in conceiving an appropriate water control and delivery concept with which to meet the remodelling and modernisation objectives of the project. Tellingly, a different consortium of consultants was commissioned in 1990/91 (i.e. Swabi-SCARP Consultants (SCC)) to execute this task together with WAPDA.

(...continued)
Tarbela reservoir, which delimits the maximum discharge capacity to 28.3 m^3/s, was already built in 1974.

7.3.1 Post-Mardan: Re-Interpreting the SCARP Remodelling Objectives

The general objectives for the remodelling of USC by Swabi-SCARP, as defined by the feasibility study and FPP, were thus very similar to those of Mardan-SCARP (see section 4.2.2):

I. increase the water delivery capacity of the systems;
II. provide for sub- and surface drainage capacity and the reclamation of 16,000 ha (40,000 acres) of CCA affected by water logging and salinity;
III. provide 'enough' flexibility in the system so that some form of 'modified-demand' operation can be established.

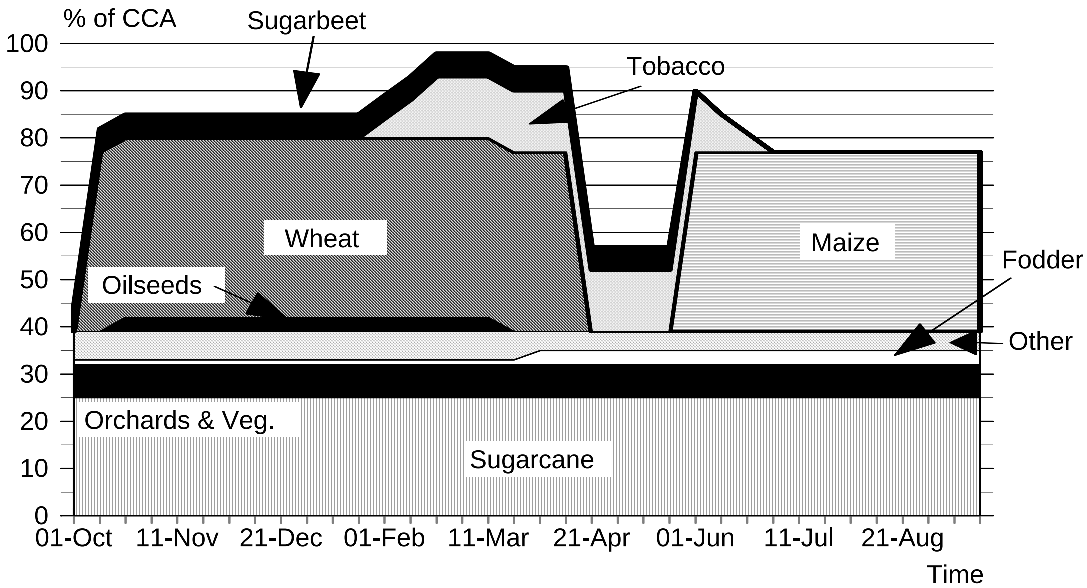
As in Mardan-SCARP, the water delivery capacity for USC was determined on the basis of meeting crop water requirements of an assumed cropping pattern, by application of the same methodology. Both the cropping pattern as the irrigation requirement calculations were determined by the FPP for Swabi-SCARP. The cropping pattern assumed for USC was slightly different from the one used for Mardan-SCARP, with a cropping intensity of 175 percent (90 percent in *Kharif* and 85 percent in *Rabi*), with slightly lower intensities for sugarcane and orchards & vegetables, and slightly higher intensities for Tobacco (*cf.* fig.7.4 in comparison with fig. 4.4).

The 'normal' increased water supply capacity for Swabi-SCARP was defined as providing a *water allowance* of 0.64 l/s/ha (9 cusecs/1000 acres), with which the peak crop water requirements of the assumed cropping pattern could be met (*cf.* fig. 7.5).[115] The 'modified-demand'[116] water delivery capacity for USC was set at the same level as for Mardan-SCARP, at a *Water Allowance* of 1.34 l/s/ha (19 cusecs/ 1000 acres). This value was derived from the crop water requirement analysis for the design of LSC (*cf.* section 4.3.2)

[115] The peak crop water requirements of the design cropping pattern for USC actually exceed the normal *Water Allowance* of 0.64 l/s/ha. This is, however, dependent on the calculations. The value of 0.64 was determined in the feasibility study for Swabi-SCARP. Although the calculations conducted by Swabi-SCARP Consultants, as presented here, yielded slightly higher crop water requirements than the feasibility study, the original value of 0.64 l/s/ha as normal *Water Allowance* was retained for the project. In these calculations, it was assumed that the overall tertiary unit conveyance and application efficiency would lie around 60 to 75 percent. (SSC; 1991a)

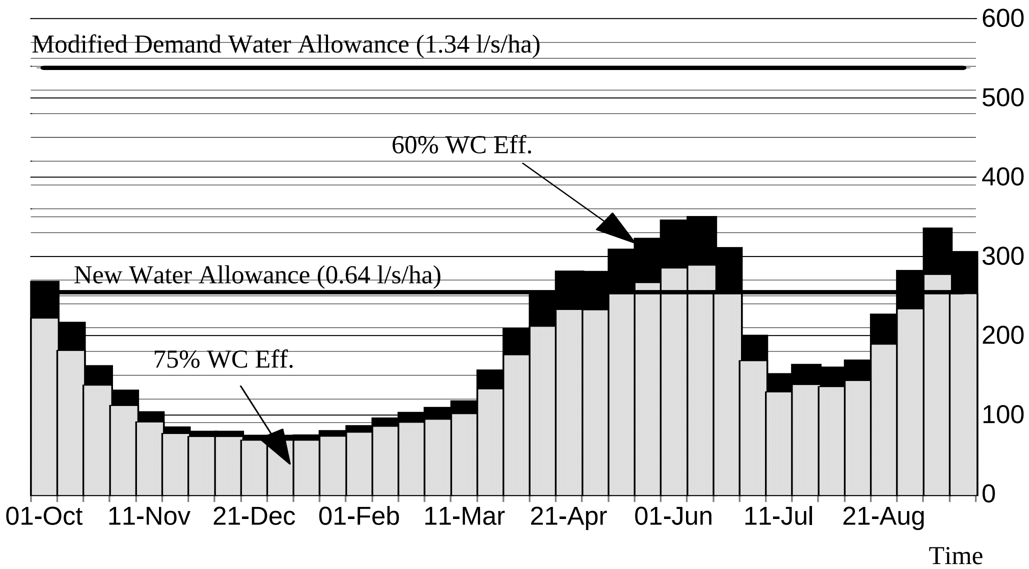
[116] It is curious to see this notion of 'modified-demand' pop-up in Swabi-SCARP documents as early as 1991. It is not clear where this notion came from, apart that it has been introduced in the vocabulary of the modernisation debate in NWFP after the troubles started in Mardan-SCARP. In the latter project, documentation always referred to demand-based irrigation. The CBIO also started using the notion 'modified-demand', alongside its preferred notion of 'crop-based'. What is clear, however, is that the notion 'modified-demand' was intended to appease some of the fears of the ID that surfaced during Mardan-SCARP, in which demand-based was being associated with freedom of water use.

Fig. 7.4: Design Cropping Pattern for Swabi-SCARP



(SSC; 1991a)

Fig. 7.5: Swabi-SCARP Irrigation Requirements
At Watercourse Head, for 400 ha (10-day periods) [l/s]



(SSC; 1991a)

From an early stage, in 1991 when the conflict around the operational management procedures for Mardan-SCARP was reaching its highest intensity, the project team (consisting of WAPDA and a consortium of foreign and national engineering companies named SCC) explicitly questioned the feasibility of introducing controlled variation of water supply in USC in the immediate future. The experiences in Mardan-SCARP prompted the Swabi-SCARP project team to postpone any decisions on the 'modified-demand' operations and water control concept to a future stage. Instead, it proposed to remodel the USC for proportional supply at the increased 'normal' supply of 0.64 l/s/ha, but with enough capacity to accommodate the 'modified-demand' capacity of 1.34 l/s/ha, so that the system could be 'upgraded' for modern operations in the future with relatively low investments in water control structures and regulable outlets. This proposition was readily approved by both the Government of NWFP, as the ADB.

Swabi-SCARP thus opted for a phased modernisation process for USC, in which the decision on responsive canal operations and water scheduling methods were postponed into some future stage. In the first phase, conducted by the Swabi-SCARP project, the USC would be upgraded for its future water requirements, while the self-acting proportional water distribution would be re-established for the new normal supply level. In this phase, the remodelling of USC would thus be mainly restricted to the improvement of the irrigation conditions – in terms of higher water availability, improved drainage conditions and rehabilitation of the proportional water distribution – under traditional water management practices. Once these improvements were established under traditional management practices, they would create potentials to modernise the operation and management for a more responsive water delivery service at a future date.

As becomes evident from a comparison between the irrigation requirement figures for Mardan- and Swabi-SCARP (*cf.* figs. 4.5 and 7.5), the option to revert back to Crump's self-acting proportionality – while simultaneously better meet the crop water requirements – was much more feasible in the case of Swabi-SCARP than that of Mardan. The variation of irrigation requirements is less pronounced in the case of Swabi-SCARP, while the periods of low water requirements have to be met by rotational water supply due to the shortages in water availability at Amandara (i.e. October - March), or by reducing or closing down the system supplies in response to monsoon rainfall (i.e. July - August) as has been common practice for decades (*cf.* fig. 5.1). Swabi-SCARP's choice for reapplying Crump's self-acting proportionality thus bares remarkable similarities with the original ideas for the operational stage one of Mardan-SCARP, as expressed in the latter's FPP (*cf.* §4.4.1).

The drainage component of Swabi-SCARP followed, as originally intended, largely that of Mardan-SCARP, in which the same machinery and drainage materials were used for the sub-surface network, and further work continued on establishing the optimal drainage coefficients and drain spacings.

Proportional Distribution and Rotational Delivery

At the secondary level of the system the self-acting proportional water distribution, as conceived by Crump in 1922 (*cf.* § 2.6), was to be re-established by Swabi-SCARP by using the traditional Open Flume and AOSM outlets. In order to maximise the benefits of the increased supply and the potentials for future modernisation, the Swabi-SCARP design foresaw in adding a downstream refusal gate on all the outlets. The design thus anticipated the practice of water refusal operation by water users, as evolved in LSC and CRBC, by opting for purpose built refusal gates. Water users would thus be formally allowed to close their outlets and start taking into account their actual water requirements in their water management practices. This, as was frequently stressed by CBIO, is a good preliminary stage for the modernisation of canal operations. The relatively low 'normal' *Water Allowance* of 0.64 l/s/ha (9 cusecs/ 1000 acres) does, however, not provide much excess supply for such an inducement of refusal operations (*cf*. fig. 7.5), particularly when water will be supplied in rotation during *Rabi*. In order to accommodate the water refusal operations of the outlets, the design foresaw provision of escape structures at the tail of each distributary and minor, and at locations along these canals where the freeboard would be reduced by 50 percent when 60 percent of the upstream outlets are closed.

The carrying capacity of the distributaries, minors and water courses had to be determined by the 'modified-demand' water requirements, so as to prepare the system for future modernisation of operation and management. Since during the first phase the canals would be operated at the normal supply level, and the maximum supply of 'modified-demand' would be required only during short peak-demand periods, the distributaries and minors were designed to accommodate this higher flow in their freeboards. The outlets were thus to be configured according to Crump's criteria for the 'normal' full supply level of 0.64 l/s/ha. The determination of the 'modified-demand' canal capacities was done by applying the same criteria as Mardan-SCARP (*cf.* section 4.3.2):

CCA < 250 acres (100 ha)	Q = 0.019 * CCA (including losses)
250 acres < CCA < 10,000 acres	Q = 0.057*(CCA)^0.8 (+ canal losses)
CCA > 10,000 acres	Q = 0.009 * CCA (+ canal losses)

Based on the decision that PHLC should supplement the shortages in USC, rather than *vise versa*, the maximum capacity for USC main canal was set at the high option of 88 m^3/s (3100 cusecs). Once PHLC would be completed, the water delivery capacity of USC would be supplemented with water from Tarbela to alleviate any water shortages in the tail of USC and allow for the further expansion of its command area with 12,500 ha (31, 250 acres). This meant that Swabi-SCARP had to take into account in its design for Machai branch and the operational plans for USC, three different stages of water supply and command area development:

I. USC remodelled, but PHLC not yet completed and no new area developed;

II. USC remodelled and PHLC completed, but not all new area within USC command yet developed;

III. both projects completed as well as all new area fully developed.

The main issue being, that the rotational requirements and 'blocks' would change over the years. Following-up on the traditional proportional water distribution methods of the ID, Swabi-SCARP intended to apply the winter rotation at main system level according to the traditional rules: sub-dividing the command area in two halves, each of which receives its full supply flow (or all available flow) for eight consecutive days, after which the other half is supplied. The rotation is required as soon as the supply levels fall below 75 percent FSL, in order to secure the proper proportional functioning of the self-acting outlets. This is a feasible option since crop water requirements are much lower during winter. As can be derived from figs. 7.6 and 7.7 the pivot point for rotational flow on Machai branch will move upstream (from RD 115+000 to RD 50+800) after completion of PHLC, reducing the command area requiring rotational supply from USC by about one third. Cross regulators, that allow for complete closure, were thus required at these locations. However, since Machai branch also feeds 61 direct outlets with a command area of 3400 ha (8,500 acres), cross regulators are also required to assure their proper supply during their rotational turns. The Swabi-SCARP design therefore included 12 cross regulators in total on the Machai branch.

7.3.2 Choices in Technical Design Criteria

The remodelling or upgrading of an existing irrigation system, like USC and LSC, places particular demands on the design and construction, that have to be taken into account by the project from the start. The most important are the requirements to make optimal use of the existing infrastructure and conduct the construction phase with the minimal disruption of the existing irrigation and cultivation seasons. Particularly the latter is a most demanding requirement from a project's point of view, since it usually means that the construction of the main and secondary conveyance network needs to be conducted in the delimited time-span of the annual closure and maintenance period (i.e the month of January in this case). This means that the construction has to be phased out over a number of closure periods, while during such periods construction at various sites in the system has to be carried out simultaneously in order to make optimal use of the scarce time. In a project like Swabi-SCARP the design should thus take these requirements into account, in that it seeks the least time consuming construction method, and facilitates the supervision of multiple construction sites.

Increasing Canal Capacities and Regime Considerations

For the conveyance canals the above requirements mean that preference is given to enlarge their capacity within their existing width and alignment. One thus has to seek to increase their depth and/or flow velocity in order to accommodate their increased design capacity. Furthermore, in the case of USC, and Pakistan in general, the issue of silt and Regime will have to be taken into account in order to guarantee stable canal dimensions. To address the latter issue, the Swabi-SCARP design team decided to review ten different hydraulic formulae for the dimensioning of canals (including Lacey, Manning, Tractive Force and others) on the basis of a hydraulic data set of existing canals compiled by ACOP, and the use of the computer programme DORC (Design of Regime Canals) developed by Hydraulics Research, Wallingford (*cf.* SSC; 1992b). Since "[t]*he design parameters, calculated using Manning, did not differ widely from the results of other methods*" it was justified according to the design-team to apply Manning for the design of the remodelled USC canals, "*especially since the canal*[s] *will be partially lined*" (Op.cit.:29).

Fig. 7.6: Rotational Blocks for Rabi Deliveries in Upper Swat Canal
After completion of Swabi-SCARP and before completion of PHLC

Fig. 7.7: Rotational Blocks for Rabi Deliveries in Upper Swat Canal
After completion of Swabi-SCARP and after completion of PHLC

The strategy adopted by the designers for the canal design forms a logical consequence of the afore mentioned requirements. The design uses the original canal alignment, and creates the increased discharge capacity by raising the canal banks and the flow velocity. The latter is then primarily achieved, in theory, by reducing Manning's *n*-factor by applying side or complete lining of the canal. This has been an important method to make optimal use of existing canal alignments, enabling quick lining at multiple sites during closure period, and accommodate the increased design capacity. For the unlined canal sections, the designers adopted a *n*-value of 0.021 - 0.025, which was derived from the measurements taken by ACOP. For the side and fully lined sections, the *n*-value adopted ranged from 0.016 - 0.019. These lower values for lined canal sections are common for normal flow conditions reflected in the hydraulic text books, where differentiation is made between the relative smoothness of lined surfaces and the relative roughness of natural embankments. In the case of Swabi-SCARP, this differentiation in Manning's roughness coefficient is quite crucial, in that it enables the designers to increase the canal capacities to the required level through the application of canal lining, particularly for the extra capacity required for the 'modified-demand' operations for the future. It is, however, questionable in how far this differentiation in *n*-values is valid for the high silt-load conditions encountered in USC and Pakistan. (SSC; 1992b, 1993a) As Chow (1959) clearly states on the issue of suspended material and bed load: "*The suspended material and the bed load, whether moving or not moving, would consume energy and cause head loss or increase the apparent channel roughness* [i.e. the *n*-value]."(Chow; 1959:106) The latter has been supported by the findings of the CBIO project in CRBC, which found *n*-values in lined sections equal to the Swabi-SCARP unlined values of 0.021, and by the hydraulic simulation of Swabi-SCARP's Jalala distributary in Duflow, which also found similar values for the lined sections (*cf.* Durani; 1999 and section 7.4.2). This after all is not so surprising, since observations in the field reveal that lined canals are quickly covered by a thin layer of silt on the sides, while bedload continues to move over the bed. How far this actual increase in roughness coefficient will lead to canal capacity reductions remains to be seen. In the case of Jalala distributary, it turned out that the drop-structures were far more decisive in determining the actual water levels in the canal than the Manning factor. This will, however, be different for each individual canal, and in those cases where relatively low *n*-values were used (i.e. 0.016) concerns on whether the 'modified-demand' capacity can be carried might be warranted. Furthermore, the installation of Vortex tubes in the mainline canal, just downstream of the headworks, is expected to take out 50 percent of the silt-load during the *Kharif* season, and might result in lowering the actual Manning roughness coefficients emerging in the lined canal sections. There is, however, no reliable method to quantify this relationship beforehand, and will thus have to be established empirically after commissioning of the newly remodelled system.

Pre-Fabricating Traditional Outlets

Although the traditional Open Flume and AOSM type outlet structures were used by Swabi-SCARP for the remodelling of USC, the project decided to apply new construction methods to facilitate the implementation. In stead of using the traditional method of *in-situ* masonry work, it gave the preference to use pre-fabricated concrete outlet structures, that could be produced at a few production sites and once produced fairly quickly installed in the canals. This method should facilitate the construction quality control by delimiting inspection to a few sites and enable its regulation through the issuing of certificates. The Swabi-SCARP design itself for the outlet structures did not differ significantly in a hydraulic sense from Sharma's (1940) improvements to Crump's original design. It consists of pre-fabricating three basic parts in re-enforced concrete that can be used for both the Open Flume as the AOSM outlet: (i) a bottom plate with crest; (ii) a downstream curved side wall and; (iii) an upstream protruding side wall. For the AOSM an additional roof-plate consisting of a concrete filled steel roofblock is constructed that can be placed on top of the side walls to create the orifice. For the installation of the outlet, the bottom plate is then to be installed at the required depth, conform the desired hydraulic configuration, and the side walls placed on top of the bottom plate according to the required throat width. The walls can be locked into place using two metal bars at the top of the walls. In case of an AOSM the roofblock is then placed on top to the desired orifice height above the crest. The whole structure is then to be cemented in place and backfilled with earth. Since a new construction method was used, calibration tests were done to determine the discharge coefficients of these 'new' outlets.[117]

Further innovations to the outlet structures consisted of the intended installation of a downstream water refusal gate, and standard installation of a gauge in the upstream outlet wall from which the H-value (i.e. water depth above crest) could be directly monitored. The first item, however, did not get implemented. The 'H-gauge' got implemented after Kalpani by impressing the scale during construction in the cement of the upstream side wall.

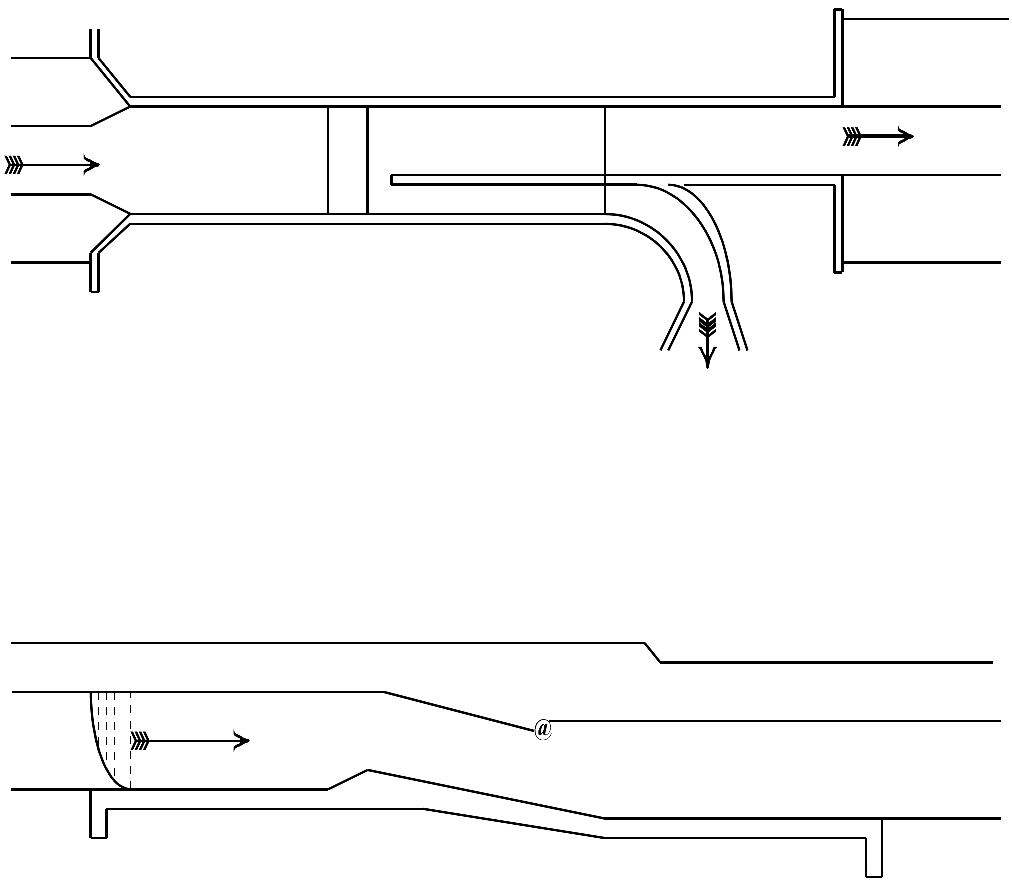
For those locations where more than 10 percent of the parent channel flow is to be drawn-off by the outlet, a proportional flow divider is installed instead of an Open Flume or AOSM. This structure consists of a Crump weir that regulates the water level across the parent channel, on which one or two partition walls are placed to subdivide the flow in proportional shares (*cf*. fig. 7.8). This structure is also used to regulate the flow division between distributaries and their minors.

The water distribution at the main system level would be regulated through the traditional means, in which all the distributary heads are equipped with a manually operated undershot sliding gate. In order to facilitate their operation and the general monitoring of the water supply, the Swabi-SCARP design added the installation of a Crump-weir in the head reaches of each distributary for discharge measurement. This feature represents a marked improvement on the traditional monitoring of the staff gauges, which are prone to inaccuracies and sensitive to siltation and other hydraulic changes in canal parameters. For the regulation of the water distribution in Machai branch, 12 new cross-regulators consisting of manually operated radial undershot gates were installed by Swabi-SCARP.

Another innovation introduced by Swabi-SCARP was the use of pre-fabricated concreted parabolic canal sections for the lining of water courses and minors of relatively small flow. The

[117] Not surprisingly, the discharge coefficients did not differ much from the ones established in the 1930-40s. For the AOSM it remained the same: i.e. Cd = 7.3 for Q= Cd*B*Y*(H-y)^0.5. While for the Open Flume, the Cd varied slightly for different throat width: Cd = 2.85 for $0.2 < B < 0.3$; Cd = 2.90 for $0.3 < B < 0.6$, and Cd = 2.95 for $0.6 < B < 1.5$, in Q= Cd*B*(H)^1.5. (All measures in imperial values) (SCC; 1994b)

Fig. 7.8: Proportional Crump Divider



philosophy behind this choice is the same as for the outlet, in that it facilitates the quality control and provides the opportunity for regulations through certification of producers. In Swabi-SCARP the water courses were not built under OFWM, but under the SCIAP/ADC project, which was a Swiss financed project conducted with the Department of Agriculture (*cf.* Durrani; 1999 and chapter eight).

Conscious of the 'engineering heritage' that the original canals and structures of USC represented, the chief designer of Swabi-SCARP tried to accommodate the new discharge requirements for USC by preserving as much as possible the original engineering works that were still in good condition. This included the headworks and Dargai trifurcator, which were virtually kept in tact and enlarged by adding the necessary compartments, and the stone-pitched main channel between the Benton tunnel and Dargai, which could be kept in tact by raising its embankments. In order to accommodate the extra discharge capacity, an auxiliary tunnel was driven through the Malakand range parallel to the Benton tunnel, with a maximum capacity of 51 m^3/s (1800 cusecs) and the Benton tunnel repaired. On the Machai branch the existing aqueducts were retained by enlarging their capacities by raising their embankments and/or adding parallel new structures. On the Abazai branch, however, the majority of the existing falls and syphons were replaced by new re-enforced concrete structures, as recounted in the canal safari of chapter one.

7.3.3 Operation & Management: Traditional Practices or Old Ideals?

Having opted for the re-establishment of the traditional self-acting proportional water distribution in USC, no major changes were foreseen for the operation and maintenance procedures after completion of Swabi-SCARP, except for the modification of the rotational schedules during *Rabi*. The obligatory Operation & Maintenance manual produced for the remodelled USC is therefore largely in essence a replication of the 'traditional' O&M manual. The latter was first produced in 1943 as "*The Manual of Irrigation Practice*", and primarily intended as a practical handbook for canal officers on the subject pertaining to O&M, rather than a proper manual that contains all the rules and procedures concerning operation. "*Due to its great utility for the Irrigation Engineers the first edition was soon sold out and for a while it was difficult to get hold of a copy of the document.*" (GoNWFP; 1992:foreword) In 1963 it was once reprinted without revisions, to satisfy the great demands for it. But in the 1980s it was completely revised and updated by the Irrigation System Management Project of USAID, and resulted in the *Operation and Maintenance Manual for Canal Systems in NWFP* in 1992.

Equitable Water Allocation & Maintenance of Hydraulic Configuration

The Swabi-SCARP O&M manual thus replicated in essence the procedures described in the 'Provincial manual', with its emphasis on full supply level operation and the administration of the operation registers; i.e. Outlet, Irrigation, Gauge, and H-register. These procedures and register will not be duplicated here, and readers are referred for a comprehensive synthesis to van Halsema & Wester (1994), or the 'provincial manual' itself (GoNWFP;1992). There are, however, three issues that in light of Swabi-SCARP are worthwhile to comment upon: (i) water allocation and its equity; (ii) the H-register and (iii) the rotational schedules for *Rabi*.

The remodelling of USC has been conducted by Swabi-SCARP on the commonly applied assumption, that the proportionality principle of water distribution is also applied to the water allocation, and thus results in an equitable water allocation and distribution pattern to the water courses served. In the case of Swabi-SCARP this has thus resulted that all the outlets are sized on this principle, to provide an equitable water delivery of 0.64 l/s/ha for every tertiary unit. As is explained in chapter two, this principle of equitable water allocation might have been part of the intentions of the self-acting proportional water distribution concept, but never got strictly implemented as such, nor formalised in a water allocation policy or law (*cf.* § 2.5). This issue was touched upon by the Swabi-SCARP project, when it complained about the exuberant outlet sizes that were drawing off more water than the designed for 0.64 l/s/ha before remodelling, and thus posed problems for implementation as water users tend not to readily accept less water after remodelling than they had before.[118]

[118] The project was highly concerned about this phenomenon, especially after the initially experiences in Kalpani, foreseeing difficulties in controlling the outlet dimensions during implementation, and saw this as an issue that needed to be set straight by the ID, implicitly assuming that all withdrawals above 5 cusecs/1000 acres (0.35 l/s/ha) constituted illegal tampering. To assess how grave and widespread this phenomenon was in the canals

(continued...)

In relation to the above issue, the matter of the H-Register is of particular interest. The H-Register, which is supposed to contain the monthly monitoring of the water level above outlet crest, was intended as a tool to control the proper hydraulic configuration of the outlets and the self-acting proportionality of the distributary canals. In the case of Swabi-SCARP it thus forms an important tool in the maintenance of the design dimensions and configurations of the outlets, and as such to safeguard the equitable water allocation and distribution imposed by the design. As has been explained in chapters two & three, the H-Register has seemingly never been institutionalised within the ID as a management tool and control mechanism for the maintenance of the hydraulic profile. Neither are there any indications to warrant an assumption that the ID circle of Mardan would suddenly start to use it for this purpose after completion of Swabi-SCARP.

Rotational Supply and the Limits of Self-Acting Proportionality

As has been mentioned in the previous section, the remodelling of USC by Swabi-SCARP will not eliminate the necessity to apply rotational water distribution at main system level during *Rabi*. The need to apply such rotational distribution will actually increase during the interim period after Swabi-SCARP and before completion of PHLC, when the whole command area, including that served by Machai branch, will have to be served by USC, while the normal supply level has been increased from 0.35 l/s/ha to 0.64 l/s/ha. This means that in normal years the available flow at Amandara will fall well below the new full design capacity of USC – i.e. 40 m^3/s (1200 cusecs) in relation to a FSQ of 88 m^3/s (3100 cusecs) (*cf*. fig. 7.5) – while it is not unusual that the available winter flows fall down to one third of FSQ – i.e. around 28 m^3/s (1000 cusecs) as the one in five years average low (SSC;1992a). In order to safeguard the proper functioning of the self-acting proportional water distribution in the distributary canals, rotational distribution will have to be applied at the main system to ensure that the secondary level is operated above its theoretical threshold value of 70 percent of FSL. Swabi-SCARP thus proposed to apply the traditional rotation rules in USC, which state that whenever supplies fall short of the 75 percent threshold value, the water supply should be rotated over two blocks that alternatively receive their full supply level for eight consecutive days.

This rule was derived from the limitations encountered during *Rabi* in the numerous systems developed during colonial time which, however, as a general rule would not face shortages far exceeding 50 percent of their full capacity. Swabi-SCARP has followed this principle by sub-dividing the command area dependent on the USC in two more or less equal rotational blocks (*cf*. figs. 7.6 & 7.7). During the interim period, however, the available *Rabi* flow will thus fall well below 50 percent of FSQ and render impossible the full supply operation in rotation. The Swabi-SCARP O&M manual therefore suggests to further sub-divide the flows below 43 m^3/s

(...continued)

prior to remodelling, the project issued a public tender through its ADC component for the measurement of all outlet dimensions and discharges. Although WAMA's bid was by far the lowest, it did not get commissioned. It is therefore not possible here to provide any quantification of the dis-proportionality of water distribution in USC prior to remodelling, and to what extent this practice had been legally formalised by the ID through annotations in the Outlet and Irrigation Registers.

(1500 cusecs) proportionally over the command area of a rotational block. To this end the manual contains two tables (one for the interim period, and one for the period after completion of PHLC) that list the proportional division at Dargai between Abazai and Machai branch and the distributaries of Machai upstream of Km 73.7 (RD 242+000), for various available flows at Amandara below 43 m^3/s (1500 cusecs).

Unfortunately, a small mistake has been made in the composition of these tables in the 1994 draft version of the O&M manual, in that they simply list the proportional division of the available low flow over the command areas served by the canals of the rotational turn. They do not take into account the limitations imposed by the minimum threshold discharge above which the self-acting proportional distribution is secured (in case of the table for the interim period), nor the maximum value of the canals' FSQ (*cf.* SSC; 1994a). In theory the minimum threshold value for canal operation is 70 percent of FSL, or 55 percent of FSQ[119]. In the flow distribution table for the interim period, this theoretical threshold value is reached for available flows at Amandara between 30 m^3/s (1050 cusecs) and 32.5 m^3/s (1150 cusecs). In practice, however, the actual threshold value will depend on the hydraulic configuration of each particular canal after construction, and is highly sensitive to the depths of the crests and roofblocks in relation to the actual established water levels. The actual values will thus depend on the accuracy of construction and the degree to which the design water levels reflect the actual water levels. These issues are dealt with in the next section. The hydraulic simulation of Jalala distributary after remodelling revealed, however, that the actual threshold value for minimum operation lies much higher than the theoretical value, around 80 percent of FSQ (*cf.* Durrani; 1999); a value that would be already reached, according to the draft O&M manual table 2.8, at an available flow of 41 m^3/s (1450 cusecs) at Amandara. It is therefore questionable whether it is feasible to rotate the low *Rabi* flows over two blocks during the interim period, even when the theoretical threshold values are assumed to take hold, without running into water distribution problems at the distributary level. To avoid such problems, it would thus be advisable to rotate the low *Rabi* flow over three rotation blocks. This is an option that should be fairly easy to implement with the relatively large amounts of cross regulators available at Machai branch after completion of Swabi-SCARP.[120] [121]

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[119] This value is derived from the Q-H relationship for open channel flow, where Q ~ H^(5/3) (*cf.* §2.6).

[120] After completion of PHLC and the substantial reduction of the *Rabi* rotational command area of USC, these problems of water shortages are essentially eliminated. The actual threshold value of 80 percent FSQ for Jalala is then only reached at a low flow of 27.5 m^3/s (975 cusecs) at Amandara, while its FSQ of 4.3 m^3/s (155 cusecs) is already reached at a flow of 34 m^3/s (1200 cusecs) at Amandara, making thus more water available for other areas in the system than has been acknowledged by table 2.9 in the draft O&M manual.

[121] I do not know if the Swabi-SCARP draft O&M manual has been converted eventually into a final version, and whether in that case the errors in the water distribution tables for rotational operation have been corrected. The continuing references to the establishment of two rotational blocks, rather than three, during the interim period in later publications concerning the PHLC (*cf.* Bozakov & Laycock; 1997), however, suggest not. However, the ID can be trusted to stick to its traditional operational rules of not supplying canals with less than 70 percent of their FSL, nor much more than 100 percent of their FSL, providing thus a practical resolution.

7.4 IMPLEMENTATION: CASTING WATER DELIVERY PERFORMANCE INTO CONCRETE

The self-acting proportional water control concept, as applied by Swabi-SCARP, requires an accurate construction of the water control structures and canal profiles in order to establish the desired hydraulic configuration (*cf.*§ 2.6). Due to the non-regulability of the water control structures, there are no operational means to adjust the water distribution after implementation to compensate for inaccuracies in construction, or amend the water allocation and distribution pattern. Once construction is completed, the water distribution pattern of each canal is literally cast into concrete, allowing modifications to be made only through re-configuration of the water control structures. The relative ease of operation of the 'self-acting' water distribution requires thus an accurate control of the construction. The hydraulic flexibility, determined by the relative hydraulic head over each outlet structure, is crucial with regard to the establishment of the minimum threshold value of each distributary canal, above which the self-acting proportional water distribution is secured, and water can be delivered without rotation at the main level.

Below two distributary canals remodelled by Swabi-SCARP are evaluated to determine their hydraulic performance after commissioning, and to ascertain whether they indeed meet the criteria of Crump's self-acting proportionality as those of the designers. The next section presents the results of the performance evaluation of Kalpani distributary that WAMA conducted right after its commissioning on request from the ID, and with funding from the ADB. The evaluation was carried out from February till May 1997 through an intensive measurement, calibration and monitoring programme. In section 7.4.2 the performance of Jalala distributary is evaluated after its commissioning in 1998. This evaluation has been carried out by Durani, with support from WAMA, as part of his MSc-degree at IHE. The evaluation of Jalala distributary differs from that of Kalpani in so far that a higher emphasis was given to the simulation of hydraulic and operational scenarios in a hydraulic model, as a means to determine the hydraulic behaviour of the canal. Both evaluations, however, clearly identify the factors that undermine the hydraulic performance of the canals: in terms of inaccuracies and deviations in construction (Kalpani & Jalala), and in deviations in hydraulic parameters as adopted by the designers (Jalala). The evaluation of Jalala also shows that despite some changes made by Swabi-SCARP in the implementation procedures and introduction of proportional dividers as outlet structures after Kalpani, the attainment of good and adequate levels of hydraulic performance remains a problematic issue. The configuration of self-acting proportionality proves to be sensitive to multiple disruptions.

7.4.1 Hydraulic Performance Evaluation of Kalpani Distributary[122]

A peculiar administrative set-up of the Irrigation Department Circle of Mardan, enabled conduct of a hydraulic performance evaluation of Kalpani distributary, before the completion of Swabi-SCARP. Hydraulically Kalpani distributary forms part of the Lower Swat Canal system, but

[122] This paragraph is largely based on previous publications, notably Halsema, van & Murray-Rust; 1997a and Murray-Rust & van Halsema; 1998. Further details are provided in the three reports of the evaluation study, Halsema,van & Murray-Rust; 1997b, c & d).

administratively it is part of the Upper Swat Canal division (*cf.* fig. 7.2). Due to this anomaly Kalpani was not part of Mardan-SCARP, but of Swabi-SCARP and was thus remodelled according to the Swabi-SCARP design criteria of self-acting proportionality, rather than 'modernised' according to the 'demand-based' design criteria of Mardan-SCARP. The hydraulic performance evaluation of Kalpani was conducted by WAMA on request of the Irrigation Department Circle of Mardan, and through finding of the ADB. The ID wanted assurance that the canal sub-system was working as intended (i.e. according to design) before resuming O&M responsibilities for Kalpani distributary.

Kalpani distributary was the first canal remodelled by Swabi-SCARP according to the new delivery and distribution criteria. The remodelling started in 1995 and was completed in 1996 in which all the construction works were conducted by a local contractor. As Kalpani distributary takes off from distributary # 9 (i.e. tail main) of the Lower Swat Canal, the capacity of which was enlarged by Mardan-SCARP, the hydraulic performance of Kalpani could be evaluated in 1997 under the new full supply capacity conditions.

Table 7.1 Kalpani Distributary after Remodelling

Distributary or Minor Canal	New FSQ (m^3/s)	Length (m)	CCA (ha)	# of Outlets	# of falls
Kalpani Distributary	4.5	15614	1887	21	4
Kodinaka minor (take off at 10,000 m)	1.28	8247	1344	16	11
Taus Minor (take off at 15,610 m)	1.19	6.471	1432	12	7
Mohibanda Minor (take off at 2,047 from Taus)	0.29	2918	365	5	2
Total		23260	5019	54	24

Kalpani distributary and its three minor canals supply a cultural command area of 5,019 ha. The basic data for this sub-system are presented in table 7.1. Before Swabi-SCARP, the distributary and minor heads were regulated through undershot gate structures. The majority of the 52 outlets were Crump type outlets, while the remaining few were pipe outlets. Kalpani distributary had 8 AOSM outlets of which 7 were located in the upper half of the canal, as is consistent with Crump's design concept. Three of the sixteen outlets along Kodinaka minor were AOSM, and there was one AOSM on Taus minor; all other outlets were open flumes.

With the remodelling undertaken by Swabi-SCARP, the full capacity of Kalpani distributary has been increased to 4.50 m^3/s (127 cusecs) in order to supply all tertiary units with the new 'normal' *Water Allowance* of 0.64 ls/ha (9 cusecs/1000 acres). In the head reach of Kalpani distributary a Crump weir has been installed at RD 7+075 ft (2156 m) as a discharge measurement structure, that simultaneously serves as a cross regulator for the first outlet. The off-take structure to Kodinaka minor at RD 33+100 ft (10, 000 m) has been converted into a proportional divider on top of a Crump weir (*cf.* fig. 7.8); while the off-take serving Taus minor at RD 51+200 ft (15,600 m) has been built as an overflow weir. In accordance with the Swabi-

SCARP design criteria all pipe outlets were to be eliminated, while the use of AOSM outlets would be restricted to canal head-reaches where the use of Open Flumes or proportional dividers would not be feasible. On Kodinaka and Taus minors several outlet structures were to be combined in proportional dividers. However, in this first remodelling contract these structures were not implemented as Crump dividers as presented in figure 7.8. They were built as traditional tail-end structures consisting of two or three Open Flumes, placed at 45 or 90 degree angles and with their crest levels placed at the same height.

Performance Assessment Criteria

The basic approach to hydraulic performance was to determine the Delivery Performance Ratio (DPR) at as many points as possible in the secondary canal system. The DPR compares the actual discharge recorded to the intended (or target) discharge (*cf.* footnote 53). Since it is a dimensionless ratio, values can be compared from different locations even though the target discharge at each location is different. In this case the target values were taken as the full supply discharges, as it provides an easy assessment of the proportionality of water distribution – i.e. at full supply delivery all DPR values should ideally be equal to 100 percent, while at 80 percent FSQ all values should equal 80 percent, etc.

To test the overall integrity of the system, discharges were measured at three operational levels: full supply level (100 percent of design discharge) which represents the normal operational target of the Irrigation Department; 70 percent of FSQ which represents the winter delivery flows; and 50 percent of FSQ which lies around the minimum theoretical threshold target.

The tolerance levels for the measured values of DPR represent the standard criteria of the Irrigation Department, whereby actual discharges should always be within ± 10 percent of target (*cf*. GoNWFP; 1992). Thus, if the canal is operated at full supply level, all discharges irrespective of location in the system should be within ± 10 percent of the design discharge. If the canal were operated at 70 percent of FSQ, all discharges should be within ± 10 percent the revised target discharge (i.e. 63 - 77 percent of design discharge). Although this is a fairly rigorous tolerance criteria it has proved workable as a target for many decades (*cf.* Sharma; 1932 & 1940). Values obtained within this range of ± 10 percent of target were thus considered as acceptable or good performance, while values outside this range were considered poor. An additional tolerance level was added, however, to identify locations where deviations from design were unacceptable. It was agreed that in locations where the deviations were more than 30 percent off target, the performance was classed as unacceptable and would require some special investigation to determine why such conditions could have occurred.

Methodology Adopted in the Performance Evaluation

With the cooperation of the Irrigation Department special efforts were made to regulate discharges in the entire Kalpani canal system, so as to provide as stable water conditions as possible for several days at a time. During each measurement period the head water level was kept constant insofar as possible. To avoid unwanted fluctuations in water levels during each measurement period, no measurements were taken during the first 48 hours of flow. The head end water conditions were monitored at least twice a day to ensure such unwanted fluctuations did not occur.

Discharge measurements were all made using current meters. Three current meters were used: one larger Ott meter for main and secondary canal measurements, and two smaller Ott Pygmy meters for watercourse discharges. The current meters were regularly cross-checked with each other to ensure consistency. In the main and secondary canals readings were taken at 0.2 and 0.8 of the water depth across the full width of the canal. The spacing between readings was normally about 1.0 metre. Where feasible, the readings were taken in lined sections. All measured sections were straight and with as little vegetation and sedimentation as possible. Since the main canal had been desilted immediately prior to the measurement programme, all cross-sections were in good condition. Watercourse discharges were measured as close to the outlet as possible. Where lined sections were available current metering was done in these sections. In most watercourses readings were restricted to a single measurement at 0.6 of the water depth due to shallow water conditions and the parabolic cross-section of the channel.

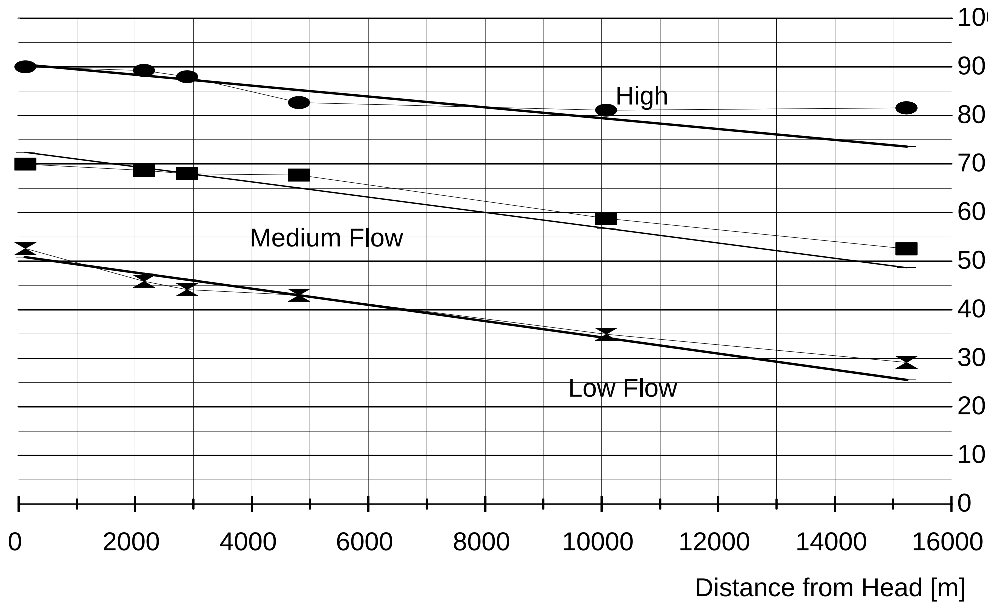
All current meter measurements were repeated until there were three revolution readings which varied less than 3 percent; the other readings being discarded. In two locations in the main canal where there were control structures (Crump weirs in both cases) the discharges calculated using the FLUME programme (*cf.* Bos et.al;1984) were within 5 percent of the measured discharges. The least satisfactory readings were those when the main canal was operating at 50 percent of design discharge. It was impossible to maintain steady state conditions for the five days requested (i.e. two days for attaining stable flow conditions, and three for measurement). All readings were taken in a three day period but the head discharge fluctuated $\pm$ 10 percent during this period. In the other measuring periods the head discharge was stable.

Hydraulic Performance of Kalpani Distributary and its Minors

Within the secondary canal system it was feasible to measure discharges accurately at several locations: six along Kalpani distributary itself (*cf.* table 7.2), while additional measurements were taken at the head of each of the three minors. Actual discharges and DPR values of each of the measurement locations are indicated in table 7.2, while DPR values for each set of readings are shown in fig. 7.9. The performance of Kalpani distributary was unsatisfactory when the discharge at the head gate was in the order of 50 percent design discharge. The inflow was measured as 2.35 m^3/s (83 cusecs) – some 52 percent of the design discharge of 4.50 m^3/s (159 cusecs). However, tail-end DPR values were only in the order of 30 percent of design discharge. These measurements show that the performance was unacceptable when the canal was operated at half of its design discharge, underlining the importance of maintaining discharge conditions above the minimum threshold value.

When the canal was operated at 70 percent of design discharge, measurements show that the DPR at the tail of Kalpani distributary was in the order of 50 percent; just around the margin between poor and acceptable performance. Given that Taus and Mohibanda minors are both

Fig. 7.9: Hydraulic Performance of Kalpani Distributary, DPR [-]



downstream of this location, they could not achieve acceptable performance levels at their tail locations. From an operation perspective it means that if the water requirements at the tail would drop down to 50 percent of design, the discharge into the system would have to be maintained at or above 70 percent of design discharge, unless there is a systematic closure of head end outlets.

Table 7.2: Hydraulic Performance of Kalpani Distributary after Remodelling

	Actual Discharge Conditions						
	FSQ	High		Medium		Low	
Location & Distance from Head	[m³/s]	[m³/s]	DPR	[m³/s]	DPR	[m³/s]	DPR
Head of Kalpani (152 m)	4.50	4.03	90	3.13	70	2.35	52
Crump Weir (2157 m)	4.36	3.90	89	3.00	69	2.00	46
U/S Siphon (2820 m)	4.28	3.76	88	2.91	68	1.89	44
D/S Siphon (4878 m)	4.08	3.37	83	2.76	68	1.75	43
Kodinaka Bifurcation (10000 m)	3.59	2.91	81	2.11	59	1.26	35
Tail of Kalpani (15396 m)	1.26	1.03	82	0.66	53	0.37	29

A final set of readings was meant to be taken when the canal was being run at design capacity. The discharge at the head of the canal was increased to the point where water started spilling at the escapes immediately upstream of the two siphons located at 2,850 m and 4,878 m downstream the head. Additional discharge into Kalpani distributary would have resulted in even further spillage. The head discharge under this condition was 4.03 m^3/s, or 90 percent of design capacity. However, this value had to be considered as the full supply discharge due to the conveyance constraints imposed by the two syphons. Under these conditions the discharge at the outlet of the second siphon – 4,800 m from the head – was measured at only 83 percent of design, while the discharge at the tail of Kalpani was 80 percent of design. Again, the minors fed by Kalpani performed less well than this. With these constraints imposed by the two syphons, roughly 90 percent of the command area could only obtain 83 percent of the intended maximum discharge.

These results indicate that the overall performance of Kalpani distributary was poor when operating at maximum capacity, and certainly did not meet the designers' expectations. Some improvement in performance could be expected if the constraints imposed by the two siphons were to be removed. However, it would be unlikely to reach acceptable levels, since there was a persistent and steady deterioration in DPR values from head to tail at all the three measured supply levels. This implies some systematic problem that affects performance irrespective of discharge, and which requires investigation before remedial measures can be undertaken.

Performance of Outlets

Parallel with the discharge measurements taken in the secondary canal system a series of discharge readings were taken in a set of sample outlets along Kalpani distributary and each of the three minors. A total of 17 watercourses were sampled, some 35 percent of the total number of watercourses in the sub-system. As far as possible watercourses were selected at random to represent a combination of head, middle and tail conditions, as well as different types of outlet structure design. As it is not possible to accurately measure all watercourses due to backwater effects and branching of ditches immediately downstream of the outlet, the sites actually selected were all ones where rating curves could be developed with some confidence.

The outlet performance along Kalpani distributary (*cf.* fig. 7.10) indicates that almost irrespective of the inflow conditions, upper end outlets received far more than their proportional share. When the distributary was operated at about 90 percent of design, the head end outlets received between 140 and 160 percent of their design target, while at the lowest operational level (46 percent of FSQ) the outlets still received about 125 percent of design. The effect on tail end outlets is obvious: most DPR values were in the order of 40-80 percent of design, although two outlets recorded still higher values.

Kodinaka minor shows a similar picture (*cf.* fig. 7.11). It should be noted that the maximum DPR obtainable at Kodinaka minor head was only 80 percent of design, when the inflow at Kalpani head was at its maximum capacity of 90 percent. DPR values were about 100 percent for most of the outlets, falling to around 80 percent at the tail. However, when the inflow was in the order of 55-60 percent of FSQ, the outlet DPR values ranged from 80 percent at the head to less than 30 percent at the tail, with the tail outlet even falling completely dry.

Taus minor showed a more complicated situation (*cf.* fig. 7.12). There is a cluster of outlets near the head that account for much of the total discharge of the minor. When it was operating at 70 percent of design – the maximum discharge that could reach the head of Taus when Kalpani was running as full as possible – some outlets still managed to obtain DPR values as high as 150 percent, while others were closer to 60 percent. When Kalpani distributary was operated at

Fig. 7.10: Kalpani Distributary, Outlet Performance DPR [%]

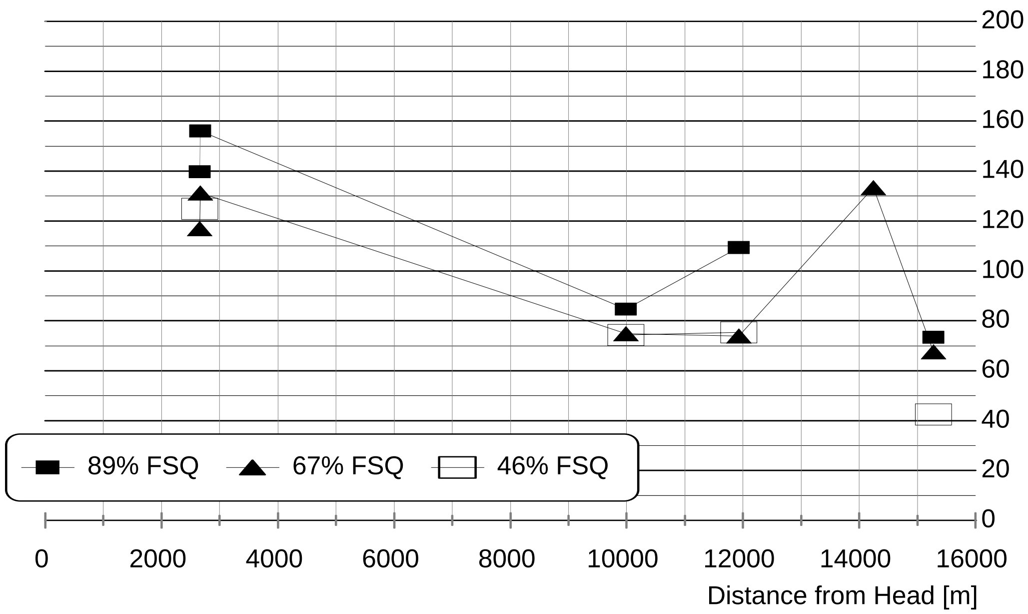


Fig. 7.11: Kodinaka Minor, Outlet Performance DPR [%}

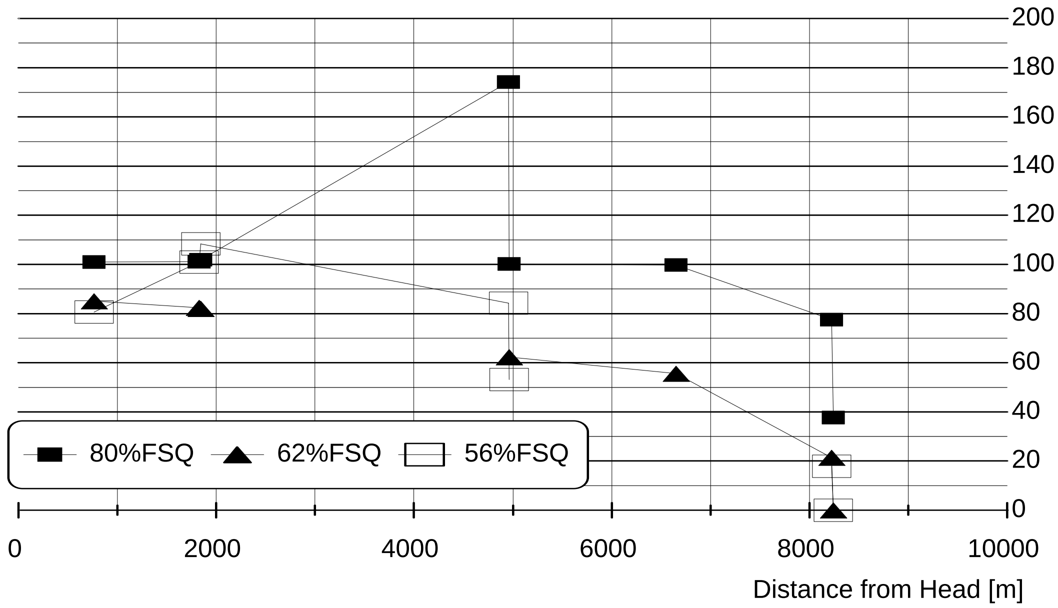
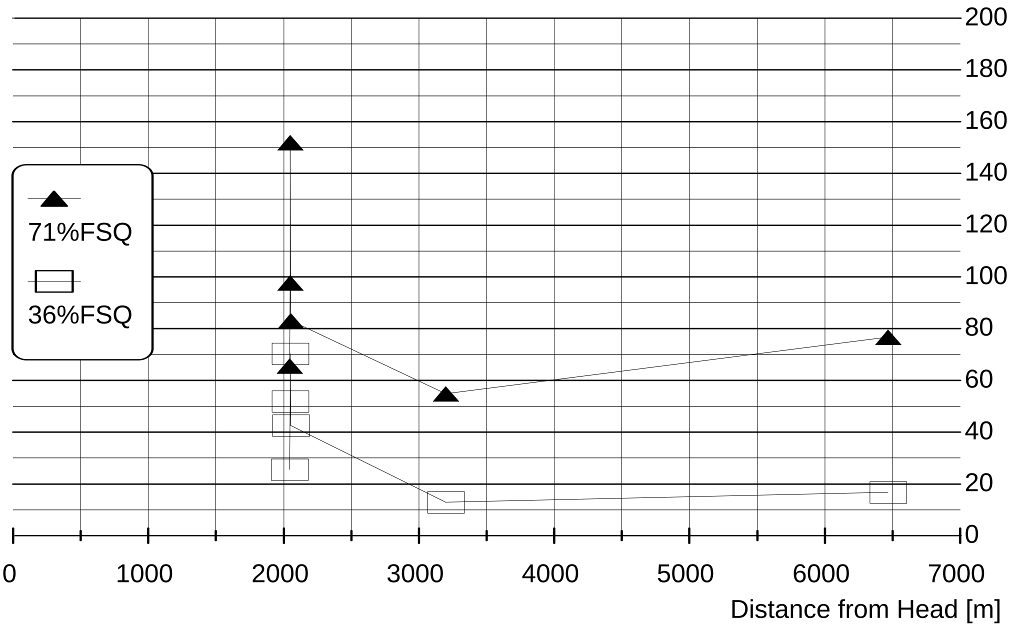


Fig. 7.12: Taus Minor, Outlet Performance DPR [%]



medium flow, all outlets performed poorly with the tail only receiving 15 percent of design discharge – a consequence of the extreme low supply level (36 percent of FSQ) on which Taus minor could be operated. When Kalpani was operated at low flow, no reliable measurements could be obtained at Taus minor as most of the outlets fall dry.

There are two immediate observations to be made from these data: there is a considerable variation in the values of DPR recorded between outlets along the same canal, and there is a persistent head to tail decline in all three cases. Both of these observations imply some problems with the outlets: if correctly constructed they should not show great variation, while if there are oversized outlets near the head, they will receive more water than intended and deprive the tail end outlets of their share.

Because the canal system had been desilted immediately prior to the measurement programme, sedimentation was not the cause of the poor performance, in contrast to similar studies in the Punjab which could be alleviated through selective desilting (*cf*. Bhutta & VanderVelde; 1993, Murray-Rust & VanderVelde; 1994b). A more credible explanation lies in defects in the construction of the outlets.

Deviations in Outlet Types and Dimensions

A survey of the type of outlet installed and their condition at the time of survey revealed that there were many cases where there were differences between the design and actual conditions. Table 7.3 provides a summary of the differences encountered in the survey of the 49 outlets (the five outlets of Mohibanda minor were not included in the survey). The Swabi-SCARP design called for 49 outlets, but only 48 were constructed due to objections of one group of water users over the planned intervention. Seven outlets differed in type from the design: four AOSM outlets were constructed as open flumes, one open flume was constructed as an AOSM, and two flumes were never built, temporary pipe outlets being used instead. These changes were made at the time of construction and were never incorporated in the design spreadsheets used for determining the hydraulic conditions along the canal

A further nine outlets were installed as designed but were subsequently bypassed by pipe outlets. In some instances even both, the original outlet and the additional pipe outlet, were used. The causes of pipe installation appear to vary from case to case. In some instances it is clear that the 'official' outlet was installed too high and would not be able to deliver adequate water. In other cases the pipe was installed to overcome problems experienced in the transition from the old to the new system: during construction there were delays in completing the two siphons along the distributary canal, so the system had to be operated for several months at the old discharge level rather than the increased new one. This lower supply level clearly created problems for some outlets during this transition period. Thirdly, and by no means insignificant, was a degree of intransigence on behalf of some powerful farmers who installed pipe outlets at the time of installation to obtain more water. As this power was sometimes backed by a display of weapons, many illegal pipe outlets remained.

Table 7.3 Condition of Outlets in relation to Design

Status of Outlet	# of Outlets	% of Total
Outlet installed as designed and not damaged	28	57
Outlet installed as designed but damaged	4	8
Outlet installed as designed but bypassed by/with additional pipe	9	16
Outlet not installed as designed	8	16

The remaining 32 outlets were of the same type as the design called for in the original specifications. However, four were damaged in such a way as to change their hydraulic behaviour – either deliberately or through collapse of the outlet structure. Thus only 28 out of 49 outlets (or 57 percent of the surveyed total) showed a direct correspondence between outlet design and the type of outlet actually installed in the field. This is too high a deviation to be acceptable for a system remodelled less than one year before. The survey also included detailed measurements of the dimensions of each outlet structure. This revealed that there were major deviations from design specifications that can easily account for the observed pattern of DPR values for the sample outlets.

The Swabi-SCARP design planned for the construction of 13 AOSM outlets, nine of which were to be installed in the head reach of Kalpani distributary, as is consistent with the design philosophy of Crump (1922). In practice, however, 10 AOSM outlets were constructed – all in the upper reach of Kalpani distributary – of which only 8 were functioning (the other two being bypassed). Measurements of the width and height of each of these eight structures showed that the area of the orifice was, in all cases, larger than designed. If the water levels in the supply channel were to reach their design levels, all of these AOSM structures would deliver excess rates; the excess being directly proportional to the oversizing of the orifice. Table 7.4 compares the design and calculated discharges for the AOSM modules, assuming the canal is operated at full supply level and the outlet is installed at the correct elevation.[123] None of the outlets would deliver within 10 percent of the design specification under these conditions, while four would deliver at least 30 percent more than design discharge. In total the eight outlets would draw an excess of 127.3 l/s (4.5 cusecs) over design if the canal were operated at full supply level; an excess that is equivalent to the average design discharge of two downstream outlets.

Table 7.4: Expected Performance of Functioning AOSM Outlets
(based on FSL conditions and actual dimensions)

Outlet #	Design Discharge [l/s]	Calculated Discharge [l/s]	Deviation from Design [%]
2	37.1	42.5	+15
3	40.2	67.6	+68
4	35.9	41.9	+17
6	19.2	47.3	+146
7	44.7	56.6	+27
8	58.9	75.6	+28
10	24.6	35.9	+46
11	53.8	74.4	+38
Total	314.4	441.8	+41

A similar degree of discrepancy in actual and design dimensions was observed for the open flumes. The width of all open flumes is comparatively easy to check, but on several occasions it was also possible to make observations on the relative elevation of the crest of the flume to the elevation of its associated drop structure. On these occasions it was thus possible to determine the hydraulic configuration of the outlets in terms of their hydraulic flexibility. Although the design clearly specified the construction of bi- and trifurcations with identical crest elevations, considerable deviations were found in the field that significantly affect the water distribution. Outlets whose crests are lower than the crest of the cross-regulator are hydraulically sub-proportional ($f < 1.0$) and will receive more then their due share, while outlets whose crests are higher than the cross regulator will receive less water than intended and function hyper-proportionally ($f > 1.0$). The lower the water elevations become in the supply channel, the more pronounced the discrepancies in water distribution will become. An additional potential source of error is the width of the cross regulator, which directly affects the water level over the outlets, and hence their discharge.

Based on measurements of width or the combination of width and relative elevations to an associated drop structure it was thus possible to predict the performance of flumes when they are all operated at 100 percent of design discharge. Of the 24 open flumes that are functioning

[123] This assumption had to be made as no funds were made available to conduct a true survey of Kalpani sub-system under the Hydraulic Performance Evaluation study. Consequently it was not possible to verify the true hydraulic configuration of the outlet structures in relation to the normal full supply water levels.

correctly, only 21 percent would deliver discharges within 10 percent of design target, while 58 percent would deliver more than 30 percent off from their design target (*cf.* table 7.5).

The reason for the poor performance of both AOSM and open flumes is clear from an analysis of the deviations of actual measurements from design. Of the 40 dimensions measured for 8 AOSM (width and height of roofblock) and 24 open flumes (width only), exactly half were more than 25 mm too large, while a further 9 (23 percent) were more than 12.5 mm too large. It is not unreasonable to expect that outlets can be built more precisely than this; the technology is standard and outlet construction has gone on for years in Pakistan at better levels of tolerance than this.

Table 7.5 Expected Performance of Open Flume Outlets
(based on FSQ conditions and actual dimensions)

Extent of deviation of actual discharge from design discharge	# of Outlets	% of Total
Within ± 10% of design discharge	5	21
Within ± 10 - 30% of design	5	21
Greater than ± 30% of design	14	58

These data suggest that there was a systematic problem inherent in the construction process, and one that was not remedied as a result of the surveillance and monitoring of as-built construction in the field. Without additional information it is not possible to determine the exact cause of imprecise construction: it could be poor performance of the contractor, it could be independent tampering by water users at the time of construction, or it could be a consequence of rent-seeking by the contractor in collusion with water users. It is, however, clear that there were some problems with the contractor that carried out the construction work of Kalpani. Immediately after completion of the performance study, the upstream syphon of Kalpani distributary had to be temporarily put out of use, diverting the water instead through the smaller old British syphon still in place. The newly constructed syphon was still settling, with the effect that the pressure at the connection between the upstream lined canal section and the syphon became too large and eventually cracked. As both survey benchmarks in the vicinity of the syphon had been dislocated during the construction work, it was difficult to accurately monitor this ongoing settling process, or check the elevations of the syphon's in- and outlets. The problem was attended to by Swabi-SCARP and the syphon repaired and put into proper use soon afterwards.

Whatever the cause, these deviations in as-built structures far exceeded the normal specifications for installation of outlets, which requires that they can be built to deliver within 10 percent of the design discharges. It is obvious that if outlets in the upper reach of a canal are able to draw more than their fair share then the tail end reach will automatically be deprived of its fair share because the total volume of water delivered is directly related to the designed discharge of each outlet.

7.4.2 Jalala Distributary: Performance under threat...

After Kalpani the implementation procedure was slightly changed, in that the outlets were no longer to be installed by contractors, but by the Irrigation Department itself.[124] An other important change concerned the outlet structures to be used in the remaining canals of Swabi-SCARP. In all instances where 10 percent or more of the parent flow would be taken-off by an outlet, the proportional Crump divider (*cf.* fig. 7.8) would be used instead of the open flumes. Construction-wise the Crump divider has many advantages over the complex flume structures used in Kalpani. Most notably the use of one sill, instead of two or three, provides for significantly less potential errors in construction to upset the hydraulic configuration of the composite structure, while the exact width of the structure is relatively insignificant as long as the partition wall is placed on the proportional location of the sill. With the composite structures used in Kalpani, the exact width of the cross regulator was a determinant for the establishment of the water levels, and thus hydraulic configuration, over the off-takes, requiring exactitude in its installation.

In 1998 the remodelling of Jalala distributary (the first distributary taking off from Machai branch (*cf.* fig. 7.2)) was completed along these new implementation procedures. The canal capacity was increased to accommodate the new normal supply discharge of 4.38 m^3/s (155 cusecs) with a freeboard that would enable it to carry the ‘modified demand’ discharge of 4.43 m^3/s (156.4 cusecs). This increasing of the carrying capacity of the canal – largely by deepening and lining – the falls, intake and escape structures, as well as the measuring Crump weir at the head of the canal, were all constructed by a sub-contractor. However, contrary to Kalpani, the outlets were installed by the Irrigation Department. The parabolic pre-fabricated water courses were all installed by SIAP/ADC, which organised all water users for this purpose into WUA, and moreover federated the WUA into a Farmer Support Unit to provide agricultural services (*cf.* Durrani; 1999).

Durrani (1999) conducted a study on Jalala distributary to determine the hydraulic properties of the canal and its operational requirements for realising proportional water distribution in light of turning over the O&M responsibilities to the water users following the implementation of the PIDA Act (*cf.* chapter eight). To determine the minimum and maximum threshold discharges with which proportional distribution could be ensured, Durrani carried out a hydraulic simulation of Jalala distributary in DUFLOW. As in the case of Kalpani distributary, the results of Durrani’s study clearly show that the hydraulic properties (*cum* configuration) of the newly remodelled Jalala distributary did not meet those specified by the Swabi-SCARP design.

Jalala distributary is comparable in size to Kalpani, with a total length of 21+000 m (69+000 ft). In total it serves 39 off-takes, which include one minor canal that serves seven outlets, and features over its total length 51 drop-structures that can serve as cross-regulators. The Swabi-SCARP design foresaw in realising the self-acting proportionality by installing 1 pipe, 16 AOSM (the majority of which in the head-end half of the canal), 10 open flumes, 6 proportional bifurcators (including the minor intake) and 3 trifurcators. The proportional Crump dividers were

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[124] This decision, as the one on the use of the proportional Crump weir, was already made prior to the completion of the hydraulic performance evaluation of Kalpani.

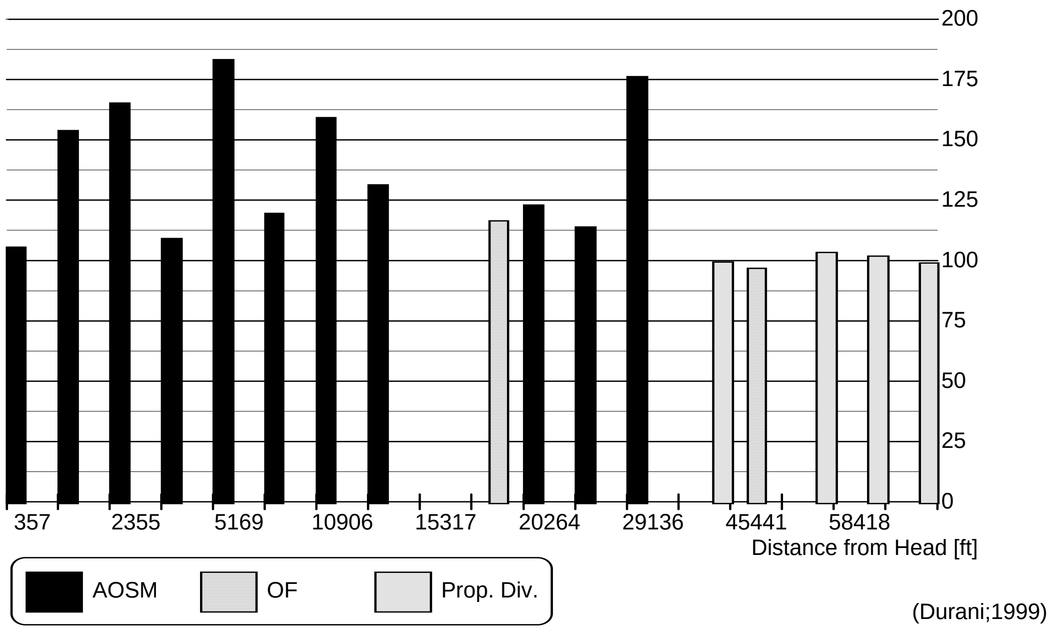
mainly restricted to the tail-end where the design criteria of taking off more than 10 percent of the parent discharge could be met.

...by Changing Outlet Dimensions and Configurations

Measurements by Durrani on a sample of outlets from Jalala distributary revealed that, in particular, the AOSM outlets as installed by the ID bore little resemblance to the design specifications. In the Swabi-SCARP design, the designers aimed to configure the AOSM outlets with an orifice width (*B*) to height (*Y*) ratio of unity (1.0), and not less than 0.8 or more than 1.2. These criteria were adopted to ensure that the assumed coefficient of discharge *Cd* of 7.5 (imperial units) (4.14 for metric units) would be valid. In practice, however, the ID installed the AOSM outlets according to other criteria, changing both the width and height setting. Figure 7.13 shows this resulted in substantial larger orifice areas than the Swabi-SCARP design had specified. The proportional Crump dividers, on the other hand, were built very close to design specifications.

Apart from changing the specified outlet widths and heights, the directorate of the ID responsible for the outlet installation decided also to change the crest levels. This would seem at first instance a logical, and required, consequence of changing the widths and heights, to assure that the outlets were configured for drawing off their design discharges at FSL. However, one would thus expect the crests to be higher than that specified in the design, to compensate for the increase in orifice area or throat width, and not for crests to be installed at lower levels which will even further increase the discharges of the outlets. The directorate, however, decided for the latter, and to *"install the crest of the new offtakes at the same levels as those of the old offtakes"* (Durrani; 1999:57). The crest levels specified in the Swabi-SCARP design were considered to be at too high a level, which prompted the decision to install the new outlets at the same, but

Fig. 7.13: Jalala Distributary, Ratio of Actual Outlet Orifice/Width to Design [-]



considerably lower, level as the old ones. This further exacerbated the effect of larger than design orifices, and basically resulted in allocating the head-reach outlets substantial higher water allowances than the one specified in the design as the 'normal' proportional water allowance of 0.64 l/s/ha. Basically, the hydraulic configuration of the canal was changed during construction, of which it is not possible to determine its precise water distribution properties without an extensive survey of the canal and its structures.

...by Deviations in Hydraulic Parameters

Durrani also conducted a hydraulic simulation of Jalala distributary in DUFLOW to evaluate the design of Swabi-SCARP to determine how the canal would behave under different supply levels and identify its minimum threshold discharge with which the proportional water distribution ± 10 percent could still be guaranteed. In the design the hydraulic configuration of the canal was established by determining the water levels through application of Manning's equation for steady state flow and the back-water levels produced by the falls *cum* cross regulators. The water levels in the parent channel are thus determined by the Manning factors applied for the canal, as well as the coefficients of discharge (*Cd*) adopted for the fall structures/cross regulators. The outlet structures are then configured according to the hydraulic flexibility required, and sized to deliver design discharge at FSL adopting specific coefficients of discharge for the structures used.

Applying the values adopted in the Swabi-SCARP design in a FSL simulation of Jalala distributary, Durrani obtained a fairly good water delivery performance: 29 of 39 off-take structures conveyed their FSQ ± 10 percent, and the remaining ten (i.e. 25 percent of total) conveyed ± 20 percent of FSQ. However, one important amendment to the original design had to be made to obtain such results: one of the fall/cross-regulator structures had to be raised by 0.2 m. In its original design configuration it was causing a draw-down effect, rather than a back-water effect, which was affecting the upstream off-takes. With the applied raising of the sill, water levels were obtained the designers were aiming for.

In a second FSL simulation, the fall/cross-regulator in question was simulated as designed; that is, with its low crest level. In addition, Durrani lowered the coefficients of discharge of the fall structures. Traditional coefficients used in Pakistan range from 3.6 to 3.0 [for imperial units] (1.99 to 1.66 for metric units) to determine the water levels regulated by fall structures, depending on the width of the structures. Today these values are considered to be quite high for semi-broad crested overflow weirs. For this second simulation, Durani used lower coefficients of discharge of 1.2 (metric units), which is in line with literature recommendations and conform to discharge measurements taken in Jalala (*cf.* Ibid). As a result, the water levels behind the fall structures will be higher than those anticipated by the designers. As a consequence, the simulated performance of Jalala distributary dropped, with only 20 off-takes (i.e. 51 percent of total) drawing off FSQ ± 10 percent, 10 off-takes drawing off between 110 - 120 percent of FSQ, 4 off-takes with less than 80 percent of FSQ, and 5 outlets drawing off more than 125 percent.

The value of the Manning's roughness coefficient might have a similar effect on the hydraulic configuration and performance of a canal, resulting in higher or lower water levels than anticipated in the design. As mentioned Swabi-SCARP designers adopted fairly low *n*-values for the lined canal sections, considering the quantities of silt carried in the system. Durrani's work also confirms, like that of CBIO in CRBC, that the actual values for lined channels are close to those of the unlined channels, and in the order of $n = 0.021$ (*cf.* Ibid). In the case of Jalala distributary, however, this turned out to be of minor effect. The water levels in the canal are much more determined by the numerous falls/cross-regulators, rather than by the canal roughness. However, in those canals where the water levels are not regulated by fall structures, a marked disruption of hydraulic configurations and lower performances, might be expected to occur as a consequence of higher than anticipated flow resistance in lined canals.

These hydraulic simulations of the Swabi-SCARP design show that the hydraulic configuration of self-acting proportionality can be easily upset by either inaccuracies and alterations in construction and also by hydraulic parameters that turn out to be different in practice than anticipated in the design. Furthermore, the case of Jalala distributary indicates that the construction and configuration of the falls/cross-regulators can be as crucial and determinant for the hydraulic performance of a canal as that of the outlets. This relationship, that was also found to be of significant influence in the performance evaluation of Kalpani (*cf.* Halsema, van & Murray-Rust; 1997c), is often overlooked in other evaluation studies.

7.4.3 Project Implementation & Institutional Control of Hydraulic Configurations

The changes made by the ID in the configuration and construction of the outlets in Jalala distributary and the other canals of USC reflect two important issues pertaining to implementation of the Swabi-SCARP project. The lowering of the outlet crests to their original pre-remodelling levels reflects a typical remodelling issue. With a remodelling project like Swabi-SCARP the interim period between the progressive completion of the remodelling and the moment of commissioning when the system is operated according to its new capacity causes difficult water management problems. In essence, it represents a period in which parts of the system have to operate sub-optimally and the water can not be distributed according the allocation and distribution criteria, as the hydraulic conditions for which the system was designed can not yet be attained. In the case of Swabi-SCARP the AOSM outlets particularly stand to be affected by this limited water delivery capacity during the interim period, and draw substantially less than their design discharge and/or proportional share. This issue requires thus specific attention during the project implementation in order to mitigate its negative consequences for the affected water users, and prevent it causing severe water management problems. There are two possible means to do this: (i) supply the newly remodelled canals with their new target discharges immediately after completion of the construction work, and thus incrementally and progressively increase the water supply in the main system, when feasible; (ii) keep water users well informed of this temporary set-back in water delivery service that is required to provide them with better services after commissioning, and compensate them for this set-back by means of, for instance, temporary lower water service fees. In the case of Swabi-SCARP neither these nor any other specific measures were taken during implementation to cope with this problem. The resulting lowering of the outlet crests to their old original level is of course an inappropriate response; it might mitigate the problems during the interim period, but seriously undermines the water delivery capacity and performance of the system after commissioning.

The second issue pertains to the specific organisational set-up of irrigation development and management in Pakistan, in which the ID and WAPDA are in continuous rivalry. The SCARP project arrangement gives WAPDA and consultants full responsibility over design and construction of the projects, while the ID has to resume the full O&M responsibilities after completion of the projects. This has only enforced this sense of rivalry between the two line agencies, rather than overcome it by institutionalising cooperation in design and construction. In Swabi-SCARP the ID was for the first time handed a piece of the project cake by being allowed to conduct the construction of the outlets themselves. However, this still entails a very limited form of participation, as the ID's role is limited to the implementation of the design as made by WAPDA and consultants, even though it provides access to financial resources. That the ID decided subsequently to change the dimensions and configurations of the outlets, overruling the design decisions made by WAPDA and consultants, seems to be an assertion of their jurisdiction over the outlets as defined by the Canal & Drainage Act. Under this Act it is the ID that is the juridical owner of the outlets, and as such possesses the discretionary powers to set their dimensions, configurations and discharge capacities (*cf*. chapter two). In the Swabi-SCARP design WAPDA and consultants decided to configure the USC according to the self-acting proportionality criteria of Crump, and according to the water allocation principle of equity. Thus sizing all outlets for a discharge capacity of 0.64 l/s/ha (9 cusecs / 1000 acres), assuming that this conformed with the criteria and objectives with which the ID has to operate and manage their systems. As argued in chapter two this only constitutes the implicit ideal; it has frequently been abnegated in practice to accommodate administrative and other 'pressing' criteria and objectives.

The extent to which the actual outlet configuration in Jalala distributary is a result of construction inaccuracies, cannot be assessed without detailed information on pre-remodelling conditions. It nevertheless remains remarkable that the issue of clear and unambiguous water allocation, and distribution rules and procedures that safeguard and maintain the proportionality and equity of water distribution, were not addressed by the SCARP-projects. Even without ID involvement in outlet installation, this issue was important for Swabi-SCARP, since the ID would bear the legal ownership and responsibility after commissioning. Swabi-SCARP thus created an awkward situation, in which it designed the system for a proportional and equitable water distribution, but to which the ID does not have to commit itself in the execution of its O&M responsibilities, nor from which the water users can derive any guarantees in water delivery service.

Given the sensitivity of the Swabi-SCARP design to errors in construction and deviations in hydraulic parameters, it is all the more remarkable that no specific measures were taken in Swabi-SCARP to control these hazards to the operational and delivery performance of the system. The cases of Kalpani and Jalala distributaries clearly show the urgent need to establish control mechanisms that are aimed at preventing poor performance being built into canal systems that otherwise require substantial additional investments and re-configurations shortly after commissioning. This is not only a matter of quality control that can be conducted with routine testing of the hydraulic performance before commissioning, or for that matter, field calibration of the hydraulic configuration to the prevailing conditions. It also requires a formal commitment from the part of the ID to the water allocation and distribution principles in the operation and maintenance of the canals. In the continuing absence of such control mechanisms it is to be feared that newly commissioned systems as Swabi-SCARP will perform far more sub-optimally than intended by the quote of Swabi-SCARP Consultants presented at the start of this chapter. In the case of USC, the ability of the system to deliver the lower winter flows equitably, even through the application of rotation, is seriously undermined by the construction qualities attained in Kalpani and Jalala. The continuing absence of project attention to clear water allocation policy and juridical commitment to the maintenance of such systems, as well as to the quality of the construction, threatens to render the outcomes of such remodelling projects obsolete.

7.5 INTO THE FUTURE: AUTOMATED WATER CONTROL & FLEXIBLE WATER DELIVERY SERVICE FOR PHLC

The decision on how the Pehur High Level Canal Project would link-up to the Machai branch of USC and the criteria for supplementing the water supply to the USC tail-end area, were already taken during the design of Swabi-SCARP. By the start of the PHLC project in 1994/95, the major design objectives were thus already defined by Swabi-SCARP. The decision to opt for automatisation of water control in PHLC to regulate the confluence of two water sources in Machai branch of USC was already made within Swabi-SCARP in 1992 (*cf*. SSC; 1992b) – by the same consultants that constituted the PHLC consultant team to WAPDA.

Technical Design Choices

This early choice for automatisation of water control in the PHLC main canal came as a logical one given the water supply criteria for its linkage to USC and the unique opportunities provided by Tarbela reservoir as the water source. Since the valuable water of Tarbela reservoir[125] should be used prudently by PHLC and its supply to USC should be supplemental, the flow variation to be controlled in PHLC main canal was from the onset bound to be substantial and governed by the flow variation of the Swat river and of the water use in the upper reaches of USC. Given the confluence with Machai branch canal, this means that these flow variations would have to be controlled accurately and frequently in order to avoid dangerous situations of overtopping. Manual operation would in such circumstance require relatively complex procedures that would place large demands on the agency in terms of staff and information gathering and processing. This had the risk that in trying to establish simplified operational procedures the water of Tarbela would be used less prudently than intended and/or the flow variation would result in variation in supply in the tail reach of the Machai and Maira canals. As the water taken from Tarbela reservoir is furthermore relatively free of silt – at least for the time being – the automatisation of water control in PHLC also became a technically feasible option.

The PHLC design thus introduces a number of new water control concepts and features to the Indus-basin, that are radically different from those to which the ID is accustomed in its operation

[125] Valuable in two senses: economically as hydro-power generated at Tarbela dam, and hydrologically as the most important regulable water resource of the Indus-basin system.

and maintenance of the ‘protective’ irrigation systems. By opting for the automated downstream control, it chose to technically shape the shift towards ‘demand-based’ operations, rather than managerial/operational as in the case of Mardan-SCARP; which was a choice available thanks to the opportunities provided by Tarbela reservoir.

The main objectives for the PHLC project were thus to build the PHLC main canal taking off from Tarbela and link it up to the Machai branch of USC, and supply the tail 32,000 ha of USC with supplemental water. In addition, to develop 4,000 ha of new command area supplied directly by the PHLC main canal, in the so called Topi area. The full fruition of the maximum carrying capacity of 28.3 m^3/s (1000 cusecs) of the new main canal is, however, to be realised gradually over time, by enabling a further expansion of the USC command area by 12,000 ha upstream of the confluence point, and by supplying the water for the planned 2,000 ha Jhanda-Boka lift scheme.

In the PHLC design it was decided to opt for downstream automated water control in the main canal, with an in-line storage capacity to respond rapidly to changes in water requirements *cum* use. This was a feasible option as PHLC takes off from Tarbela reservoir and is thus unsusceptible to variations in supply. To create the in-line storage capacity, the PHLC main canal was designed as a parabolic level top canal, running along the contour. The water for PHLC is taken directly from Tarbela reservoir through the pressurised Gandalf tunnel, which was already built in 1974 with the commissioning of Tarbela dam and reservoir. The water intake is to be regulated at the outlet of the tunnel by free discharge valves, that will respond automatically to the downstream water level in the main canal. A small hydropower station will generate up to 18 MW of electricity at the tunnel outlet to recoup some of the power forgone at Tarbela.

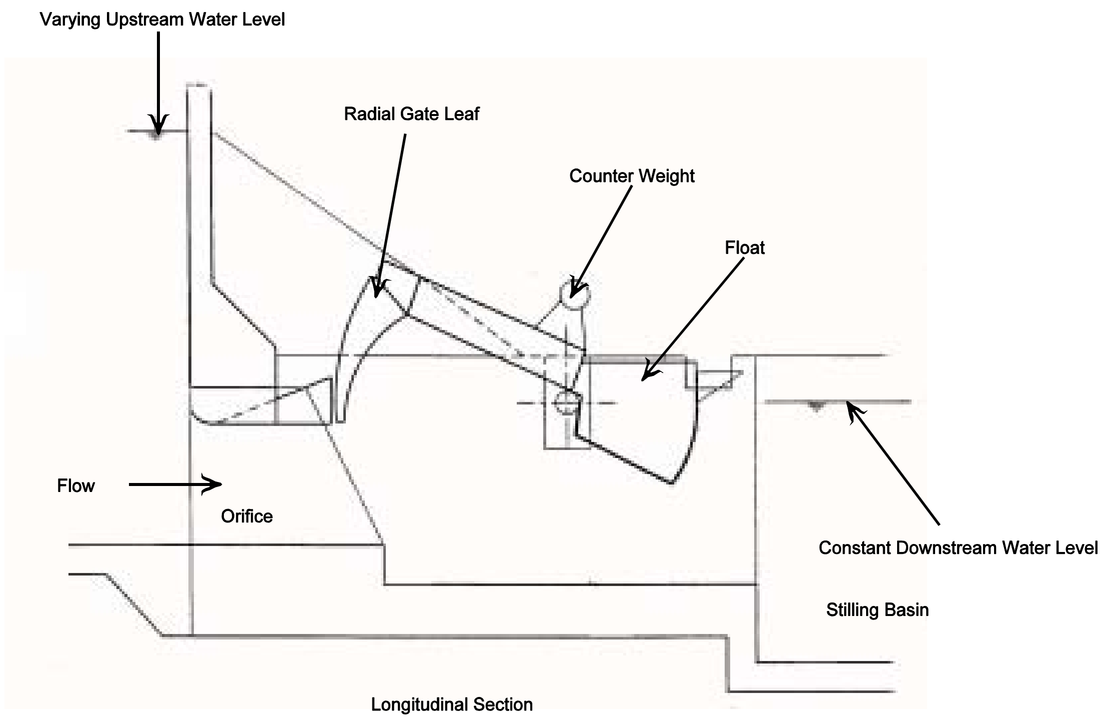
For the automated water level control and flow regulation, the PHLC main canal is to be fitted out by hydraulically self-regulating AVIO (*cf.* fig. 7.14) and AVIS gates (*cf.* fig. 7.15) that keep a constant downstream water level by regulating the discharge through the structure in response to fluctuations in the downstream canal section. The ability of the system to respond rapidly to downstream flow fluctuations is determined by the in-line storage capacity created in the canal compartments between two cross-regulators. The volume of which is determined by the wedge between the maximum upstream[126] (horizontal) water level at zero flow, and the minimum upstream water level at maximum flow. The automatic control of the gates consists of the self-regulation of the gate opening on changes in the downstream water level by means of the float mechanism. This water control concept, and the AVIO/AVIS structures were developed by the French in the 1930s, and have been successfully in use since then in France and Northern Africa. The AVIO gates are used to regulate the flow through an orifice and are applied in PHLC at the outlets of the cross-drainage siphons in the main canal, while the AVIS gates are used to regulate normal free flow canal sections.

The PHLC project decided to extend the automated downstream water control concept into the tail area of USC and configure the Maira canal according the same principles as the PHLC main canal, rather than limit its application to the PHLC main canal itself. Operationally, this

[126] That is, upstream of the AVIO/AVIS structure, which equals to the downstream end of the canal compartment in which the volume is stored.

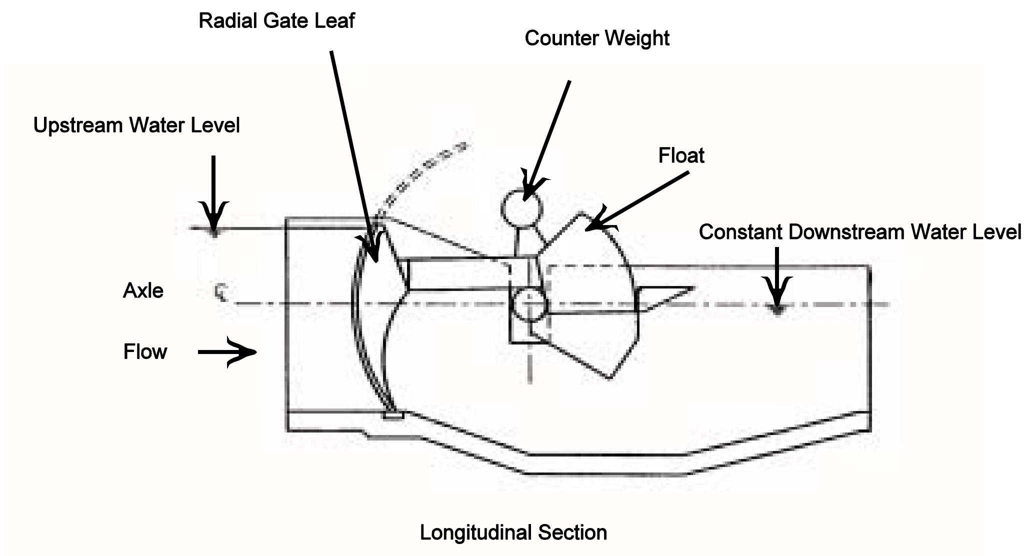
extension of the automated downstream water control into the Maira canal was not strictly necessary to manage the confluence of PHLC with USC. To meet the requirements of safety and operational ease for this confluence it would have sufficed to limit the automated downstream water control to the PHLC main canal up to the confluence. This decision to extend its application up to the tail of Maira canal is thus a deliberate choice to modernise the water control

Fig. 7.14: AVIO Downstream Automatic Cross Regulator



(PHLCC; 1995d)

Fig. 7.15: AVIS Downstream Automatic Cross Regulator



(PHLCC; 1995d)

and delivery service at the tail of USC from the part of the PHLC project. In all, three AVIO and two AVIS structures are to control the water in the PHLC main canal and its confluence with the Machai branch canal, and an other eight (8) AVIS structures will be placed in the Maira canal of USC (*cf*. PHLCC; 1995).

Devising New Water Delivery Concepts

With this decision for automated water control at the main system level, the PHLC design team could basically choose from a wide range of technically feasible water control and delivery service concepts to apply at the secondary and tertiary levels of PHLC/tail USC systems. Conscious that the automated water control at the main system level represented a 'modernity' for the irrigation sector in Pakistan, the PHLC project tried to apply a 'modern' water delivery concept as well for the secondary and tertiary levels of the newly to develop Topi area. By trying to make maximum use of the unique opportunities provided by the automated downstream water control of the main canal and Tarbela reservoir, the project proposed to extend the automated downstream water control up to the farm gate for the 4,000 ha of Topi area. The aim was to provide for a 'true' on-demand water delivery service that would provide the maximum managerial flexibility to the water users. The most obvious and easiest way to achieve this, is to provide for a low-pressured (i.e. gravity) buried pipe-system at the secondary and tertiary level, where the only imposed restriction would be a limited maximum rate of off-take at the farm-gate. The Government of NWFP and the ADB, however, did not give their full approval to this proposal. Concerns to lose control over water supply to water users, who in Topi area are moreover new to government irrigation, was sufficient to refute the extension of the pipe system up to the farm-gate. As a compromise, it was settled that the secondary level of Topi area would consist of the proposed low pressured buried pipes, but that the water will be delivered through free valve outlets at the water course *cum* tertiary unit head. This solution provides the opportunity for the ID to control and operate the water distribution and delivery at a reasonable number of points in the system, which moreover coincide with their juridical mandate and legal property.[127] In the newly developing Topi area, the water delivery service to the tertiary unit can thus, in principle, be 'on-demand' with a limited maximum rate. In practice, the water delivery service will largely depend on the frequency and extent to which the ID will allow, or operate and regulate the outlet flow in response to changes in crop water requirements *cum* water users' demands.

For the 32,000 ha of the USC commanded by the Maira canal, the 'on-demand' buried pipe system was never an option. This tail-end area of the USC was to be remodelled as the rest of USC under Swabi-SCARP, making use of the same design criteria, outlets and hydraulic configurations at the secondary level. This decision was taken already at the early stages of Swabi-SCARP. However, the subsequent decision taken by the PHLC project to configure also the Maira canal for automated downstream water control, essentially departs from the this

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[127] It is good to remember in this regard, that the handful of farmers in Merriam's buried pipe system at Mardan-SCARP never got the control over their farm-gate outlets, but that to date they are still operated by a representative of the ID who is in possession of the key; a workable compromise that would be unfeasible to replicate over the 4,000 ha of the Topi area.

remodelling objective. Since the secondary canals are remodelled according the self-acting proportional concept of Crump, the configuration of Maira canal by PHLC would seem rather over capacitated. In the reasoning of PHLC, however, the extension of the downstream control into Maira canal was seen as a logical anticipation on the 'modified-demand' operations that were expected to be established in USC in some future stage, for which increased demand capacities were taken into account in the remodelling (i.e. the 'modified-demand' supply rate of 1.34 l/s/ha). As the automated downstream control was to be applied in PHLC main canal anyway, its extension into Maira canal came quite 'naturally' as a preparation for a future shift to 'modified-demand' operations in the whole of USC. While for the upstream part of USC the water control could be converted likewise: *"In future, downstream control could be extended further up the main system* [i.e. the Machai branch] *by automating the radial gate cross regulators using computerised control."* (Bozakov and Laycock; 1997:113)

The tail-end area of USC served by the Maira canal will thus undergo a major transformation with the completion of PHLC, in which it effectively ceases to be a classical and structurally water short tail-end area to be become the area of the USC with the best water delivery service. It will not even be subjected to rotational water distribution during the *Rabi* season. In addition the secondary level water distribution problems that might result from inaccuracies in hydraulic configuration, as those that occurred in Kalpani and Jalala, might be substantially mitigated by running the canals continuously at their full supply levels or substantially above the prevailing water requirements. It is thus not unlikely, that a similar water delivery and use strategy will develop in the command area of Maira canal as the one that emerged in the remodelled LSC.[128]

Hydraulic Limitations for Water Control

There are a number of issues that require special concern in the case of PHLC in order to make sure that the automated water control indeed functions as intended by the designers:

First of all, the issue of sediment. For the time being, the water taken from Tarbela reservoir will be virtually free of sediment. However, Tarbela reservoir is silting up rapidly and the flushing of sediment in the months of June and July has become one of the main operational concerns for WAPDA. Inevitably Tarbela reservoir will silt-up, and the sediment will reach the intake of PHLC. Estimations as to when the so called sediment delta might reach the dam – and consequently the PHLC and Tarbela powerhouse intakes – range from the year 2005 to 2015, with latest studies favouring the earlier rather than late date. When this occurs, the sediment trap efficiency of Tarbela reservoir is expected to drop from its current level of 90 percent to about 10 percent in the course of 10 to 20 years. Once the sediment load in the water released from Tarbela starts to increase, this will have consequences for PHLC as the configuration of the PHLC main canal is particularly sensitive to sedimentation. The capacity for in-line storage at the main canal is created by an inverted Q-H relationship at the downstream end of the canal compartments. This results in low flow velocities for discharges below maximum capacity (i.e. below FSQ) as water is ponded upstream the self-regulating gates. Once sediment loaded water

[128] Provided of course, that adequate drainage facilities are in place with which the water users can manage their excess water.

starts to enter PHLC specific measures will have to be taken in order to avoid that the Pehur main canal becomes an effective silt-trap in itself. The most obvious and preferred solution would be to built a ‘true’ (i.e. purposefully) sediment extracting device in the head reach of the main canal (either a stilling channel or vortex tubes). Although the project has acknowledged the need for such a sediment-extracting device in the future, no detailed decisions and provisions have yet been made at this time. Alternatively, or additionally depending on the effectiveness of the sediment extraction, the Pehur canal could be operated according to the maximum flow (and thus velocity) criteria during the *Kharif* months when the sediment load of the Indus is at its highest. This would, however, constitute a serious delimitation of the automated downstream water control capacity. Moreover it would defy the supply criteria established for PHLC which stated that during *Kharif* its supply should be supplemental, and thus variable with the shortfalls of Swat river water at the confluence with USC in Machai branch.

Similar concerns surrounding over sedimentation are valid for the Maira canal of USC, with the difference that sediment will enter the Maira canal in any case with the water from the Swat river supplied by the USC during the *Kharif*. The severity of the sedimentation risk is in this case, however, mitigated by two factors: (i) the concentrations of sediment will be reduced as long as the supplemental water from PHLC is relatively free of sediment; (ii) the Maira canal is not supposed to run on reduced flows during the *Kharif* when all its secondary canals are to be supplied with continuous FSL supply. The latter operational target, however, raises questions on the necessity to configure also Maira canal for automated downstream control. Also any possible future use of the storage and response capacity of the canal will immediately raise the risk of sedimentation, as the ponding of water behind cross-regulators easily results in too low flow velocities, as experiences in CRBC have shown.

A second issue concerns the potential problem of hunting that is endemic to all automated control systems. Automated control structures placed in series, as the cross-regulators along Pehur and Maira canal, can become prone to hunting, which will render the system unstable. Hunting will occur when the AVIO/AVIS gates react with too much sensitivity to fluctuations in the downstream water level – as for example on waves created on the water surface due to strong wind, to give a potential, but extreme, example. This will cause a chain reaction along the canal, in which each gate reacts on too small water level fluctuations, and the gates will be in perpetual movement rendering it impossible for the system to reach steady state flow conditions. The closer the gates are placed to each other (i.e. the smaller the canal compartments are) the higher the risk will be that the system will enter such a state of hunting.

The original French manufacturers and patent holders of the AVIO/AVIS gates are well aware of this potential danger of hunting, and have thus taken pre-cautionary measures to avoid canal systems equipped with their gates from entering such a state. The principle of this measure is to create a specific ‘dead range’ of water level fluctuation on which the gate will not react; which in the case of the AVIO/AVIS gates is determined by the specifications of the weights and floats that regulate the hydro-mechanical movements of the gates. The size of ‘dead range’ required to avoid hunting, depends on the length of the canal compartments and the Q-H relationship of the gate size used. The licensed manufacturer can thus provide guarantees against hunting provided the gates are: installed according to specifications, used over the discharge and hydraulic head range as specified by type, and are not installed in smaller canal compartments than recommended.

Due to some topographical limitations the designers of PHLC were forced to place some of the gates at intervals less than the minimum recommended by the manufacturer. However, the designers carried out hydraulic simulations on the PHLC design to determine the propagation of flow fluctuations under different operational conditions, and are confident that the Pehur and Maira canal configurations are stable. (*cf*. Bozakov and Laycock; 1997:113-114) For the construction work of PHLC project, a Turkish contractor has been contracted that will carry out all the construction work at the main level, and secondary level of Topi area. This contractor will also carry out the installation of the AVIO/AVIS gates, which are purchased from a Turkish, but licenced, manufacturer. It should be hoped, that due attention is given to their correct installation, and that higher levels of accuracy will be attained than in Swabi-SCARP.

7.6 DISCUSSION & CONCLUSIONS

The hydraulic performance evaluation of Kalpani distributary shows that poor performance can be built into a system if there is inadequate control over the quality and accuracy of construction. Although this is generally true for all type of irrigation systems *cum* projects, the ‘self-acting’ proportional water distribution concept applied by Swabi-SCARP is particularly sensitive to disruption of its hydraulic configuration as a consequence of inaccuracies in construction. Any resulting inequities in water distribution can only be remedied by hydraulically re-configuring the canal in question through an additional ‘remodelling’, or mitigated by the cumbersome and dreaded operational practice of *tatiling* (*cf.* chapter two). In the case of USC the proportional configuration of the canals is furthermore essential to attain the capability of rotating the low *Rabi* flows over the command area.

It is clear that Kalpani distributary, as commissioned in 1997, did not meet the design criteria. Its hydraulic capacity was distorted to such an extent that it could only be operated acceptably around full supply level.[129] Clearly, better accuracies in construction – especially in hydraulic configuration – should be attained in the other canals of USC, to secure an adequate water delivery capacity in the newly remodelled system, as specified by the design. This is a prerequisite to be capable of maintaining a proportional distribution over the wide range of water levels on which the system has to be operated over the different seasons and project stages. The case of Jalala distributary furthermore indicates, that the attainment of the required hydraulic configuration is not only a matter of exactitude of construction, but also of the accuracy and reliability of the hydraulic parameters used (i.e. roughness factors and discharge coefficients) to determine the water levels.

The strategy adopted by Swabi-SCARP for the remodelling of USC, with its choice for re-instating Crump’s self-acting proportionality, is a direct result of postponing the ‘modernisation’ of USC to a future stage in response to the experiences in Mardan-SCARP. From the problems Swabi-SCARP encountered during the implementation, however, it becomes evident that the

[129] Acceptably in the sense that it would be capable of supplying its full command area, even though the actual delivery to the outlets would still be highly disproportional, with head-end outlets receiving far more than their targets.

project underestimated the complexities and hydraulic delicacy of the concept of self-acting proportionality. The 'traditionality' of the concept seems to have barred the project from executing a full conceptualisation, and instead treated the remodelling of USC more as a modified rehabilitation. The adoption, without questioning, of the operation & maintenance procedures, including that of the seemingly never institutionalised H-register, support this impression. While the mistakes that crept in the O&M manual on the proportional distribution during rotation are symptomatic of neglect of the interrelationship between operation and hydraulic properties and thresholds.

The events in Jalala distributary, where the ID was responsible for part of the configuration of outlets, reveals two issues of operation and maintenance that needs addressing. The indiscriminate altering of dimensions, configurations and sizes of outlets, cannot continue. The Canal & Drainage Act, and the rules and procedures for the ID, need urgently to be revised to unambiguously determine the water allocation, as well as the control, regulation and maintenance procedures for the hydraulic configuration of self-acting proportionality. Without clear-cut rules and procedures, and without working experience of remodelling, it is a concern whether the ID can take up the hydraulic configuration of complete distributary canal systems.

The problems of accuracy in construction and hydraulic configuration have had, as mentioned, several reasons and contributing factors. The degree of externalisation and compartmentalisation with which the remodelling of USC was conducted, however, contributed to the inability to control these problems. The most striking, in this sense, has been the fact that the design team of the consultants and WAPDA – i.e. the people that made the hydraulic configurations and kept the overview of the hydraulic integrity of the system – had to move on to PHLC by the time Swabi-SCARP started its implementation phase. The implementation phase was thereby reduced to a construction phase, with as primary concern the logistics of arranging and supervising the construction at multiple sites, by multiple sub-contractors.

The conceptual turn for irrigation modernisation that has taken place with the PHLC project, is as radical as it is surprising given the previous attempts and experiences in Mardan- and Swabi-SCARP and CRBC. The choice for the concept of automated downstream control with wedge storage capacity, seems to be born as much out of technological opportunism provided by the favourable conditions of Tarbela reservoir as a resource, as by the strategy to seek closure of the irrigation system by reducing its management requirements. For the handling of the risks inherent to the confluence of PHLC with Machai branch, and the new command area of Topi, these are valid opportunities to explore. As far as the tail area of USC (i.e. Maira branch) is concerned, however, the downstream control concept leads to a rather odd combination with the traditional self-acting proportionality at the secondary level. This raises fears that a similar situation will emerge there, as the one that emerged in LSC, of generous water delivery as a means for the ID to simplify its management tasks. The latter has now become an issue that the ID circle of Mardan will have to come to grips with. After completion of PHLC, it will bear the O&M responsibility for the three canal systems, that provide four different control options (i.e. LSC, USC head reach, USC tail reach and PHLC/Topi). Without any purposefully set-up programme with the ID to transform their water management practices and diversify their water delivery services, by making use of the established control options, the task to match the irrigation water supply to the crop water requirements will fall to the water users. As the water users in Sheikh Yousaf minor have shown, this is then not so much a matter of water control concepts and scheduling, but more of relative water supply and drainage opportunities.

CHAPTER EIGHT

AN EPILOGUE ON INSTITUTIONAL REFORMS

A FRESH WIND IN WATER MANAGEMENT STRATEGIES FOR THE 21ST CENTURY?

8.1 INTRODUCTION

From the interventions treated in the previous four chapters it becomes clear that modernising irrigation in NWFP, and the Indus basin as a whole, is no simple matter. Attempts to create a technical capability to better match irrigation water supply with crop water requirements and water demands did not yield the unbound successes the irrigation and water sector in Pakistan is in dire need of. These technical interventions ran into the problem of having no 'counter parts' with which to implement the operational tasks and procedures of their elaborate concepts of demand-responsive water delivery management. The ID turned out, in the view of many, to be obtuse to change over to a dynamic water management system, in which irrigation water delivery is matched to actually water requirements and demands, and farmers are seen and treated more as customers whose wishes should be served, rather than users that have to cope with what they (can) get.

As argued in the previous chapters, the resistance to change was fuelled by the sense of the ID that the water control and delivery concepts of these interventions were largely imposed upon it, while demanding too much changes in the water control procedures which fuelled the fear of handing over too much decisional power to 'unprepared' water users. At the same time, there were no (formal) organisations of water users 'available' (i.e. present) with which the tertiary and secondary level operations could be given shape in concrete procedures and tasks, to create a water users' 'counter force' of demanding services that could act as a check and balance on the discretionary powers of the ID and a process of accountability.

The absence of formal water users organisations that actively participate and bear formal and active responsibility in the management of irrigation systems, is increasingly regarded as an obstacle to the modernisation and improvement of irrigation in the Indus basin. The international wave of participatory irrigation management (PIM) and irrigation management transfer (IMT) has also come to Pakistan, to be ridden by the multilateral donor agencies, policy makers and consultants engaged in the development and management of the IBIS from the early 1990s onwards. This ‘new’ wave of thinking in the sector quickly leads to new problem analyses that emphasise management issues of irrigation. The resulting IMT/PIM programmes are largely a response to a different analysis of the problem situation, in which the poor performance of irrigation – and in particular that of large scale systems – is primarily attributed to a dysfunctional organisation of irrigation water management. The widespread tendency of bureaucratisation of irrigation management by government agencies is regarded in such analyses as one of the prime causes of dysfunctional water management. The bureaucratisation is seen as the inability of O&M agencies to respond to water users’ needs and the inability to maintain the system with subsidised, low, and increasingly poorly collected, water fees and generally decreasing budgets. The associated problems of such dysfunctional management are presented as: excessive rent-seeking, deterioration of infrastructure and water delivery services, rising conflicts in water management, inequality in water distribution, and the final ‘losing-out’ of small farmers and complete tail-end areas. Usually this bureaucratisation of water management is presented as a downward spiral that leads to ever deteriorating performances, wherein the dysfunctionality of management and poor performance are mutually reinforcing. The institutional reform programmes of IMT and PIM seek to halt this spiral of deterioration through decentralisation and democratisation of irrigation water management, in which the market principles of the neo-liberal economic policies can act as regulators of the water demand-supply process.

The next section presents the institutional reform objectives of the multilateral donor agencies (i.e. World Bank and ADB) for the water (management) sector in Pakistan. With its ‘Issues & Options’ paper of 1994, the World Bank set out its vision and objectives for the water management reforms in Pakistan, in which disengagement and decentralisation were presented as central elements of reaching better performance levels of the IBIS; in the realms of finance, water use efficacy and efficiency, and agricultural productivity. After fifty years of Bank sponsored technical interventions in the IBIS, the ‘Issues & Options’ paper came as a landmark change of policy making in the water sector. Rather than merely opting for further infrastructural improvements to enhance the regulability and control of water in the designed physical system of the IBIS, emphasis was given to the institutional and management issues. With the paper, the Bank presented it’s vision for a dynamic water management system for the IBIS, in which localised and decentralised investments in, and optimisation of, the irrigation system could be pursued. The bureaucratisation and fossilisation of the state’s management structure were presented as one of the prime causes of low performance, and impediments to future improvements. A situation that could be characterised at best, as a dysfunctional administration of the state’s interests in maintaining the status quo. In the Bank’s view the time had come to turn management around, and facilitate local management and investment, in which the matching of the water users’ irrigation requirements would become a central element of water management.

In section 8.2 the Bank’s vision for such a dynamic, decentralised and participative, water management structure for the IBIS is presented and reviewed. The central premisses of this vision are discussed and reflected against the context and dynamics of water management in the IBIS over the past fifty years. Central to this, is the emphasis that has been put on making water a tradable good, so that water users can meet heir irrigation requirements through trade, acquisition and investment in their decentralised irrigation systems. The strategy of IMT/PIM has thereby not only been put forward as a strategy to improve the efficiency and efficacy of the existing 'protective' irrigation systems, but as a prerequisite to facilitate and stimulate the investment in irrigation, and the modernisation of water management. Not by the traditional means of matching requirements through central (state) scheduling, but by the dynamic mechanisms of trade. The premisses of this presented vision are reflected against the constraints imposed by the institutions of water management and designed physical systems of the IBIS, that governed the water management practices over the past hundred - fifty years.

Section 8.3 describes how the federal government of Pakistan has reached an accommodation for the institutional reforms, that were called for by the multilateral agencies. The accommodation was, however, primarily exacted by the multilateral agencies by demanding a consent on the institutional reform programme as a condition for the 785 million US$ loan agreement for the National Drainage Programme (NDP). The eventual outcome of the formal PIDA-act reflects this political accommodation, in that it formally opens the way to initiate a restructuring process for the water management sector, in which decentralisation and water users participation can formally be pursued, but in which the traditional laws and modalities for water management of the Canal & Drainage Act are still attained.

In section 8.4 the first practical initiatives undertaken to set-up water users organisations and engage them in O&M activities at the secondary level, are treated. These first initiatives in PIM, that were tried out through a set of pilot projects prior and during the enactment of the PIDA reforms, in Punjab, Sindh and NWFP, are reviewed for the lessons they provide for giving shape to the institutional reform processes in the IBIS. From these first experiences – primarily derived from the pilots conducted in Punjab and Sindh, which have yielded the most experiences – it becomes apparent that, although water users can successfully be organised into formal structures, the central issue of water management in the IBIS remains the same: namely, the matter of water allocation and equitable water distribution. An issue that remains to be governed by the technological and natural-physical constraints imposed by the IBIS, as well as hampered by an emerging institutional dilemma and conflict on the settlement of operational mandates and discretionary powers. In the conclusion to this chapter (section 8.5) it is argued, that the settlement of this central issue, and the progress of the institutional reforms, is primarily a matter of process management, rather than institutional structure building.

8.2 1994: A POLICY STORM OF INSTITUTIONAL REFORM

> *"In Pakistan, as in many other countries, government treats irrigation water as a public good, whereas it is a private tradable good, for which markets can operate (now they operate informally). However, lack of well defined individual property rights and the illegality of sales of surface water severely constrain informal irrigation water markets. Instead of rooting out the barriers to water markets, Government publicly administers irrigation water. Inefficient pricing of water, resource misallocation, rent seeking*

behavior, and 'illegal' trading is the result.

"The Government has not even adequately met the requirements of an administered system. It has failed to make budgetary provisions for operations. Moreover, the public body responsible for irrigation maintenance is separate from (and has poor coordination with) the agency responsible for revenue collection. In the past, administrative discipline was adequate but it has now broken down and the cost of irrigation maintenance has vastly increased. Nor are there any measures available to restore discipline. And even if there were, economic efficiency in irrigation delivery and use cannot be achieved, because the present system cannot offer the right incentives." (World Bank; 1994:ii (executive summary))

Thus, the World Bank entered the policy debate on institutional reform as a fox into the henhouse of water management in Pakistan, with its paper *"Pakistan Irrigation and Drainage: Issues and Options"*. A paper that was drafted in 1993 by the Bank's Agriculture Operations Division, and finalised in March 1994 after consultation with the Government of Pakistan and its federal and provincial agencies. The paper heralded the dawn of a new era of institutional reforms in the water management of the IBIS, that would root out the *"sources of the problems"* – as quoted above – the nation was facing. Substantial reforms were then required, and foreseen, to: decentralise the irrigation water management system, create autonomous and financially self-sufficient public utilities (PU) and farmer organisations (FO), that would (or could?) conduct the water management transparently and accountably, and enable, and engage in, the trading of 'private water' (vested in *"enforceable property rights"*) which the market forces would direct to its best and most efficient use. In unabashed wording, the executive summery of the paper promises that the proposed institutional reforms in the water sector can bring Pakistan the long awaited and yearned for goose that lays the golden eggs:

"The new system of irrigation and drainage (emerging from the implementation of the strategy outlined here) will not only get the system out of the present crisis, it will bring in sustainable benefits to farmers. The new system will guarantee a reliable supply of minimum amount of water determined as the basic right and offers possibility of acquiring more water through purchases. Most farmer organizations will be able to plan ahead for such purchases and, therefore, availability of water will be known in advance with reasonable certainty. Water charges under the new system are expected to be less than the old system, because part of the O&M will be carried out by the farmers themselves more efficiently than public institutions and PUs will be cost-conscious. The water losses now incurred will be greatly reduced and, so, farmer organizations will have increased supplies of water. In short, the new system will allow farmers to manage their own affairs, adopt a distribution pattern they prefer, and will generate greater farm output and income." (op.cit.:iv)

The outlined strategy for institutional reform of the water management sector in Pakistan as presented in the 'Issues & Options' paper, shook the establishment with its radical departure from the view that irrigation is a public service for which the state should bear responsibilities in providing it. The long term picture, in which the state's role would be primarily confined to the enabling and regulation of the market of water allocation and distribution, the paper presented, was quickly perceived as a threat to the existence of the state and provincial agencies, and in particular by the irrigation departments. The polemic it raised, and which was actively fed by the critiques ventilated by the provincial irrigation departments, farmers associations and newspapers (*cf.* VanderVelde & Tirmizi; 2002, that provide a nice critical review of the introduction of the reforms), was that the proposed reforms contravened the very notion of the state's role as guardian of the natural and national water resource base and its equitable allocation and distribution among its citizens.[130]

The Bank, as reflected in the 'Issues & Options' paper, clearly opined differently: *"In fact, due to administrative, institutional, and technical problems, declining performance by civil service administrators has become the underlying cause of deterioration in the whole system."* (op.cit.:11) The poor performances and continuing deterioration of the IBIS needed to be turned around to secure the needed growth in agricultural production[131] and warrant the continued investments of the Bank and Government of Pakistan in the system. Clearly, the time had come to take drastic measures to achieve just such a turnabout.

The objective underlying the proposed reforms, was to create management organisations and institutions that would be motivated, disciplined, financially sound and autonomous, and geared towards optimising the water delivery service and its use in their own demarcated (hydraulic) management domains. Decentralisation and participation seem then the obvious means to do so, and create water management organisations that possess a sense of collective ownership and self-interest, that urges them to pursue the improvement, maintenance and high performance of 'their' systems. The premisses behind this thinking is, that a positive spiral of irrigation management and development can be entered; in which improved (most of all in the sense of reliable) water delivery services leads to a willingness to pay service charges, which on its turn induces a willingness to invest to further improve the services.

The proposed reforms suggested to achieve the above by re-structuring the management of the IBIS into the following structure and tasks (see also fig. 8.1): The provincial irrigation departments were to be reformed and split into two distinct types and functions of water management; the Provincial Water Authority and the Public Utilities (PU).[132] The former would be responsible to delivery water to the PU, guarantee that they receive their allocated shares, and maintain the provincial irrigation and drainage structures and facilities that are required to deliver the water among the systems and dispose the drainage effluent. The PU would be

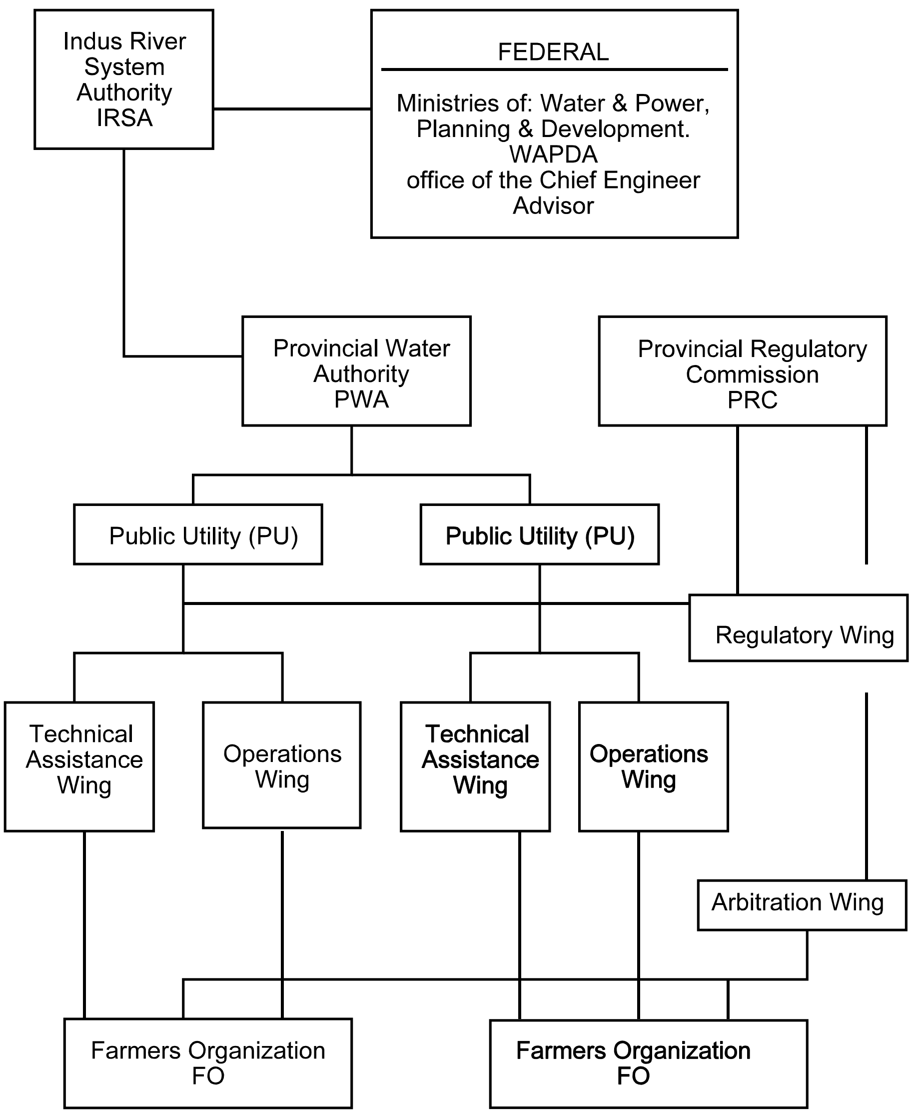
[130] Never mind that the latter had proven to be a near impossible task to fulfill over the last decades. It still was the prime task and responsibility of the state's irrigation agencies to provide such equity, and the further development and support of the IBIS should thus continue to be geared at increasing the state's ability to guarantee the equity in water allocation and distribution; so the argument would go.

[131] During the first three decades of its independence, Pakistan was able to achieve an acceptable average annual growth rate of 5 percent in agricultural production, well above its annual population growth rate of 3 percent. During the 1980s, however, the growth in agricultural production started to decline, and moreover shift to non-food production (i.e. cotton), whilst the population growth only diminished slowly (2.6 percent at present). For the period 1995-2000 it was projected by the Bank and the Government of Pakistan that the growth in agricultural production would decline further to an annual rate of 1.9 percent, if no further measures were taken to improve the IBIS. This revealed thus a major political and economic problem, as the rate of agricultural growth would, for the first time, fall substantially behind the population growth. (Ahmad & Kutcher; 1992)

[132] Basically, the proposal was that the ID staff from the XEN (the canal officer that is responsible for a canal command) down would constitute the members and professional staff of the PU, the SE and superiors would then form the provincial water authority.

responsible for the management of irrigation and drainage of one canal command system. Its main task would be to allocate and deliver the irrigation water among the FO it serves. The FO would be set up as true farmer cooperatives, that exist of federations of tertiary unit water users associations, and bear the full operation and maintenance responsibility for irrigation and drainage at the secondary and tertiary level of the system. Once the FO would be well established and working, they could take over the PU by filling all seats of the board. The basic idea, as presented in 'Issues & Options', is thus that each of these new water management organisations would constitute an autonomous body that purchases the water from an other organisation

Fig. 8.1: Proposed Management Structure for Decentralised Water Management



(World Bank; 1994:35)

(primarily vertically, but also horizontally as means of water trade) and adds on surcharges to its members or 'clients' for the extra services, or quality in service, it provides.

The creation of a new institution was proposed with the establishment of the Provincial Regulatory Commission, that would have as primary task to act as regulator and arbitrator on all issues pertaining to water allocation and distribution, and the sound working and functioning of the PU. They would act as register of the water rights, and as regulators of the service fees charged by the PU. The regulatory commission was thus meant to act as an independent judicial institution for the arbitration of all water disputes that could occur within FO, between FO, between PU and FO, between PU, and between PU and the provincial and federal agencies.

At the federal level, the agencies responsible for the allocation, distribution and operation and management of the IBIS (i.e. the IRSA and WAPDA) would retain their responsibilities. Their primary task would be to enable and conduct the water delivery to the provincial water authorities, as stipulated by the water allocations agreed in the Indus Water Apportionment Agreement of 1991.

Water as a Private Good: The Incentive of Trading & the Issue of Rights

The proposed reforms aimed at changing the principles and strategies of the control mechanisms of water allocation, scheduling, and distribution substantially, in order to provide the public utilities and farmer organisation with the capacity to become financially autonomous and the incentive to invest in improving their irrigation services and performances. Ultimately, the goal embedded in this reform policy is to enable cultivators to better match their irrigation requirements and to realise higher levels of water use efficiency and efficacy than obtained in the present system. The principal mechanism to enable this is the trading of water. As is implied by the 'Issues & Options' paper, by turning a widespread vice (i.e. of illegal *Warabandi* exchange and the selling of pumped groundwater) into a virtue.

Enabling and stimulating the trade of water is a fundamental aspect of the proposed reforms, as it should act as the prime stimulus to pursue optimisation of irrigation and drainage water management. By facilitating the purchase of 'extra' water cultivators are enabled to optimise their irrigated agricultural production, while the selling of water enables the utilities and FO to capitalise their surpluses which enables them to invest in further improvements of their systems and services. Moreover, the market forces of trade will induce the users to use their water efficiently; either to save on costs or to maximise the capitalisation – or so the argument goes.

To enable the free trade of water, it is thus paramount to establish *"enforceable property rights"* on water in a new and unambiguous legislation. The 'Issues & Options' paper then also argued for creating such a new legislation that would supersede the ancient Canal & Drainage Act of 1873, to be administered by the newly to establish regulatory commissions. The issue is then, however, by which legislative principle should these *"enforceable property rights"* be created, and *which* water becomes then available for trade through *what* means of trade, in the social, natural and physical environment of the IBIS.

The first question is, whether the water rights should be allocated on the basis of volumes or on the basis of share of flow. Based on the traditional experiences and water control and regulation capacity within the IBIS, the latter would seem an obvious choice to make. In order to enable and stimulate the water market, however, it is preferable to allocate volumetric shares. As the 'Issues & Options' paper points out: "[...] *a true volumetric pricing is needed to eliminate the rent seeking"* and avoid the disadvantages of allocation of shares of flow that lead to an *"inability* [...] *to address the tailender equity problem and the reduction in the size of water market due to increased uncertainty and thus increased transaction costs."* The paper thus argues to pursue volumetric allocation as, *"volume based rights, where technically feasible, seem preferable."* (World Bank; 1994.:20)

The reasoning behind this volumetric allocation, as that behind the whole proposal for reforms and decentralisation, is clearly based on the way things are run and work with the water districts in the USA and the modulos in Mexico. The latter of which is heralded throughout the paper as a great success story of what benefits such reforms as proposed can bring. The principal difference with Pakistan is, of course, that both the USA and Mexico dispose over substantial storage capacity that enables the annual or seasonal allocation of volumes that can provide the security and reliability for cultivators at the start of their irrigation and cultivation seasons. (*cf.* Waller; 1994, Kloezen; 2002 and Wester *et al*; 2001) Within the IBIS, the storage capacity is extremely limited and moreover decreasing with an annual rate of 0.25 km^3 (0.2 MAF) due to siltation (Ahmad & Kutcher; 1992). The problem is thus, that the available volume for allocation and irrigation in the IBIS is as variable as the flows of the rivers, particularly during the water short and critical stages at the transitions between the growing seasons of *Rabi* and *Kharif.* The security and reliability sought by volumetric allocation, then has to be (and frequently is, at present) acquired by additional fresh ground water use, which can only be viable when the fresh water aquifer is managed as a natural storage facility.[133]

The next question becomes according to what judicial principle the water allocation should be conducted and be vested in *"enforceable property rights"*: prior appropriation, proportionality, equity or riparian. The aim, as set out in the proposal, is to set the starting conditions for the market place in which every water user is granted a 'basic right, that guarantees a minimum amount of water' with which (s)he can enter the market. To ensure that all water users enter the water market with the same possibilities, and tail-enders are also granted access, the suggestion was thus made to allocate the basic water rights according to the principle of equity:

- *"The volume of water based on the approved water allowance at the watercourse head and the designed capacity factor for the distributary will form the lower bound for the water right.*
- *"The volume estimated, based on an average capacity factor during the post Tarbela*

[133] The issue of groundwater and the need for its integrated management with surface water will come back later. The use of storage facilities as a means to facilitate the volumetric allocation and its marketing and trade between water users is, however, acknowledged in the proposal: "[...] *a watercourse with a well organized user group might wish to capture some of the delivery cost themselves and receive the entire volume at the watercourse intake (mogha) or even at the distributary or minor."* (World Bank; 1994:20) Akin of the 'melons on the vine' irrigation systems found in China, that were heralded as great examples of flexible water delivery systems in the 1980s. As argued, this is not a viable option in the IBIS, due to the high silt content in the surface water.

period, will form the upper bound.[134]

- *"In determining actual water rights, consideration would be given to: (i) soil and groundwater conditions; (ii) delivery losses within the FO area; (iii) land distribution/farm size within the FO; and (iv) location of the delivery point."* (World Bank; 1994:37)

The basis of the suggested allocation procedure is thus to 'restore' the mythical proportional and equitable water allocation and distribution of the protective irrigation water delivery, as a basic right and service. The third criteria to correct the proportionality for equity, is surprising as it would seemingly open up the allocation procedure for 'horse trading'. Moreover, it would seem to go against the grain of the purpose to induce FO and PU to invest in water saving measures, and recoup those investments through trade.[135]

The problem with trying to 'restore' the mythical proportional water allocations, as supposedly expressed in the approved or 'authorised' water allowances is, as is argued in chapter two, that these water allowances are (nor were) hardly ever proportional or equitable; not on the level of the distributary or minor (i.e. the FO domain), nor on the level of the canal command area (i.e. the PU domain), and certainly not on the level of the IBIS. The principal of proportionality has, one could argue, been superseded (or, at least amended) by the principle of prior-appropriation. The historical differentiations in water distribution and delivery have resulted in vested claims on entitlements to water, that are bound to be contested at all levels of the system, when they are subjected to a process of re-allocation, as was the case during the process of *Chakbandi* conducted between *ca.* 1880-1950. A settlement of this fundamental issue, by enforcing the proportional allocation at the distributary or minor level (i.e. the FO domain), while permitting differentiations among the upper levels of the system to reflect the historically achieved conveyance capacities and distribution patterns – as would seem the most likely solution – would, however, distort the water market between FO and between PU. The resulting differentiation in water entitlements and 'property rights' would not only result in a differentiation in, and between, the willingness to pay and willingness to accept in the price mechanisms of the market that are supposed to direct the tradable water to its most economic and efficient use (*cf.* Gaffney; 1997 for a critical analysis of how the differentiation of these

[134] The designed capacity factor, is an expression of the limited volume available for any given distributary during water short periods, mainly during the *Rabi* season; expressed as the number of days the canal can not be run on full supply level. With the completion of Tarbela more water became available during this period, which enabled more canals to be run at FSL for longer periods; hence the upper limit.

[135] The same issue emerged in the Bank's "success story" of Mexico. In the Lerma-Chapala basin the seasonal allocation and scheduling of irrigation turns between the modulos (i.e. the Mexican equivalent to FO) was initially clouded by that different modulos used different water layers for their irrigation turns. An issue that was raised by the efficient modulos, as a practice that lead to deviation in the actual water scheduling from the, in principle, proportional water allocation rules. By pushing to conduct the actual scheduling according to proportional volumes, instead of equal turns, the less efficient modulos were thus forced to pursue water saving measures if they wanted to maintain the number of irrigation turns with their reduced volumes. (*cf.* Kloezen; 2002, Wester *et al*; 2001) It thus seems rather peculiar, to forego this mechanism for water saving in the context of Pakistan, given the general purposes underlying the proposed reforms.

economic factors lead to a distortion of the water market in California), but will also result in a differentiation in the ability to sell and the ability to pay.[136]

The judicial reform, required to establish unambiguous water rights and enable the trading of water, is one of the most important, but also contentious, elements of the reforms as proposed by the World Bank. Together with the proposed establishment of the regulatory commissions, it forms a fundamental element to create '*enforceable property rights*' and pull the allocation of water out of the dark rooms of discretionary decisions and power, into an open process of accountability and judicial ruling. Such a process is, however, bound to open up a Pandora's box of contested claims on water rights vested in customary practices and historically granted or realised allowances, that will need to be handled with prudence. Particularly, since the contestations on water rights, and the therefrom arising conflicts, can put enormous institutional strains on the new to establish FO and PU.

The water that would possibly become available for trade and supplementation of the basic water share, seems rather limited when the existing canal allowances are to be formalised in a new water legislation. The most obvious, and most desired by the policy makers, is water that becomes available for trade through effecting water savings in the irrigation system. Based upon the currently used assessments of efficiency, that value the water losses at around 60 percent, a 40 to 45 percent saving seems attainable in the near future (World Bank; 1994, Ahmad & Kutcher; 1992). It is, however, questionable whether this water would become immediately tradeable. As such savings are only possible with substantial investments in the conveyance system, it seems logical and fair to spread its benefits over the investors, and that the water will be used first within the domains where the savings have been realised (i.e. the tertiary unit, the secondary canal, the canal command area). Until the room to increase the productivity and intensity of cultivation within these domains are used, it is unlikely the water will be offered on the market.

Another option would be that water becomes available through reductions in water use, as less water demanding crops and cropping patterns are cultivated. For an individual cultivator that applies such a strategy, however, the obvious choice is to expand his/her cultivation to the maximum intensity, before offering the water on the market. As the basic water rights are bound to be relatively low (in terms of l/s/ha) there is a lot of room to do this.

Much has been made in the literature on water management in Pakistan about the widespread exchange of *Warabandi* turns as examples of the occurrence, and good practice, of 'illegal' trading of water. Not in the least in the 'Issues & Options' paper, where it is sited as evidence that water users in Pakistan can, and do, deal with water trading, and that it is good to enhance the flexibility and productivity of the irrigation system. It is, however, questionable in how far these frequently practised exchanges constitute true trades that can be brokered on a water market. In practice, these exchanges are not so much trades of water shares, but primarily adaptations of schedules to adjust the timings of irrigation turns to more practical and productive

[136] In the eyes of true free market proponents it is, of course, not necessarily a bad thing if differentiation takes place and marginalised and inefficient users are eventually "squeezed" out of the market, and economic optimisation can take place. For Pakistan such a scenario is, however, not an option, as its economy will for the foreseeable future not have the capacity to absorb many agricultural 'losers' to provide them with an alternative living.

times. (*cf*. Wahaj; 2001 for a detailed study on the practices and dynamics of *Warabandi*)

Then there is the option that water rich utilities, as those to be formed in the Lower and Upper Swat Canal, can sell off their excesses to the less fortunate in Punjab and Sindh, on a seasonal or more long term basis, and capitalise on their fortunate allowance/allocations. As well as the auctioning of extra water that has become available through extra acquisitions and savings at the level of the IBIS by the federal government.

The easier ways left to acquire tradeable water on the market, seem then to be: (i) Water that becomes available by closing off defaulters in payment from water supply. Which is, according to the proposals, to be introduced as the disciplinary stick with which PU, FO and WUA have to ensure their financial self-sufficiency and autonomy. Which, of course, would not be a desirable effect, as it can lead to further marginalise the deprived. (ii) Tapping the (fresh) groundwater as an additional source, and offer this on the market. The latter is the most obvious and easiest option, but has some strings attached.

Integrating Ground and Surface Water Management: A Challenge

Fresh ground water is the ideal source for acquiring extra water to supplement the basic water share. Particularly since the aquifer can act as a natural storage facility, from which water can be tapped in the quantities and timings it is needed. The question is then, how this additional water should be allocated, marketed, and regulated (i.e. controlled), without depleting the resource.

In the ‘Issues & Options’ paper, it is suggested that WAPDA should assess the safe volume of annual extraction from the aquifer for each canal command area. This additional available water should then be allocated (in terms of a right to use and trade) to the PU and FO in each command area. The PU’s share should then be defined as the volume of water equivalent to which the canal water system contributes to the recharge of the aquifer (i.e. the canal system losses). The remaining part of the ‘safe volume’ should then be allocated to the water users on the basis of their surface water allocations. (World Bank; 1994:22) The farmer’s share of the ‘safe volume’ will thus also mainly constitute of their surface water losses that recharge the aquifer through deep percolation.

The FO would then have the task and responsibility (according to the Bank’s proposals) to develop the groundwater and stimulated its trade within their command areas and management domains, so that cultivators can meet their water needs and enhance their productivity. They are expected to attain (regulative ?) control over the extraction of groundwater by their members, and ensure that not more than the allocated ‘safe volume’ is extracted. Apart from the far fetching implications this suggestion has in terms of developing the required institutional capacity to monitor, regulate and restrict the development and extraction of fresh ground water, this raises substantial issues on how to balance the available water resources, with the growing water requirements and use.

A first, and paramount, issue relates to the relationship between surface water losses and the replenishment of the aquifer. A relationship that has been clearly acknowledged in the proposed allocation rules for the extraction of the ‘safe volume’ of groundwater, but which has much wider implications for the conception of an integrated water management concept. The much desired savings in surface water losses – which are clearly hoped to be stimulated with the proposed reforms – would represent a mining of their 'safe volume' of fresh groundwater for the PU and FO that realise such savings. Economically, this would also represent a destruction of capital, as the opportunity cost of stored water – that can be used in the quantities and at the timings when it is most needed, and when it can yield the highest financial and productive return – is much higher than that of non-stored surface water, that needs to be used, or wasted, at the quantities and timings it is available. Particularly, as the periods of surface water scarcity are concentrated at specific timings for nearly the entire IBIS.

The issue of water losses and efficiencies is, of course, widely affected by the scale of analysis, and where and how the boundaries of the system under consideration and conceptualisation are defined. With the widening of the attention span to integrated water management at the basin or catchment level, the water delivery and use efficiencies are increasingly considered in the framework of the hydrological water balance. This has increasingly led to the realisation that somebody's loss in water is, or can be, someone else's gain in water, whether it is percolation, drainage or spillage loss. When such an analysis is applied to the prevailing situation in the IBIS, a rather different picture tends to emerge than the one that has, and continues to feed the OFWM programme that aims to reduce the conveyance losses at the tertiary level. In a study conducted in the right bank command areas of the Guddur and Sukkur barrages in Sindh, the use of ground water and residual soil moisture to grow a *Rabi* wheat crop, that was replenished through the surface irrigation of the *Kharif* rice crop, yielded quite a different figure for water use efficiency, when regarded in combination. When regarded over the two cropping seasons, the water use efficiency turned out to be 80 percent, which is twice as high as the 40 percent that is usually adopted. It was thus concluded, that use of the aquifer as a natural storage facility made good sense as a means to achieve higher overall efficiencies, as well as much cheaper than storing water in surface reservoirs. (*cf*. Clark & Aniq; 1993 and Trimmer; 1990)

The purposeful management of the fresh water aquifer as a natural storage reservoir for irrigation water would thus seem a viable and promising option given the context of the IBIS. This has, however, some implications for the regulation and pricing of groundwater use. The replenishment of the aquifer has some transaction costs; either hidden when replenished through seepage and percolation losses, or more directly when it is purposely recharged with surface water, as is currently practised in the western USA. As Gaffney (1997) argues, the free usage of the ground water (i.e. no charges are levied as such on the water itself, but only the pumping and conveyance costs are borne) tends to lead to a mining of the source, while the transaction costs to replenish it need to be borne by others (usually the state, as in the case of California). The same holds true in the context of Pakistan, where the SCARP and private tubewells can pump the groundwater for free. As long as this valuable resource is free, the market mechanisms heralded by the Bank will tend to exploit it for maximum benefit and profit (*cf*. Gaffney; 1997 for a sharp analysis of this market distortion in California). Under such circumstances, it is also bound to become difficult to regulate and curb the usage of groundwater by each FO to its allocated share, while other FO, PU, the provincial and federal agencies contribute to the replenishment of the aquifer. After all, the overexploitation of the aquifer is already a fairly widespread practice in Pakistan today (*cf.* Ahmad & Kutcher; 1992).

The conjunctive use of ground and surface water, and the active and purposeful management of the aquifer as a natural storage facility, is a promising strategy to pursue in the context of the IBIS, that can both enhance its overall efficiency and productivity. It presents, however, still many challenges that need to be addressed in new conceptualisations of integrated water management and water regulation and control. The available options to purposely replenish the aquifer for storage, instead of only considering the 'natural' sources of precipitation, percolation and seepage, need to be further explored. A process that will require from the water and policy sector to further review and reassess its concepts and notions of efficiency, drainage and spillage losses. This will also demand an revaluation of the water control and delivery technologies that, instead seek to control and match the water delivery with the actual water requirements as accurate as possible, provide the means and options to replenish and regulate the natural reservoir capacities of the aquifer.

The issues of water losses and groundwater use are starkly different for the areas affected by the double menace of water logging and salinity, where the aquifer contains salt ground water. The conjunctive use and integrated management is not a viable option for these areas. The conventional notions of water use efficiency, and the reduction of percolation and seepage losses are still valid in these areas, as all the water entering the salt aquifer is lost for irrigation purposes. The reduction of these losses, and provision of adequate drainage facilities, is thus still a valid strategy to pursue in these areas. The proposed reforms to establish '*enforceable property rights*' to water, that are tradable on a water market throughout the IBIS, are then considered to provide the appropriate means to finance such developments in the salt groundwater areas. It has been estimated that it would require roughly 3 to 6 billion US$ to provide all the area affected with severe waterlogging and high salinity with sub-surface drainage (which at the moment is considered the appropriate measure to take). Since it is out of the question that such a high investment is provided by the federal or provincial governments, it is thus suggested that these areas sell some of their water to fresh ground water areas, so as to obtain the financial means to improve some restricted area of their own. (*cf.* Ahmad & Kutcher; 1992)

Cost Recovery & Financial Autonomy

A primary aim of the proposed reforms, that is generally associated with the decentralisation, or turn-over, of the irrigation sector, is the establishment of financially autonomous water management organisations that are able to recoup their O&M costs as well as their capital costs. A policy objective that is closely related to the general policies of neo-liberalism that were adopted by the multilateral donor and financial agencies during the 1990s. In light of this new economic paradigm, the state should disengage itself from subsidising the primary sectors of its economy as agriculture, industry and services. Since the early 1990s the government of Pakistan has been urged to adopt these policies to reduce its debt burdens, and restructure its tax base and generally reduce its state expanses and civil services.

In the 'Issues & Options' paper, the issue of cost recovery is presented as one of the major reasons for pursuing the proposed reforms. The general deterioration of the canal irrigation systems in the IBIS, and its resulting loss in equity and reliability in water distribution, are primarily attributed to the structural deficit in revenue. The inability to merely recoup the O&M

costs through *Abiana* charges has led to a structural neglect of the maintenance requirements, as the obvious post on which savings can be easily realised. As argued in chapters two and three, this is a direct consequence of the management and revenue structure Pakistan inherited from the British colonial state.

The allocation of O&M funds by the provincial government is part of the yearly provincial budget allocations, that are restricted by the overall budget of the exchequer. From the general budget allocated to irrigation, the fixed costs of operation (primarily salaries) have to be met, while the remaining funds have to be split over maintenance of existing systems and investments in expansion and remodelling of the irrigation sector. This started to become a problem when irrigation ceased to be a net contributor to the provincial exchequer, and started increasingly to strain the provincial budgets to meet its O&M and investment requirements. This turnabout started to emerge during the 1970s and worsened over the years, until it reached problematic proportions during the late 1980s and early 1990s (see table 8.1).[137]

With the institutional reforms, it is aimed to sever the budget dependency of the newly to create management organisations from the provincial exchequer, and make each management unit responsible for its own cost recovery and financial autonomy. It is hoped that this will induce and enable the FO to increase their revenue collection, as the proposed reforms would introduce a direct link between services rendered and fees charged. It should, so the argument goes, also motivate water users to pay their fees, as this will enable 'their' FO to maintain and improve the water delivery system and service. To further increase the relationship between services rendered and fees charged, the PU and FO should be granted to employ the stick of excluding defaulters from the water delivery services. The principle to be applied for the financial and management reforms is based on that of the 'service agreement': each management unit provides a defined O&M service in irrigation and drainage to the management entity below, for which it charges a defined service fee; each management entity will then increment the service charges for the incremental O&M and investments it makes on the irrigation and drainage services it provides at its level of the system. It is thus hoped, that the whole water management system will enter into a positive spiral, in which more revenue will be collected from the water users, that enables the investment and improvement of the water delivery service – particularly in the facilitating of water trade and the reduction of transaction costs – which on its turn enables further increases in revenue and further improvements in the system. What checks and balances should be build into the system to prevent it from entering a downward (or negative) spiral, as occurred during the 1980s, however, is not made clear by the proposals.[138]

Table 8.1: Operation & Maintenance Expenditure and Revenue Gap; Financial Years 1982, 1987 and 1992 (PRs million)*

[137] The worsening rate of irrigation revenue collection can be attributed to two elements: (i) a stagnation in rise of *Abiana* rates, with which it fell far behind inflation rates, and (ii) a decrease in the collection rate (World Bank; 1994, ADB; 1995)

[138] Presumably, a check could be provided by a regulation of the exclusion of defaulters, that states that defaulters can only be deprived of their basic water right till their debts have been recouped by the FO or PU through the auction of their water share. It is, however, questionable whether defaulters would be able to resume payment when they have been deprived of water, and thus income, for one or more seasons. What measures should be employed to curb the marginalisation of small farmers, or bankrupt organisations, in the private water market, will thus need some further careful thought.

Location	1982	1987	1992
Punjab			
Expenditure	978.66	1,771.70	2,101.20
Revenue	655.40	734.60	726.10
Subtotal	-323.26	-1,037.10	-1,375.10
Deficit (percent)	33	59	65
Sindh			
Expenditure	408.00	816.50	1,409.10
Revenue	203.00	355.80	279.00
Subtotal	-289.40	-503.40	-857.00
Deficit (percent)	71	62	61
NWFP			
Expenditure	118.60	313.10	552.10
Revenue	26.20	38.90	51.40
Subtotal	-97.40	-277.10	-488.60
Deficit (percent)	82.1	89	89
Balochistan			
Expenditure	21.20	36.00	63.5
Revenue	4.90	14.70	13.10
Subtotal	-16.30	-21.30	-50.40
Deficit (percent)	77	59	79
Pakistan			
Expenditure	1,526.46	2,937.30	4,125.90
Revenue	805.10	1,101.30	1,342.70
Subtotal	-721.36	-1,836.00	-2,783.20
Deficit (percent)	47	63	68

* The data is as presented by the ADB, no responsibility is taken for whether all figures add up. Part of the large deficit is also attributable to mis-allocation on the part of the Revenue department; that is to say, true revenue collection in irrigation is estimated to be somewhat higher than listed here, although no reliable estimations to what extend are available.

(ADB; 1995)

Although the proposals for reform of the water management sector, and its attempts to restore the dynamism of investing, tinkering and remodelling the irrigation and drainage system to improve the services of irrigation and drainage – as marked the golden age of the Irrigation Department from *ca*. 1880 - 1950 (*cf.* chapter two) – should be welcomed, the proposals are marred by the absence of any serious self-reflection on the role the World Bank and other multilateral agencies and donors have played in disturbing this dynamism. A disruption that has taken place on two fronts: a straining of the budget and the diminishing of the design and development capacity.

The large investments that have been made to expand, integrate and further improve the IBIS under the auspices of the Bank and ADB, have set the agenda for investment prioritisation of the federal and provincial governments in the irrigation and drainage sector. With an increasing deficit of the collected revenue to expended O&M budgets (*cf*. table 8.1), the actual expenditure is bound to fall short of the requirements, as has been noted in the 'Issues & Options' paper (World Bank; 1994). A shortfall that is further aggravated by the commitments the federal and provincial governments have to make from their central exchequers to the co-financing of the expansion, integration and improvement projects.[139] This unwittingly further exacerbates the downwards spiral of deterioration. The, in these terms, most dramatic projects that have had a direct impact on the O&M budgets, has been the SCARP-tubewell programme, that was implemented during the 1960s-70s. This has been acknowledged by the World Bank and ADB, as this programme resulted in a direct exponential rise of the O&M costs: *"In the 1970s, most of the O&M budget was absorbed by SCARP tubewells, resulting in shortfalls to meet needs for canals* [...]*"* (World Bank; 1994:13).[140] This issue was addressed from 1987 onwards, when the SCARP-transition projects were initiated with financing of the World Bank and ADB to privatise and turn-over the SCARP tubewells to their users, in order to relieve the provincial O&M budgets of this unbearable burden (VanderVelde & Tirmizi; 2002). The project orientation of the World Bank, and the dangers that its formulated and financed projects, within and between sectors, can easily lead to competition for resources and adverse effects, has been raised before within the Bank as an issue that obstructs the formulation and implementation of a comprehensive water resources management policy (*cf*. Rogers; 1992).

The 'side effect' that emerged with the creation and prolonged sustention of WAPDA as a federal agency that obtained a dominant role in the planning and development of the IBIS system, born out of the need to integrate water management over the basin to offset the effects of partition, has been presented in chapter three. One of its most profound effects being, that the water wing of WAPDA effectively became the 'elite corps' of civil engineering in Pakistan, that attracted all the top engineers with aspirations in design and development away from the Irrigation Department, as well as from the universities. The continuing role of WAPDA as the primary counterpart in the design and construction of all the major new and innovation projects in irrigation and drainage, after completion of the Indus basin project, has, as is argued throughout the thesis, contributed heavily to the externalisation of the design process, and its

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[139] Unfortunately the World Bank, nor the ADB, provide an overview in their presentations of the financial problems of O&M expenditure and collection, of how much money of the central exchequers has been allocated to new projects, that might alternatively have been spend on regular and required O&M expenditure. Which would, after all, be a 'normal' procedure for comparison of the opportunity costs to determine what would constitute the economically most efficient investment option for the water sector.

[140] An indication of the extent to which the SCARP tubewells deprived the ID from a maintenance budget, is given by the Bank's own assessment that the gap in O&M expenditures and recoveries for the financial year of 1992 would fall from 60 to 30 percent for the Punjab and Sindh provinces, if the expenditure on government tubewells (i.e. SCARP) were excluded. (World Bank; 1994)

domination by outside experts rather than by internal water management practitioners. A process that, as is shown with the cases in this thesis, all to easily leads to conflicting views on what is considered ‘modern’ v ‘desired’, or ‘required’ v ‘possible’, that hamper their accommodation in a comprehensive concept of the irrigation system and the purposeful development and establishment of its control mechanisms. With the billions of US dollars that have been invested over the past five decades in extension and innovation projects, WAPDA has not only been enabled to establish and consolidate its position in the irrigation and drainage sector, but also to regard design and construction as one of its main tasks and purposes.

The proposed reforms do address these issues, albeit as a ‘mere’ intention to change the conditions that maintain the system in its vicious spiral of deterioration. The problem with merely condemning the current system of O&M, in which the ID plays a primary role, is that it is not very conducive for stimulating a change process of institutional reform. Nor is it, as argued above, quite so fair a representation of the process of deterioration. Moreover, both WAPDA as the multilateral agencies have been present and involved all along this process. The harm of not being willing to acknowledge this is, as has been consistently underestimated or ignored, that the ID has been pushed since long into the defence and conservation of its institutional position in relation to its main rival and competitor WAPDA. The continuing denial of this institutional conflict, that affects the acquisition of the financial and human resources, is then bound to induce further entrenchment of the ID to protect its position and resist changes that are perceived as further threats to its institutional role and capacity.

This is to be deplored, as the proposed reforms contained two potential benefits for the ID to reinvigorate and innovate its role in water management. The first concerns with the proposals to achieve financial autonomy at the hydraulic entities of the system; once realised, this could provide the ability to invest and partake in improving the O&M and the hydraulic system – either directly as PU or provincial authority, or on request or under contract of the FO. The second concerns with the implications of the proposed decentralisation, with which the PU and provincial authorities would regain the function and responsibility to supervise and conduct design and development of improvements and innovations in the canal command system. Benefits that have largely been unnerved by the proposal’s remarks on the need to further strengthen the institutional capacity of WAPDA as a federal agency with the reforms.[141]

8.3 THE PIDA ACT: REFORM ACCOMMODATIONS & DISCRETIONARY LAWS

The proposals for institutional reform, as expressed in the ‘Issues & Options’ paper, signalled a ‘change of heart’ from the side of the multilateral agencies towards the strategy that should be adopted in future to address the irrigation and drainage problems in Pakistan. With the paper, and its discussion within Pakistan’s policy circles, the World Bank took the initiative to give a clear

[141] Meant is to strengthen WAPDA’s capacity to monitor and allocate the groundwater resources, and monitor and regulate the surface water and drainage water at the main IBIS level. Thus to strengthen, but also clearly restrict, its role to management activities at the basin/federal level. The wrong message, however, stuck: the reforms are to strengthen WAPDA’s role, while reforming, or reducing in the view of some, the role the ID is to play in future.

signal that institutional and management reforms were required to improve the performance and impact of the technical interventions in the IBIS, and the overall performance of the IBIS itself. In other words, it would no longer do, to continue investing in technical interventions and ameliorations, when the performance and impact of such investments would continue to be frustrated by institutional and managerial inadequacies.

The government of Pakistan had little choice but to take up the issue of institutional reforms in its composure of its future investment strategies and plans for the irrigation and drainage sector. Much was seemingly at stake, as all the investments and developments it had undertaken in the IBIS since its independence had primarily been achieved with foreign financial assistance, on which it continued to depend to realise all its future needs and plans.[142] The question was now, whether it would be able to conduct a similar tour de force as it had realised during the Indus Water Treaty and Indus Basin Project negotiations (*cf.* chapter three), and secure enough support to continue with its plans for technical improvement and expansion of the IBIS without compromising those plans too much with a purely reform driven policy.

In December 1995 the government of Pakistan (GoP) responded by putting forward a draft of the PIDA-Act, with which it proposed to pursue the reform and decentralisation of water management in the IBIS. The GoP's proposal foresaw in:

- transforming the provincial Irrigation Departments into autonomous Provincial Irrigation & Drainage Authorities (PIDA);
- decentralise the management of canal systems by devolving it to newly to establish Area Water Boards (AWB);
- and encourage farmers to engage in management of the distributary/minor level of the system through FO, that would be formed out of federations of tertiary level WUA.

Although a significant first step in the right direction, the GoP's proposal was restricted to the establishment of the PIDA. For the establishment of the AWB and FO no legislation was put forward yet by the GoP, as it aimed to establish these gradually by means of pilot projects, that would have the primary task to determine what management roles and functions these new organisation should, and feasibly could, perform in giving shape to decentralised management. Moreover, the Canal & Drainage Act of 1873 was, in the GoP's proposal, retained as the principal legal framework with which water management should continue to be governed.

In the eyes of the World Bank and ADB this initiative of the GoP went not quite far enough in committing itself to the primary principles and objectives of reform and decentralisation. Namely, to ensure enough autonomy, both judicially as practically, with which the AWB, FO and WUA would take over the primary functions and roles of water management as revenue collection, operation and maintenance, and water distribution. In the eyes of the multilateral

[142] Over the period 1990-95 alone, 1.09 billion US$ of foreign assistance (comprising of loans and grants) were committed to projects in the irrigation and drainage sector of Pakistan. Of this investment, 504 and 258 million US$ were provided by the ADB and World Bank, respectively. (ADB; 1995)

agencies the reforms should provide for a clear division of responsibilities and tasks, with which the different new management entities could enter into clear service agreements with each other. The PIDA-Act required thus further legislation for these lower levels of the management structure, that would explicitly enable, and implicitly commit the GoP to, the decentralisation and devolvement of management tasks and responsibilities to autonomous and self-sustaining management organisations at the lower levels of the system.

The GoP's draft for the PIDA-Act, and the feasibility study for the Lower Bari Doab Canal project wherein concrete plans were made to use it as one of the pilot projects for initiation of the reform and decentralisation process, made it suddenly clear to everyone involved in the sector that this call to reform the water management of the IBIS had to be taken seriously. What followed was a flush of heated discussions and strong objections, voiced by those who had the means to be heard (i.e. members or sections of the provincial irrigation departments, large landowners, the media and members of provincial and national assembly). Objections that were primarily voiced in the notions and rhetoric used in the 'Issues & Options' paper, by agitating against the privatisation and commercialisation of irrigation water and the disengagement of the state, that would surely result in higher water prices and water services only for those who could afford to pay private services. (*cf.* VanderVelde & Tirmizi; 2002, who provide an excellent overview of the chronology of the reform process and the ensuing objections that were raised in an attempt to stall the process.)

The flurry of protests brought the GoP into an awkward position, as the multilateral agencies demanded more enabling legislation, while objections against the reforms were being voiced ever louder and fiercer in the public domain. Finding a workable accommodation in the form of a reformulated PIDA-Act, that could both appease the most stringent demands for reform of the multilateral agencies, and muster enough support to get passed and enacted by the provincial assemblies, became thus a delicate and problematic issue. The issues of contention with which the GoP was struggling were centred around the recovery of costs, that were limited to O&M costs only rather than including investment and capital costs; and the notion of handing over large parts of the system to water users (i.e. privatising), that would undermine the state's role and responsibility to manage and deliver a basic water delivery service.

Seeing that the GoP was getting nowhere near to a solution that could be mustered through the provincial assemblies, the multilateral agencies closed ranks during the course of 1996. They notified the GoP that if by the third week of December 1996 no formal agreement was reached in all four provinces to establish PIDA, and basically enact the legislation for reform, no loan agreement would be reached for the National Drainage Programme (NDP). Not willing to risk of being deprived of the 785 million US$ programme that contained important and major projects to improve the drainage and water management capacity of the IBIS, as well as any future investment opportunities, the by then interim government neatly obliged by notifying the PIDA Ordinances. The latter were duly passed and enacted by the provincial assemblies by mid 1997. (VanderVelde & Tirmizi; 2002)

The multilateral agencies were, for the time being, appeased with the passing of the limited PIDA-Act. At least, it opened up the way to start the reform process on two important fronts: (i) attaining cost recovery of the O&M costs, as the PIDA-Act foresaw in the abolishment of subsidies over a period of seven years, after which each PIDA would have to become financially autonomous; and (ii) it provided the possibility to pursue participative irrigation management through establishment of FO and WUA in pilot projects under NDP.

NDP: Building for the Future...

With the passing of the PIDA-Act through all provincial assemblies, the conditions were thus met to proceed with the NDP project. The NDP had been formulated by the GoP, WAPDA and the multilateral agencies as a sector wide investment programme to improve the water management and delivery capacity in the IBIS, and secure a sustainable growth in agricultural output in the future with which Pakistan could meet its demands. The emphasis of the project was set at further increasing the efficiency and productivity of water use within the IBIS, and tackling the double menace of water logging and salinity that increasingly affected large areas of the IBIS. In essence, the NDP represents a continuation of the objectives of the Indus Basin Project (IBP), to increase the water regulation and control capacity at the basin, or main system, level of the IBIS, to ensure its optimal allocation and use.

As captured in the name of the project, the emphasis in NDP is on establishing adequate drainage facilities within the IBIS to secure its sustainability in future. A requirement that was already identified and formulated with the appraisal and feasibility study for the IBP conducted by the Lieftinck commission in the 1960s. The latter set a clear path for the development of the IBIS, with a central role for WAPDA[143]: to (i) create the capacity to divert and regulate the surface water over the basin, so that it can be managed as one continuous system, and the effects of the water lost with partition can be off-set; (ii) increase its efficiency and secure its sustainability by integrating drainage with irrigation; (iii) further increase the capacity to store and regulate water in the IBIS to improve the ability and capability to match irrigation requirements adequately and timely.

The first stage was thus realised through the IBP, which provided the required link canals, barrages and storage facilities on the Indus (*cf.* chapter three). The second stage was started with the SCARP-tubewell programme, with limited success. The principal component of this stage, however, was to provide for drainage facilities, with as major components the Left and Right Bank Outfall Drains, that would be able to dispose off the drainage effluent to the Arabian sea or Indus river. The third stage was then to concentrate at effecting further savings, and create additional storage capacity in the IBIS, with construction of new dams such as Kalabach. (*cf.* Lieftinck *et al*; 1968 & 1969).

The NDP project is thus primarily a continuation of this development trajectory for the IBIS, with its main stay of investment allocated to the completion of stage two for the development of a drainage network (see table 8.2). The aim is to realise the Left and Right Bank Outfall Drains, as conceived during the 1960s and supported by the Lieftink commission's strategy

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[143] As is presented in chapter three, WAPDA was clearly supported by the World Bank during the IWT and IBP negotiations and settlement to become the central organisation to bear responsibility over the management and development of the IBIS. It should become the one organisation that would have the overview and capacity to regulate and allocate the water resources at the basin level. Interestingly, Lilienthal, the founder and chairman of the Tennasee Valley Authority (TVA), acted during this time as an adviser to both the IWT and the IBP, and was instrumental in proposing to style the new WAPDA on the TVA. (*cf.* Michel; 1967)

recommendations. The main stay of the project activities is to provide for these and other inter- and intra-provincial drainage facilities, with WAPDA involved as primary agency. Stage three of the development trajectory remains on the agenda, with the feasibility and design for Kalabach dam already lying on the shelf. The NDP, however, has relayed this issue to the future, not in the least because the building of Kalabach has become a politically contentious project between the different provinces, notwithstanding the settlement of the Indus Water Apportionment Accord in 1991. The view that it is desirable to create additional storage capacity in the foreseeable future is, however, supported in 'Issues & Options' as in the NDP and water sector strategies. It is regarded as essential for the creation of the capacity to better match the irrigation water delivery with actual water requirements, as well as to enable the trade of water on a basin (or system) wide water market. The inclusion of major infrastructural works on future investment agendas for the water sector in Pakistan can thus be expected to continue for the foreseeable future. In this regard, NDP contains little new conceptions on how water management in the IBIS should be conducted: the how and what are primarily governed by the notions of the natural-physical process and the designed physical systems conceived in the 1960s; the innovative thinking is primarily restricted to who should be responsible for the management, and how they should bear the responsibility institutionally.

The institutional reform component is thus only a minor financial component of the NDP project, with a mere three percent of the budget reserved to give shape to the reform of the irrigation departments.[144] Although in the words of the Bank it is *"the most important component and is aimed at decentralizing PIDs"* (World Bank; 1997:12). The reforms are to be given shape, by establishing a pilot project in each of the four provinces, in which an AWB is established alongside the creation of FO and WUA in its canal command area. These pilots should serve to find ways of giving shape to decentralised and participative water management, in feasible structures of the FO and WUA and organisation of their functions and tasks in operation, maintenance and cost recovery. Once positive experiences and satisfactory results are achieved, the process of reform and decentralisation should be reproduced in wider areas of the IBIS.

The importance the multilateral agencies attach to this component is given shape by the conditionality that progress should be made in reform and decentralisation process, which will be reviewed on an annual basis. First, and paramount, in these, is the further establishment and approval by the provincial assemblies of the statutes, rules and regulations for the AWB, FO and WUA.

[144] This conforms to the general policy of the GoP, that wants at least 90 percent of the loans committed to infrastructural works.

Table 8.2 National Drainage Project Cost Summary (in US$ Million)[145]

Component	Local	Foreign	Total
A. Sector Planning & Research			
Sector Planning and Policy Studies	8.3	1.0	9.3
Research Programs	12.8	1.0	13.8
Subtotal	21.1	2.0	23.1
B. Institutional Reforms			
Institutional Program WAPDA-Water	25.4	2.9	28.3
Institutional Program for PID	17.1	6.7	23.8
Subtotal	42.5	9.6	52.1
C. Investments			
Off-farm Drainage	281.4	122.2	403.6
On-farm Drainage	54.5	28.6	83.1
Irrigation Systems	49.0	36.3	85.3
Operation and Maintenance	64.7	0.7	65.4
Subtotal	449.6	187.8	637.4
D. Program Coordination & Supervision			
Total Baseline Costs	528.9	200.1	729.0
Price Contingencies	37.8	18.2	56.0
Total Project Costs	566.7	218.3	785.0

(World Bank; 1997:21)

Domesticating Decentralisation in the Practice of 'Protective Irrigation'

With the signing of the NDP loan agreement, it was concurred that each province would establish an AWB within one year, with which the NDP project could initiate the establishment of FO and WUA and the decentralisation of O&M activities on a pilot scheme basis (World Bank; 1997). The first step, the provincial governments were required to take in this regard, was to establish the legislation with which the new organisational structure could be created, and the decentralisation conducted. This proved to be more time consuming than anticipated. It was not before the second half of 1999 that the rules and regulations for the administration of the AWB,

[145] The listed costs make a distinction between funds to be provided in local and foreign currency. This is not an indication of who provides the funds. The total costs are split over the investors as follows: federal and provincial governments (29 percent); farmers (4.1 percent); ADB (17.9 percent); OECF (Japan) (12.7 percent); and IDA (World Bank) (36.3 percent).

FO and WUA were drafted, and were finally enacted by the first half of 2000.

The principles of decentralisation and participation that are to be established with the reforms, are to be secured through the formal structuring of the organisations by means of assemblies and representation. Principles that had to be laid down in the rules and regulations. In organisational sense, these have been established in a straightforward and standard manner. At the lowest tier of the WUA, all landowners, and thus water right holders, are to form the general assembly of the WUA, who will select their standard office bearers of chairman, secretary, treasurer, and any additional office. In addition, they will also select their representative to the FO. The FO is structured in the same manner, with a general assembly of representatives, that will select their office bearers. The FO will in its turn select their representatives to the AWB, where together with the canal officers they will form the board. Assurance for representation have been provided in the rules and regulations by stipulating that among the representatives of the FO and AWB at least one office bearer is from a tail-end area.

The 'designed' organisational structure thus provides the possibility for each of the organisational layers to recover their costs, and organise and execute their maintenance activities; be it by themselves, or by entering into service contracts with specialised contractors. These provisions should thus enable and stimulate the water users to take up and execute the burdens of maintenance in irrigation and drainage in an effective and efficient manner. They should bear this responsibility through concessions of at least 20 years of use of the physical infrastructure, that shall be granted to them through contracts with the AWB. The critical issue is, however, what provisions have been made to grant the WUA and FO a significant say in the 'benefits' of irrigation; namely the allocation, scheduling and distribution of irrigation water.

Although the 'Issues & Options' paper called for a substantial reform of the Canal & Drainage Act of 1873, and the division of the judicial and executive powers through the establishment of a regulatory commission, this backbone of water management was left essentially untouched by the provincial governments. An outcome which was already deemed likely in a discussion paper produced within the Bank, that assessed the chances to establish a new system of water rights as low, as it would be contested by numerous stakeholders involved (*cf.* Dinar *et al*; 1997). The assuming of the Canal & Drainage Act of 1873 within the PIDA-Act, however, risks to severely limit the potential benefits for, as well as the scope of, decentralisation of and participation in water management.

With the Canal & Drainage Act, the judicial structure is essentially retained with the reforms. The adjudication of water conflicts thus is to remain the task of the 1st and 2nd class magistrates of the Canal & Drainage Act. With the PIDA-Act the FO are granted *"the powers and authority of a Divisional Canal Officer under the Canal and Drainage Act 1873 and any officer subordinate to him"* (Gov. of Punjab; 1999). With these powers comes attached, the power and office of 2nd class magistrate, for the implementation and administration/adjudication of the Canal & Drainage Act. As such, the FO would, in principle, be granted the powers and discretion to handle all matters pertaining to irrigation and drainage within its domain of the distributary/minor. At the level of canal command area, administered by the AWB, the same powers are vested to its members; i.e. the XEN and FO representatives are granted the office of 2nd class magistrate.

The highest authority, however, is vested in the office of the 1st class magistrates and their superiors, who have to settle all conflicts brought before them, and whose ruling is final. These powers are vested in the office of SE, and are thus granted to the PIDA. The PIDA thus represents the 'high court' of the water jurisdiction, where all appeals and disputes are to be finally settled.

The central issue is of course how the water allocations can be vested in unambiguous rights for the FO, WUA and individual water users, and guaranteed, under a judicial system that has been ambiguous on this very matter for as long as it has been in place (*cf.* chapters two & three). The contention of these water rights is potentially high, as the water users nurture high expectations towards the reforms, in that they expect better water delivery services to be realised, as well as more water reaching the deprived tail-ends. In those cases where the formal water allowances have been differentiated over time – and the cases are numerous where the differentiation has occurred both within distributaries, as among distributaries – the transpiring of these differences through open access to information in the decentralised and participative management, is bound to lead to contestations of what should constitute equitable allocation. The more so, since the well off will be able to capitalise on their surpluses through trade.

So far, there are no signs of provisions being made to tackle this issue unambiguously. The rules and regulations are primarily limited to the establishment of a concession between AWB and FO, and *mutatis mutandis* between FO and WUA, that is centred around the 'authorised water allowance'. As has been argued in chapter two, the adjective 'authorised' is subject to the substantial discretionary powers of the Canal Officers, vested by the Canal & Drainage Act. Discretionary powers that have been devolved partially to the FO, but to no extent curbed. The only reference made in the draft rules and regulations of Sindh to this issue, provide little comfort. In section 22 of the regulations, and section 17 of the rules, it is stipulated that the AWB will have to review the off-take structures in the area under its jurisdiction, and rule whether modifications and alterations to the structures have been "[...] *improperly approved or constructed without sanction in a period not exceeding twenty (20) years prior to the date of that AWB's establishment* [...]" (Gov of Sindh; 1999a:19). In other words, older differentiation in allocations are to be left untouched, and those made over the past twenty years are to be subjected to the discretionary procedures of the Canal & Drainage Act.

8.4 THE RESTRAINTS OF PRACTICE

Organising Participation: Providing a Structure for Decentralisation

One of the prime and immediate concerns in the context of water management reforms in the IBIS is seen as establishing water users organisations, that can act as counterparts in the process of reform and become the beneficiaries of the decentralisation. Notwithstanding the widespread formation of formal WUA in the OFWMP, this is still a process that needs to be conducted almost from scratch, as over the last decade there has grown a widespread agreement, that the formal WUA created by OFWMP were primarily tokens to which the water users conformed in order to receive the assistance in watercourse improvement. In essence, OFWMP has also been a construction driven programme that sought to realise its construction and water saving targets, rather than geared towards institutional capacity building for improved water management. The object lesson to be drawn from the OFWMP experience is, as is increasingly acknowledged, that the new formal organisations and institutions will need to provide clear advantages for water users over their customary practices and informal arrangements. As has become clear from the preference to continue to conduct the watercourse maintenance through the traditional and informal arrangements, rather than the new formal structure of the WUA that requires more social investment from the part of the users. (*cf*. chapter three, Byrnes; 1992, World Bank; 1996) (and van Leeuwen; 1997 on informal water management arrangements and the scope for formalising collective action).

The process of institutional reform, as formally initiated with the passing of the PIDA-Acts and the signing of the NDP loan agreement, faces a difficult dilemma: it needs to formally organise the water users to provide for a structure for decentralisation, while the decentralisation and devolvement of responsibilities will have to be realised in order to provide the benefits for the water users to formally organise. – Benefits in terms of opportunities to improve the water delivery service, and opportunities to realise a transparent and efficient financial management of the O&M activities. – Rather than being a ‘simple’ reinforcing relation, this constitutes a delicate balancing act between providing enough responsibilities and benefits to stimulate the water users for participative water management, and guarding against providing too much responsibility (and its encompassing O&M requirements) for a newly established organisation whose institutional capacity is still under development.

The first step has thus, predictably, been to establish new formal WUA, and federate them into a distributary or minor based FO. To this end a number of pilot projects were initiated during the course of 1995, thus before agreement on PIDA and NDP, to gain experience and develop methodologies in this field within the context of Pakistan and the IBIS. These pilots[146] have initially concentrated on developing methodologies to mobilise the water users for the formation of the WUA and FO, as a preparation for taking over tasks and responsibilities of O&M on the distributary or minor level. The method adopted was essentially the same in all the pilots, by making use of social organisers, who would initiate and guide the formation of the WUA and FO. IWMI, however, in its pilots in Sindh and Punjab, adopted a slightly different approach than the others, in that it made use of community volunteers to act as socials organisers, instead of using dedicated field staff for this task (*cf.* VanderVelde; 1998, Bandaragoda; 1999, and Memon *et al*; 2000).

The pilots were all fairly successful in establishing the new organisational structure of WUA, and their federation into a FO, in the sense that they were able to mobilise a sound majority of water right holders (i.e. landowners) to take part in the organisations, and establish and fill the primary offices of chairman, secretary and treasurer. In all, the pilots experienced an initial eagerness among the water users to participate, which was strongly fed by the excitement of the prospect of taking over O&M responsibilities for the distributary/minor. In this sense, the pilot initiatives provided enough ammunition to bring home the message that farmers in Pakistan can

[146] The pilots in question are: Pabbi and Surizai Minors of the Warsak Gravity Canal system in NWFP, conducted by OFWM and Halcro; Bhaderwah and Bhukan minors of the Eastern Sadqia system in Pujab, conducted by OFWM; Hakra 4 R, of Eastern Sadqia system in Punjab, conducted by IWMI; Bareji and Heran minor in Nara system, and Dhoro Naro minor in Rohri Canal in Sindh, conducted by IWMI. (VanderVelde & Tirmizi; 2002)

be organised. (VanderVelde; 1998, and VanderVelde & Tirmizi; 2002)

After establishing the new organisations the issue becomes, as posed above, to provide or create new concrete tasks in O&M, with which the organisations can realise benefits and improvements for its members, and establish its *raison d'être*. In the realms of distributary O&M, there are three basic functions that could play this role, either on its own or in combination. Namely, maintenance, monitoring and regulation of water distribution and financial management (i.e. charging and collecting of fees). Functions that require specific capacities from the organisations, as well as specific mandates, to perform theme effectively and sustainingly. Both issues, that form the kernel of the reform process.

Reaching Collective Action for Maintenance

A natural first activity to employ with a newly established FO, is the maintenance, primarily desilting, of the distributary/minor. As has been pointed out in paragraph 3.3.2, substantial improvements in water delivery can be obtained by restoring the self-acting proportionality of the canal, through targeted desiliting (*cf.* fig. 3.6 and 3.7). Within the pilot projects conducted by IWMI in Punjab and Sindh, this has been one of the first O&M activities to organise with the FO. The activity of taking up the maintenance of the distributary/minor was used as a first test case for the FO's capacity for resource mobilisation (mainly in the form of labour) and organisation of collective action. In all cases the desilting of the canal during annual closure, was reported as a success, in that the FO managed to conduct substantial amounts of work in one or two seasons. (Bandaragoda; 1999)

The success of desilting as a prime O&M activity, however, should also be attributed to, what could be framed, the 'burden relieve factor'. Although it represents a clear intrusion into the traditional management domain of the ID, the latter is disposed to tolerate such intrusion as it represents a relieve from a burden for which it has insufficient funds at its disposal to conduct properly. An element that was stressed on an other occasion, when the Pakistan Army organised and conducted a national desilting campaign in January 2000, in which it mobilised the army and the water users to desilt the irrigation channels throughout the nation.[147]

As the Army campaign demonstrated, desilting is an activity that can be realised with some dedicated ad-hoc efforts. For the FO, however, such activities need in the long term to be embedded in the wider and more structural activities of O&M as water distribution and financial management. As the cases of Pir Mahal and Lagar distributaries discussed in paragraph 3.3.2 also demonstrated, desiliting is inevitably going to touch upon the issue of water distribution and allocation; be it by conveying more water to the tail-end at the cost of the head-end (i.e. as in the case of Lagar distributary fig. 3.6), or by exposing the differential water distribution through hydraulic configurations of the outlets (i.e. as in the case of Pir Mahal disributary fig. 3.7). Issues that are bound to feed ambiguity and contentions among the stakeholders, on what should be the

147 The achievements of this desilting campaign were reportedly unprecedented. On January 21st 2000, the Frontier Post (an English daily newspaper of NWFP), reported that in the Mardan, Swabi and Charsadda districts, 75 percent of the canals had been desilted. In Charsadda district alone, out of a total of 200 canal miles about 162 miles had been cleared and about 55.08 lakh cubic feet (131.256 cubic metre) of silt excavated.

proper water allocation and distribution pattern that should be maintained by the FO.[148] In order to handle and settle these issues, the FO will need to have a clear mandate and jurisdiction to regulate the water allocation and distribution within its domain of the distributary/minor.

Venturing into Remodelling and Operation

An attempt to address the issue of water allocation and distribution was made in the pilots of the Nara Canal system in Sindh, that form part of the Left Bank Outfall Drain project. Apart from focussing on the establishment of WUA and FO in initially three, and in a later stage an additional eleven, distributaries/minors, this pilot project conducted by IWMI also focussed on building capacity for structural O&M activities for the FO at the secondary system level. To this end, the project provided for basic training in matters as discharge measurement, maintenance assessment, assessment of water charges, and the basic hydraulics of outlets next to the general aspects of organisational management. (*cf.* Memon *et al*; 2000)

Thanks to the monitoring conducted by the project over a set of growing seasons, it became apparent that the water allocations and distribution were highly differentiated, both among the distributaries as along the distributaries (*cf.* Murray-Rust *et al*; 2000, and Lashari & Murray-Rust; 2000). Fed by the initial enthusiasm among the water users and the apparent success of establishing the new water users organisations, the project ventured into addressing this core issue of O&M in one of the first three pilot distributaries with the FO. To this end, the FO in question had seemingly reached an agreement with the ID in the course of 1997 to embark on the remodelling of outlets and the operation of the water delivery within the distributary.

In the joint management agreement, the FO and its members were sweetened by being promised an assured water supply at 'their' disitrubatary that would amount to around 130 percent of the old designed FSQ. Enthused by the prospect of having 30 percent more water at its disposal to tackle its water shortage and distribution problems, the FO set out to resize its outlets to distribute its new FSQ proportionally, with the technical assistance of the project. Unfortunately, it did so by starting to enlarge the head-end outlets first, and progressing down towards the tail. Not before long, however, by the time the remodelling activities had reached the middle reach, the actual and initial higher water delivery to the distributary started to vacillate and fall well below its new target. As a consequence, the tail-end of the canal suffered dearly by receiving water shares well below its traditional low supplies. The resulting acrimony between tail and head enders, in which the former complained bitterly about their worsened situation at the clear benefit to the latter after this endeavour of the FO in water allocation and distribution, resulted in a contentious situation that threatened the viability of the FO. (VanderVelde & Tirmizi; 2002)

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[148] As ensued in Sindh after the Army desilting campaign of January 2000: the Frontier Post reported on the 10th of February 2000, that large landowners and head-enders were raising a controversy over their "undue loss of water" by restoring the water distribution to that of the British colonial era. Arguing that this threatened to undermine the increases achieved in cropping intensities and productivity since independence, bringing intensities back to the meagre old colonial 30 percent.

Reportedly, a similar controversy ensued with the desilting campaign of the FO of Hakra R 4, when head end water users refused to partake in the desilting. Unfortunately, Bandaragoda (1999) does not provide the data to either confirm, or deny this report.

The ensuing problems in this first unfortunate attempt to handle the issue of water allocation and distribution were used as a pretence by the ID to re-enter the management domain of the FO. After only two weeks, the joint management agreement was suspended by the government of Sindh, accompanied by the replacement of the provincial secretary of irrigation who had sanctioned the agreement. Subsequently, the ID took over the O&M responsibility of the distributary and resized the outlets back to their old dimensions.

This whole unfortunate experience reeks, of course; it has seemingly all the attributes of a cunningly executed process to discredit and dislodge a young water users organisation in its first attempt to come to terms with the ambiguous issue of water allocation and distribution. At the same time, it represents an important experience that deserves to be discussed openly and genuinely within the sector involved in the reform processes in Pakistan, as it exposes important issues that will have to be confronted and settled in the course of the reforms underway.

In essence, the primary issue at stake is that of the institutional and judicial mandate of O&M responsibilities. At the time of this episode (i.e. 1997), the provincial irrigation departments were just trying to come to terms with the fact of the enactment of the PIDA-Acts through the provincial assemblies – a measure they were not too content with, as it was primarily perceived as yet another attempt to encroach upon their management domain and further reduce their roles and responsibilities. The whole incident around the water delivery and sizing of outlets can thus be seen as an unabashed attempt to reassert the need for a central management role for the ID.[149] It raises, however, important questions on how the management and service relationship between PIDA/AWB and FO can be given shape in concrete procedures and control mechanisms, and how the contestation of mandates can be regulated and accommodated.

One of the elementary operational tasks to give shape to the joint management agreement (or service agreement, in the parlance of reform policy makers and 'modern irrigation' conceptualists), and that was not adequately arranged in this first trial, is the monitoring of the water delivery and distribution. In the absence of a structural monitoring of the delivered discharge at the head of the distributary, the ID could lower and vacillate the supply without being immediately contested by the FO with its own monitoring data (VanderVelde & Tirmizi; 2002). The absence of such daily monitoring data also contributed to the unchecked proceeding of the outlet resizing to a point that its adverse effects became too prominent and acute a problem. The monitoring of its own water distribution, and the entering in a regular dialogue and exchange of information with the PIDA/AWB and other FO should be a primary task of each FO, that it better fulfills before embarking upon amending its water allocation and distribution.

The endeavours of remodelling outlets and canals, and the subsequent suspension of the management agreement, raises a more fundamental issue of regulation and division of mandates, that still needs addressing. As long as FO will be able to secure an equitable distribution and a proportional division of relative excess and shortfalls in water supply, the rigorous monitoring and checking of the management agreement between FO and PIDA/AWB stands a chance to lead to a workable solution. The moment differentiation in water distribution starts to emerge (or for that matter continues) into a head-tail problem, the FO is at a risk to become dissolved under the

[149] In this regard, the similarities with the episode around distributary # 3 in Mardan-SCARP (*cf.* section 4.5) are remarkable.

new Act and regulations. Either on instigation of dissatisfied tail-enders or on its own initiative, the PIDA can resolve to dissolve the FO on the grounds of acting against public interest (*cf.* Gov. of Sindh; 1999a & b). A crucial element is then, how the actual water delivery to the distributary and FO is regulated and guaranteed in the joint management agreement. Under the current regulations and rules, only the maximum design supply (i.e. FSQ) is to be stipulated as the allocated water share. As to the variability and regulation of that supply, this is to remain the responsibility of the AWB governed by section 32 of Canal & Drainage Act of 1873 (*cf.* chapter two). The provisions to regulate this paramount element, and control its abuse as a means to stall or dislodge the reform process, are at present not sufficiently provided for. Particularly as the arbitration on such matters is vested with the first class magistrates of the PIDA, that constitute the tribunal.

The issue of flow regulation to the distributary and FO will clearly need to be addressed in the joint management agreements that are to be established between the AWB and FO. Within the current framework, it would seem preferable to establish those as a set of clearly and unambiguously defined set of operational rules and procedures, which also stipulate when and how the supply may/can deviate from its target value, and that act as a specification of the provisions provided in the Canal & Drainage Act. The elaboration of such operational rules can be conducted in each case and jurisdiction of AWB, and be subjected to the specifics of water regulation capacity and water availability of the context of each canal command area.

It must be noted here, that since 1997 the pilot in Sindh has given more attention to the issue of monitoring water supply and distribution by the FO. Deliberations have been made since, for instance, to whether it would be recommendable to have the FO keep up an H-register as part of its structural O&M activities. The issue of restoring some form of equitable distribution through remodelling of the outlets, is now also pending, while awaiting the reaching of firm joint management agreements with the ID. (*cf.* Lashari & Murray-Rust; 2000) Secondly, the critical review of IWMI's endeavours in establishing participative water management through the establishment of FO should be placed in perspective. They seemingly have to bear the grunt of some critical analysis, but this is primarily a consequence of that they have actually ventured as one of the few in trying to get the FO involved in concrete O&M activities at the distributary/minor level. That this, in the context of the IBIS, has lead to some hick-ups in the first attempts, was only to be expected, and should be part of a sound learning process. So, if any critique should be given, it should be directed at the reluctancy IWMI has shown in its publications about the pilots to share and discuss these hick-ups, rather than on the attempts itself. It should be appreciated by all involved, that drawing lessons from experiences within Pakistan are to be considered more valuable than those drawn from experiences abroad, in finding workable solutions and accommodations in the reform process in the IBIS.

Deliberations on Cost Recovery

One of the other primary elements of the decentralisation and reform process is the issue of establishing procedures for the FO to assess, collect and disperse the water service fees. Within the PIDA-Act and Rules and Regulations, provisions have been made to grant the FO permission and responsibility to assess and collect the irrigation water fees, and establish their financial solvency (*cf.* Gov. of Punjab; 1999 and Gov. of Sindh 1999a & b). In essence, the FO are thus expected to take over the tasks of the *Patwaries*. The question arrises, according to what principles these irrigation service fees should be assessed and charged; elements that will have to be specified in the joint management agreements, including the partition of the collected fees among the different tiers of the new management structure (i.e. WUA, FO, AWB, PIDA, WAPDA).

The traditional system of *Abiana*, that charges on the principle of crop classes that have been brought to maturity through irrigation, has been under discussion ever since its introduction (*cf.* Ali; 1988, Famine Commission; 1881, 1885 & 1898, and Bolding *et al*;1995). In its principles of charging, it is a rather peculiar accommodation between charging for granted water allowances and indirect volumetric charging through crop water consumptive classes. The 'Issues & Options' paper expresses a clear preference to convert the irrigation service charges eventually to volumetric charges, with which the saving and trading of water can be stimulated (World Bank; 1994). This option can not be realised before the technical and operational capacity to measure and regulate the volumetric delivery of irrigation water is established.

Within the current frame work of the PIDA-Act, the tendency is strong to simply retain the *Abiana*, and devolve its assessment and collection to the FO. Within the pilot project in the Nara Canal in Sindh, IWMI has anticipated on this, by providing specific one day training sessions in assessment of *Abiana* to the FO members. An element of capacity building that was appreciated, but at same time perceived as a difficult element by the trainees. (*cf.* Memon *et al*; 2000) Given this relative complexity of the *Abiana* system, coupled to its long record of horse trading and jobbery in its execution (*cf.* chapter two), it might be worthwhile to consider alternative and simpler principles of charging irrigation service fees. In this light, VanderVelde & Tirmizi (1996) proposed to simply charge a base rate in proportion to the water share of every share (land) owner. This seems worthwhile to consider as a viable option in a first stage of reforms, as it directly relates to the value of each water right share, while leaving it open to the discretion of the water user whether the water will be used for a restricted cultivation of high water consumptive crops, or for a more intensive cultivation of low water consumptive crops.

Issues & Dilemmas of Reform

A good part of the problems that were encountered in the initial pilots conducted on establishing FO at the distributary/minor level, centred eventually around the inability to reach a joint management agreement with the ID, or PIDA since July 1997. This has been the case in the pilots conducted by IWMI in Sindh and Punjab[150] , as in the other pilots conducted in Punjab and NWFP. In the absence of such agreements to provide the mandate for the FO, the attempts to involve the FO in O&M of the distributary/minor were either severely hampered or completely suspended. This difficulty in reaching agreements with the irrigation departments, was primarily fed by the continuation of the resistance by the latter towards the initiated reforms with the

[150] Within IWMI's pilots, there have thus been two concrete attempts to establish an agreement: the one in Sindh which lasted for two weeks;and in Hakra 4R in Punjab. In the latter, however, the proposal of the Punjab ID was unacceptable, as it only was willing to devolve the cost and burdens of O&M while retaining all discretionary power in operation, allocation and regulation of water distribution.(*cf.* VanderVeld & Tirmizi; 2002)

passing of the PIDA Act in July 1997; an element it was still trying to come to grips with on its own terms. The set-up of the pilot projects that in first instance concentrated primarily on the establishment of the new organisational structure, however, was in all cases neither very conducive for cooperation with the ID/PIDA, as none of the pilots had formally engaged them as a counterpart in the process. An element that has enforced the sense of defence against encroachment on, and replacement of, the management role of the ID within its cadre.[151]

These events surrounding the initial pilot projects reflect the dilemma the reform process has to deal with in creating institutional capacity among the water users to take over the management at the lower levels of the system, while disengaging and re-directing the management of PIDA into new and dynamic areas of management and development. Arguably, the formert has to be achieved first, before the latter can be attended to. In doing so, however, the institutional competition will be stimulated, as long as no clear role and future prospect is provided for the disengaging party. It is in this latter aspect, that the initiated reform process in Pakistan has been very poor, by failing to elaborate and promote any potential benefits that might be provided for the professional cadre of officers by a changed role in management and development. In failing to do so, the reforms have fed the sense that the ID has payed the price to get WAPDA’s NDP through. While the reform process risks to evolve into a polarised atmosphere, in which reformers will want to prove their right with showing that water users can organise themselves and take O&M responsibilities at the secondary level, while the ID will want to prove them wrong in defence of their own management role.[152]

In the case of the official first pilot project in NWFP at the Pabbi and Surezai minors of the Warsak Gravity Canal system, the project did not reach the stage of getting the newly established FO venturing into concrete O&M activities at the minor level in the absence of a management agreement with the ID/PIDA. In this case, the project even encountered sever difficulties in getting the WUA and FO formally registered and recognised as organisations, despite the available mandate provided by the WUA amendment in the NWFP Canal & Drainage Act (*cf.* VanderVelde & Tirmizi; 2002). This raises the question, why the project has not tried to involve the FO in the monitoring of the water distribution at the minors, despite the absence of a formal management agreement, as a way to get the water users accustomed with the operational tasks of their minor and as a means to provide them with the tools and information to engage the ID/PIDA into an accountability process.

The problem is, that this proved, after conducting of hydraulic assessment and evaluation studies by WAMA, to be a highly problematic issue, as it would bring to light a highly differentiated water distribution practice within the minors. As both minors in question were already receiving at least their full supply discharge, there was little scope to pressure the

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[151] Indicative of this defensive attitude has been the attempt of the Punjab PIDA to claim the OFWM activities of the Agricultural Department as activities that henceforth should be incorporated within PIDA, seeing as they were increasingly venturing into the management domain of the distributary/minor. An ironic turn of events, as the ID ‘gently passed for the honour’ to develop the water management activities in the tertiary unit during the 1970s when the OFWM programme was initiated. (*cf*. VanderVelde & Tirmizi; 2002)

[152] In this sense, the reform initiatives in Pakistan stand in large contrast to those taken in Mexico during the 1990s that have been the great example for the World Bank. In the latter the CNA took part in the initiative for reforms as a means to acquire and consolidate a central role for itself in the new water management structure *vis a vis* the role the ministry of Agriculture had played during the 1980s (*cf.* Rap & Wester; 2002)

ID/PIDA for more water. Instead, the monitoring revealed a structural head-tail end problem, with DPR values ranging from 2.0 to 0.4, and RWS values ranging from 3.0 to 0.2 (*cf.* Ahmad; 1999, Babar; 1999 and Younas Khan; 1999). To tackle this elementary and contentious issue of water allocation and distribution requires not only a high capacity for potential conflict resolution from the newly established FO, but also a clear mandate to set new water allocation rules and reconfigure the hydraulic capacity of the canal accordingly.

In the continuing absence of getting the newly established FO practically and structurally involved in concrete O&M activities of 'their' distributaries/minors, the risk is great that these new organisation will be drawn into developing side activities, as occurred with the WUA set up under Swabi-SCARP. There the WUA, that were initially set up by SIAP/ADC (Swabi Irrigated Agriculture Project/Agricultural Development Component) for the watercourse improvement component of Swabi-SCARP, were stimulated by the project to federate into FO in anticipation and preparation of the reform processes that were to come after the enactment of the PIDA-Act. In the absence of a clear O&M function for these new organisations within Swabi-SCARP, the WUA and FO ventured into the procurement and provision of seeds and fertilisers, as an agricultural service activity to establish their *raison d'être*. Although there is per se nothing wrong with such developments that fulfill a clear need, they divert the organisation to other activities and functions that require other institutional capacities and characteristics than those needed for O&M. An element that is stressed by that the FO established under Swabi-SCARP are not based on hydraulic unit boundaries of the system, but comprise WUA of more than one distributary/minor. (*cf.* Durrani; 1999)

An other issue that emerges with this venturing into agricultural services is the potential side effects this might lead to. The concern relates, particularly for those areas where water is already relatively scarce, that the services in seeds and fertilisers may lead to increases in the water requirements, and thus the relative water scarcity, inadvertently increasing the stakes and contention for the future settlement of the water allocation and distribution issues. Given the current context and environment of the IBIS, the long term water management strategy should preferably pursue the increase of yield per unit of water, rather than per unit of land. Which would require that the agricultural services are geared towards optimising the agricultural production in clear acknowledgement of the restrictive water availability; a strategy that has not received much attention as of yet.

With the signing of the loan-agreement on NDP, the provincial and federal governments and their line agencies involved in the water management sector, were committed to proceed further with the reform process and achieve better progress in the joint management of canal irrigation; both in formal agreements as in practices. To this end, the NDP contained project components to establish pilot projects that could work on all the elements of the reform; establishing WUA, FO and AWB, remodelling of canals, and providing on-farm and tertiary unit improvements. As specified in the programme, each of the provinces was expected to select one canal command area for such a pilot. This aspect of the NDP has been progressing slowly up till now, even though the pilot areas have been formally selected. In NWFP and Punjab, however, this has been marked by having selected other areas than those where the initial PIM pilots, discussed above, were initiated. Leaving thus for the time being the newly formed WUA and FO to find their own prospects to deliver services and a reason to maintain active.

A New Formalised Attempt

The next phase of decentralisation and devolvement of water management is now to get under way in concrete pilot projects, that have to give shape to participative water management in a more integrated approach of the broader frame work of PIDA and NDP. To this end, the ADB decided to fund an additional project on 'farmer-managed irrigation' in the Punjab. This project has laid out a more comprehensive approach on institutional capacity building, hydraulic remodelling and management restructuring than has been tried heretofore in the context of the IBIS. It foresees in establishing FO and decentralising O&M activities on two relative large distributaries in Punjab, that together comprise a command area of 53,000 ha: the Dijkot distributary on the Lower Chenab Canal and the 12-L (Ayub) distributary on the Lower Pakpatten Canal.

The issue of water allocation and distribution, as that of creating hydraulic functionality for the newly established water users organisations, is one of the prime elements of the project around which it is to centre the reform process in these two locations. To cope with the organisational complexities of managing the large distributary canals, the project intends to remodel the canals into multiple small hydraulic units, through creation of parallel minor canals on the right of way alongside the distributary, that will serve a number of the outlets. Thus creating smaller hydraulic units, along which WUA can be federated into, so called, *Mogha* groups. The water allocation principle with which the distribuataries are to be remodelled is that of 'proportional equity', through application of proportional dividers in the old distributary canal that will feed the new minor, and traditional 'Crump outlets' within the new minors.

From the onset, the project intends to work directly with the Punjab PIDA as one of its principal counterparts, that will be involved in the remodelling activities. The remodelling work is, however, not to be commenced before the formation of all the WUA, *Mogha* groups and the FO, that will participate in the remodelling activities, especially as 'controllers' on the quality and specifications of the construction work and hydraulic configuration.[153] The new water users organisations are to receive a focussed training on monitoring and evaluation of the water delivery and distribution, taking over O&M activities for their respective hydraulic units.[154] (ADB; 1999)

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[153] This is of course an important aspect, with which it is hoped to prevent the problems that plagued the remodelling activities of Kalpani and Jalalla distributaries in Swabi-SCARP (*cf.* chapter seven).

[154] In this regard, the planned remodelling structure raises two hydraulic issues for the O&M activities that will need to be attended to: (i) the construction of the parallel minors might upset the regime balance of the old distributary canal, as the flow through the old bed will be relatively smaller downstream of each proportional divider. In principle the smaller flows will require a steeper slope in order to avoid siltation. Without detailed information, it is impossible to assess these regime dynamics, but it is to be hoped that comprehensive attention will be given to this aspect in the remodelling. (ii) the relatively lower parent flow through the distributary and the new minors, will have as effect, that the hydraulic configurations for proportional distribution will be more sensitive toward disproportionality: in other words, slight deviation in the hydraulic flexibility of the off-take structures (i.e. the f value), will have a larger impact on the hydraulic flexibility of the parent channel (i.e. the F value) (*cf.* chapter two). This is not necessarily a bad thing, as deviations in proportionality will be easier identified at the tail-ends as they will be amplified. It means, however, that the new water users organisation will have to be capable of controlling the hydraulic configurations of the off-takes with higher exactitude.

This new approach to the reform process is thus hopeful, particularly as it attempts to give shape to a more comprehensive approach that comprises both the PIDA as the water users, and tries to focus them on concrete measures for the operation of water delivery and distribution. It is to be hoped that it will be successful in settling the contentious issue of water allocation in the planned for proportional configurations for water allocation and distribution, and that in the process of building institutional capacity among PIDA and the water users it draws on the experiences obtained so far in this field within the IBIS.

For NWFP, the newly remodelled canal command area of the Lower and Upper Swat canal systems have been selected as the official PIDA pilot area, where the process of decentralisation and devolvement has to be given shape in the near future. As both systems were just remodelled, emphasis is to be given at creating the new management structure and institutional capacity of the water users organisations, although the objective to transform the management into a crop-responsive operation of the system has returned, as one of the objectives to achieve. Within the context of the Lower Swat Canal, it remains to be seen what benefits can be provided for the water users to invest in formally organised collective action on O&M. Currently, the water supply conditions are very favourable at extremely low social and financial investment costs, which are already being perceived as the normal conditions. The decentralisation of management ten years after the benefits of remodelling have been realised, risks thus to evolve into a transfer of primarily costs and burdens to water users in the field of maintenance. The potential benefits to be exploited are limited to the reduction of the excess irrigation and leaching of water, by allowing operational losses at the secondary level, combined with the incentive to capitalise on the favourable water allocations by selling of the non-utilised excess.

8.5 A MATTER OF PROCESSES, NOT STRUCTURE

The PIDA-reforms would seemingly constitute for Pakistan an important departure from the interventionist development strategy of building new technological system as a means to improve the characteristics and performance of the irrigation water delivery services in the IBIS. The ‘Issues & Options’ paper and the ensuing PIDA-Act seemed promising in opening up the possibilities and means to engage in a change management process. In which institutional invigoration, innovation and development could take place to realign the water management processes and control mechanisms in the establishment of a new equifinal state of the hybrid systems of irrigation, and the dynamic maintenance and development of the system could be nurtured as the essential elements of management.

Unfortunately, the ‘Issues & Options’ paper started on a wrong footing by presenting a very specific appreciation of the new system the reforms should lead to, as well as of the ailments that plagued the present system and needed to be cured. Rather than creating a climate of change, the predilection for the system of private marketable water shares, public utilities and disengagement of the ID resulted in an initial agitation of the water management sector and ignition of a defence strategy for the political and organisational interests. Fuelled by the success story of reforms in Mexico and the participative irrigation management initiatives in the Philippines and Turkey, the multilateral agencies ‘imported’ a conceptual model of an organisational structure for decentralised and self-governing management. Spurred by neo-liberal economic thinking, the objective of the reforms became the creation of new entities of management and governance within the IBIS, that could become economically self-sustaining, and act as economic market players in the relocation of financial and natural resources. The role of the state was hereby to be reduced to regulation of the market place, and provide the infrastructure, in the form of the IBIS, for the trade of water. The management of water, in this view, should no longer be governed by the socio-political contestation of a natural resource, and the futile attempts for its regulation, but by economic market mechanisms. The self-governing entities for water management, could then invest in optimising their efficiencies and lowering their opportunity costs to improve their competitive position as buyers or sellers on the basin wide water market.

This new vision for the IBIS as an economic market place is of course a radical visionary picture of a perfect future that is far detached from the realities encountered on the ground in 1994 at the time of its presentation. As such, it must primarily be viewed as a political strategy of the Bank to enter the negotiations with the government of Pakistan with high stakes, with the objective to reach an accommodation that would still represent a marked change in policy and initiation of a reform process. This objective was eventually realised, by twisting the arm of the interim government on the loan agreement for NDP. The accommodation reached, settled on two principles of reform: (i) reform of the organisation structure to allow for the creation self-governing and financial autonomous entities; and (ii) financial rationalisation of the irrigation and water management sector by eliminating all subsidies for O&M.

The immediate focus of the reforms in Pakistan has thus been directed to the establishment of a new organisational structure for water management; on paper, in the form of judicial amendments, as in practice by the setting up of water users associations and their federations into FO at the distributary/minor level. The structural reforms are seemingly regarded as the prerequisites for the improvement of the hybrid system of irrigation water delivery and management. Structural reform and organisation building have thereby become the new intervention domains, alongside or instead of the technological DPS, to structure the hybrid systems and its new equifinal state for water management.

As has become clear, however, from the first experiences in Pakistan such a new organisational structure for water management, is only of secondary concern in directing the sociotechnical management processes; *how* to organise and structure a management process, presupposes that the *what*, in terms of the tasks, procedures, elements and objectives of the process, is already known. When this sequence is turned around, or the existing organisational structure is non-negotiable in a process of change management, the structure risks to become an impediment for effective change by imposing a dysfunctional structure and inducing organisational defence politics. The early experiences in Pakistan ran into both predicaments of change management, when the water users organisations were set up without a clear decision on what management processes they were to conduct, while the ID strongly engaged itself in defending its institutional domain and organisational interests in defiance of the changed policy.

At the core of the management issues that govern the conditions at present, that needs to be addressed for any change and development in the future, lies the matter of water allocation and distribution. In the absence of the option to strike as generous new balances between water supply and use/demand as in Mardan-SCARP and CRBC-stage I, this matter needs to be settled as the central element in any process of change and development in irrigation water management. For the water users it forms the core element that determines their water management strategies, opportunities and constraints. Without a clear settlement of this issue, with which to establish the principles of the process of water distribution and water management arrangements, one might devolve the responsibilities to the water users to resolve this issue, but one does not provide them with the means to settle any conflicts between themselves, or between them and the AWB or PIDA. The resolution of this issue is a delicate matter that will inevitably lead to a contestation of interests and established rights, that will need to be handled with prudence, and with engagement of the AWB and PIDA that retain a crucial function in both the allocation (as arbitrators) and distribution (as providers).

Prudence does in this regard, however, not equate to the pilot project approach that is in such swung among the multilateral agencies and the government of Pakistan, and that seems to have become the *modus operandi* to search for workable solutions in determining what management processes can be taken up by the new organisations and what arrangements of water allocation and distribution this can result in. For one, this provides the opportunity for those with established interests, be it sections of the old ID or water users with privileged water allowances, to protect those interests in the absence of clear arrangements and regulations. Secondly, the pressure is great to alleviate the problems of water scarcity and distribution by increasing the water supply conditions – both, from the part of water users who expect a better water delivery service, as among the donors to prove the success of the reform. On the scale of the IBIS, this can only be done at the deprivation of others, while it is to be hoped that it will not be conducted on the scale of the canal system, where it will be at the deprivation of other distributaries and future FO and partners in management.

CHAPTER NINE

DISCUSSION & CONCLUSIONS

IRRIGATION DESIGN & MODERNISATION: FROM EVOLUTIONARY PROCESS TO PURPOSEFUL DEVELOPMENT

The attempts for modernisation of irrigation undertaken in NWFP have not, as yet, led to the changes in water management and performance that were anticipated and intended with the design and remodelling of the irrigation canal network and its hydraulic and technological configuration. The initial purpose, formulated by policy makers and the multilateral agencies, and interpreted and given shape by the designers, to effectuate a change towards a 'productive' (demand- or crop-based) irrigation water delivery service, has not been realised. 'Productive irrigation' turned out to be primarily appreciated by the ID and water users, as the ability to provide enough water and regulate its use through excess water management and drainage. This option was made possible by the very interventions that pursued another concept of water management.

This tendency for emergence of divergent system properties is not new, nor restricted to irrigation or NWFP. The history of development, and technological interventions, is strewn with examples of outcomes that diverged from the one anticipated and planned. The question thus arises whether we can still regard engineering and technological interventions as the purposeful development process it seeks and pretends to be. The frequent diverging outcomes of technological interventions, such as the irrigation modernisation attempts undertaken in NWFP, are seemingly more analogous to a Darwinian evolution process. The technological interventions to the DPS mimic the mutations in a system, after which the evolution of the system will determine whether the mutation is functional, by finding a purpose for its use, for its adaptation and survival in its environment, or not. Is development by technological intervention then merely an evolutionary process, dubbed 'development' when leading to adaptations that lead to a 'better' functioning of the system in its environment, and in which trial and re-trial constitutes the process of mutation in the hope of providing functional properties for the system?

The issue at hand, then is that of purpose and functionality. Can purpose and functionality be predetermined and purposefully designed and developed, as lies at the centre of engineering and technological development, or is this simply a matter of (evolutionary) chance? To meet the conditions for predetermination and purposeful design and development, there should first be an accommodation and consent of what the desired purpose and function should be of the technological DPS. As we have seen from the cases of irrigation modernisation in NWFP, this is not a simple matter of problem analysis and optimisation of the natural and designed physical process of irrigation. It involves the complex matter of reaching consent on the strategies, objectives and purposes that users and operators are willing and capable of pursuing in water management. This constitutes an elaborate managerial process of mediation and accommodation of the appreciations of the 'stake-holders' in the conceptualisation of the systems under change. In which the purpose, function and characteristics of the technological DPS therein, and the management function, processes and mechanisms that should be deployed to reach and maintain the new equifinal state of the system, are all elements subjected to appreciations that need to be accommodated in a concept. To be purposefully functional, the design and DPS should follow the purpose and strategic objectives that are pursued in the dynamic management of the system, rather than that management should follow technological function.

Trial & Re-Trial: In Search of a Match Between Purpose & Function

Modernisation often corresponds to the wish to improve a process through application of the new possibilities provided by science and technology, and particular 'fads' of modernity that seem promising (this is particularly true of the attempts undertaken in the irrigation sector of NWFP). The cases treated in this thesis were driven by the policy objective to transform the irrigation water delivery systems into 'crop-based' irrigation systems. In these, the water supply and delivery could be varied and matched to crop requirements, with the ultimate aim of increasing both the efficiency and efficacy of water use in irrigated agriculture. The projects of Mardan- & Swabi-SCARP, CRBC/CBIO and PHLC, have all concentrated on composing a particular technological function for purposefully controlling the flow variation and matching of water supply with crop requirements. As has been shown in this thesis, each of these projects has tried to give shape to the technological function and managerial purpose by adopting specific technological 'solutions'. These included water regulation structures that enable the measurement and control of discharges as opposed to mere water levels; procedures for planned and computational delivery of water; hydraulic simulation; rehabilitation; and automatisation of water control. The diversity and changes in technological strategy represent the trial and re-trial to find a match between the technological function, and the purpose and strategy that water users and system operators are willing and capable of pursuing in their water management practices. Chapters four to seven have shown that in none of these projects has there been an holistic view for the transformation of the water management practices that water users and operators would have to effectuate in a process of change. The projects failed to understand the need to define 'irrigation concepts' in which the DPS has a specific function and relation in the wider hybrid system of irrigation water management, in which a synergy has to emerge between the technological function and capacity, and the management strategies.

The predilection to focus on the DPS is strongly rooted in engineering and the positivistic discourse of technological determinism of development policies. The central issue hereby is not whether the technological DPS has a central role and function in the hybrid irrigation systems; they are undeniably instrumental in shaping the central transformation process of irrigation water delivery. The question is, however, whether the wider hybrid system and its social components (should) determine the functionality/purpose and equifinal state of the system at large, and thereby that of the technological DPS, and how it is used to shape and perform the core transformation process; or whether a reversed relation can be nurtured. The engineering and development traditions are strongly grounded on the latter belief. In this the discourse of positive technological determinism centres around the capacity of the DPS to shape the processes and elements of the wider hybrid system, into the problem solving and natural-physical transformation system it seeks to establish.

With the externalisation process in design *cum* modernisation, the technological DPS has increasingly been developed by external specialists, that are engaged to conduct the technological intervention as a means to structure and determine the characteristics of the system of water delivery. This system is then defined in terms of its natural-physical and scientific characteristics. The (operational) management elements of these systems tend to get defined in terms of technical and physical targets and objectives that need to be achieved and controlled in the water allocation, scheduling and distribution mechanisms. The focus is thereby primarily directed towards the outputs that need to be achieved by management, rather than on the sociotechnical process with which those outputs can/should be achieved. As a result, there is a tendency to de-humanise and de-socialise the management processes into measurable and 'objectified' targets. The operational targets become thereby confounded with the purpose itself of the system, rather than being subjected to the (changing) appreciations, objectives and strategies of the people that constitute and define the wider hybrid and sociotechnical system. At best, the objectives and targets, and the characteristics of the system to be 'created', are subject to changes in the development policy discourse.

The attempts to 'create' new irrigation systems with 'crop-based' water delivery services have, however, revealed that the technological DPS is not as deterministic for the system at large as was initially hoped by the policy makers. The 'objectified' target management for the variation of water supply to match accurately the water delivery with crop water requirements, was quickly superceded by the strategy of FSQ deliveries and excess water management at the tertiary and quaternary level in the cases of Mardan-SCARP and CRBC. The exclusion of the irrigation departments and water users from the conceptualisation and design of the DPS meant that this was a near inevitable outcome.

In the elaboration of the O&M procedures for these projects, too much focus went on the technical management requirements for the DPS. There has hardly been any scope and attention for the processes of management in terms of institutionalising the control mechanisms of allocation, scheduling and distribution within the management practices and domains of the irrigation departments and water users. These include the process of elaborating procedures for the gathering of data; the valuation and processing of information; the issuing and managing of operational tasks and instructions; and above all, the organising of water scheduling and distribution arrangements while appeasing the individual requirements/demands. These processes have been delegated to the O&M training and extension, or the realms of models and information systems. They were treated as being parameters that can be regulated to conform with defined objectives and targets. However, these elements of management form sub-systems of their own, to execute and manage processes of their own, with their own in- and outputs, including human tasks, skills and procedures, information requirements and outputs. In the absence of any elaboration and development of these sub-systems and processes for management, the ID and water users had little choice than to accommodate the operation of the new DPS in their existing management systems and processes, and develop adaptations to the new opportunities and conditions it created.

In the process of adaptation, both ID and water users elaborated on their own appreciations of the notion and concept of ‘crop-based’ irrigation as the management of a high relative water supply. This was partly an accommodation of the new water delivery capacity and drainage opportunities in their established water management procedures and strategies, in the absence of any institutionalised changes for water management. At least as important, however, is that in their appreciations there was no real need for an accurate planning and regulation of the water delivery, and all its required arrangements, as adequate deliveries could be secured with FSQ operations, and the drainage effluent could be re-used elsewhere. This aspect was not really contemplated in the attempts to establish new irrigation systems that would be ‘modern’ and efficient according to the standards of timely and adequate water delivery for productive irrigation. The imposed concepts of ‘modern’ irrigation failed to consider the integration of irrigation and drainage and return flows, into a system the ID and water users adapted to. With the accommodations made by the ID and water users, the functionality and purpose was in essence changed to another concept than that was defined and contemplated by the policy makers and designers.

The externalised approach and set-up of the modernisation projects has not been conducive for a systems and development approach (as opposed to an approach of creation and implementation) for the improvement of the irrigation systems in question. Both the process of developing management systems – through institutionalisation of new control mechanisms and their processes of monitoring, evaluation and feed-back and -forward regulation and adaptation – and the accommodation of differing appreciations on what the characteristics and function/purpose of the system should be, were hampered by this externalised approach. Not only is this a consequence of the compartmentalisation and specialisation, but also of the politics of institutional competition, that stand in the way of an open consultation and accommodation process.

In the case of Swabi-SCARP and the remodelling of USC, the issues would at first seem to be turned around, as the ‘modernisation’ of the operational management for ‘crop-based’ irrigation was postponed in favour of a remodelling that would closer match the established practices of operation and water management of the ID and water users. The re-application of Crump’s concept of self-acting proportionality, however, resulted more in a rehabilitation than in a reinvigoration and development of a hybrid system for purposeful management of a water delivery service. With the choice made to reapply Crump’s concept, the project could concentrate on the design and construction of the DPS, with the rehabilitation argument that the management system and procedures could essentially remain the same. What has thus not been addressed in the realms of new management, is the issue of water allocation and the process of monitoring and regulating the hydraulic configuration as essential elements of the feed-back control, that also never got settled and institutionalised in the past. The externalised approach of Swabi-SCARP has led to a misapprehension of the issue of water allocation and the dynamics of remodelling. The equitable proportional allocation was 'simply' applied as a design target for the configuration of the outlets. While with the disproportional arrangements made in Crump's time, the remodelling of canals and the allocation of water was a matter of striking new balances of water delivery and use in each canal, through the process of *Chakbandi* to settle the CCA, duty, cropping intensity and social-political privilege of the *Chaks* in question. In Swabi-SCARP the issue still remains the settlement of allocation and distribution. This is because the level of relative water supply, though significantly increased, remains at such a level, particularly during *Rabi*, that the contest for more water is bound to continue, as has been customary practice among water users. There also remains a continued need to establish a controlled water distribution pattern to guarantee the tail-end areas of a secured supply. The functionality of Pehur High Level Canal, with its concept of automated downstream control, is expected to primarily alleviate further the relative water scarcity, so that in USC and PHLC the same workable mode of productive irrigation by excess water management can emerge, as that manifested itself in LSC and CRBC-stage I.

The incapacity of these technological interventions to address the sociotechnical processes of water management, and reinvigorate the institutions that have to constitute those management processes, provides a worrying outlook for the capacity to develop and improve irrigation systems to the requirements of the future, and the role of technological development in enabling and facilitating such developments towards a desired outcome. From a systems point of view, the essence of management as a means of controlling the system and its equifinal state, points to actions different from those functionalist models proposed. Rather it is to establish a structural process of monitoring, evaluation, setting of new objectives and measures of performance and adaptation of processes to changes in its environment and appreciations on its functionality and purpose. Ironically, the externalised creation and implementation of new engineered DPS denies this very essence of management, by excluding the managers of the system from the conceptualisation and changing of one of its core sub-systems.

Water, Technology & Management, and the Systems Management Framework

There is a clear need for a management framework in irrigation design and development that goes beyond the mere functional task management for the processes of the DPS. This framework needs also to include a comprehensive framework for the sociotechnical processes that govern the institutions of water management, both in their establishment as in their dynamic maintenance. This then not only is a matter of capacity building for technical operation, but also of social interaction processes with which the human activities can be geared towards a congruent process of management, in which the (water) control mechanisms can be directed towards the purposes they should serve. In the extreme open and hybrid nature of irrigation systems these purposes cannot be regarded as a 'simple' unified purpose of performance and target management of the natural and the designed physical system. The hybrid and extreme open nature of irrigation implies that the purposes people pursue in their water management activities are not only diverse (in aim as well as in nature). They will also change over time, as the appreciations people have of the problems, constraints and opportunities that the system provide in their pursuing of their purposes change. The historical review of irrigation transformation since the 19th century in the IBIS has shown these changes.

For the design and modernisation of irrigation, this means that there is a need to create a management capacity to mediate in the appreciations of what the system to develop should look like, and that the conceptualisation of the DPS, and its role and function in the wider hybrid system, is primarily a process of accommodating a consent on the purposes it should serve. The design of the technological DPS should come second to this mediated conceptualisation of the system, if its to be purposefully developed. Rather than the import and imposition of any concept of modernity, the new maxim that irrigation water delivery is a service, should be extrapolated further, so that the process of design and modernisation itself becomes a service for the people and institutions that make up the hybrid system. Ideally, the function of design and technological intervention should be to enable the development, adaptation and reaching of a new equifinal state of the hybrid system of irrigation, in order to enable it to adapt to changes in its environment (be they socio-political, natural-physical or economic).

Policy makers, and external interventionists as the multilateral agencies, are primarily part of the environment, rather than of the hybrid system of irrigation. With policy changes, rules and regulations, and manipulations of the economic market conditions, they may impose certain constraints and stimuli on the system. The principle of equifinality, however, will in the first instance induce a system to maintain its properties and reproduce the same outcome/output in its changed environment. Only when this is not feasible (i.e. the changes and constraints are too big) will it be forced to change its properties to reach another equifinal state. Systems that are capable to resist changes in their environment, are thus strong systems with a resilient and adaptive property of equifinality. This forms an intrinsic dilemma for policy makers, when they seek to impose changes on the equifinal state of systems, as in the case of Pakistan, where they seek to change the water management properties and state of irrigation water delivery service.

Change can therefore better be initiated internally to achieve purposeful development, and not by imposing constraints from the environment. First of all, constraints invoke consolidation, and when change is provoked, it is difficult to direct it. To realise internal change, the mediation and conceptualisation process, should be regarded as a management process in itself, that seeks to effectuate change and innovation of the system. In extreme open systems, this is a complex task of mediation of multiple appreciations on what the system is, what the problems are, and what the system should be and should be able to do or deliver. The externalised import of concepts of modernity are limited attempts to enter or re-create the system. The principle of equifinality, and the new capacities and opportunities provided by the modernisation, however, tend as we have seen to lead to other outcomes than anticipated and planned. The externalised intervention method constitutes in this respect also a denial of the 'development process', as it seeks to 'jump-start' the development by creating a new system that is capable in its DPS to better regulate the natural physical processes, and to which management institutions have to conform in a reactionary evolution process. Whilst for a progressive and purposeful development process, the system should constitute a dynamic management and maintenance sub-system, that is geared towards the purposeful improvement and innovation of the system, its equifinal property and control mechanisms. In classical management parlance: the innovation and development should be the products of the strategic management decision taken within the system; and to induce development one should invest in building the capacity for strategic management.

How to stimulate the capacity for dynamic (or strategic) management for a purposeful development? This requires an approach in which the conceptualisation of the wider system and the DPS sub-system forms the primary and essential part of reaching accommodations in a process of change management, but in which the institutions and sociotechnical processes of water management are perceived as much part of the essential elements of the hybrid system as the DPS. The water sector will need to appropriate for itself such a management framework.

For this thesis a choice was made to adopt one management framework, that specifically dealt with systems, management and change management, and that was not driven by technology but by human activities and the appreciations and purposes that drive them in what constitutes the processes of management. This thesis has worked to expand understanding of the systems framework and its application in the field of irrigation and water management. However, it has not been able to provide empirical examples of congruent efforts to change the management institution and process in an attempt to gear them towards the establishment of a new water delivery service, and in which the technological DPS serves the means to achieve this, rather than becoming the means of change itself. Regrettably, it has thus not been able to test the systems framework fully. It did not find examples showing the dynamics of accommodating differing appreciations and reaching of effective consent on the control mechanisms for the extreme open systems that irrigation represents. It has necessarily been restricted to an analysis of the failures to address the management issues in congruent relation to the technological DPS, and the function and purpose it could serve in the institutional environment of NWFP. Also of how the purposes and strategies that have governed the practices of the ID and water users for the past 50 years might have been better served by different choices and a more congruent attention to the sociotechnical processes of management.

On the one hand this a result of the author having to confront the ingrained perceptions and concepts that govern the field of water management, and that are deeply rooted in the manipulation and regulation requirements and objectives of the natural-physical process of water management, by means of an engineered technology. The enrichment of these perceptions and concepts with those of the management sector, that encompass rich concepts and notions of its own, in interventions already in place, was too much to be undertaken by this researcher on its own. On the other hand, the case material of this thesis proved to be neither very conducive for such an undertaking. The cases proved to be governed by the conflict of perceptions on, and concepts of, what modern irrigation should entail in the context of NWFP, as a consequence of the externalised process of design and implementation. In the absence of any concerted effort for change management to develop and invigorate the institutions and capacities for water management, any attempt to rigorously analyse the intended or wished for management procedures, would quickly result in a paper exercise as those produced in some of the O&M manuals.

Any appropriation of a management framework for design and transformation will have to come from a concerted effort and renewed focus from the water sector on the issues of management. The current developments on a framework for ‘integrated water management’ do not yet seem to provide this focus. Thus far, the developments seem primarily to have constituted an enlargement of the 'system for water management'. In particular, by expanding the boundaries and conception of integrated water management at the catchment/basin level, as the regulation and manipulation of the natural-physical processes on a grander, more complex and integrated scale. Management-wise, the focus is primarily still on producing models for manipulations and regulations of natural-physical processes on larger scale, and the formulation of new management tasks and objectives that are still driven by the conceptions of the DPS for regulation of water resources. The capacity to handle social processes of management is still weak. A positive development, however is been, that with the concept of integrated water management, the dilemma of different conceptions of the systems for water regulation and the purposes it should serve, has come to the forefront as differences originating from the different sectors of water use (i.e. agriculture, environment, industry, urban, etc), that need to be accommodated in an integrated concept. The next step to take now is to realise that in management such differentiation of conceptions and purposes are not confined to unitary sectors of water use, but constitute the daily aspects of management within the sub-systems of each sector. Here accommodations have to be continuously elaborated to keep the institutions and the mechanisms of control geared towards the dynamic maintenance of the systems and the functioning of their equifinal properties in these sectors.

Irrigation in the Indus Basin: What is Next?

The degradation and stigmatisation of the irrigation departments, have become a problem in itself, that forms a serious obstacle to change and the realisation of a purposeful development process. As has been shown throughout the thesis, any capacity for dynamic maintenance and development has been lost. In the agitation and entrenchment of positions, fed by the externalised development approach, the maintenance of their management position and discretionary powers, has become a purpose on its own for the ID as an institution. As they retain a central position in the management of the systems, they play a central role in the establishment of control mechanisms for water management. It is high time to engage them actively as an agent in change, as opposed to a mere target of change. To this end, it is recommendable to curb the existing predilection for externally created pilot projects. Instead the means and effort could be concentrated on the building of capacity for dynamic maintenance, innovation and development within the ID, by promoting training, exchange, and above all experimentation with different concepts of water control and water management strategies and principles. The PIDA-reforms provide an opening to engage the ID again actively in the development and implementation of new technological DPS and control mechanisms for water management. This opportunity should be taken with both hands, and actively supported by all involved in the sector.

The institutional reforms and decentralisation that are foreseen with the PIDA-act can provide a reinvigoration of the management and dynamic maintenance processes, for the improvement of the irrigation conditions. Apart from the necessity to also engage the old ID in this process, there is, however, one other concern. The process of decentralisation and water user participation has great potentials when it is initiated and perceived as a means to facilitate the process of mediation, and accommodation of appreciations and conceptions of what the system should look like, and the purposes it should serve. In practice, however, there is also a strong tendency to see it as a mere means of delegating tasks and procedures of a preconceived concept of the system, rather than true decentralisation and devolvement of responsibilities.

New research into the field of water *management* should be integrated with such initiatives to reinvigorate the dynamic maintenance capacity of the ID, and reform initiatives, for the mediation and accommodation of conceptions of the system and the purposes it should serve. In order to reach any meaningful appropriation of a management framework in the water sector, such a research should be part of a collective initiative, and not a conglomeration of individual efforts (such as this thesis).

The cases of irrigation modernisation treated in this thesis were governed to a large extent by the predilection for engineering conceptions of modernity and crop-based irrigation water delivery. The context of IBIS, however, is more suited for concepts that are based on the principles of maximisation of yield per unit of water, than per unit of land. In the current political discourse of water scarcity, this notion is gradually gaining ground again. Irrigation-wise, this provides a whole new range of challenges for the conceptualisation of new water regulation systems, and water delivery services. There are clear challenges ahead for the integration of surface and ground water, and utilization and purposeful management of the aquifer and soil moisture retention as natural storage facilities, that may provide viable options to integrate closer with the prevailing water management strategies. This is, however, not only an issue for the development of irrigation systems. The establishment of new balances between water supply and use/demand also involves the systems and processes of irrigated agriculture. There is also a clear scope to address this issue in the planning and management of the cropping strategies and individual irrigation strategies. These are elements of the farmer's system of irrigated agriculture. This needs to be addressed by other means, such as agricultural extension and services, which are virtually non-existent at present in Pakistan.

In all attempts to be undertaken in the future, however, it would be wise to take stock of Strachey's words:

> "[...] *the full benefit of the engineering skill and knowledge can never be applied to the construction and maintenance work unless the engineers are constantly watching their operation and have an intimate acquaintance with all their peculiarities and the precise wants which they are to supply. Not only is professional knowledge necessary to secure the best management, but a complete practical knowledge of the details of management in necessary to secure the most satisfactory application of professional skill to the works."* (Strachey, quoted in: Famine Commission; 1885:443)

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SAMENVATTING

"Trial & Re-Trial"
The Evolutie van Irrigatie Modernisatie in NWFP, Pakistan.

> *"De spreiding en instandhouding van civilisaties in het stroomgebied van de Nijl, de Tigris en de Euphraat, en in verscheidene delen van het Indiase subcontinent, zijn vanaf zeer vroege tijden verbonden geweest met irrigatie. Toen in de loop der geschiedenis Britse irrigatie-ingenieurs met deze gebieden in contact kwamen, ontdekten zij dat het principe van gecontroleerde inundatie al sinds de vroegste tijden gepraktiseerd werd. Het was hun taak om de toepassing van dat principe te transformeren van een vaardigheid in een wetenschap, om zo de vruchten van het industriële tijdperk ten dienste te stellen van de problemen in de landbouw, en de steeds maar groeiende bevolking te beschermen tegen de gevolgen van droogte en overstroming."* (Newhouse, Ionides and Lacey; 1950: voorwoord)

De onmiskenbare trots en het optimisme van bovenstaande quote omtrent de ‘ontwerpbaarheid’ (i.e. maakbaarheid) van irrigatie en de voordelen die zij levert aan de maatschappij dient men te vergeven, wanneer men haar beschouwt tegen de achtergrond van haar ontstaanstijd. Pakistan en India hadden zojuist hun onafhankelijkheid bereikt, waarbij de Britten en hun ingenieurs een groots netwerk van irrigatiesystemen hadden achtergelaten,een imposant areaal van in totaal 14 miljoen ha bevloeide oppervlakte. De apotheose van de ingenieurskunst op het gebied van irrigatie en haar wetenschappelijke ontwikkeling werd gevormd door de transformatie van de 8 miljoen ha woestijnachtige woeste grond van het stroomgebied van de Indus in de graanschuur van de Raj, en dit in een tijdsbestek van slechts 70 jaar. Dit imposante resultaat riep dan ook makkelijk gevoelens van zelfgenoegzaamheid op, zoals verwoord door Sir Douglas Harris: *"De Britse ingenieur kan met trots terugkijken op miljoenen acres vanwaar de dreiging van hongersnoden permanent verbannen is, en nog eens miljoenen acres waarop nu gewassen gedijen waar vroeger nog niet eens een grasspriet kon groeien; zelfs al is hij te bescheiden om te zeggen: Si monumentum requiris, circumspice’"* (Harris, in: op.cit.: vi, voorwoord)

De bevolking van Pakistan, en daarmee van het stroomgebied van de Indus, is echter sinds 1950 meer dan verdubbeld.Hierdoor wordt Harris z’n ‘permanente verbanning van hongersnoden’ bedreigd door de toekomst die nog komen moet. De grenzen van de groei zijn bijna bereikt in de 14 miljoen ha geïrrigeerd areaal van vandaag in het Pakistaanse gedeelte van het stroomgebied van de Indus. Daarbij wordt de duurzaamheid bedreigd door hoge grondwaterstanden en verzilting, terwijl de druk op de beperkte en eindige hoeveelheid water blijft toenemen door de vraag naar verhoogde voedselproductie.

Dit proefschrift behandelt de pogingen die sinds 1980 zijn ondernomen in de ‘North West Frontier Provincie’ (NWFP) om ‘moderne’ irrigatiesystemen te ontwikkelen, die zouden kunnen voldoen aan de toekomstige irrigatiebehoeften van de natie.Men dacht dit te bereiken door het bewerkstelligen van hogere efficiëntie in watergebruik, als mede een hogere doeltreffendheid in landbouwproductie, dan die tot nog toe werden bereikt in de door de Britten ontwikkelde traditionele ‘protektieve’ irrigatiesystemen. De voornaamste doelstelling hierbij was te proberen om de irrigatiesystemen, als ook het management van het waterbeheer van zowel het Irrigatie Departement als van de watergebruikers, te transformeren in een waterleverings ‘service’, waarin aan de variërende gewas-water-behoeften kon worden voldaan door middel van aangepaste variaties in waterlevering. Op deze wijze hoopte men de irrigatiesystemen op het niveau te brengen van de wetenschappelijke ontwikkelingen en inzichten die gedurende de jaren zeventig hadden plaats gevonden op het vlak van irrigatie. Daarbij waren in de Groene Revolutie steeds hogere niveaus van efficiëntie en doeltreffendheid nagestreefd en had men de waterverdeling afgestemd op de gewas-water-behoeften.

De context en condities omtrent irrigatieontwikkeling vandaag de dag zijn echter substantieel anders dan die ten tijde van het koloniale tijdperk. De modernisatie van irrigatie is niet langer ‘enkel en alleen’ een kwestie van wetenschappelijk ondernemen, waarbij ‘eenvoudig weg’ de optimalisatie van de efficiëntie and doeltreffendheid van waterbeheer kan worden nagestreefd door middel van de ontwikkeling van de nieuwste technologische toepassingen.. De waterbeheerspraktijken van vandaag en morgen worden beïnvloed door verworven waterrechten, ingesleten tradities, en politieke en institutionele belangen. Kortom, de ontwikkeling van irrigatie is heden ten dage net zo zeer een kwestie van (water)beheersvraagstukken, als een kwestie van technologische ontwikkeling en applicatie. Als gevolg hiervan lijkt de tijd dat men als irrigatie-ingenieur nog met trots en zelfgenoegzaamheid kon terugkijken al lang vervlogen, nu beheersproblemen als daar zijn:ongelijke waterverdeling, slecht onderhoud en ingesleten tradities voortdurend naar voren komen als onoverkoombare obstakels bij de verwezenlijking van de beoogde optimalisatievan de wetenschappelijke concepten van ‘moderne’ irrigatie.

De vier modernisatieprojecten die in dit proefschrift worden behandeld (i.e. Mardan- & Swabi-SCARP, het Crop Based Irrigation Operations project en Pehur High Level Canal) vertegenwoordigen een reeks van pogingen die ondernomen zijn gedurende de jaren tachtig en negentig om een concept van ‘moderne’ irrigatie te ontwikkelen. Deze projecten vormen een reeks van "trials & re-trials" om een bruikbaar en werkbaar concept van ‘moderne’ en ‘productieve’ irrigatie te ontwikkelen, waarmee de praktijk van het waterbeheer van zowel irrigatiedepartement als watergebruikers effectief getransformeerd kan worden, resulterende in een betere afstemming van de waterverdeling op de variabele gewas-water-behoeften. Deze studie richt zich op hoe beheersvraagstukken kunnen worden opgenomen als een integraal onderdeel van de conceptualisatie, ontwerp en ontwikkeling van irrigatiesystemen. De vier casussen in deze studie zijn gebruikt om te onderzoeken hoe beheersvraagstukken, en in het bijzonder die betrekking hebben op het operationeel beheer, zijn opgenomen en verwerkt in deze projecten door de betrokken ingenieurs, instanties en donoren, en tot in welke mate deze visies omtrent het beheer aansluiten bij de waterbeheersdoelstellingen, -strategieën en -capaciteiten van de gebruikers (het irrigatiedepartement alsook de boeren).

Het theoretisch- en analysekader, uiteengezet in **hoofdstuk een**, is gebaseerd op de systeemtheorie van Bertalanffy, en dat van de "Soft-Systems" ontwikkeld door Checkland *et al*. De systeemtheorie is gekozen om een analysekader te ontwikkelen waarin (water)beheer beschouwd wordt als een integraal onderdeel van irrigatie, en haar ontwerp en ontwikkeling. Irrigatie*systemen* worden hierbij beschouwd als extreem open en hybride *systemen*, waarin de controlemechanismen **–** zoals waterallocatie, -planning en -verdeling **–** welke ingezet worden voor de totstandkoming en onderhoud van de ‘equifinale staat’ en ‘emergerende eigenschappen’ van het systeem, beschouwd worden als hibryde sociaal-technische subsystemen. De elementen en processes van deze subsystemen worden dan in een zelfde mate gestuurd door de technische en technologische eigenschappen van het irrigatienetwerk, als door de doelstellingen en strategieën die worden nagestreefd en toegepast door de "social agents" die betrokken zijn bij het waterbeheer. Dit laatste element wordt dan voornamelijk bepaald door de percepties die de betrokken mensen hebben ten aanzien van hoe het systeem er uit zou moeten zien en wat het zou moeten kunnen bewerkstelligen. Met andere woorden: de concepties die zij hanteren betreffende het irrigatiesysteem. Het bewust, en congruent, ontwikkelen van irrigatie wordt daarmee voornamelijk beschouwd als zijnde een proces van conceptbemiddeling, in een poging om tot overeenstemming te komen betreffende de eigenschappen van het systeem en haar controlemechanismen voor (operationeel) beheer. Betoogd wordt, dat het veld van irrigatieontwerp en -ontwikkeling nog steeds voornamelijk beheerst wordt door de wetenschappelijke en technologische concepties van het irrigatiesysteem en haar controle mechanismen, die een adequate en integrale benadering van beheersvraagstukken en de transformatie van de praktijk van het waterbeheer in de weg staat. Dit theoretisch kader wordt toegepast om de verschillende concepties ten aanzien van 'moderne' irrigatie onder de betrokken ontwerpers, beheersinstanties, watergebruikers en andere betrokkenen in the casussen te analyseren, en om aan te tonen dat het gebrek aan integratie van de technische- en beheersconcepten leidt tot een praktijk van waterbeheer die substantieel afwijkt van datgene wat aanvankelijk beoogd was.

Hoofdstuk twee geeft een historische analyse van de ontwikkeling van het concept van 'protectieve' irrigatie zoals ontwikkeld door de Britten, en toegepast in het stroomgebied van de Indus. Deze historische analyse is gemaakt om inzicht te krijgen in de achtergrond en dynamiek die bepalend zijn geweest voor de ervaringen, tradities en strategieën van waterbeheer van overheidsinstanties en watergebruikers gedurende de afgelopen honderd jaar. In dit hoofdstuk wordt betoogd dat de ontwikkeling en handhaving van de protectieve irrigatiesystemen gedreven werden door een dynamische aanpassing van de waterallocatie en **–**verdelings- mechanismen, om zo periodiek een nieuw evenwicht te bewerkstelligen tussen de waterbeschikbaarheid enerzijds, en de groei en intensivering van het geïrrigeerde areaal anderzijds. Alhoewel het onmiskenbaar is dat deze ontwikkelingen gemotiveerd werden door nieuwe ontwikkelingen in de hydraulische wetenschap en irrigatietechnologie, wordt er tevens aangetoond dat de waterallocatie en -verdelingsovereenkomsten in een zelfde mate beheerst werden door administratieve en politieke doelstellingen, als door technische. In tegenstelling tot het wijdverspreide geloof, wordt er betoogd dat de Britten nooit in staat zijn geweest om een strikt proportionele en billijke waterallocatie en -verdeling te implementeren. Zelfs niet, nadat het technische concept van 'zelf-regulerende' proportionaliteit, ontwikkeld door Crump in 1922, tot het nieuwe paradigma van irrigatieontwikkeling werd verheven. De administratieve en politieke noodzaak om gunstige waterallocaties te kunnen vergeven, werd begunstigd door het handhaven van de beslissinsbevoegdheden van de 'kanaal-officieren', zoals vastgelegd in de 'Canal & Drainage Act' van 1873. Dientengevolge is deze wet ook nooit geamendeerd om de nieuwe mogelijkheden tot waterbeheer te weerspiegelen die ontstonden als gevolg van de vooruitgang in de hydraulische wetenschap **–** zelfs niet in de vorm die deze wet heeft in het hedendaagse Pakistan.

In **hoofdstuk drie** wordt een overzicht gegeven van de ontwikkelingen die hebben plaatsgevonden in de Indus-irrigatiesystemen, nadat Pakistan haar onafhankelijkheid heeft verworven in 1947. Deze periode wordt gekarakteriseerd door belangrijke institutionele veranderingen in de watersector en ontwikkelingen ter consolidatie en expansie van de Indus-irrigatiesystemen. De ontwikkelingen in irrigatie werden voornamelijk gemotiveerd door de noodzaak om de effecten van de "deling", waarbij de afvoer van de drie oostelijke zijrivieren van de Indus toegewezen werden aan India, te niet te doen. Om dit verlies te kunnen compenseren, is er een groots ontwikkelings-programma, bestaande uit stuwen,verbindingskanalen en dammen en reservoirs, uitgevoerd onder beheer en met financiële hulp van multilaterale donoren. Voor de supervisie en implementatie van deze kolossale werken is er een nieuwe federale overheidsinstantie gecreëerd: de Water and Power Development Authority (WAPDA). Betoogd wordt, dat als gevolg van deze ontwikkelingen de irrigatie departementen hun capaciteit voor dynamisch onderhoud en periodieke bijstelling van de irrigatiesystemen verloren hebben, aangezien alle middelen en inspanningen voor irrigatieontwikkeling geconcentreerd werden in handen van WAPDA voor de consolidatie en expansie van de Indus-irrigatiesystemen. Deze periode vertegenwoordigt ook het begin van de externalisatie en internationalisatie van het ontwerp- en ontwikkelingsproces, aangezien alle werkzaamheden werden uitgevoerd door WAPDA en haar internationale consultants, terwijl de rol van de irrigatiedepartementen in vorm en inhoud gereduceerd wordt tot dat van operationele- en onderhoudsinstantie.

In **hoofdstukken vier en vijf** wordt de modernisatie van het Lower Swat kanaal systeem door Mardan-SCARP behandeld. In hoofdstuk vier wordt het ontwerp- en implementatieproces geanalyseerd als een proces van conceptualisaties. In hoofdstuk vijf volgt een analyse van de impact van de modernisatie, met een studie naar hoe het irrigatiedepartement en de watergebruikers hun praktijk van waterbeheer hebben veranderd als gevolg van het project. Mardan-SCARP vertegenwoordigt een eerste poging om in de context van Pakistan een 'productief' irrigatiesysteem te realiseren, waarin aan de gewas-waterbehoeften voldaan zou kunnen worden door de waterverdeling te variëren en op de behoeften af te stemmen. Tevens zou dit een van de eerste systemen zijn waarin irrigatie volledig geïntegreerd zou worden met drainage, om de gevolgen van hoge grondwaterspiegel en verzilting tegen te gaan. WAPDA en haar internationale consultants besloten tot een ontwerp van een op vraag gebaseerde irrigatie, waarbij de watervoorziening door elke aftapsluis met een hoge frequentie gevarieerd en gereguleerd zou moeten worden in antwoord op de variërende vragen van gebruikers. Dit wijkt compleet af van de ervaringen van zowel watergebruikers als irrigatiedepartement. Gedurende de implementatiefase brak er echter een conflict uit tussen het Mardan-SCARP project en het irrigatiedepartement, betreffende de wenselijkheid en de geschiktheid van het geselecteerde type aftapsluis. Onder het mom van een technische discussie volgde een conflict omtrent de appreciatie en conceptualisatie van waterplannings- en verdelings-principes die gehanteerd zouden moeten worden. Het vraagstuk of de watervoorziening gereguleerd zou moeten worden in antwoord op vragen van gebruikers, dan wel op basis van overeenkomsten tussen gebruikers en irrigatiedepartement onder controle van de laatste, alsook de principes en frequentie waarmee de variaties in watervoorziening geïmplementeerd zouden moeten worden gezien de personele capaciteit van het departement, lagen in wezen ten grondslag aan dit conflict. Doordat er geen oplossing voor dit conflict van concepties gevonden werd, was het uiteindelijk aan het irrigatiedepartement om tot een werkbare oplossing te komen met de watergebruikers omtrent hoe het systeem nu te beheren. De resultaten van deze eerste poging tot modernisatie zijn vrij verwonderlijk gegeven de Pakistaanse context, aangezien het resulteerde in een transformatie van het ooit waterschaarse en protectieve Lower-Swat-kanaalsysteem, in een systeem waar nu water in grote overvloed is, en water voornamelijk beheerd wordt door middel van drainage.

Hoofdstuk zes behandelt de casus van het Crop-Based Irrigation Operations project (CBIO) in de Chasma Right Bank kanaal-systeem. Dit project wordt hier kort behandeld op basis van secundaire data, omdat het de tweede poging vertegenwoordigt die ondernomen is om een vorm van gereguleerde variatie in watervoorziening, afgestemd op de gewas-waterbehoeften, te introduceren. De doelstellingen voor het CBIO project waren specifiek geformuleerd om de verwarring omtrent de concepten van productieve irrigatie die Mardan-SCARP parten had gespeeld op te klaren. Daarom was duidelijk als doel gesteld dat men tot een waterverdeling op basis van overeenkomst wilde komen (in tegenstelling tot op basis van vraag), waarbij het irrigatiedepartement een duidelijke controle over de waterverdeling zou behouden. Het project werd echter gauw beperkt, doordat de hydraulische configuratie van het kanaalsysteem niet echt geschikt was voor de regulatie van variërende watervoorziening. Daarbij waren het irrigatiedepartement noch WAPDA wezenlijk bereid om een variërende watervoorziening te implementeren, die regelrecht ingaat tegen de beheersregels ter voorkoming van sedimentatie van kanalen waarmee beide instantie zijn opgegroeid. Uiteindelijk resulteerde het project meer in een studie naar de mogelijkheden ter introductie van enige vorm van productieve irrigatie, (dan dat men tot een akkoord kwam met de instanties en watergebruikers over wat een wenselijk en werkbaar concept van productieve irrigatie zou zijn dat uitgevoerd zou kunnen worden.

Zowel Mardan-SCARP als CBIO zijn in hun succes gehinderd door een voorkeur voor technische en ingenieursconcepten van 'moderne' irrigatie, die voornamelijk gefocust zijn op het management van technische doelstellingen in hun controlemechanismen. In beide gevallen waren de voor het beheer verantwoordelijke instanties niet bereid om deze concepten van technisch beheer van doelstellingen te accepteren als zijnde wenselijk en verwezenlijkbaar, terwijl weinig aandacht is geschonken aan enig proces van 'change management', om veranderingen in de praktijk van waterbeheer te institutionaliseren.

Met de verbouwing van het Uper-Swat-kanaalsysteem door Swabi-SCARP, behandeld in **hoofdstuk zeven,** die volgde op de voltooiing van Mardan-SCARP, leek het irrigatiemoderniserings-programma in NWFP een rustiger fase in te gaan. Na het conflict in Mardan-SCARP, leek men in Swabi-SCARP de gemoederen wat tot rust te willen brengen door voor minder veranderingen in technologie en waterbeheersprincipes te kiezen. Vanaf het begin concentreerde Swabi-SCARP zich op het vergroten van de draagcapaciteit van de kanalen, en het creëren van de mogelijkheid om in de nabije toekomst over te gaan op een 'moderne' vorm van waterbeheer en watervoorziening. Voorlopig zou dezelfde traditionele methode van 'zelfregulerende' proportionaliteit, welke door de Britten ontwikkeld was, gehandhaafd worden, zij het met innovaties in de constructie van kunstwerken. Als zodanig, had Swabi-SCARP dus meer weg van een rehabilitatie project, dan van een moderniseringsproject, daar het zich voornamelijk concentreerde op de technische reïnterpretatie van het traditionele concept van proportionele verdeling, in de veronderstelling dat de beheersprocedures in beginsel gelijk konden blijven aan die welke in de laatste zeventig jaar gebruikt waren.

Het ontwerpproces in Swabi-SCARP was al voltooid aan het begin van dit onderzoek, terwijl de constructie werd uitgevoerd gedurende het onderzoek. Dit bood de mogelijkheid om het concept van het opgewaardeerde proportionele distributie systeem, en haar implementatie in het veld te bestuderen. De centrale aandacht in de analyse gepresenteerd in hoofdstuk zeven gaat uit naar de kritische punten die inherent zijn aan het concept van proportionele verdeling. Het gaat hierbij om het vaststellen van de hydraulische capaciteit benodigd om het water proportioneel te verdelen in de reeks van seizoengebonden variaties in de watervoorziening, en om het bepalen van de operationele- en onderhoudscapaciteit die nodig is om deze condities te controleren en te onderhouden. Dit laatste wordt bestudeerd tegen de achtergrond van de algehele achteruitgang van de proportionele waterverdelingscapaciteit in de traditionele systemen zoals die heeft plaatsgevonden in de laatste vijftig jaar, en van de dynamiek in het waterbeheer die geleid hebben tot, en het gevolg zijn van dit proces. Tevens zijn twee studies ondernomen vlak na voltooiing van de constructie, waarin geverifieerd wordt of de ontwerpaannames betreffende de hydraulische capaciteit voor proportionele verdeling ook daadwerkelijk gerealiseerd werden in het veld. Studies, die beide tot zorgelijke conclusies leiden.

Met the laatste casus van de Pehur High Level Canal (PHLC) project nam de poging tot modernisatie van irrigatie in NWFP een nieuwe vlucht. Door gebruik te maken van de voordelen die het hebben van het Tarbela reservoir als bron van watervoorziening(in tegenstelling tot het gebruik van aftappunten van rivierwater in de andere drie cases) met zich mee brengt, werd het PHLC systeem ontworpen als een volledig geautomatiseerd systeem, op basis van benedenstroomse waterfluctuaties. Dit biedt de mogelijkheid tot het realiseren van een optimaal en flexibel watervoorzieningssysteem dat geschikt is voor waterdistributie op grond van overeenkomsten of op grond van vraag naar behoefte. De keuze voor een geautomatiseerd systeem is genomen als zijnde de beste oplossing om de risico's te beperken die inherent zijn aan het reguleren van de waterfluctuaties op het punt waar het PHLC kanaal samen komt met een groot distributiekanaal van het Upper Swat systeem .Als een laatste fase in de modernisering van irrigatie in NWFP, valt het PHLC project op als een laatste poging om tot een concept van 'moderne' irrigatie te komen.Men heeft daarbij getracht om een gecontroleerde variatie in watervoorziening die aansluit bij de variatie in gewas-water behoeften, tot stand te brengen door technologische 'sluiting'van het irrigatiesysteem. De casus van PHLC wordt eveneens in hoofdstuk zeven behandeld, samen met Swabi-SCARP, aangezien beide systemen met elkaar verbonden zijn en in de toekomst een geïntegreerd systeem zullen vormen .Daar de constructie van PHLC pas begonnen is na voltooiing van dit onderzoek, beperkt de behandeling van deze case zich tot de ontwerpkeuzes die gemaakt zijn.

Hoofdstuk acht behandelt, als een epiloog op het modernisatie programma in NWFP, het programma van institutionele hervormingen voor de watersector van Pakistan. Dit is geïnitieerd in 1994 en uiteindelijk van start gegaan in 1999/2000. Dit laatste lijkt een belangrijke verandering in de politiek en de wijze van benadering van de problemen van het waterbeheer in Pakistan en lijkt ook een welkome verandering te zijn ten aanzien van de technologische interventies die in dit proefschrift behandeld worden. Een analyse van de uitgangspunten die dit hervormingsprogramma tot nu toe bevat voor de "gewenste"toekomst voor IBIS noopt tot een beperking van het optimisme ten aanzien van wat dit plan vermag om de waterbeheerssituatie in de nabije toekomst te verbeteren.

Tenslotte, in **hoofdstuk negen** worden enkele conclusies getrokken ten aanzien van het ontwerpen van fysieke systemen in het brede hybride systeem van waterbeheer in de irrigatie. Om een proces van verandering en innovatie tot stand te brengen is het nodig om greep te krijgen op de uitgangspunten van het management in de irrigatie als sociaaltechnische processen die in interactie staan met het technologische systeem in de gezamenlijke vaststelling van de eigenschappen van het systeem. Het systematische raamwerk dat gebruikt werd in dit proefschrift kan van nut zijn bij het analyseren van deze interrelaties, en kan dienen als middel om de uitgangspunten van het systeem expliciet te maken zodat een proces van aanpassing kan worden geïnitieerd als onderdeel van het
beheer van veranderingsprocessen. Er bestaat echter nog een duidelijke behoefte aan een *management* raamwerk in de watersector. Daarvoor is echter nodig een meer gezamenlijke actie en een collectief initiatief. Hetgeen buiten het kader en de mogelijkheden van dit proefschrift valt.

SUMMARY

"In the Nile Valley, in the basin of the Tigris and Euphrates, and in various parts of the sub-continent of India the spread and maintenance of civilisation were very early bound up with the practice of irrigation. When at length the pattern of history introduced British engineers to these parts of the world, they found the principle of controlled inundation established from time immemorial. It was their task to turn the application of that principle from an art into a science, to bring the power of the machine age to bear upon the problems of agriculture, and to defend ever-growing populations against the risks of drought and flood." (Newhouse, Ionides and Lacey; 1950: preface to the booklet "Irrigation")

The unmistakable pride and optimism on the 'engineerability' (i.e.' makability') of irrigation and its beneficial role for society at large in the above quote should be forgiven, considering its origin and place in time. Pakistan and India had just achieved their independence, with the British and their engineers leaving behind a vast network of irrigation systems, commanding a staggering 14 million ha. Of which the conversion of the 8 million ha desert-like 'crown waste land' of the Indus basin into the granary of the Raj in a mere 70 years, had formed the apotheosis of irrigation engineering and its scientific development. A remarkable achievement that readily induced feelings of satisfaction, as expressed in the words of Sir Douglas Harris: "*There are millions of acres from which the threat of famine has been permanently averted, and millions more which are bearing crops where previously not even a blade of grass would grow, on which* [the British engineer] *can look back and reflect with pride, even if he is too self-effacing to say: 'Si monumentum requiris, circumspice'*."(Harris in: op.cit.:vi foreword)

Since 1950, however, the population in Pakistan, and hence the Indus-basin, has more than doubled, bringing Harris' permanency of famine aversion under threat for the future still to come. The limits of expansion have nearly been reached in today's 14 million ha of irrigated command area in Pakistan's part of the Indus-basin. Simultaneously, its sustainability is threatened by waterlogging and salinity, while the demands on the limited and finite sources of water and requirements for (food) production continue to rise.

This thesis deals with the attempts undertaken in the North West Frontier Province (NWFP) since 1980 to establish 'modern' irrigation systems that could handle the future requirements put upon irrigation by the nation: Realising both higher efficiencies of water use, as well as higher agricultural production, as compared to the traditional 'protective' irrigation systems established by the British. The primary objectives in these attempts have been to transform the irrigation systems, as well as the water management practices of the Irrigation Department and water users, to establish an irrigation water delivery service in which the varying crop water requirements could be met by varying water supplies. Thus, the irrigation systems were to be brought in line with the scientific developments and insights in the field of irrigation that had taken place during the 1970s, where ever higher levels of efficiency and efficacy had been pursued with the green revolution and the matching of water supplies with crop water requirements.

The conditions governing irrigation development today, however, are markedly different from those that governed colonial time. The modernisation of irrigation is no longer a 'mere' scientific enterprise that can 'simply' seek optimisations in efficiencies and efficacy of water use by developing the newest technological application packages. The practices of water management today and tomorrow are governed by established water rights, ingrained practices, and political

and institutional interests. In short, the development of irrigation has become as much an issue of (water) management, as that it is a matter of technological development and application. With it, the time that irrigation engineers could look back with pride and satisfaction seems long gone as management problems – such as unequal water distribution, poor maintenance and ingrained practices – persistently seem to crop up and prevent the realisation of the planned for optima of the scientific concepts of 'modern' irrigation.

The four modernisation projects reviewed in this thesis (i.e. Mardan- & Swabi-SCARP, the Crop-Based Irrigation Operations project in Chasma Right Bank canal and the Pehur High Level canal) represent a series of attempts undertaken during the 1980s-90s to establish a concept of 'modern' irrigation. The cases represent a series of "trial & re-trials" to come to an appropriate and workable concept of 'modern' and 'productive' irrigation with which the water management practices of the Irrigation Department and water users can be effectively transformed to better match irrigation water delivery with crop water requirements. The focus of this study is on how management can be taken up as an integral part of the conceptualisation, design and development of irrigation. The four cases in this study were used to investigate how management issues, in particular those of operational management, were taken up and dealt with in these projects by the engineers, agencies and donors, and how well these management ideas conformed to the water management objectives, strategies and capacities of the eventual users (the Irrigation Department and farmers).

The theoretical framework for analysis, presented in **chapter one**, is based on the systems theory of Bertalanffy and that of Soft-Systems of Checkland *et al*. The systems framework was adopted to establish a framework for analysis in which (water) management is regarded as an integral part of irrigation, as well as of its design and development. Irrigation *systems* are presented as extreme open and hybrid *systems*, in which the control mechanisms – such as water allocation, scheduling and distribution – for the establishment and maintenance of the equifinal state and emergent properties of the system, are regarded as hybrid sociotechnical sub-systems. The elements and processes of which are governed as much by the technical and technological characteristics of the irrigation network, as by the purposes and strategies pursued and deployed by the social agents involved in water management. The latter element primarily depends on the views that people have on what the system should look like and should be able to do; in other words, on the concept they have of the irrigation system. The conscious and congruent development of irrigation is then primarily regarded as a process of concept mediation in an attempt to reach consent on the system's characteristics and the control mechanisms for its operation and maintenance. It is argued that the field of irrigation design and development is still primarily governed by scientific and engineering (i.e. technological) conceptions of the irrigation system and its control mechanisms, thereby hampering a congruent and integrated approach to management issues and the transformation of water management practices. The framework is used to analyse the different conceptions on 'modern' irrigation held by designers, operation agencies, water users and others, in the cases studied, and how the failure to integrate the technical concepts with the managerial ones leads to the establishment of control mechanisms and water management practices that substantially diverge from the ones initially planned for.

Chapter two presents a historical analysis of the development of the concept of 'protective' irrigation by the British, in the Indus-basin. This historical analysis is made to gain an understanding of the background and dynamics that have shaped the experiences and strategies of water management of the operation agencies and water users for nearly a hundred years. The chapter argues that the development and maintenance of the protective irrigation systems were governed by a dynamic adjustment of the water allocation and distribution mechanisms, to periodically strike new balances between water availability and growth and intensification of the irrigated command area. Though these developments were unmistakably driven by new developments in hydraulic science and irrigation technology, it is shown that the water allocation and distribution arrangements were as much governed by administrative and political concerns, as by technical ones. Contrary to widespread believe, it is argued that the British never managed to implement a strictly proportional and equitable water allocation and distribution system, not even after the technical concept of 'self-acting' proportionality developed by Crump in 1922 became the new paradigm of irrigation development. The administrative and political needs to apply favourable water allocations were accommodated by retaining the discretional powers of the canal officers granted by the Canal & Drainage Act of 1873. The latter, as a consequence, was never amended to reflect the new water control capacities gained by the advances in hydraulic science – not even in the form it is retained in present day Pakistan.

Chapter three provides an overview of the developments that have taken place in the Indus Basin Irrigation System after Pakistan gained independence in 1947 and prior to the commencement of the modernisation programme in NWFP. This period is characterised by important institutional changes in the water sector and developments for the consolidation and expansion of the IBIS. During this period the developments in irrigation were primarily fed by the need to offset the effects of partition, in which the flow of the three eastern tributaries to the Indus were allocated to India. To compensate this loss, an elaborate development programme consisting of several barrages, link-canals and dams/reservoirs was initiated under auspices and aid of multilateral donors. To supervise and implement these major works, a new federal agency was created in the form of the Water and Power Development Authority. It is argued that with these developments, the Irrigation Departments lost their capacity for dynamic maintenance and periodic re-adjustments of the canal systems, as the development means and efforts were concentrated on the consolidation and expansion of the IBIS by the newly created WAPDA. This period also represents the initiation of the externalisation and internationalisation of the design and development processes, as all major works were conducted by WAPDA and their international consultants, while the Irrigation Departments were effectively reduced to operation & maintenance agencies.

In **chapters four and five**, the case of modernising the Lower Swat Canal system by Mardan-SCARP is presented. The design and implementation is analysed as a process of conceptualisation in chapter four. In chapter five the impact of the project is analysed by looking at how the irrigation department and water users have changed their water management practices after commissioning of the project. Mardan-SCARP represents a first attempt in the context of Pakistan to realise a 'productive' irrigation system, in which the crop water requirements could be met by varying water deliveries, and in which irrigation would be integrated with drainage to combat the double menace of waterlogging and salinity. WAPDA and its foreign consultants settled for a design and concept of demand-based irrigation in which the water delivery through each outlet structure would have to be varied and controlled on a frequent basis in response to varying demands or request from water users. This represented a complete departure from the experiences of both water users and operation agency. During the construction phase, however, a conflict ensued between the Mardan-SCARP project and the Irrigation Department around the desirability and feasibility of the selected metergate-outlets. Under the pretext of a technical discussion a conflict ensued on the appreciation of the scheduling and distribution principles to be established. The issue of whether the water delivery should be varied in response to demands or on the basis of arrangements controlled by the ID, and the principles and frequency with which the variations should be implemented in light of the institutional and staffing capacity of the ID, were essentially the sources of the conflict. In failing to settle this ensuing conflict of conceptions, the ID was essentially left to find an accommodation with the water users on how to operate the newly remodelled system and manage the water delivery after its commissioning. The initial result of this modernisation attempt was quite remarkable for the Pakistani context, as the LSC was transformed from an original water scarce ‘protective’ water delivery system, into a system were water became abundant, and the ID and water users were enabled to manage the water through the regulation of the water delivery and/or the integrated drainage facilities.

In **chapter six**, the case of the Crop-Based Irrigation Operations project (CBIO) in Chasma Right Bank Canal is presented. This case is shortly treated on the basis of secondary data, as it represents a second attempt to introduce some form of controlled variation of water supply in response to crop water requirements. The objective of the CBIO project was specifically set to clarify the conceptual confusion that had ensued in Mardan-SCARP on productive irrigation. The aim was therefore clearly set to devise a concept of ‘arranged’ water scheduling and delivery (as opposed to demand-based) in which the ID would clearly retain the control over water distribution. The project, however, was quickly bogged down by the fact that the hydraulic configuration of the canal system was not really appropriate for highly varying water control, while the ID and WAPDA were not very predisposed to implement variations in supply that went against the regime maintenance requirements (i.e. avoidance of canal siltation) with which they had been brought up. In the end, the project resulted more in a study on the feasibility of establishing some form or productive irrigation, rather than reaching consent among the line agencies and water users on a desirable and workable concept that could be implemented.

Both Mardan-SCARP and CBIO were hampered in their success by a predilection for technical and engineering concepts of ‘modern’ irrigation, that concentrate on technical target management in their control mechanisms. In both cases, the operation agencies were not disposed to accept these concepts of target management as either feasible or desirable, while little attention was paid to any processes of change management for institutionalising change in the water management practices of water users and agency personnel alike.

With the remodelling of the Upper Swat Canal (USC) through Swabi-SCARP, presented in **chapter seven**, which followed upon completion of Mardan-SCARP, the irrigation modernisation programme in NWFP was seemingly suspended, or at least conducted with less ambitions towards establishing crop responsive irrigation operations. After the confronting experience in Mardan-SCARP, Swabi-SCARP seemingly sought to calm the atmosphere with the remodelling of USC, by opting for less changes in the water distribution technology and scheduling and distribution mechanisms for the time being. From an early stage Swabi-SCARP concentrated on revamping the traditional irrigation system of USC, by upgrading the conveyance capacity of the system in order to appease the increasing water scarcity it had faced over the last decades and enable a future modernisation of the water delivery service into, what was termed, a ‘modified-demand’ service. As to the water distribution and delivery principles, the proportional distribution as conceived by the British in the 1920s-30s was to be retained for the time being, be it with innovations in construction materials and water control structures. As such the Swabi-SCARP conducted its remodelling efforts almost as a rehabilitation, in which it concentrated on the technical re-interpretation of the traditional concept of proportional distribution, assuming that the operation and management procedures could essentially remain the same as practised over the last seven decades.

The design process of Swabi-SCARP was completed at the start of, and the construction work proceeded over the research period. This provided the opportunity to review the conception of the ‘revamped’ proportional distribution system, and its implementation in the field. The analysis presented in chapter seven centres on the critical issues inherent to the proportional distribution concept: establishing the hydraulic capacity to distribute water proportionally over the range of seasonal water supply variations, and establishing the operation and maintenance capacity to control and maintain those conditions. The latter is reflected against the deterioration of the proportional distribution capacity in the traditional system that has taken place over the last five decades, and the dynamics in water management practices that has lead to, and resulted from, this process. Further two case studies are presented on the implementation that were conducted shortly after construction, and that enabled to verify whether the design assumptions on the hydraulic capacity for proportional distribution were attained in reality. Both studies yielded worrying results.

In the last case of Pehur High Level Canal (PHLC) the modernisation attempts for irrigation in NWFP got reinvigorated as quite a turnabout was made in the conceiving of a concept of modern irrigation water delivery service. Making use of the excellent opportunities provided by having Tarbela reservoir as the water supply source (as opposed to the river intakes in the other three cases), PHLC system was designed for automated downstream water control, with which an optimal flexible water delivery service can be established for both arranged, as demand, water scheduling and distribution principles. The choice for automated downstream control was justified as the best solution to handle the precariousness of controlling the water flow and variations at the confluence where the PHLC canal is to link up to the a major branch canal of the USC system, to alleviate the water shortages at the latter's tail end. As a last stage of the modernisation attempts undertaken in NWFP, the PHLC project stands out as a final attempt to conceive a modern concept of irrigation in which the controlled variation of water supply to meet the variations in crop water requirements and demands is sought to be achieved by technological closure of the water conveyance and delivery system. The PHLC case is also presented in chapter seven, together with Swabi-SCARP, as both projects are interlinked and will constitute an integrated system in the future. As the construction of PHLC only started after completion of the research, the treatment of the case is limited to the design decisions made.

Chapter eight deals, as an epilogue to the modernisation programme, with the institutional reform programme for the irrigation sector in Pakistan, that was initiated in 1994 and finally got underway in 1999/2000. Seemingly this would represent an important shift in the policy and intervention approaches to tackle the problems of water management in Pakistan, that would come as a welcome change to the technological interventions reviewed in this thesis. An analysis of the conceptions this reform programme contains thus far on the 'desirable' future for the IBIS, however, calls for a restraint of optimism towards its capacity to ameliorate the water management situation in the near future.

Finally, general conclusions are drawn in **chapter nine** on the function of engineering and designed physical systems in the wider hybrid system of irrigation water management. To effectuate a process of change and innovation, there is still a need to come to grips with the issues of management in irrigation, as socialtechnical processes that interact with the technological system in the establishment of the equifinal properties of the system. The systems framework adopted in this thesis can be useful to analyse these interrelations, and as a means to make the appreciations and conceptions of the system explicit, so that a process of accommodation can be initiated as part of the process of change management. There is, however, still a clear need for an appropriation of a *management* framework in the water sector, for which a more concerted and collective initiative will have to take place than this thesis could provided for.