Agro-Ecology and Irrigation Technology

Comparative Research on Farmer-Managed Irrigation Systems in the Mid-Hills of Nepal

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Cover photo: An indigenous proportioning weir, locally named as *baraha mukhe dhara* meaning weir with twelve notches, in the Sankhar Irrigation System.

Cover sketch: The schematic layout of the Sankhar Irrigation System with proportioning weirs and their water shares.

CONTENTS

Preface and acknowledgements vi
List of tables viii
List of figures viii
List of photos x
List of appendices x
Glossary of local terms used in this thesis x
List of units of measurement used in this thesis xi
List of acronyms used in this thesis xii

1 Introduction 1

1.1 Problem definition 1
1.2 Focus of the research 3
1.3 Theoretical approach 4
1.3.1 Ecology and irrigation 4
1.3.2 Conceptualizing technology 5
1.3.3 Agro-ecology and technology 6
1.3.4 Design-management interaction 8
1.3.5 Technology, management functions and objectives, and management domains 9
Operational (management) objectives-10; *Management domains*-11
1.3.6 Summary of theoretical approach 12
1.4 Research questions 13
1.5 Methodology 14
1.5.1 Site selection criteria 14
1.5.2 Organization of research 16
1.5.3 Intensive data collection 16
Land surveying and water measurements-17; *Structured and non-structured interviews*-18; *Observation*-18; *Problems and limitations of irrigation system research in Nepal*-18
1.6 Outline of the thesis 19

2 The Agro-Ecological Differentiation of Irrigation Systems in the Mid-hills of Nepal 21

2.1 An overview of the country 21
2.1.1 Physiography 21
Terai-22; *Siwaliks*-23; *Hills*-23; *High Himalayas*-24
2.1.2 Climate 24
2.1.3 Farming systems and principal crops 25
2.2 An overview of irrigation development in Nepal and present government policy 26

2.3 Irrigation systems and their classifications 28
2.3.1 Classification of irrigated land and respective irrigation systems 29
Foothill terraces (khola khet) and foothill irrigation systems-29; *Slope-hill terraces (Tar) and slope-hill irrigation systems*-32; *River-valley terraces and river-valley irrigation systems*-34
2.4 Water allocation and distribution 37
2.4.1 Principles of water allocation 37
2.4.2 Water distribution 37
2.4.3 Water division structures 38
Open-close-38; *Ad hoc adjustment*-38; *Fixed proportion*-40
2.5 Summary 40

3 Design Considerations of Proportioning Weirs 43

3.1 The indigenous proportioning weir 43
3.2 Hydraulic characteristics of a proportioning weir 44
3.2.1 Hydraulic flexibility 44
3.2.2 Basic hydraulics of the weir 45
Coefficient of velocity-46; *Coefficient of discharge*-46
3.2.3 Flow constriction 46
3.3 Sankhar Irrigation System 47
3.4 Flow measurements and constraints 49
3.4.1 Flow measurements 49
3.4.2 Difficulties in flow measurements in the field 50
3.4.3 Accuracy of the flow measurement in the field 51
3.5 Farmers' considerations of hydraulics in the design of proportioning weirs 52
3.5.1 Length of the approach canal and the width and the height of the weir 55
Length of an approach canal-56; *Weir height above the canal bed*-56
3.5.2 Operational consequences of raising the weir 57
3.6 Flow constriction 57
3.7 Design of notch width 63
3.7.1 Hydraulic considerations 63
3.7.2 Operational/topographical considerations 63
3.7.3 Notch width per unit of water share (unit notch width) 65
3.8 Summary and conclusions 66

4 Julphe Irrigation System 69

4.1 Agro-ecological and social settings 69
4.1.1 Landscape 70
4.1.2 Land use 71
4.1.3 Farming system 71
4.1.4 Landholding and land tenure 73
4.1.5 The village and its residents 74
4.2 Historical development 75
4.2.1 Development of the physical system 75
Modification in the distribution system-78
4.3 The physical system 79
4.3.1 Water source 79

Propositions

1. The more the island of knowledge expands in the area of ignorance, the larger its boundary to the unknown.

   L.S.Rodberg and V.F. Weisskopf sited by Firey (1960)

2. It is not possible for any human being to take a step forward without putting one foot firmly on the ground. Similarly, a society which tries to move ahead without keeping itself firmly rooted in its own tradition, tends to fall.

   Mahadevi Verma, cited by Agrawal, A. and Narain, S. (1997)

3. The naturalness of natural rights to access and use of water as a resource rests on a belief that, all people, because they are people, whatever be their moral, legal, social or civil status, have a natural right to water since water as a resource is another way of describing the right to life.

   Upendra Baxi, cited by Khadka, S.S. (1996)

4. Great things are done when men and mountains meet; this is not done by jostling in the street.

   Gnomic Verses, William Blake (1757-1827).

5. So in natural science, it is the composite thing, the thing as a whole which primarily concerns us, not just the materials of it, which are not found apart from the thing itself.

   Aristotle, cited by Altieri *et al.* (1987)

6. Farmer managed irrigation systems follow the principle of proportional distribution of opportunities, benefits and risks.

   This thesis

7. Farmer managed irrigation systems are socio-technical systems adapted to local environment. Their infrastructure do not entirely follow the standard engineering design. Besides technical considerations, the infrastructure are shaped by a number of other social, managerial and environmental factors.

   This thesis

8. Irrigation is a man-made ecological system, in which water is transferred into a location with the help of a certain technology to increase agricultural production.

   This thesis

9. Farmers are knowledgeable by experience. Their design of hydraulic structures conforms to the modern theory of hydraulic science.

   This thesis

10. An integration of indigenous and modern technology is essential in the development of irrigated agriculture to minimize the environmental degradation and unsustainable mining of natural resources.

11. Smiling faces and a cooperative attitude are the common quality of hill farmers in Nepal. They believe in the philosophy of '*atithi debo bhaba*', meaning 'guests are god'.

4.3.2 Intake ... 80
4.3.3 Main canal ... 82
4.3.4 Distribution canals ... 83
4.4 Water distribution structures ... 85
4.4.1 The proportioning weir ... 85
Weir height above the canal bed-86; *Design of notch width*-87; *Accuracy in flow division*-88
4.5 System operation ... 90
4.5.1 Organizational and institutional arrangements ... 90
Irrigation organization-90
4.5.2 System maintenance ... 93
Basis of resource mobilization-95
4.5.3 Water acquisition ... 96
4.5.4 Water allocation ... 98
Water trading-98
4.5.5 Water distribution ... 99
Water distribution for paddy transplantation at the upper end-101; *Water distribution for paddy transplantation at the lower end*-102; *Water distribution after the completion of paddy transplantation*-103; *Night irrigation and access to female-headed households*-105; *Water distribution through proportioning weirs*-105; *Operational principles across fully and partially proportionate areas*-110
4.6 Conclusions ... 112

5 Bachcha Irrigation System ... 115

5.1 Agro-ecological and social settings ... 115
5.1.1 Landscape ... 117
5.1.2 Land use ... 118
5.1.3 Farming system ... 118
5.1.4 Landholding and land tenure ... 120
5.1.5 The village and its residents ... 121
5.2 Historical development ... 122
5.2.1 Irrigation system ... 122
5.2.2 Irrigation organization ... 123
5.2.3 Agriculture ... 124
5.3 The physical system ... 125
5.3.1 Water source ... 125
5.3.2 Intakes ... 125
5.3.3 Main canal ... 126
5.3.4 Distribution canals ... 129
5.4 Water distribution structures ... 129
5.4.1 The proportioning weir ... 129
Location-130; *Design and construction of proportioning weir*-131; *Proportioning weirs in the secondary canal*-134; *Notch width of proportioning weir*-134
5.4.2 Fixed orifice in the main canal ... 134
5.4.3 Ungated turnouts in khola khet ... 135

5.5 System operation 136
5.5.1 Organizational and institutional arrangements 136
5.5.2 Water acquisition 137
5.5.3 Water allocation 139
5.5.4 Water distribution 140
Water distribution by proportioning weirs-142; *Timed rotation within sub-block*-145; *Water distribution during winter and spring crops*-147
5.6 Conclusions 148

6 Sankhar Irrigation System 151

6.1 Agro-ecological and social settings 151
6.1.1 Landscape 153
6.1.2 Land use 153
6.1.3 Farming system 153
6.1.4 Landholding and land tenure 155
6.1.5 The village and its residents 155
6.2 Historical development 155
6.3 The physical system 157
6.3.1 Water source 157
6.3.2 Intake 158
6.3.3 Main canal 159
6.3.4 Distribution canals 160
6.4 Water distribution structures 160
6.4.1 The proportioning weir 160
6.5 System operation 161
6.5.1 Organizational and institutional arrangements 161
6.5.2 System maintenance 162
6.5.3 Water acquisition 163
6.5.4 Water allocation 165
6.5.5 Water distribution 165
Water distribution during the monsoon season-165; *Water distribution through proportioning weirs*-167; *Water distribution during the winter season*-170; *Water distribution during the spring season*-170; *Continuous versus rotational irrigation for cultivating paddy*-174; *Yield response to seepage and percolation losses*-176
6.6 Conclusions 177

7 Patne Irrigation System 181

7.1 Agro-ecological and social settings 181
7.2 The physical system 183
7.3 System operation 185
7.3.1 Organizational and institutional arrangements 185
7.3.2 Water allocation and distribution 186
Ad hoc adjustment of flow through turnouts-188; *Measure of equity*-189
7.4 Conclusions 190

8 Summary and Conclusions ... 191

8.1 Irrigation systems, water division structures and hydraulic control ... 192
8.1.1 Irrigation systems ... 192
8.1.2 Water division structures ... 192
Indigenous proportioning weirs and hydraulic control-192
8.2 Conditions determining the acceptability of water division structures, especially the indigenous proportioning weir ... 193
8.2.1 Socio-cultural conditions ... 194
Knowledge and practice-194; *Labour resources and water rights*-194; *Power*-195; *Operational requirements*-195; *Agricultural livelihood strategies*-196
8.2.2 Agro-ecological conditions ... 196
Physiographic location of irrigation system-196; *Altitude*-197; *Topography*-197; *Shape of the irrigated area*-198; *Availability of water*-198; *Crop*-200; *Size of an irrigated area*-200
8.3 Operational consequences of different types of water division structures ... 201
8.3.1 Organizational and institutional support ... 201
Ad hoc adjustment-201; *Open-close*-201; *Fixed proportional*-202
8.3.2 Transparency of equity ... 202
Ad hoc adjustment-202; *Open-close*-202; *Fixed proportional*-202
8.3.3 Chances of mismanagement and water related disputes ... 203
Ad hoc adjustment-203; *Open-close*-203; *Fixed proportional*-203
8.3.4 Devolution of water management tasks to users ... 203
Ad hoc adjustment-203; *Open-close*-204; *Fixed proportional*-204
8.3.5 Operating cost ... 204
Ad hoc adjustment-204; *Open-close*-204; *Fixed proportional*-204
8.3.6 Trading of water ... 204
Ad hoc adjustment-204; *Open-close*-205; *Fixed proportional*-205
8.3.7 Flexibility ... 205
Ad hoc adjustment-205; *Open-close*-205; *Fixed proportional*-205
8.4 Conclusions ... 206
References ... 209
Dutch summary (Nederlandse samenvatting) ... 219
Appendices I – XI ... 225
Curriculum vitae ... 254

Preface and acknowledgements

Farmers in many parts of the world have developed indigenous irrigation systems over the ages in accord with their social and physical environment. Many of these systems are still operating. Until recently, the technologies and management practices of the indigenous irrigation systems were largely ignored. It was the usual practice of development planners to introduce technology developed elsewhere without thought for their relevance for the management of indigenous irrigation systems. In the present context of irrigation development, in which the local community is considered as the major actor, recognition of indigenous technologies has become essential. Thus, realising the importance of indigenous technologies and management practices for further developing them, this thesis aims to document the little known irrigation technologies and management practices in the hills of Nepal to generate new scientific knowledge in this area.

The study of indigenous technology and management practices involves intensive fieldwork, and would not be possible without the help and support of people of that area. I am grateful to farmers of Julphe, Bachcha, Sankhar and Patne Irrigation Systems for contributing their valuable time, warm hospitality and allowing me insights into their irrigation systems.

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List of tables

1.1 Salient features of irrigation systems selected for the detailed study 15
1.2 Types of data collected in each system 17

2.1 Total land area and the land use pattern in the physiographic regions of Nepal 22
2.2 Relationship between elevation and climatic zones in Nepal 24
2.3 Present situation of irrigation development in the country 28

3.1 The widths, water shares and crest levels of the notches in Dui Dhare 48
3.2 The area of flow, average approach velocity and the measured flow at different sections of the approach canal 55
3.3 Flow fluctuation through the notches of the main proportioning weir 58-59

4.1 Area covered, cropping calendar and average yield of main cereal crops 72
4.2 Mean monthly flows of the Girwari River 80
4.3 Density of offtakes in various parts of the irrigation system 85
4.4 Main differences in irrigation management among sub-systems 90
4.5 Principal features of *ghante palo* in various sections of the irrigation system 103
4.6 Flow per *kattha* of water share at various points in the system 107

5.1 Areas covered, cropping calendar and yields of main cereal crops 119
5.2 Principal features of proportioning weirs in the main canal 130
5.3 Number of farmers, their water shares and irrigated area in sections of various sub-blocks in Saat Bise Ko Kulo 146

6.1 Area covered, cropping calendar, fertilizer used and average yields of main cereal crops 154
6.2 Chronological development of agriculture in the area 156
6.3 Flow per *mato muri* of water share at various points in the system 169
6.4 Pre-designed allocated time and actual water use time by farmers in the Naubise Khanda during last rotational schedule of *lamo palo* 172
6.5 Water shares used, area and the average yields of paddy in four plots 177

7.1 Principal physical features of the turnouts (*muhan*) 184

8.1 Socio-cultural and agro-ecological conditions determining the choice of water division structures 194
8.2 Agro-ecological conditions for the suitability of fully/partially proportionate system... 196
8.3 Operational consequences of different types of water division structures 205

List of figures

1.1 Conceptual framework of the study 13
1.2 Location of irrigation systems selected for the detailed study 15

2.1 Physiographic regions of Nepal 22
2.2 Location of *khola khet* and *tar* in the hills 30
2.3 Plan and section of a temporary brushwood weir 35

3.1 Proportioning weir 44

3.2 Water division layout 45
3.3 Flow through weir 45
3.4 Flow constriction through notches 47
3.5 Layout plan and section of Dui Dhare 49
3.6 Velocity distribution in cm per sec 54
3.7 Flow fluctuations through notches and incoming canal 60-61

4.1 Monthly variations in rainfall, temperature and evaporation 69
4.2 Landscape map of the system area 70
4.3 Chronology of the development of the physical system 77
4.4 Layout of the intake 81
4.5 Layout of the distribution canals 84
4.6 Longitudinal section of the Julphe Kulo 87
4.7 Typical plan and profile of a proportioning weir 88
4.8 Structure of the water user organization 91
4.9 Flow variation in the main canal and the labour mobilized to maintain the diversion weir in the river 97
4.10 Schematic layout of system with proportioning weirs and their water shares 106
4.11 Time discharge curves upstream of selected proportioning weirs 108
4.12 Unit flow versus corresponding irrigated area served by terminal points of proportioning weirs 110

5.1 Monthly variations in rainfall, temperature and reference crop evapotranspiration 115
5.2 Canal layout plan of Bachcha Irrigation System 116
5.3 East-west cross-section of the irrigated area 117
5.4 Proportioning weir 130
5.5 Layout of the proportioning weirs and secondary canals 131
5.6 Section of the first proportioning weir (Mul Gaav) 132
5.7 Flow fluctuations in the main canal upstream of the first proportioning weir 138
5.8 The schematic layout of the irrigation system with proportioning weirs and their water shares 143

6.1 Monthly variations in rainfall, temperature and evapotranspiration 151
6.2 Landscape map of the system area 152
6.3 Flow fluctuations in the river superimposed with the monsoon rain 158
6.4 Layout of the intake 159
6.5 Time series flow in the main canal 164
6.6 The schematic layout of irrigation system with its proportioning weirs and their water shares 168
6.7 Time discharge curves upstream of the selected proportioning weirs 169

7.1 Layout of Patne Irrigation System 182
7.2 Typical plan and profile of a turnout 184
7.3 Propagation of flow fluctuations 187
7.4 Flow fluctuations in the main canal and through three turnouts 189

8.1 Flow per unit area Vs fully/partially proportionate systems 199

List of photos

2.1 Foothill terraces 30
2.2 Slope-hill terraces 33
2.3 Open-close water distribution structure 38
2.4 Farmers adjusting flows through ad hoc adjustment turnouts 39
2.5 Proportioning weir 40

4.1 Flow constriction in the notch of a proportioning weir 89

List of appendices

I Schedule of the field research work 225
II Systems studied under the Rapid Appraisal Survey 226
III Principal physical features of proportioning weirs (Julphe Irrigation System) 227
IV Amount of labour mobilized by the Julphe and Basantpur sub-systems for system maintenance 231
V Farmer's water shares and landholdings with respect to terminal points of proportioning weirs in Julphe Irrigation System 232
VI A copy of water right certificate issued by Basantpur irrigation committee 234
VII Water distribution in Bikase Khanda 235
VIII Principal physical features of proportioning weirs (Sankhar Irrigation System) 240
IX Written authority given by the farmers to the chairman (Sankhar Irrigation System) ... 244
X Irrigated areas and water shares of a few farmers in the Sankhar Irrigation System ... 245
XI Questionnaire for structured interview 246

Glossary of local terms used in this thesis

adhiya	The share-cropping system in which the harvest is shared equally (50/50) through the landowner and the tenant
adhyakchhya	Chairman
bandhaki	A tenure arrangement in which the tenant pays a fixed amount of money in advance to the landowner and cultivates the land as long as the landowner does not return the money; in economic term, *bandhaki* is called mortgage
bari	Unlevelled and unirrigated terrace
bhir pakho	Sub-vertical land
bigha	Unit of measurement of land, one *bigha* is equivalent to 0.66 ha
biraute	Levelled terrace converted recently from the sloped land
chaukidar	A title of a person who works as a peon as directed by his supervisor in a village or in an irrigation system
chaur	Flat or mildly sloping grass land
dhara	Proportioning weir
dhunga	Boulder or stone
doko	A basket, especially to carry goods on one's back
dui	Two
gaav	Proportioning weir
ganhu	Wheat
ghaiya	A variety of paddy which is grown in a sloped terrace (*bari*)
goth	Shed where livestock is kept
guthi	Land alienated by the state or by individuals to finance religious functions
zamindar	Landlord

jimmawal	A non-official functionary who collected taxes only on the *khet* land
katuwal	A messenger
khanda	A part of an area (section)
khar	Natural thatch grass (*cymbopogon microtheca*)
khara	Fine to be paid by a farmer, in cash, for being absent during the maintenance of an irrigation system
khet	Levelled irrigated terrace
khola	Stream
kot	A local fort
kulo	Canal
mal adda	Land revenue collection office
mato	Soil
mato muri	It has two meanings: *a* traditional measure of land and a unit to designate a water share. In this text it is used mainly to designate a water share. For a more detailed definition, see section on water allocation in Chapter 5
muhan	Turnout
mukhiya	A non-official functionary who collected taxes only on the *bari* land
mul kulo	Main canal
muri	Measure of volume, one *muri* of paddy approximately equals 50 kg
naya	New
pahad	Hills
palo	Turn
panchayat	The partyless political system under which Nepal was ruled for about three decades until it was overthrown following the popular movement of 1990
paani	Water
pathi	A measure of volume, one *pathi* of paddy approximately equals 2.3 kg
phant	A moderately sloped to flat land
ropani	A measure of land; one *ropani* is equal to 0.05 ha
saat	Seven
saathi	Sixty
sachiv	Secretary
sal	A type of hard wood (*shorea robusta*)
saamiti	Committee
sancho	Proportioning weir
saya	Hundred
sirwar	The title of a person managing the land of a *zamindar*
tallo	Lower
tar	Raised terraces, which is formed as a result of landslide and soil erosion during the mountain-building process
teen mahale moth	An official document certified by the then land revenue collection office
terso	Aligned along the contour
thado	Aligned across contour
uppallo	Upper

List of units of measurement used in this thesis

cm	centimetre(s)
cm/sec	centimetre per second
ha	hectare(s)
hr	hour(s)
kg	kilogram(s)

lps	litre per second
mi	minute(s)
mm	millimetre(s)
m	metre(s)
m^3/sec	cubic metre(s) per second
m/sec	metre(s) per second
sec	second(s)
sq.km	square kilometre(s)
sq.m	square metre(s)
t	tonne(s)

List of acronyms used in this thesis

ADB	Asian Development Bank
AMIS	Agency Managed Irrigation System
APP	Agriculture Perspective Plan
APSC	Agricultural Project Service Centre
BSI	British Standards Institution
CBS	Central Bureau of Statistics
CIWEC	Canadian International Water and Energy Consultants
DHM	Department of Hydrology and Meteorology
DIDP	Dhaulagiri Irrigation Development Project
DOI	Department of Irrigation
FAO	Food and Agriculture Organization
FMIS	Farmer Managed Irrigation System
GO	Government Organization
HMGN	His Majesty's Government of Nepal
IAAS	Institute of Agriculture and Animal Sciences
ICIMOD	International Centre for Integrated Mountain Development
IIMI	International Irrigation Management Institute
ILC	Irrigation Line of Credit
ILO	International Labour Organization
ISO	International Standards Organization
ISP	Irrigation Sector Project
ISSP	Irrigation Sector Support Project
ITECO	International Technical Co-operation and Development
LRMP	Land Resources Mapping Project
MOF	Ministry of Finance
MOWR	Ministry of Water Resource
MPE	Ministry of Population and Environment
MPID	Master Plan for Irrigation Development
NGO	Non-government Organization
NPC	National Planning Commission
SPWP	Special Public Works Programme
UNDP	United Nations Development Programme
VDC	Village Development Committee
WECS	Water and Energy Commission Secretariat

Exchange rate: One US$ equals to about Rs 60 (1996 exchange rate)

1 Introduction

1.1 Problem definition

Nepal is predominantly a mountainous country with over 85 per cent of its area covered by hills and mountains. There are wide altitudinal variations within a short horizontal distance, which makes the physiography of the country unique in the world. As a result, the country has extreme variations in physiography, bio-diversity and agro-ecology. Agriculture forms the backbone of the Nepalese economy, contributing over 40 per cent to the gross domestic production (MOF, 1998; APSC, 1995; 1997). Over 80 per cent of the population directly or indirectly derive their livelihood from agriculture (MOF, 1998), and about 80 per cent of them are classified as subsistence farmers.

Depending upon the agro-ecological conditions and social organization of an area, farmers all over the country have developed indigenous irrigation systems, referred to here as farmer managed irrigation systems (FMISs). Traditions of self-governing systems and strong community participation are important and common features throughout the management of these FMISs. Local ingenuity and skills have been applied over the ages to develop these systems.

In Nepal, over 69 per cent of the country's total irrigated area and over 89 per cent of the irrigated areas in the hills and mountains are covered by these FMISs (Table 2.3), which contribute considerably to the national economy and which have now become the main source of livelihood for the hill farmers. Like Nepal, other countries also have considerable areas which are irrigated by such FMISs in their hill and mountain areas such as: the Hindu-Kush Himalayas other than Nepal (Pakistan, India, Bhutan and China), the Philippines, Bali (Indonesia), Thailand, Switzerland, the Andes (Bolivia, Peru, Chile and Equador) and East Africa (Kenya and Tanzania). The physical components (though smaller in size in comparison with those in the plain areas) and the management practices of these systems have a unique relationship with their agro-ecological conditions and social organizations.

Despite the fact that hills and mountains are the largest storehouse of freshwater at lower altitudes, for the people living in the hills, use of this water for livelihoods has remained a major problem. Inaccessibility due to geographical constraints, topographical complexities, wide seasonal variations in water availability and increasing trends of seasonal and permanent migration are in part some of the prime causes for this underutilization.

The situation is further aggravated by an ever-increasing human population. It is estimated that the average annual growth rate of the country is about 2.5 per cent (APSC, 1995; MOA, 1997)[1]. The present population density in the hills of Nepal, 700 persons per square kilometre (sq km) of cultivated land, is one of the highest in the world (Farrington and Mathema, 1991).

[1] Considerable uncertainties exist regarding the population growth rate of the country. MPE (1998) estimates the population growth rate during 1991-1996 to be 2.37 per cent while CBS (1994a) estimates it to be 2.66 per cent.

With the increase in population and intensification of human activities in land resources, the demand for irrigation water has also increased very rapidly. While these indigenous irrigation systems coped fairly well in the past, today these systems are becoming more and more inadequate and incapable of responding to the ever-increasing needs and demands of hill farmers. With the increasing scarcity of water resources, declining soil fertility and degradation of other natural resources such as forests (Mishra, 1998; Abington and Clinch, 1992; Shrestha, 1992), living in the hills has become even more difficult. As a result, migration has been taking place from the hills to the Terai (plain areas in the southern parts of Nepal) over the past 30 years.

As in other parts of the world, technical and institutional interventions in the existing FMISs were identified as one of the means of raising the standard of living of farmers. In Nepal, for the past few decades, the government and various donor agencies have been intervening in FMISs in order to meet the basic objectives of poverty alleviation, agricultural intensification and/or diversification and employment opportunity creation.

Despite the allocation of more than a quarter of its development budget to the agriculture sector, Nepal's agricultural growth rate during the plan period 1992-1997 was only 3 per cent against the targeted growth rate of 3.7 per cent (NPC, 1997). Once a foodgrain exporting country, Nepal has turned into net importer of foodgrains since the beginning of 1980s (CIWEC, 1990). What is alarming is the fact that the country's population is increasing at a rate of 2.5 per cent while the food production is increasing only at the rate of 2.3 per cent (CBS, 1997; APSC, 1995). Though part of the causes may be geographical inaccessibility and unfavourable socio-political conditions, part of them lies in the lack of understanding of the physical components of FMISs in relation to their agro-ecological conditions and social organizations for proper intervention. NPC (1998) also notes that poor management, unsatisfactory water utilization efficiency and defective design of Nepal's irrigation systems are in part some of the causes for the dismal performance of the irrigated agriculture sector.

As a result, the basic question in the past and in the present has always remained the same, that is: How can the livelihood of the hill farmers, with an average holding of less than 0.5 hectare (ha) (LRMP, 1986) of irrigated land per household, be raised?

The physical components of an FMIS are designed to match the local conditions of water control. The rehabilitation of such FMISs occurs in a situation in which patterns of water use, water control and organizational structure already exist, indicating a living socio-technical entity. Thus, for its success, the rehabilitation should be designed in such a way that its outcome supports the past procedures of water control. Failure to do so can erode the existing management practices and the contribution of irrigation to local livelihoods. In this context, non-recognition of the customary rights to irrigation water by some external assistance programmes has already become a major issue (Benda-Beckmann *et al.*, 1997; Pradhan, 1994; Gerbrandy and Hoogendam, 1996; Hecht, 1990; Sutawan, 1989; Parajuli and Sharma, 1998). This ultimately hampers the targeted objectives and also increases the farmers' dependence on the government (Biswas, 1989; Coward and Levine, 1989).

Due to lack of understanding of the local procedures of water control, many cases of inappropriate planning in the rehabilitation of the existing systems have been reported (Horst, 1996; Sutawan, 1989; Yabes, 1990; Coward, 1990). In Nepal, in some cases external assistance has eroded local management practices and resource mobilization capability (Yoder and Upadhyay, 1987). Structures designed and constructed during the process of rehabilitation are frequently modified or even wholly removed by farmers. In an action research in the irrigation systems conducted by Water and Energy Commission Secretariat (WECS) and the International Irrigation Management Institute (IIMI) in Nepal, 30 structures out of 47 installed had to be modified during implementation at the farmers' requests (Bhattarai, 1990).

Thus, understanding of the physical components of FMISs in relation to their agro-ecological conditions and social organization is very essential to further developing the systems to meet the demands of a growing population.

1.2 Focus of the research

Worldwide, many of these FMISs operate under the basic principle of proportional distribution of cost and benefit. The famous *subak* in Bali (Horst, 1983), *sancho/dhara* in Nepal, *tablon* and *padila* in the Philippines (Yabes, 1990) and *thelu* in India (Coward, 1990) are examples of some of these structures which distribute water (benefit) proportionally. The principle of proportional division of cost and benefit is also practised in many indigenous irrigation systems in North Africa and on a large scale in Spain (Horst, 1983).

Though many of the FMISs are being operated with proportioning devices, such physical components have received very little attention from researchers. The vast majority of completed research describes these physical components in the background to their studies, as these studies have been very heavily social science-oriented and primarily concerned with organizational and institutional arrangements.

Almost all the completed studies mention that FMISs in Nepal are very efficient and well-managed. However, they do not provide answers to questions such as: how well-managed they are with respect to their physical system, what are their relationships with agro-ecology and wider local social organizations, and what engineering and hydraulic principles are adopted for operation? There is a need to answer such questions to further develop these FMISs in close partnership with the users with the ultimate objective of raising the standard of living of the present and the future generations.

This study is, therefore, intended to explore the relationship between the environment (social and biophysical), infrastructure of FMIS and its irrigation management practices. Of the various components of an irrigation system this study concentrates on water delivery structures, especially indigenous proportioning weirs used by many FMISs in the mid-hills of Nepal.

The specific objective of this study is to examine how the irrigation infrastructure integrates local environment and irrigation management in terms of its functions and objectives in managing an irrigation system.

1.3 Theoretical approach

This study focuses on the interaction between people, agro-ecological conditions (land, water and vegetation) of an environment[2] and the irrigation system and considers them within a framework of an agro-ecological system. Coward (1990) has noted that irrigation is conducted in a socio-natural milieu. For this, people use their labour, knowledge and institutions for producing food and fibre to maintain their livelihood. Irrigation is developed and managed by the people's interaction with agro-ecological conditions for the creation of water environment suitable for agricultural production.

In irrigation, an ecological perspective has been increasingly important. Coward (1990) and Wade (1995) have used this perspective to understand why certain organizational and institutional patterns exist. Ambler (1989) examines the relationship between irrigation system maintenance and water allocation/distribution using this perspective. Similarly, Bottrall (1992), using this perspective, examines the fits and misfits over time and space between technology, institutions and their environments.

Though it is recognized that agro-ecological conditions influence an irrigation system, ecological perspectives are rarely used to understand design and management of an irrigation system. Regarding its distinctive features, Coward (1980) notes that ecological perspectives put emphasis on the role of the physical environmental factors in shaping, limiting, or determining various forms of group-shared behaviour and the regularities which lie behind them.

1.3.1 Ecology and irrigation

Ecology is the study of inter-relationships between living organisms and their environment. These are studied in order to discover the principles which govern their relationships (Vincent, 1997b; Forman and Godron, 1986; Kormondy, 1969; Geertz, 1961). Ecological relationships are manifested in particular organism-environment settings in which fundamental transformations of energy take place for biomass production. An ecological system or ecosystem is a specific structure of this setting in which biomass production can be studied in relation to natural cycle of water and nutrients, and a habitat in which climate and topography also determine these natural cycles and biomass production.

Irrigation is a classic example of a man-made ecological system, in which water is imported into a location to change and increase agricultural production. Irrigation is thus an agro-ecological system, or an ecological system modified for agriculture through control of inputs and trophic levels[3]. The concept of irrigation as an agro-ecological system thus includes not only relationships between man and environment but also with its spatial and temporal components and all other phenomena altered or created by human endeavour for agricultural production. Examples of such phenomena are transformation of natural landscape into terraces, shaping and re-shaping landscape features to develop irrigation

[2] Environment here refers to the natural environment that includes all phenomena apart from people and the things they create (Monkhouse, 1965).

[3] Trophic level refers to a step in a nutritive series of an ecological system. An ecological system consists of several trophic levels. In irrigation, control of trophic levels can be seen as means of controling output.

infrastructure and replacement of natural vegetation by man developed varieties of crops (paddy, wheat and others). Altieri *et al.* (1987) note that in an agro-ecological system, other than infrastructure like terraces, trenches and irrigation works, indigenous knowledge is also central to the continuing performance of these production systems. This implicitly highlights the importance of technology in these agro-ecological systems.

1.3.2 Conceptualizing technology

Irrigation is made possible through the use of technology to direct and use water. Technology in its widest sense is the capacity of transformation of goods into desired things (Vincent, 1997b). However, a number of other definitions exist to operationalize the concept for different kinds of research on technology. Many researchers define technology as an artefact or material object (Mollinga, 1998; Farrington, 1980; Feibleman, 1982 and Lattimore, 1986). The concept of technology as 'material object' focuses its attention on the material nature of the object and allows for the practical study of its design, construction and operation. Manzungu (1999) and Mollinga (1998) note that the nature of the artefact emerges through the contextual study of conditions of control and operational practices. This approach is especially helpful for understanding water delivery in irrigation systems with serious practical problems in water management, and where water delivery is often contingent on negotiation, struggle and personal agency (Manzungu, 1999, Mollinga, 1998).

Another definition of technology, as noted by Stewart *et al.* (p.xi, 1990) in their work on appropriate technology, is 'a complex of capital goods, products, processes and organizations which make good and efficient use of the means available to achieve...objectives'. This definition is helpful in identifying things which need to be present and able to work together to obtain output. It is also helpful to identify tasks and functions and fits and misfits in the design of the system. However, it is less helpful for understanding the dynamics of social action (negotiation, power) that often make technology work in practice. It is also vulnerable to imposition of particular norms of production and organization, most notably the criteria of efficiency. By seeing artefacts as a capital good and investment, it proves weak as a framework for the study of the design and operation of the artefact itself. However its reference to processes, allows study of the preferred ways in which systems are operated and managed and the objective of technology use, which this study wished to explore in relation to artefact design. It also facilitates study of how materials and products come together for both artefact construction and use, and production.

These approaches are normally seen as exclusive, because of difference in focus, guiding concepts and methodology (Mosse, 1997). However, this study takes elements of both approaches.

Following Stewart *et al.* (1990), this study considers technology as a system consisting of artefact, products, management processes and organization necessary for irrigated production. However, following Mollinga (1998) it undertakes a study of institutions with attention to actual social action, giving recognition that farmers do act strategically to change technology and water delivery, and that power can be exerted through and against existing institutions to control everyday water use. It thus recognizes that other social forces shape the choice and management of technology besides rational economics. Thus, Stewart *et al.*'s definition of technology as 'a system' is used as an initial functional framework to look at knowledge, institutions and production shaping the use of artefacts and water supply, and management functions. However, the operational realities in systems are also discussed alongside institutional and organizational principles, to understand how power and negotiation shape flexible use of the irrigation system, so that everyday realities are not simply generalized or ignored as rule flexibility or anarchy.

This was also justified in relation to the objective of the research. The research sought to understand the principles through which artefact, agro-ecology and management functions were potentially integrally adapted in these indigenous systems, as well as any contingent water management in systems under stress (Manzungu, 1999). It was also thought that in well-established farmer-managed irrigation systems, considerable effort would be made to evolve an institutional structure capable of operating a system with minimal stress. Thus negotiation with visible signs of disagreement would be rare, and some forms of negotiation and exertion of power would be hard to capture. Thus a broader approach through institutional analysis made it easier to capture negotiated variation from general institutional principles. To help in the study, Giddens's concept of power[4] was used as something that exists when put into action, in which certain actions modify others.

1.3.3 Agro-ecology and technology

As mentioned above, there are a few definitions of technology in use that make reference to agro-ecology and the influence of the technology on environment (biophysical and social). For this study, a working definition of technology in use was developed as 'a capacity to transform, involving material objects whose creation and use are socially mediated'.

Social conditions of control and evolution help determine whether this capacity is coordinated systematically or negotiated through contingent action. However, its actual transformative capacity is also shaped by the capacity of these artefacts (infrastructure[5]) to operate successfully in a locality, as defined by users criteria. This is a result of not only the function, operational principle, physical configuration, material composition and condition of an infrastructure, and the local social construction of use, but its capability to encompass the dynamic complex of 'agro-ecology, people and society' of the locality where it is operated[6] (Parajuli and Vincent, 1999).

In this definition, people are presented as an additional element to society to indicate that there are ergonomic, experiential and psychological aspects in the human use of

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[4] Power is the ability of an individual or a group of individuals to achieve an aim or interest they hold (Giddens, 1989).

[5] Hereafter, in this study, the term 'structure' or 'infrastructure' is used in place of the term 'artefact' because it looks at both individual and multiple structures acting together. Further, this term is a more familiar in design and engineering debates.

[6] In the subsequent study, hydraulic conditions (subsequently referred to as hydraulics) and water availability are studied as outcomes that can indicate the actual transformative capacity of irrigation technology, and demonstrate its relationship with agro-ecology.

infrastructure. These aspects also affect their actual capacity of transformation, separate from concerted social action that shape negotiation, organization, and knowledge for use or change of technology. Furthermore, it is the involvement of people in the design of the infrastructure they use, that leads to optimal operations in reality. Agro-ecology is used here as a concept with dual meanings (Parajuli and Vincent, 1999). It is first used as a concept to describe the biophysical environment of a location where people are involved in production, and their adaptation of (or to) the natural environment for human use. It is also used as a concept expressing the relationships which control the elements of this biophysical world and their use by people

To develop the study of agro-ecology, the study used several sets of approaches. Firstly, it used a typology of elements of the biophysical environment: land, water, vegetation and climate. It then sought concepts that integrated elements of human use of the environment, or described aspects of natural elements that shaped human use of them. The study looked at local land use classification (especially in relation to topography and landscape) and used ideas from the field of landscape ecology[7]. It used the concept of the farming system which integrates crop production activities along with livestock raising, soil type and land features, water and agrarian conditions to study integration of resources and production. It used the concept of river regime (dynamics of quantity) and water scarcity to study adaptations of water use in the system. It also looked at existing typologies of irrigation systems related to environment (Vincent, 1995; Pradhan 1989a)

These concepts which include agro-ecology and agrarian conditions were integrated and studied as a 'sub-complex' on 'agro-ecological conditions' of the locality of the irrigation system. Further details of these typologies and their relation to data collection are given in the section on methodology.

Work in the fields of cultural, agrarian and political ecology was studied to gain better understanding of critical relationships shaping resource access and use. However, no one form of social relationship was made central to the study. Instead information on these factors was also collected as part of a broad sub-complex on 'people, society and livelihoods', hereafter referred to as 'socio-cultural conditions'. Socio-cultural conditions, thus, integrate agrarian conditions, local irrigation organizations and irrigation institutions. In this study, agrarian conditions include population, land tenure and production relations, and agricultural labour conditions. It also includes power and knowledge that structure social relations. Similarly, irrigation institutions refer to institutions of access to and use of water.

Further, historical information on change in irrigation systems and locality were also given attention to understand change in socio-cultural and agro-ecological conditions.

The field of ecological anthropology and resource economics was also surveyed to find out more about possible concepts helpful to understanding social relations in resource access and use (Bromley, 1992; Bromley and Cernea, 1989; Gale, 1998; Gelles, 1996, Geertz, 1961, Mosse, 1997; Netting, 1974, 1993). Two concepts considered for this study were

[7] Landscape ecology concerns with the relationship between spatial and temporal components of a landscape and its use by the people (Bunce and Jongman, 1993).

those of hydraulic property rights (Coward, 1983, 1990 and Pradhan, U., 1988, 1990) and symbolic capital (Mosse, 1997). Hydraulic property rights can be seen when the access to water is related to investments in development or maintenance of an irrigation system. Mosse (1997) uses Bourdieu's concept of symbolic capital to argue that irrigation systems (tanks in his study) should be viewed not only as sources of water but also as forming part of the village public identity, through which social relations are articulated. These are relations that exist apart from material interests and involve status, honour and prestige. This concept proved important in this study in understanding the intensity of involvement in water management in some villages. However, it is not easy to identify how this is manifested within infrastructure.

Irrigation infrastructure were studied in the way the above working definition proposed, by looking at the function, operational principle, configuration, material construction and condition as a means of documenting the infrastructure. This framework drew on commonly used available typologies of irrigation structure and hydraulic conditions. The relationship of infrastructure and agro-ecology was studied both in relation to water supply and hydraulic conditions, to catchment characteristics, the materials used in construction, and the topography and configuration of the system, using some of the above-mentioned concepts in the sub-complex of agro-ecological conditions.

The study also thought it important to look at practical operational questions related to people's capabilities in crafting, using and maintaining infrastructure. These are not documented in irrigation, and the study thus developed its own assessment by noting the actions of users and craftsman involved with the infrastructure. The study also developed ideas from the literature on design-management interaction.

1.3.4 Design-management interaction

In recent years, the interest in the relationships between infrastructure and institutions has grown into a thematic debate on design-management interactions. Researchers have become concerned to understand further both how infrastructure encapsulates management functions and management objectives, and demonstrate knowledge about the hydraulics and the environment. There has also been a concern to ensure that structures are designed to be appropriate to local knowledge and skills and local objectives in water management (Lankford, 1998; Horst, 1998,1996). This study also sets out with a hypothesis that infrastructure does integrate these management functions and objectives, and shows the capabilities of builders and operators in knowledge of hydraulics and their environment. This will be shown in detail by case studies of how proportioning weirs are maintained in relation to operational and hydraulic needs[8], as well as how their construction and operation encapsulate local water institutions.

[8] Operation is the actualization of water delivery by any division structure. In practice, actual operation takes place by fulfilling certain operational conditions. These conditions arise from practical, ecological and hydraulic points of view, which are referred to here as operational and hydraulic needs.

1.3.5 Technology, management functions and objectives, and management domains

At this stage, before describing the approach used in the study of design-management interaction, it is worth looking at the types of irrigation system according to their development objectives, and scope of irrigation management and its definition used in this study.

Keller (1990) categorized irrigation systems into four types, according to their objectives, which determine their management pattern. They are for commercial production, for the well-being of farmers, for environmental objectives and for geostrategic objectives. Although most irrigation systems contain elements of all the above objectives, well being and environmental objectives were ranked at higher priority by farmers in the irrigation systems studied, and these objectives were well integrated in the development and management of these systems.

An irrigation system needs to be managed. This also reflects objectives. Keller (1990) classified irrigation management at two levels–scheme and system[9]. This study used the second classification of irrigation management, which Lenton (1988) calls 'irrigation water management'.

Definitions of irrigation management are numerous (Lenton, 1988). It involves collective action by the people and includes multiple activities including the management of both the water and infrastructure. Vincent (1995) notes that the arrangements for coordinating these activities are often described as irrigation management. In this study, irrigation management is defined as the management of system operation as a whole for directing/controlling water to meet the desired operational objectives.

Management of system operation is a complex process of actualization of delivery of water. It is caused by the interaction between hydraulic parameters–water level, velocity and discharge–of infrastructure, organizational/institutional arrangements and the people, and includes multiple functions. In order to study these management functions and objectives this study used the approach as noted by Uphoff (1986). Uphoff categorized these management functions into three groups and named them as water use activity (acquisition, allocation, distribution and drainage), control structure activity (design, construction, operation and maintenance) and organizational activity (decision making, resources mobilization, communication and conflict resolution). These management functions and objectives were studied by looking at actual practice of system operation and rules and regulations guiding these practices. This included study of organizational arrangements of irrigation organization (structure, functions); resource mobilization and its principles for system maintenance; water acquisition; principles of water allocation, water trading and water rights; and water distribution to achieve operational objective. The following few paragraphs describes the concept of operational objectives used in this study.

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[9] Irrigation management at scheme level refers to management of entire irrigated agricultural production system including the management of inputs, credit, markets and so on. Irrigation management at system level refers to management of water within the physical boundary of irrigation system.

Operational (management) objectives
In this study, the term 'operational objectives' refers to the output objective of irrigation system in relation to water delivery. Recent irrigation literature often assesses them through performance indicators. There has been work on the development of these indicators to asses system performance to guide improvement of agency scheme and to identify farmer's indicators for a well-performing scheme (Hoeberichts, 1996; Gowing *et al.*, 1996). Hoeberichts (1996) has noted that farmer's indicators in improving system supply in agency scheme include adequacy, timeliness, water quality, tractability, predictability, equity and hassle. However, in farmer's systems (FMISs) in Nepal, indicators rated important by farmers are equity and flexibility.

This discrepancy in the farmer's indicators between the agency and farmer's systems is caused mainly by two reasons. First, in the agency systems, users and supplier constitute two different groups, while in FMISs they are the same. This makes indicators of predictability and reliability of less importance in FMISs as farmers determine supply themselves. Second, in agency systems, indicators developed are based on the crop-water requirements, while in FMISs these indicators are not judged based on crop-water requirements, but judged in comparison with the water supply of others. For example, in FMISs, the quantity, quality and utility of water received by one farmer is always judged with respect to the water received by other farmers. For this reason, in FMISs, in Nepal, rather than indicators like adequacy, tractability and timeliness, farmers prefer indicators of equity and flexibility. The following paragraphs outline farmer's concepts of equity and flexibility in FMISs in Nepal.

Equity:
Equity is a difficult concept. In irrigation, the term equity has been used to denote many things. For example: social equity (Chambers, 1988), economic equity (Howe, 1990) and land based production equity (Horst, 1996; Levine, 1998; Diemer, 1998). This study considers that 'if actual water delivery in time and space matches the allocation–the assignment–of water', irrespective of land, equity is achieved. Therefore, the term equity does not necessarily imply equality. Equity–fairness or spatial distribution–is a subjective term. A concept of equity, therefore, depends on empirical context. Its actualization is determined by agro-ecological, social and technological considerations.

Indigenous irrigation systems in Nepal mainly operate under the basic principle of equitable distribution of cost and benefit, although other principles are found elsewhere (Vincent, 1995). Therefore, equity is a user-friendly operational objective. Levine (1998) notes that three basic principles of equity are usually found in indigenous irrigation systems. They are proportional sharing of water, sharing the utility of water, and sharing the economic potential of water. Each of these principles of equity reflects different types of technology and agro-ecological conditions.

Further, in indigenous irrigation systems, equity also refers to the notion of water right and to the rules that people develop and use in the governance and management of their irrigation systems.

Flexibility:
Flexibility refers to the ability of the irrigation systems to change delivery of irrigation water–both the interval of irrigation and flow rate–to a field or group of fields over time and space to optimize water use. Flexibility is needed for two reasons. First, when the demand is reduced, the supply needs to be reduced to save the valuable water. This concept of flexibility is highly applicable in a system supplying water through the reservoir. In a run-off-the-river system, however, this concept of flexibility is not applicable at least from farmer's perspective, because the unused water cannot be saved. Further, the unused water ultimately rejoins the river through return-flow for downstream use. Second, flexibility is needed to meet the diversified water demand within an irrigation system. This concept of flexibility is highly applicable in a run-off-the-river system.

However, flexibility involves setting and re-setting the delivery structure to adjust flow, which requires human involvement. The involvement of humans in flow adjustment raises several questions regarding the accuracy, simplicity and efficiency of flow adjustment. It also requires additional management inputs and thus raises question about 'manageability' of structure and flow. Thus, in FMISs, in Nepal, this objective of flexibility is adopted only when the benefit derived from flexible water delivery is more that the additional management inputs (both social and economical).

Management domains
Further, to study the design-management interaction, this study used Keller's (1990) concept of management domain. Keller has noted that an irrigation system consists of three primary physical/managerial domains. These are watershed, agricultural and water supply domains, in which particular institutions or organizations might be involved. The physical/managerial interfaces of these domains reflect the water demand and supply conditions, and the institutional arrangements for the use and supply of water.

The watershed domain includes catchment characteristics, agro-climatology and river regime. These determine the amount of water availability at the source. All the water available at the source is not usable, because it is likely that more than one community or groups of people would like to use the same source. Accordingly, different groups of people interact with each other to define the social control of water use at the source.

The agricultural domain includes crop, soil and land features. These determine the technical requirements of irrigation water for both the crop need and physical stability of land, especially in the hilly region. Besides technical considerations, the water demand is shaped by a number of other social factors such as water right, simplicity in water delivery and livelihood strategies which are often non-planable (Boelens, 1998).

The water supply domain includes the infrastructure of irrigation system to acquire, convey and deliver water to land or crop. This domain is central in this study. The physical/managerial characteristics of this domain are mediated by the physical/managerial characteristics of the first two domains.

1.3.6 Summary of theoretical approach

This study focuses on the relationship between people, agro-ecological conditions (land, water and vegetation) of an environment and the irrigation system. To examine this relationship, this study considers irrigation as a man made agro-ecological system, in which water is imported into a location using a certain technology to increase agricultural production. This concept highlights the role of technology in agro-ecological systems.

Technology in its widest sense is the capacity of transformation. However, a number of other definitions exist to operationalize the concept of technology. Two such definitions are worth noting here. They are technology as an artefact (material object), and technology as a system consisting of artefact, product, management process and organization. Each of these definitions has its own advantages and disadvantages in operationalizing the concept of technology, and the use of these definitions is guided mainly by the focus of the study and methodology. This study, however, uses the elements of both the above definitions.

In order to study the above-mentioned relationship, this study develops a working definition of technology as 'a capacity to transfer, involving material object whose creation and use are socially mediated'. The transformative capacity of infrastructure, which is socially mediated through management principles and negotiations, is shaped by the capability of this infrastructure to integrate processes in a dynamic complex of 'agro-ecology, people and society', consisting of two interrelated sub-complexes on 'agro-ecology' and 'people, society and livelihoods'. In the subsequent study, these sub-complexes are referred to as agro-ecological and socio-cultural conditions respectively.

To develop the study on agro-ecology sub-complex, various concepts like landscape ecology, farming system, river regime, water scarcity, and existing typology of biophysical environment and irrigation systems were used. To develop the study on 'people, society and livelihoods' sub-complex, no one form of social relationship was made central. However, two concepts considered for this study were those of hydraulic property rights and symbolic capital.

This study also looked at practical operational questions related to people's capability in developing and managing infrastructure and related institutions. In recent years, this relationships between infrastructure and institutions has grown into a thematic debate on design-management interactions. As other researchers have noted, this study also sets out with a hypothesis that infrastructure does integrate these management functions and objectives which largely depends on user's knowledge on hydraulics and local environment.

In order to study the design-management interaction, this study considers irrigation management, whose objective depends on the objective of system development, as the management of system operation as a whole for directing/controlling water to meet the desired operational objectives. System operation involves multiple management functions as management activities. This study uses Uphoff's categorization of these activities.

Further, to study the design-management interaction, this study considers an irrigation system in three physical/managerial domains. They are watershed, agricultural and water supply domains. In this study, the physical/managerial characteristics of water supply domain are central, which is mediated by the physical/managerial characteristics of the first two domains.

Figure 1.1 shows the graphical presentation of the conceptual framework used in this study.

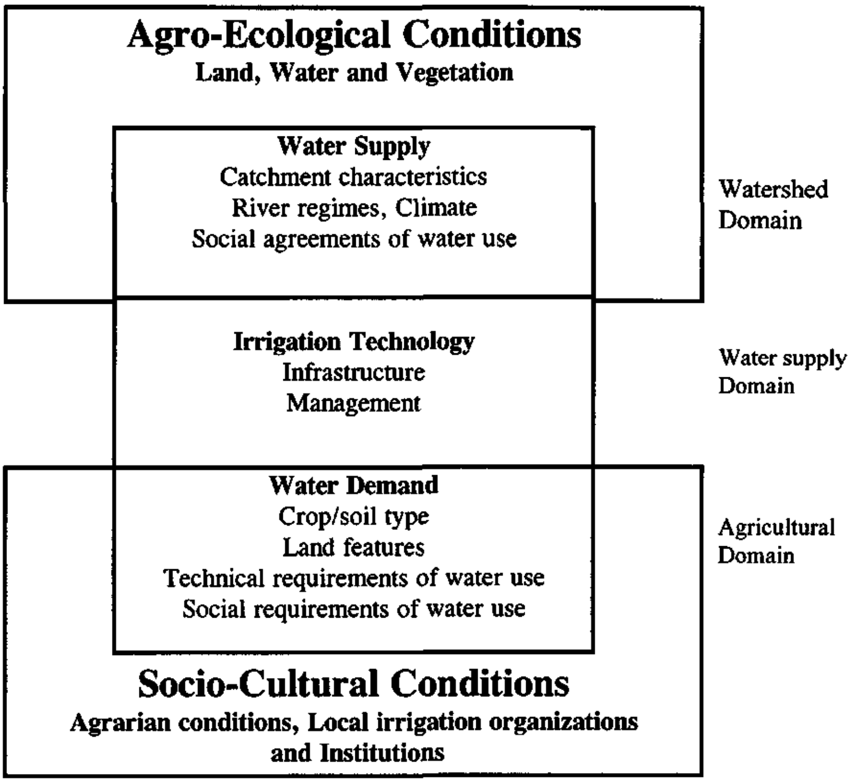


Figure 1.1: Conceptual framework of the study

1.4 Research questions

Based on the foregoing theoretical approach, this study sets out a central research question as follow:

> 'what are the relationships between irrigation infrastructure, socio-cultural and agro-ecological conditions of an irrigation system in managing irrigation water'?

This relationship is examined through a set of specific research questions, which focus more specifically on this relationship for the purpose of analysis. The specific research questions of this study are:

- what is the hydraulic behaviour of a proportioning weir and how do farmers visualize this hydraulic behaviour;
- how do the various types of water delivery structures, especially proportioning weirs, integrate the agro-ecological and socio-cultural conditions, and what conditions determine their acceptability and durability in an irrigation system, and
- what characteristic properties of the irrigation institutions and local organizations have evolved in managing an irrigation system with different irrigation infrastructure, and how do different types of water delivery structures shape irrigation management functions, objectives and local organization's primary objective?

1.5 Methodology

This research is based on the case study method. In this research, both quantitative and qualitative data were collected using various tools and techniques like survey, measurements, structured and non-structured interviews and observation. Regarding the usefulness of the case study method, Yin (1984) notes that this method is most appropriate if the purpose of the research is to seek answer to "why" and "how" types of question.

1.5.1 Site selection criteria

The agro-ecological and infrastructural differences were the main criteria for the selection of the systems for the detailed study. However, the selection of case studies required an understanding of differences in the infrastructure of FMISs and their adaptation to their environment. Thus, a rapid appraisal study was also performed in the region for identification of sites with and without proportioning weirs and to understand the spread of locations and agro-ecological conditions shaping the choice of infrastructure. This survey showed the significance of water availability, crop choice and topography of the command area and lands crossed by conveyance canals in shaping technology choice. Based on these findings, first, the following four broad categories of physical configuration were identified:

1. One hill irrigation system with a few proportioning weirs placed at key points of the distribution system;
2. One hill irrigation system with proportioning weirs placed at all the canal bifurcation points of the distribution system;
3. One hill irrigation system distributing water continuously up to individual farmers' field by means other than proportioning weirs; and
4. One river valley irrigation system with proportioning weirs for water distribution.

The other criteria developed for the selection of systems within the above four broad categorization were as follows:

- System with moderate and scarce water supplies;
- System with flat and steep irrigated areas;
- System having partly or fully single and double crops of paddy;

- System located near and far (remote area) from the town center; and
- System with established water users' organization and operating for at least last 30 years.

Based on the above site-selection criteria and the rapid appraisal study, two systems were initially selected for the detailed study. Two other systems were selected during the actual field research of the first two systems. Table 1.1 shows the salient features of the irrigation systems which were selected for the detailed study. Figure 1.2 shows their locations.

Table 1.1: Salient features of irrigation systems selected for the detailed study.

Name of system	Type of irrigation system	Type of water distribution structure	Water supply (relative)	Slope of irrigated area	Crops of paddy grown	Accessibility
Bachcha	Hill	Proportioning weirs at key points	High	Steep	One crop of paddy	Remote
Sankhar	Hill	Proportioning weirs at all the canal bifurcation points	Scarce	Mild	Two crops of paddy	Remote
Julphe	River valley	In parts of the area, proportioning weirs are located at all canal bifurcation points, and in parts they are located only at key points	Moderate	Mild	One crop of paddy	Accessible
Patne	Hill	Controlled turnouts	Moderate	Mild	One crop of paddy	Accessible

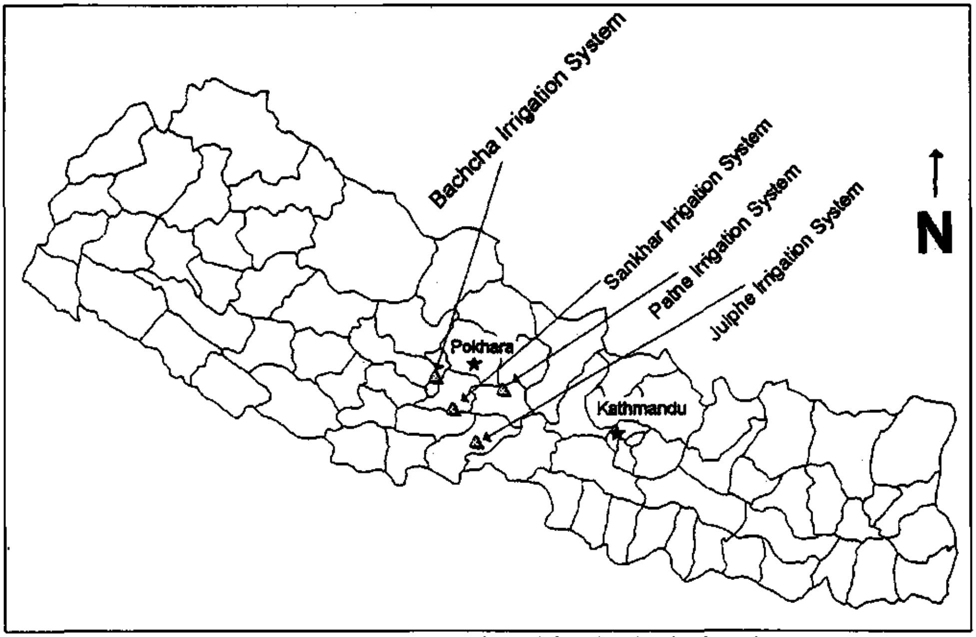


Figure 1.2: Location of irrigation systems selected for the detailed study.

After the detailed case study work, an additional rapid appraisal study was conducted to test some of the hypotheses generated by the research. Appendix II shows the salient features of the systems studied under rapid appraisal.

1.5.2 Organization of research

The study of an irrigation system consists of physiographic, technical, social-institutional and agronomic components, which are interwoven. Ideally, such a study requires a team of researchers from each of the above-mentioned disciplines for a comprehensive analysis, but it was beyond the scope of this study to have such an interdisciplinary team. Therefore, two research assistants were hired from the study area to help the researcher. Of the two research assistants, one was a university graduate in the field of humanities, who had a few years of experience in implementing various rural development programmes. Both the research assistants were also farmers. The research team also consisted of five high school graduates, at least one in each site, who were trained to read gauges installed in the canals and in the water measuring flumes to measure the flows. The gauge readers were hired locally from the sites concerned.

In each site, the researcher established a site office. Intensive data collection was started in January 1996 and continued till September 1997. Because of the transportation difficulties between the systems, it was not possible to conduct field research simultaneously in more than two systems. For this reason, two systems were studied in 1996 and the other two in 1997. In each study period, the researcher visited both the systems in turn (See Appendix I for the schedule of the field research work).

In Nepal, the majority of the FMISs are designed to cultivate rice (paddy) during the monsoon season (June-October). In this season, almost all the irrigation management activities are performed and the systems operate as designed. For this reason, the study was conducted mainly in the monsoon season. The next important season to study an irrigation system in Nepal is the spring season (March-May). In this period, the water supply in the source is limited. As a result, only a few systems operate at about 20 per cent or less than their designed flow capacity. From the perspective of demand and supply this period can be considered as a water scarce period. Accordingly, in this season, irrigation management practices differ from those in the monsoon season. For this reason, the study also concentrated equally on those systems which were operating during the spring season.

1.5.3 Intensive data collection

As mentioned earlier, both quantitative and qualitative data were collected using various tools and techniques. In general, types of data collected and techniques used were similar in all systems. However, depending on the need in some systems, there was some variation in types of data collected and the techniques used. For example, a typical agricultural practice adopted by the farmers in Sankhar Irrigation System demanded measurement of seepage and percolation losses in the paddy field. Such data were not collected in other systems. Similarly, in Patne Irrigation System, because of its smaller irrigated area and small number of farmers, structured interviews were not conducted. In Patne, the intensive data collection was focused mainly on the system operation. Table 1.2 shows types of data collected in each system.

Agro-meteorological data like temperature, rainfall, relative humidity, wind velocity and sunshine hours were collected from the nearby meteorological stations. Where the data on only temperature and rainfall were available, Blaney-Criddle method was used to compute evapotranspiration. This method provides only an indicative value. For this type of study, very accurate estimate of crop water requirement is not needed.

Table 1.2: Types of data collected in each system

Types of data collected and technique used	Julphe Irrigation System	Bachcha Irrigation System	Sankhar Irrigation System	Patne Irrigation System
1. Topographic land survey	No	Yes	Yes	No
2. Layout survey of infrastructure, their types and conditions	Yes	Yes	Yes	Yes
3. Time series flow measurements				
• at the source	No	Yes	Yes	No
• at the main canal	Yes	Yes	Yes	Yes
• at the distribution canals	Yes	Yes	Yes	Yes
4. Seepage and percolation losses in the paddy field	No	No	Yes	No
5. Detailed observation of water management at system level	Yes	Yes	Yes	Yes
6. Detailed observation of water management at farm level	Yes	Yes	Yes	No
7. Time series measurement of flows through notches of proportioning weir	No	No	Yes	No
8. Detailed layout of water division structures	Yes	Yes	Yes	Yes
9. Yield of paddy	No	No	Yes	No
10. Structured interviews	Yes	Yes	Yes	No
11. Non-structured interviews	Yes	Yes	Yes	Yes

Land surveying and water measurements

In order to explore the contribution of agro-ecological variations in an irrigation system, following surveys and measurements were conducted. The surveys and measurements were carried out without interfering with the actual operation of the system.

The physical layout of the entire system was mapped. The length of the canal system and its capacity, types of various structures and materials used, and the quality and condition of physical systems were recorded. Detailed plans of the proportioning weirs, including the reduced levels, and the upstream and/or downstream conditions were mapped. Topographical features along the main canal and at the intake were recorded. In both the Bachcha and Sankhar irrigation systems, topographical survey of the entire irrigated area was conducted at a scale of 1:2500. In Julphe Irrigation System, because of its relatively flat and large irrigated area, a topographical map of 1:25000 prepared by the Department of Land Survey was used. In Patne Irrigation System, only a cross-section profile of the irrigated area was drawn.

Sources of water related to the system were assessed. In both the Sankhar and Bachcha irrigation system, gauges were installed at the source in order to collect the time series flow data. Gauge readings were recorded twice a week. The flow in the source was periodically measured using a current meter, and a stage discharge curve was prepared. The stage discharge curve was used to compute the flows corresponding to the measured gauge readings (water depth). In Julphe Irrigation System, the existing data on river hydrology were used. In Patne Irrigation System, flows at the source were periodically measured using a current meter.

The inflow of water was measured in all the systems by installing gauges in the canal at the head of the irrigated area. Gauge readings were recorded daily. Flows were computed with the help of stage discharge curve prepared by periodic measurement of flows with current meter. To examine the flow fluctuations at various points of the irrigated area with reference to the incoming flow, flows were also measured at different points of the system. When the proportioning weirs were functioning, flows were measured by measuring the head of flow above the weir crest. However, when the proportioning weirs were not functioning, or in system where there were no proportioning weirs, V-notch and cut-throat flumes were used to measure the flows in the irrigated areas.

In order to study the hydraulic behaviour of the proportioning weir, an experiment was conducted by measuring the flows both at the upstream and at all the branch canals downstream. This experiment was conducted only in Sankhar Irrigation System during the spring season. The reason is, in other systems, proportioning weirs function only during the monsoon season. In the monsoon it is not possible to install water measuring flumes in the canals to conduct this experiment because installation of a water measuring flume in a canal carrying a large flow creates substantial depth of afflux upstream of the weir and farmers object to this[10]. The details of this experiment are given in Chapter 3.

Structured and non-structured interviews
To gather information regarding the various issues of an irrigation system, non-structured interviews were conducted with various key informants like water users committee members, actors involved in the development of the systems, development workers (GOs and NGOs) and local political leaders. In each system, except Patne Irrigation System, demographic, agricultural and irrigation management data were collected by conducting about 80 structured interviews with farmers. Structured interviews were conducted only after the researcher had become familiar with the farmers. The questionnaire used for this interview is given in Appendix XI.

Observation
Various water management activities such as resource mobilization, water distribution, process of decision making and resolution of water-related disputes were observed in all sites. A few farmers' meetings related to irrigation management were also attended. Installation of the proportioning weirs by the farmers and the operation of the systems were observed in detail.

Problems and limitations of irrigation system research in Nepal
In Nepal, especially in the mountain environment, there are a number of problems and limitations associated with the irrigation system research. One of the main problems and

[10] Please see Chapter 3 for difficulties in flow measurements in the field.

limitations is their geographical inaccessibility. In the hills of Nepal, the average road density is only 4 km per 100 sq km of area (APSC, 1995), of which also a considerable length consists of the fair weather type which does not operate during the monsoon season. Many of the farmer managed irrigation systems are located far from the road heads. One-day walk from road head to reach an irrigation system is not uncommon. This imposes a serious problem and limitation in selecting sites for detailed study, in transporting research equipment like flow-measuring flumes and in managing other logistic support for the research.

The unavailability of long-term time-series data is the other limitation. As mentioned earlier, in Nepal, time-series data related to hydrology, agro-meteorology, agriculture and socio-economics are not available at the system level. A researcher has to depend on the data collected by himself.

The third problem usually encountered in the irrigation system research is the language barrier and gaining the confidence of the farmers. There are cases where researchers are not accepted by the farmers (Giddens, 1989). However, on these issues, the researcher had an advantage over other researchers in being Nepali-speaking. Also, being an engineer with the Department of Irrigation, His Majesty's Government of Nepal, the researcher could very easily explain the purpose of the study to the farmers.

1.6 Outline of the thesis

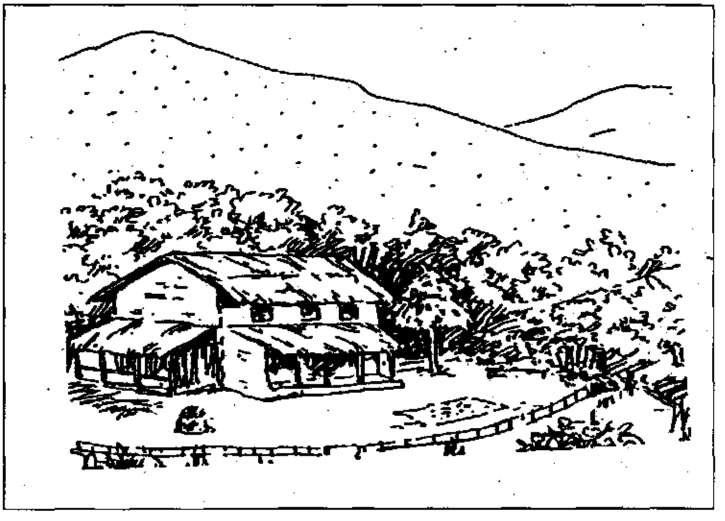
This thesis consists of eight chapters. Chapter 2 outlines physiography, climate and farming system of Nepal, which is followed by the country's irrigation development and present government policy. The subsequent section of this chapter develops the typology of irrigation systems in the hills of Nepal. This chapter ends with the description of principles of water allocation/distribution and types of water division structures used by many FMISs in the hills of Nepal.

Chapter 3 examines the design of indigenous proportioning weirs used in many FMISs in the hills of Nepal. This chapter includes detailed analysis from the Sankhar Irrigation System.

Chapter 4 through 7 presents detailed case studies on four irrigation systems namely Julphe, Bachcha, Sankhar and Patne Irrigation Systems respectively. Table 1.1 provides salient features of these irrigation systems.

Each chapter on the case study first outlines the system's agro-ecological and social setting followed by the description of the system's infrastructure. Each chapter then presents a detailed examination on system operation, and examines the relationship of the water delivery structure with the environment (both social and ecological) to see how water is managed, directed and used, and why these management methods are used.

Chapter 8 comprises a summary and conclusion.



2 The Agro-Ecological Differentiation of Irrigation Systems in the Mid-hills of Nepal

This chapter first describes the country's physiography, climate and farming systems. It then briefly reviews the history of government intervention for irrigation development in Nepal and presents government policies in this field. Finally, this chapter develops the typology of irrigation systems in the hills of Nepal based on agro-ecology. This agro-ecological typology is based mainly on classification of irrigated land according to their geographical location, where irrigation systems show considerable differences in both physical and social organization. This chapter ends with the description of principles of water allocation/distribution and types of water division structures used by many FMISs in the hills of Nepal followed by a brief summary.

2.1 An overview of the country

The kingdom of Nepal is a landlocked country located along the southern slopes of the Himalayas, and sandwiched between two giant countries: India on its south, east and west, and China on the north[1] (Figure 2.1). The country has roughly a rectangular shape; its length is about 885 km from east to west, while its width varies between 144 and 240 km from north to south. The total area of the country is about 147,480 sq km, covering about 0.09 per cent (Jha, 1992) of the total land surface of the earth. Administratively and politically, the country is divided into five development regions extending from north to south and 75 districts.

2.1.1 Physiography

Nepal is predominantly a mountainous country with over 85 per cent of its area covered by hills and mountains. The elevation of the country varies between 60 m in the south-east corner and about 8,848 m high Mt Everest, locally known as *Sagarmatha,* in the north. As a result of the wide altitudinal variations within such a small area, the country has extreme variations in physiography and agro-ecology, which is unique in the world.

Traditionally, Nepal is divided into three physiographic regions: Terai, mid-hills and high Himalayas, each of which runs across the country from east to west. Based on the two parallel Siwaliks and the Mahabharat mountain ranges, Metz (1989) further divided the mid-hills into two regions: Siwaliks and hills. Carson *et al.* (1986a) further sub-classified the hills into two categories named as middle mountains and high mountains. This study, however, follows the classification presented by Metz (1989). Figure 2.1 shows this classification. The following paragraphs describe each of these physiographic regions independently. Table 2.1 shows the land area and the land use pattern in all the four physiographic regions.

[1] The country is located between longitude 80-88^0 East and latitude 26-33^0 North.

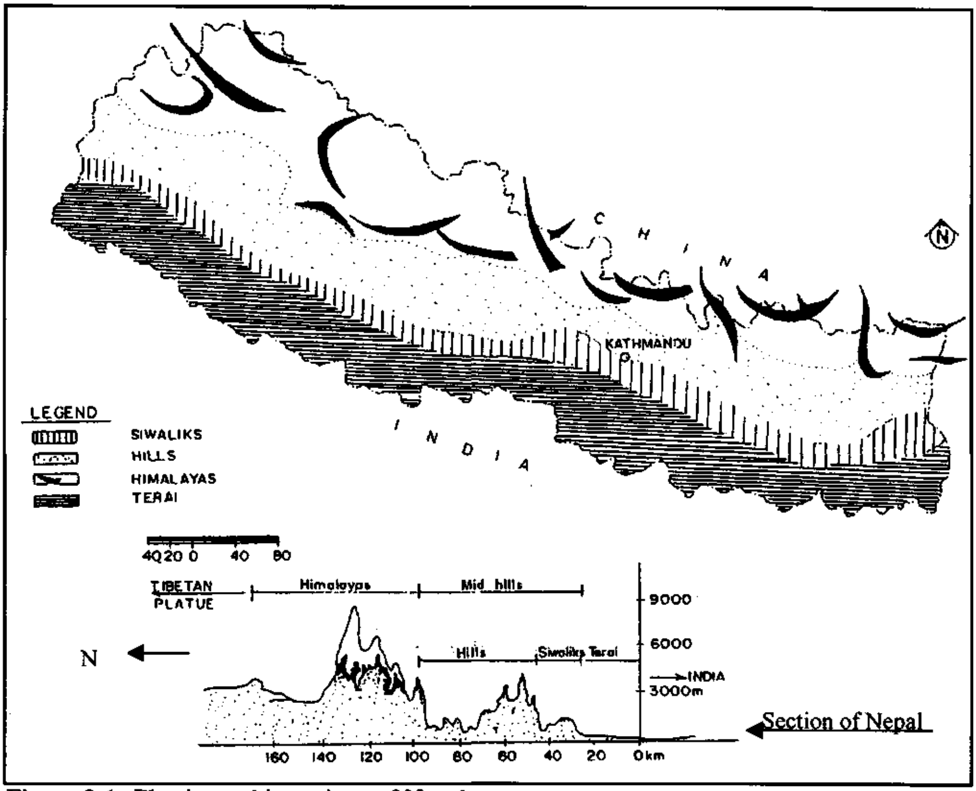


Figure 2.1: Physiographic regions of Nepal.
Source: Jha (1992).

Table 2.1: Total land area and the land use pattern in the physiographic regions of Nepal.

Description	Terai	Mid-hills		High Himalayas	Nepal
		Siwaliks	Hills		
Total land area	2122 (14.4)	1879 (12.7)	7250 (49.2)	3497 (23.7)	14748 (100)
Cultivated land	1201 (45.82)	239 (9.12)	1174 (44.8)	7 (0.26)	2621 (100)
Irrigated land	829.8 (79.7)		203.7 (19.5)	7 (0.8)	1040.5 (100)
Forest	593 (10.18)	1441 (24.74)	3632 (62.34)	160 (2.74)	5826 (100)
Grazing land/ shrub	93 (2.77)	126 (3.75)	2142 (63.78)	997 (29.70)	3358 (100)
Others	235 (7.99)	73 (2.48)	302 (10.26)	2333 (79.27)	2943 (100)

Note: Unbracketed number: area in '000 ha.
Bracketed number: percentage of the country
Irrigated land under Siwaliks physiographic region is included in both the hills and Terai.
Source: Land System Report, LRMP, prepared by Carson *et al.* (1986a)
Database for irrigation development in Nepal (DOI, 1997)

Terai

The 30-40 km wide lowland strip in the extreme south of the country is known as Terai. Its elevation varies between 60 and 300 m. This area is an extension of the Indo-Gangetic plains, and occupies about 14 per cent of the total land area of the country.

Culturally and topographically, this area is similar to the northern states of India. Prior to the 1950s much of these areas was covered by malaria-infested thick *sal* (*shorea robusta*) forest. People from the mountain areas seldom went there because of the fear of malaria. Migration from the mountain areas into these areas started only after the eradication of malaria in the late 1950s. With the start of migration[2], large areas of these *sal* forests were converted into cultivated land.

Siwaliks

The Siwalik range of hills, also known as the Churia, rises abruptly from the north of the Terai up to an elevation of about 1,300 m, and follows the east-west alignment. The land area between the north of Terai (southward foothills of the Churia) and the southward foothills of the Mahabharat mountain range is known as Siwaliks. In some parts of the country, along the east-west axis, the Siwalik and Mahabharat ranges of mountain merge together, while in some they are well separated, forming a valley known as the Doon valley.

Like the Terai, much of the area in the Siwaliks was also covered by malaria-infested thick *sal* forests. Settlements in these areas were started by encroaching upon some of these forests following the eradication of malaria in the late 1950s.

Hills

The southward foothills of the Mahabharat mountain range which rises abruptly from the north of Siwaliks up to an elevation of about 3,000 m is the southern boundary of the hills, while its northern boundary are the main peaks of the Himalayas. This is the largest physiographic region having its width varying between 70 and 110 km. This physiographic region, locally known as the *pahad*, is where the majority of the hill people live and is considered to be the heart of Nepal.

In this physiographic region, the east-west aligned mountain ranges form barriers to the south-flowing rivers draining from both the high Himalayas and the peaks of these mountains. Many of these rivers flow along north-south, east-west and west-east directions forming sequences of several ridges and valleys along them. These rivers join each other and finally drain out of the Mahabharat range through their gorges as four major rivers, namely Mahakali, Karnali, Narayani and Kosi.

This region constitutes rugged mountain topography with great variations in altitude within a short horizontal distance. As a result, the climate shows considerable variations, and there is a great ecological diversity and complexity. Because of the rugged mountain topography, this region has virtually no flatland. Small river-valleys and slopes up to 30-40 per cent are traditionally formed into innumerable terraces for cultivation.

This research is located in this region.

[2] Land slides and floods in 1955 also accelerated the migration of hill people in the Terai of Nepal.

High Himalayas
The northern part of the country, with an average width of about 45 km, consists of high Himalayas. In this region, there are several peaks, of which nine are taller than 8,000 m. About 24 per cent of the country's land area is located in this region, of which about 14 per cent (located above 5,500 m from the mean sea level) is perpetually covered with snow. The areas below 5,500 m are sparsely inhabited.

In some places, the country extends towards the north of high Himalayas, usually referred to as the inner Himalayas. The inner Himalayas lie in the rain shadows of the high Himalayas. Culturally and topographically, the inner Himalayas are very similar to the Tibet region in China.

2.1.2 Climate

In Nepal, climatic conditions vary from freezing cold in the high Himalayas to sweltering heat in the Terai. Mainly, altitude and its resulting aspects are responsible for such a wide range of climatic conditions. Shrestha (1992) notes that the mean temperature decreases by 5.5^{0}C for every 1,000 m rise in altitude. Based on altitude, Carson *et al.* (1986a) categorized Nepal into five climatic zones (Table 2.2).

Table 2.2: Relationship between elevation and climatic zones in Nepal.

Altitude from mean sea level	Climatic zone	Mean annual air temp.(^{0} C)
Less than 1000 m	Sub-tropical	20 – 25
1000 – 2000 m	Warm temperate	15 – 20
2000 – 3000 m	Cool temperate	10 – 15
3000 – 4500 m	Sub alpine, alpine	3 – 10
Greater than 4500 m	Arctic-like	less than 3

The irrigation systems in this study are located in the sub-tropical climatic zone.

About 80 per cent of the annual rainfall in the county occur during four months (June-September) due to the east to west summer monsoon. The summer monsoon advances east to west and withdraws west to east. Thus the duration and the amount of the summer rainfall decrease from east to west. The average annual rainfall in the eastern parts of the country is about 1,736 millimetre (mm), while its value in the west is about 1,440 mm.

The east-west aligned mountains also create localized effects in the annual rainfall. In some parts of the country, slight rain shadows occur in the north of the Mahabharat mountain range, while the high Himalayas obstruct the entire monsoon and create complete rain shadows in their north.

Unlike the summer monsoon rain, winter rain advances from west to east. Although the winter rains are very erratic, their reliability is higher in the western parts of the country than in the eastern parts.

2.1.3 Farming systems and principal crops

The farming system in Nepal is characterized by the general integration of crop production with livestock raising, by the use of local forest products for some farm inputs and the importance of non-farm activities to generate supplementary cash income (CIWEC, 1990). The extent of their integration, however, varies with the physiographic region. For example, in the high Himalayas, livestock farming dominates the production of cereal crops, while in the Terai, crop production dominates the livestock farming. In the mid-hills, both livestock farming and cereal crop production are well-integrated. Any change in one component would exert a considerable effect upon the other.

In the high Himalayas, the farming system mainly depends on livestock raising such as yak, *chauri* (yak and cow cross) and mountain goats. The livestock grazes on pastures, which are often far from the homestead.

In areas above 3,000 m from the mean sea level, barley, buckwheat and potato are the principal crops grown. In this area, all crops are grown in summer, and only one crop can be grown per year. Cultivation of paddy has been recorded up to an altitude of about 2,200 m (Whiteman, 1985), which can be rotated with wheat or barley in a very tight cropping pattern.

Trading between Tibet and low elevation areas, porters work for tourists and seasonal migration during winter to places where there is a demand for labour are the other off-farm activities of farmers living in the high Himalayas. These porters also played a role in carrying equipment to the site of Bachcha and Sankhar Irrigation Systems on this study.

In the mid-hills, two distinct types of cultivated land exist: *bari* and *khet*. *Bari* is a sloping unbunded terrace where rainfed crops like maize, millet, soyabean and blackgram are grown. In the levelled, bunded and irrigated terraces, known as *khet*, paddy followed by wheat and maize are grown. As mentioned earlier, in the mid-hills, agro-ecology shows considerable differentiation due to great variations in altitude within a short horizontal distance. As a result, the principal cropping sequence in both the *khet* and *bari* varies considerably with altitude.

Unlike the mid-hills, in the Terai, due to heavy alluvial soil and flat topography, paddy is cultivated as the principal crop even under rainfed conditions. Thus, a *khet* in the Terai can be unirrigated. Paddy is mainly followed by wheat. In some areas, sugarcane, jute, potato and other cash crops are also grown. However, the area covered by these cash crops is nominal and the share of cash crops in the total agricultural production is only about 10 per cent (MOF, 1998).

The major difference in the farming system between the Terai and the mid-hills lies in the management of soil fertility. The following paragraphs explain this difference.

In the Terai, *khet* consists of imperfectly drained alluvial land. The average landholding of *khet* is about 2.60 ha (LRMP, 1986). In general, paddy-fallow-fallow or paddy-wheat-fallow is the main cropping pattern. Carson *et al.* (1986b) note that the paddy-fallow-fallow system is relatively stable from fertility viewpoint, and is considered sustainable.

They further mention that a well-managed paddy-fallow-fallow system could result yields of over 4,500 kg per ha without any chemical fertilizers. Where second crops are grown, a little chemical fertilizer is added. Usually dung and crop residues are burned instead of fuelwood. Use of compost for fertilization is limited. Livestock is raised mainly for draught power and as a source of cash income from milk and its products. Farms are relatively independent of forest and grazing land (CIWEC, 1990). Fodder requirements are met primarily from the crop residues.

Unlike this, in the mid-hills, livestock is an integral part of the farming system, mainly for fertilization and animal power. The average landholding of *khet* is about 0.43 ha (LRMP, 1986). From a fertility point of view, *khet* in the mid-hills is not sustainable without import of nutrients usually derived from animal manure and compost. Subsistence farming involves production from the combination of land types such as *khet, bari* and *bhir pakho*[3]. Also, smaller landholdings result in high cropping intensity in *khet*. Farming systems in the hills have been developed over a long period of time to suit their micro-climates and land types. For this reason, improved varieties of crops and chemical fertilizers are not easily adopted. Compost is extensively used for fertilization. Farms depend heavily on forest and other land for the production of fodder to maintain the livestock.

2.2 An overview of irrigation development in Nepal and present government policy

Until recently, irrigation development nation-wide was a result of farmers' own initiation and investment in the construction and management of irrigation systems. These systems are referred here as farmer managed irrigation systems (FMISs). Such irrigation systems are based on indigenous technology to suit their agro-ecological and social settings. Some of them are reported to be as old as 400 years (Pradhan, 1989a). Many of these FMISs are still functioning. These systems were built under various arrangements such as religious trust, community efforts, royal directives[4] and forced labour[5]. At present, these FMISs make a substantial contribution to the national economy.

Due to lack of well-documented data on FMISs, uncertainties exist regarding the area irrigated and the number of FMISs in the country[6]. Recent data published by the Department of Irrigation indicates that in total FMISs irrigate about 403,503 ha in the Terai and 188,807 ha in the hills and mountains (DOI, 1997).

The government's direct involvement in irrigation development started with the first five year plan in 1957 with the construction of medium and large surface irrigation systems in

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[3] *Bhir pakho* is a sub-vertical land

[4] A few *raj kulo* in Kathmandu which were constructed in the seventeenth and eighteenth centuries are examples of royal directives.

[5] Ostrom *et al.* (1992) note that before the 1950s landlords mobilized tenants, probably slave labour, to construct irrigation systems.

[6] APSC (1995) estimates that Nepal has more than 20,000 FMISs irrigating about 75 per cent of the then irrigated area (which comes to about 576,000 ha), while Pradhan (1989a) notes that about 458,000 ha in the Terai and 150,000 ha in the hills are irrigated by FMISs. Similarly, CIWEC (1990) estimates that FMISs irrigate about 475,000 ha in the Terai and 193,000 ha in the hills and mountains.

Terai[7]. Until then the government did not recognize the contribution made by FMISs to the agricultural economy of the country. It was only in 1981 that the government acknowledged this for the first time, and began to consider ways to enhance and expand FMISs (Pradhan, 1989a). Other than the minor irrigation programme[8], which was launched during the second and the third plan periods (1962-1970), till the mid-1980s the government's attention was focused mainly on the construction of infrastructure in the large irrigation systems in the Terai (Pradhan, 1996). Management of these systems virtually received no attention. As a result, most of these large irrigation systems followed a construction-deterioration-rehabilitation cycle with a constant record of poor performance (APSC, 1995).

Since the mid-1980s the government and various donor agencies shifted their attention from the construction of large scale Terai irrigation systems to the rehabilitation and improvement of FMISs in both the hills and the Terai. As a result, the government brought out a new irrigation policy in 1989, which was revised in 1997. The new irrigation policy clearly emphasized the participatory and demand-driven approach. The basic concept of this participatory approach is that greater farmer participation in all stages of irrigation development increases the farmers' sense of ownership and control over the system, which ultimately leads to better use of the scarce water resources and increased agricultural production. In this line, the government and various donor agencies started intervening in FMISs to meet the basic objectives of poverty alleviation, agricultural intensification/diversification, local resource generation and mobilization, and employment opportunity creation. The World Bank-funded Irrigation Line of Credit (ILC) (1988), the Asian Development Bank (ADB) funded Irrigation Sector Project (ISP) (1988), the UNDP/World Bank/ADB-funded Irrigation Sector Support Project (ISSP) (1989), and the Danida/UNDP-funded Dhaulagiri Irrigation Development Project (DIDP) (1989) are some examples of this.

Further, in 1995, the government of Nepal brought out a 20-year Agricultural Perspective Plan (APP) expecting to accelerate Nepal's agricultural growth rate of the time from 3 to 5 per cent per annum (APSC, 1995). The APP considers irrigation as one of the prime inputs for agricultural development. In the hills, APP emphasizes improvement of existing FMISs based on farmers' genuine demands and farmer participation in all stages of irrigation development. About 40 per cent of the total irrigation investments of the APP are to be in the hills. Of this, about 63 per cent are to be spent on the improvement of the existing FMISs, and the rest on the construction of new surface irrigation systems and management transfer of existing agency managed systems. In the hills, the APP expects to concentrate the investments on the means of increasing the water control and aims to expand the farmers' ownership so that by the end of the plan period all the systems in the hills are farmer-managed. At present, the government's irrigation development programme follows

[7] Prior to this, a few irrigation systems were constructed with the assistance of the then government of British-India. See Pradhan (1996) for detail.

[8] Under the minor irrigation development programme, both the construction of new FMISs and the improvement of the existing FMISs in Terai, covering about 37,000 ha (CIWEC, 1990), received government assistance. In assisting FMISs, though emphasis was given to farmer participation, due to lack of clear directives, many of these systems were re-engineered. As a result, the government took on the management of many of the assisted systems (Pradhan, 1996).

the recommendations made by the APP. Table 2.3 shows the present situation of irrigation development in the country.

Table 2.3: Present situation of irrigation development in the country.

Physiographic region	Population ('000)	Total irrigable area	Irrigated by 1997 (excluding groundwater irrigation)			
			AMIS	Assisted FMIS	Non assisted FMIS	Total
Terai	8628	1338	239.7	139.6	263.9	643.2
Hills and Mountains	9863	428	21.03	78.20	110.6	209.83
Total			260.73	217.8	374.5	853.03

Note: AMIS refers to agency managed irrigation systems
The areas are in '000 ha.
Source: (CIWEC, 1990; DOI, 1997)

2.3 Irrigation systems and their classifications

The irrigation systems discussed here refers to the run-off-the-river type of system, which is widely available in the hills of Nepal. Vincent (1995) classified them as offtake systems. These systems are designed depending upon the various ecological features of an area, like land, water and crops, which in turn determine its organizational and institutional arrangements. Of the above ecological features, in the hilly areas, land is the main criterion. This is because availability of water and type and/or intensity of crop grown in an irrigation system are in part a response to the geographical location of the irrigated land in the hills.

Based on the physical characteristics, Pradhan (1989a) and Ostrom *et al.* (1992) classified the irrigation systems in the hills into two types: hill and river-valley irrigation systems. This classification is also primarily based on the geographical location of the land in the hilly environment. Similarly, Ambler (1989) classified hill irrigation systems into four types. His classification is based on the availability of water at the source and conveyance losses, mainly to explain both the physical and organizational arrangements of the irrigation systems. Conveyance loss is determined by measuring the distance between the intake and the irrigated area, which also primarily depends upon the geographical location of the irrigated land in the hills.

For example, an irrigation system whose irrigated area is located along the banks of a river slightly above the river flood plain would have a much shorter canal length. Consequently, such systems receive relatively more flow because the conveyance loss is minimum and maintenance is easy. In contrast, the irrigated area of a system located in the hill slope much above the river floor of deeply incised mountain stream would have much a longer canal length. Consequently, such systems receive relatively small flow because the conveyance loss is relatively high and maintenance is difficult.

In Nepal, due to extreme variations in physiography and agro-ecology within a short horizontal distance, it is not an easy task to physically demarcate a line in the classifications of land and irrigation systems. As a result, some land and irrigation systems may fall in more than one category. However, in general, these classifications may help in visualizing the types of land and irrigation systems from the perspective of irrigation management.

This section, therefore, first classifies the types of irrigated land in the hills based on their geographical locations where irrigation systems show considerable differences in both physical and social organizations. The section also discusses both physical and social organizations of irrigation systems in each of these land types. This classification further supports the typology of the irrigation systems developed by Vincent (1995) and Pradhan (1989a).

2.3.1 Classification of irrigated land and respective irrigation systems

Many authors (Shah, 1993; SPWP, 1992; Carson *et al.*, 1986a) have classified the land in the hills of Nepal based on their slope, drainage and soil type mainly from soil stability, erosion and fertility considerations. From the perspective of irrigation management, based on their geographical location, irrigated land (*khet*) can be categorized into mainly three types:

1. **Foothill terraces**: terraces located along the banks of a small stream in the foothills in the gorge. They are locally known as *khola khet*.
2. **Slope-hill terraces**: terraces located in the slope of a hill much higher from the big or medium rivers flowing through the bottom of a deeply incised valley. They are locally known as *tar*.
3. **River-valley terraces**: terraces located on the floor of a wide valley.

In the classification of the irrigation systems in the hills, Vincent (1995) classified the irrigation systems irrigating river-valley and slope-hill terraces as river-valley offtake and slope offtake systems respectively. Since there exists a third category of land (foothill terraces) and to differentiate them from each other, this section classifies the irrigation systems irrigating foothill, slope-hill and river-valley terraces as foothill, slope-hill and river-valley irrigation systems respectively.

Foothill terraces (khola khet) and foothill irrigation systems

Khola means a small stream. The *khet* located along the banks of a stream (tributaries of medium or big rivers) slightly above the stream floor in the same valley as the source river is named as *khola khet* (Figure 2.2). Such valleys are characterized by roughly narrow V-shaped cross-sections with moderate slope at the foothills (lower section) and steep slope as the land rises uphill (upper section). The moderate lower slope is terraced mainly for paddy cultivation, and the steep upper slopes contain either forest or grassland. The average land slope of the *khola khet* depends on the overall width of the valley. The wider the valley the smaller is the land slope. In general, the *khola khet* is steeper than a *tar*[9]. The *khola khet* usually consists of a long strip of land parallel to the source river, often heavily dissected by natural gullies or vertical cliffs into smaller patches. Because of their topographical discontinuation, usually each patch of the *khola khet* has its own irrigation system. Therefore, the foothill irrigation systems irrigating *khola khet* are usually small in size. The average size of the foothill irrigation system ranges from a fraction of a hectare

[9] For example, in Bachcha and Sankhar irrigation systems (discussed in Chapter 5 and 6 respectively), the average land slope of *khola khet* are in the ranges of 10-25 and 13-20 per cent, while that of the tar are 8-14 and 2-3 per cent respectively.

to about 10-15 ha. Although their individual sizes are small, in Nepal, a considerable number of irrigated areas fall under this category. Photo 2.1 shows foothill terraces (*khola khet*).

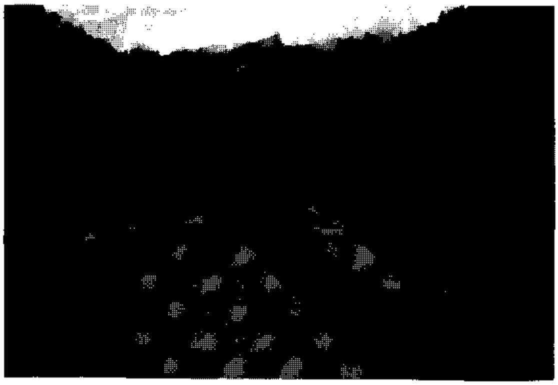

Photo 2.1: Foothill terraces (*Khola khet*)

By virtue of its location in the gorge, many of the *khola khet* areas are shaded during some parts of the day, which affects exposure to sunlight and wind. For this reason, farmers do not live there, and as a result houses or villages are not seen in the vicinity of a *khola khet*. Farmers living up in the hills, referred to the upper villages, use this land resource mainly to cultivate paddy because paddy cannot be grown profitably in the upper villages due to water shortage or low temperature. In the past, paddy used to be the only crop grown in the *khola khet*. At present, due to population growth, in some of the *khola khet*, farmers have started cultivating a second crop during winter or spring. The *khola khet* supports only part of the food demand of farmers who own the land. Thus, people using *khola khet* also use lands in the uphill for their livelihood indicating vertical diversity in land use, which is an important characteristic of many hill farming systems (Vincent, 1995)

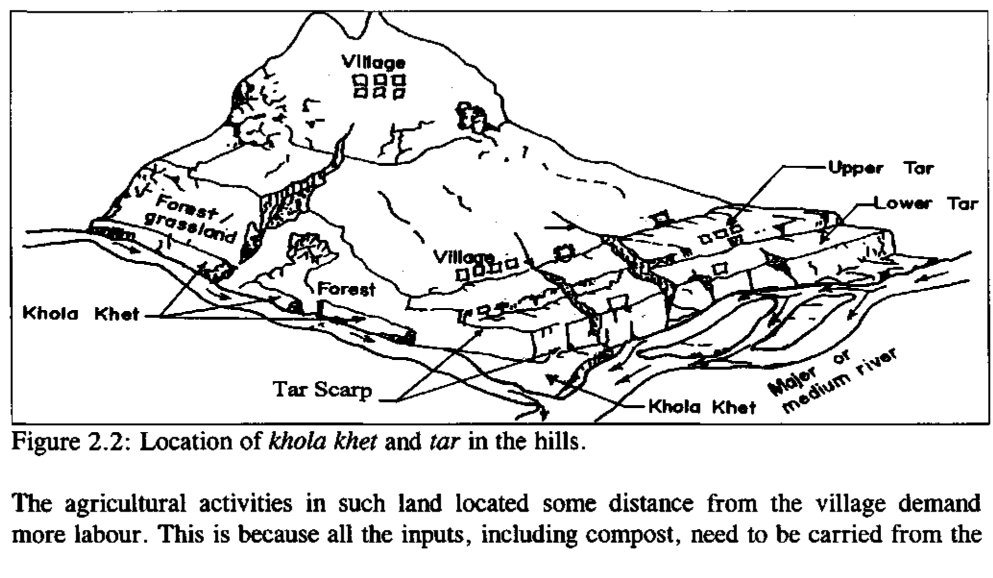

Figure 2.2: Location of *khola khet* and *tar* in the hills.

The agricultural activities in such land located some distance from the village demand more labour. This is because all the inputs, including compost, need to be carried from the village down to the *khet*. This is quite an arduous task, especially when the village is located at a very high altitude. It has been observed that in some places farmers first dry the compost in the sunlight and then carry it down to the *khet*. This method helps in reducing the amount of labour required to transport the compost.

In the *khola khet*, since the houses are not located close to it, the chances of wild animals and birds, like monkeys, rats and other pests damaging the crops is relatively high. To minimize damage, usually the type/species of crops grown and the frequency of cropping are kept the same after consultation among farmers (Tamang, 1994). In many *khola khet*, to avoid the temperature stress, mainly caused by shading at the later stages of crop growth[10], paddy is transplanted earlier (in mid-June) than in the *tar*. For this reason cultivating three crops per year in this land is difficult.

The combined effects of some of the above causes have resulted in relatively low cropping intensity in the *khola khet*. For these reasons, the *khola khet* is valued less compared to other *khet* even though this land receives relatively more water.

Foothill irrigation systems

The source rivers for both the foothill and the slope-hill irrigation systems are relatively small in terms of flow carrying capacity. They have very steep gradients with a series of natural vertical drops made of rock outcrops or big boulders.

These rivers are fed by perennial and/or seasonal springs in their catchment, which almost entirely depend on the rain. During the monsoon season (June-September), these rivers discharge maximum flow, which gradually reduces to about 10-20 per cent or even less (with respect to the monsoon base flow) during the spring season (April-May). Even during the monsoon season, relatively short dry spells lead to considerable reduction in the river flow. For this reason these rivers exhibit high fluctuation of flow in response to the monsoon rain.

The source river is usually tapped by a series of intakes to divert water into their respective systems. The intake simply consists of a temporary diversion weir constructed across the river and an unregulated opening connected to the main canal. Usually, there is no need to raise the water level in the river to divert the flow into the main canal. Locally-available materials like boulders and brushwood are used to construct the intake. In most of these systems, intakes are located at a place where natural rock outcrops or big boulders can be used to divert the water easily. Temporary arrangements are also made at the intake to control the entering of flood water into the main canal. Although the diversion weirs need frequent maintenance, it is not considered as a big task. Usually a few farmers can maintain them in a few hours.

In most of these foothill irrigation systems, irrigation begins a short distance after the main canal takes off from the intake. Consequently they have a relatively short idle length[11]. The

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[10] For example, the *khola khet* of Bachcha Irrigation System receives sunlight only up to around noon during the harvest of paddy.

[11] The portion of the canal from the source (river) up to the beginning of the irrigated area is termed as idle length.

main canal is aligned along the contour through the uppermost terraces, which is usually the steepest section of the irrigated area. Many of these systems have only one order[12] of canal networks for the distribution of irrigation water. In such systems, the main canal directly supplies water to a series of field channels through their respective turnouts. Each of these field channels belongs to an individual farmer. These field channels are small and are aligned down the hill. Flows entering these field channels need to be checked in order to protect the crops and terraces.

This may raise a question why these systems usually have only one order of canal system. The reason is, as mentioned earlier, many of these areas constitute a long strip of land parallel to the main canal, and most of the landholdings are connected to it. This facilitates direct supply of water from the main canal to individual landholdings.

By virtue of its location, right along the river bank, the foothill terraces exercises a prior water right over the slope-hill terraces. Because of its shorter idle length, conveyance losses are minimum. As a result, availability of water in the foothill terraces is relatively high compared to that in the slope-hill terraces. Usually, in these systems, controlled entry of flow into *khet* receive higher priority in design and operation than the distribution of available water, in order to protect crops and terraces. Thus, in these foothill irrigation systems, the priorities in irrigation management is different compared to other types of irrigation systems. Quite often farmers have to watch the intake at the source not to allow more than required flow into the main canal. Some times intakes are even broken to prevent high flows and flood surges into the canal. For this reason, in the majority of these systems, water distribution is not an important task. Because of the shorter idle length of the main canal, maintenance is also much simpler. In summary, the management of irrigation water in the foothill irrigation system is much simpler and easier than that in other types of irrigation system. For these reasons, foothill irrigation systems do not have well-defined organizational and institutional arrangements to manage the irrigation system. Part of Bachcha Irrigation System is an example of foothill irrigation system.

Slope-hill terraces (Tar) and slope-hill irrigation systems

Tar are located in the hill slope much higher from the river floor (Figure 2.2). They are found along the banks of big and medium rivers. They are heavily dissected by natural gullies into smaller patches.

A *tar* is formed as a result of landslides and soil erosion during the mountain-building process. A combination of geologically rapid uplift and a monsoonal climate, high temperature combined with high and intense seasonal rainfall, dominated by rock-weathering, landslides and erosion (SPWP, 1992) results in such *tar*.

Usually, more than one layer of such *tar* is found, which are connected by a steep often sub-vertical land, referred here as *tar* scarp. The upper *tar* are usually steeper than the lower *tar*. In the *tar*, series of levelled and bunded terraces are well-constructed and managed by the farmers, especially for the cultivation of the monsoon paddy. These terraces are the most striking features of irrigated agriculture in the hills. The use of *tar*

[12] A system having only one hierarchy of common canal (main canal) is referred to as a one-order canal system.

scarp, however, depends on its slope. If the slope is very steep, it is used either as a *bari* or as a grassland; otherwise it is used as *khet*.

In the *tar*, houses are located in the vicinity of the *tar*, and most of the farmers live there. In the past, as in the *khola khet*, farmers used to live much higher in the hills, in the upper villages, which required significant time to travel. With the increase in population, pressure has increased on the *khet* land. Farmers have started cultivating more than one crop in the tar. It became difficult for the farmers to manage agricultural activities in the *tar* living in the upper villages. For about the last three decades, farmers who have *khet* in the tar have started living in its vicinity. Photo 2.2 shows slope-hill terraces (*tar khet*).

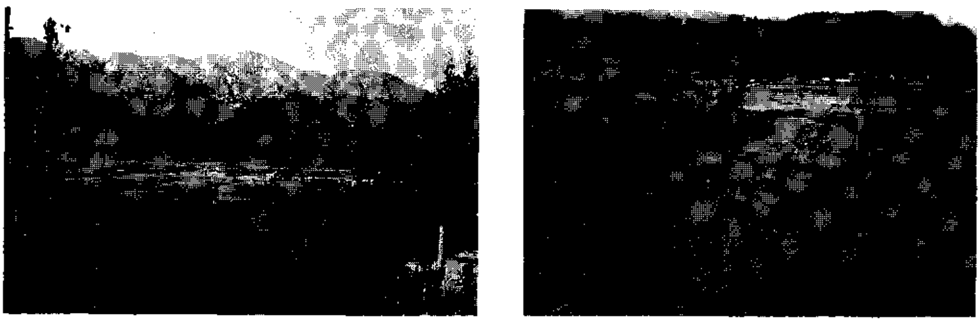

Photo 2.2: Slope-hill terraces (*Tar khet*)

Unlike in the *khola khet*, many farmers depend only on the *tar* for their livelihood. For this reason agricultural activities in the *tar* are very intensive and there is, as a result, very high cropping intensity under irrigated condition. Paddy, wheat and maize are the principal crops grown in the *tar*. Depending on the availability of water, two crops of paddy are also grown in some of the *tar*.

Slope-hill irrigation systems

The difference in level between these *tar* and the large or medium river flowing in the deeply incised valley floor is so high that the water from the river cannot be conveyed for irrigation. For this reason, water from the tributaries of these large rivers located in a different valley is tapped and conveyed to irrigate these *tar*.

The area of a tar varies from about 10 ha to more than 1,000 ha. The government-built slope-hill irrigation systems have areas up to 600 ha. However, most of the farmer managed slope-hill irrigation systems have areas varying between 15 and 60 ha.

Since the source river irrigating both the foothill and slope-hill irrigation systems is the same, in both the systems, the characteristics of the intakes (construction and maintenance) and river regime are similar. The main difference in the physical components between the foothill and slope-hill irrigation systems is that in the slope-hill irrigation systems, the idle length[13] of the main canals is usually much longer and the canal passes through difficult terrain. Therefore, the stability concern of the main canal, high conveyance losses and high resource mobilization for its maintenance are the common characteristics of slope-hill irrigation systems. A series of small and steep earthen contour canals aligned across the steeply sloped hills to irrigate layers of fragmented tar located at different elevations are the technical characteristics designed and developed by the farmers to reduce the conveyance losses, danger of instability and the maintenance requirement of the main canals.

In these systems, the distribution network consists of a hierarchy of two to three canals. The main canal is usually aligned along the contour and the secondary canals down the hill. Usually, the secondary canals are aligned along the valleys-mostly through the natural drainage. This is one of the main technical differences from the Terai irrigation systems, where the secondary canals are usually aligned along the ridge.

High conveyance losses, difficult maintenance of canal alignment, relatively large irrigated area and large flow fluctuations (especially during the monsoon season) are some of the causes of water scarcity, making water a valuable commodity. Resource mobilization for maintenance, allocation and distribution of valuable water, and resolution of water-related disputes are, therefore, the prime objectives of irrigation management. To fulfill these objectives these systems have an elaborate distribution network supported by organizational and institutional arrangements to match the environmental conditions.

Depending on the water supply, topography, crops grown and perception of equity, various methods of water distribution are used in an irrigation system. These methods are discussed separately in the following section.

Most of these systems are managed by specific irrigation organizations, while in a few of them the village-level political organization (VDC) manages the irrigation. Usually, a single-tiered irrigation organization consisting of 1-10 members in an executive committee manages the irrigation water. In some systems, the chairman is elected annually, while in some the post of chairman is hereditary. Social norms and traditional practices are the basis of system operation. Part of Bachcha, Sankhar and Patne Irrigation Systems are the examples of slope-hill irrigation system.

River-valley terraces and river-valley irrigation systems

The land located on the floor of a wide valley along the banks of a river is known as a river-valley. Like the *khola khet*, land in this category is also located in the same valley as the source river. However, this land exhibits considerable amount of differences compared to the *khola khet*. The major differences are: river-valleys allow a relatively large irrigated area; they have no effect of shading; and they are almost flat.

Because of the relatively flat and wide irrigated area, the irrigation systems in these types of land exhibit some of characteristics of the Terai irrigation systems. Pokhara, Chundi, Deukhari and Girwari in Nepal are some examples of river-valley systems.

[13] Based on a study of 41 irrigation systems in the hills, Ostrom *et al.* (1992) noted that the average length of the main canal is 2,159 m (76 m per ha and 34 m per household).

Like in the *tar*, in a river-valley also, houses are located close to or within the irrigated area. The majority of the farmers depend solely on this land for their livelihood. For this reason, agricultural activities in the river-valley are intensive and the cropping intensity is much higher. Because many of these river-valleys are connected to motorable roads, prospects of crop diversification are high. Paddy, wheat and maize are the main crops grown in the river-valley. In some areas, cash crops like potato, mustard and vegetables are also grown. Depending on the availability of water, two crops of paddy are also grown in some of these river-valleys.

River-valley irrigation systems
The source rivers irrigating river-valleys are relatively wide and have relatively flat gradients. As a result, these rivers have a meandering characteristic with a tendency of lateral shifting. During the monsoon, these rivers discharge substantial amounts of water. In some rivers, during the monsoon period, the level of water becomes so high that irrigation operations in the rivers become difficult so that farmers abandon all irrigation-related activities and rely on rainfall instead (Pradhan, 1989a). However, with the reduction in the water level, farmers again divert the flow from the river. Because of frequent flash floods occurring in these rivers, diversion weirs need frequent maintenance.

In such river-valley irrigation systems constructed by farmers, a headwork consists simply of a temporary diversion weir, and an open intake with some type of flow-controlling mechanism such as an orifice. The diversion weir constructed across the river checks the flow and raises its water level to feed the canal. Sengupta (1993) classifies this type of weir as diversion by check. A diversion weir is constructed by layers of boulders with brushwood in each layer. The brushwood is laid in such a way that the leaves are placed facing the upstream and the sticks downstream. Figure 2.3 shows a typical cross-section of a temporary weir. Boulders increase the stability of the weir by their gravity and brushwood leaves help deposit sediments upstream by partially sealing the holes between the boulders, which in turn reduces the leakage of water through the weir.

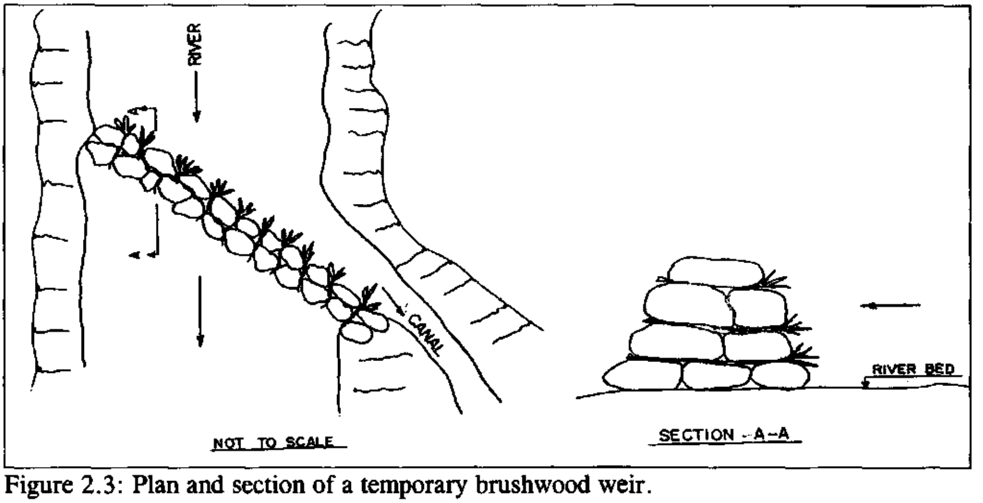

Figure 2.3: Plan and section of a temporary brushwood weir.

Unlike the conventional engineering design in which weirs are placed perpendicular to the direction of flow, the weir in these rivers is constructed skewed to the main direction of flow[14], as shown in Figure 2.3. The idea is to increase the crest length of the weir across the direction of flow. Although this increases the construction cost, it reduces the discharge intensity[15], thereby increasing the stability of the weir. With larger discharge intensity, the action on the river bed will be more intensive and the section will be heavier, though the crest length is also reduced. Further, a larger discharge intensity involves greater risk of outflanking and damage due to local concentration of flow (Singh, 1972:311).

The inclined weir also has some hydraulic advantages. The water level upstream of the weir (head of flow over the weir) fluctuates with the fluctuation of flow in the river. This fluctuation is reduced in the case of long crest length[16]. This hydraulic characteristic of a long crest weir has a direct impact on the operation of an irrigation system with an open intake. Note that the flow into the main canal through an open intake is also directly affected by the water level upstream of the weir. In a system with an open intake, with high flow fluctuation upstream of weir, inflow into the main canal would vary considerably. Thus, a weir with longer crest length stabilizes the inflow into the offtaking canal in contrast to a weir with a shorter crest length.

In these systems, the main canals are usually earthen and are aligned along the contour. These canals convey fairly large discharges. Because of the relatively easy terrain, they do not present much problem in conveying the flows. Unlike the slope-hill irrigation systems, the river valley systems require less attention to maintain the canals.

As mentioned earlier, because of frequent flash floods occurring in these rivers, diversion weirs need frequent maintenance. This makes the water available a valuable commodity. Like the slope-hill irrigation systems, these systems also require resource mobilization for maintenance of intake, allocation and distribution of valuable water, and resolution of water-related disputes, which become the prime objectives of irrigation management. To fulfill these objectives these systems also have an elaborate distribution network supported by organizational and institutional arrangements to match the environmental conditions.

As in slope-hill irrigation systems, in these systems, there is also likely to be a specific irrigation organization for managing irrigation water. Because of their large size, some systems have a two or three-tiered irrigation organization. Many of these systems have written rules and regulations. Julphe Irrigation System is an example of a river-valley irrigation system.

[14] Pandey (1995:55) notes that, in the Indian Himalayas, farmer-constructed weirs are usually laid at an angle between 30 and 60 degrees to the river axis. He further mentions that weirs constructed right angle to the direction of flow have to be replaced frequently.

[15] Discharge intensity is the flow per unit width of the weir.

[16] Flow over the weir is directly proportional to both weir crest length and head of flow over the weir.

2.4 Water allocation and distribution

The preceding section shows that by virtue of their location, the foothill irrigation systems receive relatively more water. Consequently, in these systems water distribution is not a major task. Unlike this, in both the slope-hill and river-valley irrigation systems, water which reaches the irrigated area becomes a valuable commodity, though the reasons are different. Accordingly, these systems have intricate network of distribution systems with some physical devices to distribute water, and water distribution is carefully managed.

This section describes and discusses the various principles of water allocation and methods of water distribution adopted by farmers in both the slope-hill and river-valley irrigation systems.

2.4.1 Principles of water allocation

Allocation–the assignment of water–from an irrigation system to an individual farmer or farmer's group specifies who will get how much water and when. As a principle agreed upon by the farmers, it also reflects the right of a farmer to irrigation water. The principles of water allocation may differ from crop to crop and may even change within the same cropping season. Some of the widely-adopted principles that determine water allocation in the hills of Nepal are:[17]

- in proportion to the size of a farmer's landholding in the irrigated area
- on the basis of a farmer's share, which may be determined on the basis of his initial investment
- on the basis of a farmer's purchased or inherited shares, or
- on the basis of a farmer's demand or request.

2.4.2 Water distribution

Water distribution is the process of implementing allocation principles and rules with the help of some division structures within an institutional arrangement sanctioned by the farmers. It is the actual process of making water available to the farmers through some division structures. The division structures can be either permanent or temporary, and can be made of stone, timber, brushes, bamboo and mud. Many water distribution methods developed by the farmers consist of physical devices, which are supported by institutional arrangements to ensure that the rules of water distribution match the physical devices. Some of the widely-used methods of water distribution are:

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[17] On the basis of their work in Spain and in the western parts of the United States, Mass and Anderson (1978), cited by Martin (1986), document six principles of water allocation in run-off-the-river diversion irrigation systems. These are: (a) farm priorities: farms are served in order of priority; (b) allocation by location: farms receive water in the order of their location along a canal; (c) shares: allocation in proportion to the area irrigated or by purchased shares; (d) rotation: allocation in proportion to area irrigated or by purchased shares; (e) crop: allocation by crop priorities; (f) Market: allocation by price, irrigators bid each period for water to irrigate their crops.

- continuous flow to every user on the basis of a fixed percentage of total water available
- continuous flow to certain sections of the irrigated area and timed rotation within each section as per some understanding agreed upon by the farmers
- by a person (operator) specifically assigned to supervise distribution, and
- distribution on demand or request. This method is usually used for winter crops in Nepal.

2.4.3 Water division structures

From the point of view of operation, Horst (1983) categorizes water division (distribution) structures into three types: open-close, gradual adjustment and fixed proportion. Gradual adjustment usually refers to a situation where flows are regulated gradually with the help of vertical spindle gates. However, in many irrigation systems in the hills, flows are adjusted (or regulated) more or less on an *ad hoc* basis with the help of stone or mud. This section, therefore, proposes another simple classification as an ad hoc adjustment instead of gradual adjustment.

Open-close

The flow in this type of distribution option is fixed and there is no need to split the flow into two or more parts. When closed the flow is zero; when opened the water flow is total. The open-close type of water distribution is mostly used at the lower end of a distribution system where the flow can easily be handled by individual farmers. Photo 2.3 shows an open-close water distribution structure. Water distribution by this method is discussed in detail in the case studies presented in Chapters 4, 5 and 6.

Photo 2.3: Open-close water distribution structure

Ad hoc adjustment

In this method, the flow is adjusted either by changing the opening of an orifice/turnout or by changing the operating head (the difference in water levels between the parent and the branching canals at the point of bifurcation). The operating head is changed by changing the upstream and the downstream flow conditions at the turnout. For example, putting an obstruction downstream of a turnout in the parent canal creates an afflux, which changes the upstream flow condition at the turnout, and the head is increased. Raising or lowering the water level at the branching canal can similarly change the downstream flow condition of a turnout. Photo 2.4 shows an ad hoc adjustment type of structure.

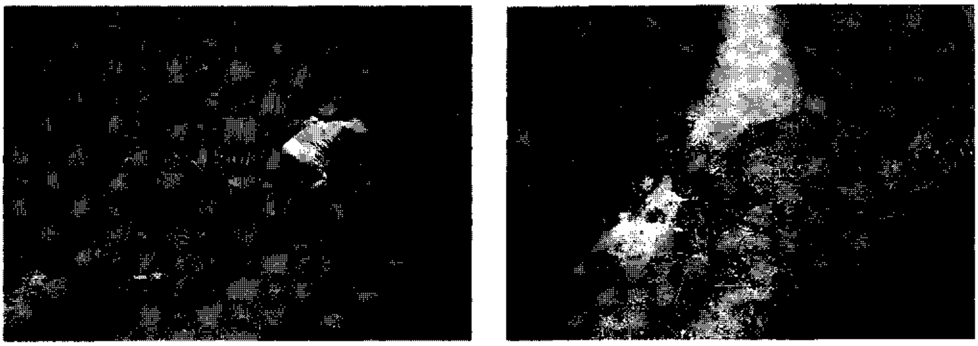


Photo 2.4: Farmers adjusting flows through ad hoc adjustment turnouts

Water distribution by this method is mostly used when the water needs to be split into two or more parts according to requirement. In this method, human intervention is essential to adjust the flow. The involvement of human in the flow adjustment raises a number of questions such as: Who diverts how much water, at what time and from what point of the canal? If all the farmers start diverting the water themselves, disputes may arise. Thus, this method of water distribution is heavily supported by institutional arrangements defining the above queries. Consequently, in systems distributing water by this method, water distribution is one of the main objectives of irrigation organization. In Nepal, two different models of water distribution using ad hoc adjustment methods are observed. They are:

- by controlling the size of a turnout based on certain rules. This model of water distribution is discussed in detail in Chapter 7 (Patne Irrigation System), and
- by a person (operator) specifically assigned to supervise distribution.

Water distribution by an operator specifically assigned to supervise distribution
In some irrigation systems, the operator is locally known as *thekedar,* while in others they are known as *pale*. The operator not only distributes water to different sections and sub-sections of the irrigated area but also irrigates the fields of all the farmers. The functions of an operator are different from those of a water guard whose function is limited to distributing water to canals. Water distribution by an operator is used under a mono-cropping system, especially for the cultivation of the monsoon paddy.

The operator usually belongs to the local area and enjoys the confidence of the farmers. Usually, he is paid in kind by the farmers as his annual remuneration. The operator does not have a fixed term for his service. As long as an operator satisfies the majority of the farmers, he continues in his job.

During the irrigation time, depending on the flow available, the operator diverts the flow into a few sections of the irrigated area simultaneously and irrigates the farmers' field in those sections. It is the responsibility of the operator to adjust the flow to each section in such a way that the field of all the farmers in that section is irrigated as per some agreed norms. In this method of water distribution, the farmer is not allowed to irrigate his field himself nor can he interfere with the responsibility of the operator. If the farmer discovers that the operator is not properly supervising the irrigation of his plot, he has no redress but to report his suspicions to the users' committee. In this sense, water distribution management in this method is more centralized.

Distribution of water through an operator requires substantial financial resources because he has to be remunerated. Because the competition to obtain irrigation service is high in this method, water-related disputes are frequent (Pant, 1998; Yoder, 1994a). However, farmers prefer this method because they do not have to be present in their field to irrigate them. Once a farmer completes transplantation of paddy in his field, he can simply go to his field to harvest, unless by any reason his terraces are damaged or he wants to fertilize them.

Fixed proportion

The flow in this method is passed through a fixed opening (orifice or weir[18]). The shape and size of the opening and the water level in its upstream and downstream determine the flow through it. In the hills of Nepal, mostly fixed proportioning weirs are used for this purpose. Photo 2.5 shows a wooden proportioning weir. Water distribution by this method is used when the flow in the canal needs to be divided into two or more parts corresponding to the irrigated area or water share allocated to each farmer or farmers' group served by the branching canals. Water distribution by this method is discussed in detail in the case studies presented in Chapters 4, 5 and 6. The forthcoming chapter describes the physical and managerial aspects of such proportioning weirs.

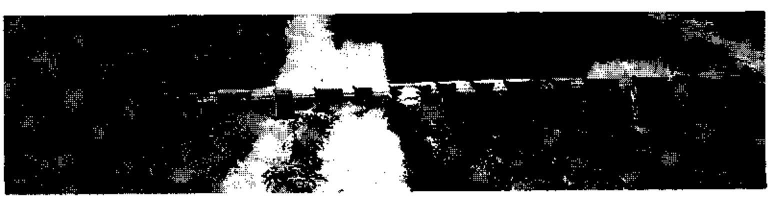


Photo 2.5: Proportioning weir

2.5 Summary

In Nepal, over 75 per cent of the land area are covered by hills and mountains, which have great variations in altitude within a short horizontal distance. As a result, the climate shows considerable variations, which in turn gives rise to great ecological diversity and complexity.

Nepal is basically an agricultural country. Over 90 per cent of the population directly or indirectly derive their livelihood from agriculture, and about 80 per cent of them are classified as subsistence farmers with an average landholding of less than 0.5 ha per

[18] Functioning of the orifice and weir are hydraulically different. In the orifice type of division structure, fluctuation of water in the branching canal is not in the same proportion as in the parent canal. In contrast, in the weir type of division structure fluctuations of flows in the branching and parent canals are in the same proportion.

household, especially in the hills. Farmers in the hills practise mixed farming with the cultivation of paddy, wheat and maize as the principal cereal crops.

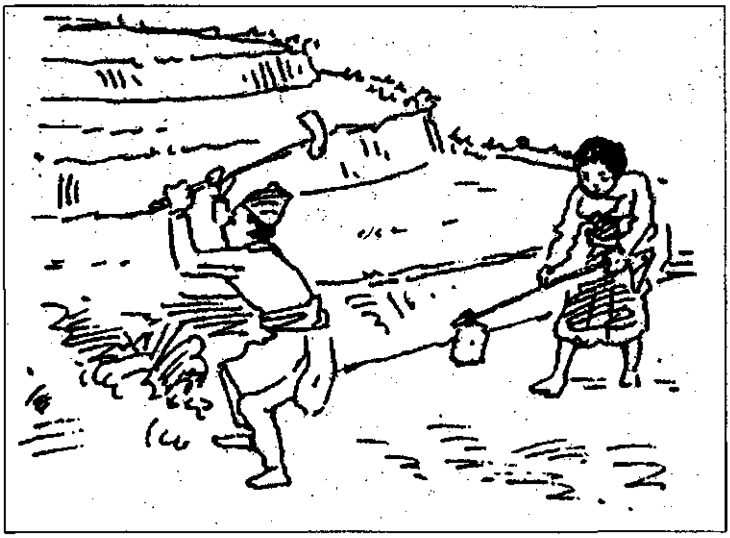
All over the hills of Nepal, farmers have developed indigenous irrigation systems, using local ingenuity and skills. Community participation is an important feature in their management. Over 90 per cent of the irrigated areas in the hills are covered by these indigenous systems. The physical components and the operating conditions of these irrigation systems vary greatly with the ecological condition and social organization of the area.

Based on the type of irrigated land, the irrigation systems in the hills are classified into three types: foothill, slope-hill and river-valley irrigation systems. The relative significance of various physical components such as intake, conveyance canal, distribution structures and management practices differ for each.

Foothill irrigation systems are located in the gorge, and most of them are shaded during some part of the day. No human settlement is seen in their vicinity, which in turn reduces their cropping intensity. These systems support only in part the food demand of farmers. By virtue of their location right along the river banks, slightly above the river floor, water supply to these systems is relatively high. Also, these systems exercise prior right of irrigation water compared to slope-hill irrigation systems. As a result, water allocation and distribution is not an important task. Also, because of much shorter idle length of the main canal and relatively easy intake, their maintenance is also relatively simple. In summary, the intensity of management required to operate these systems is much lower. Consequently, these systems lack well-defined organizational and institutional arrangements.

Unlike in the foothill irrigation systems, in both the slope-hill and river-valley irrigation systems, many farmers live in the vicinity of the irrigated area, and most of them depend solely on these systems for their livelihood. As a result, cropping intensity in these systems is relatively high.

In slope-hill irrigation systems, by virtue of the system's location much above the river, the canal length is relatively long, and the canal passes through difficult terrain. High conveyance losses, difficult maintenance of canal alignment and relatively large irrigated area are some of the causes of water scarcity, making water a valuable commodity. In contrast, in the river-valley irrigation systems, the conveyance canal is relatively easy to maintain and availability of water at the source is not a problem. Rather, frequent maintenance of the intake due to damage caused by frequent flash floods makes water a valuable commodity. This is because the source river irrigating river-valleys is relatively wide and carries substantial amounts of flow with frequent flash floods during the monsoon. Thus, both the slope-hill and river-valley irrigation systems have elaborate distribution networks supported by organizational and institutional arrangements to manage irrigation water. Many of these systems consist of some physical devices for distributing water. Of these devices, the proportioning weir is one most commonly used in the western hills of Nepal.



3. Design Considerations of Proportioning Weirs

The farmers in many countries since long back are using indigenous wooden proportioning weirs as a water distribution device. As with other water distribution structures, the design of a proportioning weir is largely dictated by hydraulics, topography, water availability and operational requirements. This chapter aims to analyze the hydraulics of this structure and some of its operational requirements, and the topographical constraints influencing the design of proportioning weirs. It also analyzes how farmers incorporate these requirements in the design to achieve proportionality of the proportioning weirs.

This chapter is based on the detailed study conducted on the Sankhar Irrigation System where a proportioning weir was mapped in detail and time series flows through its notches were recorded. The reasons for selecting the Sankhar Irrigation System have been explained earlier in chapter 1.4. The study in this chapter is further supported by the detailed case studies conducted on Bachcha and Julphe Irrigation Systems.

The chapter first describes, in Sections 3.1 and 3.2, indigenous proportioning weirs and their hydraulic characteristics. Salient features of the Sankhar Irrigation System are described in Section 3.3, though this irrigation system is also described and discussed in greater detail as a separate case study in Chapter 6. In Section 3.4, the flow measurements and constraints are discussed. Sections 3.5 and 3.6 discuss the hydraulic requirements and the methods adopted by the farmers to achieve proportionality of the proportioning weirs. The design of the weir width based on the operational, topographical and hydraulic requirements are discussed in Section 3.7. The chapter ends with a summary and some concluding remarks in Section 3.8.

3.1 The indigenous proportioning weir

An indigenous proportioning weir is a simple control structure, and is placed across the direction of flow (Figure 3.1). This structure divides the water in a canal into two or more parts, each of which corresponds to the water share allocated to each farmer or farmers' group served by the branching canal. The basic objective of proportional distribution is to proportionally distribute irrigation water to each branching canal. This means that the quantities of water flowing in the parent and in the branch canals are equally affected by any variations in the level of water in the parent canal.

The use of this type of structure by farmers in other countries, especially in mountain environments, has also been widely documented[1].

[1] The use of this structure is also found in other countries. In West Sumatra, Indonesia, proportioning weirs are called *Paraku* (Ambler, 1990); in Pakistan, they are called *Chaukhat* (Dani and Siddiqi, 1989); in Sri Lanka, *Karhankota* (Leach, 1980); in the Philippines, *Tablon* and *Padila* (Yabes, 1990); in Himachal Pradesh, India, *Thelu* (Coward, 1990); in Bhutan, *Gahs* (Pradhan, P, 1989) and in Nepal, a proportioning weir is known by several names, including *Sancho Dhara* and *Gaav*. This is not an exhaustive list. Ambler (1994) lists a number of other countries using this device and their local names.

Most of the proportioning weirs are made of timber and have several rectangular notches of uniform depth cut into them. In recent years a few cement weirs are also being used. To ensure that the flow of water is proportional to the width[2] of the notches, the sills of all the notches are kept at the same level. Only the width of the notches is varied to increase or decrease the flow.

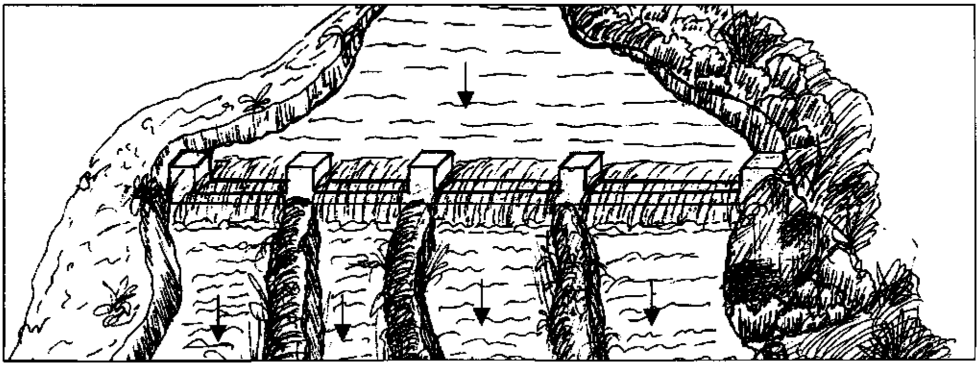


Figure 3.1: Proportioning weir

Once water distribution by proportioning weir starts, the irrigation system becomes rigid. Farmers have no opportunities to take extra water. The system runs automatically with no need to open or close or adjust the flows. Thus it does away with the need for an operator.

With the installation of proportioning weirs, equity in water distribution is judged by measuring and comparing the width of notches. Except for one rule, that is, no farmer is allowed to block other farmers' notches, the irrigation system runs without regulations.

Water distribution by proportioning weirs has the following distinct characteristics: visible distribution with reduced guesswork, it is also simple, understandable and measurable by a farmer with respect to other farmers water supply. These characteristics reduce water-related disputes. Also, when they are nested together, it reduces the management activities by reducing the number of control points.

3.2 Hydraulic characteristics of a proportioning weir

Figure 3.2 presents a simple water division layout. To judge the proportionality of the structures, the concept of hydraulic flexibility should be considered.

3.2.1 Hydraulic flexibility

In Figure 3.2, the inflow, Q, in the parent canal is distributed into two branching canals, Q_1 and Q_2. If, for any reason the water level in the parent canal is changed, will the flows, Q_1 and Q_2, change by the same percentage? To answer this question, the concept of

[2] In this text, the width of the structure or any part of it refers to the width across the direction of flow. Similarly, the length and the height (depth) are always mentioned along and perpendicular to the direction of the flow.

hydraulic flexibility (F) is used. It is defined as the ratio of rate of change of flow in the offtake canals.

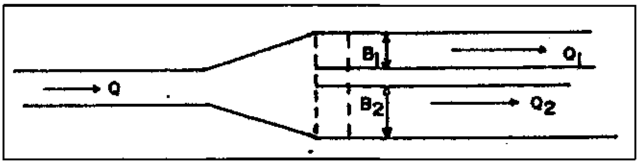


Figure 3.2: Water division layout.

By definition, $F = (dQ_1 / Q_1) / (dQ_2 / Q_2)$
To be proportional, $F = 1$ and thus $dQ_1 / Q_1 = dQ_2 / Q_2$

3.2.2 Basic hydraulics of the weir

The basic equation of the stage discharge relation of a rectangular weir with control section (critical stage of flow) occurring somewhere above the weir axis is given by:

$$Q = C_d * C_v * K * B * (h_1)^{1.5}$$

where, K= constant (numerical constant including gravitational acceleration); C_d = Coefficient of discharge; C_v = Coefficient of velocity; B = Width of weir; h_1 = Upstream head measured with respect to notch crest

The fundamental criterion of the above equation is that the critical section must occur somewhere above the weir axis, which means the flow must be critical above the weir. For this reason, the downstream crest reference head, H_2, should be sufficiently smaller than the upstream crest reference head, H_1 (Figure 3.3). Otherwise, the criterion of critical flow will not be maintained.

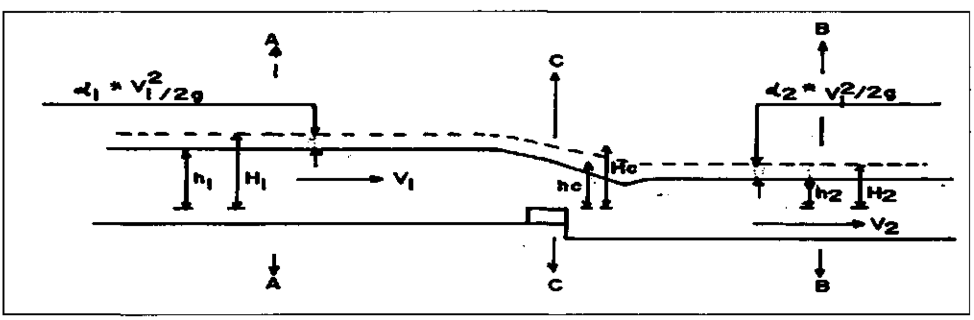


Figure 3.3: Flow through weir.

In Figure 3.2, assuming the critical section occurs above the respective notches of the weir:

$$Q1 = C_{d1} * C_{v1} * K * B_1 * (h_1)^{1.5}$$
$$Q2 = C_{d2} * C_{v2} * K * B_2 * (h_1)^{1.5}$$

The values of K and h_1 are the same for both the notches (having the same crest level), and B_1 and B_2 are constants. The structure is then approximately proportional for constant flow if the coefficients of discharges and velocities are the same for both the notches. However, for the varying flows, if the rate of change of C_{d1} and C_{v1} is equal to the rate of change of C_{d2} and C_{v2} respectively, then the flexibility of the structure becomes one (F=1) and proportional distribution is achieved.

Coefficient of velocity

The coefficient of velocity (C_v) corrects for the use of crest reference head of water surface (h_1) instead of crest reference head of energy line (H_1) in the above head discharge equation.

$$C_v = (H_1/h_1)^{3/2}$$
$$= [1 + \alpha_1 V_1^2 / 2g]^{3/2}$$

where α_1 and V_1 are the velocity distribution factor and the approach velocity respectively.

From the above equation, it is clear that the value of approach velocity, V_1, and the velocity distribution factor, α_1, affect the value of C_v. If the approach velocity, V_1, is very small and distributed uniformly (in the case of the stilling basin upstream of the weir), then the energy head ($\alpha_1 V_1^2/2g$) will be very small. In such a case the value of C_v just exceeds one. On the other hand, if V_1 is quite high and distributed non-uniformly, then C_v will have significant value. Under such cases the proportionality of the weir will not be maintained.

Coefficient of discharge (C_d)

The head discharge relationship of a weir assumes the following conditions:

(a) There is no energy loss between sections A-A and C-C (Figure 3.3)
(b) Velocity distribution is uniform at both the above sections, and
(c) There is rectilinearity of parallel streamlines

In reality, these assumptions are rarely found. Hence, the coefficient of discharge is introduced to take into account the effect of energy losses due to friction and curvature of the streamlines. In general, C_d is a function of the head causing the flow, length of the crest, the roughness of the crest and the h/L ratio. These elements are reasonably similar for all the notches of a proportioning weir.

3.2.3 Flow constriction

In a proportioning weir, when the flow enters a notch, flow constriction occurs, as shown in Figure 3.4. The small notches could be affected more by this constriction than the wide notches. The constriction effect along with the friction losses may cause differential flow fluctuation through the notches, affecting the proportionality of the weir. The effect of flow constriction is usually so complicated that the result of the flow pattern is not readily subject to any analytical solution.

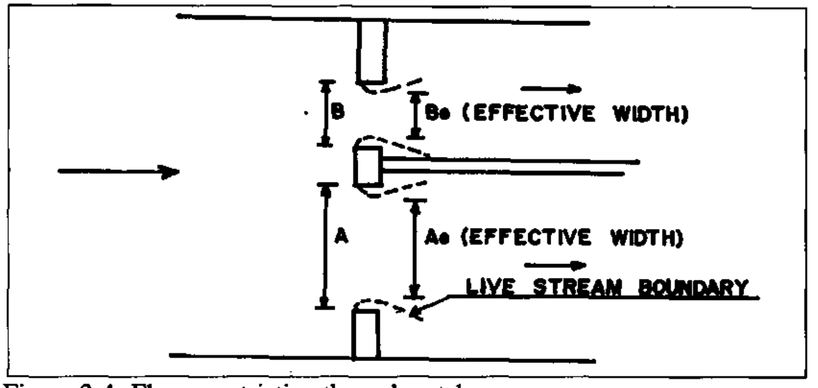


Figure 3.4: Flow constriction through notches.

The factors increasing the effect of flow constriction are:

- The state of flow upstream of the proportioning weir
- Influence of surface tension and viscosity because of the sharp-edged notches at the entrance. This effect could reduce the effective width as well as effective head of the flow through the notch.
- h/L ratio of the proportioning weir
- Boundary geometry of the notch, and
- The curvature of the streamlines of the flow entering the notch

In short, the state of flow above the weir, coefficient of velocity (C_v), coefficient of discharge (C_d) and the effect of flow constriction are the four main factors influencing the proportionality of the weir. Other than the effect due to flow constriction, the following conditions should be fulfilled to achieve proportional distribution:

(a) Critical state of flow above the weir axis
(b) Uniform distribution of velocity upstream of the weir, and
(c) Minimum approach velocity upstream of the weir.

3.3 Sankhar Irrigation System[3]

The Sankhar Irrigation System, located in the Syangja district of Western Nepal, is a farmer managed gravity irrigation system. This system irrigates about 37 ha of land, using the water of a small stream draining across its hill side. The average slope of the irrigated area varies between 2 and 3 per cent.

The average canal discharge during the cultivation of the monsoon paddy season (July to October) varies between 70 and 110 lps. Monsoon paddy is the main crop in the area followed by wheat in the winters and maize or early paddy in the spring season (April to June).

[3] For a detailed description of the Sankhar Irrigation System, see Chapter 6.

The canal system consists of a temporary diversion at the intake, a 1.3 km long main canal, two branch canals, namely Thado Kulo and Terso Kulo, 12 distributary canals and numerous field channels. Figure 6.2 shows the canal layout plan of the irrigation system in a topographical map. Other than the above physical components, the indigenous wooden proportioning weirs placed at all canal bifurcation points to continuously distribute water to every user, especially during the monsoon paddy season (July to September), are the most striking features of this system.

The available water is considered to be 2,270 units of water shares, locally known as *mato muri*[4]. This water is distributed among 112 farmers according to their shares with the help of 61 such proportioning weirs. Figure 6.6 shows the schematic layout of the distribution system and the proportioning weirs with their water shares.

Of the 61 proportioning weirs, the main proportioning weir, locally known as Dui Dhare, was selected to study the combined effect of flow constriction and friction losses. Figure 3.5 shows the layout plan and section of Dui Dhare. The reason for its selection is that, during the spring season (April to June), only three proportioning weirs in the main canal were in operation, with the first two weirs having insufficient head to install measuring flumes downstream. The other reason for its selection is that this weir has four notches with large variations in their widths. It was presumed that the effect of flow constriction could be clearly seen in such weirs.

Of the four notches, two larger notches distribute water to two branch canals, known as Thado Kulo and Terso Kulo. However, two smaller notches distribute water to individual farmers' field channels, known as Chalees Muri Ko Kulo and Bees Muri Ko Kulo. The total incoming water to this weir is considered to be 2,230 *mato muri*. Table 3.1 presents the notch width, water share and crest level of each notch.

Table 3.1: The widths, water shares and crest levels of the notches in Dui Dhare.

Branch canal From right to left	Notch width (cm)	Water shares (in *mato muri*)	Crest level of the notch (in metre)
(a) Terso Kulo	201	1000	368.584
(b) Chalees Muri Ko Kulo	(with *moko*[5]) 10	40	368.586
(c) Thado Kulo	235	1170	368.585
(d) Bees Muri Ko Kulo	(with *moko*) 6	20	368.586
Total	452	2230	

Source: Field measurements (April 1996).

Note the accuracy of the crest levels of the weirs (Table 3.1), considering the indigenous way of installing the weirs based on the principle that water finds its own level.

The depth and the length of the notches are 6.7 cm and 20 cm respectively. The crests of the notches are slightly inclined downwards in the direction of the flow. This inclination is not uniform throughout the weir width, and varies between 0.3/20 and 1/20 (1.5 and 5 per cent). It seems that the warping of the timber due to weathering caused this inclination. In

[4] In this text, *mato muri* is used mainly to designate water share. For a more detailed definition, see section on water allocation in Chapter 5.

[5] *Moko* is an additional width provided to the smaller notches (refer Section 3.7).

this weir, the h/L ratio[6] varies between 0.1 and 0.4. Accordingly, this weir is classified as a broad crested weir (ISO 3846, 1977).

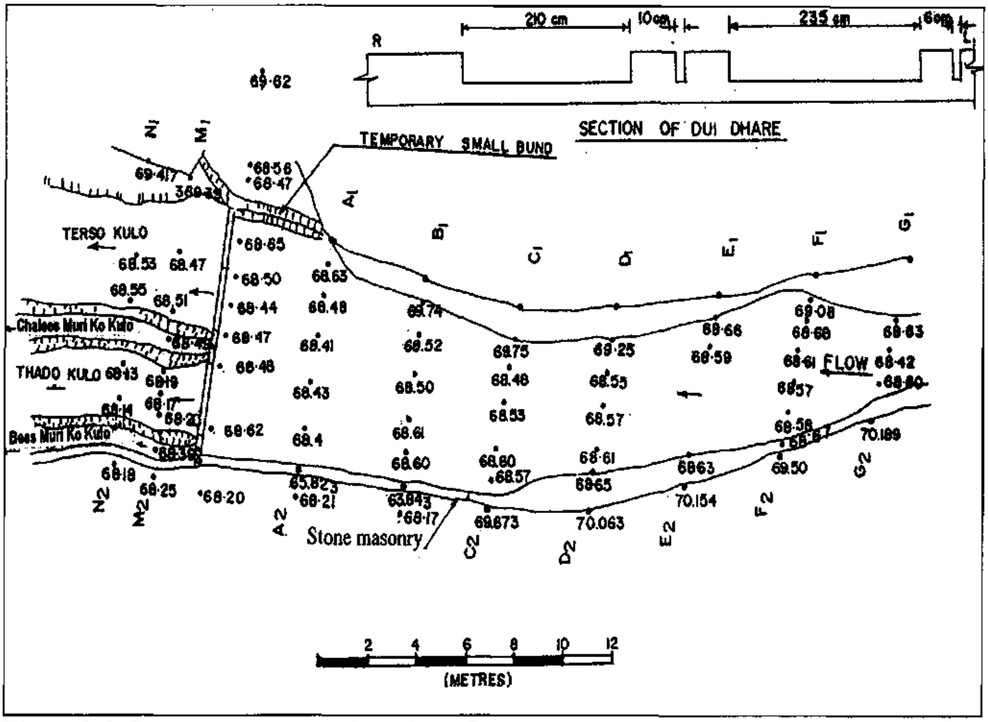


Figure 3.5: Layout plan and section of Dui Dhare

3.4 Flow measurements and constraints

A time series flow (April to June) through all the notches of Dui Dhare were measured. Though it was intended to measure the flow during the entire operating season of the proportioning weir (April to September) to cover a wide range of supply level, because of some difficulties, explained later in this section, it was not possible to measure the flow during July to September.

3.4.1 Flow measurements

To measure the flows, cut-throat flumes were selected because of their simplicity. A cut-throat flume creates less head losses and can also work even under submerged condition (Keller, 1984; Skogerboe, G. V. *et al.*, 1972). Head losses and the flow to be measured were the main criteria for the selection of the flume size. In Terso Kulo, there was a vertical drop of 32 cm between the crest of the notch and the downstream canal bed. Estimating the average monsoon flow of about 75 lps in both Terso Kulo and Thado Kulo, cut-throat flumes 30 x 90 cm in size were selected and installed about 5 m downstream of

[6] h/L ratio refers to the ratio of the head of the flow above the crest to the length of the crest along the direction of flow.

the proportioning weir. With this flume size, the maximum upstream head required for free flow condition through it was 28.5 cm and the upstream head to length ratio remained less than 0.4 for greater accuracy (Kraatz and Mahajan, 1975). Also, with this maximum head of 28.5 cm for the flume, free flow through the respective notches of the proportioning weir located upstream could still be maintained. Equations and curves given by Kraatz and Mahajan (1975) have been used to compute the flows through the cut-throat flumes.

During the period April to June, flow through the central Chalees Muri Ko Kulo notch was rejoined with the flow in Terso Kulo immediately downstream of the proportioning weir. This is because the stream size in Chalees Muri Ko Kulo was very small in comparison to the canal length. There was no space to install a flume for measuring the flow in this canal. As the flows were very small in both Chalees Muri Ko Kulo and Bees Muri Ko Kulo, flows through them were measured directly by collecting the water in a container of known volume for specified time. Every day three consecutive readings were taken at the same time, and the average of the three readings was taken for analysis. The flows through the notches were measured daily at the same time.

A staff gauge was installed 33 m upstream of the weir in a rectangular lined section to measure the flow upstream of the proportioning weir. The water surface elevations 30 cm upstream of the weir were also recorded to measure the head of the flow in the proportioning weir.

3.4.2 Difficulties in flow measurements in the field

Installation of any flow measuring device in a canal creates afflux upstream. Therefore, head loss was considered as the main criterion in the selection of the flume size. As stated earlier, cut-throat flumes were installed in the canals and a range of flows varying between 7 and 48 lps were measured during the spring paddy season.

During the monsoon season, the afflux created by the flume in Terso Kulo became a problem. In early July, a group of farmers from Terso Kulo requested the researcher to remove the flume from the canal. They argued that the afflux created by the flume upstream would induce seepage through the banks and bed of Terso Kulo into Thado Kulo because the former is at a higher elevation than the latter. They suspected that the afflux could also affect the functioning of the weir. They argued that despite the ponding in the canal during the period April to June, they had co-operated by allowing the installation of the flume and so during the monsoon they should be helped by removing the flume from the canal.

Some of the points farmers had raised were theoretically valid. However, cut-throat flumes were so designed and installed that up to a flow of 100 lps (which never occurred in practice), the afflux would not have any effect on the functioning of the weir. Nevertheless, the researcher did not argue with them as the farmers had no experience regarding the functioning of the cut-throat flumes. The researcher gave them the permission to remove the flume.

The next day even the other flume located in Thado Kulo was removed, although practically there was no affect of afflux because the canal was completely in cutting[7]. The farmers simply said that there was no sense in keeping the flume in Thado Kulo since the flume in Terso Kulo had already been removed.

Similar incidents were observed by TMS Pradhan[8] in 1992 when he was doing his field research.

This shows that farmers are very much aware and concerned about water losses through canal banks and bed. For this reason, they do not want to have any obstruction in the canal for a long period of time.

The available flumes were too large to measure the flows in the lower order canals, and it was not possible to arrange another set of suitable flumes in a short time because of inaccessibility. Also, with the set of data that had already been collected, it was realized that the differential flow fluctuation through the notches is very much site-specific, and it is not possible in the field to measure the flow up to that accuracy within which the actual differential flow fluctuates.

3.4.3 Accuracy of the flow measurement in the field

Accuracy of the flow measurement in the field depends on the accuracy in the fabrication and installation of flume, accuracy in the head measurement, and the accuracy of the equations and curves used to compute the flow. In a small-sized measuring device with a small head of the flow, the percentage change in error is magnified by minor errors in the fabrication/installation of flume and measurement of flow depth.

In this study, flumes fabricated by the DOI for the general purpose of water measurement were used. They were made of mild steel. Although the accurate measurement of the throat width, especially at the bottom, was very difficult, the dimensions were checked up to the possible accuracy of an ordinary steel ruler. The dimensions almost conformed to the standard size.

Besides the fabrication errors, what is important to mention here is that the flume plates had deformed during the process of their transportation to the site. Because of the inaccessibility, the flumes had to be transported by various means. By the time they reached the site, some of the flumes were deformed because of excessive jerking and vibration along the rough hill roads while transporting them on the trolley of a tractor.

[7] Canals in cutting refer to those canals which have their sections located below the average ground level.

[8] Based on personal communication. The incident narrated by TMS Pradhan was as follows:

In Pithuwa irrigation system, when he installed a measuring device downstream of the turnout to measure the flows through it, he had to shift the instrument two times downstream of the canal because the farmers suspected that its afflux affected the functioning of the turnout, though there was hardly any effect. Similarly, in Banganga Irrigation System, farmers diverted the flow from upstream of the measuring device through its side and again rejoined it with the canal downstream without disturbing the measuring device. Also, refer to Pradhan (1996) for the above incident in Pithuwa irrigation system.

Although they were repaired by a local blacksmith, their accuracy was only up to the tape measurement and the eye judgement.

During the period of flow measurement, repeated unequal settlements of the flumes across the direction of flow were observed, though the flumes were installed on firmed ground with compacted earth fill. The maximum value of unequal settlement was observed to be 7 mm. This may have been caused either by human interference[9] or by the seepage through the sides or bed of the flume because of ponding upstream. To compensate for this, heads of flow were measured on both of its sides and the average of the two readings were taken, as suggested by Utah Water Research Laboratory (1967).

The heads of the flow were measured at the specified location on an ordinary steel scale. The flumes did not have any measuring well to reduce the effect of water surface irregularities. Direct measurement of flow depth of about 7 to 12 cm in a 50 cm deep flume might have increased errors because of the higher angle of inclination of eye sight. To reduce this error, a smooth piece of timber of known depth was fixed on the top of the flume and the water surface depths were measured from the top surface. The readings were then subtracted from the total depth to get the actual depth of flow. However, repeated measurements show some variations in the water depth (about 2 to 4 mm), which may have been caused either by irregularities in water surface or by human errors. In a smaller flow range (about 8 to 10 lps), such small errors in head measurement would result in an error of about 5 per cent in the total flow.

In the vertical gauge fixed in the canal upstream of the proportioning weir, the percentage error was even higher because the gauge was marked up to an interval of 10 mm and to read within 10 mm an eye judgement had to be made.

3.5 Farmers' considerations of hydraulics in the design of proportioning weirs

As discussed earlier, the proportionality of a weir is influenced by the following three hydraulic criteria:

- Critical state of flow above the weir axis
- Velocity distribution and approach velocity upstream of the weir, and
- Effect of flow constriction in the case of large variations in the notch widths.

Farmers are aware of these hydraulic effects by experience. Various methods adopted by the farmers to achieve uniform velocity distribution, minimum approach velocity and the critical state of flow were observed and analyzed. These methods are discussed below.

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9 After the installation of the flumes, which were completely new to the farmers, many people used to come and see the functioning of the flume. They used to ask different questions and would also try to shake them to see how firm they were. It became a very good place to play, especially for those children who came to swim in the canal upstream of the proportioning weir.

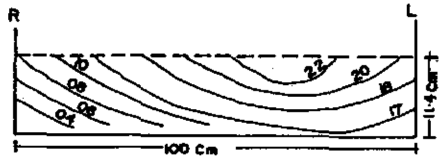
First, a proportioning weir is located only at such places where a canal is reasonably straight, gently sloping and free from any local obstructions. In a bend or steep canal, the flow velocity would be high with uneven distribution across its section.

Second, a pond is created upstream of the proportioning weir by raising the weir above the normal canal bed. By doing so, water falls freely into the branching canals. This fulfills the criterion of the critical state of flow. Raising the weir above the normal canal bed also helps minimize the approach velocity and distribute the flow velocity more evenly as it approaches the weir. The following discussions verify this.

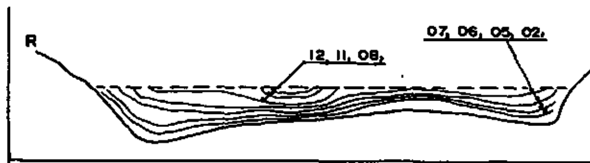
Referring to Figure 3.5, unlike the conventional engineering structures where the canal width converges towards the structure and diverges again in its downstream, the canal width here is first expanded to 7.3 m from the normal width of 1.0 m. The length of the diverging section of the canal, hereafter referred to as the approach canal, is about 30 m. At the end of the approach canal, the proportioning weir is installed on a temporary stone wall constructed above the canal bed. The crest of the notch is located about 32 cm above the average upstream canal bed. The percentage opening of notches with respect to the total weir (canal) width is about 61 per cent. This percentage opening has important implications because if it is very small in a canal with negligible approach velocity, the shape of the approach canal will be insignificant (ISO 1438, 1975).

Figure 3.6 presents the velocity distribution[10] across the three sections of the approach canal. By creating a pond upstream of the weir, the change in the velocity distribution pattern and the reduction in the average approach velocities can be clearly visualized. Velocity distribution which was concentrated on the left bank of the canal at the section 33 m upstream (Figure 3.6a) became more even at the section 15 m upstream (Figure 3.6b), and further became almost uniform at the section 1.5 m upstream (Figure 3.6c). Note that the velocities were measured by a pigmy current-meter. At section 1.5 m upstream of the weir, the flow velocities at various depths were so low that the current-meter could not record them. Out of a total of 42 measurement points, a surface velocity of only 4 cm/sec was observed at two points. Such a low velocity of 4 cm/sec near the surface may also have been caused by wind action along the water surface. The area of flow, average approach velocity and the measured flow at the above three sections are presented in Table 3.2.

[10] To observe the change in the approach velocity and the velocity distribution pattern in the approach canal, three sections across the approach canal, 1.5, 15.0 and 33.0 m upstream of the weir axis, were selected. Each section was further sub-divided into various sub-sections and at every sub-section velocities were measured by current-meter at various depths.

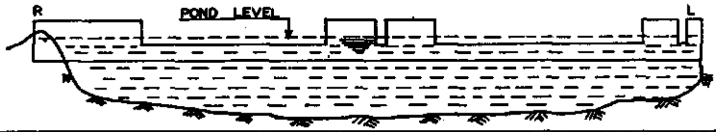


(a) At Section 33 m upstream of weir (April 1996)



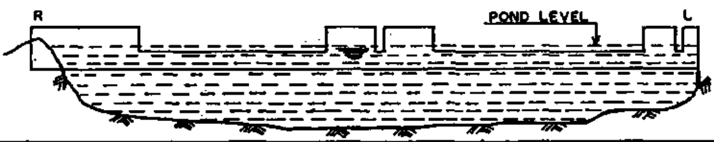
DISTANCE (M)	0·5	1·0	1·5	2·0	2·5	3·0	3·5
WATER DEPTH (M)	0·15	0·11	0·07	0·07	[illegible]	0·08	0·10

(b) At Section 15 m upstream of weir (April 1996)



DISTANCE (cm)	50	100	200	250	300	350	400	450	500	550	600	650	700	750
WATER DEPTH (cm)	21	26	30	30	32	32	32	30	30	30	30	25	25	20
VELOCITY: WATER SURFACE	-	-	-	04	-	-	-	-	-	-	-	04	-	-
VELOCITY: 5 cm BELOW SURFACE	-	-	VELOCITY BELOW SURFACE ARE ALL ZERO						-	-	-	-	-	-
VELOCITY: 10 cm BELOW SURFACE	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(c) At Section 1.5 m upstream of weir (April 1996)



DISTANCE (cm)	50	100	200	250	300	350	400	450	500	550	600	650	700	750
WATER DEPTH (cm)	22	27	30	30	32	34	34	35	32	33	32	28	27	20
VELOCITY: WATER SURFACE	-	-	-	-	-	-	-	-	08	04	09	08	-	-
VELOCITY: 5 cm BELOW SURFACE	-	-	-	-	-	-	-	-	06	04	07	06	-	-
VELOCITY: 10 cm BELOW SURFACE	-	-	-	-	-	-	-	-	04	04	04	04	-	-
VELOCITY: 20 cm BELOW SURFACE	-	-	-	-	-	-	-	-	04	-	-	04	-	-

(d) At Section 1.5 m upstream of weir (July 1996)

Figure 3.6: Velocity distribution in cm/sec

Table 3.2: The area of flow, average approach velocity and the measured flow at different sections of the approach canal.

Sections	Area of flow (sq m.)	Average approach velocity (cm/sec)	Measured flow (lps)
33 m upstream	0.1156	15.50	17.91
15 m upstream	0.3125	5.15[11]	17.19
1.5 m upstream	2.1925	0.73[12]	16.07[13]

Source: Field measurement (April 1996).

To study the change in velocity distribution and the approach velocity in a high flow condition, velocity distributions were again measured at the section 1.5 m upstream of the weir in July 1996. Figure 3.6d shows this velocity distribution. The head over the crest and the corresponding flow on that day was 4.7 cm and 85.8 lps respectively.

Although some differences were noted in the velocity distribution, their values still remained below the recommended value of 15 cm/sec (Hansen *et al.*, 1979). For this reason, even in the higher flow, significant differential flow fluctuations are not likely to exist. The differential flow fluctuations through the notches, if any, would be so small that it would be difficult to trace them out in the field, unless a laboratory model test is conducted.

The third method used by the farmers in Nepal to minimize the approach velocity is to construct a check weir upstream of a proportioning weir (Pradhan, N, 1990; Yoder, 1994).

The fourth method used by the farmers to achieve proportional distribution of water is to make all the notches of equal width first, then two or more flows are rejoined again downstream of the weir to convey in a single canal. This method has also been used in Bhutan (Yoder, 1994). This method requires wider weirs. A wider weir means more area of flow upstream and smaller percentage of the opening across a structure. This ultimately results in the reduction of the approach velocity and distributes the flow velocity more evenly as it approaches the weir for distribution.

Further, this method also helps reduce the effect of flow constriction and friction losses if the h/L ratio exceeds 0.4, as explained in the forthcoming section. The reason is, the effect of flow constriction and friction losses would also be similar to all notches because of their similar notch width.

3.5.1 Length of the approach canal and the width and the height of the weir

The above discussions imply that the length of the approach canal, and the overall width and the height of the weir are three important physical features to conform to achieve

[11] Average of the velocities at all the sub-sections.

[12] Computed average velocity (dividing the flow measured by cut-throat flumes installed downstream of the weir by the flow area of the section 1.5 m upstream of the weir).

[13] Flow measured by cut-throat flumes installed downstream of the weir.

uniform velocity distribution and acceptable approach velocity for proportional distribution of water.

Length of an approach canal

Regarding the length of the approach canal required to achieve uniform velocity distribution, ISO 4374 (1990) states:

> "A length of the approach channel equal to five times the water surface width at maximum flow will usually suffice, provided that the flow does not enter the approach channel with high velocity..."

In Dui Dhare, the criterion laid by ISO 4374 (1990) was fulfilled.

This indicates that the proportioning weir is best suited for a canal conveying water with a low velocity. In an irrigated area having a steep land slope, canals aligned down the slope are also steep. The flow velocity in such canals is quite high and turbulent. Under such conditions, it is difficult to have a long and flat approach canal to bring the approach velocity within a reasonable value. Also, on steeply sloped land, the topography restricts the alignment of distribution canals. It is difficult to align distribution canals wherever needed. These problems are further aggravated when the flow increases. In steeply sloped topography, therefore, proportioning weirs are not usually seen in canals running down the slope. However, in relatively flat irrigated areas, as in Sankhar and Julphe Irrigation Systems[14], the topography does not restrict the alignment of distribution canals. Neither do the flow velocities in canals exceed the sub-critical[15] level. In sum, the viability of dividing water by proportioning weirs increases with the increasing flatness of the topography. This implies that a fully proportionate[16]system is viable only if the irrigated area has a relatively flat land slope.

The overall width of the proportioning weir has been fixed based on the combination of three criteria. They are discussed separately in section 3.7.

Weir height above the canal bed

Two main criteria for fixing the height of the weir above the normal canal bed have been observed. They are: canal bed slope and the bed level of the offtake canal. For example, in a contour canal having a flat gradient, the weir height is fixed just to obtain free flow through it. In such a canal, water flows very slowly and there is no need for extra weir height to reduce the approach velocity. However, in a ridge canal, which usually has a deep section because of its relatively steep gradient, the weir height is raised to match the

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[14] The average land slope of the Julphe and Sankhar Irrigation Systems are about 1.06 and 2.5 percent respectively.

[15] A flow having low velocity often described as tranquil and streaming is referred to as a sub-critical velocity (Chow, 1985).

[16] An area is said to be fully proportionate if all individual farmers receive water on a continuous basis through the proportioning weirs. In a partially proportionate area, continuous flow is delivered on a proportional basis to certain sections. Other means are used to divide water at the lower ends within sections (Ambler, 1989).

level of the offtake canal[17]. For this reason, besides the flow division, many proportioning weirs located in ridge canals also work as a drop-cum-check structure.

3.5.2 Operational consequences of raising the weir

Raising the weir above the canal bed also has some operational consequences. This increases the seepage and leakage losses due to the ponding of water upstream. The main advantage is that the system can be brought under rotational regime simply by removing a few stones under the weir, and the stones are replaced again when a continuous flow regime[18] is required. This minimizes the seepage and leakage losses upstream of the weir under rotational regime. Also, the weir can remain undisturbed in its place, and the chances of manipulating its notch sizes are also minimized.

3.6 Flow constriction

Several authors have raised concerns about the proportionality of proportioning weirs due to flow constriction and friction losses (Yoder, 1994; Ambler, 1990; Dani and Siddiqi, 1989). Also, various methods adopted by farmers to maintain their proportionality, especially in a weir having large variations in notch widths, have been noted. One of such methods is to make all the notches of approximately equal width.

To study the combined effect of flow constriction and friction losses in the proportionality of a proportioning weir having large variations in its notch width, the flows through the notches of the main proportioning weir (Dui Dhare) were measured at various supply levels[19]. Table 3.3 presents the h/L ratio, the flow through the notches, flow fluctuation in percentage with respect to the previous flow[20] and flow per unit width of the notch. To be proportional, flow fluctuations in percentage through all the notches and in the approach canal should be the same. Figure 3.7 presents the flow fluctuations in a graphical form[21].

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[17] For example, in Terso Kulo, which is a contour canal with a very flat average gradient of 1 in 1500, the weir height varies between 5.6 and 16.2 cm. However, in Thado Kulo, which is a ridge canal with average gradient of 1 in 45, some proportioning weirs are installed even at 100 cm above the normal canal bed because of the higher level of the offtake canals, and also to reduce the approach velocity.

[18] Sometimes, even under rotational regime when the flows are very low, water is allowed to flow through the weir by partially blocking the notches (Yoder *et al.*, 1987b; Pradhan, 1989). However, this method still maintains the ponding upstream of the weir, and increases the seepage and leakage losses. Such losses could be very critical, especially during low flows. Also, adjusting the flows for diversified cropping system by partially or fully blocking the notches is equally cumbersome (Ambler 1990).

[19] The instruments used to measure flows and their placement in canals with respect to the weir are mentioned earlier in section 3.4 (flow measurements and constraints).

[20] In Table 3.3, the values in the column 'flow fluctuation with respect to preceding flow', are calculated using the values given in the column 'flow passing through notches'. For example, let us consider the flows through Terso Kulo. On 10 April, flow through Terso Kulo notch was 7.944 lps, which reduced to 7.559 lps on 12 April. So, flow fluctuation on 12 April with respect to 10 April is [(7.559-7.944)/7.559 * 100] = -5.1 per cent. The negative value indicates reduction in flow.

[21] Values presented in the Table 3.3 in the column 'flow fluctuation with respect to preceding flow' are used for this figure.

Table 3.3: Flow fluctuation through the notches of the main proportioning weir

Date	Head over weir	h/L ratio	Flow passing through notches					Flow fluctuation with respect to preceding flow					Flow per metre width of notches				
	(cm)		Terso Kulo (2.01m) (lps)	Chalees Muri Ko Kulo (0.10 m) (lps)	Thado Kulo (2.35 m) (lps)	Bees Muri Ko Kulo (0.06 m) (lps)	Notch Total (4.52m) (lps)	Incoming flow (In percentage)	Terso Kulo (In percentage)	Chalees Muri Ko Kulo (In percentage)	Thado Kulo (In percentage)	Bees Muri Ko Kulo (In percentage)	Incoming flow (4.52m) (lps/m)	Terso Kulo (2.01m) (lps/m)	Chalees Muri Ko Kulo (0.10m) (lps/m)	Thado Kulo (2.35m) (lps/m)	Bees Muri Ko Kulo (0.06m) (lps/m)
10-Apr-96			7.944	0.410	9.693	0.243	18.290						4.05	3.95	4.10	4.12	4.04
12-Apr-96			7.559	0.369	7.928	0.212	16.067	-13.83	-5.10	-11.11	-22.27	-14.50	3.55	3.76	3.69	3.37	3.53
13-Apr-96			8.541	0.471	11.369	0.267	20.648	22.19	11.50	21.74	30.27	20.62	4.57	4.25	4.71	4.84	4.45
16-Apr-96	1.90	0.10	8.172	0.398	8.571	0.269	17.410	-18.60	-4.51	-18.23	-32.65	0.71	3.85	4.07	3.98	3.65	4.48
19-Apr-96	2.30	0.12	11.834	0.547	12.125	0.350	24.856	29.96	30.94	27.19	29.31	23.22	5.50	5.89	5.47	5.16	5.83
20-Apr-96	2.00	0.10	9.454	0.471	10.397	0.239	20.561	-20.89	-25.17	-16.17	-16.62	-46.26	4.55	4.70	4.71	4.42	3.99
21-Apr-96	2.10	0.11	9.003	0.461	11.619	0.293	21.375	3.81	-5.01	-2.22	10.52	18.25	4.73	4.48	4.61	4.94	4.88
22-Apr-96	1.90	0.10	9.214	0.250	12.381	0.269	22.114	3.34	2.29	-84.62	6.16	-8.67	4.89	4.58	2.50	5.27	4.49
23-Apr-96	2.00	0.10	9.660	0.499	11.122	0.269	21.552	-2.61	4.62	50.00	-11.32	0.00 *	4.77	4.81	4.99	4.73	4.49
24-Apr-96	2.00	0.10	9.223	0.470	10.397	0.263	20.353	-5.89	-4.74	-6.27	-6.98	-2.43	4.50	4.59	4.70	4.42	4.38
25-Apr-96	1.70	0.09	7.577	0.351	9.925	0.250	18.102	-12.43	-21.73	-33.94	-4.75	-5.38	4.00	3.77	3.51	4.22	4.16
27-Apr-96	2.30	0.12	11.567	0.557	12.381	0.360	24.866	27.20	34.50	37.08	19.84	30.60	5.50	5.75	5.57	5.27	5.99
28-Apr-96	2.10	0.11	9.647	0.278	11.870	0.280	22.075	-12.64	-19.91	-100.23	-4.30	-28.60	4.88	4.80	2.78	5.05	4.66
29-Apr-96	2.10	0.11	10.057	0.340	10.397	0.290	21.083	-4.71	4.08	18.08	-14.18	3.53	4.66	5.00	3.40	4.42	4.83
30-Apr-96	2.20	0.11	8.978	0.486	11.122	0.286	20.872	-1.01	-12.02	30.04	6.53	-1.34 *	4.62	4.47	4.86	4.73	4.77
01-May-96	1.90	0.10	8.408	0.382	9.237	0.227	18.253	-14.35	-6.78	-27.14	-20.42	-26.27	4.04	4.18	3.82	3.93	3.78
02-May-96	1.70	0.09	6.926	0.381	10.160	0.198	17.665	-3.33	-21.39	-0.34	9.08	-14.19	3.91	3.45	3.81	4.32	3.31
03-May-96	1.80	0.09	7.744	0.396	11.122	0.229	19.491	9.37	10.55	3.80	8.66	13.41	4.31	3.85	3.96	4.73	3.82
04-May-96	1.90	0.10	9.302	0.392	9.925	0.299	19.917	2.14	16.75	-1.06	-12.06	23.34 *	4.41	4.63	3.92	4.22	4.98
05-May-96	1.90	0.10	7.119	0.392	8.139	0.228	15.879	-25.43	-30.65	0.16	-21.94	-30.81	3.51	3.54	3.92	3.46	3.81
06-May-96	1.50	0.08	6.827	0.278	9.464	0.178	16.747	5.18	-4.28	-40.92	13.99	-28.42	3.71	3.40	2.78	4.03	2.97
07-May-96	2.70	0.14	11.940	0.701	12.902	0.380	25.922	35.39	42.82	60.27	26.65	53.12	5.73	5.94	7.01	5.49	6.33
10-May-96	2.20	0.11	7.845	0.509	10.397	0.283	19.034	-36.19	-52.19	-37.74	-24.10	-34.01	4.21	3.90	5.09	4.42	4.72
11-May-96	2.10	0.11	8.523	0.490	9.012	0.240	18.264	-4.21	7.95	-3.92	-15.36	-18.00	4.04	4.24	4.90	3.83	4.00
12-May-96	1.90	0.10	7.526	0.401	8.354	0.200	16.482	-10.82	-13.24	-22.01	-7.88	-19.81	3.65	3.74	4.01	3.55	3.34
13-May-96	2.10	0.11	9.168	0.525	9.555	0.293	19.542	15.66	17.90	23.63	12.57	31.66	4.32	4.56	5.25	4.07	4.89
15-May-96	2.70	0.14	12.051	0.851	14.000	0.400	27.302	28.42	23.92	38.27	31.75	26.72	6.04	6.00	8.51	5.96	6.67
16-May-96	2.50	0.13	12.307	0.595	12.742	0.346	25.990	-5.05	2.08	-43.01	-9.88	-15.74	5.75	6.12	5.95	5.42	5.76
17-May-96	2.50	0.13	12.310	0.592	12.500	0.320	25.722	-1.04	0.03	-0.54	-1.93	-8.00	5.69	6.12	5.92	5.32	5.33
18-May-96	2.10	0.11	9.064	0.400	9.200	0.300	18.964	-35.64	-35.82	-48.00	-35.87	-6.61	4.20	4.51	4.00	3.92	5.00
19-May-96	2.00	0.10	8.556	0.456	10.834	0.237	20.083	5.57	-5.93	12.28	15.08	-26.76 *	4.44	4.26	4.56	4.61	3.95
21-May-96	2.20	0.11	8.638	0.598	10.600	0.300	20.137	0.27	0.95	23.80	-2.20	21.11	4.46	4.30	5.98	4.51	5.00
22-May-96	2.10	0.11	10.389	0.489	11.797	0.342	23.018	12.51	16.85	-22.38	10.15	12.34	5.09	5.17	4.89	5.02	5.71

Note: * These data are not incorporated in the curve. Negative value indicates reduction in flow

Table 3.3 (continued)

Date	Head over weir	h/L ratio	Flow passing through notches					Flow fluctuation with respect to preceding flow					Flow per metre width of notches				
			Terso Kulo (2.01m)	Chalees Muri Ko Kulo (0.10 m)	Thado Kulo (2.35 m)	Bees Muri Ko Kulo (0.06 m)	Notch Total (4.52m)	Incoming flow	Terso Kulo	Chalees Muri Ko Kulo	Thado Kulo	Bees Muri Ko Kulo	Incoming flow (4.52m)	Terso Kulo (2.01m)	Chalees Muri Ko Kulo (0.10m)	Thado Kulo (2.35m)	Bees Muri Ko Kulo (0.06m)
	(cm)		(lps)	(lps)	(lps)	(lps)	(lps)	(In percentage)					(lps/m)	(lps/m)	(lps/m)	(lps/m)	(lps/m)
23-May-96	2.10	0.11	8.736	0.500	9.100	0.300	18.637	-23.50	-18.92	2.30	-29.64	-14.07	4.12	4.35	5.00	3.87	5.00
24-May-96	2.00	0.10	8.390	0.400	9.200	0.260	18.250	-2.12	-4.12	-25.12	1.09	-15.52	4.04	4.17	4.00	3.92	4.33
25-May-96	2.00	0.10	10.571	0.551	10.575	0.312	22.010	17.08	20.63	27.41	13.00	16.80	4.87	5.26	5.51	4.50	5.21
26-May-96	2.10	0.11	9.796	0.600	10.100	0.350	20.847	-5.58	-7.91	8.21	-4.70	10.79	4.61	4.87	6.00	4.30	5.83
27-May-96	2.00	0.10	8.290	0.500	9.100	0.269	18.160	-14.80	-18.16	-20.10	-10.99	-29.93	4.02	4.12	5.00	3.87	4.49
28-May-96	1.70	0.09	7.151	0.360	9.165	0.206	16.883	-7.56	-15.93	-38.84	0.71	-30.54	3.74	3.56	3.60	3.90	3.44
29-May-96	2.00	0.10	8.737	0.500	9.100	0.300	18.637	9.41	18.15	27.98	-0.71	31.24	4.12	4.35	5.00	3.87	5.00
30-May-96	2.10	0.11	8.390	0.400	9.200	0.260	18.250	-2.12	-4.13	-24.96	1.09	-15.52	4.04	4.17	4.00	3.92	4.33
01-Jun-96	3.00	0.15	17.090	0.931	19.905	0.515	38.441	52.52	50.91	57.04	53.78	49.50	8.50	8.50	9.31	8.47	8.58
02-Jun-96	3.40	0.17	20.861	1.000	25.001	0.500	47.362	18.84	18.08	6.85	20.38	-2.81	10.48	10.38	10.00	10.64	8.34
03-Jun-96	1.90	0.10	8.170	0.401	9.100	0.220	17.891	-164.72	-155.34	-149.52	-174.72	-127.33	3.96	4.06	4.01	3.87	3.67
04-Jun-96	2.30	0.12	12.494	0.672	15.346	0.390	28.902	38.10	34.61	40.38	40.70	43.61	6.39	6.22	6.72	6.53	6.51
05-Jun-96	2.10	0.11	9.013	0.451	9.000	0.300	18.764	-54.03	-38.62	-49.15	-70.50	-30.34	4.15	4.48	4.51	3.83	4.99
06-Jun-96	2.10	0.11	8.390	0.401	9.500	0.260	18.550	-1.15	-7.43	-12.46	5.26	-15.27	4.10	4.17	4.01	4.04	4.33
07-Jun-96	1.90	0.10	8.091	0.480	10.481	0.269	19.321	3.99	-3.69	16.53	9.36	3.33	4.27	4.03	4.80	4.46	4.48
08-Jun-96	2.00	0.10	8.736	0.500	9.000	0.300	18.537	-4.23	7.39	4.09	-16.46	10.26	4.10	4.35	5.00	3.83	4.99
09-Jun-96	2.00	0.10	8.390	0.401	9.000	0.259	18.049	-2.70	-4.13	-24.92	0.00	-15.84	3.99	4.17	4.01	3.83	4.31
10-Jun-96	1.70	0.09	8.416	0.374	9.494	0.230	18.515	2.52	0.31	-7.01	5.20	-12.22	4.10	4.19	3.74	4.04	3.84
13-Jun-96	2.40	0.12	13.859	0.663	15.087	0.369	29.978	38.24	39.28	43.53	37.07	37.50	6.63	6.90	6.63	6.42	6.14
14-Jun-96	2.50	0.13	12.303	0.599	12.500	0.401	25.803	-16.18	-12.65	-10.68	-20.70	7.99	5.71	6.12	5.99	5.32	6.68
15-Jun-96	2.50	0.13	11.474	0.650	12.000	0.320	24.445	-5.56	-7.22	7.87	-4.17	-25.20	5.41	5.71	6.50	5.11	5.33
16-Jun-96	3.00	0.15	18.976	0.923	20.916	0.547	41.362	40.90	39.53	29.54	42.62	41.52	9.15	9.44	9.23	8.90	9.12
19-Jun-96	2.80	0.14	16.937	0.780	19.294	0.480	37.491	-10.33	-12.04	-18.39	-8.40	-14.00	8.29	8.43	7.80	8.21	8.00
20-Jun-96	3.00	0.15	16.615	0.800	19.501	0.517	37.432	-0.16	-1.94	2.56	1.06	7.18	8.28	8.27	8.00	8.30	8.62
21-Jun-96	3.70	0.19	24.115	1.201	28.001	0.700	54.016	30.70	31.10	33.37	30.36	26.14	11.95	12.00	12.01	11.92	11.67
22-Jun-96	4.50	0.23	38.087	1.540	44.839	1.018	85.483	36.81	36.68	22.03	37.55	31.19	18.91	18.95	15.40	19.08	16.96
23-Jun-96	4.00	0.20	27.628	1.371	32.908	0.721	62.628	-36.49	-37.86	-12.32	-36.25	-41.23	13.86	13.75	13.71	14.00	12.01
24-Jun-96	3.50	0.18	22.142	1.073	24.001	0.600	47.816	-30.98	-24.77	-27.80	-37.11	-20.02	10.58	11.02	10.73	10.21	10.01
25-Jun-96	3.20	0.16	19.929	0.941	21.809	0.557	43.235	-10.60	-11.11	-14.01	-10.05	-7.82	9.57	9.91	9.41	9.28	9.28
26-Jun-96	2.50	0.13	11.061	0.558	13.500	0.380	25.499	-69.55	-80.18	-68.58	-61.54	-46.46	5.64	5.50	5.58	5.74	6.34
27-Jun-96	3.00	0.15	18.045	0.905	21.001	0.401	40.351	36.81	38.71	38.33	35.71	5.11	8.93	8.98	9.05	8.94	6.68
28-Jun-96	2.10	0.11	13.728	0.518	15.040	0.311	29.598	-36.33	-31.45	-74.57	-39.63	-28.81	6.55	6.83	5.18	6.40	5.18

Note: * These data are not incorporated in the curve. Negative value indicates reduction in flow

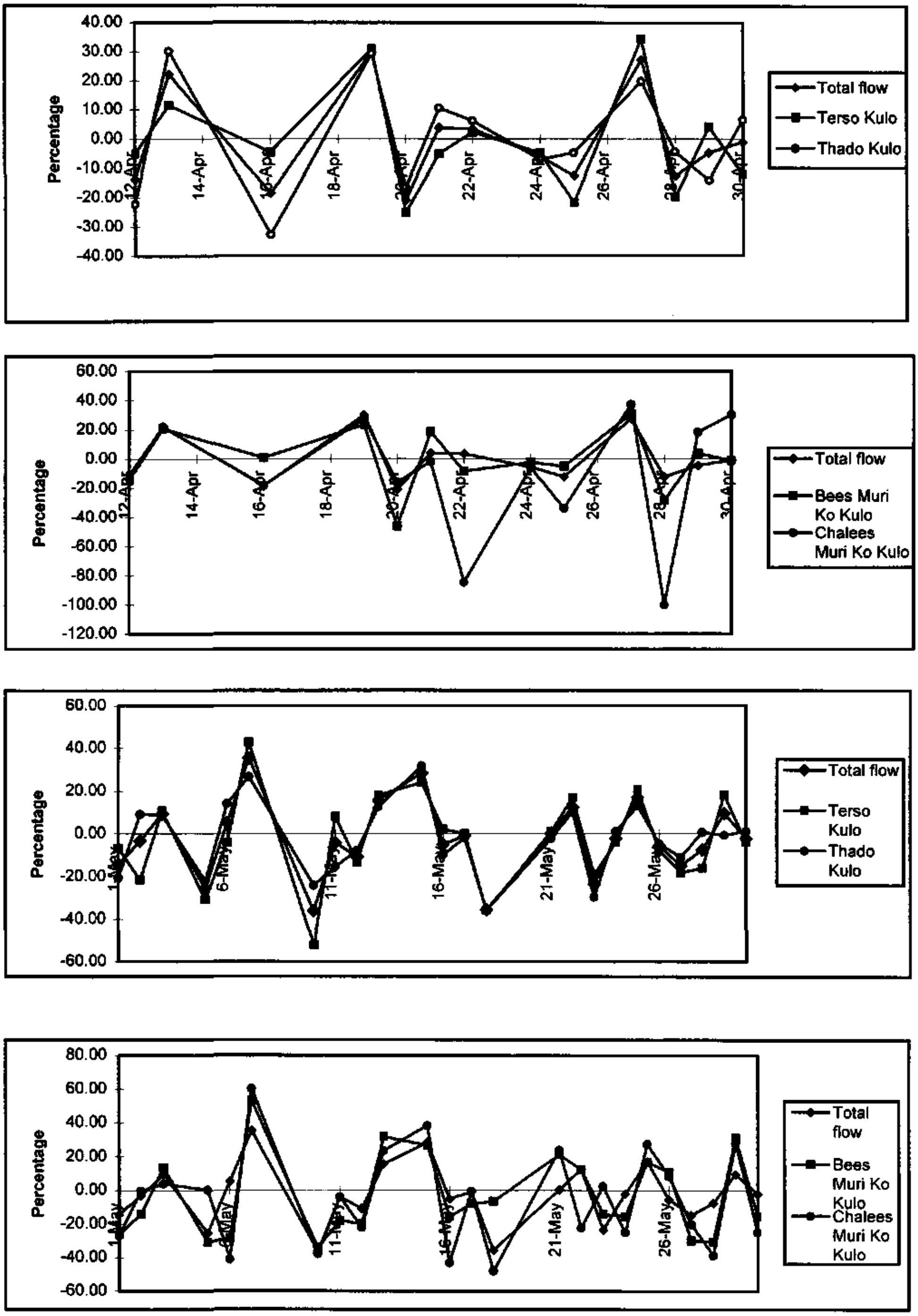
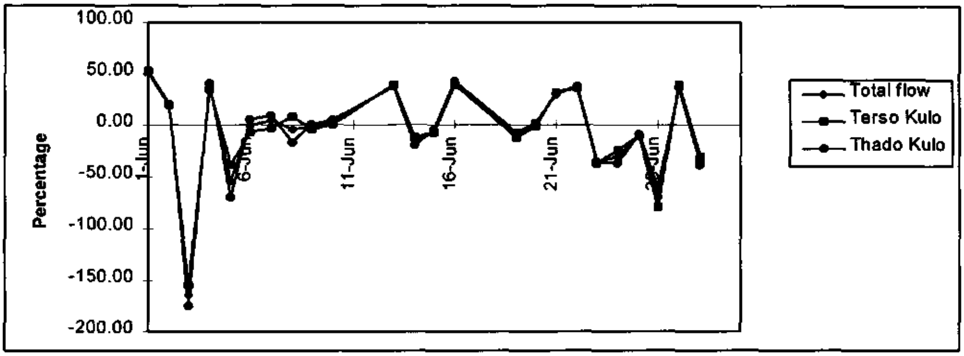


Figure 3.7: Flow fluctuations through notches and incoming canal



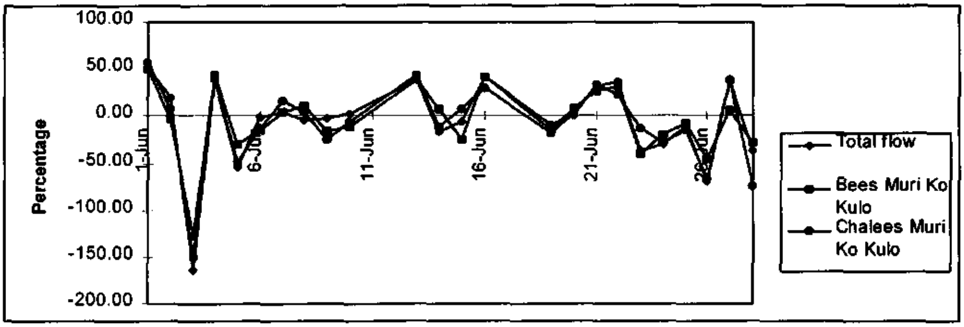


Figure 3.7 (continued): Flow fluctuations through notches and incoming canal

Within the range of accuracy of the flow measurement in the field, Figure 3.7 indicates that the flows through the notches are fairly proportional. The differential flow fluctuations, which are higher in April and which reduce gradually towards June, may have been caused due to the reduced measurement errors as the recorder gained experience over time. During the entire period, the differential flow fluctuations through the smaller notches were higher than through the bigger notches. The reason is: the measured flows through the smaller notches are of very small range (varying between 0.2 and 1.0 lps), and a small error in the flow measurement shows as a high value in percentage. For example, an error of 0.1 lps in a measured flow of 0.5 lps shows an error of 20 per cent. Further, the higher percentage of reduction in the flow through the smaller notches compared with that of the bigger notches, recorded occasionally, may have been caused due to the partial blocking of the notches by floating leaves.

Furthermore, the combined effect of construction, installation and maintenance of the weir may also have caused the differential flow fluctuations. To check the crest level of the notches, farmers use the basic knowledge of the principle that water finds its own level. However, it is probably difficult to detect an error of about 1-2 mm because of the surface tension of the flow. Note that variations of about 2 mm were observed in the crest level of the notches. Similarly, the notch widths are not truly rectangular. Variations of a few mm were found in them. The continuous flow of water over a long period of time would have caused wearing and tearing of notches, resulting in differences in their designed widths.

Also, as stated earlier, the crests of the notches are slightly inclined downwards along the direction of flow, and this inclination is not uniform throughout its width.

It was observed that because of the very small head causing flow upstream of the weir, floating leaves and moss collected inside the notches obstruct the flow. The frequency of such obstruction is much higher in narrower notches. The notches, therefore, need frequent cleaning.

Although the construction, installation and maintenance of the weir do enhance the differential flow fluctuations through the notches, the extent of their effect is site-specific and cannot be quantified. It is also not possible to represent their effect in the calibration of the flow through the notches in the field.

The above discussions indicate that the observed differential flow fluctuations through the notches are primarily caused by the difficulties in the flow measurement in the field, and by the construction as well as the maintenance work of the weir. The flow constriction and the friction losses do not seem to have significant effect on the differential flow fluctuations. Its effects, if any, are so small that it is not possible to trace them out in the field, unless a laboratory model test is conducted.

At this stage, one may raise the question: What physical features or what state of flow are responsible to maintain the proportionality of the weir even with such a large variation in its notch width? Although it is not possible to trace out analytically such physical features or the state of flow which help maintain the proportionality of the weir, some attempts have been made to explain this.

While developing the stage discharge relationship, an assumption of the rectilinearity of parallel streamlines over the crest of the notches had been made. However, in this case, because of the sharp edge of the notches at their entrance, it is also assumed that the rectilinearity of parallel streamlines would not be achieved above the crest. The non-rectilinearity of parallel streamlines could affect the flow through notches depending on their width. In any weir, the effect of curvature of the streamlines is represented by the coefficient of discharge, which remains constant for h/L ratio less than 0.33 to 0.40 (BSI 3680, 1969; ISO 3846,1977; Vierhout, 1973). This implies that the curvature of the streamlines would not cause any significant deviation in the flow provided the h/L ratio remains within 0.33 to 0.40. Apparently, the h/L ratio is the main physical feature responsible to maintain the proportionality of the proportioning weir.

Surprisingly, in Dui Dhare, the h/L ratio has always remained much below 0.4 (Table 3.3). This indicates that the indigenous proportioning weirs designed by farmers based on their experience conform to the hydraulic boundary conditions as laid down in ISO and hydraulic handbooks.

This indicates that in a proportioning weir having large variations in the notch width, substantial differential flow fluctuations would not occur if the h/L ratio is less than 0.4. However, with the higher h/L ratio, the proportionality of the proportioning weir having large variations in its notch width may be doubtful.

3.7 Design of notch width

A notch width in a proportioning weir has important implications for water distribution. Its design is determined based on the hydraulic, operational and topographical considerations. In an irrigation system, the extent to which these considerations are taken into account depends on the water supply situation and farmers' perception of equity. In Sankhar Irrigation System, as it is relatively a water scarce system[22], the above design considerations are carefully taken into account. However, in a water abundant system, like in the Julphe and Bachcha Irrigation Systems, some of these considerations are ignored.

3.7.1 Hydraulic considerations

The design of the notch width involves two hydraulic considerations. They are: limiting the ratio of h/L and providing the notch width required to pass the design discharge. In a weir having large variations in notch widths, limiting the value of h/L ratio below 0.4 is the main hydraulic consideration. However, in a weir where the notches are approximately of similar width, h/L ratio does not impose serious errors, unless it is beyond the recommended upper limit value[23]. This is because the effect of flow constriction and other losses would also be similar. In such a situation, the width to pass the design discharge is the main hydraulic consideration. A notch width depends on the head of the flow upstream of the weir, which in turn depends on the availability of timber of the size required. For this reason, in a proportioning weir of similar notch width, the available depth of the notch (depth of notch plus the water surface drawdown gives the maximum possible head) usually dictates the design of the notch width.

3.7.2 Operational/topographical considerations

Operational considerations involve providing a minimum operable width to a weir notch. In the Sankhar Irrigation System, the relative difference in the flow size between the parent canal and the offtake canal in Dui Dhare and in the first weir (P1) are about 58:1 and 113:1 respectively (Figure 6.6), as against the recommended value of 15:1 (MacDonald *et al.*, 1990 M8-2). In such a situation, if the total[24] notch width is designed only from hydraulic considerations, the notch width available for an individual farmer could be too small for operation. For example, in Dui Dhare, the total notch width required from hydraulic considerations is about 2.7 m for the average maximum flow of about 100 lps[25]. So, if the weir is designed only from hydraulic considerations, a farmer having 20 *mato*

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[22] The Sankhar Irrigation System is relatively a water scarce system in the sense that in this system, the average water supply during the monsoon season varies between 1.89 and 2.97 lps per ha, whereas in other systems studied (Bachcha, Julphe and Patne), the average water supply during the monsoon season exceeds these values.

[23] The recommended upper limit of h/L ratio is 1.6 (ISO 3846, 1977), which is not likely to be crossed in a wooden proportioning weir.

[24] Total notch width here refers to the sum total width of all the notches in a proportioning weir, while notch width refers to the width of an individual notch.

[25] For h/L equal to 0.4 and Cd equal to 1.599 (the value of Cd is based on the actual measurement of discharge).

muri of water share would have a notch width of only 2.4 cm[26]. This notch width is definitely not practical. For this reason, the total notch width of 4.52 m is provided based on the combined criterion of land availability (topography) and operable notch width.

The question is: What would be the required operable notch width? Empirical evidence from Sankhar Irrigation System shows that there are two important considerations for it. The notch width should be sufficiently wide so that (a) it is not choked frequently even by a small leaf, and (b) cleaning of the moss collected inside the notch is easy in order to achieve higher hydraulic efficiency[27]. In Sankhar, about 80 per cent of the farmers have water shares varying between 15 and 25 *mato muri*. The average notch width for this range of water share in the lower order canals varies between 10 and 20 cm. Except for the seven notches in the six proportioning weirs located at the head reach of the system[28], 97 per cent of the proportioning weirs have been designed in such a way that farmers having water shares more than 10 *mato muri* have the notch width of 10 cm or more[29]. This indicates that a notch width of 10 cm seems to be the minimum average practicable notch width from an operational point of view, although MacDonald *et al.* (1990 M8-2) have recommended a value of 30 cm for this.

This implies that in a fully proportionate system, the notch width is governed not only by the hydraulic criterion but also by the operational criterion. However, in a partially proportionate system, the notch width is governed mainly by the hydraulic criterion. The reason is, in a partially proportionate system, the relative differences in the flow size between the parent and the offtake canals are usually not so excessive so that the minimum operational notch width has to be met. For this reason, the overall width of a weir required in a fully proportionate system is much wider than that of partially proportionate system. The recorded total notch width of 168 cm in the first weir in the Chherlung Irrigation System[30] (Yoder, 1986) also verifies this. The requirement of a wider proportioning weir in a fully proportionate system, which is difficult in a steeply sloped topography from stability considerations, is one of the reasons why fully proportionate systems are available only in gentle topography.

Also, it should be noted that the maximum relative difference in the flow size between the parent canal and the offtake canal would further increase if the system size increases with the increase in flow. For this reason, a fully proportionate system is not likely to exist in a

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[26] Note that the total incoming water in this weir is considered to be 2,230 *mato muri*.

[27] Moss is a kind of aquatic plant, which exerts more friction on the flow. For this reason it was observed that farmers clean the moss in the notches quite frequently in order to achieve higher hydraulic efficiency.

[28] In these six proportioning weirs, if the criterion of minimum notch width had been used, the total weir width would have been excessively high. For example, in the main proportioning weir, if a notch width of 10 cm is provided for a farmer having water share of 20 *mato muri*, the sum total notch width required would be about 1,120 cm against the present sum total notch width of 452 cm. Such a wide weir would not be possible from land availability (topography) considerations. However, the present sum total notches width of 452 cm is still much higher than that required from the hydraulic considerations.

[29] For physical details of proportioning weirs refer Appendix VIII.

[30] The Chherlung Irrigation System is a partially proportionate system with irrigated area of 34.8 ha and average flow of 150 lps in the main canal (Yoder, 1986). Note that the area and canal flow are very similar to those of Sankhar, but the total weir width is about 2.5 times smaller.

large irrigated area. The Raj Kulo in Argali with an irrigated area of 46 ha (Martin, 1986) is probably the largest fully proportionate system in Nepal.

3.7.3 Notch width per unit of water share (unit notch width)

In this text, unit notch width refers to the notch width per unit of water share. A notch width is important as it represents the water share. In Sankhar Irrigation System, since the notch widths are designed based on the combination of hydraulic, operational and topographic considerations, there is no standard unit notch width throughout the system. The unit notch width differs from weir to weir, although its value remains the same within a weir. In the main canal, where the land availability to install the weir plays an important role, its value varies between 0.125 and 0.20 cm. However, in the lower order canal its value increases up to 1.5 cm.

In some irrigation systems, for example in the Bachcha Irrigation System, the standard unit notch width is applicable to all the proportioning weirs. This makes it very simple and easy for farmers to check the correctness of their notches irrespective of their location in the system. In such systems, to check the correctness of one's notch, it is not necessary to know the water shares of other farmers' notches. However, in the case of varying unit notch width, the farmer has to calculate the correctness of his notch by comparing it with those of other farmers who draw water from the same weir. This would be very cumbersome and would require skilled personnel, especially when water shares keep changing frequently.

As mentioned above, in the headreach of the Sankhar Irrigation System, the unit notch width is much lower. For this reason, farmers drawing water at the headreach have much smaller notches (in most of the cases they are even smaller than the minimum practical notch width of 10 cm) in comparison to other farmers having the same unit of water shares but drawing water from the lower order canals. In such a situation, farmers with water allocation from the smaller notches have to suffer more maintenance inputs than the other farmers. This is because the chances of floating debris blocking the smaller notches are much higher, and thus they require more frequent supervision. It was observed that some farmers install temporary vertical trash racks made of wooden sticks in front of the smaller notch to check the floating debris from entering their respective notches, which is an extra burden for them.

To compensate for this disadvantage (extra burden), additional notch widths (equivalent to approximately 3/4 inch), known as *moko,* have been provided to those farmers who draw a small fraction of water from the higher order canals. Altogether seven notches in six proportioning weirs have this privilege irrespective of their location in a proportioning weir. Farmers who have this privilege also have an additional operational responsibility. For example, if the flow of water is disrupted or some untoward incident happens in the main canal, it is their duty to immediately inform the chairperson of the irrigation committee because they are located at the head-end of the distribution system and they would know the incident first.

To overcome these disadvantages, wherever possible, in the lower order canals, farmers have made all the notches of approximately equal width. However, this method is not always feasible because it requires larger weir width. Referring to Dui Dhare, if all the notches are to be made of equal width here, there would be more than 60 notches of about 6 cm. This means a weir width of at least double the present weir width would be required. Such a wide weir with more than 60 notches is obviously not practicable.

3.8 Summary and conclusions

This chapter attempted to analyze some of the design considerations of indigenous proportioning weirs used by many farmer managed irrigation systems in Nepal. This chapter showed that the indigenous proportioning weirs designed by farmers based on their experience conform with the hydraulic boundary conditions as laid down in ISO and hydraulic handbooks. This further implies that farmers are knowledgeable and capable actors, and can develop hydraulically-sound distribution structures.

Free flow through the weir, uniformly distributed low approach velocity and the lower h/L ratio (especially to minimize the effects of flow constriction and friction losses through notches with large variations in their widths) are the main hydraulic boundary conditions to achieve the proportionality of the proportioning weirs. In Sankhar Irrigation System, during low flows, the approach velocity and the h/L ratio remain well within the recommended values of 15 cm/sec (Hansen *et al.*, 1979) and 0.33 to 0.4 (Vierhout, 1973; BSI 3680, 1969; ISO 3846, 1977) respectively. However, during the average maximum flow, though some deviation in the velocity distribution upstream of the weir was observed, the approach velocity and the h/L ratio still remained within the recommended values. These hydraulic boundary conditions are achieved by creating a pond, with the installation of the weir above the normal canal bed at the end of a long and diverging approach canal.

Two types of weirs (a) with approximately equal notch widths and (b) with varying notch widths, have been observed. From the hydraulic and operational points of view, the former has more advantages. This is because, in equal notch width, the effect of flow constriction (in case of higher h/L) and friction losses is distributed equally among all the notches and the chances of floating leaves blocking the notches are also the same for all. However, this type of weir requires a much larger width; but quite often it is not feasible because of topographical constraints.

Operational considerations involve designing minimum possible notch width so that (a) it is not blocked frequently, and (b) cleaning of moss collected inside the notch is easy in order to achieve higher hydraulic efficiency. Weirs designed on operational considerations are usually wider in comparison to weirs designed on hydraulic considerations.

The design of proportioning weirs depends also on the type of system, such as a fully or partially proportionate system. In a fully proportionate system, the higher relative difference in the flow size between the parent and the offtake canals at its headreach requires much wider weirs in comparison to that of partially proportionate systems, because of operational considerations. This makes it difficult to adopt a standard notch width per unit of water shares throughout the system. However, in partially proportionate systems, the standard notch width per unit of water shares can be adopted because operational considerations are of less importance and the weirs are usually designed on hydraulic considerations.

The higher relative difference in the flow size between the parent and the offtake canals at the headreach of fully proportionate systems restricts the viability of fully proportionate system in larger irrigated areas. Similarly, their hydraulic requirements (uniformly distributed low approach velocity) restricts the use of proportioning weirs in a steeply sloping canal, which in turn restricts the viability of fully proportionate system in a steeper irrigated area.

Irrigation is very much site-specific. Perceptions of farmers about the structure use depend on socio-cultural, agro-ecological and technical requirements. For example, in the Sankhar Irrigation System, which is a water scarce system, the hydraulic boundary conditions are not ignored in favour of the operational requirements and topographical constraints in the design of proportioning weirs for higher accuracy of water division. However, in a water abundant system, some of the hydraulic requirements may be ignored because higher accuracy in water division may not be the primary consideration.

Certainly, in such water abundant systems, the indigenous proportioning weir, as designed and constructed by farmers, may not perform perfectly but it is still a wonderful invention that enables them to match the water distribution closely to the water allocation rules they agreed to. Even more important is that they can easily use local methods to check and monitor the functioning of this structure.

In sum, this study showed that the design of proportioning weirs and their locations in the distribution system integrates well the agro-ecological conditions and irrigation management practices. Different designs of notches and configurations of distribution system (fully or partially proportionate) are the examples, which mediate relations between water availability, land topography, mode of water delivery, and irrigation institutions in an irrigation system.

4 Julphe Irrigation System

4.1 Agro-ecological and social settings

Julphe Irrigation System falls under the Deurali and Tamsariya Village Development Committees (VDCs) in the Nawalparasi district in the Western Development Region of Nepal[1] (Figure 1.2). The area is situated about 6 to 10 km north of Chormara village. Chormara village is located along the Narayanghat-Butwal Highway, about 40 km west of the Narayanghat town. A gravel road connects the irrigation system to Chormara village.

The irrigation system is located at the foothills of the Mahabharat mountain range, in the river valley characterized as Siwaliks or Doon valley (Carson *et al.*, 1986a). This area has a sub-tropical climate. The mean monthly rainfall varies from 7 mm in November to 726 mm in July. The average annual rainfall is about 2,509 mm. About 85 per cent of the rainfall occur during the monsoon season (June to September). Figure 4.1 shows the monthly variations in the rainfall, temperature and evaporation[2].

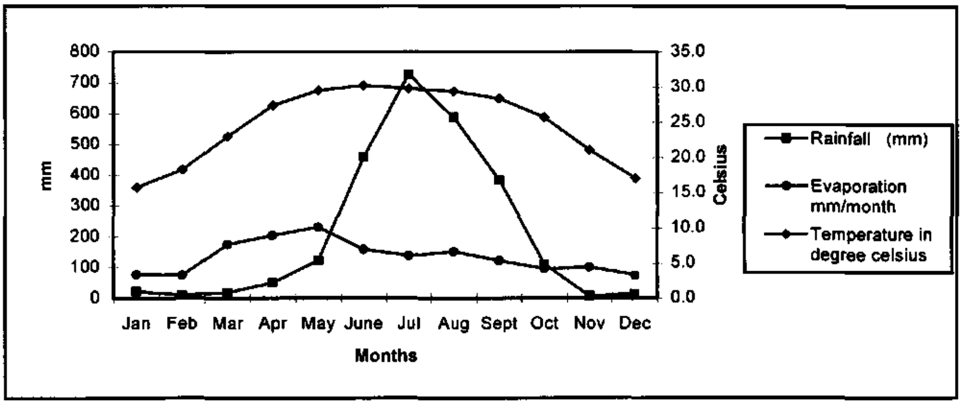

Figure 4.1 Monthly variations in rainfall, temperature and evaporation.

Figure 4.1 shows that between June and October, the mean annual rainfall is much above the average evaporation. Note that the irrigation system is designed mainly to promote the cultivation of monsoon paddy in the same period. The figure generates the question: Why is an irrigation system needed when rainfall exceeds evaporation? The answer is that the rainfall is so erratic that its effectiveness is too little for paddy cultivation. Relatively short dry spells during this period lead to water stresses. The need for an irrigation system from November to May, however, is self-evident.

[1] The irrigation system lies between latitude 27°39' and 27°41', and longitude 84°01' and 84°03'.

[2] Data on class "A" pan evaporation and temperature were obtained from the nearest meteorological station located at Damkauli (DHM, 1997; DIHM, 1986). Data on rainfall were obtained from the system area (MacDonald *et al.*, 1990 M3).

Julphe Irrigation System serves about 200 ha of land belonging to about 340 farmers. From the point of view of irrigation management, the system is divided into three sub-systems, namely Julphe, Kola and Basantpur, each of which is discussed below.

4.1.1 Landscape

Figure 4.2 is a landscape map of the area. Based on elevation with respect to the source river, the land has been classified into two types, *khaal* and *dhick*. *Khaal* is *khet* land located along the sides of the river, slightly above the river floor. Occasionally, the floodwater in the river enters the *khaal*, and the area gets inundated quickly. This area is almost flat and poorly drained. For this reason, during the monsoon, controlled entry of flow into the *khet* land receives higher priority than the distribution of available water. The average width of *khaal* ranges from 240 to 400 metres (m). There are no houses in this area.

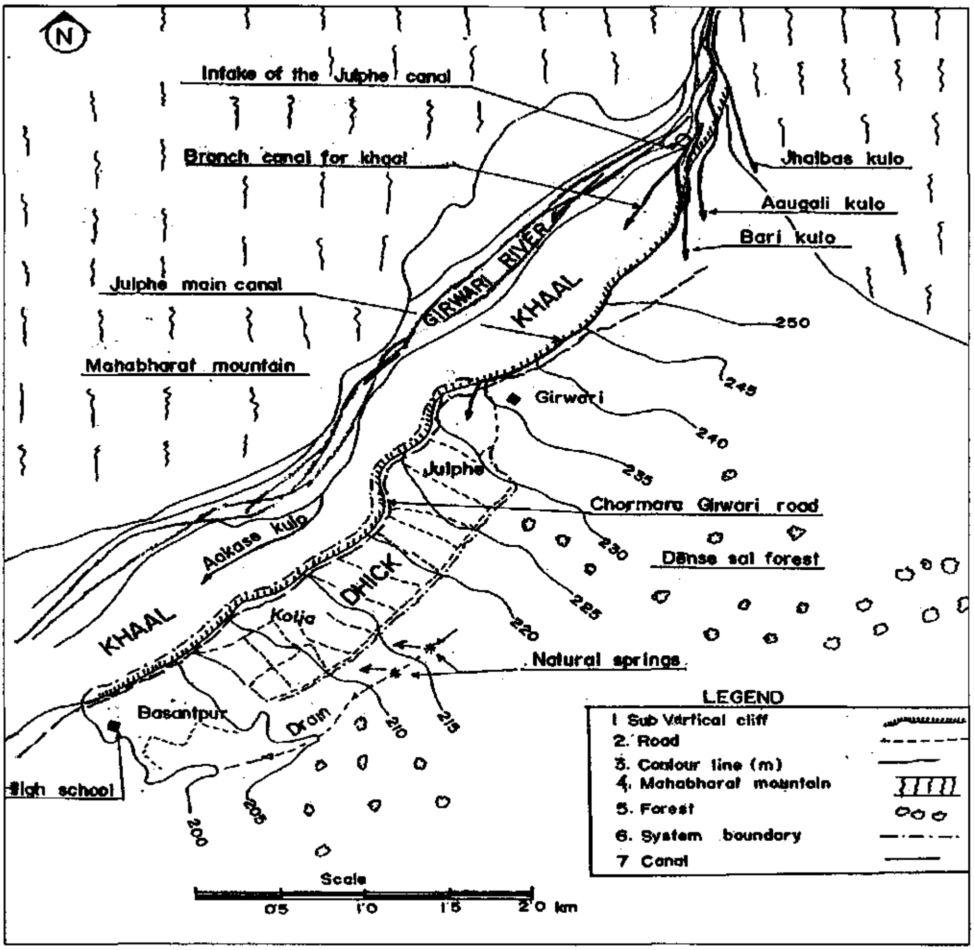

Figure 4.2: Landscape map of the system area.

A sub-vertical small cliff separates *khaal* from *dhick*. *Dhick* is high land located well above the river. A major portion of the irrigated land is located in this area[3]. The soil composition is medium-textured alluvial silt and clay loam (DOI, 1987), and is well-drained. The altitude of the *dhick* varies between 200 and 240 m above mean sea level. It slopes from north to south at an average slope of 1.06 per cent. The irrigated area is long and narrow; its length is about 4.0 km, while its width varies between 500 and 750 m.

A major portion of the *dhick* area has been developed for cultivation under the government's re-settlement programme. For this reason, the area has a series of parallel motorable roads. Landholdings in the new settlement area are rectangular in shape[4].

A dense *sal* forest in the east[5], the Chormara-Girwari road in the west, Girwari village in the north and Basantpur High School in the south form the system's boundaries.

4.1.2 Land use

Till the early 1960s, most of the areas in the *dhick* were covered by forest. Parts of these forests were encroached upon and converted into the present irrigated area. Even at present, a large area in the east is still covered by a forest of mature *sal* trees with a crown density of more than 70 per cent.

The land use pattern for cultivation is clearly dictated by the availability of irrigation water and by the socio-cultural conditions. In the *khaal,* only one crop of paddy is grown during the monsoon. Although irrigation water is available, most of this area remains fallow during winter. This is because the *khaal* is located far from homesteads. Agricultural activities on land located some distance from homesteads require more labour, especially for winter crops. Also, free grazing practice in the *khaal* during the winter and spring seasons restricts the crop cultivation during these periods.

All irrigated land in the *dhick* can be regarded as *khet*. Irrigated paddy and other crops are cultivated on them. The types of winter and spring crops planted depend on the availability of irrigation water. Land which does not have any source of irrigation water can be regarded as *bari,* locally known as *bhit*, although they are suitable to be *khet*.

4.1.3 Farming system

The farming system in Julphe is a mixture of the main Terai and hill farming systems[6], and is defined as the Doon Valley farming system (CIWEC, 1990). Farmers predominantly

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[3] This irrigation system also irrigates a small portion (about 15-20 ha, based on visual estimation) of the *khaal* area at its headreach (see also Section 4.2 on historical development). However, this study concentrated mainly on the irrigation system in the *dhick*. This is because the intensity of irrigation management in the *dhick* is much higher compared to the *khaal*.

[4] The dimensions of most of the landholdings are 33x100 m. This is equivalent to 0.5 *bigha* (0.33 ha)

[5] Close to the system boundary on the east there exists a natural depression. This depression is more prominent at the tail-end of the irrigated area and acts as a drain. During the monsoon, a few springs originate in this drain. These springs supplement additional water to the tail-end of the irrigated area.

[6] Please see Chapter 2 for both hill and Terai farming systems.

practice subsistence agriculture. During monsoon, a monocrop of late paddy dominates most of the *khet* land. Some farmers also grow leguminous crops on terrace bunds. Late paddy is usually followed by irrigated wheat during winter. Some headreach farmers also cultivate a cash crop of potatoes along with wheat. A nominal area of land is covered by mustard. During spring, rainfed maize dominates most of the irrigated areas. Maize is the main crop for livestock, both as green fodder and grain.

Both the time for sowing maize and its yield depend on the rain. Even if it rains late, farmers still sow maize expecting some yield. This is because, unlike in the hills[7], paddy transplantation can be delayed slightly as it will not have temperature-related constraints during the period of paddy maturity. Table 4.1 shows the cropping calendar, area covered and average yield of the main cereal crops cultivated during 1997.

Table 4.1: Area covered, cropping calendar and average yield of main cereal crops in 1997.

Crop	Area covered (percentage)		Dates		Fertilizer	Varieties[8]	Average yield
	Julphe sub-system	Kolia and Basantpur sub-systems	Sowing or transplantation	Harvest			(T/ha)
Monsoon paddy	90	90	July-Aug	Nov-Dec	Compost and CF	*Mansuli* *Savitri* *Radha 17* *Sarju 52*	3-3.5
Wheat	69	65	Nov-Dec	Mar- Apr	Mainly CF		1.8-2.5
Maize	80	70	April-May	July-Aug	Mainly compost		1.5-2.5
Potato	11	-	Oct-Nov	Mar-Apr	Mainly CF	*Kufri Sindhuri*	9-15

Source: Field observation and household survey 1997.
Note: CF refers to chemical fertilizers

Note that the average cropping intensity of the Julphe sub-system is higher than those of the Basantpur and Kolia sub-systems. This is because the Julphe sub-system is located at the headreach where reliability of water supply is higher than elsewhere. In addition, this sub-system has relatively more water shares than the other two (Appendix V).

Except for maize, farmers use improved varieties of seed. However, the practice of replacing seed from outside is rare. Other than for potato crop, seeds for all crops are either produced by the farmers themselves or are procured locally.

All agricultural activities are carried out by human labour and animal draught power. The use of tractor is limited to big landholders. Since the area was only recently opened for cultivation, stumps also preclude the use of tractors for ploughing. Also, farmers say that puddling land by tractor for paddy transplantation requires more water than the traditional

[7] In the hills, it is virtually impossible to cultivate maize on *khet* land without pre-sowing irrigation unless there is timely rain. This is because paddy transplantation cannot be delayed as the temperature constraint during the paddy maturity period affects its yield.

[8] Farmers use many other varieties of crops. Since seeds are produced by themselves or procured locally, farmers are unable to tell the names of crop varieties.

method using bullocks. This may be because since tractors plough faster, a larger flow may be required for more rapid advancement.

The household survey showed that the area does not have any shortage of labour for agricultural activities. During the peak period of cultivation, especially during paddy transplantation and harvesting, exchange of labour is usually practiced, although some big landowners hire wage labourers.

Agricultural tasks are clearly divided between men and women. Ploughing, irrigating, threshing and preparing land for transplantation are usually performed by men. Weeding, harvesting, transporting compost and harvested product, and all other domestic jobs are the responsibilities of women. Maintaining the irrigation system is a common responsibility of both men and women.

In this system, agricultural tasks are much easier. This is because, unlike in the hills, houses are located close to farms. This makes haulage distance for carrying compost and harvested products much smaller. For bulk haulage, bullock carts are often used, whereas for smaller loads bicycles are very popular. As this area is newly deforested, plenty of *sal* wood is available around each household, making agricultural tasks even easier. It is estimated that the area will not have any problem of fuelwood for another ten years. The relatively easy agricultural tasks are a prime reason for large-scale migration to this area from the hills.

The average number of livestock[9] per household is 3.3. The majority of farmers have two water buffalo and about 60 per cent of the households have a pair of bullocks. Livestock is left free to graze in the forest, along river banks, in the *khaal* during winter and spring, and on the sides of roads. Fodder requirements are met primarily from crop residues. Natural grasses cut on *khet* during the monsoon and green maize plants during the spring also supplement the fodder supply as fodder trees are limited.

4.1.4 Landholding and land tenure

The average landholding per household is 0.58 ha. About 78 per cent of the farmers have landholdings less than 0.4 ha. Farmers having landholdings between 0.4 and 1.0 ha and more than 1.0 ha are 17 and 5 per cent respectively. The *zamindar*[10] has the largest landholding–about 6.6 ha. The majority of the farmers have only one parcel of *khet* in the command area.

The common tenure arrangement in this system is sharecropping. The mode of contract for sharecropping depends on the availability of irrigation water and the production capacity of *khet*. Three types of contracts are reported: *tiya* (2/3:1/3), *panch hissa* (3/5:2/5) and *adhiya* (1/2:1/2).

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9 Livestock includes cows, water buffalo and oxen.

10 In Nepal, the term *zamindar* usually refers to a landlord who also acted as a non-official functionary to collect land taxes. The system of tax collection by zamindar was abolished long back. However, in the village, such landlords are still known as *zamindar*. Thus, in this text, *zamindar* refers to a large landholding farmer.

The *tiya* form of sharecropping is used at the headreach of the system, where farmers have relatively high water shares. In this form, the owner gets two-thirds of all the paddy produced. In *khet* with moderate and scarce water supplies, *panch hissa* and *adhiya* forms of sharecropping are used respectively. In the *panch hissa* form of sharecropping, the owner gets three-fifths of the paddy produced, while in *adhiya,* the produce is divided equally. Variation in the forms of sharecropping does not mean that the production of paddy also varies. Rather, inputs needed to manage irrigation water during the cultivation of paddy and the possibility of winter production have caused this difference[11].

The above ratios of sharecropping are applied only for paddy. In all three forms of sharecropping, the rest of the produce are divided equally between tenant and landowner. In all three forms of sharecropping, the costs of inputs requiring capital investment, such as seeds, chemical fertilizers, insecticides and pesticides are shared equally by tenant and landowner. The mobilization of labour to maintain the irrigation system is the sole responsibility of the tenant. When capital investment is needed to maintain the irrigation system, the landowner provides all the funds needed.

4.1.5 The village and its residents

The present settlement is largely the result of the government's resettlement programme launched after the 1950s. Since people from nearby mountain districts (especially Palpa, Syangja and Tanahu) have migrated into this area, a heterogeneous society with a wide range of cultural norms[12] has been formed. Farmers introduce themselves as migrants from the place of original residence.

As mentioned earlier, the area has a network of parallel roads, which connects many landholdings. Houses are constructed in front of the holdings, parallel to roads. For this reason, the settlement pattern is dispersed. Livestock is kept close to households.

The total population of the system is about 2,210, and the average family size is 6.5. Brahmins, Chettris and Kumals[13] are the predominant ethnic groups in this area. It is believed that Kumals are the native people of this area. At present, however, this ethnic

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[11] Due to the relatively greater water supply at the headreach, inputs to be provided by the tenant to manage irrigation are minimal. In the *tiya* and *panch hissa* forms of sharecropping, though tenants receive a smaller percentage of paddy produced, they can get higher returns by cultivating crops like potato during winter. Cultivation of potato during winter is possible because of the ensured water supply at the headreach.

[12] Because farmers migrated from different parts of the hills, their social values and norms of irrigation system operation differ. This has resulted in the formation of well-documented irrigation principles and rules to operate the system. In contrast, in the irrigation systems in the hills, such principles and rules are usually not well-documented. This is because the social values and norms of system operation, which have been developed over many years, are accepted by all farmers as an unwritten constitution.

One simple example in this irrigation system is the differences in the local names given to the wooden proportioning weirs. Farmers from the Tanahu district call the wooden proportioning weir *rath* and those from the Syangja district call it *dhara.* The reason is that these are the local names given to it in their original villages in the hills. However, in the written documents it is called *dhara.*

[13] The ethnic composition in the system is: Brahmins and Chettris (32%), Kumals (30%), Magars (22%) and others (16%).

group has the least landholdings and make up most of the tenant population. Brahmins and Chettris occupy the major portions of irrigated land.

Two high schools, a few primary schools, one primary boarding school, one post office, one health sub-centre and one co-operative are located in the area. The co-operative is functioning well. It supplies some fertilizers and other essential domestic commodities like sugar and kerosene, but does not buy any food grain from farmers. The area does not have an agricultural service centre. The nearest big market is Narayanghat, in Chitwan district, but there are some small markets nearby. For essential domestic commodities a few shops exist within the system area itself. Daily bus services are available from the system area to Narayanghat, Butwal and to Parasi, the district headquarters.

4.2 Historical development

To understand the historical development of the irrigation system, it is worth looking at the history of settlement in the area. It is believed that prior to the 1890s, Kumals were the only inhabitants of this area. The evolution of the present settlement was influenced only after the 1890s, when an influential person from the Pyuthan district became the *zamindar*. During those days, the *khaal* used to be the main *khet* and the areas in the *dhick* were used as homesteads. The Julphe, Kolia and Basantpur sub-systems had about 14, 11 and 20 ha of homesteads respectively. These plots of land were known as *numbari*[14].

4.2.1 Development of the physical system

Farmers believe that the present irrigation system was first constructed by a *zamindar* during the 1910s to irrigate 14 ha of the *numbari* area in the Julphe sub-system[15] (Figure 4.3a). Until the early 1960s this area belonged to the *zamindar*. In the early 1960s, six other farmers bought lands from the *zamindar* and migrated to Julphe. Some of the survivors among these six farmers say that it was very difficult for them to divert water from the river into the main canal as they did not have sufficient farmers to maintain the intake. They recall that once they lost their intake site and they were forced to negotiate with the farmers of the upstream system to merge their intake with the upstream intake[16] as there was no other suitable site.

[14] *Numbari* is derived from the word number. The lands, which are registered with the land revenue office, are known as *numbari*, meaning lands with registration numbers. Such lands are cultivated since long back, and therefore, can be counted as traditionally cultivated land. Public lands, such as forest, which were encroached upon and converted into cultivated land by individuals, are not easily registered. In this area, such lands are known as *naya abadi*, meaning newly developed lands. Although at present most of these newly developed lands are also registered, the term *numbari* is still used to differentiate between the newly developed and traditionally cultivated lands.

[15] In those days, both the Basantpur and Kolia sub-systems also had some cultivated highland in the *dhick*. However, the canal was only up to the Julphe sub-system. The main reason was the lack of resources (especially labour) to extend the canal.

[16] The upstream system used to irrigate the *khaal* area belonging to the farmers of the Belani village. Two intakes were merged into one under the condition that the merged intake would be maintained by the farmers of Julphe. However, farmers of the Belani village would get the first preference for irrigation water. Even today farmers of Belani do not mobilize resources for the intake maintenance but continue to divert the water they need.

The *zamindar* used to mobilize the available tenants to maintain the system, and the water rights were attached to the land. The flow in the main canal was small. Water was distributed by rotation at the system level. Paddy was the only crop grown in the area.

In the 1960s, migration from the nearby hills increased. People started settling in Julphe by encroaching on the forest. By the early 1970s, large areas of forest had been converted into cultivated land. The new settlement area is known as *naya abadi*.

During the early 1970s, because the farmer population had increased, the farmers of Basantpur and Kolia sub-systems united and entered into an agreement with the farmers of the Julphe sub-system to rehabilitate the main canal. The main canal, whose width at that time was 3 *haath*[17], was widened to 5 *haath*, and was extended up to the Basantpur Village. The farmers of Kolia and Basantpur acquired the right to two-fifths of the incoming water in the main canal. The new settlers of Julphe also mobilized their resources to rehabilitate the main canal and also claimed water rights. The extended portion of the main canal (Dhick Kulo) started operating in 1975.

To divide the water according to the agreed upon shares, wooden proportioning weirs were introduced. Note that farmers in this area had migrated mainly from the Palpa, Syangja and Tanahu districts, where the technology of wooden proportioning weir is popular. A proportioning weir placed at Girwari divided the incoming water into two parts, one of which went to Julphe and the other to Kolia and Basantpur. The water shares of Kolia and Basantpur were further divided by placing a proportioning weir at Hattigaunda (Figure 4.3b). The division of water shares was based on the amount of resources mobilized by the sub-systems.

Since 1975, all three areas, Julphe, Kolia and Basantpur, have been functioning as independent sub-systems with independent shares of water. Each has its own organizational and institutional arrangements.

Within both the Kolia and Basantpur sub-systems, water shares were further allocated to various sections and sub-sections based on the amount of resources mobilized. In the Julphe sub-system, however, the major portion of the water was retained by the old irrigators[18]. Only the increased volume of water was allocated to new settlers. Among the old irrigators, water shares were allocated with respect to the percentage of irrigated *numbari* area[19] each used previously. For this reason, the unit of a water share is named

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[17] *Haath* is a measure of distance. One *haath*, which is equal to the distance from the elbow to the tips of the fingers, is approximately equal to 0.45 m.

[18] The term 'old irrigators' here refers to those farmers who had irrigation facilities prior to the system rehabilitation.

[19] For example, a farmer having a certain percentage of the *numbari* area (with respect to the total *numbari* area) was allocated the same percentage of the total available water to this area. This principle was used initially to allocate the available water to farmers in the *numbari* area. Since then, however, this principle has not been used.

kattha[20]. Since the rehabilitation, water share is no more attached to the land. Farmers consider their water shares to be private property.

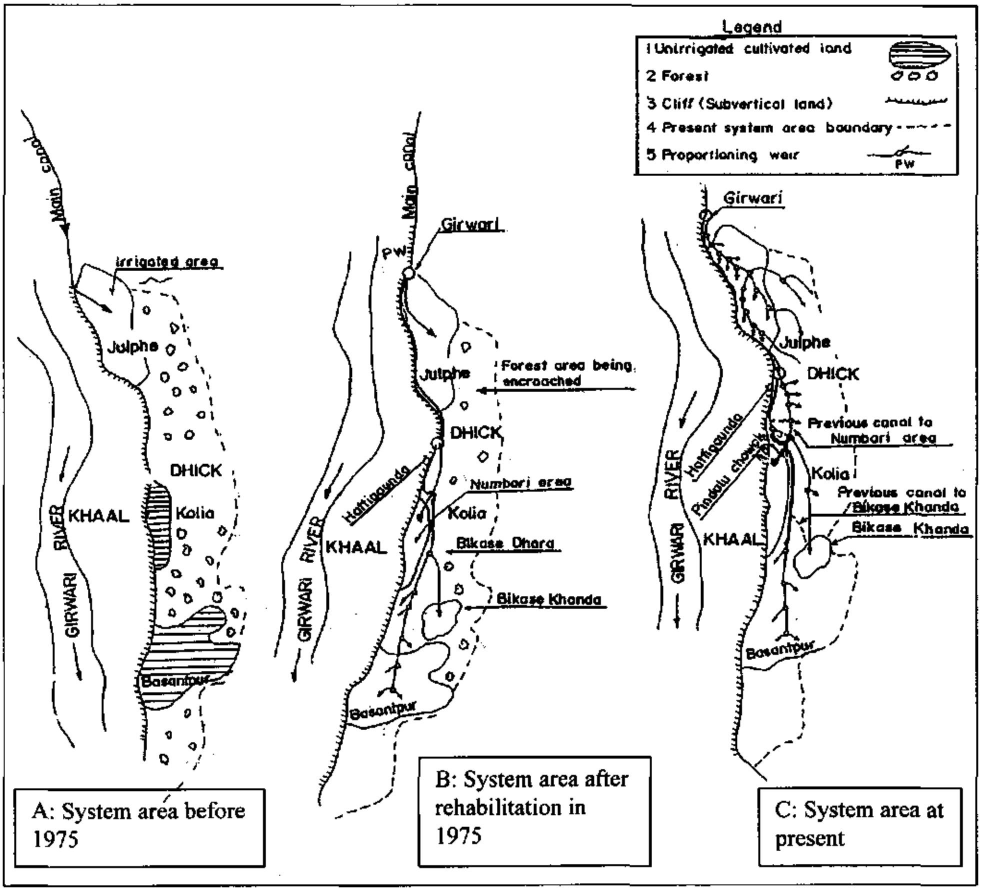

Figure 4.3: Chronology of the development of the physical system.

The available old records show that in 1975, the number of farmers was 83 and the area of land irrigated was 48 ha. Since water shares were no longer attached to land, farmers started selling parts of their shares to the new settlers[21]. This has resulted in the expansion of the irrigation system, both in terms of the number of farmers and the area of irrigated land. At present, the system irrigates about 200 ha belonging to about 340 farmers.

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[20] *Kattha* is a unit of measurement of land. One *kattha* is approximately equal to 0.033 ha. However, here, *kattha* also represents water shares. In those days, one *kattha* of water share represented that volume of water which was allocated to one *kattha* of land in the *numbari* area.

[21] Most water trading was done on an individual basis. Some farmers in Basantpur, residing in the Bikase Khanda (one of the new settlement areas), found it difficult to arrange money to buy water shares from others. They united and formed a group of 19 farmers. As banks do not lend money to buy water shares, they applied for a loan to construct an irrigation canal. In 1986 (2043 BS), their loan was approved. With that money they procured water shares from various other farmers and extended the canal to their area by using their own labour.

Modification in the distribution system

In the Kolia sub-system, the system was developed mainly to irrigate the *numbari* area. This area used to receive its water shares from the canal at Hattigaunda, located about 750 m upstream. Except for small patches, the major portion of land between Hattigaunda and *numbari* area was not irrigated. However, after the system was expanded, most of these areas started getting irrigation water. Accordingly, many proportioning weirs were installed upstream of the *numbari* area. Consequently, the main targeted area, which was located at the physical head, ended up being located at the tail in terms of water delivery.

In any irrigation system, if the physical location of his land permits, a farmer would like to be located at the head of a subsequent branching canal rather than at the tail of the preceding branching canal. There are two interrelated reasons for this. First, minimal supervision is needed to watch the upstream control points as many farmers downstream already watch them. Second, the likelihood of receiving irrigation water at the head of a subsequent branching canal than at the tail of the preceding branching canal is higher.

Farmers in the *numbari* area of the Kolia sub-system had relatively more land and were influential. They wanted to change their offtake point from the canal at Hattigaunda to the one at Pindalu Chowk, which belonged to the Basantpur sub-system. In 1986, they asked (in writing) the Basantpur Irrigation Committee if they could install an additional proportioning weir at Pindalu Chowk. They also requested that they be included in the Basantpur organization.

Since the farmers of Kolia were influential, their request was discussed repeatedly by the Basantpur Irrigation Committee. However, the farmers of Basantpur refused their request. They simply did not want to add another control point to their sub-system. They argued that the more control points there are in a canal, the more likely is the chance of mismanagement of the water flowing through it.

After their proposal was refused by the Basantpur Irrigation Committee, the farmers of Kolia started playing an internal power game. Finally, in 1989, they succeeded in installing an additional proportioning weir at Pindalu Chowk.

In those days the Basantpur sub-system had seven proportioning weirs[22]. Farmers of Kolia managed to persuade the influential farmers of Basantpur to remove one proportioning weir, known as Bikase Dhara, belonging to the farmers of Bikase Khanda. They further proposed to merge this weir with the proposed proportioning weir at Pindalu Chowk. The influential farmers of Kolia argued that the number of proportioning weirs in the sub-system would remain the same and that except for the farmers of Bikase Khanda, nobody would object. Since the farmers of Bikase Khanda belonged to the weaker section of society, their voice was suppressed. In 1989, the Basantpur Irrigation Committee allowed the installation of an additional proportioning weir at Pindalu Chowk[23]. Bikase Dhara was

[22] Later on, in 1993, two of them were merged into one.

[23] Farmers of Kolia were allowed to install an additional proportioning weir at Pindalu Chowk on the following conditions: (a) They should follow the rules and regulations of the Basantpur Irrigation Committee; (b) They should replace the wooden proportioning weir at Hattigaunda with a cement weir and

removed from its place in the canal and merged with the proportioning weir at Pindalu Chowk (Figure 4.3c). The new branching canal at Pindalu Chowk is known as Pindalu Chowk Ko Kulo.

The farmers of Bikase Khanda repeatedly requested that their proportioning weir be re-installed at its previous location. However, their voice was not heard. By this re-arrangement of the distribution system, the farmers of Bikase Khanda ended up at the tail of the preceding branching canal, while the influential farmers of Kolia were located at the head of the following branching canal.

With this re-arrangement of the distribution system, the structure of the irrigation organization also changed. An irrigation sub-committee was formed to look after the Pindalu Chowk Ko Kulo. Farmers of Bikase Khanda were also included under the jurisdiction of the new irrigation sub-committee. As farmers of Bikase Khanda were unhappy, they neglected this sub-committee[24] and formed an irrigation committee exclusively for their area[25].

Similar changes in the distribution canals of the Julphe sub-system were also recorded. Accordingly, a few proportioning weirs were relocated. However, in Julphe, most of the causes related to land constraints. For example, a few distribution canals which had been previously aligned through private land were realigned by buying land for them.

4.3 The physical system

Julphe is a river-valley irrigation system and irrigates about 200 ha of cultivated land. From the managerial point of view, the system is divided into three sub-systems, Julphe, Kolia and Basantpur. The hydraulic boundaries of these sub-systems are defined physically, and each has defined water rights. The intake and the main canal are common to each of the sub-systems, but the distribution canals are independent. The following sections describe and discuss the various physical components of this irrigation system.

4.3.1 Water source

The Girwari River, a perennial river, is the main source of water for the system[26]. It is a tributary of the Narayani River, and flows from north to south. In this area, the river discharges into a wide river valley from a narrow valley of the Mahabharat mountain range. This has resulted in the formation of bed bars and islands of coarse materials

install a cement proportioning weir at Pindalu Chowk at their own cost; (c) They should be responsible for the proper functioning of weirs in their area; (d) To be a member of the Basantpur Irrigation Committee, each farmer concerned of Kolia should pay an amount equivalent to the balance available per previous user at the time of approval to the Basantpur Irrigation Committee.

[24] This sub-committee is defunct despite its repeated formation.

[25] This irrigation committee actively manages water distribution and resolves water-related disputes. The committee also collects fines, in cash, from its beneficiaries who do not follow the rules of water distribution. Such fines are deposited in their bank account for later use exclusively in their area.

[26] The catchment area of the Girwari River is about 50 sq km, with 65 per cent covered by forest, 23 per cent by cultivated land and the remaining portion by other land uses (DOI, 1987).

(pebbles, gravel and boulders) on the riverbed. This, in turn, further resulted in the formation of multiple unstable river channels[27] even at below average flow. The average overall width of the river at the diversion point is about 200 m, and the average river gradient is about 1.8 per cent.

East Consult (1982) estimated[28] the mean monthly flows of the Girwari River about 1.0 km upstream of the intake of this irrigation system (Table 4.2).

Table 4.2: Mean monthly flows of the Girwari River.

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Flow (lps)	820	620	460	340	310	930	3810	4740	3400	2220	1550	1130

The values during monsoon (June-Sept) presented in the above table are the base flows. Actual flows are usually higher. East Consult (1982) also estimated a peak flow of about 390 m^3/sec over a return period of five years. The observed peak flow as recorded by DOI (1987) is about 180 m^3/sec.

There are four other irrigation systems diverting water from this river. All of them have temporary diversion weirs. Three of them are located upstream and one downstream of the intake of Julphe Irrigation System[29] (Figure 4.2). The three systems upstream irrigate about 550 ha (DOI, 1987) of land. During the monsoon, the river has enough water for all the four systems. However, from March to mid-June, Julphe Irrigation System experiences water shortage[30].

4.3.2 Intake

Figure 4.4 shows the layout of the intake. It consists of three main components, the temporary diversion weir across the river, the approach canal and the check structure. The river morphology described above makes it difficult to divert water into the main canal.

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[27] Nepalese rivers, in such a stage, exhibit the tendencies of both aggradation and degradation of the river bed, with perhaps an overall tendency of aggradation (MacDonald *et al.*, 1990 M7). Lateral shifting, by eroding the banks, is a common feature.

[28] The mean monthly flows were estimated on the basis of regional hydrographs and of a few low flow measurements (East Consult, 1982).

[29] The system, located downstream, which is known as Aakase Kulo, irrigates the *khaal*. As mentioned earlier, in the *khaal*, only one crop of paddy is cultivated. For this reason, the Aakase Kulo operates only during the monsoon whereas the other systems operate in all seasons.

[30] During the spring season, meetings are held among the members of the irrigation committees of all systems to manage sharing of river water. The chairman of the Deurali Village Development Committee coordinates this meeting. In principle, it is agreed that all systems should share the river water equally. However, in practice, the upstream systems divert most of the river water, and the Julphe Irrigation System remains virtually dry during this period.

There are two reasons for this. First, the actual division of flow takes place about 1.0 km upstream of the intake of the Julphe Irrigation System, where the intakes of the other systems are located. For the farmers of Julphe, this point is far and away, and thus they cannot provide frequent supervision. Second, the available flow to Julphe Irrigation System is further conveyed down to its intake through the river channel. Most of this flow seeps through the river bed, and only a small flow is available at the intake. Conveying a small flow in a wide and long main canal is not efficient.

However, farmers' knowledge about the river hydrology and the labour resources they contribute to maintain the intake make it possible to divert water.

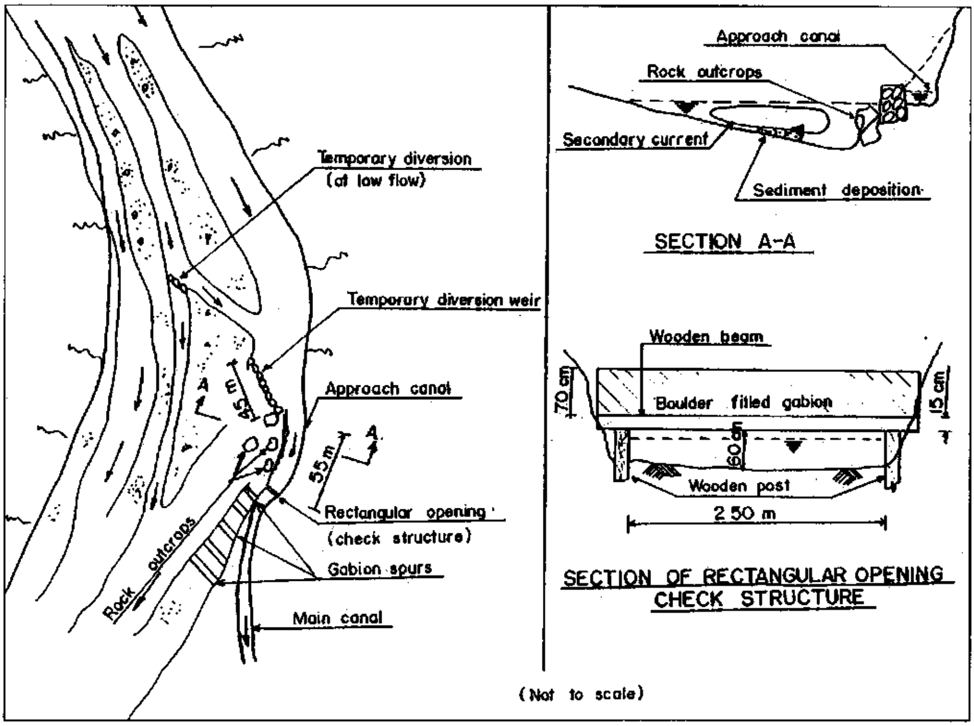

Figure 4.4: Layout of the intake.

At the diversion point, the river has three defined channels. During high flow, the channel located towards the intake side discharges enough flow. However, during low flow, additional diversion weirs upstream are needed in order to divert the flows from other channels to the channel close to the intake side.

The location of the intake is carefully planned. It is located at the downstream end of the outside bend (concave side) of the river. The river bank at this point also has a series of rock outcrops. This location has two main advantages. First, sediments (especially coarse sediments) are prevented from entering the canal[31]. Filtering the sediments is a major criterion for selecting the site of an intake. Second, a deeper and more permanent flow is available at the concave side of the river. By locating the intake at the outside bend, there is a tendency of bank scour. Erosion, however, is prevented by the series of rock outcrops.

The diversion weir across the river checks the flow of the river and raises its water level to feed the approach canal. The diversion weir is temporary. It is constructed with layers of

[31] By locating the intake at the concave side of the river, a secondary current is generated. This means that surface water tends to move outwards and the water near the bed inwards. As a consequence, the sediments near the bed move to the inner bank and the cleaner surface water moves outward. In addition, the angled bed movement encourages scour near the outside bank and shoaling at the inside bank.

boulders with brushwood in each layer, and it is laid skewed to the main direction of flow– the reasons are explained in Chapter 2. Because of flash floods occurring in the river, the diversion weir needs frequent maintenance[32].

The headreach of the approach canal lies within the floodplain. It has been constructed partly by cutting the river bank and partly by constructing a temporary dry boulder wall on the river bed. This wall acts as an outward canal bank. In some places, the approach canal has been strengthened by constructing gabion walls. It is also strengthened by a series of natural rock outcrops. For this reason, the approach canal is relatively safe and requires less maintenance than does the diversion weir across the river. However, big floods in the river can wash away the approach canal. At the end of the approach canal, water passes through a rectangular opening (an orifice type of check structure). Figure 4.4 shows a cross-section of this structure.

The approach canal is about 4-5 m wide and has shallow flow. The flow velocity in this canal is also very low. The approach canal has two main functions. First, it acts as an overflow side spillway and controls the flow entering the main canal. During high flows, the rectangular opening at its end acts as a submerged orifice and checks the flow entering the main canal. This creates an afflux in the approach canal[33], which in turn increases upstream head through an orifice. The crest level of the outward back of the approach canal is fixed in such a way that the excess water (afflux) automatically spills through it and ultimately discharges back into the river. Second, the approach canal also acts as a settling basin. Because of its relatively low flow velocity, some of the sediments which enter this canal settle down. This sediment is automatically flushed out when the outward bank gets washed away by big floods.

4.3.3 Main canal

As in many other irrigation systems where the nomenclature of the canal is based on the rights and responsibilities of its users (Vincent, 1995), in this irrigation system also, the canal which is common to all the three sub-systems is termed as Mul Kulo, meaning the main canal. The main canal starts from the intake and ends at the first proportioning weir, P1, placed at Girwari. At this point, the main canal bifurcates into several branches, each having its own set of rights and responsibilities attached to particular users' groups.

The main canal is a contour canal, with an average gradient varying between 0.2 and 0.8 per cent. Its total length is 2.1 km. The average width and depth of the main canal are about 2.3 and 1.0 m respectively[34]. The canal has a fairly stable 1.5 m wide bank on the valley-side. From its intake down about 220 m, it is aligned along the *khaal khet*[35]. From

[32] See the later section on water acquisition.

[33] The flow through an orifice depends on the upstream head. To check the flow through an orifice, the upstream head (afflux) needs to be minimized

[34] The average maximum flow depth at flatter sections of the main canal is about 0.6 to 0.7 m.

[35] At its chainage of about 155 m from the intake, a small canal bifurcates for the *khaal*. There is no denomination of water to be diverted into this branch canal. Random measurements of flow indicate that this branch canal diverts about 40-70 lps during the monsoon. Flows are adjusted based on visual

220 m down to its end, it passes across fairly stable steep cliffs. This portion of the main canal has some minor problems with slides from the hill. Occasionally, such slides obstruct the flow, resulting in a canal breach[36].

4.3.4 Distribution canals

Other than the main canal, this irrigation system has a three-tier hierarchy of distribution canals. They are termed here as sub-main canal, secondary canal and field channel.

A sub-main canal is the primary canal for a sub-system. There are two such sub-main canals, known as Julphe Kulo and Dhick Kulo. Both of them start from the first proportioning weir, P1. The Julphe Kulo irrigates the Julphe sub-system and the Dhick Kulo irrigates both the Kolia and the Basantpur sub-systems. Flow to the Kolia sub-system is further separated from the flow to the Dhick Kulo by the proportioning weir, P36, placed at Hattigaunda. The continuing Dhick Kulo irrigates the Basantpur sub-system. Figure 4.5 shows the layout of the distribution canals.

All the sub-systems have independent secondary canals. The total number of secondary canals in the Julphe, Kolia and Basantpur sub-systems are three, one and two respectively[37].

All distribution canals run across the contour and irrigate land on both their sides. The distribution system is designed for a continuous flow regime for cultivating paddy. This means that the capacity of lower order canals is smaller than that of higher order canals. At all but three canal bifurcation points, fixed proportioning weirs are placed to divide the flow.

A canal at the lower end of the distribution system is termed here as the field channel. Flows at the field channels are not divided. Where one field channel serves more than one farmer, an open-close system of distribution is used. Field channels receive water through offtakes in their parent canals. The density of such offtakes per unit of irrigated area varies within the system (Table 4.3).

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estimation using stone and mud. Other than this branch canal, there are three or four direct outlets in the main canal to irrigate the additional *khaal* area. Each of them diverts about 10-15 lps of water.

[36] When such canals rupture, it not only damages the canal but also damages the crops cultivated in the *khaal*. Under such a situation, farmers of this system need to pay in cash an amount equivalent to the crop damage. In addition, they need to repair the damaged portion of the *khet*.

[37] In the Julphe sub-system, the sub-main canal (Julphe Kulo) ends at Ishwori Chowk. The first secondary canal, known as Dabdabe Purba Kulo (meaning Dabdabe east canal), starts from the proportioning weir, P7, placed at Dabdabe. The other two secondary canals, known as Dabdabe Dakshin Kulo and Dabdabe Pachchhim Kulo (meaning Dabdabe south and Dabdabe west canals respectively), start from the proportioning weir, P8, placed at Ishwori Chowk. Of the three secondary canals, the Dabdabe south canal is the longest and irrigates the largest area.

In the Basantpur sub-system, the sub-main canal (*dhick kulo*) ends at Pindalu Chowk. Both the secondary canals, known as Basantpur Ko Kulo and Pindalu Chowk Ko Kulo, start from the Pindalu Chowk.

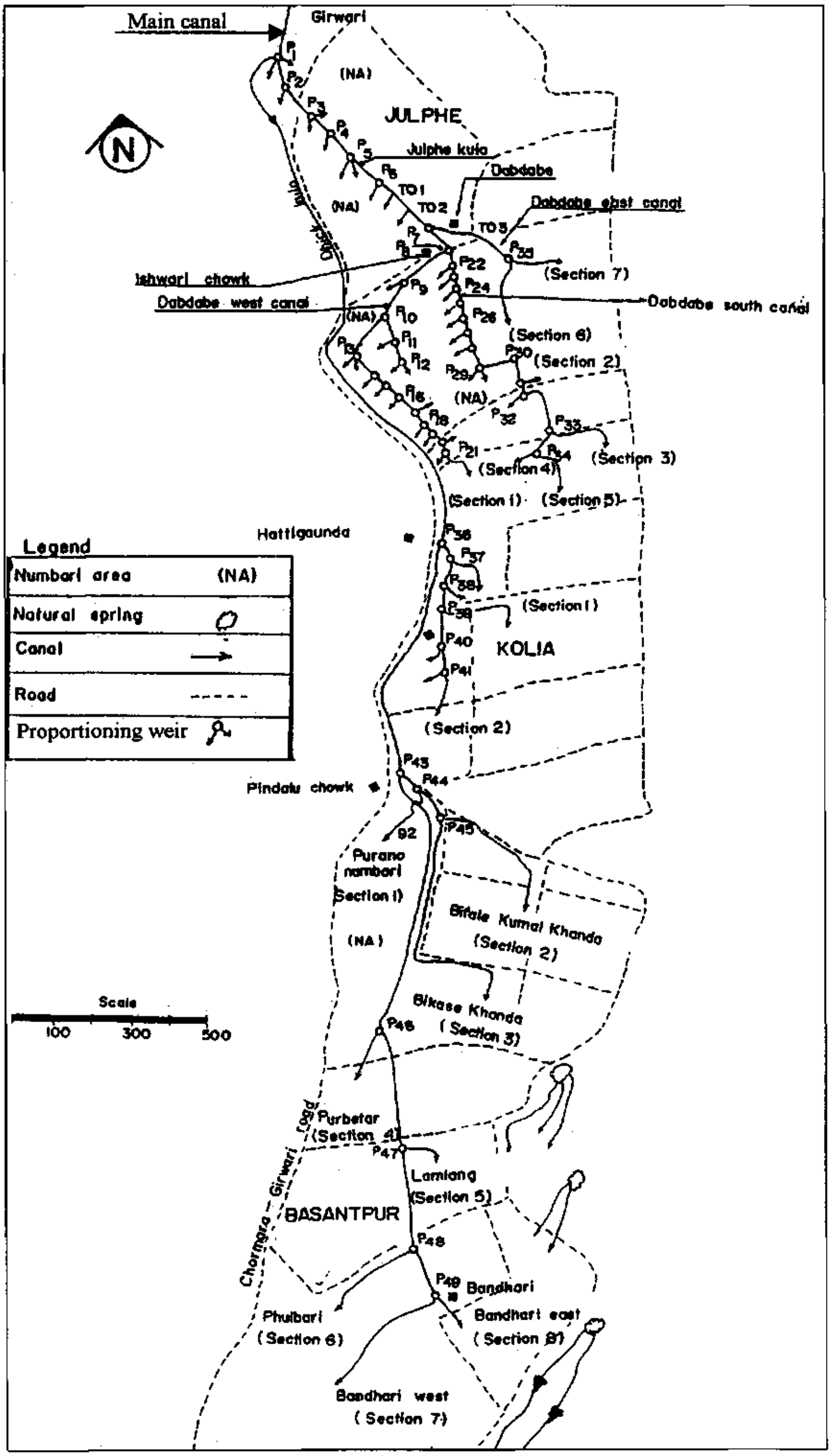

Figure 4.5: Layout of the distribution canals

Table 4.3: Density of offtakes in various parts of the irrigation system.

Sub-system	Number of offtakes	Average area served by one offtake (ha)	Average number of farmers served by one offtake
Julphe sub-system			
Numbari area	35	0.83	1.62
New settlement area	7	5.77	16.5
Kolia sub-system			
Headreach area	4	0.53	1
Remaining area	2	8.22	18
Basantpur sub-system	8	14.0	29.5

The *numbari* area of the Julphe sub-system and the headreach area of the Kolia sub-system have a higher density of offtakes than any other area. In the *numbari* area of Julphe, of the 35 offtakes[38], 32 receive water through proportioning weirs. The other three (two in the Julphe Kulo and one in the Dabdabe east canal) receive water through fixed orifices. They are denoted here as TO1, TO2 and TO3 (Figure 4.5).

During the cultivation of paddy, the Julphe *numbari* area and the Kolia headreach area receive continuous flow[39]. Ambler (1989) defines such areas as fully proportionate[40].

The rest of the areas of the Julphe and Kolia sub-systems, and the entire area of the Basantpur sub-system are partially proportionate. In the Julphe, Kolia and Basantpur sub-systems, partially proportionate areas are divided into seven, two and eight sections respectively. Each of these sections receives water through one offtake from its respective secondary canal.

4.4 Water distribution structures

As mentioned earlier, Julphe Irrigation System uses proportioning weirs and open-close structures for irrigating paddy. At the higher end of distribution, proportioning weirs are placed in most of the canal bifurcation points. At the lower end of the distribution system, especially within sections, the open-close type of distribution is used.

4.4.1 The proportioning weir

The general design considerations and management aspects of a proportioning weir are similar to those discussed in Chapter 3. Locally, the proportioning weir is known as *dhara*. In this system, most of the proportioning weirs are made of timber. In recent years, a few cement weirs have also been used. Due to frequent water trading[41] among farmers,

[38] In this area, about 40 per cent of the farmers have individual offtakes, about 30 per cent have a common offtake for two of them, and the rest have one offtake for four or five farmers.

[39] Although about 60 per cent of the farmers have to divide the flow internally, during the cultivation of paddy all landholdings receive continuous flow. This is because farmers do not have individual drainage channels. Excess water flows from terrace to terrace. This results in continuous flow to all landholdings.

[40] An area is said to be fully proportionate if all individual farmers receive water on a continuous basis. In a partially proportionate area, continuous flow is delivered on a proportional basis to certain sections. Other means are used to divide water at the lower ends within sections (Ambler, 1989).

[41] See also the section on water trading discussed later in this chapter.

notch widths in a proportioning weir need frequent adjustments. In proportioning weirs made of cement, it is difficult to adjust notch widths. For this reason, in a few cases, timber has been placed on the cement weirs to facilitate adjustment of notch width.

This irrigation system has 49 proportioning weirs in the main, sub-main and secondary canals. Appendix III shows the principal physical features of these weirs.

Other than the general considerations for its location discussed in Chapter 3, the location of a weir in a canal also depends on whether the canal is in a state of cutting or of filling[42]. Note that from chainage 500 to 650 m, the average canal bed is above the normal ground level (Figure 4.6). This means that the canal is constructed by artificially raising the banks. Such banks are relatively weak. A proportioning weir results in the ponding of water upstream. Thus, proportioning weirs are best suited for places where the canal banks are stable enough to retain the swollen water. Installing a proportioning weir in a canal which is already in a state of filling further weakens the canal banks. For this reason, in this reach fixed orifice offtakes have been used instead of proportioning weirs[43].

Weir height above the canal bed

Two main criteria for fixing the height of the weir above the normal canal bed have been observed: the canal bed slope and the bed level of the offtake canal.

In segments of a canal having very flat gradients[44], the height of a weir is fixed just to obtain free flow through it. In a deeper canal, however, where the bed level of a branching canal is located much above that of its parent bed, the weir height is raised accordingly.

Figure 4.6 shows a profile of the Julphe Kulo aligned across the contour. Note that from the beginning down to the chainage 405 m, the canal bed is located below the average ground level. In this reach, the offtake canals are located at higher elevations than the parent canal bed. This necessitated the raising of the supply level in the parent canal so that free flow can be delivered to the branching canals. This fact implies that proportioning weirs work not only as a distribution structure but also as a check-cum-drop structure. Depending on the differences in the bed levels between the parent and the offtake canals, the weir height above the parent canal bed varies between 0.25 and 0.70 m. The proportioning weirs functioning as a check also reduce the approach velocity.

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[42] Canal in-cutting refers to a canal section located below the average ground level. Where a canal section is located above the average ground level, it is referred to as canal in-filling.

[43] The crest of the orifice is located about 15 cm above the normal canal bed. A hollow timber is used to make the orifice whose average diameter varies between 10 and 15 cm.

[44] Examples of such segments of canal are (a) from proportioning weir P43 down to P45 in Pindalu Chowk Ko Kulo and (b) from proportioning weir P29 down to P30 in Dabdabe south canal. This portion of Dabdabe south canal has a canal gradient of 0.08 per cent, whereas the average gradient of canals aligned across the counter varies between 0.7 and 1.5 per cent. Also, note that the crest of the proportioning weirs, P30 and P44, are located only about 10 cm above the canal bed. This is equivalent to the depth of the timber.

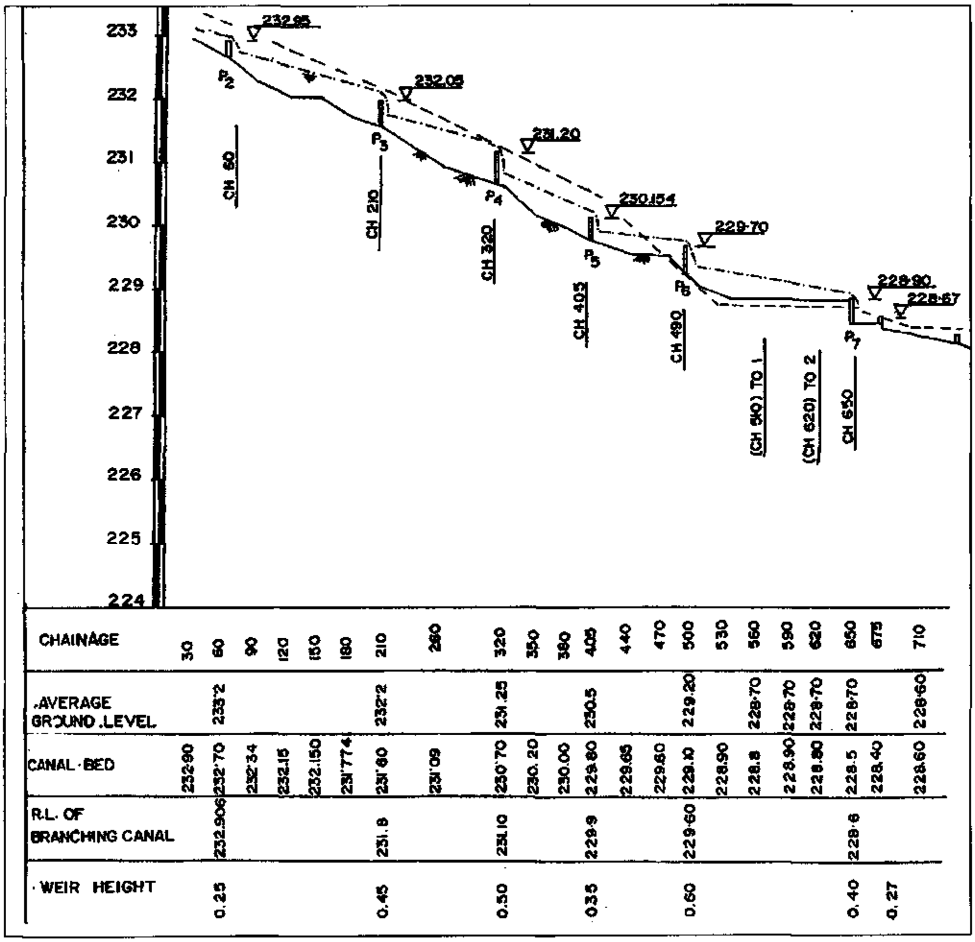

Figure 4.6: Longitudinal section of the Julphe Kulo.

Design of notch width

In this system, the notch widths of proportioning weirs are designed according to land availability and hydraulic considerations. Since the average overall weir width required is much more than the average canal width, land availability is also an important consideration.

The main hydraulic consideration is providing the width required to pass the design discharge. The width needed depends on the head of the flow upstream of the weir, which in turn depends on the availability of timber of the size required to construct a weir. As mentioned earlier, the forest in this area consists of mature *sal* trees, with an average girth of more than 2 m. For this reason, the timber used for constructing proportioning weirs is very thick[45], and it is therefore possible to distribute water with this structure even with a large average incoming flow of about 850 lps.

In the headreach of the system, relative differences in the flow size of the parent and the offtake canals are high. In some weirs, this value reaches 1:100. As a result of the large differences in the flow size, notch widths, too, exhibit wide variations, and some notches are very narrow. About 19 per cent of the notches have widths less than 10 cm, and 10 of them (out of the total 95 notches) are even less than 5 cm in width. Interviews with farmers suggest that land constraints on constructing a wider weir has resulted in narrow notches.

Accuracy in flow division

The critical state of flow and uniformly distributed low approach velocity are the main hydraulic requirements for the proper functioning of a weir. The lower the approach velocities, the higher is the accuracy in water division. The effect of the approach velocity is more prominent in a weir having varying notch widths, especially when a narrower notch is located at the edge and a wider one at the centre of the canal. In such a situation, the flow may not be proportional to notch widths. This is because flow velocities are usually greater at the centre than at the edges, and wider notches are more likely to be located more towards the centre of the canal.

In this system, to minimize the effect of the approach velocity, the bigger notch is simply divided into two parts by a flow-divider (Figure 4.7). This flow-divider usually lies towards the middle of the canal. Flow-dividers also have a substantial width varying between 20 and 45 cm. To some extent, a flow-divider helps to check the approach velocity and to redistribute it more evenly across the canal.

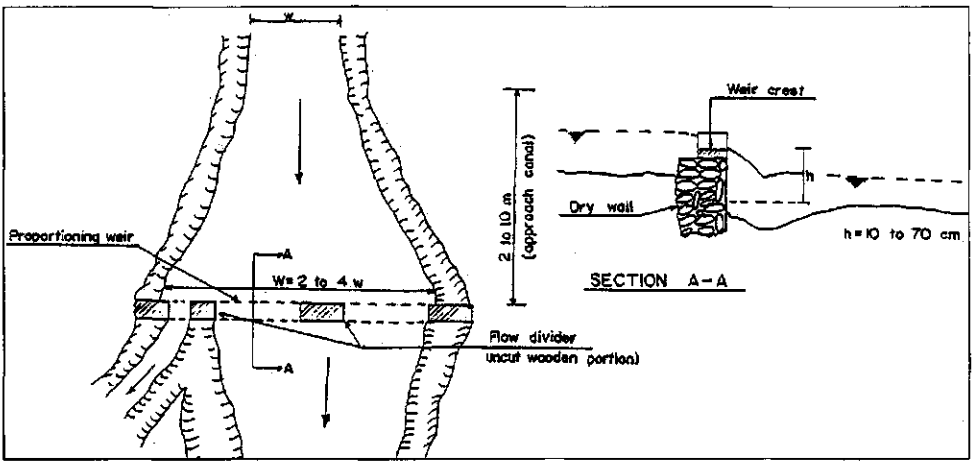

Figure 4.7: Typical plan and profile of a proportioning weir.

[45] In the headreach of the system, the average notch depth, notch length and the overall width of proportioning weirs are about 0.22, 0.27 and 4.13 m respectively.

In a weir having varying notch widths, flow constriction may also affect the flows passing through narrower notches. If the h/L ratio exceeds 0.4, the flow constriction effect is more prominent[46].

In the headreach of the system, the h/L ratio (for average flow) in many proportioning weirs is more than 0.5. For higher flow, this value is exceeded, and its effect is clearly visible[47] (Photo 4.1). However, in the design of the notch, no considerations have been made to compensate for the losses caused by flow constriction.

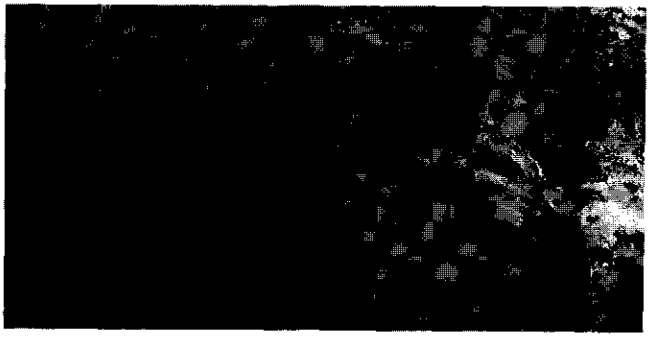

Photo 4.1: Flow constriction in the notch of a proportioning weir.

Farmers' consideration of hydraulic effects (approach velocity and flow constriction) in the design of proportioning weirs depends on the accuracy needed and their perception of equity - both of which differ from system to system. In a water scarce system, like the Sankhar Irrigation System, all hydraulic effects are carefully considered. However, in the headreach area of this system, farmers' perceptions of equity have overlooked some of these hydraulic effects. The reason is, in the headreach area of this system, the average flow available is much higher than in the tail-end area. This made the effects of approach velocity and flow constriction insignificant, though their values may be relatively high. Unlike this, in the tail-end area, where the available flows are relatively small, the effects due to flow constriction and approach velocity are minimal. These effects are also fairly distributed among all branch canals. This is because, in the tail-end area, large variations do not occur in the notch widths.

[46] Please see Chapter 3.

[47] The effects due to flow constriction were more prominent in the proportioning weirs placed in the Julphe Kulo and the Dabdabe south canal. During monsoon, flows in these canals varied between 200 to 400 lps. For this reason, it was not possible to measure these flows to quantify the losses due to flow constriction.

4.5 System operation

In Julphe Irrigation System, arrangements for system operation mainly include: (a) organizational and institutional arrangements for water control and maintaining the physical system, (b) principles of water allocation and water trading, and (c) methods of water distribution. These arrangements vary greatly between the three sub-systems, the Julphe, Kolia and Basantpur. Table 4.4 summarizes some of these differences at a glance. Devolution of water management tasks to the users in the sub-systems has resulted in these differences. The following sections describe and discuss them in detail.

Table 4.4: Main differences in irrigation management among sub-systems.

Main features	Julphe sub-system	Kolia sub-system	Basantpur sub-system
Sub-system irrigation organization	Defined committee with written rules Direct election of office holders Irrigation committee changes annually	Ad hoc committee No written rules	Defined committee with written rules Indirect election of office holders Irrigation committee is not changed annually
Labour mobilization for system operation with respect to water shares	Low	Records not available	High
Fines from absentee farmers for system maintenance	Fines are collected, and redistributed among all farmers	Farmers do not pay fines	Farmers do not pay fines. By rule, fines are to be deposited in a central account
Basis of labour mobilization for general maintenance	Households	Households	Water shares
Average water allocation	10.40 *kattha* per ha (about 7.2 lps per ha)	5.55 *kattha* per ha (About 2.2 lps per ha)	6.63 *kattha* per ha (about 2.3 lps per ha)
Trading of water between farmers	Not allowed Irrigation committee sells water shares from common pool	Allowed Irrigation committee does not sell water shares.	Allowed Irrigation committee does not sell water shares
Water distribution	About 42 per cent of the sub-system area is fully proportionate. The rest of the area is partially proportionate	About 12 per cent of the sub-system area is fully proportionate. The rest of the area is partially proportionate	The entire sub-system area is partially proportionate
Installation of proportioning weirs	Installed after the completion of paddy transplantation in the sub-system area	Installed after the completion of paddy transplantation in the sub-system area	Installed in the beginning of paddy transplantation in the sub-system area

4.5.1 Organizational and institutional arrangements

Irrigation organization

Figure 4.8 shows the three-tiered structure of the irrigation organization. The organization at the highest level is known as *mul samiti*, or the main committee. The second and third tiers of the organization deal with the sub-system and section levels respectively. Clearly, this organization is based on the physical system.

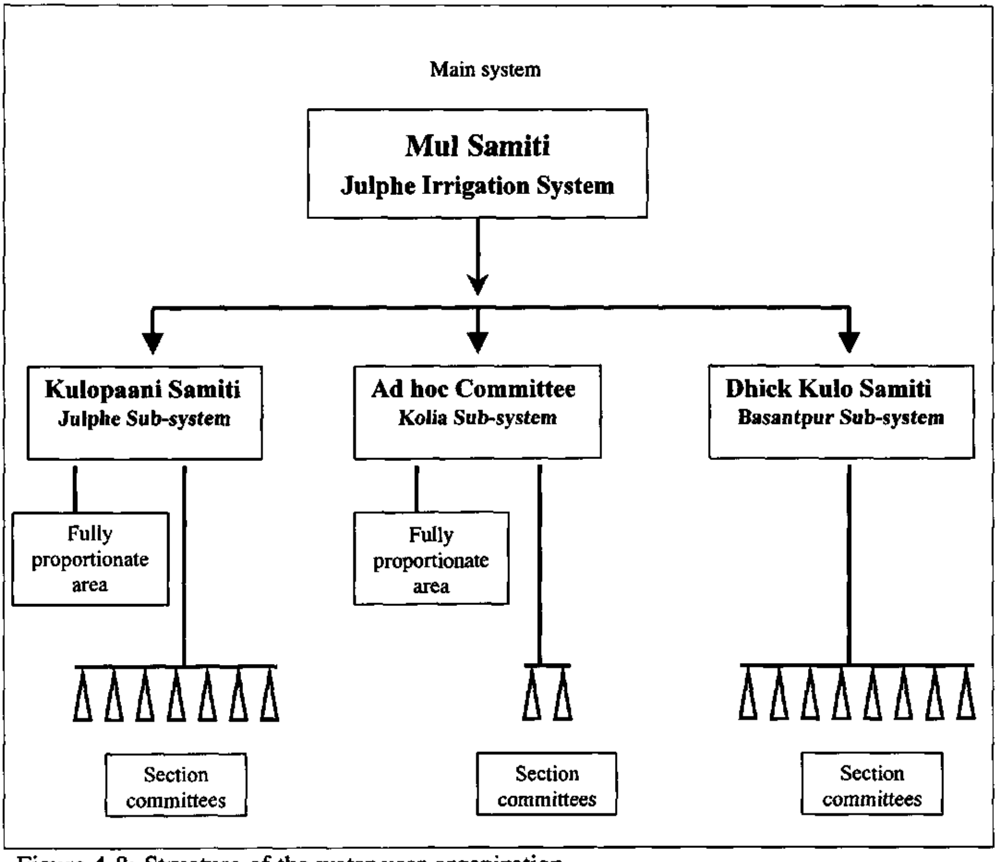

Figure 4.8: Structure of the water user organization.

The *mul samiti* was defunct at the time of the study period in 1997 so its activities could not be observed. Ordinary farmers did not even know about the existence of this committee, though the key farmers did. For ordinary farmers, the main committee meant the irrigation committees of the respective sub-systems.

The *mul samiti* was established at the initiative of the farmers of Basantpur to avoid disputes between or among the sub-systems over water distribution and system maintenance[48]. For this reason, the chairman of the Basantpur irrigation committee was also nominated as the chairman of the *mul samiti*. Since the farmers of Julphe did not co-operate with this committee, it became inactive. However, if external assistance is needed or is available, this committee becomes active. This is because none of the sub-system irrigation committees can represent the entire system.

48 In the past, disputes arose between the farmers of the Basantpur and the Julphe sub-systems. The farmers of Julphe have blocked water to Basantpur many times. Some such cases are even registered with the District Administration Office.

The day-to-day irrigation management activities are performed independently by the sub-system irrigation committees in their respective sub-systems.

Both the Julphe and the Basantpur sub-systems have defined sub-system irrigation committees with written rules and regulations, whereas, in the Kolia sub-system, the irrigation management activities are performed by an *ad hoc* committee, which does not have any written rules.

The formation process of the sub-system irrigation committees also varies between the sub-systems. In the Julphe sub-system, prior to the expansion of the system in 1975, there was no defined irrigation organization. The *sirwar* used to manage irrigation activities as most of the irrigated land belonged to the *zamindar*. With the expansion of the system in 1975, farmers started organizing themselves to manage irrigation activities. Written rules came into existence in 1986. Since then, Julphe has created a formal sub-system irrigation committee, known as *kulopaani samiti*[49].

In Julphe, all farmers are members of the general assembly. From the general assembly, farmers directly elect the members of the *kulopaani samiti*, which is changed annually[50].

In Basantpur, the sub-system irrigation committee has existed since 1975[51]. At that time, the irrigation committee did not have any written rules. Written rules were made only in 1985 - one year before those in Julphe were written. Unlike in Julphe, in Basantpur, farmers elect their executive committee indirectly. All farmers who have access to water first elect a body consisting of farmers, known as *sadharan sabha*[52]. The *sadharan sabha* then elects an executive committee, known as *dhick kulo samiti*[53], from among its

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49 The *kulopaani samiti* consists of one chairman, one vice chairman, one treasurer, one secretary and a few other members. Members of this committee are elected in such a way that they represent all the areas of the sub-system. Although the written rules clearly specify that the *kulopaani samiti* shall consist of seven members, including the chairman, the number of members varies every year. In 1996, the *kulopaani samiti* had 13 members. There were only nine members, including the chairman, in 1997. Other than not being required to provide labour for system maintenance, members of the *kulopaani samiti* do not have any incentive.

The *kulopaani samiti* also has one *chaukidar*. The *chaukidar* is appointed by the chairman for a period of about three months. He is paid at the rate of Rs2 per *kattha* of water shares by farmers. His main duties are to communicate the decisions of the *kulopaani samiti* to farmers, to go to the intake every day and report its condition to the chairman, and to maintain the attendance records of farmers present for maintenance activities.

50 Although the chairman and some members of the *kulopaani samiti* are changed annually, the treasurer remains the same. This is because if the treasurer is changed annually accounts may not be maintained systematically.

51 Note that the irrigation system was extended up to Basantpur in 1975.

52 The first *sadharan sabha*, formed in 1985, had 17 members. This number increased to 25 when it was re-formed in 1993.

53 The present *dhick kulo samiti* consists of one chairman, one vice chairman, one treasurer, one secretary, one joint secretary and six other members. Unlike in Julphe, there is no separate *chaukidar* specially for irrigation management. The ward (village) *chaukidar* are used for this purpose. As this sub-system irrigates two wards, it has two *chaukidars*. The *chaukidars* are paid in kind at the rate of 3 *pathi* of paddy per *bigha* of cultivated land. The functions of the *chaukidar* are similar to those of the Julphe sub-system.

members. Unlike in Julphe, the *dhick kulo samiti* is not changed annually. Existing records show that this committee has been changed twice since 1985.

The *ad hoc* committee of the Kolia sub-system is usually headed by the political representative of the ward[54]. The farmers of Kolia follow the rules of both the Julphe and the Basantpur sub-systems, whichever suits them, depending on the time of year.

A general assembly is held once a year in each sub-system[55], prior to the start of the regular system maintenance. All important issues related to system operation are discussed. Decisions are usually based on consensus and are minuted.

The functions of the sub-system irrigation committees are similar. The main tasks of these irrigation committees are as follows:

- to mobilize resources for the operation and maintenance of the intake, main canal and other canals
- to allocate new water shares to farmers and to transfer water shares from one farmer to another
- to co-ordinate activities with the irrigation committees of other sub-systems
- to operate the main canal and the intake
- to resolve water-related disputes within the sub-system
- to maintain the accounts and documents of the sub-system, and
- to install proportioning weirs in canals once a year.

Each of the sub-systems has a number of sections within it. The water users' organization at the section level is known as *tol samiti* (section committee). Distributing water and resolving minor disputes are the main tasks of the section committee. The number of section committees in Julphe, Kolia and Basantpur sub-systems are seven, two and eight respectively. In Julphe, such committees exist only in the partially proportionate areas. In the fully proportionate areas (the *numbari* area), no such committee is required as continuous flow is practiced there. The section committee is formed on an ad hoc basis by the farmers in each section.

4.5.2 System maintenance

Maintenance of the system involves the reconstruction and repair of the intake and cleaning of canals. Regular maintenance of canals is done once a year, but the intake on the Girwari River needs more frequent maintenance. Observations in 1997 revealed that labour was mobilized seven to eight times a month to repair the intake during the monsoon.

Sometimes the main canal may rupture during operation. Farmers say such ruptures occur once every two to three years. During the study period, the main canal ruptured on 17th

[54] One Village Development Committee (VDC) has nine wards. Most of the irrigated area of Kolia is located in ward number 2 of the Deurali VDC.

[55] During 1997, the general assemblies of the respective sub-systems were held in May.

September 1997 due to a landslide. It took nine days and at least 1,800 labour days to reconstruct the main canal[56].

The maintenance of the intake and the main canal is the combined responsibility of all the three sub-systems[57]. As far as possible, the maintenance job is divided into three parts based on the water shares of each sub-system. For example, to clean the main canal, it is divided into three sections[58]. The respective sub-systems clean their portion of the main canal at a time suitable to them. This principle was applied to reconstruct the ruptured main canal in September 1997. Whenever it is not possible to split the volume of work, especially when the diversion weir in the river needs reconstruction, either labourers from all the sub-systems are mobilized to work together or each sub-system mobilizes labour in rotation.

For such combined maintenance work, key members of all three sub-system irrigation committees discuss and make the maintenance plan. The *chaukidars* of each sub-system co-ordinate the maintenance activity. For regular system maintenance farmers of Julphe sub-system take the initiative to manage combined maintenance work because they transplant paddy earlier. For the periodic maintenance work, especially to repair the intake, farmers of Basantpur take the initiative, because they are at the tail-end and they have less water shares.

In principle, each of the sub-systems is required to mobilize labourers in proportion to its water shares. However, in practice, it has been observed that the Basantpur sub-system mobilizes labour more frequently, especially to repair the diversion weir at the intake[59]. Note that the average incoming flow to Julphe and to Basantpur are about 7.2 and 2.3 lps per ha respectively. This means that farmers in Basantpur cannot afford to allow any reduction in the incoming flow. This makes it necessary for them to mobilize labour more frequently in order to maintain a constant supply.

In each of the sub-systems, there is a rule to fine farmers who do not report during the maintenance period. Such a fine is known as *khara,* which is collected in cash. However, except in the Julphe sub-system[60], farmers do not pay this fine.

The question arises why such fines are collected in Julphe but not in the other sub-systems. In this system, there is a fundamental difference in the management of revenue collected

[56] This value excludes labour mobilized by the Kolia sub-system. Records of the labour mobilization by the Kolia sub-system were not available.

[57] The respective irrigation committees plan the mobilization of labour. Depending on the volume of work, each sub-system mobilizes labour from its sections on a rotation basis. The *chaukidars* register attendance and members of the irrigation committees supervise the maintenance work.

[58] Deposition of sediments in the main canal is almost uniform, and is not excessive. For this reason, the total length of the main canal is divided into three sections, irrespective of the sediment deposition in it.

[59] See Appendix IV.

[60] The Julphe sub-system has special arrangements to collect *khara*. The chairman of the *kulopaani samiti* nominates four or five *khara* collectors. Every day the *chaukidar* submits the attendance record of farmers to the *khara* collectors. Based on this, *khara* collectors collect fines from absentee farmers the following day.

from fines. In Julphe, fines are redistributed among all the farmers at the end of the paddy cultivation season, whereas in the other sub-systems it is supposed to be deposited in a central account for later use.

Farmers do not invest unless they are confident about the proper use of their money. In both the Basantpur and Kolia sub-systems, since the fine is supposed to be deposited in their central accounts, farmers may suspect that their money is not being used wisely. Also, more than 25 per cent of the farmers are tenants. For tenants, the future strengthening of the system by using such revenue is of no importance. This is simply because they are not the owners of the land which they cultivate. They might be more willing to pay fines if they were redistributed among the farmers, like in Julphe. With redistribution, they would benefit within their period of tenancy.

Basis of resource mobilization

The basis of resource mobilization (especially labour) for the operation and maintenance of the irrigation system varies greatly between the sub-systems.

In the Basantpur sub-system, the basis of labour mobilization depends on the type of maintenance. For regular maintenance, the basis is farmers' water shares[61], whereas for emergency maintenance, the basis is the household. In contrast, in the Julphe sub-system, irrespective of the various provisions made in the written rules, labour is mobilized on the basis of household. The following few paragraphs discuss these issues separately. The Kolia sub-system follows the same basis as the Julphe.

According to a written rule in the Julphe sub-system, the maintenance work is classified into two types: short-term and long-term[62]. Accordingly, the basis of labour mobilization differs for them. For short-term maintenance, the basis of labour mobilization is the land[63], whereas for long-term maintenance, the basis is the farmers' water shares. However, in practice, it has been observed that labour is mobilized with respect to household for both short-term and long-term maintenance. When cash is needed, either to pay the *chaukidar* or to implement any rehabilitation work, it is mobilized with respect to farmers' water shares.

Usually in farmer-managed irrigation systems, which distribute water on a share basis, labour is mobilized with respect to water shares, unless the volume of maintenance work is small. The question, why in this sub-system labour is not mobilized as per the written rules (or water shares), can be answered with two reasons.

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[61] When mobilizing labour with respect to water shares, farmers having water shares up to 5 *kattha* need to mobilize one labourer. For every additional 5 *kattha* of water shares, one extra labourer is needed. This rate differs from the rate mentioned in the written rule. According to the written rule, one labourer is needed for water shares up to 10 *kattha*.

[62] Maintenance work requiring short periods of work (for both emergency and regular maintenance) are considered to be short-term. Maintenance work requiring long periods of work are considered to be long-term. Written rules also state that depending on the volume of work, the irrigation committee decides on the type of maintenance.

[63] Farmers need to provide one labourer for landholding up to 1 *bigha*. For every additional landholding up to 1 *bigha*, one extra labourer is needed. The written rule also states that this range is used because it is too complicated to calculate the labour required to be mobilized with respect to exact water shares.

Unequal distribution of land and water shares is the first reason. About 34 per cent of the farmers in the *numbari* area hold about 42 per cent of the irrigated land and about 70 per cent of the water shares. They are more well-to-do than the farmers of the new settlement area, and depend mostly on hired labour and tenants for cultivation. If labour were mobilized according to the written rules, the major labour force would have to be generated from the *numbari* area. The farmers in the *numbari* area may be willing to pay for the labour, but this arrangement would not solve the problem of making labour available in emergency. The operation of this system, therefore, completely depends on the farmers of the new settlement area. This necessitated the mobilization of labour with respect to households.

The attempts to establish water rights based on labour mobilization is the second reason for not mobilizing labour according to the water shares. Farmers of the new settlement area know very well that the system cannot be operated smoothly without their help. At present, by mobilizing labour with respect to households they are at a disadvantage. However, they believe that in the future they will be in a position to demand equal water rights on the ground that they have been mobilizing equal labour for a long time. Two incidents in which new settlement farmers have acquired more usufruct rights have already occurred. First, around 1990, farmers in the new settlement area broke the proportioning weir, P8, placed at Ishwori Chowk, demanding more water. This happened while a wooden weir was being replaced by a cement weir. They succeeded in increasing the notch width of the proportioning weir in their part, and are now receiving more water than their actual shares[64]. Second, trading of water shares by individual farmers has been prohibited. Since then water has been considered to be common property, as discussed separately in the forthcoming section.

4.5.3 Water acquisition

In the Julphe Irrigation System, water acquisition to prepare paddy seedbed starts with the beginning of the pre-monsoon rain in early June. In this period, the supply in the source river is quite low. The main canal receives an interrupted supply, depending on the occurrence of flash floods in the river[65]. If the pre-monsoon rains are delayed, sometimes farmers even break the intakes of the upstream systems at night to acquire water for preparing paddy seedbed.

The main canal starts flowing continuously with the start of the monsoon in late June. The flow in the main canal increases gradually with the increase in the river flow. During the

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[64] Note that the ratio of notch widths to corresponding water shares for the Dabdabe south canal in the proportioning weir, P8, is 0.47, whereas this ratio for the Dabdabe west canal is only 0.36 (Appendix III). The Dabdabe south canal irrigates four of the seven sections in the new settlement area. Also, note that the flow per *kattha* of water share upstream of the proportioning weir, P31, in the Dabdabe south canal is about 0.49, whereas this value upstream of the proportioning weir, P7, in the Julphe Kulo is only 0.465 (Table 4.6). This indicates that the farmers supplied by the Dabdabe south canal receive more water than their actual shares.

[65] On 12th June 1997, there was a flash flood in the river. On the evening of that day the main canal had a flow of about 300 lps. This dropped to 15 lps on the morning of 14th June. The next day the main canal was again dry.

monsoon, the river discharges enough flow to supply water to all the systems. However, frequent damage to the temporary diversion weir by flooding in the river causes sudden interruptions of flow in the main canal. For this reason, the mobilization of labour for maintaining the diversion weir in the river determines the flow in the main canal.

Figure 4.9 shows the flow variation in the main canal[66] and the labour mobilized[67] to maintain the diversion weir in the river. A sudden decrease in the supply is primarily caused by damage to the diversion weir. Note that a sudden increase in supply is usually associated with the mobilization of labour for weir maintenance.

From the end of July to the end of August, the flow in the main canal varies between 700 and 1,000 lps. The flow gradually decreases until it varies between 400 and 700 lps during mid-September. Interviews with farmers suggest that this range of flow continues till the end of the paddy cultivation period in mid-October.

During winter (December-February), the average flow in the main canal is about 100-125 lps. From March to June, the system experiences a water crisis. In this period, water is acquired mainly to feed livestock, and farmers are not allowed to irrigate their crops. *Chaukidars* are appointed to acquire water from the river[68]. The average flow in the main canal in the morning is about 10-15 lps. In the daytime the canal is virtually dry.

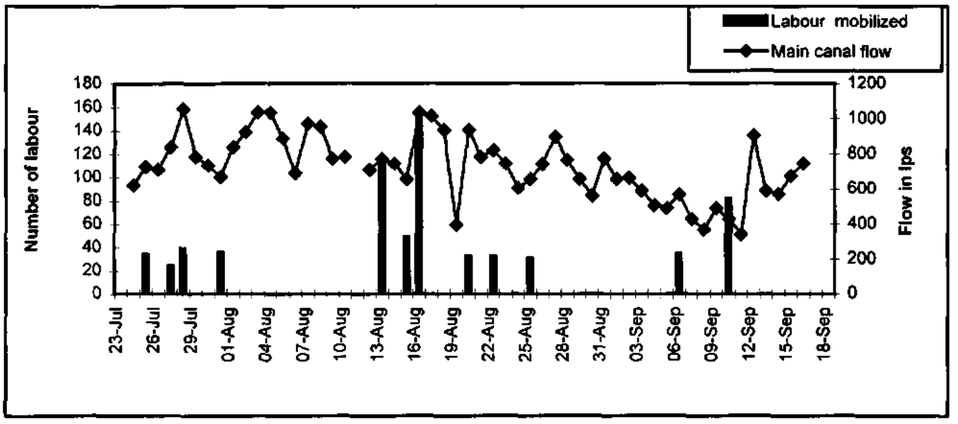

Figure 4.9: Flow variation in the main canal and the labour mobilized to maintain the diversion weir in the river.

66 Flows were measured daily at the end of the main canal upstream of the first proportioning weir (P1).

67 The data on labour mobilization presented here does not include labour mobilized by the Kolia sub-system.

68 As mentioned earlier, in this period most of the water is diverted by the systems upstream. Every night, the *chaukidar* re-diverts water from the river into this system.

4.5.4 Water allocation

The principle of water allocation for cultivating paddy changes within the cropping season. The paddy cultivation period is divided into two parts: the period of paddy transplantation and the period after the completion of paddy transplantation. In the first period, water demands are diversified. Accordingly, the principle of water allocation also differs.

In all areas, water is allocated based on the requirements for preparing land for paddy transplantation. There is a general consensus among farmers that all those farmers who have access to water should get enough water - at least to transplant paddy, irrespective of their water shares and landholding.

After the completion of paddy transplantation in all areas, water is allocated with respect to farmers' water shares. Appendix V shows the water shares of farmers with respect to terminal points in proportioning weirs. This appendix also shows the corresponding area irrigated. As the water shares are not attached to land, farmers can transfer their water shares from one area to another within a sub-system. Farmers even practice water trading. Due to the trading of water, farmers' water shares change every year.

Water trading

Water trading involves the permanent transfer of water entitlements (shares) from the seller to the buyer. Water trading started only after the expansion of the system in 1975, and is practiced only within a sub-system. Management practices of water trading differ between sub-systems.

In the Julphe sub-system, all individual farmers had the right to sell their water shares partly or fully until 1986. Accordingly, many farmers in the *numbari* area sold some of their water shares to others[69]. This helped to expand the irrigated area. However, in 1986, farmers of the new settlement area objected to such individual water trading. These farmers were in the majority in this sub-system. Since then, the irrigation committee has started selling[70] water shares to farmers from the common pool. This has resulted in an increase in the total number of water shares from 686 *kattha* in 1986 to 730 *kattha* at present. However, the incoming water has remained the same. The arguments given by the farmers of the new settlement area for prohibiting individual water trading are as follows:

First, although farmers in the *numbari* area have more water shares, farmers of the new settlement area believe that their efforts ensure the system operation effectively. This is because they mobilize labour on the basis of equal contribution (by household). They recognize the water rights of all farmers, but argue that water rights should be limited to use right and should not be tradable. They believe that by allowing individual water trading, money goes to individual farmers, and therefore cannot be used to strengthen the system. However, when water is sold from the common pool by the irrigation committee,

[69] Note that farmers in the *numbari* area still have relatively more water shares per unit of irrigated land than the farmers of the new settlement area.

[70] The latest rate per *kattha* of water share fixed by the Julphe irrigation committee is Rs1,800.

capital is generated. This money can be used to strengthen the system and to increase the incoming flow.

Second, the *numbari* area is located at the headreach. If farmers there are allowed to sell their water shares, they may sell most of them. However, they may continue to use water by virtue of their location in the sub-system[71].

Farmers in the *numbari* area are unhappy with the new rule. They believe that it is their right to sell their water shares. As they are influential, a few of them have sold some of their water shares to others[72] despite the objection of the irrigation committee. At present, individual water trading has reduced considerably. Even so, the issue of an individual farmer's right to trade water receives much attention from the farmers in the sub-system.

Unlike in Julphe, in both Kolia and Basantpur, irrigation committees do not sell water shares from a common pool. Farmers are free to sell their water shares to others[73]. In Kolia, the trading of water shares is not systematically recorded, whereas in Basantpur, water trading is systematically recorded, and farmers have to follow certain rules for this[74].

In the Basantpur sub-system, about 10-15 acts of water trading take place annually. The rate varies between Rs2,500 and 3,000 per *kattha* of water share. Trading takes place only within those areas where wooden proportioning weirs exist, because the cost of readjusting the notches of proportioning weirs has to be borne by the buyer. In a weir made of cement this would be very expensive.

4.5.5 Water distribution

In this system, water distribution starts with the paddy seedbed preparation in early June. As mentioned earlier, water supply is scarce and unreliable in this period. Because of this, all the farmers make themselves ready to prepare the paddy seedbed as soon as water is available. Some farmers even prepare the paddy seedbed at night. Unreliable water supply

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71 Some such incidents have already occurred in this sub-system. Some farmers in the *numbari* area first sold all their water shares to others and finally sold the land to new settlers. Trading of land usually takes place during winter when irrigation activities are not observed seriously. New settlers are usually unaware of the local customary water rights. Some of these new settlers were again forced to buy the water shares from others to irrigate their new land.

72 Around 1993, the *zamindar* and the ex-chairman of the irrigation committee sold about 40 *kattha* of water shares to others at a rate of Rs2,000 per *kattha*.

73 Other than selling water shares permanently, the temporary transfer of water rights is also practiced in this area. Such temporary transfers of water rights take place mainly for paddy cultivation. For this, the buyer has to pay about 30-35 *pathi* of paddy (one *pathi* is equivalent to about 2.3 kg) per *kattha* of water share for one cropping season.

74 For example, to sell water shares, farmers need permission of the irrigation committee. After the completion of water trading, both the buyer and the seller must apply in writing to the irrigation committee, requesting official transfer of water rights. For this, the buyer needs to pay a service fee of Rs15. Accordingly, the irrigation committee issues a water right certificate signed by its chairman, secretary and treasurer. Appendix VI shows a copy of such a certificate. Notches in proportioning weirs in the field are adjusted only after the issue of this water rights certificate.

has also resulted in adaptation of the germinated seed sowing method[75] for preparing paddy seedbed.

Depending on the flow available, all the sub-systems receive water continuously[76]. Within a sub-system, water is distributed among the farmers turn by turn, starting from the head and moving to the tail. It takes about two weeks to prepare all the paddy seedbed in a sub-system.

Paddy transplantation starts in early July[77]. By this time the main canal starts flowing continuously. Accordingly, all the sub-systems receive continuous flow corresponding to their water shares. The average flow during the period of paddy transplantation available to the Julphe, Kolia and Basantpur sub-systems are 7.2, 2.25 and 2.3 lps per ha respectively (Figure 4.11).

In this period, two types of water demand occur simultaneously[78]: the demand for water to prepare land for paddy transplantation and the demand for water to maintain the standing water in paddy fields. This makes the task of water distribution more difficult. The diversified demand for water, variations in water supply among the sub-systems and differences in the physical layout of the distribution system have resulted in different water distribution practices among the sub-systems.

During the period of paddy transplantation, in both the Julphe and Kolia sub-systems, water is distributed to each farmer or farmers' group as per their requirements, irrespective of their water shares and irrigated areas. The physical layout of the distribution system makes delivering a continuous flow corresponding to the water shares difficult. This is because distributing water continuously on a share basis would result in simultaneous small flows to the fully proportionate areas[79]. Such small flows are not enough to transplant paddy, though they are enough to maintain the standing water in the

[75] In this method, first, raw paddy is kept soaked in water for at least 24 hours. The wet paddy is then kept in the sunlight in closed and non-ventilated sacks for the next 24 hours. By this process the paddy germinates. The germinated paddy seeds are spread in an airy room. Farmers say, they can be kept in good condition up to a month. As soon as water is available, fields are puddled and the germinated paddy seeds are sown in standing water (after all suspended silt settles down) in the field.

The main advantage of this process is that it saves water. If ungerminated raw paddy seeds are sown, standing water in the field is required for at least four to five days–a length not possible in this area because of unreliability and scarcity of water supply. With this pre-germinating process, paddy seedlings grow well with an occasional pre-monsoon shower.

[76] If the flow in the main canal is small, all water is diverted to the Julphe sub-system. This is because a small flow cannot be delivered to either the Kolia or Basantpur sub-systems due to the long canal length in these areas.

[77] In 1997, it started on 9th July in the Julphe sub-system and on 14th July in both the Kolia and Basantpur sub-systems.

[78] In some parts of the system area there exists a third type of water demand. This is water demand for keeping the puddled field submerged (in case paddy transplantation is not completed in a single day). If the standing water is not maintained in the puddled field until the transplantation of paddy is complete, the earth becomes hard and paddy cannot be transplanted. If such a situation occurs, the entire process of land preparation and puddling needs to be repeated.

[79] Note that both the Julphe and Kolia sub-systems have fully proportionate areas in their headreach.

paddy fields after transplantation. In any case, farmers do not transplant paddy simultaneously. The fully proportionate layout of the distribution system necessitates flow adjustment in the higher order distribution canals (secondary and sub-main canals).

In contrast, in the Basantpur sub-system, the entire irrigated area is partially proportionate. In this sub-system, continuous flow is delivered to all the sections corresponding to their water shares. Farmers of each section manage to meet diversified water demands independently. The partially proportionate layout of the distribution system requires that flow be adjusted only in the lower order distribution canals (field channels) within a section.

Water distribution for paddy transplantation at the upper end

Water distribution at the upper end refers to the distribution of water to various higher order distribution canals within a sub-system. This is applicable in both the Julphe and Kolia sub-systems, where water is distributed by adjusting the flows on an ad hoc basis.

In Julphe, with the start of paddy transplantation, most of the proportioning weirs are installed. Water flows over the weirs, but notches are not adjusted corresponding to water shares. The weirs are installed mainly to function as check structures[80].

Paddy transplantation proceeds from the head to the tail. During the early stage of paddy transplantation, more water is diverted to the *numbari* area to facilitate early transplantation[81]. When paddy transplantation in the *numbari* area is nearly complete, flows to new settlement areas are increased. All sections there receive continuous flow. Water distributions within sections are discussed below separately. Because of limited canal capacity, all incoming water cannot be delivered to the new settlement areas. For this reason, the *numbari* area also continues to receive a continuous supply but with reduced flow. In the *numbari* area, farmers independently manage to fulfil their diversified water demands. In the daytime, preference is given to those who need water to prepare land for paddy transplantation whereas at night water is distributed mainly to maintain the standing water in paddy fields which are already transplanted.

Every evening, members of the irrigation committee and other farmers concerned gather at a common place to evaluate the paddy transplantation of that day. In this meeting, the current demands for and supplies to all sections are discussed. Accordingly, farmers decide the flow adjustments required for the following day. Flows to various sections are adjusted by adjusting the notches of some of the proportioning weirs. As the system has a relatively high flow of water at this time, no disputes regarding water distribution arise. Visual estimation is the basis for flow adjustment. The farmers concerned adjust the flows themselves, as agreed upon with the other farmers.

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[80] Note that most of these proportioning weirs also work as a check (see section 4.4)

[81] Usually, flows are adjusted by partially blocking notches in proportioning weirs. However, some farmers who have very small notches in their proportioning weirs divert water into their fields by cutting the canal banks.

Water distribution for paddy transplantation at the lower end
Water distribution at the lower end refers to the distribution of water within a section, and has two-fold purpose: water distribution in the daytime and water distribution at night. The basis of water distribution in the daytime is similar in all sections. However, the basis of water distribution within section at night varies from section to section.

In the daytime, water is distributed to farmers exclusively to prepare land for paddy transplantation. Within each section, the incoming flow is temporarily divided into two or more parts. Usually this is done based on visual estimation. In each part, farmers receive water in turn as decided by the respective section committee. In one's turn, a farmer receives water till he completes the irrigation of his land.

At night, water is distributed mainly to irrigate the paddy fields. In a few sections, water is also distributed to maintain the standing water in the field which is already puddled but is yet to be transplanted. Three different principles of water distribution at night were observed.

In the Purbetar section of the Basantpur sub-system, water is distributed according to priority. Land requiring water to submerge a puddled field gets the first priority. The second priority goes to the land requiring water to irrigate paddy. Distribution under the second priority is decided according to the moisture status of a field. Land which is the most dry gets irrigation water first.

In Sections 4 and 5 of the Julphe sub-system, water is distributed according to farmers' water shares. A farmer having one *kattha* of water share gets water for one hour, irrespective of the area transplanted. A farmer needs to manage all his water demands in the time duration allocated to him. Farmers who have not started transplantation do not get a turn. For this reason, the frequency of night irrigation changes with time.

In Bikase Khanda, Section 3 of the Basantpur sub-system, water is distributed based on the combination of both the farmers' water shares and area of land transplanted. As the area of land transplanted increases every day, the schedule for night irrigation also changes daily. For this reason, a new rotational schedule has to be prepared every night. Because of its relatively large area and small flow, the water distribution in this section was observed in detail, which is described in Appendix VII.

Clearly, the basis of water distribution in Bikase Khanda is very scientific as it takes into account both the area of land transplanted and the farmers' water shares. However, preparing a new rotational schedule every night involves higher administrative costs and organizational inputs.

The question arises: Why does Bikase Khanda, unlike other sections, needs an intensive effort to manage water distribution at night arises. Note that the average flow available per unit of irrigated area in this section is relatively low (about 2 lps per ha). This is probably the lowest flow rate among all sections. With a decrease in flow rate, the intensity of management inputs increases (Martin, 1986; Yoder, 1986). In this section, there are more farmers and more irrigated area served than in any other section. Also, all farmers in

Bikase Khanda do not have access (rights) to irrigation water. The combined effects of the above causes have resulted in an intensive effort to manage water distribution at night.

Water distribution after the completion of paddy transplantation

Once paddy transplantation is completed, mono-water demand[82] prevails simultaneously in each of the system areas. The principle of water allocation and the pattern of water distribution also change accordingly. In this period, all the farmers receive water corresponding to their water shares.

In the fully proportionate areas of both the Julphe and Kolia sub-systems, farmers receive continuous flow. In partially proportionate areas, however, continuous flow is delivered up to a section. Within the section, the flow available is distributed among all the farmers based on a time share method. Locally this method of water distribution is known as *ghante palo*. In the section, water distribution proceeds from the head to the tail. Equity in water distribution is judged in terms of time and not in terms of quantity of water, even if the flow is erratic. Table 4.5 shows the principal features of *ghante palo* used in various sections.

Table 4.5: Principal features of *ghante palo* in various sections of the irrigation system.

Sections	Time allocation per unit of water share (m/*kattha*)	Starting date of *ghante palo*	Date of fixing proportioning weirs	Area irrigated (ha)	Number of farmers	Water share (*kattha*)	Average flow[83] (lps)
Julphe							
FPA	-	-	8 Aug	31.64	57	529.95	
Section 1	60		8 Aug	5.36	10	22.5	
Section 2	60	3 Aug	8 Aug	6.22	24	39.0	
Section 3	60	3 Aug	8 Aug	5.82	17	28.5	14.0
Section 4	60		8 Aug	4.96	14	22.0	
Section 5	60	8 Aug	8 Aug	7.61	21	25.5	
Section 6	60	8 Aug	8 Aug	3.01	10	27.0	12.7
Section 7	60		8 Aug	4.99	18	36.0	17.3
Kolia							
FPA		-		2.15	4	20.0	
Section 1		3 Aug	8 Aug	12.48	26	48.5	
Section 2		8 Aug	8 Aug	3.97	10	31.5	
Basantpur							
Section 1	22	3 Aug	17 July	21.85	17	98.0	30.8
Section 2	39	4 Aug	CPW[84]	9.10	27	56.0	15.2
Section 3	20.5	7 Aug	Do	23.07	54	105.0	28.7
Section 4	18	31 July	Do	13.77	31	119.0	
Section 5	51	1 Aug	18 July	6.78	18	41.0	
Section 6	22	5 Aug	18 July	8.34	20	99.7	
Section 7	15	1 Aug	18 July	13.35	30	141.0	34.7
Section 8	21	9 Aug	18 July	16.16	39	100.3	26.2

Note: FPA refers to fully proportionate area.

[82] In this period, only one type of water demand exists. This is the demand for water to maintain standing water in paddy fields.

[83] Average during the period of *ghante palo*.

[84] CPW refers to the cement proportioning weir. This type of weir does not need fixing.

As the time of starting *ghante palo* depends on the completion of paddy transplantation in the section, it varies among the sections. In this system, two different methods of *ghante palo* were observed.

In the first method, the time duration per unit of water shares is fixed (one hour per *kattha* of water shares). Accordingly, the interval of irrigation in a section varies. For example, in a section having total water shares of 22.5 *kattha*, a farmer receives water at intervals of 22.5 hours. This method is complicated, especially for an illiterate farmer. In this method, the actual time to receive irrigation water changes after every turn. Either a farmer needs to calculate himself or he has to ask others about the time for his next turn. This method is used by all the sections in the Julphe sub-system.

In the second method, the interval of irrigation is fixed as 36 hours. Accordingly, the time duration per unit of water share in a section varies among the sections. For farmers this method is very simple. This is because the actual time to receive water is always the same. For example, a farmer who first receives water at 5 AM, receives water in his next turn at 5 PM. Also, the chance of receiving water continuously at night for a long period is minimized. In this method, a rotational schedule is prepared once a year. In some sections, the rotational schedule is prepared up to a fraction of a minute, whereas in others it is prepared up to a measurable time. Preparing the rotational schedule up to a measurable time may result in some time remaining unallocated. Such unallocated time duration is allocated to farmers who have land at the tail-end. This method is used by all the sections in the Basantpur sub-system[85].

As discussed above, different sub-systems use different methods of *ghante palo*. Other than convenience, one of the reasons for this is the large variations in their water shares. Note that in the Julphe sub-system, the number of water shares in a section varies between 17 and 39 *kattha*. Accordingly, intervals of irrigation also remain between 17 and 39 hours. In Basantpur, on the other hand, water shares in a section varies between 41 and 137 *kattha*. If the same method were used in the Basantpur sub-system, the interval of irrigation would also be between 41 and 137 hours. This interval may be too high for irrigating the paddy.

One can argue that in Basantpur, like in Julphe, the section areas could have been further divided into smaller areas. By doing so, the total number of water shares in a section would reduce. This would make the first method of *ghante palo* feasible with an acceptable range of irrigation intervals. However, since this would also reduce the flow size to each section, the viability of sub-dividing a section into smaller areas is restricted. This issue is discussed separately in a forthcoming section[86].

The above discussions show how farmers in various sections manage water distribution independently. Different management practices observed in different sections are the result of the devolution of water distribution tasks among the farmers. This became possible

[85] Water distribution by this method is observed in detail in Bikase Khanda (Section 3). Appendix VII presents this.

[86] Please see the section on operational principles across fully and partially proportioning areas.

because the proportioning weirs divide the system into several sub-systems, and further into sections and sub-sections, each with its fair shares of continuous flow. This enables the farmers to manage water within their sections according to their convenience, physical system and supply conditions.

Night irrigation and access to female-headed households

Night irrigation is commonly practiced in this area. In *ghante palo*, farmers (including female-headed households) sometimes get their irrigation turn at night. Although farmers realize that it is difficult for a female-headed household to perform irrigation at night, the irrigation schedule is not changed. This is because, by shifting the time of one farmer from the night to the daytime, the order of irrigation turns gets disturbed. Note that irrigation proceeds from the head to the tail. Shifting the time of one farmer results in extra transient loss in canal which nobody is willing to bear. For this reason, female-headed households usually depend on others. Usually, the preceding farmer diverts water into her field, and the following farmer diverts water from her field to his field at a proper time. Sometimes a third person irrigates for her.

Water distribution through proportioning weirs

Once water distribution through proportioning weirs starts, the irrigation system becomes rigid, and equity in water distribution is judged by measuring and comparing the width of notches. The other water distribution characteristics are similar to those explained in Chapter 3.

The first proportioning weir, P1, placed at Girwari, divides water into four parts. The first part (40 per cent of the incoming flow) goes to both the Kolia and Basantpur sub-systems through two notches in the weir. This flow is considered to have a water share of 845 *kattha*. The remaining three parts[87] (60 per cent of the incoming water) go to the Julphe sub-system through five notches in the weir. Although the number of water shares of farmers in Julphe is only 730.45 *kattha*, at this point the flow is considered to be 750.45 *kattha*. The difference of 20 *kattha* is allocated for conveyance losses in the canals[88].

The flow to Kolia and Basantpur is again divided at Hattigaunda through the proportioning weir, P36. Of the 845 *kattha* of water, 100 *kattha* go to Kolia and the remaining 745 *kattha* to Basantpur.

Within each of the three sub-systems, water is further divided by installing proportioning weirs at every offtake. Figure 4.10 shows the schematic layout of the irrigation system with its proportioning weirs and their water shares.

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[87] Of the three parts, two go to individual farmers, and the remaining part continues to flow in the Julphe Kulo for further distribution downstream.

[88] At the end of the Julphe canal, at the Dabdabe proportioning weir (P7), the incoming water share is 528.5 *kattha*. However, at this point, the incoming water is considered as 508.5 *kattha* (Appendix III). It is presumed that the 20 *kattha* of water allocated for the conveyance loss is proportionally distributed from this point onward.

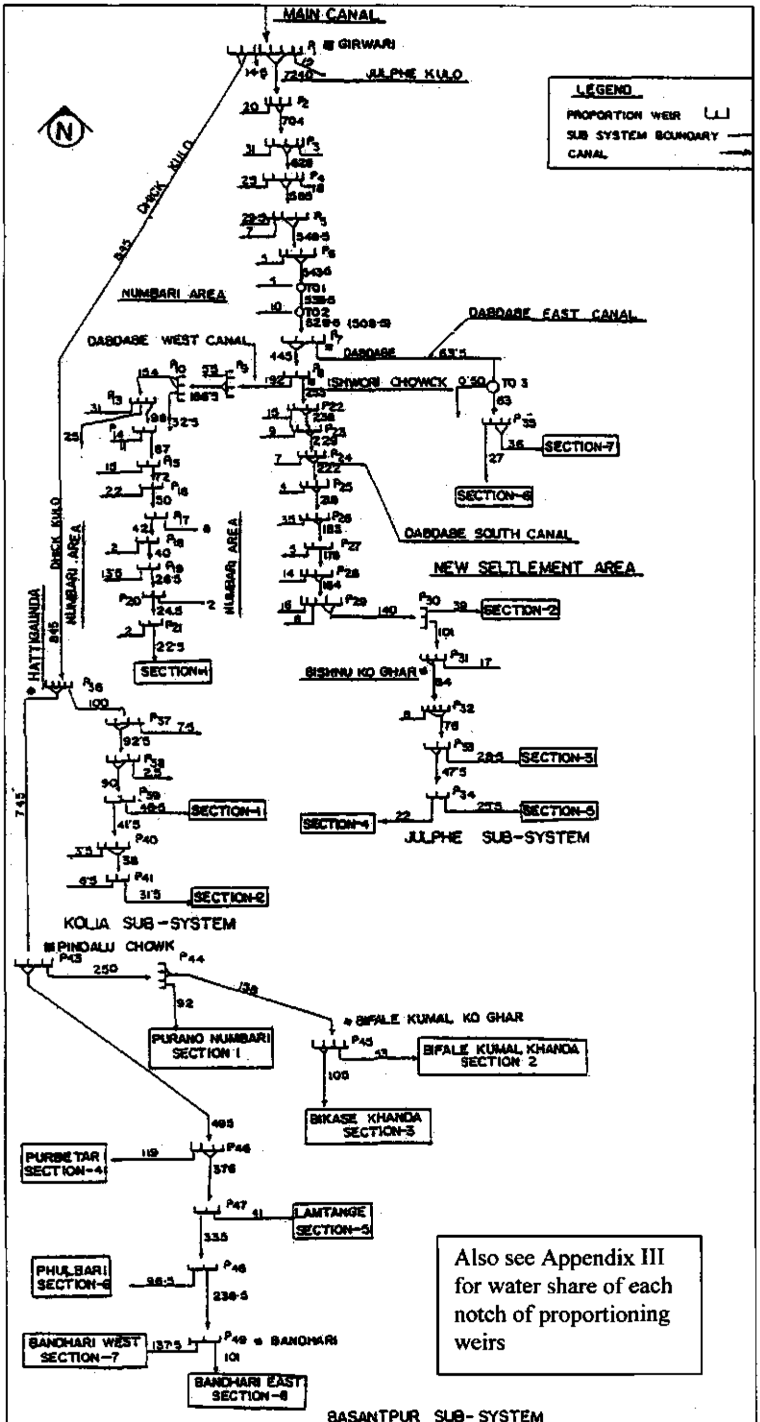


Figure 4.10: Schematic layout of system with proportioning weirs and their water shares.

Although water shares are distributed proportionally at every offtake, the corresponding actual flows are not truly proportional due to conveyance losses in the canals. Table 4.6 shows flow per *kattha* of water share at various points in the system.

Table 4.6: Flow per *kattha* of water share at various points in the system.

Proportioning weir and its location	Total water shares (*kattha*)	Average flow (lps)	Flow per *kattha* of water shares (lps per *kattha*)
Julphe sub-system			
Girwari (P1)	750.45	411[89]	0.548
Dabdabe (P7)	508.50	236.66	0.465
Bishnu Ko Ghar (P31)	101.0	49.49	0.490[90]
Kolia and Basantpur sub-systems			
Girwari (P1)	845	274.39	0.32
Hattigaunda (P36)	845	289.01	0.34[91]
Pindalu Chowk (P43)	745	240.75	0.32
Bifale Kumal Ko Ghar (P45)	158	43.88	0.27
Bandhari (P49)	238.5	60.92	0.25

These figures imply that the farmers' perception of equity does not take into consideration the actual conveyance losses in the distribution canals[92], which amounts to about 20 per cent.

In any run-off-the-river system, flow in the parent canal fluctuates considerably. In principle, proportioning weirs are installed to distribute such fluctuations proportionally at every offtake. To examine this hypothesis, flows were measured upstream of the seven proportioning weirs. Figure 4.11 presents the time discharge curves at those points.

Figure 4.11 shows that flow in the canal is fairly proportional[93]. However, a comparison of the proportionality of flows in the canals in the Julphe and the Basantpur sub-systems reveals that flows are relatively more proportional in Basantpur. This implies that the proportioning weirs in the Basantpur sub-system function more accurately than those in the Julphe sub-system.

[89] 60 per cent of the total average incoming flows (685.98).

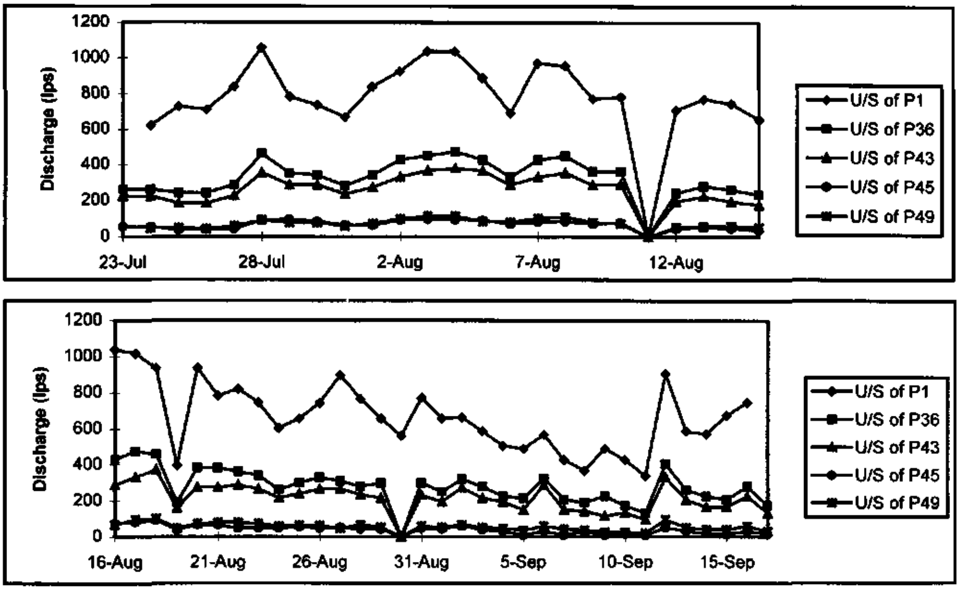
[90] Note that the flow per *kattha* of water shares at this point has been more than its upstream value. The reason has been explained earlier (see the section on the basis of resource mobilization).

[91] The canal to Basantpur (Dhick Kulo) also collects part of the surface overflows from *numbari* area of Julphe. This has caused higher flow per *kattha* of water shares at Hattigaunda.

[92] Although an allowance of 20 *kattha* of water is provided for the conveyance losses in the Julphe Kulo, it is far less than is required.

[93] In the Julphe, notches in proportioning weirs were fixed according to the water shares of the branching canals on 8th August after the completion of paddy transplantation. For this reason, flows are fairly proportional from 8th August onward.

Basantpur sub-system (23 July 1997 to 17 September 1997)



Julphe sub-system (23 July 1997 to 17 September 1997)

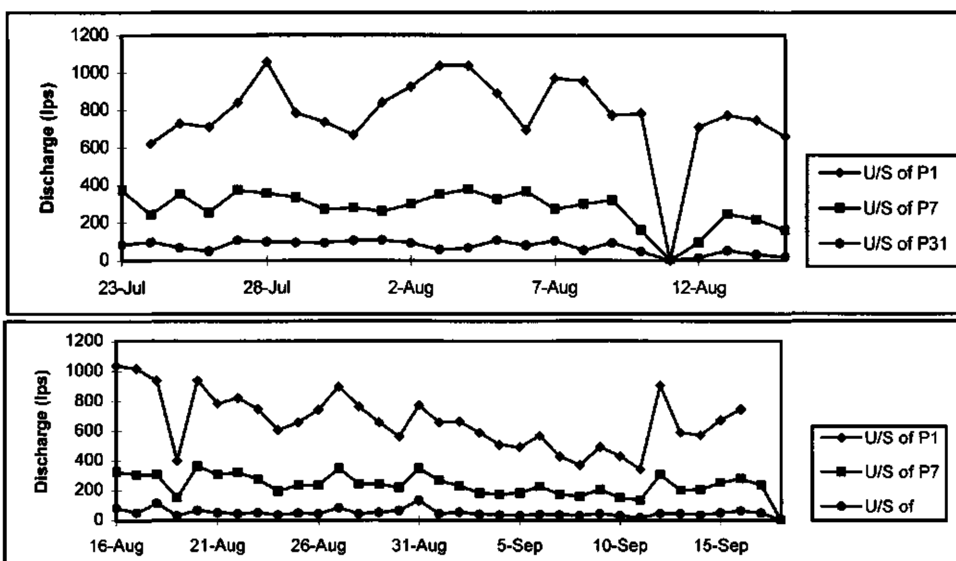


Figure 4.11: Time discharge curves upstream of selected proportioning weirs

Accuracy in water division depends on the supply and demand situation. When the supply is scarce, higher accuracy in flow division becomes significant. For example, the Basantpur sub-system receives relatively low flow per unit of irrigated area than the headreach area of the Julphe sub-system does. Farmers here are, therefore, more concerned about the proper functioning of the proportioning weirs. In contrast, in the headreach area of the Julphe sub-system, farmers hardly care about the proper functioning of the weir. The following few examples, which examines the actual functioning of the proportioning weirs in the headreach area of the Julphe sub-system, verify this.

First, in Julphe Irrigation System, canals convey large amounts of floating debris. The flow-dividers of a proportioning weir trap this debris easily. This is one of the disadvantages of a proportioning weir. Such debris affects the flows through both the narrow and the wide notches of the proportioning weir. It has been observed that farmers in the headreach area of Julphe rarely remove such obstructions, whereas in Basantpur such obstructions are frequently removed.

Second, in the headreach area of the Julphe sub-system, operational consequences were overlooked in the design of the notch width of a proportioning weir. Therefore, in this area, many notches are so narrow that they do not function at all. For example, during the study period, two narrow notches in the first proportioning weir, P1, never functioned. Most of the time they were choked by sediments and floating debris. These two notches were supposed to supply water to two individual farmers. Of the two farmers, one diverts water from the side of the weir and the other diverts water direct from the Dhick Kulo. Flows are diverted based on visual estimation simply by cutting the canal banks. An interview with one of the farmers suggested that because the downstream farmers do not object to this practice, it has become an accepted practice. Similar incidents involving a few other narrow notches were also observed.

Third, in the Dabdabe west canal of the Julphe sub-system, although proportioning weirs are installed, some of them do not function properly. It was observed that water flows below in some of these weirs. In this canal, some farmers even block their inlets (notches) to protect their *khet* from excessive flooding. Note that this canal acts as an intercepting drain and collects surface overflows from the upstream areas. Frequently the flow in this canal (upstream of the proportioning weir, P21) exceeds 80-100 lps in the monsoon[94]. This further increases during heavy rainfall. The actual irrigated area (downstream of this point) served by this canal is only about 5.3 ha. Distributing water through a proportioning weir in a canal functioning as an intercepting drain may lead to excess flow in *khet*.

The above discussions may raise the question: why do the farmers in the headreach area of the Julphe use proportioning weirs when supply exceeds demand? There are two reasons for their use.

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[94] To measure flows in this canal, a gauge was installed upstream of the proportioning weir, P21. However, during the later period of paddy cultivation, it was learnt that part of the water was flowing below the weir. Due to larger flow this was not visible earlier.

First, excess flow in this area is the result of farmers' water rights, which are claimed as per initial investments. Every farmer would like to maintain his water right irrespective of his supply-demand situation. Had there been no proportioning weirs, the differences in water rights among farmers may have slowly been narrowed down.

Second, proportioning weirs also safeguard the interests of the tail-enders. Since water is an important input for crop cultivation, it would not become surplus if it were not regulated properly. Without a defined arrangement for water regulation, free-riding over the use of water could take place and tail-enders usually suffer the most. This could lead to disputes among farmers.

Operational principles across fully and partially proportionate areas
Ambler (1989), in his study in Indonesia, notes that fully proportionate areas are likely to exist in conditions of scarce water supply. This case study, however, suggests that the fully proportionate area is viable only in a condition of excess supply.

Appendix V shows farmers' water shares, irrigated areas and corresponding flows served by terminal points of proportioning weirs. In this system, a relationship exists between the flow per unit area (hereafter referred to as unit flow) and the area served by the corresponding terminal point of a proportioning weir. Figure 4.12 shows this relationship.

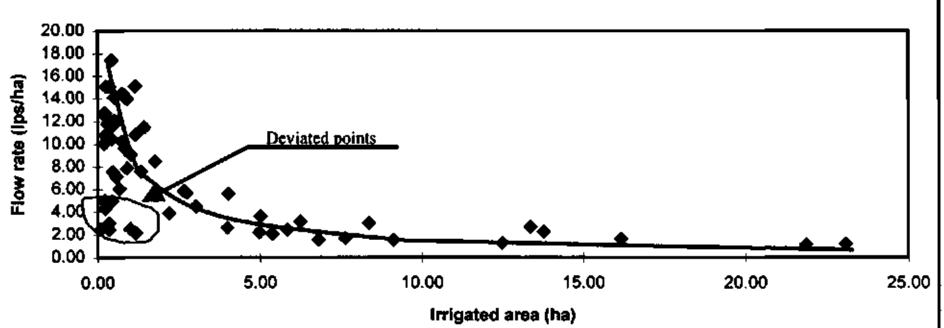

Figure 4.12: Unit flow versus corresponding irrigated area served by terminal points of proportioning weirs.

The above curve shows that the higher the unit flow, the smaller the corresponding area. This leads to a continuous flow to individual farmers[95]. The fully proportionate area in the

[95] Under a continuous flow regime, the flow size required also depends on cultural practice. For continuous submergence, a small continuous flow more than the rate of losses due to evapotranspiration and deep percolation will suffice. However, in this area, farmers use more water, and allow a considerable amount of surface overflow (after maintaining a certain depth) from their paddy fields. This maintains the water temperature in the paddy field. If the standing water gets warmer, especially in the early stage of paddy growth, paddy seedlings may be damaged.

headreach of Julphe is the result of this relationship[96]. A smaller unit flow tends to serve a larger corresponding area, leading to partially proportionate areas.

For cultivating paddy, with a small unit flow, it is not possible to achieve continuous submergence[97]. In such a situation, intermittent wetting of the paddy fields with a large flow for short periods is a preferable irrigation method for higher water use efficiency. The reason is that a large flow advances faster, and thereby deep percolation below the root zone is minimized. This requires that farmers form a group to maintain and rotate a larger flow among them.

Forming a group, however, increases the managerial input for rotational distribution. The larger the group, the higher the managerial input. The size of the group (or section area) is, therefore, determined considering the available unit flow and managerial inputs.

With a small unit flow, irrigation water needs to be used efficiently. In such situation, therefore, the section area is increased to achieve higher efficiency in water use. This increases managerial inputs. With moderate unit flow, farmers can afford to have relatively low efficiency in water use. Thus, the section area is reduced, which in turn also reduces managerial inputs. With high unit flow, continuous flow to individual farmers is practiced, which minimizes managerial inputs.

This relationship implies that the fact whether an area is fully or partially proportionate is completely dictated by the unit flow available. Accordingly the operational principles vary in them.

The desire to practice continuous flow irrigation also depends on the location of one's land. If the land of a farmer with many water shares is surrounded by land with few water shares, it becomes difficult for him to practice continuous flow irrigation, unless he has his own terminal canal from the nearest proportioning weir. Usually this is not likely. Similarly, if a farmer's land is geographically disconnected from other farmers' land, he cannot form a group. Such farmers usually need to have many water shares to practice continuous flow irrigation. The areas irrigated by the proportioning weirs, P40 and P41, are examples of this[98].

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[96] A few farmers in the headreaches of both the Julphe and the Kolia sub-systems also practice continuous flow irrigation, even though their unit flows are considerably low (up to 2 lps per ha). The deviated points in Figure 4.12 represent these areas. This is because, in practice, they do not depend only on their water shares. By virtue of their location, these areas benefit by the surface overflows from the other land. For example, the headreach area of the Kolia sub-system benefit from the surface overflow from the *numbari* area of Julphe through the Dabdabe west canal.

[97] Note that many farmers in Basantpur irrigate 0.5 *bigha* (0.33 ha) of *khet* with one *kattha* of water share. This is equivalent to about 0.8 lps per ha (at the terminal points of proportioning weirs). This flow decreases at the farm inlet.

[98] This area is bounded by the road in the west, the old Basantpur canal in the south, the parent canal in the east and a school in the north.

4.6 Conclusions

This case study attempts to analyze what socio-cultural and agro-ecological considerations are associated with the presence or absence of proportioning weirs as a water distribution structure in an irrigation system. This study also tries to analyze the operational consequences for an irrigation system which distributes water through proportioning weirs. It has also analyzed how weir location links with the spatial organization of water management and system management.

This study shows that labour is one of the most important resources farmers have to invest in an irrigation system for its construction, expansion and maintenance. It shows how farmers expanded the Julphe Irrigation System after the number of farmers increased in the area. Variations in the farmers' investment during the expansion of the system created differential water rights among farmers in different parts of the system. This in turn influenced the design of the distribution system and also became the basis of system operation.

This study further shows that power, which is the ability of an individual or a group of individuals to achieve an aim or interest they hold, is an important resource for farmers in influencing the design of a distribution system.

Dani and Siddiqi (1989) note that, in an irrigation system, irrespective of the causes, any modifications in the norms of water use will adhere to the logic of the underlying water right regimes. However, this study indicates that when a system undergoes a major expansion, the existing norms of water use may change accordingly. The change in the pattern of water rights in the previously irrigated area from land-based right (non-transferable usufruct right) to tradable right (ownership rights) is an example of this.

In an irrigation system, irrespective of how water rights were claimed earlier, the present basis of resource mobilization for the operation and maintenance of the system has more influence in determining the pattern of water rights. The change in the pattern of water rights in the Julphe sub-system - from tradable right to usufruct rights - is an example of this. Furthermore, this study shows that water rights claimed as per the resources mobilized for the operation and maintenance of a system will be limited to usufruct right.

This study shows that the use of wooden proportioning weirs in a system is best suited where water in a canal needs to be divided into two or more parts, each of which corresponds to water rights attached to a farmer or group of farmers. Other than dividing water, in canals aligned across the contour, weirs also work as checks and raise the supply level in the parent canal. The study also shows that from the hydraulic perspective, use of proportioning weirs in an irrigation system is viable if *sal* wood of the required size is available to construct the weir that can discharge the required flow.

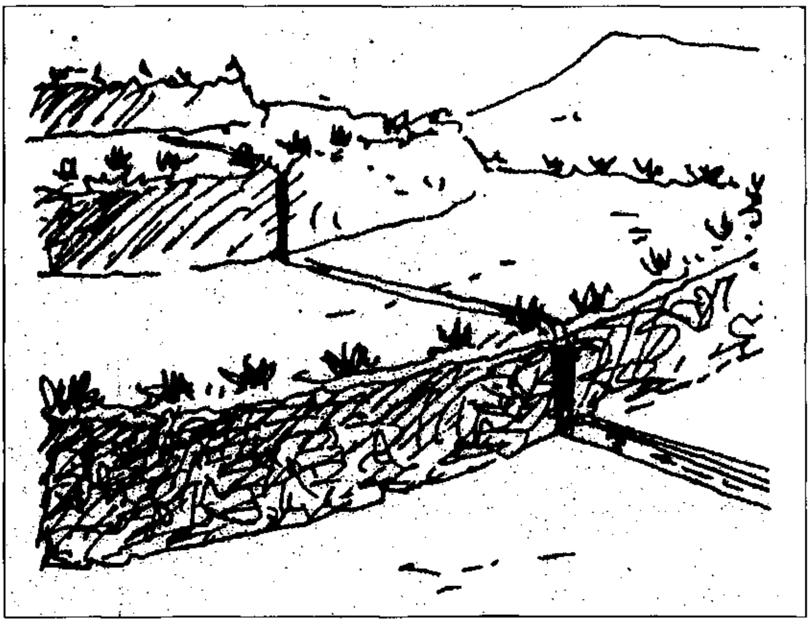
A proportioning weir is a fixed control structure. It distributes both low and peak flows in the same proportion. In any irrigation system where controlled entry of flow into the field is a more important consideration than the distribution of available water, distributing water through proportioning weirs is not desirable.

This study also shows that the fact whether a system is fully or partially proportionate is completely dictated by the flow available per unit of irrigated area. High flow per unit of irrigated area permits a fully proportionate system. In such a system, a farmer receives continuous flow to manage irrigation activities independently. Although this decreases water use efficiency, management inputs are minimal. In contrast, low flow per unit of irrigated area necessitates having a partially proportionate system with an open-close method of water distribution at the lower end. In such a partially proportionate system, water use efficiency is relatively high, although management inputs also increase at the lower end of distribution.

A fully proportionate system is best suited to mono-demand occurring simultaneously throughout the irrigated area, especially for the cultivation of paddy. A partially proportionate system, on the other hand, is suitable even for diversified cropping. The area served by a terminal point of a proportioning weir in a partially proportionate system varies with the crop grown.

This study has clearly indicated that proportioning weirs help fragment an irrigation system into several smaller sub-systems, each with its fair share of continuous flow. This in turn helps to devolve the water management tasks to the farmers of the respective sub-systems, and each sub-system functions as an independent system with its own organizational and institutional arrangements depending on its convenience, physical layout and the supply conditions. Managing a large number of small independent sub-systems through independent organizations is much easier than managing a larger single system. Further, proportioning weirs help facilitate water trading within and among such sub-systems, which in turn facilitates system expansion.

Since the proportioning weir works automatically without requiring opening or closing or adjusting it, organizational and institutional inputs required for water distribution are minimal. In such systems, resource mobilization for maintenance becomes the main objective of irrigation management. Because of the distinctive characteristics of proportioning weirs - visible distribution with reduced guess work, simple and understandable, measurable by farmers with respect to others and equitable distribution - water-related disputes are minimal.



5 Bachcha Irrigation System

5.1 Agro-ecological and social settings

The Bachcha Irrigation System falls under the Bachcha Village Development Committee (VDC) in the southern part of Parbat district in the Western Development Region of Nepal[1] (Figure 1.2). The area is linked to the Pokhara-Baglung Highway at Kusma, the district headquarters by a mule track, and takes about seven hours' walk. Kusma is the nearest road head to the system. Mules or porters are the only means of transportation from the district headquarters to the system.

The Bachcha Irrigation System falls under the sub-tropical climate in the hills. The mean monthly rainfall varies from 6 mm in November to 614 mm in July. About 80 per cent of the rainfall occur in the monsoon season (June-September). Figure 5.1 shows the monthly variations in rainfall, temperature and reference crop evapotranspiration at the nearest meteorological station.

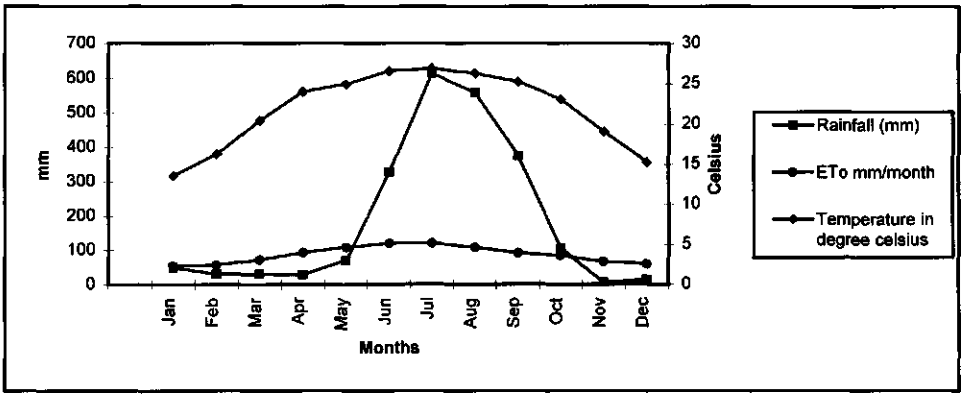


Figure 5.1: Monthly variations in rainfall, temperature and reference crop evapotranspiration

The irrigation system irrigates 51.3 ha[2] of land belonging to 197 farmers. *Tar khet*, also known as *phant*, constitutes the major portion of the irrigated area. The system also irrigates about 4 ha of *khola khet* at its headreach (Figure 5.2). A sub-vertical cliff separates the *khola khet* from the *tar khet*. A north-south contour canal (Bachcha Mul Kulo) and a main trail are aligned parallel to each other from the uppermost terrace of the *tar khet*.

[1] The latitude and longitude of Bachcha irrigation system are 28°07' north and 83°37' east respectively.

[2] This area is calculated on the basis of landholding of the *khet* land of all farmers.

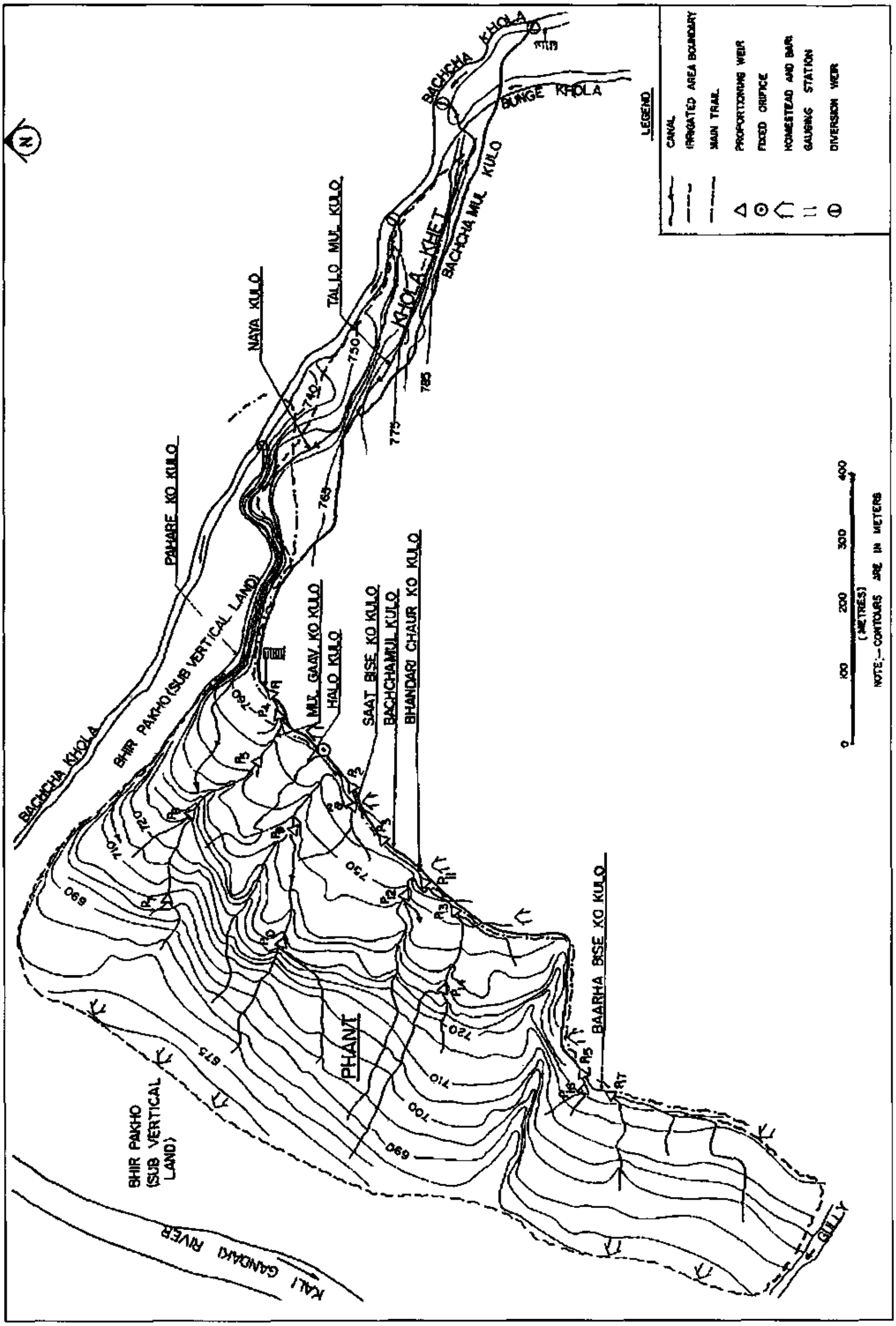


Figure 5.2: Canal layout plan of Bachcha Irrigation System

5.1.1 Landscape

Figure 5.2 shows the landscape of both the *phant* and the *khola khet* with the system layout superimposed on it. The *khola khet* area consists of a long strip of land parallel to the main canal and the source river. Its width across the canal varies between 20 and 125 m, and the length is about 700 m. The land slope of *khola khet* varies greatly. In the headreach, its land slope from the canal up to the toe of the mountains varies from 30 to 40 per cent. However, in the flood plains of the river and at the tail portion of the *khola khet*, the land slope varies between 5 and 15 per cent. The land area above the *khola khet*, up in the hills, is covered by a forest that is largely degraded. The *khola khet* faces north with steep mountains on its south, which completely blocks the afternoon sun during winter. Except for three or four houses along the main trail belonging to some Newar families settled specially for trade purposes, there are no other houses in the vicinity of *khola khet*.

The *phant* has two layers, upper and lower, connected by steep land, referred here as *tar* scarp. This *phant* is situated on the left bank of the Kali Gandaki River, about 225 m above it. The altitude of the irrigated area varies between 670 and 760 m from the mean sea level. It slopes from east to west. The average land slopes of upper *tar*, lower *tar* and *tar* scarp vary between 10 and 12, 14 and 20, and 35 and 40 per cent respectively. The land area connecting the edge of the lower *tar* and the Kali Gandaki River, referred here as *bhir pakho*, is almost sub-vertical. Bachcha Khola at the north, the Kali Gandaki River at the west, and a deep gully at the south form the system's boundaries. To the east, mountains rise steeply, blocking the morning sun. Figure 5.3 shows the east-west cross-section of the irrigated area.

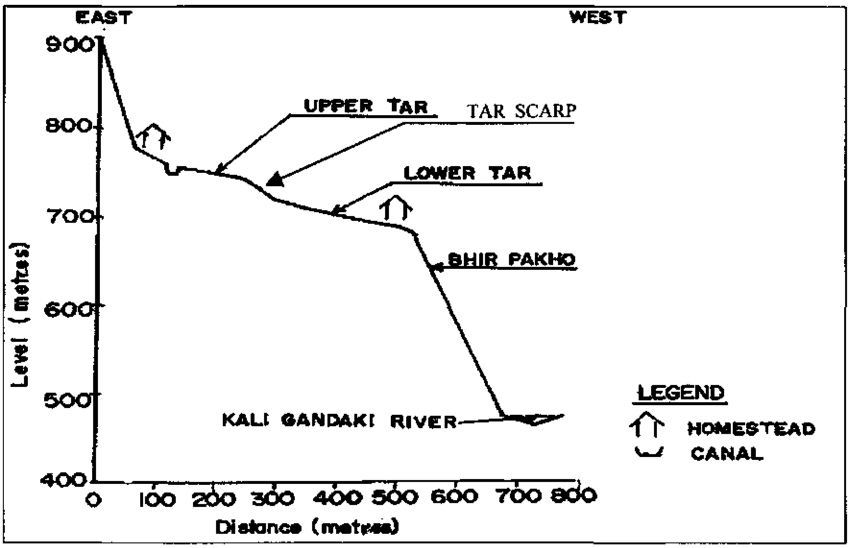


Figure 5.3: East-west cross-section of the irrigated area.

Six east-west natural gullies drain the *tar khet*. Of the six gullies, one major gully dissects the irrigated area into two parts. The five small gullies are physically more prominent in the *tar* scarp because of their steep slopes, and some of them disappear in the lower *tar*.

5.1.2 Land use

The land use pattern is clearly dictated by the topography and availability of irrigation water. Although water can be made available, *bhir pakho* is used mainly for production of rainfed *khar*[3]and fodder trees[4]. This is because such a natural vegetative cover stabilizes the hill slope. This part of the land is known as *khar bari*.

Tar khet is used mainly for cultivation of paddy during the monsoon. Adaptation to the slopes by constructing series of terraces is the basic feature of the hill farming system. This adaptation is primarily a response to perceived agricultural advantages, which increases soil depth and assists water control (Vincent, 1995). Along with paddy there are many other wide varieties of crops that are grown in the *tar khet* during winter and spring.

In the past, the *tar* scarp used to be *bari* because of its relatively steep land slope (35-40 per cent). However, with the increase in population and availability of irrigation water, farmers started converting their *bari* land into *khet*. Most of the *bari* land have now been converted into *khet*. The stability of this *tar* scarp has always remained a matter of great concern. From the point of view of water allocation these new *khet* are known as *biraute*.

The flatter land above the canal is used as *bari* because of unavailability of irrigation water, though it is suitable to be a *khet*. However, the steeper land is partly covered by degraded forest and partly used as *khar bari*.

The types of forests in the area mainly consist of immature (small sized) trees of tropical mixed hard wood with crown density varying between 40 and 70 per cent (Land utilization map, 1984).

5.1.3 Farming system

The farming system in the hills is characterized as a mixed farming system (Vincent, 1995), comprising production of cereal crops both in *khet* and in *bari*, livestock raising and agro-forestry, all of which have strong interrelations for the entirety of the agro-ecosystem. The types of production adopted here are very similar to the lower elevation production types (Metz, 1989) with substantial input from emigrant wage labour.

In the Nepal hills, farmers predominantly practise traditional subsistence agriculture. During the monsoon, monocropping of late paddy dominates most of the *khet* land. Along with late paddy, soyabean, inter-cropped with blackgram, is grown in the terrace bunds. Cultivation of such legumes in the terrace bunds strengthens the bund by soil binding and helps maintain soil fertility because of their nitrogen-fixation characteristics. Late paddy is followed by mainly irrigated wheat, inter-cropped with peas, which is again followed by spring maize. The time available to cultivate spring maize between wheat harvest and paddy transplantation is short. A part of the maize harvested is always pre-mature with a low yield. For this reason, big landowners keep some of their land fallow during winter so

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[3] *Khar* (*cymbopogon microtheca*) is a natural thatch grass. It is used mainly as fodder.

[4] Most commonly grown fodder trees are *dabdabe* (*Garuga pinnata*), *phaledo* (*Erythrina spp.*), *gaaya*, *khirro* (*Sapium insigne*) and bamboo.

that matured maize can be harvested. Other than wheat in the winter, potato, mustard and vegetables occupy nominal amounts of land, mainly for domestic consumption. Table 5.1 shows the cropping calendar, area covered and the average yield of the main cereal crops observed during 1996.

The use of improved varieties of crops, except for wheat, is practically nil. Seeds for all crops are either produced by the farmers themselves or are exchanged by the farmers among themselves. Even for improved varieties, seeds are rarely replaced from outside. The main reasons for preferring local varieties, as reported by the farmers, are: high yield of both grain and straw, better taste and less susceptibility to disease.

Table 5.1 Areas covered, cropping calendar and yields of main cereal crops.

Crops	Area Covered in Percentage	Dates			Fertilizer	Varieties	Average yield (T/ha)
		Seedbed Preparation	Sowing or Transplantation	Harvest			
Monsoon Paddy	100	May 3rd week to June 2nd Week	June 4th week to July 4th Week	Before 15th November	About 30 *doko* of compost per *ropani*	Mostly Local *Panhele Thapachiniya*	3 to 3.5
Wheat	75		November 3rd Week to December 1st Week	Before end of March	About 40 *doko* of compost per *ropani*		1.2 to 1.5
Maize	100		March 1st week to April 3rd week	June 4th week to July 4th week	About 60 *doko* of compost per *ropani*	Local	2 to 2.5

Source: Field observation and household survey, 1996.

Compost is extensively used as a fertilizer for all crops. The rate of compost use is maximum for maize, followed by those for wheat and paddy. About 20 per cent of the farmers use nominal amount of chemical fertilizers as a top dressing for wheat. Unavailability of chemical fertilizers, fear of soil degradation and low adaptation of improved varieties of crops are the main reasons for not using chemical fertilizers. Use of pesticides and insecticides is also practically nil.

Almost every household has one or two oxen and one or two buffaloes. Farmers living in the upper village[5] have more buffaloes than those living in the *phant*. In the *phant*, the livestock is stallfed and fodder requirements are met primarily from the cultivated land[6].

All the agricultural activities are carried out by human labour and animal draught power. Except during the harvest of maize and transplantation of paddy, which occur almost simultaneously, household labour is sufficient to manage the agricultural activities on their

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[5] The 'upper village' is the old Bachcha village located much above in the hills. It takes about one hour to reach this village from the *phant*.

[6] Fodder trees, straw of cereal crops, *khar* and other natural grasses are the main sources of fodder. Use of various types of fodder depends on the season.

own. During transplantation of paddy and harvest of maize, usually exchange of labour is practised. However, some big landowners hire wage labour.

Division of agricultural tasks between men and women is clearly distinguished. Women never plough the land and men never transplant paddy. Land preparation, irrigation and threshing are exclusively performed by men. However, weeding, harvesting, transporting of compost and harvested product, and all other domestic jobs are left exclusively for women.

In the past, with the increase in population, people first increased their labour input into agricultural intensification and diversification to maintain their livelihoods. However, these processes continued only up to a certain limit, beyond which additional input of labour produced a smaller increase in production. As a result, both seasonal and permanent migration began from the system, to earn livelihoods. The household survey showed that about 80 per cent of the households have one or more member (average 1.3) working outside the system area, especially in the Indian Army or other jobs in India. The average annual income from the remittances per such household is Rs42,800 (US$713[7]) .

The migrants fall under all categories of social hierarchy. Among the wealthy farmers, except a few who are more concerned about their social status, many have permanently migrated to the plain areas of Nepal. Most of the seasonal migrants fall under the category of marginal and small farmers. Also, the seasonal migrants are mostly men, which has created an extra burden for the women. At present, the younger generations have the least interest in agriculture. Their first preference goes to jobs outside the village. Those who cannot manage a suitable job outside stay in the village and continue agriculture.

This increasing trend of seasonal and permanent migration is becoming increasingly stressful in the village because of two main reasons. First, due to migration of the more entrepreneurial farmers, the reflective thinking capacity in the village is shrinking. As a result, it has become increasingly difficult to maintain social norms and values in the community/village. The decreasing interest of the young generations towards agriculture is the second reason for this.

5.1.4 Landholding and land tenure

The average landholding per household for *khet*, *bari* and *khar bari* (*pakho*) are 0.26, 0.29 and 0.33 ha respectively. About 3.5 per cent of the farmers own only *khet*, the rest have either *bari* or *pakho* or both along with *khet*.

Many farmers have *khet* land located in more than one place. The average parcel of land per household is 3.1 number. Such scattered distribution of landholdings has serious implications for farming and irrigation management.

The common tenure arrangement in this system is the fixed share contract. The mode of contract depends on the production capacity of *khet*. For example, if a *khet* can produce 10

[7] Based on 1996 exchange rate

muri[8] of paddy, the tenant has to give the landowner almost the same amount of paddy or slightly less as agreed between them. The rest of the produce goes to the tenant. Some farmers who live in the upper village reduce the amount of paddy but include a fixed quantity of paddy straw in the contract because it is not available there. In this fixed share contract, except the paddy seed, the liability of all other inputs, including irrigation system maintenance, usually goes to the tenant.

Another tenure arrangement is *bandhaki*[9]. In *bandhaki*, a written agreement is made between the tenant and the landowner specifying the period of agreement and the payment amount. This agreement is legally valid. In *bandhaki*, the tenant gives a fixed amount of money to the landowner and cultivates his land as long as the owner does not return the money. The minimum period of *bandhaki* is one year. The present rate of *bandhaki* in this system is about Rs15,000 (US$250) for the land capable of producing 5 *muri* of paddy.

In this system, since about 40 per cent of the farmers live in the upper village and at least one member of almost every household works outside the village, the percentage of land under tenure agreements is very high. The household survey showed that about 35 per cent of the households have rented their land to tenants, either partly or fully.

5.1.5 The village and its residents

The settlement pattern in the *phant* is dispersed. Most houses are located either immediately above the *tar khet* on the sides of the main trail or along the edges of the lower *tar* above the *bhir pakho*. Except for a few cases, no houses are seen in the *tar khet*. Almost all the houses have some *bari* and homestead land. Livestock is kept close to houses.

The total population of the system is 1,292, and the average family size is 6.5. Brahmins and Chettris[10] are the predominant castes in this system in terms of population and the amount of land owned. Some Gurungs, followed by other ethnic groups, also have some land here.

One high school, two primary schools and one agricultural sub-station with a livestock development sub-centre[11] are located in the *phant*. The nearest market is Phalebas; it takes about three hours to reach the market.

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8 *Muri* is a measure of volume. One muri of paddy approximately equals 50 kg.

9 In economic term *bandhaki* is a mortgage.

10 Ethnic composition in the system is: Chettri (36%), Brahmin (35%), Gurung (20%), Newar (3%) and others (6%).

11 The presence of a livestock development sub-centre here does not mean that livestock is more important in this village. This sub-centre is one of the government's regular service centres established to provide veterinary support to the farmers in this and a few other VDCs around. The main activities of this sub-centre are: to castrate goats and young bulls; to assist in the delivery of water buffaloes, and to provide other minor medical treatment to livestock.

5.2 Historical development

5.2.1 Irrigation system

Four canals, namely Bachcha Mul Kulo, Tallo Mul Kulo, Pahare Ko Kulo and Naya Kulo irrigate the system area. Of these, Bachcha Mul Kulo is the main and oldest canal. Tallo Mul Kulo merges with Bachcha Mul Kulo before the main irrigated area starts. Pahare Ko Kulo and Naya Kulo are independent canals, but they do not have separate irrigated areas. They simply supplement additional water to parts of the irrigated area of Bachcha Mul Kulo.

Naya Kulo and Pahare Ko Kulo were constructed within the memory of the farmers. The farmers cannot, however, recall the design and construction of the Bachcha Mul Kulo. Although it is difficult to conclude the original construction period of Bachcha Mul Kulo in the absence of well-researched historical data, there is very little evidence to show that the system was constructed before the unification of the present day Nepal[12].

The existence of an irrigation system in the hills can be traced out by the presence of a *jimmawal* in an area. A *jimmawal*[13] was a non-official functionary who collected taxes only on the *khet* land. The presence of *jimmawal* in an area indicates the existence of *khet* land, which in turn shows the existence of an irrigation system.

In the Bachcha village, Acharya families were holding the post of *jimmawal*, probably since the origin of this method of tax collection. Discussions with the now 82-year old last *jimmawal* and other members of Acharya families indicate that the presence of *jimmawals* in this area can be traced back until the mid-1850s. The *teen mahale moth*[14] testifies the name of such *jimmawal* working during that period. It also showed that some of the *bari* land in the Bachcha phant was registered as *khet* during 1879, indicating presence of other *khet* land prior to this. This implies that the irrigation system existed before the mid-1850s.

Except for oral history, other historical evidences regarding the existence of the irrigation system before the mid-1850s are limited. Farmers believe that this area was ruled by the Paiyun Kot principality before the unification of Nepal. The area was economically

[12] Historically, Nepal constituted many semi-autonomous principalities known as *baise* and *chaubise rajya* (meaning 22 and 24 kingdoms) till the end of the eighteenth century, before its unification. The process of unification and expansion was checked only after the Anglo-Nepal war of 1814-16 (Regmi, 1978a: 4).

[13] Regmi (1978a: 128-138) notes that the post of *jimmawal* was hereditary, and the *jimmawal* were appointed from the village concerned. He further notes that the process of tax collection by *jimmawal* started primarily because the state administrative machinery was then ill-equipped for collecting taxes from a large body of landholders. This indicates their origin after the unification of Nepal. The *jimmawal* had the authority of not only collecting taxes on the *khet* land but also of transferring ownership rights in case of trading of land, allotting the unused *khet* land to others and seizing the ownership of *khet* land in case farmers did not pay taxes in time. Besides this, *jimmawal* were also involved in village administration. By virtue of their authority, they were very powerful in the village and could harass the farmers in many ways. Regmi (1978a: 175) also notes that they have been notorious for mismanaging land records and exacting illicit levies from the farmers.

[14] *Teen mahale moth* is an official document certified by the then revenue collection office (*mal adda*). This document contains a list of farmers, the landholding of their *khet* land with the description and annual revenue of each *khet*.

prosperous as the trails passing through this area used to form one of the main trade trails between Tibet and India. Although at present three main sub-ethnic groups (Acharya, Silwal and Gurung) occupy most of the irrigated land in the system, Acharya and Silwal had migrated during early nineteenth century from Kathmandu and Baglung respectively. Gurungs were the only inhabitants of this area prior to the unification of Nepal. Both Acharya and Silwal families believe that this area had irrigation facilities prior to their migration. The seventy-six year old last *mukhiya*[15] told the researcher that the system was constructed by their ancestors with the help of the then king of Paiyun Kot. In the Bachcha Phant, as there was a provision of *guthi*[16] (for 45 *muri* of paddy annually) for conducting religious ceremonies at the temple in the local fort, it is likely that the system was constructed by the then king of Paiyun Kot.

Not much is known regarding the original design and irrigated area of Bachcha Mul Kulo. Oral history suggests that Bachcha Mul Kulo was very small in terms of flow-carrying capacity and irrigated area. Over time, its irrigated area increased, and as a result water scarcity was felt. Therefore, Pahare Ko Kulo and Naya Kulo were constructed by the ancestors of Silwal and Acharya families during the second and fourth decades respectively of the twentieth century. These canals were then constructed as private canals. At present, the former canal has about 20 and the latter canal 75 farmers[17]. These farmers also receive water according to their shares from the Bachcha Mul Kulo.

Farmers received outside assistance two times–in 1959 and in 1993/94–to maintain and strengthen the Bachcha Mul Kulo. In 1959, farmers received Rs11,000 from the local government for its improvement. In 1993/94, HMGN contributed Rs900,000 to rehabilitate the system under the DIDP[18]. The long-term objective of the DIDP was to secure food production and improve the living condition of the farmers in the area[19]. Under this programme, a semi-permanent weir with an orifice type of intake, and lining of about 600 m long main canal of Tallo Mul Kulo, was constructed. Interviews with farmers suggest that the lining of the canal helped reduce the seepage losses, especially during the spring season. Farmers recall that prior to this intervention, pre-sowing irrigation of spring maize used to require longer time because of high conveyance losses.

5.2.2 Irrigation organization

The system did not have a separate irrigation organization. Irrigation management was the responsibility of the *jimmawal*, who was very powerful. Resource mobilization for

[15] *Mukhiya* is a non-official functionary who collected taxes on *bari* land. In Bachcha village, Gurung families were holding the post of *mukhiya*.

[16] Land alienated by the state or by individuals to finance religious functions.

[17] During the field work in 1996, Naya Kulo was never operated although it could have been operated any time with a little effort. The reason was, Bachcha Mul Kulo had been improved several times, and the flow in this canal during 1996 was sufficient to irrigate the entire area.

[18] Dhaulagiri Irrigation Development Project (DIDP), funded by DANIDA.

[19] Other than the long-term objective, the DIDP also had some immediate objectives. They were: to improve the situation of the small landowners; to address the situation of women groups and the landless; to enhance the capacity of the local administration and the private sector (NGOs); and to influence the decision makers at the central level for policy advice (Imschoot *et al.*, 1996).

cleaning the canal was one of the main activities of irrigation management. Although resource mobilization was based on the household, only poor farmers and tenants had to work in the canal and influential farmers always got excused. Poor farmers and tenants were treated as slaves. Farmers recall stories how poor farmers and tenants sometimes even used to get physical punishment due to being late for cleaning the canal. In a way, the system was operating with the autocratic rule of the *jimmawal*.

Following the introduction of the Panchayat democracy in the country in 1960, a Village Panchayat was established in the Bachcha village in 1963/64. The village Panchayat was then responsible for the overall administration of the village. Those farmers who had been harassed by the *jimmawal* started ignoring him. Further, the Land Act of 1964 abolished the tax collection by the *jimmawal* system (Regmi, 1978a: 584) and reduced his powers. Due to this political change in the country, the existing irrigation organization headed by the *jimmawal* became defunct. Since then, farmers started organizing themselves to manage the irrigation activities. Until 1987, the system was managed by various persons on an *ad hoc* basis. In 1988, an influential person was selected by the farmers as the leader of their irrigation organization, as irrigation management requires co-operative effort, which only influential farmers are capable of organizing. In 1993, the irrigation organization was registered with the district administration office with 11 members on its working committee, as a prerequisite for being eligible for the government assistance programme. The main objective of the registration is to give the organization a legal identity so that the government or any other agency can enter into an agreement with it for participatory intervention assistance.

5.2.3 Agriculture

Paddy used to be the only irrigated crop grown in this area until the beginning of the twentieth century, implying that the irrigation system was mainly designed for the cultivation of paddy. After the harvest of paddy, farmers used to take their livestock to the *khet* for winter grazing as well as for fertilizing the *khet*. They also used to keep their livestock in the *khet*, in a temporary shed, known as *goth*. With the increase in population over time, pressure on the *khet* land increased and farmers started cultivating spring maize in the *khet* land. Before this, maize used to be a *bari* crop. It is not known when the spring maize was first introduced in the *khet* land of Bachcha. As the area is close to Argali where the cultivation of maize began between 1910 and 1920 (Yoder, 1986:74), it is most likely that the farmers of Bachcha started cultivating spring maize in the *khet* land about the same time. Introduction of spring maize might have initiated construction of two new canals, namely Pahare Ko Kulo and Naya Kulo. Note that these canals were constructed about the same time. Similarly, wheat was introduced in 1957 to supplement the annual domestic food need as maize was completely damaged by the big drought of that year. This shows that minimization of the risk of starvation due to failure of crops is one of the reasons why hill farmers in Nepal grow mixed grain crops in the cultivated land. The wheat was of local variety, known as *mudule ganhu*; later improved varieties were introduced during late 1960s.

5.3 The physical system

The Bachcha irrigation system irrigates 51.3 ha of irrigated area. The system has two main canals, upper (Bachcha Mul Kulo) and lower (Tallo Mul Kulo), receiving water from the same river but at different locations. The intake of Bachcha Mul Kulo (referred here as upper intake) is located about 250 m upstream of the intake of Tallo Mul Kulo (referred here as lower intake). The Tallo Mul Kulo joins the Bachcha Mul Kulo about 600 m downstream of the lower intake, just at the beginning of the main irrigated area (*phant*).

5.3.1 Water source

Bachcha Khola, which is a perennial river (stream), is the main source of water for the system[20]. It is a small tributary of the Kali Gandaki River, and flows from east to west. The Bachcha Khola is in the boulder stage[21]. The average width of the river at its diversion point is about 5 m, and the average gradient is about 6 per cent. Besides Bachcha Khola, Bunge Khola supplements water to the system, especially during the monsoon.

The average monthly flow of the river in March 1996 was 95 lps, which gradually reduced to 50 lps in May[22]. With the start of pre-monsoon in June the flow in the river started increasing. The average monthly flow in June was 120 lps. During monsoon, the river has sufficient flow to supply the irrigation system.

There are about nine temporary diversion weirs in the river, diverting water to various canals, both upstream and downstream of the intakes of Bachcha Irrigation System. Of these weirs, two divert a considerable amount of water to Bachcha and Pangrang.

The intake of the Pangrang Irrigation System is located about 500 m upstream of the upper intake of the Bachcha Irrigation System. Pangrang Irrigation System irrigates about 33 ha on the other side of Bachcha Khola. In the past, an inter-system conflict over the water right at the source, especially during the spring (March-May), arose between the farmers of Bachcha and Pangrang. The conflict was settled by allocating the right of water use on a time-share basis. The Bachcha farmers were to use the water for 12 hours at night and the farmers of Pangrang were to use the water for the remaining 12 hours in daytime. During other times of the year, this arrangement is not necessary as the river has enough water for all the systems.

5.3.2 Intakes

The upper intake, as in many other farmer managed irrigation systems, consists of an unregulated open intake with a temporary diversion weir constructed across the river. The

[20] The catchment area of Bachcha Khola is about 10 sq km, with 60 per cent area covered by forests, and the remaining area by shrub and cultivated land (DIDP, 1991).

[21] A river having most of its bed materials in the form of boulders is referred here as a boulder stage river. Such boulders are likely to move with floods in the monsoon season. Usually, it is not advisable to construct any permanent structure across such rivers.

[22] These flow data are based on actual measurements during 1996. The flows were measured two times a week upstream of the upper intake.

weir is constructed with layers of boulders, with brushwood in each layer. The weir is laid in the river slightly skewed to the main direction of flow. During the period of low flows in the river, the weir helps raise the water level to facilitate flow diversion into the main canal. As a result, small pools of water are created in the upstream. The weir is easily damaged by the floods in the monsoon. During the period of high flows in the river, due to its higher water level, the weir simply diverts the water into the main canal.

The lower intake also had a similar type of structure. During the external intervention in 1993/94, it was replaced with a gabion weir[23], constructed perpendicular to the direction of flow. The intake consists of an unregulated rectangular orifice.

Mountain rivers carry a large amount of sediments, especially during the monsoon. Passing of these sediments downstream into the river is also an important criterion in the design of weirs across the rivers. To some extent, temporary weirs constructed by farmers are successful in achieving this objective. As mentioned earlier, in the upper intake, a small settling basin is formed during the construction of the temporary weir. This basin collects the incoming sediments. As this temporary weir is bound to collapse in high floods, collected sediments are flushed automatically. When it is reconstructed, space is created again for the incoming sediments.

The gabion weir at the lower intake does not create such settling basins at its upstream end. It is already filled up with sediments. This increases the sediment inflow into the Tallo Mul Kulo. The deposition of 10-15 cm sediment in the headreach of the 40 cm-deep Tallo Mul Kulo testifies to this. Interviews with farmers also suggest that the sediment inflow into the Tallo Mul Kulo has increased after the construction of the gabion weir. Similar observations were made by Pant (1997) in the Ghachowk Irrigation System[24] in Nepal. This implies that semi-permanent or permanent weirs increase the chances of sediments entering the main canal as compared with the temporary weirs, unless they are constructed with special consideration of sediment trapping - which is not likely in this type of small mountain systems.

5.3.3 Main canal

Bachcha Mul Kulo is the main canal[25]. It is a contour canal with an average gradient[26] of 1.6 per cent. Its total length is 2.6 km. The average width and depth of the canal in the idle length are about 1.2 and 0.6 m respectively. From its intake down to about 200 m, it is aligned slightly above the river flood plains. In this section, the Bachcha Mul Kulo is in boulder stage and is as steep as the source river. Because of its steepness, it does not need

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[23] A gabion weir is considered to be a semi-permanent weir. It works for a few years with little maintenance.

[24] Ghachowk Irrigation System is a run-off-the-river scheme. This is a farmer managed irrigation system. A permanent diversion weir was constructed across the river during the government intervention in 1990. This system had a temporary diversion weir before the intervention.

[25] The nomenclature of canal differs with system. In this system, the canal which conveys water from the source (the upper intake) down to the end of the irrigated area is named as the main canal (Bachcha Mul Kulo).

[26] The gradient of the canal is very irregular. Its minimum value is about 0.5 per cent, and the maximum as high as 4 to 5 per cent.

annual cleaning. After a distance of about 200 m, it crosses a stream, known as Bunge Khola. A level crossing structure made of boulders and brushwood is constructed at Bunge Khola. The level crossing structure also regulates the flow in the Bachcha Mul Kulo by raising or lowering its crest level at certain points.

From Bunge Khola down to its confluence with Tallo Mul Kulo at chainage 850 m, the main canal is aligned across fairly stable steeply sloping mountains. From this confluence down to the end of this canal, its alignment passes across relatively flat hill slope of about 30 to 50 per cent.

One escape structure is located immediately downstream of Bunge Khola. The escape simply consists of an open cut in the canal bank. To close the escape it is plugged by boulders, and to open it, boulders are removed[27].

Tallo Mul Kulo is also a contour canal with an average gradient of about 1.2 per cent. It is small in size[28]. It runs along the uppermost terraces of *khola khet*, across moderately sloping hills. The total length of this canal from the intake to where it joins the Bachcha Mul Kulo is about 600 m.

Both Bachcha Mul Kulo and Tallo Mul Kulo have irregular sections and bed slopes. Like many other irrigation systems in the hills[29], these canals have higher gradient than the recommended values. Recommended values are usually based on research findings on plain areas, and are not suitable for the mountain environment.

Unlined canals, except those excavated in rock, are usually subject to erosion. The design of an unlined canal is based on non-scouring and non-silting conditions. With varying canal discharge and sediment load entering the canal, silting and scouring is difficult to predict, given the limited study on sediment transport in the mountain regions (MacDonald *et al.*, 1990 M8-1:78). Therefore, experience and judgement are the only criteria to judge the sufficiency of the canal bed slope.

The main canals of Bachcha were not developed at a single point of time. Their present state is the result of many years' efforts and experience. Usually, farmers first start digging the canal from the head, with a small track of flowing water just to establish the slope. Gradually, the canal is widened and deepened. The flow also enhances the increase in the shape of the canal and results in the deposition of colloidal materials on the canal bed. Where there is a tendency of scour, a canal first gets deeper, and gradually its shape gets stabilized over time. This is because, scouring is primarily caused by the bottom velocity, and at the same mean canal velocity, bottom velocity is less in deep canals (Chow, 1985). Such stabilized canals can stand a much higher velocity compared to the new ones, particularly because of the deposition of colloidal materials on their bed. For this reason, canals in the hills have irregular bed slopes and sections.

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27 Since the Bachcha Mul Kulo conveys fairly high flows during monsoon, a wider opening is provided for the escape. During monsoon, three to four persons are needed to operate this escape.

28 The average width and depth of Tallo Mul Kulo are 50 and 40 cm respectively.

29 MacDonald *et al.* (1990 M8-1:69), Jacob (1995:192) and Pandey (1995:69) note that many irrigation systems in the hills have a canal gradient much higher than the theoretically recommended value.

The steeper but stable canal bed also has important implications on the operation of the irrigation system. The flow velocity increases with the slope[30]. Under high velocity, if a small mass of soil falls into the canal, it is easily washed down, thereby requiring less maintenance when the canal is in operation. Further, the wetted perimeter and flow area would reduce with higher velocity, which in turn reduces seepage losses from the canal and increases its stability.

As in many other farmer managed irrigation systems in the hills, the canal section of Bachcha Mul Kulo is much bigger in size than that required considering the crop water requirement. This canal can convey a flow of more than 500 lps. The maximum flow measured during the monsoon in 1996 was 491 lps.

In the Nepalese hills, a water allowance of 3 lps per ha is recommended for monsoon paddy[31]. This means a canal with a flow of about 200 lps should be enough to provide the irrigation need of this area if a reliable discharge can be supplied. However, in practice, an uninterrupted supply of the designed flow during the monsoon is not possible. This is because most farmer managed irrigation systems are run-of-the-river type. Thus, many times either there is not enough water in the source, or the intake is washed out, or the canal is damaged. As a result, the supply fluctuates in the canal. Figure 5.7 shows the flow fluctuation of the Bachcha Mul Kulo during 1996.

A recent study of some farmer managed irrigation systems conducted by Sir William Halcrow and Partners showed that hill canals have bigger sections and an average water duty of 6.32 lps per ha (Halcrow *et al.*, 1997). According to this study, high duty is a reflection of the abundance of water supply and seepage losses of about 14 per cent. However, this case study suggests that the bigger cross-section is the result of higher anticipated fluctuations in the water supply. It should be noted that although the capacity of Bachcha Mul Kulo is more than 500 lps, the average flow into the canal during the paddy cultivation period was only 250 lps, which is slightly more than that with a rate of 3 lps per ha.

Many government-built irrigation systems actually irrigate less area than they are designed to, even after repeated improvement (Halcrow *et al.*, 1997; World Bank, 1997). Apparently, one of the reasons for irrigated areas being less than the designed is the failure to anticipate such likely fluctuations in the supply.

The Bachcha Mul Kulo does not have any cross-drainage structure once it crosses the Bunge Khola. This canal also acts as a catch-drain during the monsoon. Another reason for having a bigger cross-section is the use of the canal as an intercepting drain.

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[30] Farmers judge the velocity of flow by looking at the surface of flowing water. Flow velocity which produces irregularities in the flowing water surface, hydraulically known as subcritical-turbulent flow, is commonly adopted in many farmer managed irrigation systems.

[31] Irrigation requirements depend on many factors: evapo-transpiration, losses and methods of water distribution. In the hills, its actual estimation is difficult. For these reasons, many authors have recommended values varying between 1.5 and 3.0 lps per ha for the cultivation of monsoon paddy in the Nepalese hills (Jacob, 1995:101; MacDonald and Hunting Technical Services, 1982:30).

Considering the large variations in the canal flow across the year, one may raise the question how do farmers manage small flows in such a wide canal. Usually, in the earthen canal, the canal bed across its section does not remain level. A part of its section is always deeper than the other. To manage a small flow (up to a certain limit) in a wider canal, farmers simply clean the deeper portion of the canal section in such a way that a small channel is formed within its original bed. This, however, requires extra labour. When the flow further reduces below a certain limit, these canals are not used and irrigation activities are suspended. This is one of the reasons why many farmers in this system do not irrigate maize after the completion of pre-sowing irrigation.

5.3.4 Distribution canals

As mentioned above, this irrigation system irrigates both *khola khet* and *tar khet* areas. The distribution system differs in the two areas.

The major portion of the *khola khet* area is irrigated by Tallo Mul Kulo. The Bachcha Mul Kulo irrigates a small portion, down to the confluence of two canals. The distribution system in the *khola khet* area has only one order of canal. Note that the area constitutes a long strip of land parallel to the main canal. Most of the irrigated land is served by turnouts at the Tallo Mul Kulo through their respective field channels. These field channels are small, and are aligned down the hill. They convey a flow of about 3-7 lps.

The distribution system in the *phant* area consists of two canal levels. They are the main canal (Bachcha Mul Kulo) and the secondary canals. There are five secondary canals. Four of them receive water from the main canal through fixed proportioning weirs. One secondary canal, known as Halo Kulo, receives water from the main canal through a fixed orifice. All secondary canals are aligned down the hill, almost perpendicular to the main canal. As a result, the secondary canals are very steep. At many places of these canals, boulders are placed to check the flow velocities and to avoid erosion of the canal bed. At some places, these canals are split into two parts for further division of water among individual farmers' field through field channels. Unlike the *khola khet* area, the main canal does not supply water to individual farmers' field directly.

5.4 Water distribution structures

Water distribution structures are used depending on the principles of water allocation, topography and stability of canals/hill slopes. This system uses three types of water distribution structures: proportioning weirs, fixed orifices and ungated turnouts. In the *phant*, proportioning weirs are used in both the main and secondary canals, whereas a fixed orifice is used only in the main canal. Ungated turnouts are used only in the *khola khet* area.

5.4.1 The proportioning weir

Like the proportioning weir discussed in Chapter 3, proportioning weirs here, too, are made of a long wooden beam with several rectangular notches of uniform depth cut into them. However, its basic design differs from that of the proportioning weir discussed earlier. These differences are discussed later in this section. Locally, the proportioning weir is called *gaav*, meaning the core part of the timber. Only the core part of the timber is used to construct a proportioning weir for durability. The widths of notches represent the water share of branching canals connected to them. The uncut wooden portions between the two notches and at two corners are known as *maadal* and *kaandh* respectively (Figure 5.4).

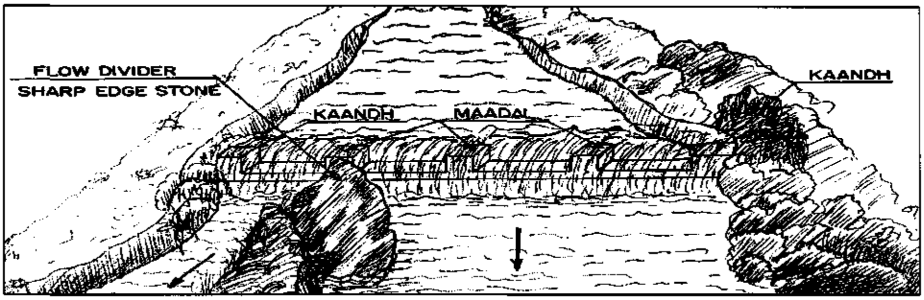

Figure 5.4: Proportioning weir.

The proportioning weir is placed perpendicular to the direction of flow. It is fixed in its position with the help of big stones placed immediately downstream of the weir at both the corners and at the centre for stability. The central stone, which is sharp-edged and pointed against the direction of flow, also acts as a flow-divider. The location of the notch size with respect to the flow-divider (sharp-edged stone) affects the flow passing to all the branching canals. Table 5.2 shows the principal features of proportioning weirs in the main canal.

Table 5.2: Principal features of proportioning weirs[32] in the main canal.

	Proportioning weir	Incoming water (*mato muri*)	Total width of notches (cm)	Notch width per *mato muri*	Notch depth (cm)	Total weir width (cm)	Height of weir above canal bed (cm)
P1	62 63 61 65 550 500 490 560	2100	251	0.119	5	380	30
P2	54 54 57 500 490 560	1550	165	0.106	5	265	40
P3	49 52 490 560	1050	101	0.096	6	250	35

Location

The general considerations for location of the proportioning weir are similar to those discussed earlier. Of the various considerations, canal slope and canal width are the most important. Stretches of the main canal where the proportioning weirs are located have a

[32] The upper and lower numbers indicate the notch width in cm and the water share of the notch respectively. For example, in proportioning weir, P3, the notch widths are 49 and 52 cm, and are 490 and 560 the corresponding water shares of notches. Total weir width here refers to the sum total widths of notch, *kaandh* and *maadal* of proportioning weir.

much flatter gradient of about 0.5 per cent in comparison to the overall average canal gradient of 1.6 per cent. This helps minimize the approach velocity. Also, it is located only at such points where adequate canal width is available to accommodate the weir. Note that the average width of the canal and the width of the first proportioning weir are 1.2 and 3.8 m respectively.

The location of the proportioning weirs in the main canal is also affected by the differences in the canal bed elevations between the main (the supply canal) and secondary (offtake) canals at its bifurcation points created by terraced land. The main canal, being a contour canal, runs along the uppermost terrace. However, the secondary canals, which bifurcate from the main canal at almost right angles, start from the next lower terrace of the main canal. The height difference between the uppermost and the next lower terraces vary from 2 to 4 m (Figure 5.5). To avoid this difference in elevation, the proportioning weirs in the main canal are located about 30 m upstream or downstream from the axis of the secondary canals. By doing so, the secondary canals first run parallel[33] to the main canal for some distance and then turn right angle along the hill slope. The level differences between the main and the secondary canals are then negotiated by the parallel portions of the secondary canals.

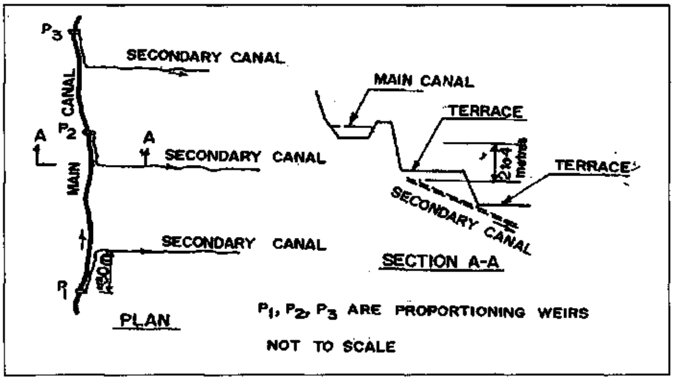

Figure 5.5: Layout of the proportioning weirs and secondary canals.

In secondary canals, there are no such problems of level difference between the secondary and the next lower order canals because all of them are aligned in the same direction down the hill.

Design and construction of proportioning weir

Figure 5.6 shows the section of the first proportioning weir, known as Mul Gaav. The main difference in its design from that of the standard proportioning weir discussed earlier in chapter 3 is that the proportioning weir of Bachcha allows the water to flow not only through notches but also over its *maadal* and *kaandh*, whereas the standard proportioning

[33] The first proportioning weir in the main canal is located upstream of the axis of the respective secondary canal. This secondary canal then runs parallel to the main canal for some distance. However, the second and the third proportioning weirs in the main canal are located downstream of the axis of the respective secondary canals. These secondary canals though run parallel to the main canal, flow in the opposite direction unless they turn at right angle down the hill slope.

weir allows the water to flow only through its notches. A sharp-edged stone of sufficient height is therefore kept downstream of the weir but adjacent to it to divide the flow from the parent canal into two or more branching canals. Usually, the flow-divider is fixed at the centre of *maadal* where the flow has to be divided. To make the structure approximately linear[34], only the widths of *kaandh* are required to be adjusted. This is done by constructing a temporary stone wall over it. The widths of the *kaandh* are adjusted in such a way that the total weir width for each branching canal remains in the same proportion to that of the width of the notches. For example, in the Mul Gaav, notch width corresponding to the branching canal (Mul Gaav Ko Kulo) and the remaining three notches (for the continuing parent canal) are 62 and 189 cm. Their ratio is 1:3.04. The widths of *maadal* are approximately the same, and vary from 21 to 22 cm. With the sharp-edged stone nearly at the centre of the *maadal*, widths of *kaandh* were fixed as 14 and 25 cm. With this adjustment, the total widths of *kaandh* and *maadal* corresponding to the branching canal and the continuing parent canal become 24.5 and 78.5 cm. This ratio is 1:3.2, which is almost equal to the ratio of notch widths of the branching and the continuing parent canals.

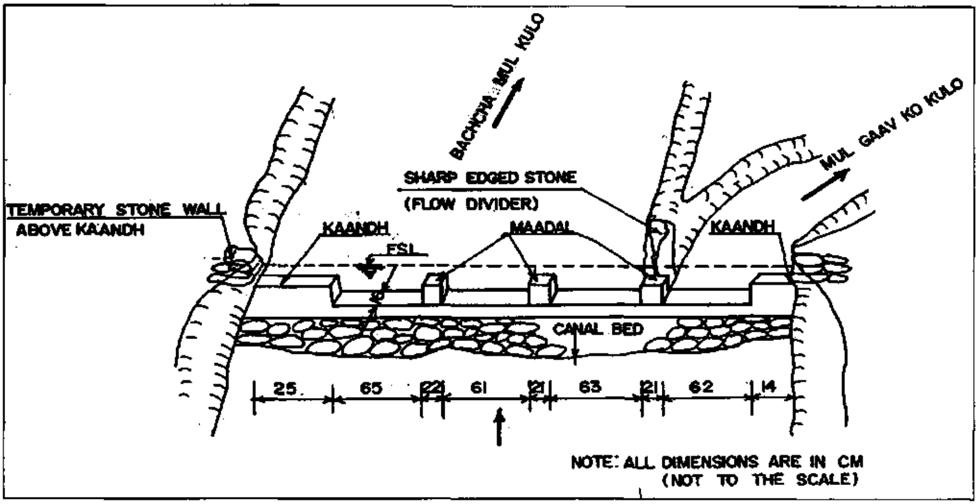

Figure 5.6: Section of the first proportioning weir (Mul Gaav).

To maintain the flow of water proportional to the width of the weir, the top surface of *maadal* and *kaandh* are kept at the same level. Usually, the widths of the *maadal* are kept same for easy computation of proportionality.

This modified design of the proportioning weir compared to the standard proportioning weirs is not only used in the Bachcha Irrigation System, they are also available in other systems nearby. There are various reasons for adopting this design in the Bachcha Irrigation System.

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34 The structure (proportioning weir) is said to be linear if the flow passing through it is proportional to the width of the structure.

The first is the availability of *sal* (*shorea robusta*) wood. The proportioning weirs used in the main canal are made of *sal* wood because of its higher resistance to water. The average depth of notches is 5 cm, and the overall thickness of the timber in all weirs in the main canal is about 18.0 cm. To allow the water to flow only through the notch (like a standard proportioning weir) with the present width, a notch depth of about 15 cm would be required. This means a timber of at least 25 to 30 cm thickness would be needed. Timber of this size is not available around Bachcha because of its higher altitude[35].

It can be argued that the depth of the notches could be increased by adding another piece of timber (or other material) on top of *maadal* and *kaandh* to allow all the water to pass through the notches. By doing so, the discharge intensity[36] would increase with the increase in afflux, which would reduce the stability of both the canal and the weir. In a system like Bachcha, which conveys more than 500 lps during flood, stability of the weir is very important. It is because of this that big stones are kept in the canal bed downstream of the weir for stability.

The second reason is the hill slope (topography). The width of a canal along the contour depends on the hill slope. The steeper the hill slope, the smaller is the canal width. By contrast, the overall width of a proportioning weir required considering hydraulic parameters is always much wider than the normal canal width. This makes it difficult to accommodate a wider weir width in the canal.

During the monsoon, the average flow in the main canal is about 250 lps, and the depth of the notches is about 5 cm. Assuming the depth of curvature of the flow above the weir to be 3 cm, the total head available would be about 8 cm. If all the water is to flow only through the notch, as in the case of the standard weir, the weir width required would be about 7 m against the present average width of 3.2 m. Such a big canal width (weir width) would not be possible in a system like Bachcha with the average hill slope of about 30 to 50 per cent[37].

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[35] The availability of *sal* wood is limited to an altitude of 1,000 m above the mean sea level (Jha, 1992). The higher the altitude, the smaller is the girth of the tree. As mentioned earlier, the forest of Bachcha VDC is covered by immature (small-sized) trees of tropical mixed hard wood. For the last few years, encroachment into *sal* wood forest is strictly prohibited by the forest users' committee. It is because of this reason, farmers started using other soft wood to fabricate the proportioning weirs to be used in the secondary and other lower order canals. Wood like *dabdabe* (*Garuga Pinnata*), *phaledo* (*Erythrina spp*), and *khirro* (*Sapium insignc*) or other soft wood are used for this purpose. These soft woods last for about one year.

[36] Discharge intensity is the flow per unit width of the weir. With higher discharge intensity the action on the canal floor will be more intensive. Also, higher discharge intensity involves greater risk of outflanking due to local concentration of flow (Singh, 1972:311).

[37] In the lowland systems, the irrigated area and the canal discharge are usually much higher than in the hills. In such systems, if wooden proportioning weirs are to be used, the weir width required would be much higher because the notch depth is restricted by the timber size. In Nepal, the maximum notch depth observed in wooden proportioning weir is about 30 cm, with a main canal capacity of about 800 lps (in Tribhuvan Tar canal, Nawalparasi). Although Yoder (1986) suspected that the head loss required in the weirs is one of the reasons why the wooden proportioning weirs are not used more widely in the lowland systems, it seems that the bigger weir width required because of the higher discharge is one of the prime considerations for not using these wooden proportioning weirs more widely in the lowland systems.

Like the standard proportioning weir, this proportioning weir is also installed on a stone wall about 30 cm high constructed above the main canal bed. The hydraulic reasons and operational consequences for installing the weir above the normal canal bed have been discussed earlier.

Proportioning weirs in the secondary canal

Proportioning weirs in the secondary canals are smaller in size and are made of soft wood. However, the design principles are the same as those for proportioning weirs in the main canal.

Two main physical factors determine the site selection for proportioning weirs. First, the proportioning weirs require a long and flat approach canal in order to bring the approach velocity within a reasonable value[38]. The steep slope of the secondary canal makes it difficult to install proportioning weirs at every bifurcation point. Second, proportioning weirs are installed only at such points where the branching canal can convey its share of peak flow, as will be discussed later in this section. These two conditions restrict the viability of a fully proportionate system in the steep topography.

Notch width of proportioning weir

Notch widths in a proportioning weir are designed at one finger width per every 20 *mato muri* of water share. This is applicable to all weirs irrespective of their location in the system. However, in weirs fabricated recently, farmers have used equivalent dimensions, at about 0.75 inch for a finger width. An example is the third proportioning weir, P3, in the main canal, fabricated in 1993. The notch width per *mato muri* of this weir is almost the same as that of other weirs (Table 5.2). The small variation may have been caused by the wear and tear of notches due to continuous flow of water over a long period of time.

Fixed notch width per unit of water share makes it simple and easy for farmers to check the correctness of their notches irrespective of their location. This became possible because of the lower relative difference in the flow size between the parent and the offtake canals (about 1:4). In case of higher relative differences, such fixed notch width per unit of water share may not be possible. This is because the notch width corresponding to smaller water shares could be too small from operational considerations.

5.4.2 Fixed orifice in the main canal

Of the four secondary canals in the *phant*, one secondary canal, known as Halo Kulo, receives water from the main canal through a fixed orifice. The other three receive water through proportioning weirs. This orifice is ungated, and is located slightly above the canal bed.

This raises the question: Why has only Halo Kulo an orifice type of intake instead of a proportioning weirs as in other secondary canals? Topography, alignment of secondary canals and hydraulic characteristics of weir help to explain this.

[38] Length of approach canal in the weirs in secondary canals varies between 2.5 and 6.5 m

Note that all secondary canals receiving water through proportioning weirs are aligned along valleys, mostly through natural gullies except for Halo Kulo, which is aligned along the ridge and has a slope up to about 30-40 per cent in the *tar* scarp (Figure 5.2). By comparison, this canal is much smaller and has a water share of only 40 *mato muri*.

A proportioning weir, being a fixed control structure, distributes both the low and the peak flows in the same proportion. For this reason, the canal which receives water through the proportioning weir should also be able to convey its share of peak flow.

The secondary canals, which are aligned along valleys, can convey large flows without damaging crops and terraces. Therefore, use of proportioning weirs in these canals becomes viable. The flow in the Halo Kulo needs to be checked in order to protect crops and terraces because of its alignment. With an orifice as an intake to the Halo Kulo, even if the parent canal is flooded, water does not enter the Halo Kulo in the same proportion as in the parent canal. This explains why an orifice has been provided instead of a proportioning weir to distribute water into Halo Kulo from the main canal.

5.4.3 Ungated turnouts in khola khet

There are a total of 24 ungated turnouts over a 700 m stretch of the main canal to irrigate 4 ha of *khola khet* area belonging to 30 farmers. The sizes of these turnouts have no defined relationship to the area served. These turnouts are constructed simply by making a rectangular opening in the lined canal. They function as a weir. The crest levels of most of these turnouts are about 15 to 20 cm above the canal bed, which is above the normal full supply level during the winter season. Usually, one turnout is provided to every landholding, but depending on the topography of terraces and the size of landholding, more than one turnout may be provided to some farmers. The shape and topography of the irrigated area necessitated many direct turnouts.

The following few paragraphs explain why such turnouts are used in the *khola khet* area instead of proportioning weirs like in the *phant*.

The first reason is the principle of water allocation. In the *khola khet* area, the principle of water allocation is as per demand[39]. The perception of equity is judged on the basis of actual need of all crops. Accordingly, farmers adjust the flow through these turnouts. To increase the flow, the supply level in the main canal is increased with the help of an obstruction (usually boulders) kept immediately downstream of turnouts in the main canal. To reduce the flow, the turnouts are partially blocked. This principle of water allocation necessitated the use of such turnouts.

As explained earlier, the need to check flows in the field channels during the monsoon is the second reason. Field channels receive water direct from the main canal. They are aligned down the hill, and have slopes up to 30-40 per cent. They are very small and convey small flows of about 3-7 lps. During the monsoon, the flow into these field

[39] See the section under water allocation.

channels needs to be checked in order to protect crops and terraces. This necessitated the use of such turnouts instead of any fixed control structures like proportioning weir[40].

5.5 System operation

5.5.1 Organizational and institutional arrangements

The system has a single tier of irrigation organization led by the chairman, locally known as *adhyakchhya*. Historical evidences indicate that till the mid-1960s, a *jimmawal* used to lead this organization. Only after the abolition of the *jimmawal* system, farmers started nominating other persons for the chairman. The present chairman was nominated by the farmers in 1988[41].

In 1992, a formal irrigation organization was formed with elaborate constitutional arrangements as a pre-requisite for receiving government assistance programme. This organization requires an executive committee headed by the chairman[42]. The then *adhyakchhya* was re-elected. At present, except for the chairman, the executive committee is inactive. Activities such as the meetings of the general assembly, the meetings of the executive committee and auditing of accounts have never been performed. Apparently, the formal executive committee acted as a construction committee during the period of intervention, although it is supposed to be responsible for the overall management of the system even after intervention. In this sense, the formal executive committee is defunct. At present, the *adhyakchhya* manages the system as it used to be managed by the *jimmawal* in the past. The only difference is that decisions taken by the *adhyakchhya* are more democratic now than during the period of the *jimmawal*. The process of system operation such as water allocation, distribution and system maintenance is still the same.

The organization does not have any written rules and regulations (except the now defunct constitution). System maintenance, fixing the dates for installing the proportioning weirs, supervising the rotational distribution during cultivation of maize and resolving disputes are the four main tasks of the *adhyakchhya*.

Every year farmers gather for system maintenance. Maintenance of the system involves repair of the temporary diversion weirs, desilting of the canals and of canal banks. Regular maintenance of the system is done once a year, before the cultivation of paddy. Although water is distributed as per farmers' water shares (during paddy cultivation), the principle of resource mobilization for annual maintenance is based on equal contribution - one

[40] In this area, the use of proportioning weirs would not be viable even if farmers were to distribute water as per landholding. This is because the relative difference in the flow size between the parent and the offtaking field channels would be too high - about 1:395.

[41] Because of his popularity as the *adhyakchhya* of the irrigation organization, people also elected him as the chairman of the Village Development Committee in 1990.

[42] The formal executive committee was formed according to the irrigation directives of the Department of Irrigation in 1989. This formal organization is registered with the District Administration Office of His Majesty's Government of Nepal. According to the irrigation directives, the executive committee should consist of at least five to a maximum of 11 members, depending on the size of the system, and should be responsible for the overall operation and maintenance of the system.

farmer per household. Whenever cash needs to be raised for system maintenance, it is collected with respect to land. As the annual maintenance is usually completed in one to two days, farmers have adopted this method instead of proportional contribution because proportional contribution involves additional administrative costs and the benefits could be less than the administrative costs. In 1995, only 161 farmers against the total 197 households reported for annual maintenance. In 1996, this reduced to 116. Although there is a rule of fining Rs30 per day on absentee farmers, no body has so far paid the fine. Even the maintenance of the diversion weir at the intake during monsoon only requires a few labourers, and no definite rules exist for this. Whenever maintenance is needed, four to five farmers who need water most urgently gather together and maintain the diversion weir. This implies that resource mobilization is not a major problem in this system.

5.5.2 Water acquisition

As stated earlier, Bachcha Khola and Bunge Khola are the two main rivers which supply water to upper and lower canals. The use of these water sources and canals differs with season.

The upper main canal (Bachcha Mul Kulo) is used during paddy cultivation. Because of its larger capacity, this canal contributes the major portion of the supply required during this period. Use of the water source by this canal differs during this period. Before the peak monsoon begins, especially during the paddy transplantation, both the sources are used. Once the peak monsoon starts, the Bunge Khola has enough supply to meet the system's demand, and water from the Bachcha Khola is no longer needed. However, a certain amount of water from the Bachcha Khola still continues to flow into the upper main canal[43]. Thus, the total available flow from both the sources is regulated at the level crossing structure at Bunge Khola in order to allow controlled entry of flow into the main canal from Bunge Khola onwards. Use of the Bachcha Mul Kulo during the winter season is limited. This canal is not used during spring (March-June).

The lower main canal (Tallo Mul Kulo) is used throughout the year. However, its contribution to the system is mainly during spring (March-June). During this period, water supply in the Bachcha Khola is very low, and the system can use the water only for 12 hours at night. Conveying a low and interrupted flow into the large upper main canal is inefficient because of high conveyance and transient losses.

Figure 5.7 shows the fluctuations of the flow in the main canal upstream of the first proportioning weir[44].

[43] During the peak monsoon period, farmers usually do not repair the upper intake because the upper intake still functions due to the high water level in the river.

[44] Interrupted lines are caused by non-availability of data for that period.

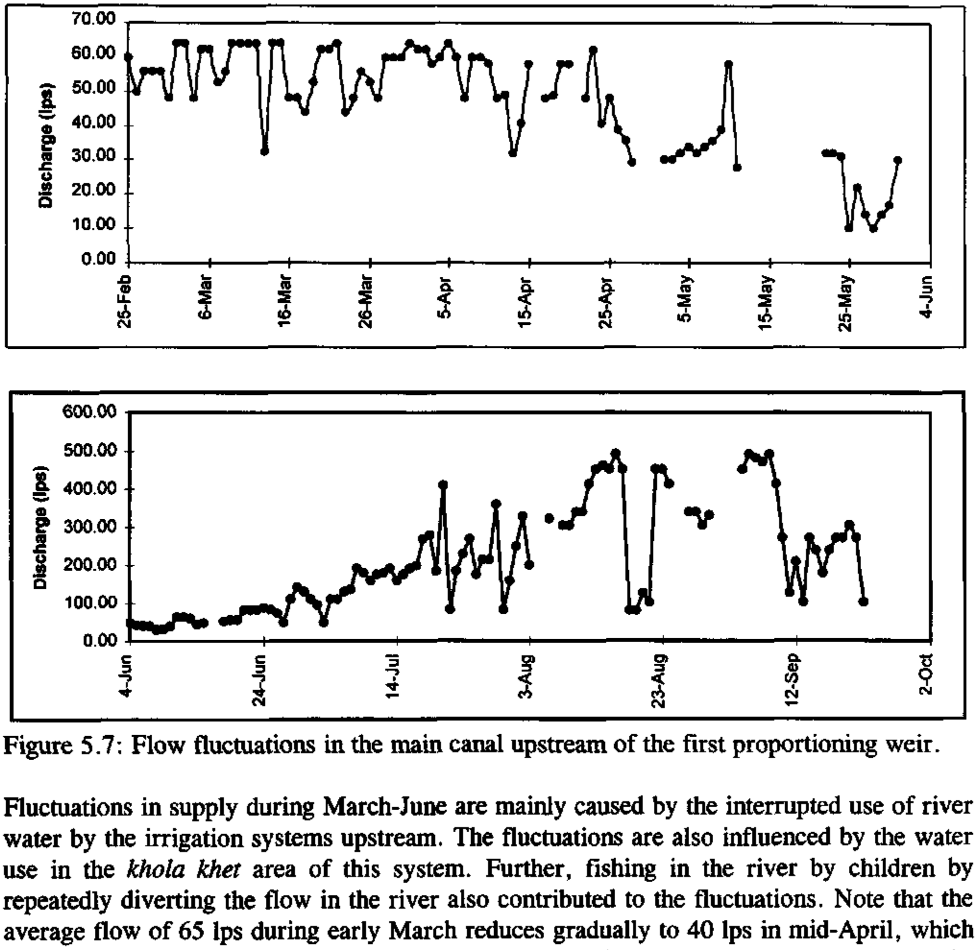

Figure 5.7: Flow fluctuations in the main canal upstream of the first proportioning weir.

Fluctuations in supply during March-June are mainly caused by the interrupted use of river water by the irrigation systems upstream. The fluctuations are also influenced by the water use in the *khola khet* area of this system. Further, fishing in the river by children by repeatedly diverting the flow in the river also contributed to the fluctuations. Note that the average flow of 65 lps during early March reduces gradually to 40 lps in mid-April, which further reduces quickly to 30 lps towards the end of April. This quick flow reduction is the result of increased use of river water by the irrigation systems upstream as well as by the *khola khet* to irrigate maize. From the end of April to mid-June, the average canal supply remains between 10 and 30 lps (only for 12 hours).

Flow in the main canal gradually increases from mid-June onwards with the start of pre-monsoon, and reaches its peak during monsoon (July-August). Note that the flow fluctuation is quite high during this period. Peak flows are caused mainly by intensive rains in the watershed. Such peak flows frequently damage the intake. Both intake damage and the flow fluctuation in the river have contributed to the variations in the water supply into the main canal. The sharp decrease in the flow immediately after the peak flow of more than 400 lps is mainly due to the closing of the main canal.

Farmers fear that a high flow beyond 400 lps may damage the canals, terraces constructed in steep slopes and houses located in the *phant* along the main trail parallel to the main canal. It has been observed that during intensive rains, if the water supply increases in the canal, some farmers living nearby gather to close the canal at Bunge Khola even at night.

The upper limit of the flow which the system can bear is judged by the water depth in the canal with respect to a stone on its bed, known as *jaisi dhunga*, located at chainage 1,150 m. This stone is close to the village and the canal at this point is aligned along the main trail. Whenever farmers feel that the flow in the canal is high, they check the water depth in this stone. If the water level in the main canal overtops the *jaisi dhunga*, the canal is closed immediately for the safety of the *phant*.

5.5.3 Water allocation

The *khola khet* area has the first priority to use irrigation water because of its location, though the *phant* is the main irrigated area. Water allocation in the *khola khet* area is made on a demand basis irrespective of the crop grown. All farmers have access to water either simultaneously or as and when needed.

As discussed earlier, ungated simple turnouts distribute water to the *khola khet* area on continuous basis during the cultivation of paddy. Farmers themselves control and regulate the flow through turnouts. The amount of water to be diverted from a turnout is decided by the individual farmers considering both the crop's need and terrace stability. For non-paddy crops, farmers divert water as and when needed.

After fulfilling the need of the *khola khet* area, the remaining water which enters the *phant* is systematically allocated to every farmer. The allocation and distribution of water discussed hereafter is mainly concerned with the *phant* (main irrigated area).

The exact basis of water allocation in the *phant* is not known. However, farmers believe that, in the past, water was allocated in proportion to the irrigated area (*mato muri*[45]) - each farmer entitled to irrigate with respect to the total irrigated area of the system[46]. For example, a farmer having a certain percentage of the irrigated area (with respect to the

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[45] *Mato muri* is a traditional measure of land. It is a production-based unit. *Mato* means soil and *muri* is a measure of foodgrain in terms of volume. For paddy one muri equals approximately 50 kg. An area of land capable of producing one muri of paddy was designated as one *mato muri* of land.

In most hill irrigation systems, where water is allocated based on the land area, the water share is also sometimes designated as *mato muri*. For example, one *mato muri* of water is that share of water which is allocated to one *mato muri* of land. In Bachcha, the water which enters the main irrigated area is also designated as 2,100 *mato muri*, this is because this water is to be allocated to the total irrigated area of 2,100 *mato muri*.

Mato muri as a measure of land is no longer used in practice. This is because there is considerable uncertainty on to what extent it represents the present land area and production of paddy. The reason is, for the past several years, the areas designated as certain *mato muri* consisting of a few terraces were reshaped by merging a few terraces into one. The terraces which were reshaped and improved represented a larger area as well as production, whereas the terraces which were further degraded represented a lower area as well as production.

[46] An analysis of the water allocation in smaller area indicates that water allocation also depends on the type of *khet* land. For example, in Dui Saya Ko Khanda (sub-block), *khet* having a spring source are allocated less water than the *khet* having no such spring source (Table 5.3). Also, there are some considerations for the size of terraces. The two bigger terraces, namely Chole Garha (0.2 ha) and Tile Garha (0.1 ha), have the allocation of the entire system water, if required, for the transplantation of paddy. This is because big terraces require larger flows for paddy transplantation and, in this system, once transplantation is started it cannot be stopped unless the transplantation in the whole terrace is completed.

total system area) would receive the same percentage of the total water available on a time-share basis.

This allocation principle was fixed long ago. Over time, many farmers have extended their irrigated land by converting the adjoining *bari* into *khet*[47]. Such new *khet* are known as *biraute*. From the point of view of water allocation, the old *khet* having the original water right is known as *pakhat*. Since there is no water allocation for *biraute* for cultivating paddy, farmers started irrigating their *biraute* using the water allocated to their *pakhat*. The area of *biraute* differs from farmer to farmer. Because of this, the present water allocation does not match with the total irrigated area (*biraute* and *pakhat*) of each farmer. Table 5.3 shows these differences. Those who have no *biraute* have a relatively high allocation and those who have larger *biraute* have a lower water allocation per unit of the total irrigated area. There are no farmers having only *biraute*.

This discrimination of water allocation between *biraute* and *pakhat* exists only during paddy cultivation, especially after the completion of paddy transplantation in the system. During paddy transplantation, water is allocated with respect to land. The mode of allocation is as per turn, which is decided based on supply, land area to be transplanted and the standing crop. During this time there is no recognized denomination of water. The basis of allocation is that all *khet* land should get enough water for transplantation.

The principle of water allocation for wheat crop (during winter) is as per demand and for maize (during spring) with respect to land. The mode of water distribution for maize is as per fixed order (farmers take turn to get water).

5.5.4 Water distribution

Water distribution is a very contentious activity because it is the final distribution of benefit of an irrigation system. The pattern of water distribution differs with the crop; it even changes within a cropping period.

For the cultivation of paddy, water distribution starts with the preparation of wet seed-beds around the third week of May and continues up to the second week of June. Paddy seed-beds do not require much water, and farmers irrigate their fields as required.

Paddy transplantation starts during the fourth week of June in *khet* where only two crops (paddy-fallow-maize) are being grown, and continues up to the last week of July in *khet* where three crops (paddy-wheat-maize) are being grown.

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[47] Because the land area in the *phant* was designated as 2,100 *mato muri*, this area was capable of producing 2,100 muri of paddy (equivalent to about 105 metric ton). The present yield of paddy is about 3.25 t/ha (Table 5.1). Thus, the present average total production of paddy in the *phant* (area: 47.3 ha, excluding *khola khet*) comes out to be about 153 metric ton. This implies an increase of 45 per cent in the total paddy production. Part of this increase may have been caused by the intensification of agriculture, while part of it seems to have been caused by the increase in the irrigated area through the conversion of the *tar* scarp and merging/reshaping of a few terraces into one.

Also, on the basis of a few known land areas in Bachcha, one hectare is approximately equal to 63 *mato muri*. This means the present *mato muri* of the *phant* is about 2,979, indicate an increasing of 41 per cent in the total land area.

In this system, paddy cultivation requires two types of water[48]. They are: water for puddling (land preparation) and water for maintaining the required water depth in the *khet* after transplantation. The pattern of water distribution therefore differs during and after paddy transplantation.

At an early stage, transplantation is easily performed with the canal water. The peak period of the transplantation is usually associated with the monsoon rain. With the monsoon rain and the canal water, transplantation proceeds very well and the competition to use canal water reduces, thereby minimizing water-related disputes.

As transplantation proceeds, all secondary canals run continuously. The amount of water to be diverted into secondary canals is decided in relation to the number of pairs of bullocks used for transplantation in each secondary canal. This is because bullocks are used to prepare land for paddy transplantation, and each pair of bullocks needs a certain amount of flow for puddling. Thus, increasing the number of pairs of bullocks in one secondary canal necessitates the flow to be increased. Flows in each secondary canal are adjusted with the help of stones and mud at their intake in the main canal. Visual estimate is the basis to judge the adequacy of water supply to operate the said pairs of bullocks. Within a secondary canal, water is further divided into a few field channels on the same principle.

During the day, water demand for transplantation gets the first priority followed by the demand for already transplanted paddy. However, during the night, water is exclusively distributed to fields that are already transplanted with paddy. No definite rotational schedules for night irrigation were observed. Within one's holding, field-to-field irrigation is practised. Usually, farmers transplant the upper terrace before the lower terraces. To transplant the lower terrace, farmers allow the water to flow through the upper terrace so that water demand of the upper terrace is also automatically met.

During paddy transplantation, a task force[49] is formed to fix the turns of transplantation and to manage water distribution in all the secondary canals. Farmers who need water for transplantation on the following day have to report to the task force. Every evening, farmers gather at a common place–around a teashop or at the house of the *adhyakchhya*–to

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[48] Although continuous submergence is desirable throughout the growing period, there is a saying that if three crucial water requirements: *maad paani*, *goad paani*, and *choad paani* are fulfilled with occasional wetting of soil in between, paddy yield would not reduce much. *Paani* means water. After puddling and transplantation, water which remains in the field is known as *maad paani*. *Maad paani* should remain in the field at least for seven to ten days so that the earth does not crack and healthy growth of paddy seedlings is secured. This means that irrigation after transplantation is very important to maintain the standing water (*maad paani*) in the *khet*. The standing water which should remain in the field after weeding (which is performed between tillering and head development stage of plant growth, about 30 to 40 days after transplantation), is known as *goad paani*, and is the second crucial water requirement. The third critical time is during grain formation, about 20 to 30 days before ripening. Water applied during this period is known as *choad paani*, which is essential to obtain uncracked rice grain, and to drive out mice from the field.

[49] A task force is an informal organization. Usually, a few socially active persons who have experience, leadership quality and who can convince farmers lead this organization. Such a task force is formed automatically and usually the same group of people manages water distribution every year.

evaluate the transplantation activities of that day and to decide about water distribution for the next day. Priority to use water is given to those farmers who have not even transplanted a single terrace. Although there are no written rules and regulations for water distribution during this period, it is socially accepted that all farmers should get enough water for transplanting their paddy; land belonging to all farmers should be transplanted almost in the same order; and all land should get transplanted. Minor disputes regarding water distribution are settled by the farmers mutually. Major disputes, if any (not observed during 1996), are solved by the *adhyakchhya*. Past records and interviews with farmers suggest there were no major disputes for many years.

This implies that equity in water distribution is judged on the basis of actual need, which is very much subjective. Together, this perception of equity, the diversified and interrupted water demand, and the erratic supply in the main canal necessitated a higher flexibility in water distribution, which in turn necessitated higher organizational and institutional inputs to distribute water and to resolve disputes during paddy transplantation. The formation of task forces in all secondary canals is the result of this. Also, minor disputes are the results of subjective measures of equity and subjective decisions made by the task forces (based on visual judgement) to achieve higher flexibility.

Once paddy transplantation is completed, mono-water demand[50] prevails, which occurs simultaneously. The pattern of water distribution also changes accordingly. Proportioning weirs are then installed at key points of the main and secondary canals on the same day. The date for installing proportioning weirs is decided by the *adhyakchhya* in consultation with a few other farmers[51]. With the permission of the *adhyakchhya*, the *katuwal*[52] announces the date for fixing weirs in all villages. On the said date, experienced farmers install weirs while interested farmers gather and observe the weir installation. Levels of notches are checked by the depth of water over it, and interested farmers can check the setting of the weir.

Water distribution by proportioning weirs

Once water distribution by proportioning weirs start, the irrigation system becomes rigid. Farmers have hardly any chance of drawing more water than their shares. The task forces are no longer required as the system runs automatically without requirements to open or close, or to adjust structure.

With the installation of proportioning weirs, the principle of water allocation and the pattern of water distribution change. Farmers receive water corresponding to their water shares. Measure of equity and the general characteristics of a proportioning weir in distributing water are similar to those explained in Chapter 3.

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[50] Water requirement to maintain the required water depth in the *khet*.

[51] In 1996, transplantation of paddy was completed by 21st July, and proportioning weirs were installed on 25th July.

[52] The *katuwal* is a messenger. He is responsible for relaying all the communication in the village. The post of *katuwal* is hereditary. The system of *katuwal* probably started after the unification of Nepal. *Katuwal* were the members of the village administration. They used to get some land for their services. Although this system of *katuwal* has already been abolished, in Bachcha village it is still working. At present, the *katuwal* gets some paddy from each household for his service.

There are three proportioning weirs located at different points of the main canal to distribute water to the four secondary canals on continuous basis. These secondary canals irrigate four different blocks. Depending on topography, each block is further divided into smaller sub-blocks with the help of smaller proportioning weirs installed on the secondary canals. The schematic layout of the irrigation system with proportioning weirs and their water shares are given in Figure 5.8

The first proportioning weir, known as Mul Gaav, has four notches delivering water to four secondary canals below. Usually, parallel canals, running almost at the same elevation for some distance, are found where proportioning weirs of multiple notches are used. Configurations of such canals occupy considerable land. This is a major disadvantage of having a proportioning weir (Ambler, 1990). But, in this system, farmers have tried to overcome this disadvantage by diverting water from one notch to the respective secondary canal below, and the water from the remaining three notches are rejoined again into a single canal for further distribution downstream. A similar method has been adopted in the remaining proportioning weirs.

Re-combining the canals again requires additional proportioning weirs (control points) for further distribution. Although this method increases the number of control points on the main canal, it avoids the parallel canals to minimize the land required. In a system like Bachcha, bigger canal width would not be possible due to topography.

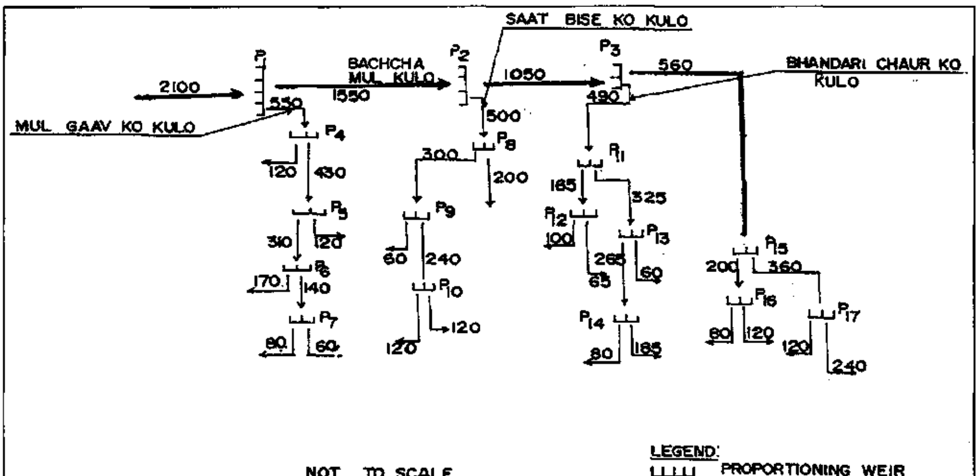

Figure 5.8: The schematic layout of the irrigation system with proportioning weirs and their water shares.

Figure 5.8 also shows the total incoming water for the Mul Gaav. This is considered to be 2,100 *mato muri*[53]. The right corner notch (along the flow direction) delivers 550 *mato muri* of water to the first secondary canal, Mul Gaav Ko Kulo. Water from the remaining three notches–total of 1,550 *mato muri*–is conveyed by the continuing main canal for further distribution through the second and third proportioning weirs.

Although the ratio of notch widths to the respective water shares should be the same for proportional distribution, its value varies up to 10 per cent[54] (Table 5.2). Occasional measurement of flow by current-meter in the branching canals of the first proportioning weir also shows variation of about 10 to 15 per cent.

Accuracy in water distribution (fabrication and installation of proportioning weirs) depends on the supply and demand situation. In a system with limited water supply[55], farmers are more concerned about the accuracy[56] of water distribution. This system has an average supply of about 250 lps[57]; farmers are not much concerned about the accuracy in the design and installation of proportioning weirs. The rotational schedule, fixed with reference to the sunlight, among sections within a sub-block (discussed later in this section) also verifies this.

This raises the question: Why do the farmers of Bachcha use proportioning weirs even when the supply exceeds the demand? Water is an important input for the cultivation of paddy and usually would not be in surplus if it is not regulated either institutionally or physically. In this system, the conversion of *bari* into *biraute* has created new demands for water, which vary greatly among farmers. Also, due to the high rate of seasonal migration, many farmers may be unable to defend their water right if someone tries to steal water. In such a situation, without defined arrangements for regulation, free riding over the use of water can take place. This will result in wastage in one part of the system and shortage in another, which may ultimately lead to disputes. The proportioning weir, as a physical device, helps to minimize such disputes by regulating the water available in accordance with the socially-accepted norms. This implies that proportioning weirs in Bachcha are not just installed to distribute the water shares correctly but also to reduce possible inequalities in water distribution that would occur without this device.

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[53] Many farmers say that the total water share at the first proportioning weir is 2,200 *mato muri*. However, repeated computation (after inquiring with many experienced farmers) of water shares of all farmers amounts to only 2,100 *mato muri*. This is because farmers do not have written records of water shares and most farmers do not remember the water shares of others. The other reason for this discrepancy may be the amount of water diverted through an orifice into the Halo Kulo which is not clearly-defined. The water share of this Kulo is taken as 40 *mato muri*, and it is not known whether it is included in the total water share. If this water share (40 *mato muri*) is added, the total water share becomes only 2,140. For the purpose of analysis here, this water share is not included.

[54] It has also been observed that the sill levels of notches vary up to 12 mm.

[55] Systems with average incoming flow less than that required under normal conditions are here termed as limited water supply.

[56] An example is Sankhar Irrigation System, discussed in Chapter 6, where the proportioning weirs are fabricated and installed with greater care, and farmers are very much concerned about their accuracy.

[57] This gives a water allowance of 4.9 lps per ha compared to the average designed water allowance of 3 lps per ha in the hills.

Note that farmers do not use proportioning weirs in a low supply condition. In a low supply condition, farmers adopt rotational water distribution[58] because rotational distribution can potentially save 20 to 50 per cent water in comparison to continuous distribution (Chow, 1960). Proportioning weirs are used only when the supply available is sufficiently high. Farmers make the best use of this high flow by distributing it continuously up to a smaller area to reduce the organizational and institutional inputs. However, where controlled entry of flow into terraces is prime consideration rather than the distribution of the water available, proportioning weirs are not likely to be used even in an excessive supply condition because of their fixed control characteristics.

This implies that distributing water by proportioning weirs would be viable only if the available supply is more than the supply required under normal condition. Empirical evidences in Nepal show that proportioning weirs are used only when the available water allowances remain between 2.5 and 6 lps per ha.

Timed rotation within sub-block

Within a sub-block, timed-rotation is practised. To manage timed-rotation, each sub-block is further divided into four semi-autonomous sections with equal water shares irrespective of the irrigated area. The number of farmers in a section varies between two and eight, and they are of a homogeneous group. In many sections, farmers are even related by blood to each other. The average flow into these sub-blocks during paddy cultivation varies between 5 and 20 lps.

As water distribution tasks are devolved among users within a section, the mode of distribution varies greatly between sections. In some sections, water is further distributed according to time-shares of individual farmers within their section time. However, in the section observed, water is distributed according to the fixed order irrespective of landholding and individual farmer's share. Table 5.3 shows the number of farmers, water shares and average area in various sub-blocks served by proportioning weirs in a secondary canal, Saat Bise Ko Kulo.

[58] Ambler (1989) notes that proportioning weirs (in main and distribution canals) are most likely to be viable in a low supply condition. His indicator of water availability (high, low, or medium), based on interviews with farmers, crop choice and crop intensity are very much subjective. Therefore, his results are inappropriate here.

Table 5.3 Number of farmers, their water shares and irrigated area in sections of various sub-blocks in Saat Bise Ko Kulo.

Sub-blocks	Sections	No. of farmers	Farmers' Water Shares (*mato muri*)	Total Irrigated Area (*ropani*[59])	Remarks
Dui Saya Ko Khanda	1	2	55	17.0	Spring source, *pakhat*
	2	6	55	18.5	Spring source, *pakhat*
	3	6	45	16.0	*pakhat*
	4	8	45	24.0	*pakhat* and *biraute*
Sub-total		**22**	**200**	**75.5**	
Saathi Ko Khanda	1	2	15	11.0	*pakhat* and *biraute*
	2	2	15	11.0	*pakhat* and *biraute*
	3	3	15	13.0	*pakhat* and *biraute*
	4	3	15	5.0	*pakhat*
Sub-total		**10**	**60**	**40.0**	
Keti Chaur Khanda	1	4	30	10.5	*pakhat*
	2	4	30	8.0	*pakhat*
	3	5	30	10.0	*pakhat*
	4	7	30	13.0	*pakhat* and *biraute*
Sub-total		**20**	**120**	**41.5**	
Musikot Khanda	1	2	30	10.0	*pakhat* and *biraute*
	2	3	30	8.5	*pakhat*
	3	2	30	7.0	*pakhat*
	4	5	30	10.0	*pakhat* and *biraute*
Sub-total		**12**	**120**	**35.5**	
Total		**64**	**500**	**192.5**	

Note: Sections in all sub-blocks receive water for 12 hours.

Every section receives water for 12 hours after every 48 hours. For simplicity, time to shift rotation (from one section to another) is not decided by watch but with reference to the sunlight. The section time starts with the sunrise and ends with the sunset. This means the section which receives water during night always receives water at night. The farmers receiving water at night said that they had no objection to this and rather desired it. According to them, water advances faster at night, and the flow is less disturbed by children and others. Also, all farmers do not have to be present in the field at night. In the evening, before the sunset, one or two members of the section having the turn divert the flow into the uppermost terraces of their sections. Irrigation is practised from terrace to terrace. Overflow from the upper terrace to the next lower terraces is designed in such a way that when the flow is diverted to the upper terrace, the entire section is automatically irrigated. Usually, all fields within a section is irrigated in one section time (12 hours). If irrigation is not completed, either they request the farmers of the next turn in the next section to wait for some time (1-2 hours), or they irrigate the remaining area in their next turn. A rotational schedule designed with respect to the sunlight implies that it is not very strict. Shifting of the rotational schedule for a few hours in close consultation among farmers is common.

At the later stage of paddy cultivation, the mode of water distribution changes. Continuous flow to all sub-blocks is no longer possible because of reduced supply in the main canal.

[59] One *ropani* is equal to 0.05 ha.

Proportioning weirs are then made defunct by removing stones placed below them[60]. At this stage, many *khet* which have springs and *khet* with paddy transplanted earlier do not need water. As such, competition for canal water is reduced. All secondary canals run continuously, and water is rotated among farmers within the secondary canals.

Water distribution during winter and spring crops

Water distribution during winter, especially for wheat, does not have any specified rules and regulations. It is because the water available is enough for the entire cultivated area. Farmers can irrigate their fields as and when required. Frequency of irrigation for wheat depends on winter shower. Usually two to three irrigations are enough for wheat cultivation.

This irrigation system experiences maximum water stress during the pre-sowing irrigation for maize[61]. During this period, the system gets water only for 12 hours at night. Because of the small flow, the entire water supply is rotated between the secondary canals. This system level rotation is known as *kulo palo*. During this period farmers in each secondary canal get water by turn. There is no fixed time share. Water from one farmer's field is diverted to another farmer's field only after the former has completed irrigation in his land.

In the first rotation, each secondary canal gets water for three nights, and irrigation follows from head to tail. Those farmers whose land is not ready for pre-sowing irrigation wait for the second rotation. It takes about 12 nights to complete the first rotation. In the second rotation, each secondary canal again gets water for two nights and irrigates those land which did not have irrigation in the first rotation. The second rotation lasts for about eight nights. In this way, it takes about three weeks to complete the pre-sowing irrigation. After the completion of pre-sowing irrigation, many farmers do not irrigate maize.

Although farmers in each secondary canal fix the irrigation turns themselves orally, the chairman of the irrigation organization remains busy allocating and re-allocating irrigation turns.

Except the *khola khet* area and some headreach land in the *phant*, the major portion of the land receives only pre-sowing irrigation for maize. This is because the flow during this period, which is available only at night, is too small to irrigate all maize. Farmers who need water have to go to the intake to divert water into the system in the specified time. Usually only headreach farmers do this and others simply wait for rain.

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[60] Proportioning weirs were made defunct on 25th September, 1996.

[61] For both maize and wheat, water is first applied by flooding the terraces prior to land preparation even though the soil is saturated. Reasons for flooding the terraces, which already are saturated, are not known. However, farmers believe that by doing so, plants are well-protected from insects and pests. After four or five days of such pre-sowing irrigation, land is brought into pulverized condition by ploughing them, which prepares them for sowing wheat/maize.

5.6 Conclusions

This case study has shown how farmers of Bachcha Irrigation System took into account various agro-ecological, socio-cultural and technical considerations in the design and management of the physical components, especially water distribution structures (proportioning weirs, fixed orifice and ungated turnouts), of their irrigation system. This has also illustrated that farmers are knowledgeable and capable actors, and can develop and manage socially and technically-sound irrigation systems by practical experience. Of the various agro-ecological considerations, land (altitude and topography), biomass (crop type) and water are the most important. Socio-cultural considerations include mainly the organizational and institutional arrangements, knowledge, and the population increase and out migration. Hydraulic control is the main technical consideration.

One of the prime ecological considerations for the choice of wooden proportioning weir is the altitude. Hard wood is required to construct a wooden proportioning weir. In Nepal, *sal* wood (*shorea robusta*) is used because of its higher resistance to rotting in water. However, availability of *sal* wood in the country is limited to an altitude of about 1,000 m. For this reason, wooden proportioning weirs are not seen in irrigation systems located at altitude above 1,000 m.

Topography is another important ecological consideration. It determines the availability of land for canals and its structures. In the hills, the land availability to construct a contour canal has always remained a constraint because of steep slope. The steeper the slope the smaller would be the canal width. By contrast, the overall width of a proportioning weir required, considering hydraulic parameters (designed flow and notch depth of weir), always tends to be much larger than the normal canal width. Distributing water by proportioning weirs would not become viable if these contrasting variables cannot be successfully negotiated in the existing land slope. The modified design of the proportioning weir in Bachcha is the outcome of this negotiation between these contrasting variables. Note that, unlike the standard proportioning weirs, it allows the water to flow over the entire body of the weir. A sharp-edged stone kept downstream of the weir helps to split the flow into two or more parts as needed.

Another example adopted by the farmers to match land constraint due to topography is the design configuration of canals. Parallel canals that are usually seen downstream of proportioning weirs are avoided by merging flows through two or more notches into a single canal for further distribution downstream. This minimizes the land required.

In an irrigation system, the shape of the irrigated area also determines the viability of distributing water through proportioning weirs. A long strip of land usually consists of single level of canal network, where the parent canal directly supplies water to individual fields. Under such a situation, the relative difference in the flow size between the parent canal and the offtake canal would be high. This restricts the viability of proportioning weirs.

This study also shows that the use of proportioning weirs in the main and lower order canals is found under mono-demand occurring simultaneously throughout the irrigated area, especially for the cultivation of paddy.

A proportioning weir is a fixed control structure. It distributes both low and peak flows in the same proportion. In any irrigation system where the entry of peak flows into terraces needs to be avoided to protect the crops and terraces, distributing water through proportioning weirs is not desirable. In such a system, proportioning weirs are used only at those points where the branching canals are capable of conveying their share of peak discharge without damaging the crops and terraces.

Continuous delivery of water down to smaller areas through proportioning weirs is viable only if the flow available is within a desirable range. The flow which is equal to optimal crop requirement conditions, is the lower limit of the desirable range. The upper limit is that flow at which the controlled entry of water into fields becomes the prime consideration rather than the distribution of the water available.

This study has clearly indicated that proportioning weirs help divide the irrigation system into semi-autonomous sub-systems, receiving their fair water shares. This in turn helps to devolve the water distribution tasks to farmers. Moreover, the water distribution task within the sub-system becomes simple because the area irrigated by each sub-system is much smaller with few farmers within. Since this system works automatically without requirements to open or close or adjust structure, organizational and institutional inputs required in water distribution are minimal. In such systems, resource mobilization for maintenance becomes the main objective of irrigation management. Because of several of its characteristics-visible distribution with reduced guesswork, being simple and understandable, being measurable by farmers with respect to others and giving equitable distribution–water-related disputes are minimum. This study also suggests that distributing water through a proportioning weir is viable if the available flow needs to be divided into two or more parts with respect to either the land area or the water shares.

6 Sankhar Irrigation System

6.1 Agro-ecological and social settings

Sankhar Irrigation System falls under the Sankhar Village Development Committee (VDC) in the southeast corner of Syangja district in the Western Development Region of Nepal[1] (Figure 1.2). There is no motorable road linking this area. It takes about 10 hours (hr) of walk to reach the system area from a place called Waling, off the Pokhara-Butwal Highway[2].

The Sankhar Irrigation System falls under the sub-tropical climate in the hills. The mean monthly rainfall varies between 6 millimetres (mm) in November and 489 mm in July. The average annual rainfall is about 1,768 mm. About 79 per cent of the rainfall occurs in the monsoon (June to September). Figure 6.1 shows the monthly variations in the rainfall, temperature and reference crop evapotranspiration[3].

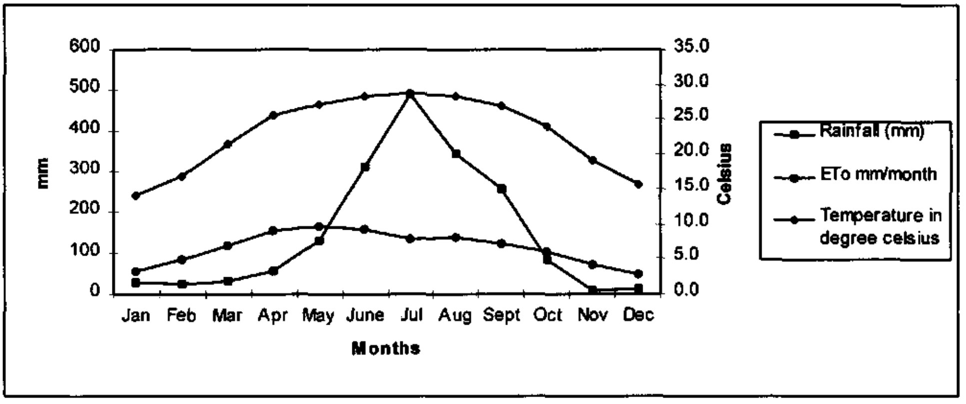

Figure 6.1: Monthly variations in rainfall, temperature and evapotranspiration.

Two parallel canals, known as Uppallo Mul Kulo and Tallo Mul Kulo, meaning the upper main canal and the lower main canal, irrigate about 37 and 8 ha of Sankhar village, belonging to 112 and 34 farmers respectively. This study concentrates mainly on the area irrigated by the upper main canal, referred hereafter as the Sankhar Irrigation System.

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1 The latitude and longitude of Sankhar Irrigation System are 27°52' north and 83°56' east respectively.

2 Recently, a fair weather road was constructed from a place known as Aryabhanjyang off the Pokhara-Butwal Highway to Rampur town in Palpa district. From Rampur it takes about two hours walking to the system area. Because of the unreliable bus service in the Rampur-Aryabhanjyang road, farmers still prefer to walk up to Waling to go to Pokhara or Kathmandu.

3 Data on rainfall and temperature were obtained from the nearest meteorological station (station number 810) located at Chapakot village (DHM, 1997; MacDonaldm *et al.*, 1990 M3). Data on reference crop evapotranspiration were obtained from the nearest agro-meteorological station (station number 815), located at Khairanitar village (MacDonald *et al.*, 1990 M3).

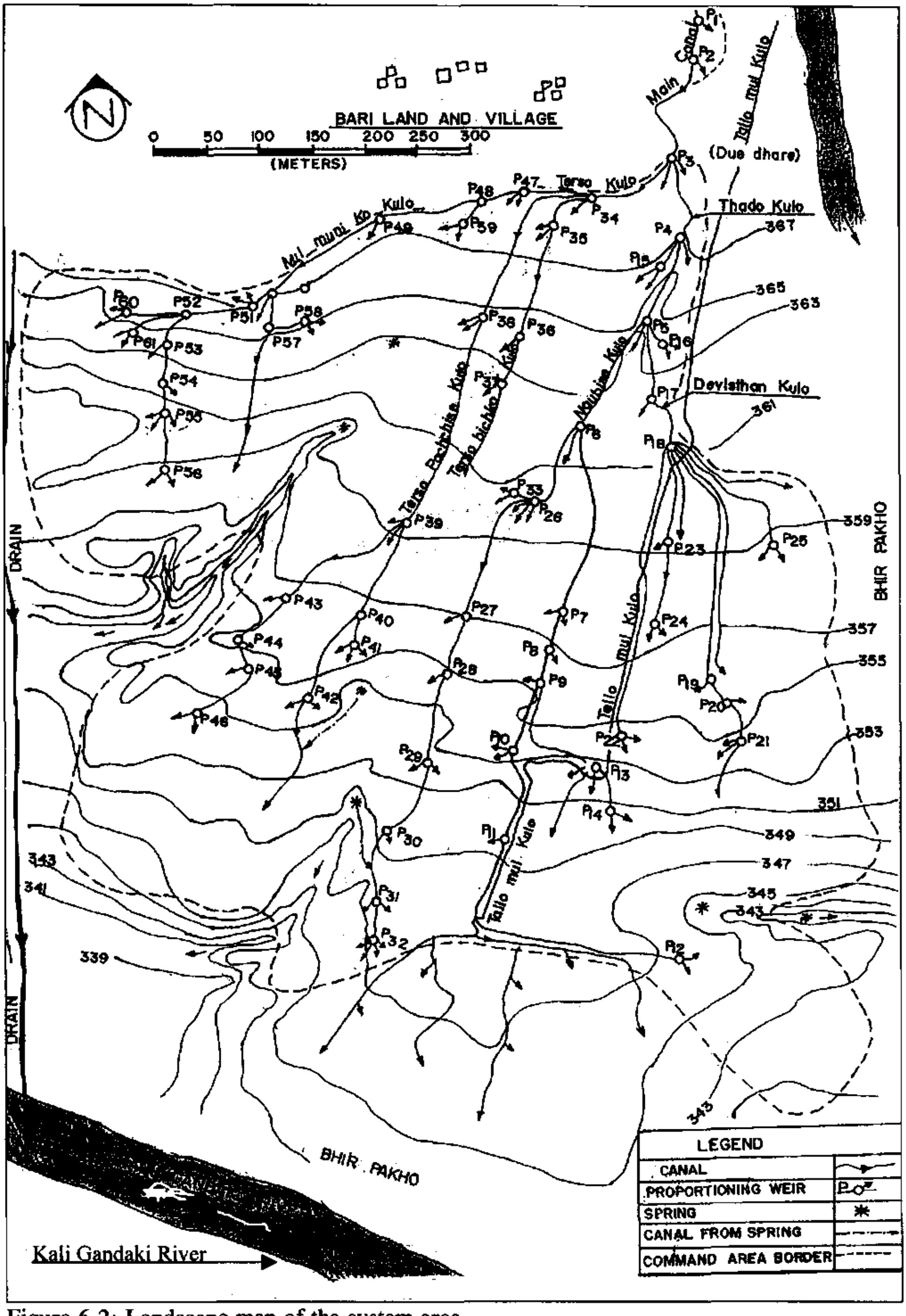

Figure 6.2: Landscape map of the system area.

6.1.1 Landscape

Figure 6.2 shows the landscape map of the area with system layout superimposed on it. The irrigated area (*khet*) is situated on the left bank of the Kali Gandaki River in a *tar* locally known as *phant*. In the *phant*, the canal is aligned along the contour from the uppermost terrace. The altitude of the *phant* varies between 343 and 367 metres (m) above mean sea level. It slopes from north to south. The average land slope is about 2-3 per cent. Because of its relatively flat land slope, the terraces here are much wider compared to those of the Bachcha Irrigation System. Except for a few, most of the terraces are bigger than 0.1 ha. The irrigated area is almost square shaped. The soils in the *phant* are of loam to clay loam types (locally known as *rato mato*). Except in a few depressions, the area is well-drained.

The land area connecting the edge of the *phant* and the river, referred here as *bhir pakho,* is almost sub-vertical. The area in the north at higher elevation than the canal is known as *bari*. The average land slope of the *bari* is the same as that of *phant*. Further north of the *bari*, the mountains rise steeply.

The area has a few natural depressions, which also provide drainage at the tail-end of the system. In most of these depressions, a few natural springs originate during the monsoon. These springs supplement water to the tail-end of the irrigated area. Flows from two of these springs merge with the flow in the main distribution network of this irrigation system.

The Keladi Khola in the east, the area irrigated by Tallo Mul Kulo in the south, *bari* in the north and a natural gully in the west form the system's boundaries.

6.1.2 Land use

The land use pattern is clearly dictated by the topography and the availability of irrigation water. Although water can be made available to *bhir pakho,* it is used mainly for the production of fodder trees, natural grasses and some rainfed crops. Because of unavailability of irrigation water, *bari* is used for homesteads and rainfed crops, though they are suitable to be *khet*. The land in the steeply rising mountains in the north is covered by a forest of *sal* trees with a girth as much as 2 m. The areas up in the high hills, known by several names like Maumi, Patsar and Danda, are referred to as upper villages. The majority of the farmers still have their homesteads and *bari* in the upper villages. It takes about one hour to reach the upper villages from the *phant*.

The *khet* in the *phant* are used mainly for the cultivation of paddy during the monsoon. In recent years, *khet* are also used for the cultivation of other winter and spring crops such as wheat and maize. These changes have occurred due to population growth and availability of new technology for crop cultivation.

6.1.3 Farming system

As in many other mid-hill areas, the farming system in this irrigation system comprises of cereal crops production (both in *khet* and in *bari*), livestock raising and agro-forestry.

Farmers predominantly practise subsistence agriculture. The principal cropping sequence in the *khet* is monsoon paddy-wheat-maize or spring paddy, whereas in the *bari*, maize, millet and blackgram are grown. Table 6.1 shows the area covered, cropping calendar, types of fertilizer used and average yield of main cereal crops cultivated in the *khet* in 1996.

Table 6.1: Area covered, cropping calendar, fertilizer used and average yields of main cereal crops.

Crops	Area covered in per cent	Dates		Fertilizer	Average yields (Tonne/ha)
		Sowing or transplantation	Harvest		
Monsoon paddy	100	Early July-mid August	Mid Nov-early Dec.	Both chemical fertilizer and compost	3.25-3.75
Wheat	100	Mid Dec-early January	Mid March-end of April	Mainly chemical fertilizer and little compost	1.0-1.2
Maize	85	Mid March-end of April	Early July-mid August	Mainly compost	1.2-1.4
Spring paddy	15	Mid March-end of April	Early July-mid August	Both chemical fertilizer and compost	3.5-4.0

Source: Field observation and household survey, 1996.

For all crops, farmers use improved varieties of seeds. However, the practice of replacing seeds from outside is rare. Seeds for all crops are either produced by the farmers themselves or procured locally. The rate of use of compost as fertilizer is maximum for maize, followed by wheat and paddy. Chemical fertilizer, pesticides and insecticides are frequently used.

Almost all households have one or two oxen, and/or one or two water buffaloes. Farmers living in the upper villages have more livestock than those living in the *phant*. In the *phant*, livestock is stallfed and fodder requirements are met primarily from the cultivated land.

All the agricultural activities are carried out by human labour and animal draught power. The household survey shows that the area does not have a labour shortage for agricultural activities. During peak hours of cultivation, especially during paddy transplantation and harvesting, usually exchange of labour is practised.

Division of agricultural tasks is clearly made between men and women. Ploughing the land, irrigating fields, threshing food grains, and preparing the land for paddy transplantation are usually performed by men. Weeding, harvesting, transporting compost, harvesting products, and all other domestic jobs are the responsibilities of women. Maintaining the irrigation system is the responsibility of men. However, a few women are also involved in this work. Unlike the agricultural tasks, there are no clear division of system maintenance tasks between men and women.

6.1.4 Landholding and land tenure

The average landholding per household is about 0.33 ha. The smallest and the biggest landholdings are 0.08 and 0.8 ha respectively. The majority of the farmers have only one or two parcels of *khet* in the irrigated area.

The common tenure arrangement[4] in this system is sharecropping, locally known as *adhiya*. In *adhiya,* the production is divided equally between tenant and landowner and it is applicable for all crops. Inputs such as seeds, chemical fertilizers, insecticides and pesticides are shared equally between tenant and landowner. The mobilization of labour to maintain the irrigation system is the sole responsibility of the tenant. When capital investment is needed to maintain the irrigation system, the landowner provides all the funds needed. The household survey shows that about 10 per cent of the farmers have rented their land to tenants under sharecropping.

Another tenure arrangement is *bandhaki*. In economic terms *bandhaki* is mortgage. The arrangements for *bandhaki* are similar to those explained earlier in the case study of Bachcha Irrigation System. The present rate of *bandhaki* in this system varies between Rs9,000 and Rs20,000 for 0.17 ha of *khet*. The household survey shows that about 7 per cent of the farmers have rented their land to tenants under the *bandhaki* arrangement.

6.1.5 The village and its residents

Although almost all the farmers have their homesteads and *bari* in the upper villages, the majority of them have started migrating close to the *phant*. The reasons are discussed in the forthcoming section. A few of them still live in the upper villages. In the *phant*, the settlement pattern is dispersed, and most houses are located in the *bari*. Except for a few cases, no houses are seen in the middle of the *phant*. Livestock is kept close to houses.

The total number of farmers and the average family size per household are 112 and 8 respectively. About 91 per cent of the farmers belong to the Brahmin ethnic group.

One high school and one primary boarding school are located in the *phant*. The area does not have any agricultural service centre. Other essential service centres like post office, health posts and VDC office are located in the upper villages. The nearest market for essential domestic commodities such as kerosene, sugar and fertilizers is Gandaki Dhick, which is located on the other side of the Kali Gandaki River in Palpa district.

6.2 Historical development

The original construction period of the Sankhar Irrigation System is not known. Farmers cannot recall the oral history of the system's construction. It is, however, believed that the system is over 150 years old. It is said that originally the system belonged to 52 farmers. The area was malaria-infested. For this reason, most of the farmers used to live in the upper villages.

[4] Verbal agreements are the basis for these tenure arrangements.

Oral history suggests that when the system was first constructed, it had its intake about 150 m downstream of the present intake. In those days, because of the vertical rock in the canal alignment upstream of the existing intake, farmers could not extend the canal further upstream. The diversion of water into the main canal was extremely difficult. This is because farmers had to raise the water level in the river for about 2 m to divert water into the main canal.

In the late eighteenth century, a farmer named Hanbir Rana Magar initiated the construction of a 125 m long tunnel upstream of the existing intake and extended the existing canal up to the present intake[5]. As a result, the diversion of water from the river into the main canal became simple as there was no need to raise the water level in the river. For this work, Hanbir Rana Magar was honoured by an allocation of 40 units of additional water shares. Although no evidence is available, some farmers believe that the present distribution of water rights among the farmers is based on the expenditure incurred by each of them in the construction of the tunnel.

In 1992/93, the government contributed about Rs1,100,000 to rehabilitate the irrigation system under the World Bank-funded Irrigation Line of Credit programme. In this programme, about 490 m of the main canal was lined with cement stone masonry.

The monsoon paddy used to be the only irrigated crop grown in the *khet* until the early 1960s implying that the irrigation system was mainly meant for the cultivation of paddy. During the rest of the period, the area used to remain fallow. In the late 1960s and the early 1970s, Khairani Agricultural Extension Centre introduced wheat and maize in the area. Accordingly, farmers started cultivating winter and spring crops in the *khet*. Table 6.2 shows the chronological development of agriculture in the area.

Table 6.2: Chronological development of agriculture in the area.

Period	Cropping pattern	Remarks
Early 1960s	Monsoon paddy-fallow-fallow	No fertilizers were used. The irrigation system used to operate only in the monsoon
Late 1960s	Monsoon paddy-Wheat-fallow	Farmers started using chemical fertilizers
Early 1970s	Monsoon paddy-Wheat-Maize	Irrigation system started operating round the year. Use of chemical fertilizers continued to increase
Early 1980s	Monsoon paddy-Wheat-Maize or Spring paddy	Use of chemical fertilizers decreased. Farmers started applying more compost to the *khet*

With the introduction of the winter and spring crops, cropping intensity in the *khet* started increasing. Consequently, the demand for agricultural labour and compost for fertilization increased. It became harder for farmers to manage the increasing agricultural activities in the *khet* by living in the upper villages. Slowly, farmers started migrating near the *phant*.

[5] Farmers believed that Mr Rana Magar was further supported by the *chautariya* family to construct the tunnel. *Chautariya* is a title given to relatives of the royal family. In 1859, in Kathmandu, the Rana family of hereditary prime ministers took over the power from the existing royal family. This political event is well-known as *kot parba*. After the *kot parba*, many relatives of the royal family who did not support the Ranas were exiled from Kathmandu. The *chautariya* family of the Sankhar Irrigation System is one such group of relatives of the royal family. In those days, a *chautariya* family was authorized to collect land taxes from certain areas as an allowance for themselves.

This process is still continuing. At present, about 30-40 per cent of the farmers still live in the upper villages.

6.3 The physical system

Sankhar Irrigation System is a slope-hill irrigation system, and irrigates about 37 ha of cultivated land. The source river, intake, main canal and the distribution canals are the main components of the physical system.

6.3.1 Water source

The Keladi Khola, a perennial river, is the main source of water for the system. It is a tributary of the Kali Gandaki River and flows from north to south. It has a single and defined flow channel. The average overall width of the river at the diversion point is about 6 m, and the average river gradient is about 4.5 per cent. The river has a series of natural vertical drops made of rock outcrops.

This is a small stream with catchment area of about 6 sq km. During the winter season (December-January), the river discharges an average flow of about 90-100 lps, which gradually reduces to about 30-40 lps during the spring season (April-May).

In the monsoon, the flow in this river virtually depends on the rain. This is because the river base flow[6] is basically supplemented by the seasonal springs in the catchment, which trigger only after the start of good monsoon rain. Once these springs trigger, the base flow in the river increases. In some rivers, relatively short dry spells during the monsoon lead to reduction in the spring flows, which in turn reduces the river base flow. However, interviews with farmers suggest that once most of these springs trigger, the river continues to discharge the increased base flow even with a relatively long dry spell. Figure 6.3 shows the flow fluctuations in the river during the monsoon superimposed with the monsoon rain.

Note that with the start of the monsoon rain in mid-July, the river base flow increased to about 150-250 lps. Since there were no successive rains after the first few rains in mid-July, most of the springs could not trigger. This has resulted in the reduction of the base flow to less than 100 lps in a period of 10 days. In 1996, good monsoon rain started only in mid-August, which helped in triggering all the seasonal springs in the catchment. Consequently, the river base flow increased to about 350 to 400 lps. The river maintained this base flow till the end of September, which gradually reduced to about 90-100 lps during the winter season.

[6] Because of its small catchment area, the peak flows resulting from the rain in the catchment last only for a few hours.

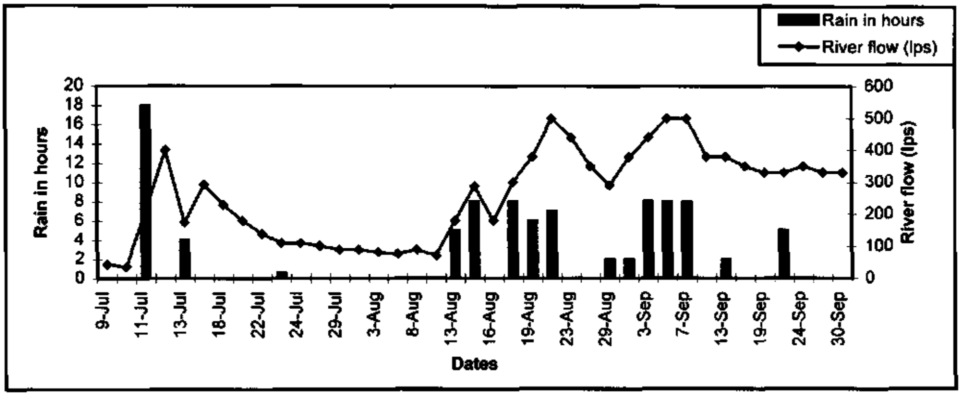

Figure 6.3: Flow fluctuations in the river superimposed with the monsoon rain.
Source: field measurement in 1996.
Note: This figure excludes some of the peak flows which are usually higher.

The Keladi Khola also supplies water to Tallo Mul Kulo, which has its intake located about 250 m downstream of the intake of Sankhar Irrigation System. During the cultivation of the monsoon paddy, both the systems share water at the intake. However, during the spring season, all river water is diverted to Sankhar Irrigation System. The reason is, during the spring season, the flow in the river is too small to be divided. During the rest of the period, the river has enough flow to supply water to both the systems.

6.3.2 Intake

The Sankhar Irrigation System has a very simple form of intake (Figure 6.4). It has two components: a temporary diversion weir and a side intake. The temporary diversion weir is constructed along the crest of a vertical drop, about 2 m deep, in the river. The vertical drop is made of natural rock outcrops. The diversion weir simply diverts the flow into the side intake without the water level in the river being required to raise even in the low flow. The length of the diversion weir is about 3.5 m and the height about 30 cm, which is equivalent to the depth of flow in the side intake.

The side intake simply consists of an unregulated opening constructed by excavating the rocks on the river bank. About 5 m downstream of the side intake, a 125 m long tunnel starts. A vertical trashrack made of gabion wire has been placed at the inlet of the tunnel to prevent debris from entering into it. Immediately upstream of the tunnel, a side spillway type of escape has been constructed simply by cutting the canal bank. The crest level of this side spillway has been adjusted in such a way that during high flow, controlled flow enters the tunnel. A bottom escape made of cement stone masonry has been constructed downstream of the tunnel where the flow into the main canal is regulated.

The temporary diversion weir needs to be maintained only during the low flows. During the rest of the period, the intake operates continuously. To close the flow in the tunnel, especially during the maintenance period, a temporary earthen embankment is constructed across the side intake.

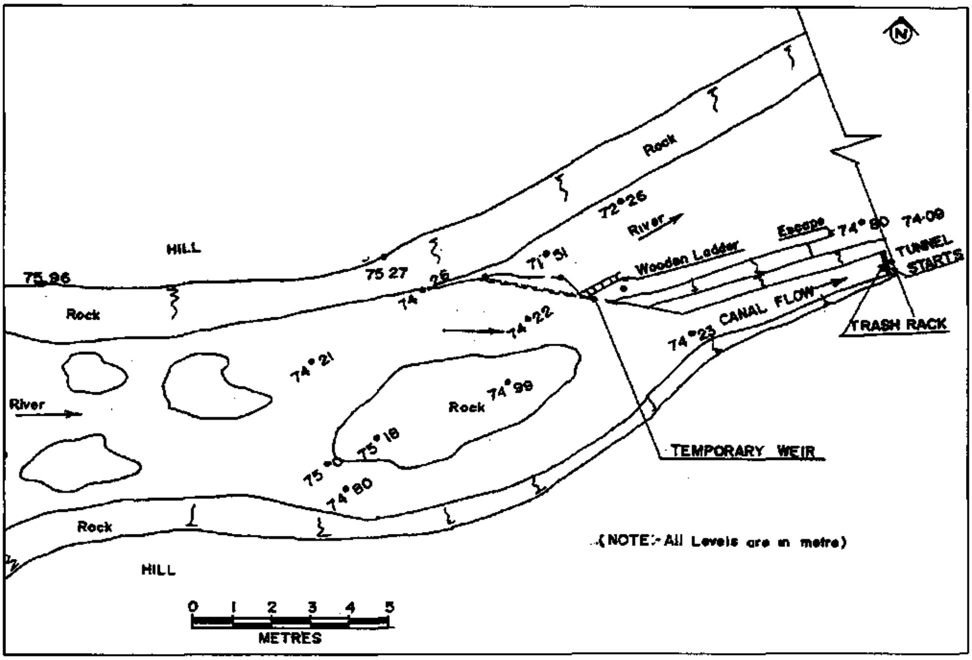

Figure 6.4: Layout of the intake.

Since the whole intake configuration has been constructed on rocky foundations, it is very stable and the intake is virtually free of maintenance.

6.3.3 Main canal

As in many other irrigation systems where the nomenclature of the canal is based on the rights and responsibilities of its users, in this irrigation system, the canal which is common to the majority of the farmers is termed the *Mul Kulo*, meaning the main canal. The main canal starts from the intake and ends at the main proportioning weir, P3, known as Dui Dhare. At this point, the main canal bifurcates into four branches, each having its own set of rights and responsibilities attached to particular users' groups.

The main canal is a contour canal, with an average gradient varying between 0.1 and 0.8 per cent. Its total length is 1.359 km. The average width and depth of the main canal are about 1.0 and 0.5 m respectively[7]. The main canal is aligned across a fairly stable hill slope varying between 20 and 30 per cent.

The main canal has three tunnels whose total length is 144 m. It has three escapes and two small cross drainage structures. About 43 per cent of the main canal is lined with cement stone masonry. The main canal also supplies water directly to two individual farmers through two proportioning weirs, P1 and P2, which are located upstream of the main proportioning weir, P3.

[7] The average maximum flow depth at flatter sections of the main canal is about 0.2 to 0.3 m.

6.3.4 Distribution canals

Other than the main canal, the irrigation system has two branch canals, known as Thado Kulo and Terso Kulo, 12 distributor canals and a large number of field channels (Figure 6.2). Any canal belonging to an individual farmer is termed here as a field channel. The average density of canals down to the field inlet (terminal points of proportioning weirs) is about 182 m per ha compared with the FAO-recommended value of 50 m per ha[8] for good water control.

Except for the Terso Kulo, all the canals are aligned down the hill (across the contour) and irrigate land on both their sides. The distribution system is designed for a continuous flow regime for cultivating the monsoon paddy. This means that the capacity of lower order canals is smaller than that of higher order canals.

Other than the distribution canals, the most striking features of this system are the indigenous wooden proportioning weirs installed at all the canal bifurcation points to distribute water continuously to all users, especially during the cultivation of the monsoon paddy.

6.4 Water distribution structures

The Sankhar Irrigation System uses mainly two types of water distribution structures, namely fixed proportional (proportioning weir) and open-close structures. The choice of distribution structure differs with the cropping season irrespective of the crop grown. During the monsoon season, proportioning weirs are used in all the canal bifurcation points to divide water, whereas during the spring season, the use of proportioning weirs is limited to higher end of the distribution system. At the lower end, the open-close type of distribution structure is used. Note that paddy is cultivated in both the monsoon and the spring seasons. Thus, the system functions as a fully proportionate one during the monsoon season, while during the spring season, it functions as a partially proportionate one.

6.4.1 The proportioning weir

The design considerations and the management aspects of a proportioning weir have been discussed earlier in Chapter 3. This irrigation system has 61 such proportioning weirs made of timber. Appendix VIII shows the principal physical features of these weirs.

In this system, the maximum width of the proportioning weirs observed is about 7.3 m, in Dui Dhare. The minimum is about 1 m with two notches in it. In many places, branching canals are nested together in a single proportioning weir. As a result, series of parallel canals are observed downstream of such proportioning weirs. Several of them even cross one another by means of wooden flumes. By nesting several branching canals in a weir, the number of control points reduces. However, the land area required to construct such parallel canals increases, which is considered as one of the disadvantages of distributing

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8 Cited by Ambler (1989).

water through proportioning weirs. In this system, constructing such parallel canals became possible because of relatively flat topography. In this system, the maximum number of notches in a proportioning weir is 12 with seven parallel branching canals downstream of the weir.

The three proportioning weirs, P1, P2 and P3, are installed before the start of paddy cultivation in the spring season and continue functioning till the monsoon seasons. The rest are installed only during the monsoon season.

Installation of a proportioning weir involves fixing the crest of the notches at the same level (setting) and sealing the holes below the weir in order to allow water to flow through the notches. Those who are interested can check the setting of the weir at the time of its installation. Once it is installed and agreed by the farmers present, others cannot question its accuracy. Most of the weirs are installed by the farmers concerned. However, the best local carpenter in the area installs the main proportioning weir, Dui Dhare.

The main proportioning weir, Dui Dhare, is installed on the last day of the regular system maintenance. A special procedure is followed for its installation. First, the weir is installed roughly with the help of an ordinary pipe level based on the principle that water finds its level. After roughly installing the weir, the flow in the canal upstream of the weir is blocked for a few minutes till the area immediately upstream of the weir completely dries up. Then the holes below the weir are sealed and a small flow is released from upstream where it was blocked before. The small flow then slowly fills up the area immediately upstream of the weir and all farmers watch to see at which points of the notches water enters first. The higher patches of the notch crest where water enter last are marked by the local carpenter, which are then lowered using a hand plane. The process is repeated till the water enters through all the notches at the same time and all farmers present are satisfied. In 1996, this process took about two hours.

6.5 System operation

6.5.1 Organizational and institutional arrangements

The system has a single-tiered irrigation organization led by a chairperson, known as *akhtiyar*[9]. Other than the *akhtiyar,* the organization does not have any executive member. The rest of the farmers are the general member of this irrigation organization. The *akhtiyar* makes all minor decisions in consultation with a few other farmers. The major decisions, however, are taken in the general assembly.

Usually, an influential person is elected as an *akhtiyar*. General consensus is the basis for this election. Once an *akhtiyar* is elected, he continues to work as long as he enjoys the trust and confidence of the farmers. The present *akhtiyar* is 75 years old and he has been leading this organization continuously since 1965. Farmers could remember four other *akhtiyars* who headed this irrigation organization before the present *akhtiyar*.

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[9] Literally, a person having authority to execute something is known as *akhtiyar*.

When the *akhtiyar* is first elected, a written authority signed by all the farmers is handed to him. (A translated version of this authority is given in Appendix IX.) The main function of the *akhtiyar* is to mobilize resources, especially labour, for system maintenance and repair. The *akhtiyar* has the right to block the water supply to those farmers who do not follow his instructions. The authority is renewed every year in the general assembly.

As in Bachcha Irrigation System discussed earlier, in this system too, in 1992, a formal irrigation organization was formed as a pre-requisite for the government assistance programme. The formal executive committee was formed with the *akhtiyar* as the chairperson[10]. At present, except for the *akhtiyar*, the executive committee is inactive. Apparently, the formal executive committee acted only as a construction committee during the period of intervention, though it is supposed to be responsible for the overall management of the system even after intervention. In this sense, the formal executive committee is defunct. At present, the *akhtiyar* manages the system as it used to be managed before intervention.

A general assembly is held once a year before the start of the regular system maintenance[11], which takes place before the cultivation of the monsoon paddy. The *akhtiyar* fixes the starting and the closing dates of the regular system maintenance according to the religious calendar. Farmers believe that by following the religious calendar, there will not be water shortage in the system. On the last day of system maintenance, worship of the goddess is performed at the intake[12]. Unless the worship is performed nobody can start paddy transplantation in his field. On that day, the majority of the farmers attend the system maintenance and worship.

6.5.2 System maintenance

Maintenance of the system involves desilting of the canals and tunnel, mudlining (mud plastering) of the porous areas of the main canal, strengthening of the canal banks and fixing of the main proportioning weir (Dui Dhare). Desilting of the tunnel and the fixing of Dui Dhare are performed on the last day of system maintenance.

The existing old records show that before the government intervention, from 8 to 20 days were required for the regular system maintenance with an average of 43 farmers working every day. This, however, reduced after the intervention. In 1996, a total of 315 farmers (person-day) were mobilized and the system maintenance was completed in five days.

Before the government intervention, women were not allowed to take part in system maintenance. During intervention, farmers were required to mobilize a large amount of

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10 The formal executive committee consisted of one chairman, one vice-chairman, one treasurer, one secretary and five members. This committee was formed according to the irrigation directives of the Department of Irrigation, 1989. This formal organization was registered with the District Administration office of His Majesty's Government of Nepal.

11 During 1996, the general assembly was held in early July.

12 In the worship, two goats are sacrificed. The *chautariya* families donate the goats; in return they do not have to contribute labour for system maintenance.

labour as their contribution[13], and it was not possible to exclude female labour resources. As a result, the rule of not allowing women in system maintenance was overlooked. Since then, women have also been allowed to take part in the regular system maintenance.

The basis of resource mobilization, especially labour, for system maintenance is with respect to farmers' water shares. At present, a farmer having 30 units of water shares needs to provide one labourer per day. A farmer having 15 units provides one labourer every alternate day. The *akhtiyar* keeps this record.

In this system, there is a rule to fine those farmers who do not report during the maintenance period at the rate of Rs30 per day per farmer. The *akhtiyar* collects such fines and redistributes it in the following year among all farmers corresponding to their water shares. The account is settled every year on the last day of the regular system maintenance.

During the monsoon season, four farmers are deputed per day to watch and repair the main canal and the intake as routine maintenance. The basis of labour mobilization for routine maintenance is with respect to household. Every day, this group walks along the main canal and performs minor maintenance of the canal. At the end of their duty, they fix a stick on the canal bank downstream of the first tunnel to prove their presence for routine maintenance. Any farmer who visits the intake can count the number of sticks to check the presence of the routine maintenance group.

6.5.3 Water acquisition

In Sankhar Irrigation System, water acquisition activity takes place to cultivate paddy during the spring (March-May) and monsoon (July-October) seasons. During the spring season, water acquisition is the responsibility of those farmers who have their irrigation turn. Such farmers maintain the intake and remove obstructions in the canal to acquire water[14]. However, during the monsoon season, water acquisition is a collective activity. The *akhtiyar* is responsible to acquire water from the source and deliver it to the irrigated area. For this reason, as mentioned earlier, every day a group of four farmers are deputed to watch and repair the main canal and the intake.

Flow in the main canal depends on the flow available in the source, which in turn depends on the rain, especially during the monsoon. Figure 6.5 shows the time series flow in the main canal[15].

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[13] In total 1,482 labourers were mobilized for 23 days (1482 person-days).

[14] In the spring season, especially during scarcity, it has been observed that some farmers who have their irrigation turn in the morning create small artificial reservoir in the canal or in the river at night. Such reservoir is then opened during their irrigation turn.

[15] Flows were measured daily upstream of the main proportioning weir, Dui Dhare.

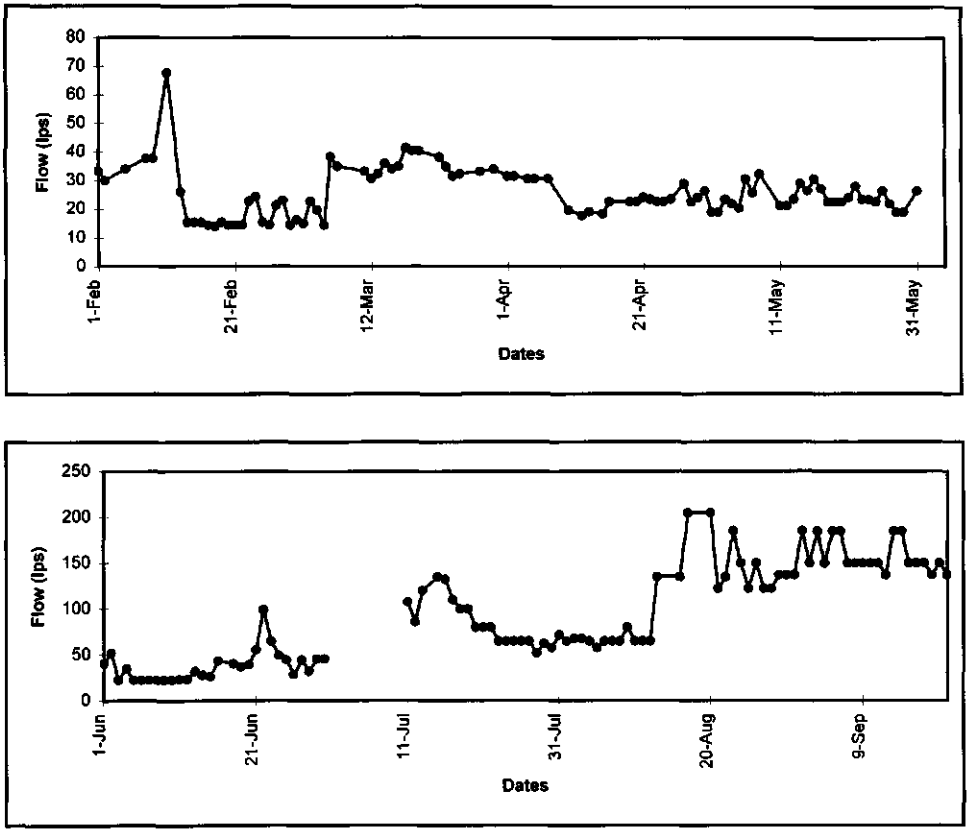

Figure 6.5: Time series flow in the main canal.

Note that the flow in the main canal fluctuated considerably. In early March, the average flow in the main canal increased from 10-20 lps to 30-40 lps. This increase in the flow is the result of increased use of water to transplant spring paddy and to apply pre-sowing irrigation for maize. By the end of May, with the reduction in the river flow, the average canal flow also gradually reduced and varied between 15 and 25 lps. During the monsoon season, the flow fluctuation in the canal is similar to the flow fluctuation in the river. Sharp increases in the canal flow in mid-July and mid-August were the result of rains in the catchment. As there were no continuous rains in the latter part of July, the canal flow reduced gradually to about 50-60 lps in about a period of one week. However, after mid-August, there were continuous rains in the area, which helped in triggering many seasonal springs in the catchment. Consequently, the base flow of both the river and the main canal increased.

6.5.4 Water allocation

In Sankhar Irrigation System, water is allocated on the basis of the number of shares held by each farmer irrespective of his irrigated area[16]. The total water flow available is considered to be 2,270 shares, known as *mato muri,* which is distributed among 112 farmers according to their respective shares. The mode of water allocation to each farmer varies with the cropping season. During the cultivation of the monsoon paddy, continuous flow is delivered to each farmer. During the cultivation of maize and the spring paddy, water is allocated based on a time share rotation.

In this system, the water shares are not attached to land. Farmers can transfer their water shares from one place to another. They can even practise water trading temporarily or permanently.

Temporary water trading involves transfer of water entitlements (shares) from one farmer to another for a fixed period of time (usually one cropping season). Farmers who do not cultivate spring paddy sell their water shares to others. For temporary water trading, transactions are made in kind. In 1995, the rate was 75 kg of paddy per 10 *mato muri* of water shares. This rate, however, reduced to 50 kg per 10 *mato muri* of water shares in 1996. This is because, in 1996, the number of farmers interested in cultivating the spring paddy decreased, which reduced the water demand.

In permanent water trading, transactions are made in cash. At present, the volume of permanent water trading is not much. Although there are many buyers, there are no sellers of water shares. The existing old records show that untill now only four farmers have sold part of their water shares to others. The last water trading was done in 1990 at the rate of Rs21,000 for 5 *mato muri* of water share.

6.5.5 Water distribution

The Sankhar Irrigation System practises both continuous and rotational methods of water distribution for cultivating paddy. As mentioned earlier, during the cultivation of the monsoon paddy, all canals flow continuously, while during the cultivation of the spring paddy, continuous flow is delivered only up to a branch canal. Within a branch canal, timed rotation is practised.

Water distribution during the monsoon season
Water distribution during the monsoon season starts with the beginning of wet seed-bed preparation in the second week of June. By this time, the spring paddy almost matures, and the seed-bed for the monsoon paddy gets the first preference for irrigation water. A paddy seedbed does not require much water; farmers irrigate their field as and when required.

Transplantation of the monsoon paddy starts during the early monsoon in mid-July. At an early stage of paddy transplantation, except for the first three proportioning weirs in the

[16] Appendix X shows the irrigated areas and water shares of a few farmers whose actual irrigated areas in hectare are known.

main canal[17], the other weirs are not installed because all the farmers do not transplant paddy at the same time. Accordingly, water is distributed as needed by the farmers, and paddy transplantation is easily performed with the available canal water.

However, as transplantation goes on, competition for water increases because the demand increases; consequently, farmers install proportioning weirs at the canal bifurcation points to divide water corresponding to their shares. By the time all the proportioning weirs are installed, each farmer completes paddy transplantation in at least one of his uppermost terraces.

Besides the increased competition to use water, the layout configuration of the branching canals at a canal bifurcation point also determines the need to install a proportioning weir. Note that some proportioning weirs work not only as a flow-dividing structure but also as a check structure. Such weirs are installed at an early stage of paddy transplantation to facilitate diversion of water into branching canals located at higher elevation. Usually, once they are installed, they also automatically start functioning as a flow-divider. However, at an early stage of paddy transplantation, mutual agreement among the farmers allows partial blocking of the notches to adjust the flows.

As mentioned earlier, the base flow in the river increases only when the seasonal springs in the catchment trigger, which usually takes place in early August after the start of good monsoon rains. Before these seasonal springs trigger, the main canal flows at an average rate of about 60 lps. With this flow in the main canal, the stream size available to an individual farmer is too small[18], especially when continuous flow is delivered to all the farmers. Although such a small stream size is enough to maintain the standing water in the paddy field, it is not enough to prepare land for paddy transplantation. For this reason, in this system, paddy transplantation (in the peak period) is performed only with the rain, which substantially increases the canal flow for a certain period of time. Farmers store their share of such peak flow in their upper terraces, which are already transplanted. The stored water is then discharged into the next lower terraces to manage land preparation in times suitable to them.

The total number of days required for paddy transplantation, therefore, depends on the frequency of rain. During the study period in 1996, about 37 days were required to complete paddy transplantation. On 11 and 13 July, there were good rains. The flow in the main canal increased to 140 lps (Figure 6.5). Farmers started paddy transplantation on 12 July, expecting continuous rains on the following days. However, there were no good rains for four consecutive weeks[19]. Consequently, the flow in the main canal dropped to its base value in a period of about eight days. By this time, about 30 per cent of the irrigated area

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[17] The three proportioning weirs in the main canal (P1, P2 and P3) are installed prior to the start of paddy transplantation, on the last day of regular system maintenance.

[18] The 60 lps of water, when divided into 2,270 shares (*mato muri*), one *mato muri* gets about 0.026 lps. In this system, about 80 per cent of the farmers have the average water share of 20 *mato muri*. This means a flow of 0.53 lps is available to an individual farmer.

[19] Interviews with farmers suggest that 1996 was an exceptional year with a long dry spell during early monsoon. Usually, such a long dry spell does not occur. In normal years, farmers complete paddy transplantation in about three weeks.

were transplanted. With this reduction in the flow, farmers stopped transplanting paddy. Paddy transplantation was again started only on 13th August with the re-start of good rain in the area. This time, there were continuous rains on the following days, and the farmers completed paddy transplantation on 19th August.

In this system, during paddy transplantation, water is demanded in three stages: land preparation (puddling), transplantation and paddy already transplanted. Once the weirs are installed, the system becomes rigid and there is no opportunity to allocate additional water to the canal served by the weir. Farmers have to manage demands for paddy transplantation with their individual shares. At night, a farmer stores all the water in the already transplanted terraces, which functions as a reservoir. In the daytime, he drains the stored water to the next lower terraces to meet the demand engendered by paddy transplantation. If a farmer feels that the collected water is not enough to meet his demand, he may continue to collect water as long he wants to. The management of the water available remains under the jurisdiction and the control of the user.

Water distribution through proportioning weirs

In Sankhar Irrigation System, proportioning weirs are carefully installed and calibrated[20] to divide water corresponding to farmers' water shares, and work perfectly like clockwork. They are well-maintained and carefully watched by the farmers. During scarcity, even the mosses collected inside the notches are removed to achieve higher hydraulic efficiency. Figure 6.6 shows the schematic layout of irrigation system with its proportioning weirs and their water shares.

A farmer must supervise his fields frequently. His activities include removing floating debris or obstructions deliberately placed in the weir. However, since supervision is the responsibility of an individual farmer, he does it at times suitable to him. He does not need to co-ordinate his schedule of supervision with those of other farmers. A farmer may simply ask his children to check the notches while they are going to school. The cost of supervision is low and the farmers do not feel unduly burdened by this task.

In any run-off-the-river system, flow in the parent canal fluctuates considerably. In principle, proportioning weirs are installed to distribute such fluctuations proportionally at every offtake. To examine this, flows were measured at various points of the system upstream of the four proportioning weirs. Figure 6.7 presents the time discharge curves at those points, which shows that flows in canals are fairly proportional in them.

[20] Calibration of a proportioning weir involves adjusting the notch width corresponding to water shares.

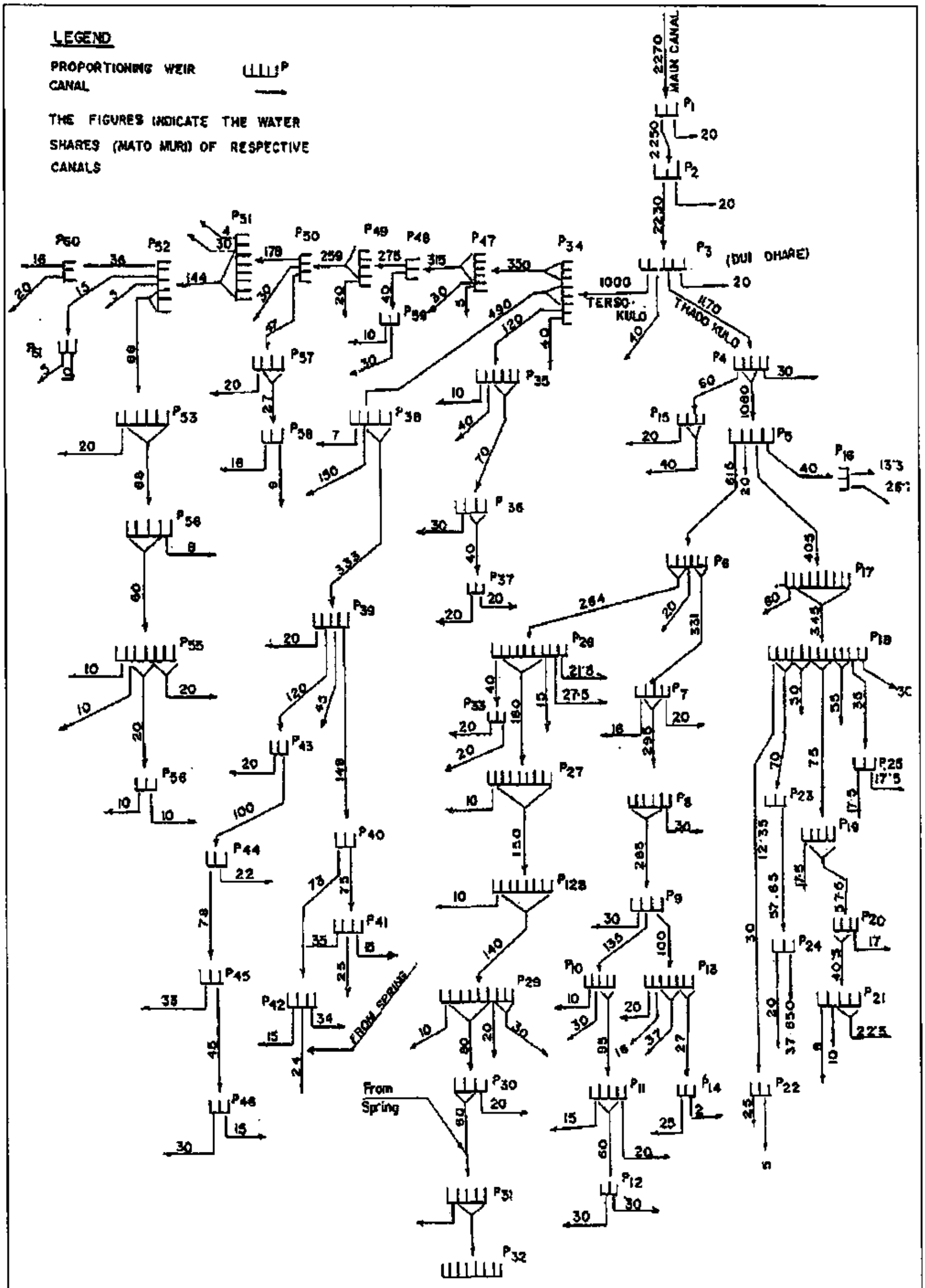

Figure 6.6: The schematic layout of irrigation system with its proportioning weirs and their water shares.

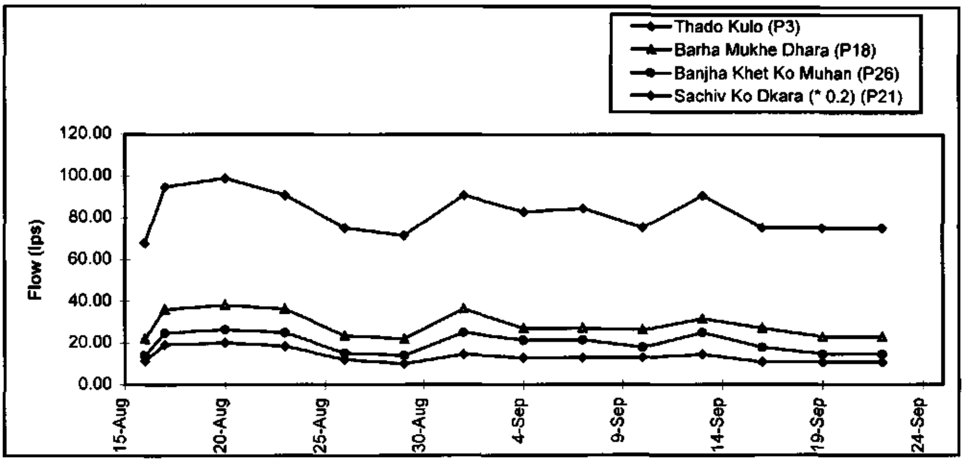

Figure 6.7: Time discharge curves upstream of the selected proportioning weirs.

The above measurements of flow also helped in examining how closely do the water shares at various points of the irrigation system correspond with the actual flow. Table 6.3 shows the total water share and corresponding actual flow at these points.

Table 6.3: Flow per *mato muri* of water share at various points in the system.

Proportioning weir and its location	Total water shares (*mato muri*)	Average flow (lps)	Flow per *mato muri* of water shares (lps per *mato muri*)
Thado Kulo (P3)	1170	82.07	0.070
Barha Mukhe Dhara (P18)	345	28.45	0.082
Banjha Khet Ko Muhan (P26)	264	19.77	0.075
Sachiv Ko Dhara (P21)	40.5	2.73	0.068

Table 6.3 shows that, surprisingly, the flow per unit of water share at proportioning weirs, P18 and P26, increases compared to its upstream value at P3, which otherwise is supposed to decrease due to the conveyance losses in the canals. This suggests that backflow from the upstream terraces into the canal is taking place due to seepage (sub-surface flow). Note that, from P3 to P6, the Thado Kulo is aligned along a depression which is about 2-3 m deep from the normal ground level (Figure 6.2). In such topography, sub-surface flow is likely to occur. Identifications of a few springs in the irrigated area where flows from two such springs are merged with the flow in the main distribution network also justify the existence of sub-surface flow from the upper to lower terraces.

The above discussions suggest that, in the monsoon, though water shares are proportionally distributed, in general, farmers at the tail-end of the area may receive almost the same amount or even more water irrespective of the conveyance losses due to sub-surface flow from the upper to lower terraces. This may also justify the additional notch width (*moko*) provided to some farmers at the head-end, as explained earlier in chapter 3.

Water distribution during the winter season
During the winter season, the water supply is more than the demand. As a result, farmers do not have any specified rules and regulations to irrigate winter crops, especially wheat. Farmers can irrigate their fields as and when required. The frequency of irrigation for wheat depends on winter showers. Usually two to three irrigations are enough for wheat cultivation.

Water distribution during the spring season
Water distribution during the spring season starts with the beginning of pre-sowing irrigation for maize and transplantation of spring paddy in mid-March. During this period (mid-March to June), the main irrigated area downstream of Dui Dhare (P3) is divided into two sections irrigated by two branch canals, Thado Kulo and Terso Kulo. Each section serves more than 50 farmers. The two sections are further sub-divided into blocks and sub-blocks. Both sections receive continuous flow through the main proportioning weir, Dui Dhare, and an open-close system is used to distribute water within the sections[21]. This is because during this period, water supply is scarce and continuous flow to all farmers, as in the case of monsoon paddy, is simply not possible. Note that during this period the flow available in the main canal at the beginning of the main irrigated area (upstream of P1) varies between 15 and 25 lps.

Because of inadequate supply of water, only about 15 per cent of the area is cultivated with the spring paddy; in the remaining area, maize is grown. Consequently, plots with spring paddy are not contiguous, and instead they are scattered all over the irrigated area.

As mentioned earlier, in this system, water is allocated on the basis of the shares that an individual farmer owns. A share is represented by the time water is allocated to an individual farmer. Equity is judged in terms of time and not in terms of the quantity of water, even if the flow is erratic.

The distribution system has two hierarchies of timed-rotation. First, within the block and second, among the blocks. The time unit per share within the block is decided according to the agricultural practice to be performed. From mid-March to mid-April, for example, the time of 9 minutes per share (*lamo palo*), which is relatively long, is allocated. From mid-April to June, however, a shorter time (*ghante palo*)[22] of 3 minutes per share is provided. This is because during *lamo palo*, various types of water demands requiring a longer period of irrigation are to be fulfilled. However, for simplicity, the time unit for distributing water to each block is maintained as standard.

For example, the section served by Thado Kulo has two blocks, named Naubise and Devisthan, each of which is further divided into eight sub-blocks. Naubise and Devisthan

[21] The small patches of irrigated area receiving water direct from the main canal through the proportioning weirs, P1 and P2, upstream of Dui Dhare continue to receive continuous flow through these weirs. This is because these areas are isolated and cannot be combined with any of the above two sections for rotational distribution.

[22] *Ghante palo* does not refer to an hourly rotation as in the case of the Pithuwa Irrigation System (Pradhan, 1996), but simply to a time-based system of rotation. For example, a farmer having 10 shares gets water for 30 minutes, and so on.

have water shares of 615 and 555 *mato muri* respectively; hence, the time units allocated for Naubise and Devisthan are supposed to be 92.25 and 83.25 hours respectively at the rate of 9 minutes per *mato muri*. However, for simplicity, farmers at Naubise and Devisthan use water for 96 and 84 hours respectively (8 and 7 *chhaak* respectively; one *chhaak* corresponds to 12 hours). The extra time (3.75 hours for Naubise and 0.5 hour for Devisthan) is allocated to those farmers who have land at the tail section of the blocks.

During *lamo palo,* the types of water demand are pre-sowing irrigation for maize, irrigation for paddy already transplanted, irrigation for land preparation and irrigation for actual paddy transplantation. During *ghante palo,* however, only one type of water demand is fulfilled: irrigation for already transplanted paddy. Each period of irrigation is shorter in *ghante palo,* but the frequency of demand is higher than in *lamo palo*.

A task force manages the practice of timed-rotation. The task force is an informal organization headed by experienced and socially-recognized farmers. Each section has a separate task force, each of which is active only from March to June in managing the timed-rotation of irrigation water. As mentioned earlier, the formal organization headed by the *akhtiyar* is involved only in system maintenance. The reason for its limited involvement appears to be that the physical system and its organization were designed to be fully proportionate for the cultivation of monsoon paddy (July-September), when not much organizational input is required to distribute water. However, the starting of early cultivation of paddy and maize (April-June) 12-15 years ago necessitated timed rotation of irrigation water and thereby organizational input to manage the rotation efficiently. The task force was established as a result.

The task force decides when to begin the rotation and when to switch from one mode of rotation to another. Preparing a rotational schedule up to the lowest measurable time is another of the task force's duties. Because a large number of farmers with different water share at different times of the year are involved, the preparation of the schedule needs careful attention. Preparation of the rotational schedule, because it demands time and resources, causes high administrative costs.

Although Tang and Ostrom (1993) claim that water distribution by rotation requires minimal supervision, the level of supervision seems to depend on the type of water demand made on the system. Under single-crop farming such as paddy, when a small number of farmers cultivate land within one rotational unit, a low level of supervision may be sufficient. In the Sankhar Irrigation System, however, the level of supervision is high because a large number of farmers with different water requirements are involved. This context necessitates frequent changes in the rotational schedule. Although the schedule is prepared in advance, it is changed in consultation with the farmers to achieve greater flexibility in water use. Sometimes, the schedule is changed two to three times in a single day. Table 6.4 presents a comparison between pre-designed allocated time and actual water use time by farmers in the Naubise Khanda during the last rotational schedule of *lamo palo*.

Table 6.4: Pre-designed allocated time and actual water use time by farmers in the Naubise Khanda during last rotational schedule of *lamo palo*.

Sub block	Name of farmer	Water right	Pre-designed allocated time				Actual water use time				Water used for
		mato muri	Date	Time From hr mi	Time To hr mi	Total hr	Date	Time From hr mi	Time to hr mi	Total hr	
1	Seshkanta	30	11-Apr	06 00	10 30	4.50	13-Apr	00 45	01 45	1.00	C
	Bishnu Bhattarai	30	11-Apr	10 30	15 00	4.50	13-Apr	06 00	08 30	2.50	A
							13-Apr	22 00	04 30	6.50	B, D
	Tulsi Khanal	10	11-Apr	15 00	16 50	1.50					
	Laxman	15	11-Apr	16 50	18 45	2.25	11-Apr	18 00	20 15	2.25	D
	Total	85									
2	Deepak Rimal	20	11-Apr	18 45	21 45	3.00					
	Em Lal	20	11-Apr	21 45	00 45	3.00	11-Apr	15 15	18 00	2.75	A
							11-Apr	22 45	00 45	2.00	B
	Devraj	20	12-Apr	00 45	03 45	3.00					
	Gopal Rimal	10	12-Apr	03 45	05 15	1.50					
	Sukmagar	10	12-Apr	05 15	06 45	1.50					
	Total	80									
3	Bishnu Adhikari	30	12-Apr	06 45	11 15	4.50	12-Apr	05 15	13 15	8.00	A
							12-Apr	18 00	21 15	3.25	G
	Lekhnath Tiwari	20	12-Apr	11 15	14 15	3.00	12-Apr	16 30	18 00	1.50	D
	Umapati	30	12-Apr	14 15	18 45	4.50	12-Apr	13 15	16 30	3.25	D
							12-Apr	21 15	00 15	3.00	D
	Total	80									
4	Rimal Khanda	40	12-Apr	18 45	00 45	6.00	12-Apr	00 45	05 15	4.50	D
	Chola Kanta	10	13-Apr	00 45	02 15	1.50					
	Kusende	20	13-Apr	02 15	05 15	3.00	13-Apr	03 45	06 00	2.25	B
							13-Apr	21 30	22 00	0.50	C
	Total	70									
5	Pitambar	16	13-Apr	05 15	07 39	2.40	11-Apr	06 00	10 45	4.75	A
							11-Apr	15 00	15 15	0.25	B
							11-Apr	20 15	20 45	0.50	B
							13-Apr	19 00	20 00	1.00	C
							15-Apr	05 15	05 45	0.50	C
	Dharmagar	30	13-Apr	07 39	12 09	4.50	11-Apr	10 45	15 00	4.25	A
							11-Apr	21 45	22 15	0.50	B
							13-Apr	00 15	00 45	0.50	B
							13-Apr	20 00	20 15	0.25	B
							15-Apr	05 45	06 00	0.25	C
	Damodar	17	13-Apr	12 09	14 42	2.55					
	Kamal Bhattarai	20	13-Apr	14 42	17 42	3.00					
	Total	83									
6	Lahure Sarkee	12	13-Apr	17 42	19 30	1.80	13-Apr	09 30	12 30	3.00	A
							13-Apr	20 15	21 30	1.25	B
	Jeevan Bikram	30	13-Apr	19 30	00 00	4.50	13-Apr	12 30	19 00	6.50	A
							14-Apr	04 30	05 15	0.75	B
							14-Apr	20 00	21 00	1.00	C
	Hari babu	15	14-Apr	00 00	02 15	2.25	14-Apr	05 15	07 30	2.25	C
	Chitragupta	30	14-Apr	02 15	06 45	4.50	14-Apr	21 00	04 30	7.50	D
	Total	87									
7	Meghini Lal	30	14-Apr	06 45	11 15	4.50	14-Apr	07 30	11 30	4.00	C
	Chiranjibi	20	14-Apr	11 15	14 15	3.00	14-Apr	11 30	14 30	3.00	C
	Total	50									

Sub block	Name of farmer	Water right *mato muri*	Pre-designed allocated time				Actual water use time				Water used for
			Date	Time		Total hr	Date	Time		Total hr	
				From hr mi	To hr mi			From hr mi	To hr mi		
8	Jyoti Lal Kandel	37	14-Apr	14 15	19 48	5.55					
	Mani Ram	16	14-Apr	19 48	22 12	2.40	14-Apr	14 30	18 30	4.00	A
							14-Apr	19 15	20 00	0.75	C
	Prem Gharti	2	14-Apr	22 12	22 30	0.30					
	Khaga Nath	25	15-Apr	22 30	02 15	3.75	14-Apr	18 30	19 15	0.75	B
	Total	80									
	Debisthan Khanda										
	Lok Nath						11-Apr	20 45	21 45	1.00	E
	Gajadhar						11-Apr	22 15	22 45	0.50	E
	Tirtha Raj Tiwari						13-Apr	01 45	03 45	2.00	E
	Tirtha Raj Tiwari						13-Apr	08 30	09 30	1.00	E
	Chandra						15-Apr	04 30	05 15	0.75	E
	Total	615				92.25					
	Unallocated time					3.75					
	Total Time					96.00				96.00	

Note: A: Water used for preparing the land (puddling) for spring paddy
B: Water used for maintaining minimum water depth in already puddled field
C: Water used for already transplanted paddy
D: Water used for pre-sowing irrigation for maize
E: Water transferred to other block either for re-paying the borrowed water or for lending.

Note that except for three farmers, no farmers used water according to the designed schedule. Those who used water for more than their allocated time in this turn have either transferred their water time[23] from the previous turn or have temporarily procured some water shares from others. Similarly, those who did not use water in this turn have either used water in the previous turn or sold their water to some other farmers.

In 1996, the unallocated time of 3.75 hours was distributed among the farmers according to their need. Previously, this time used to be allocated among those farmers who had land at the tail-end.

The reasons for changing the rotational schedule are several. First, although the time unit allocated per share is suitable for meeting the water demands for paddy transplantation and for paddy already transplanted, farmers with few shares find that there is not enough water for preparing land for paddy or for pre-sowing maize. For this reason, one farmer may borrow or shift water time from other farmers; such adjustments require changing the schedule. Borrowing and shifting is practised not only within sub-blocks and with a single rotational schedule but also among blocks and across rotational schedules. For example, a farmer in one block can borrow or exchange water time scheduled in the second rotation with a farmer in another block to merge into his water time in the first rotation. The second reason for changing the schedule is related to preparing land for paddy transplantation. Those farmers who have to prepare land but get their water time at night need to shift the time because bullocks cannot plough at night.

[23] Water time is the time allocated to an individual farmer for receiving irrigation water. Water time differs from farmer to farmer because the number of shares they own differs.

The third reason for changing the schedule is that maize is not irrigated after pre-sowing irrigation because of the inadequate stream flow. Farmers who do not cultivate spring paddy can, after completing their pre-sowing irrigation for maize, sell their water time to other farmers who cultivate early paddy. The buying and selling of water time continues until irrigation for pre-sowing for maize is complete. Once negotiations are finalized, the water times of the buyer are shifted to merge into a single water time.

In addition to the reasons discussed above, the fact that bullocks and labour are not available whenever they are required as well as the various restrictions on ploughing also lead to frequent changes in the irrigation schedules. None of the farmers object to the changes in the schedule because all of them stand to benefit from them. Although a task force prepares the original schedule, it is the responsibility of individual farmers to arrange to use the water time reallotted to him. As a result, most farmers are present in the *phant* almost every day, consulting and negotiating with other farmers to manage their agricultural activities. Those who cannot manage in this fashion have to use their share at times which may be unfavourable to them. Such farmers also run the risk of losing the time allocated to them. Those farmers who are either not present to take their share or ignorant of their turn fall into this category.

Distributing water by timed rotation with an open-close system provides flexibility in water use. However, farmers must be highly involved in management and the level of supervision required is also high. High flexibility became possible because water distribution responsibilities were devolved upon the users and the task force was able to persuade its members to follow the socially acceptable norms of water use.

Water-related disputes are of two types. The first arises out of improper synchronization of distribution time. Many times the watches of the farmers do not agree and, in any case, the exact time water is received cannot be guaranteed. When farmers claim water at the same time, disputes arise. The second problem is related to the time required for filling the canal (transient losses) and the use of the water that remains in the canal after the water time has elapsed, locally called *beg paani*. Many times transient losses are borne by one farmer while the advantage of *beg paani* goes to another farmer. These gains and losses depend solely on where one's plot is located.

After the completion of the transplantation of the spring paddy, the level of supervision required is reduced considerably because the borrowing and shifting of water time also reduces. In this method, as in other systems, the borrowing and shifting of water time by mutual agreement among the farmers is a common feature to achieve a certain level of flexibility. The Pithuwa Irrigation System is an example of this (Pradhan, 1996).

Continuous versus rotational irrigation for cultivating paddy

The above discussions on water distribution showed that farmers practise different methods of irrigation (continuous and rotational) for cultivating paddy in different seasons. Clearly, one of the main reasons for practising different methods of irrigation is the availability of water supply. Larger available flow allows the farmers to practise continuous flow irrigation whereas with smaller flow, rotational irrigation is practised. Other reasons for practising continuous flow irrigation using proportioning weirs are to minimize the organizational inputs required for managing water distribution and to lower the field water management cost of individual farmers.

Of the various reasons mentioned above, this case study also suggests that the higher risk involved in cultivating paddy under rotational irrigation makes farmers prefer continuous flow irrigation. To understand the types of risk involved, first it is worth looking at the agricultural practices of paddy cultivation.

In Sankhar Irrigation System, the land preparation (puddling) activity for paddy transplantation during both the monsoon and spring seasons is very intensive. First, irrigation is applied by flooding and ploughing is simultaneously started, which follows the advancing irrigation water. After completing the ploughing activity, the land is intensively puddled using four to eight pairs of bullock in such a way that a perfect mixture of soil and water (soil-water slurry) is prepared. During puddling, a minimum depth of water is maintained in the field to make this activity easier. The average bullock-pair-days used by farmers to prepare land for paddy transplantation is about 47 per ha, which is much more than reported elsewhere[24]. Along with the puddling, the terrace bunds are manually plastered with soil-water slurry in order to prevent lateral seepage through them.

The water level which remains in the field after puddling is marked by inserting a stick in the field, and this water level is said to be the minimum water level to be maintained for paddy cultivation. The field is then left as it is for a few hours to allow all soil particles to settle down. From next day onwards, depending on the supply, continuous or intermittent irrigation water is applied onto the field to prepare the land for paddy transplantation[25].

Interviews with farmers suggest that the main reason for such an intensive land preparation is to increase the water-retaining capacity of the soil by reducing seepage through it. The dominant soil type in Sankhar Irrigation System consists of loam to clay loam, locally known as *rato mato*. Such soil shrinks when it becomes dry, forming deep-rooted visible cracks. Once such soil cracks, it can no longer retain water and the paddy yield reduces dramatically. An experiment conducted on yield response to seepage and percolation losses and thereby soil cracking (Table 6.5), described later in this section, also testifies this.

For this reason, it has been observed that if the soil cracks during early stage of paddy transplantation, farmers remove paddy seedlings from the field. The field is re-prepared for paddy transplantation and the same paddy seedlings are again re-transplanted. Farmers say that such re-transplanted paddy yields more than the normal yield of paddy if continuous submergence in the paddy field is maintained. However, if the soil cracks after three or four weeks of transplantation, re-transplantation is not possible and the yield reduces drastically. It has been reported that to obtain an average yield, soil should remain intact at least for 45 days after transplantation. This may be because after 45 days, the

[24] Martin (1986) notes that the average bullock-pair-day used by farmers in Argali Irrigation System amounts to about 33 and 20 per ha for continuous and rotational irrigation respectively.

[25] Usually, paddy transplantation is carried out after two or three days of land preparation. Some farmers keep the puddled field as it is for even more days. Interviews with farmers suggest that by doing so, all the toxic materials which are harmful to paddy seedlings would decay by then.

main roots penetrate well below the possible crack depth and such cracks may no longer seriously damage the main roots.

The above discussions indicate that, in Sankhar Irrigation System, the cracking of soil in the paddy field is the main risk involved in cultivating paddy. The chance of soil cracking increases with increased seepage and percolation from the paddy field, which is maximum under rotational irrigation, as explained below.

Under continuous flow irrigation, there is a continuous inflow into and outflow from the field. As a result, water level in the paddy field remains constant with minimum standing water depth. Consequently, the seepage and percolation losses are also minimum. However, under rotational irrigation, the water level in the field varies between its minimum and maximum values[26], and the seepage and percolation losses increase accordingly. This is because the deeper the water in the field, the higher is the rate of seepage and percolation. The seepage and percolation losses not only take place from the field (vertical seepage) but also through the terrace bund (lateral seepage). As the water level in the terraces goes down, the terrace bunds above the descending water level crack, leading to higher seepage losses when again filled with water. For this reason, it has been observed that every time before applying irrigation water, the terrace bunds are manually plastered with soil-water slurry to reduce the lateral seepage[27].

Moreover, synchronizing the water balance (demand and supply), deciding the intensity of land preparation and managing the irrigation water in every turn are extremely difficult. A small mistake in managing one of the above-mentioned activities can cause soil cracking leading to crop failure. For this reason, in Sankhar Irrigation System, farmers who cannot manage water properly do not cultivate spring paddy. Such farmers sell their water shares to others. It has been reported that the number of farmers who are interested in cultivating spring paddy is reducing gradually[28]. Reduction in the price of water (for seasonal trading during the spring season) in 1996 compared to that of 1995 also testifies this.

Yield response to seepage and percolation losses

Originally, it was planned to measure the seepage/percolation losses and the paddy yields under both the rotational and continuous flow irrigation methods. Accordingly, water levels and the paddy yields in four plots were recorded during the cultivation of the spring paddy (rotational irrigation). However, it was not possible to conduct this experiment under continuous flow irrigation due to continuous surface overflow from one terrace to another. Table 6.5 shows the water share used, cropped area, average seepage/percolation rate and the average yield of the spring paddy under rotational irrigation.

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[26] In Sankhar Irrigation System, during the cultivation of spring paddy, water depth in the paddy field varied between 0 and 10 cm.

[27] The average man-day required for plastering the terrace bund before every irrigation turn amounts to about 2.5 man-day per ha. Of the various other labour requirements, this is an extra labour required under rotational irrigation.

[28] Note that the cultivation of the spring paddy was started some 12 to 14 years ago.

Table 6.5: Water shares used, area and the average yields of paddy in four plots.

Plots	Water shares used (*mato muri*)	Area (sq m)	Average rate of percolation (mm/day)	Average yield (t/ha)	Remarks
1 Head of Thado Kulo	20	1640	18.4	2.69	
2 Tail of Thado Kulo	75	2350	15.3[29]	1.19	Soil cracked after 21 days
3 Head of Terso Kulo	40	1600	28.8	4.30	
4 Tail of Terso Kulo	25	1050	19.9	3.15	

In each of the above-mentioned plots, the frequency of irrigation was about 55 hours and the duration of irrigation turn was 3 minutes per *mato muri*. The average inflow of water varied between 6 and 8 lps, depending on the location.

Note that the paddy yield in plot number 2 (tail of Thado Kulo) is only 1.19 ton/ha against the highest yield of 4.30 ton/ha. This is because in this plot, the soil cracked after 21 days of paddy transplantation. Although the seepage and percolation losses before the soil crack were only 15.3 mm per day, after the soil crack, it increased dramatically[30]. Consequently, no standing water was maintained in the field during the latter period of paddy cultivation.

The cracking of soil in the paddy field was also observed in the other systems studied. However, such a dramatic reduction in the yield was not reported. The lower clay content in the soil in comparison to Sankhar Irrigation System and consequently less and shallow soil cracking probably account for this. For this reason, farmers there were not so serious about such soil cracks. In Bachcha Irrigation System, farmers said that a soil crack is refilled once the field is flooded with flood water. Thus, to what extent the paddy yield reduces by soil cracking in different types of soil and how the retransplanted paddy yields more need further investigation.

6.6 Conclusions

This case study attempts to analyze what agro-ecological and socio-cultural considerations of an area help determine the types of infrastructure, especially the water distribution structures, of a farmer managed irrigation system. This study also attempts to analyze the operational consequences of an irrigation system distributing water by mainly two types of water distribution structures, namely proportioning weirs and open-close type of structures.

The study clearly shows that one of the main ecological considerations for the choice of water distribution structure is the availability of water. A larger available stream size allows farmers to practise continuous irrigation through proportioning weirs; consequently, a system functions as a fully proportionate one. However, with smaller stream size, continuous flow is viable only up to the upper end of distribution system. In the lower end of distribution system, rotational irrigation with an open-close type of structure is more feasible; consequently, the system functions as a partially proportionate one. The reason is,

[29] Before the soil cracked.

[30] Since there was no standing water in the field even immediately after irrigation, it was not possible to measure the seepage/percolation losses during the latter part of paddy cultivation.

rotational irrigation is more efficient in terms of water use, though it increases the organizational inputs for the farmer community and individual inputs for a farmer.

Also, when the available base flow in the canal is not enough to perform some of the agricultural activities, especially transplantation of paddy, and when farmers depend on the peak flow caused by sudden rain in the catchment, each farmer would like to receive his share of such peak flows. Peak flows are erratic and distributing them on a time share basis would be inequitable. In such a situation, because of its fixed control characteristic, distributing peak flows to farmers through proportioning weirs is a desirable solution for their equitable distribution.

Further, in a system where cracking of soil reduces the paddy yield drastically, continuous flow irrigation up to individual farmers' field is more desirable. This is because, under rotational irrigation, seepage and percolation losses are high; consequently, chances of soil cracking is maximum (Yoder, 1986).

In the hills, the characteristics of terrace hydrology are unique and are site-specific. This case study shows one of such unique examples. It shows, though the water shares are proportionally distributed corresponding to farmers' shares, in general, farmers at the tail-end may receive almost the same or even more amount of water irrespective of the conveyance losses due to sub-surface flow from upper to lower terraces. The additional notch width (*moko*) provided to some head-enders in the system may, in part, be justified from the perspective of this unique terrace hydrology.

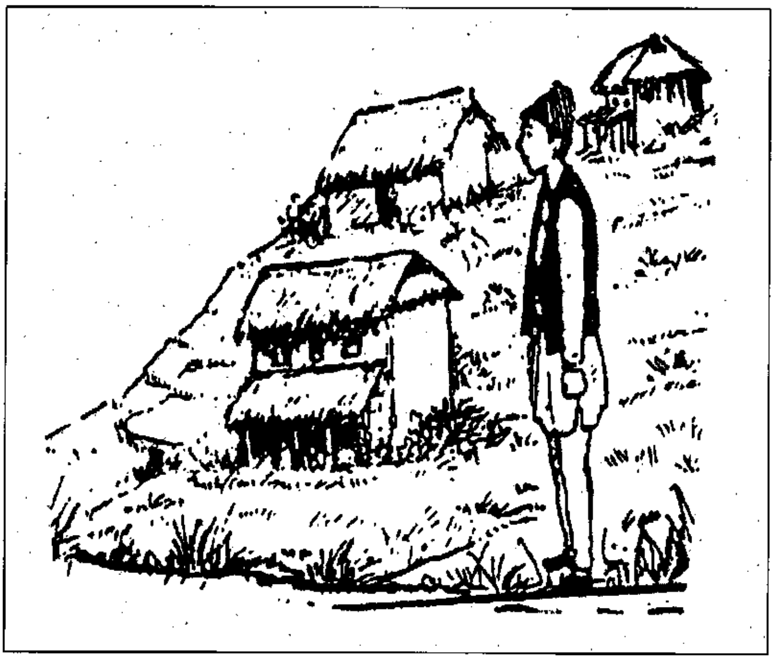
This case study shows that distributing water through proportioning weirs up to individual farmers' field (fully proportionate system) involves construction of wide proportioning weirs with series of parallel canals downstream. Such a system is viable under two conditions. First, the area should have a gently sloping topography which can produce a sub-critical flow in a canal and also allow a certain head loss through this structure. Second, *sal* wood of required size should be available to construct the weir in order to discharge the required flow.

A fully proportionate system is best suited to mono-demand occurring simultaneously throughout the irrigated area, especially for the cultivation of paddy, whereas a partially proportionate system is suitable even for diversified cropping. The terminal area served by a partially proportionate system varies with the stream size available and the crop grown.

Further, use of wooden proportioning weirs in a system is best suited where water in a canal needs to be divided into two or more parts, each of which corresponds to water right attached to each farmer or farmers' group. Other than dividing water, in canals aligned across the contour, they also work as a check and raise the supply level in the parent canal.

This case study shows that in an irrigation system, the choice of water distribution structure also dictates its operational characteristics, which in turn defines its management pattern. Distributing water using timed rotation in an open-close system necessitates a high level of supervision by individual farmers because shifting and borrowing water time by mutual negotiation demands it. As a result, the opportunity cost of farmers can be considerable. A high level of individual supervision is possible because water distribution tasks are assigned to the users.

The open-close type of irrigation systems requires a functional water distribution organization with the ability to co-ordinate its members; to enforce the rules of water distribution and to resolve water-related disputes. In such systems, water distribution is one of the main objectives of an irrigation organization. A fixed proportional system, in contrast, works automatically, and therefore elaborate institutional arrangements are not required. Disputes related to water distribution are few and operating costs are low. However, the system is rigid; once a proportioning weir is installed, there is no chance of getting additional water. In such a system, the involvement of an organization in water distribution is minimal. Instead, the main objective of management is resource mobilization for system maintenance.



7 Patne Irrigation System

7.1 Agro-ecological and social settings

The Patne Irrigation System is located in the Sishaghat village, about 18 km north of the Damauli town in the Tanahu district in the Western Development Region of Nepal (Figure 1.2). A fair weather road connects this area with Damauli, the district headquarters.

The Patne Irrigation System falls under the sub-tropical climate in the hills. The average annual rainfall of this area is about 2,100 mm, about 80 per cent of which occur in the monsoon season (June-September).

Figure 7.1 shows the layout of the irrigation system. The irrigated area (*khet*) is situated on the right bank of the Madi River, in raised alluvial terraces, known as *tar*. It is a long strip of land parallel to the main canal, which is aligned from the uppermost terrace of the irrigated area. The irrigated area slopes from west to east at an average slope of about 2-3 per cent. The land located at higher elevation than the main canal, in the west, is used as *bari* and homestead land. The average land slope of *bari* is similar to that of *khet*. Further west from *bari*, mountains rise steeply. The average altitude of the irrigated area is about 400 m above mean sea level. Bilmade Khola on the north, Madi River on the east, the main canal on the west and the main pedestrian trail on the south form the boundaries of the irrigated area.

As in the irrigation systems discussed earlier, the farming system here, too, comprises of production of cereal crops both in the *khet* and in the *bari*, livestock and agro-forestry. Farmers predominantly practise traditional subsistence agriculture. But, unlike in the irrigation systems discussed earlier, in this system, monsoon paddy is the only crop grown in the *khet*. During the rest of the period, the *khet* remains virtually fallow. Free grazing practices in the *khet* during the winter and spring seasons, and relatively large landholdings of *bari* are the main reasons for cultivating only one crop of paddy in the *khet*. In the *bari*, usually, two crops are grown. During the spring season (April-July), cultivation of rainfed paddy (locally known as *ghaiya*) and maize dominates most of the *bari*, which is followed mainly by millet and blackgram in the monsoon.

The average landholding of *khet* and *bari* per household are about 0.39 and 0.72 ha respectively, which is the highest among the irrigation systems so far discussed. Because of relatively large landholdings of *bari*, mostly compost is used there. Cultivation of the monsoon paddy in the *khet*, therefore, mainly depends on chemical fertilizer. Farmers use a nominal amount of compost in the *khet*.

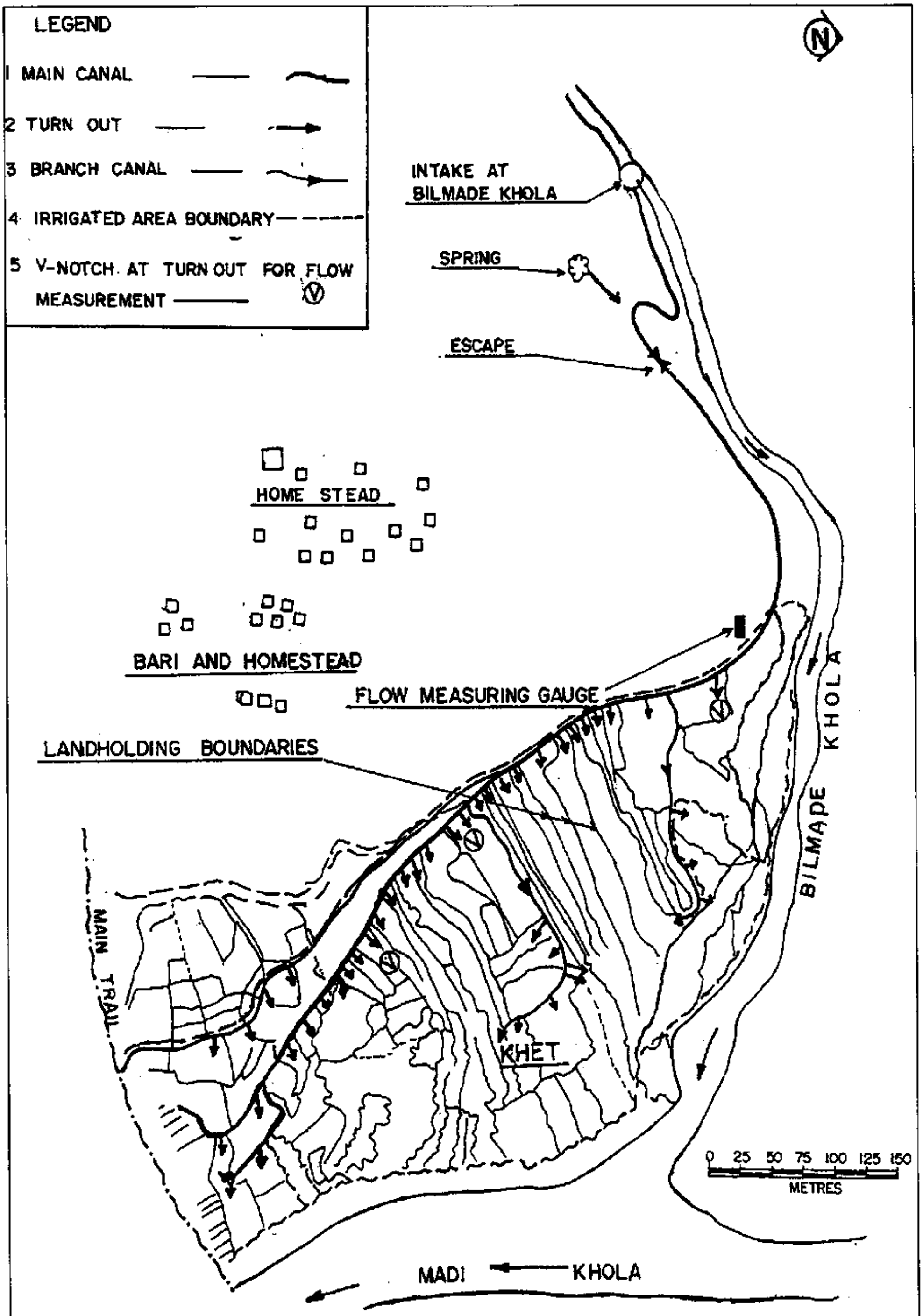


Figure 7.1: Layout of Patne Irrigation System.

7.2 The physical system

A natural perennial spring is the main source of water for the system. The average flow in this spring during the monsoon season is about 70 lps. This flow reduces to about 10 lps during the spring season (April-May). Other than this spring, Bilmade Khola also supplements water to the system, especially during the monsoon when it discharges about 80-100 lps. During the winter and spring seasons, the Bilmade Khola remains virtually dry. In this system, the average water duty for the cultivation of the monsoon paddy is about 3.9 lps per ha. Interviews with farmers suggest that usually the system does not experience water shortage in its sources.

The canal which conveys water from the Bilmade Khola down to the end of the irrigated area, is named as *Mul Kulo*, meaning the main canal. This is a contour canal with an average gradient varying between 0.1 and 3 per cent. The total length of the main canal is about 1,650 m. The average width and depth of the main canal in its idle length are about 1.2 and 0.5 m respectively.

From the intake at the Bilmade Khola down to 365 m along the main canal, the canal is aligned along the *khet*. At chainage 365 m, the canal joins the spring source, where water is further added into this canal. From chainage 365 m down to 750 m, where the main irrigated area starts, the canal is aligned across the hill slope of about 20-30 per cent.

Other than one escape structure at chainage 400 m, the canal does not have any flow-regulating mechanism. The escape simply consists of an open-close type of wooden shutters installed across the canal with a side spillway at its upstream. During rain, the wooden shutter is pushed down to close the flow in the canal. When rain stops, it is again raised to allow flow in the canal.

Patne Irrigation System is a slope-hill irrigation system, and irrigates about 21 ha of cultivated land belonging to 56 farmers. In the irrigated area, most of the landholdings lie perpendicular to the main canal, and they are of long and narrow strip with their upper end connected to the main canal (Figure 7.1). A series of turnouts, locally known as *muhan*, corresponding to each landholding are placed in the main canal. Each turnout distributes water to individual farmers' field by an ad hoc adjustment method. Some bigger landholdings have more than one turnout. There are about 30 turnouts in the main canal. The system also has three small branch canals, each of which has nine, ten and five turnouts to irrigate the remaining portion of the irrigated area.

Figure 7.2 shows a typical plan and profile of a turnout. The turnouts consist simply of an open cut in an earthen canal bank. They have trapezoidal cross-sections, and their crests are located slightly above the bed of the parent canal. The shape of a turnout is fixed with turf and stones placed on either side of the cut. Table 7.1 shows the principal physical features of some of the turnouts in the main canal.

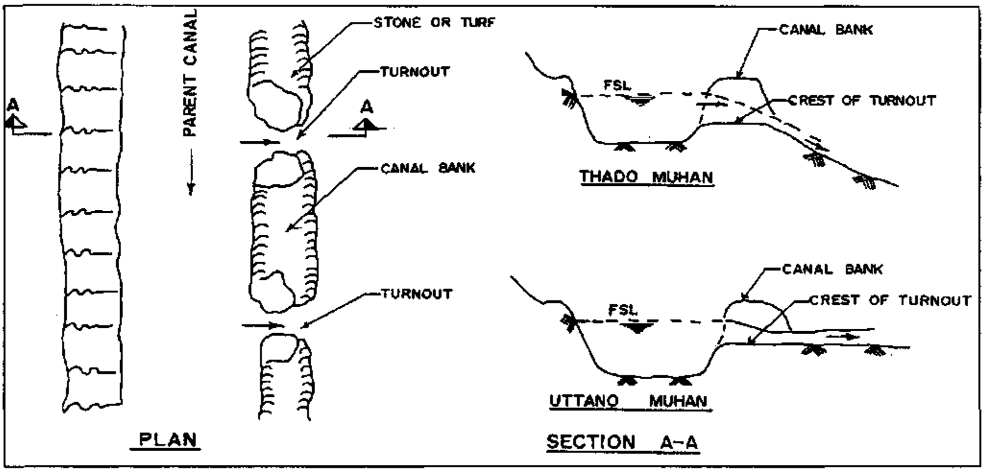


Figure 7.2: Typical plan and profile of a turnout.

Table 7.1: Principal physical features of the turnouts (*muhan*).

Chainage (metre)	*Muhan*	Reduced level (metre)			Size of *muhan* in cm		Remarks
		Parent canal		Crest of	bed	side slope	
		Bed	SL	*muhan*	width	per unit rise	
750	M1	94.995	95.235	95.165			Partially blocked by stones
833	M2	94.921	95.141	95.065	4	0.25	
867	M3	94.864	95.124	95.074	6	0.30	*thado muhan*
902	M4	94.431	94.621	94.479	10	0.25	*thado muhan*
905	M5	94.445	94.615	94.541	8	0.40	
959	M6	94.216	94.406	94.258	10	0.25	*uttano muhan*
1021	M7	93.726	93.946	93.851	8	0.30	*uttano muhan*
1029	M8	93.703	93.843	93.768	7	0.40	*thado muhan*
1041	M9	93.659	93.819	93.719			Partially blocked by stones
1055	M10	93.603	93.773	93.646	6	0.40	
1106	M11	92.45	92.62	92.516	6	0.20	
1117	M12	92.291	92.411	92.306	5	0.25	*uttano muhan*
1129	M13	92.031	92.151	92.051			Partially blocked, *uttano muhan*
1154	M14	91.736	91.886	91.824			Partially blocked, *uttano muhan*
1176	M15	91.426	91.556	91.436	12	0.20	*thado muhan*
1192	M16	91.401	91.531	91.411	7	0.40	*uttano muhan*
1230	M17	91.144	91.264	91.154	6	0.25	*uttano muhan*
1288	M18	90.616	90.746	90.676	4	0.40	*thado muhan*
1290	M19	90.594	90.734	90.638			Partially blocked by stones
1291	M20	90.611	90.741	90.664			Partially blocked by stones
1317	M21	90.536	90.666	90.551			Partially blocked by stones
1318	M22	90.521	90.661	90.616			Partially blocked by stones
1353	M23	90.356	90.476	90.434	9	0.20	*thado muhan*
1392	M24	90.206	90.316	90.207	14	0.25	

Source: Field measurement, 1997.

Note: *Thado* and *uttano muhan* are explained later in the text.
The reduced levels are computed from an arbitrary benchmark.
SL means water supply level at the time of measurement

In this irrigation system, the question arises, why is an ad hoc adjustment type of water distribution structure used instead of other types such as open-close or fixed weirs? An open-close type of distribution structure is viable only at the lower end of distribution system where flow is relatively small and can be rotated among farmers without further dividing it. Similarly, in an irrigation system where the main canal directly supplies water to individual farmers' holdings through a series of turnouts, as in this system, the higher relative difference in the flow size between the parent and the offtaking canal restricts the viability of distributing water through a fixed proportioning weir.

Further, the water allocation principle adopted in this irrigation system does not allow the use of fixed proportional type of distribution structure.

7.3 System operation

7.3.1 Organizational and institutional arrangements

The Patne Irrigation System has a single-tiered irrigation organization with two executive members, namely the chairman and the secretary. Locally, the chairman is known as *paani jimmawal* and the secretary as *sachiv*. The posts of both the *paani jimmawal* and the *sachiv* are hereditary. The *paani jimmawal* has the overall responsibility of managing the irrigation system, which mainly includes system maintenance, water distribution and resolution of water-related disputes. The *sachiv* maintains the records and accounts of the irrigation system, and manages the system in the absence of the *paani jimmawal*. The rest of the farmers are general members of this organization.

The organizational activity of this irrigation system starts with the general gathering of farmers, known as *saameli*, which first takes place in June before the beginning of paddy cultivation. Such general gatherings are held frequently throughout the paddy cultivation season. In the *saameli*, all farmers must present themselves. Those who do not attend the *saameli* have to pay a fine of Rs30 per *saameli*.

System maintenance is of three types: overall maintenance, periodic maintenance and emergency maintenance. The overall maintenance involves repair of the intake at Bilmade Khola, desilting of the main canal and strengthening of the canal banks. The overall maintenance is done once a year, and starts on the day of the first *saameli* in June and continues for about two or three days. The periodic system maintenance, which involves cleaning the canal and plugging the holes in canal banks, however, continues frequently throughout the paddy cultivation season. If the canal or intake breaches all of a sudden due to some reason, emergency maintenance is performed.

The principle of resource mobilization for system maintenance is based on equal contribution, one farmer per household. Job descriptions for the maintenance work for both men and women are clearly distinguished. Digging soil for desilting the canal, plugging the holes in the canal banks and making temporary walls are exclusively performed by men. However, transporting the maintenance materials like turf and stones for various purposes are exclusively left for women. For this reason, women are also equally encouraged to take part in the irrigation system maintenance.

7.3.2 Water allocation and distribution

The principle of water allocation in this system is that the amount of water provided is with respect to the combination of the size of a farmer's holding, type of terraces and crop stages.

The activity of water distribution starts with the start of paddy transplantation. During the period of paddy transplantation, diversified water demand exists in the system area. Also, all farmers do not transplant paddy simultaneously. Therefore, water is distributed on a rotational basis according to the needs of the farmers. There is, however, no defined set of rules to distribute water for transplantation. Usually, the number of farmers receiving water simultaneously is decided by mutual consultation. In the daytime, water is distributed exclusively to prepare land for paddy transplantation. At night, water is distributed mainly to maintain a certain water depth in the paddy field which is already transplanted.

Once paddy transplantation is complete, mono-water demand prevails simultaneously in all the system area. Accordingly, the pattern of water distribution also changes from rotational supply to continuous supply. All farmers receive continuous flow corresponding to their area through their respective turnouts. In a continuous flow regime, the *paani jimmawal* and *sachiv* closely supervise water distribution.

Every year, on the day of *saune sankranti*[1] farmers organize a *saameli* to switch from rotational supply to continuous supply. On that day, first, all the farmers collectively perform periodic maintenance of the main canal. On that particular day, in the presence of the *paani jimmawal,* flows at all the turnouts are fixed by setting their sizes. Once the turnout size is fixed, only the *paani jimmawal* or his authorized representative can adjust its flow. No other farmer is allowed to increase or decrease the flow by changing the size of his individual turnout. The reason for this is two-fold. First, during periods of scarcity, all turnouts should receive their authorized shares of water. Second, during heavy rains when the main canal gets swollen, water should also be dispersed equally among all fields so that the chances of any terrace collapsing are minimized.

In any run-off-the-river system, water supply in the parent canal fluctuates considerably. In such situations, the way such fluctuations are dispersed throughout the irrigated area depends on the hydraulic characteristics of turnouts installed at the canal bifurcation points. The weir type of turnout in a canal, like in this irrigation system, has a hydraulic flexibility greater than unity (Horst, 1983; 1996). This means that the rate of flow fluctuations through such turnouts is not uniform, and is higher at the head-reach than at the tail-end (Figure 7.3).

[1] According to the Nepali calendar, *saune sankranti* is the first day of the month of *Shrawan. Saune sankranti* is also a religious day and falls around mid-July.

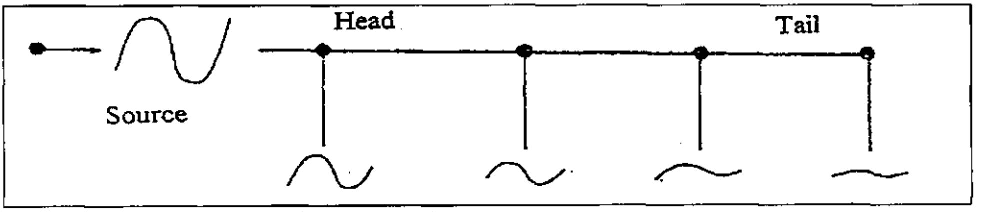


Figure 7.3: Propagation of flow fluctuations.
Source: Horst (1983).

However, for equitable distribution such fluctuations need to be uniformly distributed among all the farmers. This means flows through these turnouts need to be adjusted frequently, requiring human involvement, which is crucial, especially during scarcity. In this irrigation system, the *paani jimmawal* or the *sachiv* or their authorized representative performs the flow adjustment. The requirement of human involvement in adjusting the flows through these turnouts has resulted in the formation of strong organizational and institutional arrangements for water distribution.

In the *saameli* organized on the day of *saune sankranti*, the *paani jimmawal* makes several groups among them, each consisting of three farmers. The members of the groups are selected in such a way that at least one member is experienced in distributing water. During the study period in 1997, there were 17 such groups[2]. Every day one group works in the system. Locally they are known as *pale*.

The main duties of the *pale* are: to plug the holes in the canal banks, if any, and to perform a routine check of all the turnouts and of the water levels in every plot. If the *pale* finds some unwanted incident[3] in the system, he reports the incident to the *paani jimmawal*. Accordingly, the *paani jimmawal* rectifies such incidents immediately and the issues related to such incidents are discussed in the next *saameli*. The activities of *pale* are closely monitored either by the *paani jimmawal* or by the *sachiv*.

Every eighteenth day, all the farmers again organize a *saameli* to evaluate the water distribution arrangement of the previous seventeen days and to perform periodic maintenance. In the *saameli*, the performance of each group of *pale* is discussed, and, if needed, the *paani jimmawal* reorganizes the group for the next round. In the *saameli*, all water-related disputes are also discussed. Usually, social pressure is the basis of resolving such disputes. However, some times farmers who steal water repeatedly are penalized with

[2] The total number of farmers, excluding the *paani jimmawal* and the secretary, is 54. In this system, there is a provision that farmers who do not want to be involved in system operation can be excused by paying a certain amount of irrigation fee to the irrigation organization. The amount of such irrigation fee for an individual farmer is decided by the *saameli*, depending on his landholding and other sources of income. In 1997, four farmers paid such fees varying between Rs250 and Rs300, irrespective of their landholding. Excluding these four farmers, the groups were made up from the remaining 50 farmers. For this reason, there were 17 groups; the last group had only two farmers.

[3] Unauthorized diversion of flow through the turnouts in terms of both the quantity of flow and the location of the turnouts, and complaints of the farmers regarding water delivery to their field are some of such examples of unwanted incidents.

fines. In 1997, no such fines were imposed on any farmer. However, in 1996, such a fine was imposed on a farmer and he paid the fine.

Ad hoc adjustment of flow through turnouts

In this system, the flows through turnouts are adjusted more or less on an ad hoc basis with the help of stones or turf (mud). Accordingly, it is referred here as ad hoc adjustment.

As mentioned earlier, a turnout consists of a simple open cut in an earthen canal bank. Hydraulically, a turnout functions like a weir. From an operational consideration, a turnout is classified into two types, locally known as *thado muhan* and *uttano muhan*. *Thado muhan* is that turnout where free flow through it prevails. This means flow through *thado muhan* is not affected by its downstream condition. On the other hand, *uttano muhan* is a turnout where submerged flow through it prevails. Flow through *uttano muhan* is therefore affected by its downstream condition. This classification has important implications for the method of flow adjustment. To adjust the flow into a plot through the *uttano muhan,* either the upstream condition is changed or the width of the turnout is adjusted. The upstream condition is changed by placing or removing an obstruction in the parent canal downstream of the turnout. Such obstruction increases afflux, which in turn increases the head of the flow upstream of the *uttano muhan*. On the other hand, to adjust the flow into a plot through the *thado muhan,* either the crest or the width of the turnout is adjusted.

It is, however, difficult and cumbersome to keep on adjusting the flow through the turnouts and to synchronize the frequently changing supply level to ensure proportional distribution of irrigation water. To examine this hypothesis, the incoming flow in the main canal and flows through three turnouts (at head, middle and tail) were measured, which are presented in Figure 7.4.

Figure 7.4 shows that the flow fluctuations in the main canal and through three turnouts do not show any correlation. This implies that flows through turnouts are not proportional and the turnout size simply provides a guideline on the extent to which the turnout should be opened to irrigate the field concerned. For this reason, in this system, the equity of water distribution is judged not on the basis of the flow through a turnout but on the basis of actual field conditions.

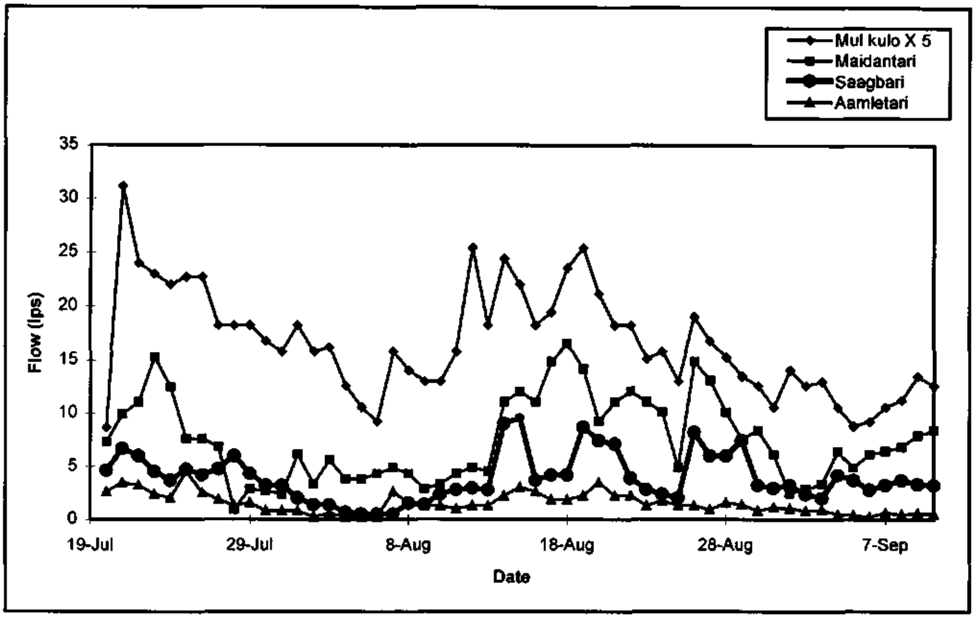


Figure 7.4: Flow fluctuations in the main canal and through three turnouts.

Measure of equity

In this system, equity in water distribution is judged neither with respect to the flow nor with respect to the time for which water is received but rather on the basis of the actual field condition. In the hills, during paddy cultivation water flows continuously from the uppermost terraces to the next lower terraces and ultimately to the lowest terraces. The continuous flow of water from upper to lower terraces is locally known as *sava chalnu*. *Sava* is the lower edge of the terrace bund over which excess water flows out of the terrace, and *chalnu* means "under operation". Farmers always check the flow through the *sava* of their lowestmost terraces and compare it with other farmers to ascertain if equal amounts of water are being received or not. Farmers are not concerned with the volume of water that flows; their only concern is that *sava* should operate. For example, if the last terrace of one farmer is dry, he also expects that the last terraces of other farmers with similar holdings should also be dry. If, on the contrary, water is flowing through the *sava* of his lowermost terraces, he expects to observe the same condition in other farmers' fields. If a farmer does not find the conditions in the field similar, he requests the *paani jimmawal,* through the *pale,* to adjust the flow in his turnout. The distribution rules do not permit him to adjust the flow by himself. In this sense, distribution is centrally-managed.

To increase the flow through the turnout of an individual farmer, the three *pale* who are on duty have to certify that water is needed and check the condition of the field belonging to the farmer concerned. Depending on the situation, either the *pale* themselves adjust the flow or they report it to the *paani jimmawal.* Accordingly, the *paani jimmawal* can issue an order to the *pale* to increase the flow.

7.4 Conclusions

This study tries to analyze what considerations determine the choice of an ad hoc adjustment structure for distributing water in an irrigation system. This case study also attempts to analyze the operational consequences in an irrigation system distributing water by this structure.

This case study shows that in a run-off-the-river irrigation system where the main canal directly supplies water to individual farmers' holdings through a series of turnouts, distributing water by an ad hoc adjustment structure is likely to exist. This is because the higher relative difference in the flow size between the parent and the offtake canal restricts the viability of distributing water with fixed proportioning weirs.

Distributing water by ad hoc adjustment structure necessitates human involvement in adjusting the flows. Involvement of humans in adjusting the flows using a temporary control structure that is made of turf and stone may lead to water-related disputes as each farmer attempts to obtain more water for himself, especially during periods of scarcity. To minimize such disputes, farmers exert control on such turnouts by implementing a set of rules, which dictate when and how flow through turnouts can be increased or decreased and who can make these changes. Since the responsibility of distribution is attached to a few authorized persons, water distribution management is more centralized.

This study further indicated that distributing water by an ad hoc adjustment structure requires a functional water distribution organization with the ability to co-ordinate its members, to enforce the rules of water distribution and to resolve water-related disputes. In such systems, water distribution is one of the main objectives of an irrigation organization.

Another important insight which the case study reveals is the notion of equity in water distribution. Equity is an important operational objective of an irrigation system. Equity does not necessarily imply equality. What farmers consider equitable among themselves may not be access to equal amount of water for all. The exact meaning of equity depends on the local context.

In distributing water by an ad hoc adjustment structure, equity is judged neither with respect to the flow nor with respect to the time for which water is received but rather on the basis of the actual field condition. Although this method of water distribution accommodates soil type, terrace condition and conveyance losses, the measure of equity is subjective. Frequent disputes are the result. To judge equity and minimize disputes, farmers have developed rules, which have often evolved over a long period of time.

Clearly, water distribution by an ad hoc adjustment structure is associated with complex institutional and organizational arrangements and relatively high operating costs. This further shows that the intensity of irrigation management depends not only on the water supply condition but also on the type of distribution structure used.

8 Summary and Conclusions

This thesis is about the relationship between irrigation infrastructure, its management and local environment. This relationship was examined on farmer managed irrigation systems in the hills, which are characterized as indigenous, self-governing and self-sustaining with strong community participation. The principal objective of this study was to examine the principles through which irrigation infrastructure, agro-ecology and irrigation management functions and objectives are integrated in an indigenous irrigation system.

To examine these principles, this study considered irrigation as a man made agro-ecological system, in which water is transferred into a location using a certain technology to increase agricultural production. Further, this study considered technology as 'a capacity to transform, involving material objects whose creation and use are socially mediated'. The 'capacity to transform' was studied both in relation to hydraulic control and water delivery. The transformative capacity of infrastructure is shaped by its capability to integrate processes in a dynamic complex of 'agro-ecology, people and society' consisting of two interrelated sub-complexes on 'agro-ecology' and 'people, society and livelihoods', referred to as agro-ecological and socio-cultural conditions respectively. Putting it on other way, agro-ecological and socio-cultural conditions in an area shape technology and its transformative capacity. These conditions were therefore the central focus of this study, and this research was aimed with the following principal research question.

> What are the relationships between irrigation infrastructure, socio-cultural and agro-ecological conditions of an irrigation system in the hills in managing irrigation water?

With this research question in mind, four irrigation systems (Chapter 4 through 7) were studied in detail using a case study method. This method was helpful in showing distinctive differences in technology in different agro-ecological contexts. Further, emphasis on actual transformative capacity laid down in the working definition of technology has proved appropriate in this study.

Having examined four case studies in the preceding chapters, this chapter compares and summarizes how the irrigation infrastructure, especially the water division structure, is interrelated with the agro-ecological and socio-cultural conditions of an area in managing irrigation water. A subsequent section compares and summarizes how the three types of water division structures namely ad hoc adjustment, open-close and fixed proportional shape irrigation management functions, objectives and local organization's primary objectives of irrigation management.

Before doing this, the following section first reviews the classification of irrigation systems which in turn determines the characteristics of irrigation infrastructure including water division structures used by farmers in the hills of Nepal. This section also briefly reviews the hydraulic characteristics of the indigenous proportioning weirs, which was examined earlier in chapter 3.

8.1 Irrigation systems, water division structures and hydraulic control

8.1.1 Irrigation systems

Based on the physiographic location of irrigated land, the irrigation systems in the hills are classified into three types. They are foothill, slope-hill and river-valley irrigation systems. The relative significance of various types of irrigation infrastructure such as intake, conveyance canal, division structures and management practices differ for each.

A foothill irrigation system irrigates the foothill terraces (locally know as *khola khet).* They are located in the gorge, right along the stream banks. A slope-hill irrigation system irrigates the hill slope (locally known as *tar* or *phant*). Such land is located much higher above the large or medium river flowing in the deeply incised valley. Water from the tributaries of these large rivers located in the different valley is tapped and conveyed to irrigate hill slopes. A river-valley irrigation system is located on the floor of a wide valley and irrigates the valley floor.

8.1.2 Water division structures

This study showed that farmers in the hills of Nepal use three types of division structures to distribute water in their irrigation systems. They are ad hoc adjustment, open-close, and fixed proportional.

An ad hoc adjustment type of structure simply consists of an open cut in the canal bank and flow is adjusted on an *ad hoc* basis using stone and mud. The flow is adjusted either by changing the width of an open cut in the canal bank or by changing the operating head.

In an open-close type of structure, there is no need to split the flow. When closed the flow is zero, when opened the water flow is total. This structure is mostly used at the lower end of distribution systems where individual farmers can easily handle the incoming flow.

In a fixed proportional type of structure, the flow is passed through a fixed opening. The shape and size of the opening, and the water level upstream and downstream of the structure determine the flow through it. In the hills of Nepal, mostly indigenous proportioning weirs are used for this purpose.

Indigenous proportioning weirs and hydraulic control

An indigenous proportioning weir is a simple hydraulic control structure made of timber. It is placed across the direction of flow. To ensure that the flow of water is proportional to the width of the notches, the sill of all the notches are kept at same level.

Sometimes proportioning weirs with large variations in their notch width are encountered in the field. In such a situation, questions may arise whether flows through such notches will be proportional with respect to their widths due to flow constriction. This study suggests that if the three hydraulic boundary conditions are fulfilled, the flows through such a proportioning weir will still be fairly proportional to its notch widths. These hydraulic boundary conditions are: free flow through the weir, uniformly distributed low approach velocity and lower h/L ratio to minimize the effect of flow constriction through notches of varying widths.

Further, this study suggests that the indigenous proportioning weirs designed by farmers based on their experience conform to the hydraulic boundary conditions as laid down in ISO and hydraulic handbooks. This implies that farmers are knowledgeable and capable actors, and can develop hydraulically sound water division structures. In an indigenous proportioning weir, the above mentioned hydraulic boundary conditions are achieved by creating a pond, with the installation of the weir above the normal canal bed at the end of a long and diverging approach canal.

The accuracy of proportionality striven for, however, is very much site-specific. In a relatively water scarce system, the hydraulic boundary conditions of a proportioning weir are not ignored in its design that faces operational and topographical constraints. In a relatively water abundant system, some of the hydraulic requirements of the weir may be ignored in its design to overcome operational and hydraulic constraints, because higher accuracy in water division may not be the prime consideration.

Proportioning weirs have multiple functions. Minimization of water related disputes by distributing water equitably as per agreed norms is one of their managerial functions. In canals aligned across the contour, proportioning weirs also work as check cum drop structures and help maintaining the upstream water level and dissipate energy as desired. Further, the proportioning weirs stabilize the canal bed avoiding its erosion, especially in a canal aligned across contours. In systems where the entry of peak flow is considerable and needs careful dispersion from stability considerations, proportioning weirs also help dispersal of such peak flows in branch canals as per their share, avoiding the possibility of its concentration at one or two locations.

8.2 Conditions determining the acceptability of water division structures, especially the indigenous proportioning weir.

As already noted, agro-ecological and socio-cultural conditions, which are interrelated with one another in a dynamic complex on 'agro-ecology, people and society' shape the technology or the infrastructure and its transformative capacity. Though these conditions are interrelated with one another, for the purpose of analysis this section first examines them separately to show their relationship with infrastructure. Table 8.1 presents some of the important socio-cultural and agro-ecological conditions, shaping irrigation infrastructure, especially water division structures in a hill irrigation system.

Table 8.1: Socio-cultural and agro-ecological conditions determining the choice of water division structures.

Socio-cultural conditions	Agro-ecological conditions
Knowledge and practice	Physiographic location of irrigated area
Labour resources and water rights	Altitude (availability of hard wood)
Power	Topography
Operational requirements	Shape of the irrigated area
Agricultural livelihood strategies	Availability of water
	Crops
	Size of the irrigated area

8.2.1 Socio-cultural conditions

Knowledge and practice

Knowledge and practice in the design and management of irrigation systems are significant in influencing choice of structures. This study suggests that usually farmers in certain localities, having similar agro-ecological conditions, use a similar type of water division structure and management practice. For example, in the Kali Gandaki River valley of Nepal, from the southern part of the Parbat District down to the Tanahu District, the proportioning weirs are very popular. In this area, it is difficult to find an irrigation system without proportioning weirs unless the agro-ecological conditions do not allow for their use. Whereas, in some other parts of the country, though the agro-ecological conditions allow the use of proportioning weirs, some other types of water division structures, which are more familiar to the people in the locality, are used.

Labour resources and water rights

Labour is one of the most important resource farmers have to invest in an irrigation system for its construction, expansion and maintenance. Variations in the farmers' investment in the form of labour during the construction and maintenance of the system create differential water rights among farmers in different parts of the system. This in turn influences the design of the distribution system and also becomes the basis of system operation.

The study also looked at the concept of hydraulic property rights (rights to access and use of water) in understanding the relationship between irrigation infrastructure and the dynamic complex on 'agro-ecology, people and society'.

Rights to mobilize water are of two types ownership and usufruct, and they can be either ascribed or acquired (Vincent, 1995). Further, these rights may or may not be attached to the land.

In irrigation systems, where ownership rights of farmers are to be actualized by allocating water either with respect to land area or water shares, proportioning weirs are the most favourable water division structure. At the lower end of distribution, however, time-share methods by open-close type of division structure may also be used.

This study suggests that a proportioning weir is an important physical device to demonstrate farmer's ownership right. In some parts of the system, where water does not need to be rationed, farmers still use proportioning weirs just to demonstrate their ownership rights. The reason is, without the use of proportioning weirs ownership rights may gradually be transferred to usufruct rights over a period of time.

Further, this study also suggests that irrespective of how ownership rights were claimed earlier, the present basis of labour mobilization for the operation and maintenance of the system has more influence in determining the types of water rights. Such water rights, claimed on the basis of labour mobilization for operation and maintenance of systems, will be limited to usufruct rights.

As with ownership rights, usufruct rights are also actualized by allocating water either with respect to land area or with respect to need (based on the combination of land area, land type and crop). In the former case, proportioning weirs may be used. In the later case, since the allocation principle also considers the crop, of which water need varies with time, ad hoc adjustment type of water division structures are used.

Further, this study also looked at the concept of symbolic capital to understand the relationship between irrigation infrastructure and the dynamic complex on 'agro-ecology, people and society'. This study suggests that the concept of indigenous irrigation systems as symbolic capital (and not just landesque capital[1]) also seems to be present in the systems studied, but could not be documented in detail given the focus and methodology of this thesis. Symbolic capital could be seen and studied more in the organization of management of water delivery through the roles people undertook to play, and it was not easy to identify how this concept is manifested with infrastructure. It is perhaps more manifested in the practices of water management and the negotiation over water delivery from infrastructure constructed and built by the people.

Power

Power, which is the ability of an individual or a group of farmers to achieve an aim or interest they hold, also influences the design of a distribution system. For example, in an irrigation system, location of distribution canals and division structures to irrigate certain fields have direct implications on management inputs and conveyance losses. As a result, farmers would like to be located at the head of a subsequent branching canal rather than at the tail of the preceding branching canal. In such a situation, this study suggests that the influential farmers may manipulate the layout of distribution canals and siting of division structures in such a way that their fields be located at the headreach of a branching canal. Such action, however, may not be favourable to some weaker sections of the society.

Operational requirements

This study suggests that the infrastructure of irrigation systems are shaped keeping in mind the operational requirements. In the hills, as far as possible human involvement in the operational tasks is minimized, unless the agro-ecological conditions do not allow doing

1 Landesque capital is an investment in land which is much more purposive in intent, has a long life, and which increases the value and future production potential of land (Blaikie *et al.*, 1987). An indigenous irrigation system is a prime example of landesque capital created by the people by integrating agro-ecological and socio-cultural conditions of an area, and which generates future production potential from the land.

so. The forthcoming section discusses separately the implications of the above mentioned three types of water division structures in system operation.

Agricultural livelihood strategies

Vincent (1995) notes that farming systems in hill areas can be characterized by its vertical diversity in land use, which in turn influences the people's agricultural livelihood strategies and irrigation practices. In the above mentioned three types of irrigation systems (foothill, slope-hill and river-valley), the degree of vertical diversity in land use varies considerably. As a result, the relative significance of various types of water division structures and management practices differ for each.

As mentioned earlier, foothill irrigation systems are located in the gorge, right along the stream banks, slightly above the stream floor. No human settlement is seen in their vicinity, which in turn reduces their cropping intensity. People living in the up hills requiring a few hours of travel time use these irrigation systems to fulfill part of the food demand for their livelihoods. Thus, in these systems, the availability of other resources for production differ considerably with that of other types of irrigation systems

Unlike the foothill irrigation systems, in the slope-hill irrigation systems, the degree of vertical diversity in land use is less. Many people depend solely on the irrigation systems for their livelihoods. The degree of vertical diversity in land use is almost negligible in the river-valley irrigation systems, and people's dependencies on the irrigation system for their livelihoods further increases.

8.2.2 Agro-ecological conditions

Before examining the relationship between agro-ecological conditions and irrigation infrastructure, it is useful to differentiate whether an irrigation system is fully or partially proportionate. Table 8.2 shows this relationship.

Table 8.2: Agro-ecological conditions for the suitability of fully/partially proportionate system

Type of System	Conditions for suitability							
	Location of Irrigation System	Altitude	Topography		Shape of irrigated area	Water availability	Crop	Size of irrigated area
			Main Canal	Irrigated Area				
Fully proportionate system	Slope-hill or River-valley	Less than 1000 m	Moderately sloped	Gently sloped	Rectangular	Needs moderate flow	Suitable for mono crop	Suitable for small area
Partially proportionate system	Slope-hill or River-valley	Less than 1000 m	Moderately sloped	Moderately sloped	Rectangular	Can operate even in low flow	Suitable even for diversified crops	Suitable even for large area

Physiographic location of irrigation system

By virtue of their location close to the river, foothill irrigation systems exercise prior right of irrigation water over the slope-hill irrigation systems. Water supply to these systems is relatively high. As a result, controlled entry of flow into field, to protect the crops and terraces, is a prime consideration than distribution of available water. This makes the ad hoc adjustment type of water division structure (with a characteristics of downstream control) more viable in this type of irrigation system. Also, because of the much shorter idle length of the main canal and relatively easy intake, their maintenance is also relatively simple. In summary, the intensity of management required to operate these systems is much lower. Consequently, these systems lack well-defined organizational and institutional arrangements.

In contrast, in both the slope-hill and river-valley irrigation systems, difficulties of mobilizing water (although the causes are different[2]) and higher maintenance requirements make water a valuable commodity. Thus, these systems tend to have fixed proportional type of water division structures with elaborate network of distribution canals supported by relevant organizational and institutional arrangements.

Altitude

One of the prime agro-ecological conditions for the choice of wooden proportioning weir is the altitude. Hard wood is required to construct a wooden weir. In Nepal, *sal* wood (*shorea robusta*) is used because of its higher resistance to rotting in water. Availability of *sal* wood in the country is limited to an altitude of about 1,000 m. For this reason, irrigation systems with wooden proportioning weirs are seen at altitude below 1,000 m.

Topography

Main canal alignment

Topography along the main canal alignment determines the availability of land for canals and its structures. In the hills, the main canal is usually a contour canal and the secondary canals run across the contour (down the slope). The land availability to construct a contour canal has always remained a constraint because of hill slope. The steeper the slope the smaller would be the canal width. By contrast, the overall width of a proportioning weir required, considering hydraulic parameters (designed flow and notch depth of weir), always tends to be much larger than the normal canal width. Empirical evidence shows that usually the width of a proportioning weir required is always 3-4 times wider than the normal canal width. In such a situation, distributing water by proportioning weirs would not become viable if these contrasting variables cannot be successfully negotiated in the existing land slope. The modified design of proportioning weirs in Bachcha Irrigation System (Chapter 5) is an example of such negotiation between these contrasting variables.

Irrigated area

This study shows that viability of a fully proportionate system depends on the topography of the irrigated area. There are two reasons for this.

First, a uniformly distributed low approach velocity is one of the hydraulic boundary conditions for the proper functioning of a proportioning weir. A fully proportionate system

[2] In slope-hill irrigation systems, by virtue of their location much above the river, the canal length is relatively long, and passes through difficult terrain. High conveyance losses, difficult maintenance of canal alignment and relatively large irrigated area are some of the causes of water scarcity, making water a valuable commodity. In contrast, in the river-valley irrigation systems, the conveyance canal is relatively easy to maintain and availability of water at the source is not a problem. Rather, frequent maintenance of intake due to damage caused by frequent flash floods makes water a valuable commodity.

requires installation of proportioning weirs even in canals aligned down the slope. In an irrigated area having a steep land slope, canals aligned down the slope are also steep. The flow velocity in such canals is quite high and turbulent.

Second, fully proportionate systems involve construction of wide proportioning weirs with series of parallel canals downstream. On steeply sloping land, the topography restricts the alignment of such parallel distribution canals. The above mentioned problems are further aggravated when the flow increases. In a steeply sloping topography, therefore, proportioning weirs are not usually seen in canals running down the slope. A partially proportionate system, however, may not require installation of proportioning weirs in such steep canals. In sum, the viability of a fully proportionate system increases with the increasing flatness of the topography.

Shape of the irrigated area

The shape of the irrigated area also determines the viability of distributing water through proportioning weirs. For example, in an irrigation system, where the irrigated area consists of a long strip of land, the distribution system usually consists of a single level of canal network. In such a system, the parent canal directly supplies water to individual fields through a series of division structures. This makes the relative difference in the flow size between the parent and the offtake canals too high. Consequently, the viability of distributing water by proportioning weirs reduces. In such a situation, ad hoc adjustment type of water division structures are mostly used.

Availability of water

Streams and rivers are the main sources of water for hill irrigation systems. The source streams irrigating the slope-hill irrigation systems are relatively small in terms of flow carrying capacity. They have very steep gradients with a series of natural vertical drops made of rock outcrops or big boulders.

These streams are fed by perennial or seasonal springs in their catchment, which depend almost entirely on the rain. During the monsoon season (June-September), these rivers discharge maximum flow, which gradually reduces to about 10-20 per cent or even less (with respect to the monsoon base flow) during the spring season (April-May). Even during the monsoon season, relatively short dry spells lead to considerable reduction in the river flow. For this reason these streams exhibit high fluctuation in terms of water availability for irrigation in response to the monsoon rain.

In contrast, the source rivers irrigating river-valleys are relatively wide, have relatively flat gradients and discharge substantial amount of flow with frequent flash floods. As a result, these rivers have a meandering characteristic with a tendency to lateral shifting. In such rivers, availability of water at the source is not a problem. Rather, as mentioned earlier, frequent maintenance of the intake due to damage caused by frequent flash floods makes water a valuable commodity.

This study shows that the availability of water in irrigation systems, irrespective of the above-mentioned conditions of water acquisition, determines whether a fully or partially proportionate system is viable in an area. To develop a relationship between fully/partially proportionate system and the flow available per unit of irrigated area, this study classifies the available flow into three ranges. They are: lower, medium and upper ranges.

The range of flow, which is less than that required under optimal crop requirement conditions is defined here as the lower range.

The range of flow, which is more than that required under optimal requirement conditions but less than that of maximum requirement level is the medium range. Maximum requirement level is that level at which controlled entry of flow into fields is the prime consideration rather than the distribution of the available water.

The range of flow, which is more than that of the maximum requirement level, is the upper range.

Figure 8.1 shows the relationship between flow per unit area and viability of fully/partially proportionate systems.

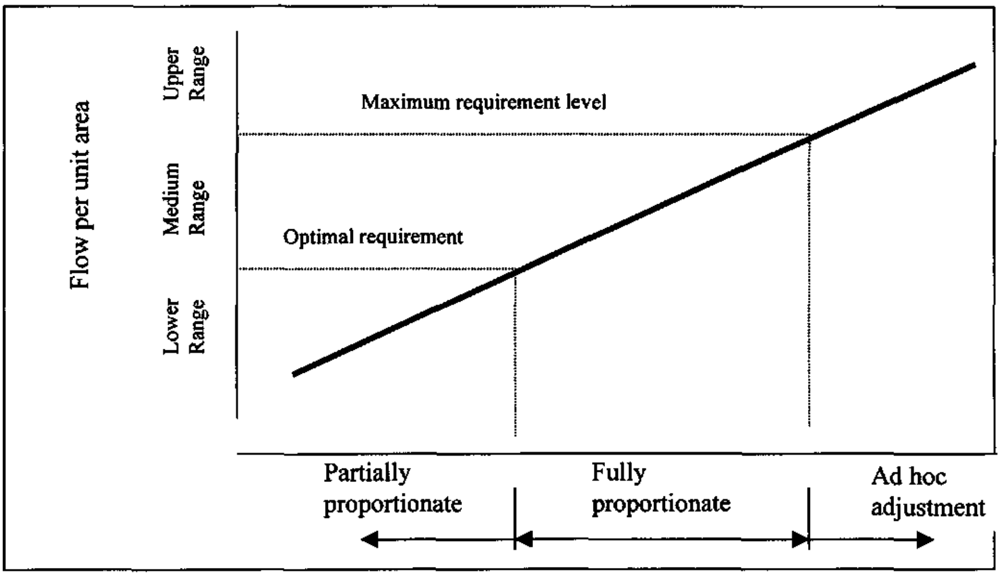


Figure 8.1: Flow per unit area Vs fully/partially proportionate systems

Lower range
The lower range of water availability implies water scarcity. This requires water use efficiency to be high. In such a situation, a partially proportionate system is more viable though it requires relatively high management inputs due to open-close type of water distribution at its lower end[3]. In such a situation a fully proportionate system is not viable. A fully proportionate system requires division of flows down to the individual farmer's share which is not practical especially when the available flow is small. Thus, with the lower range of supply, farmers use partially proportionate system to balance water scarcity by maximizing management inputs.

[3] Also refer to forthcoming section.

Medium range
Systems with a medium range of flow allow having a fully proportionate system. In such systems, farmers receive continuous flow of water to manage irrigation activities independently. In a fully proportionate system, although the water use efficiency reduces, the advantage of having more water is balanced by minimizing management inputs.

Upper range
Systems with an upper range of flow allow neither fully nor partially proportionate systems. The reason is, a proportioning weir is a fixed control structure. It distributes both low and peak flows in the same proportion. In any irrigation system where the available flow is in the upper range, flow into terraces needs to be checked to protect the crops and terraces for stability. In such systems, controlled entries of flow into terraces receive priority rather than the distribution of available water. Thus, with the upper range of water availability an ad hoc adjustment type of division structure, which can check the entry of flow into terraces, is more viable.

A system may receive all three ranges of flow depending on the season. For example, during monsoon, the available flow may lie in the upper range, while during winter it may come down to lower range. The use of division structure also varies accordingly. Further, in such a system, when the flow lie in the upper range during certain time of year, proportioning weirs are used only at those points where the branching canals are capable of conveying their share of peak flow without damaging the crops and terraces.

Crop
A fully proportionate system is best suited to mono-demand occurring simultaneously throughout the irrigated area, especially for the cultivation of paddy. A partially proportionate system, on the other hand, is suitable even for diversified cropping. The area that can be served by a terminal point of a partially proportionate system varies with the crop grown.

Size of an irrigated area
This study shows that the option to have a fully or partially proportionate system largely depends on the size of the irrigated area. The reason is, in a fully proportionate system, the relative difference in the flow size between the parent and offtake canal tends to be high. With further increase in the irrigated area, the larger would be the flow size. This further increases the relative difference in the flow size between the parent and offtake canal, especially at the system's head reach, where a few offtakes delivering water to a few farmers from the main canal are unavoidable. With the higher relative difference in the flow size between the parent and offtake canal, the overall width of the weir becomes be too wide. This restricts the viability of a fully proportionate system in a larger irrigated area.

In contrast, the size of the irrigated area does not restrict the viability of a partially proportionate system, unless a traditional wooden proportioning weir is used.

8.3 Operational consequences of different types of water division structures

This section compares and summarizes how the three types of water division structure namely ad hoc adjustment, open-close and fixed proportional shape irrigation management functions and local organization's primary objectives of irrigation management. This is done by looking at the operational consequences of these water division structures. In this context, this section supports the arguments made by Horst (1996,1998) and adds a few more operational aspects of the above mentioned water division structures.

8.3.1 Organizational and institutional support

In any run-off-the-river system, water supply in the parent canal fluctuates considerably. The dispersion of flow fluctuations throughout the irrigated area depends on the hydraulic characteristics of division structure used (Horst, 1996; 1998).

Ad hoc adjustment
In an ad hoc adjustment type of division structure, hydraulic flexibility is not equal to one. This means that the rate of flow fluctuations through such turnouts is not uniform. For equitable distribution such fluctuations need to be uniformly distributed among all the farmers. This means that distributing water by ad hoc adjustment structures necessitate frequent adjustment of flows through them. This in turn requires human involvement whose reliability is crucial especially during scarcity.

The involvement of humans in the flow adjustment raises a number of questions such as: Who diverts water and how much, at what time and from what point of the canal? If all the farmers start diverting the water themselves at the same time disputes may arise. To minimize disputes, farmers exert control over these structures by implementing a set of rules, which dictate when and how flows through them can be increased or decreased and who can make these changes. Thus, water distribution by ad hoc adjustment structures is heavily supported by institutional arrangements defining the above queries.

Further, distributing water by this structure requires a functional water distribution organization (committee) with the ability to co-ordinate its members, to enforce the rules of water distribution, and to resolve water-related disputes. Since a few authorized persons perform the water distribution, involvement of individual farmers in water distribution is minimal.

Open-close
In distributing water by open-close type of structures, involvement of individual farmers is high, especially when diversified demands exist. This is because, during the period of diverse demand, shifting and borrowing water time between farmers by mutual negotiations occurs frequently. Thus, distributing water by open-close type of structures also requires an organization with the ability to co-ordinate its members to enforce the rules of water distribution and to resolve water-related disputes. However, an open-close type of structure requires less organizational and institutional support for distributing water compared to that by an ad hoc adjustment type of structure.

Fixed proportional
A fixed proportional type of water division structure works automatically and therefore does not require elaborate additional institutional arrangements for water distribution. Thus, the organizational and institutional support required in water distribution is minimal.

8.3.2 Transparency of equity

This study suggests that perception of equity and its measure varies considerably among systems distributing water with each of the above mentioned three types of division structure, which are in part determined by the agro-ecological conditions. This implies that ecology has a profound influence on the perception of equity in water distribution and also in its measure.

Ad hoc adjustment
In distributing water by ad hoc adjustment type of structures, transparency in the measure of equity is low. In this type, as mentioned earlier, due to frequently changing supply level in the parent canal, flows through them need to be adjusted requiring human involvement. It is also equally difficult and cumbersome to keep on adjusting the flows through them and to synchronize the frequently changing supply level. Thus, in distributing water by this type of structures, the actual measure of equity in water distribution is judged neither with respect to the flow nor with respect to the time for which water is received but rather on the basis of the actual field conditions. Such field conditions differ from system to system[4]. Thus, in distributing water by ad hoc adjustment type of structures, the measure of equity is subjective and cannot be quantified.

Open-close
In distributing water by open-close type of structures, equity in water distribution is factual and can be quantified. In this type, equity is judged with respect to the time for which water is received although it does not accommodate flow variation in the parent canal.

Fixed proportional
Like the open-close type, in distributing water by fixed proportional type of structures, equity in water distribution is factual and can be quantified. In this type, unlike with open-close type of structures, equity is judged with respect to the percentage of the available flow that is provided to each farmer. This is done by measuring and comparing the width of notches. This method of measuring is undeniable. Further, the institutional arrangement needed to judge equity is minimal.

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[4] In the hills, within one's holding, water flows continuously from the uppermost terrace to next lower terraces and ultimately to the lowest terrace, especially during paddy cultivation. One of the methods used by farmers to judge the equity is to check and compare the water flow in the lowest terrace with others lowest terraces. This method is described in Chapter 7 (Patne Irrigation System). In some systems, distributing water with ad hoc adjustment type of structures, operated by a hired operator (*thekedar*), a farmer judges the equity by comparing the frequency of irrigation and the standing depth of water after irrigation in his paddy field with others field (Parajuli, 1997).

8.3.3 Chances of mismanagement and water related disputes

Ad hoc adjustment

In distributing water by ad hoc adjustment type of structures, although farmers have developed various rules to judge equity, chances of mismanagement and water related disputes are high, because the measure of equity is subjective. In this type of system, the lack of well-defined physical structure further increases the temptation for a farmer to adjust the flow during the periods of scarcity leading to disputes.

Open-close

In distributing water by open-close type of structures, because of strict supervision of individual farmers and self-enforcing water distribution characteristics, water related disputes are relatively rare in comparison to distributing water by ad hoc adjustment type of structures. However, during the period of water scarcity, some disputes still arise. In distributing water by this type of structures, water related disputes are of two types. The first arises due to improper synchronization of distribution time. Many times the watches of the farmers do not match. In any case, the exact time for which water is received cannot be guaranteed. The second type of dispute is related to the time required for filling the canal and the use of the water that remains in the canal after water time has elapsed. Frequently, the time required to fill the canal is borne by one farmer while the advantage of water that remains in the canal after the elapse of water time goes to another farmer. These gains and losses, however, depend solely on where one's field is located.

Fixed proportional

In distributing water by fixed proportional type of structures, because of its distinctive water distribution characteristics - visible and undeniable, equitable, simple and understandable, and measurable by farmers with respect to others - water-related disputes are minimal.

8.3.4 Devolution of water management tasks to users

Ad hoc adjustment

As mentioned earlier, distributing water by ad hoc adjustment type of structures necessitates frequent adjustment of flows. If all farmers start adjusting flows disputes are bound to occur. Thus, in this type of system, a person (operator) who is authorized to adjust the flow is specifically defined. In some systems, a few selected farmers act as operator, while in other a hired person does this. Irrespective of whether a hired person or selected farmers act as operator, in this type of water distribution, the farmer is not allowed to adjust his flow himself nor he can interfere with the responsibility of the operator. In system operated by a hired operator, farmers cannot even irrigate their fields themselves, only the operator can (Parajuli, 1997).

In this type of water distribution, if a farmer discovers that the operator is not supplying enough water to his field compared to others, he can simply put his demand of more water to the water committee. The chairman of water committee then evaluates his demand and takes necessary action. Since the responsibility of distribution/irrigation is attached to a few authorized persons, water distribution management is more centralized.

Open-close
Distributing water by open-close type of structures allows higher devolution of water distribution task to users compared to that by ad hoc adjustment type of structures. Borrowing, shifting and temporary trading of water time by mutual agreements among farmers to match various water needs are the examples of higher degree of devolution of water distribution task to users.

Fixed proportional
Distributing water by fixed proportional type of structures helps devolve an irrigation system into several smaller independent sub-systems, each with its fair share of continuous flow. This in turn helps to devolve the water management tasks to the farmers of the respective sub-systems. Each of these smaller unit functions as an autonomous system with its own organizational and institutional arrangements, and the main system acts as a federation of smaller sub-systems. Thus, in distributing water by fixed proportional type of structures, the management of water distribution is fully devolved.

8.3.5 Operating cost

Ad hoc adjustment
In distributing water by ad hoc adjustment type of structures, substantial financial resources are required to operate the system because the operator has to be remunerated. Empirical evidence from the case studies shows that in this type, farmers pay (either in cash or in kind) about Rs300 to 400 per ha per crop for water distribution.

Open-close
In distributing water by open-close type of structures, though individual farmers do not have to pay for it, their involvement in water distribution is high. A farmer must present himself in the field in the stipulated time to use his water turn, even though the time is not suitable for him. As a result, the opportunity cost to farmers can be considerable.

Fixed proportional
In distributing water by fixed proportional type of structures, the system runs automatically. There is no need to open or close or adjust the flows or structures. Thus, no operator is necessary. As a result, the operating cost is low. In this type, though the frequency of supervision required by a farmer is high (to remove floating debris and intentionally placed obstructions in the canal), he does it at times and in ways suitable for him. He does not need to match his time for supervision with that of other farmers. In this sense the opportunity cost of farmers for supervision is low.

8.3.6 Trading of water

Ad hoc adjustment
In distributing water by ad hoc adjustment type structures, there is no scope of water trading. Thus, there is no incentive to increase the irrigated area by more efficiently utilizing the available water.

Open-close
An open-close type of division structure allows temporary water trading. As a result, the incentive to increase the irrigated area by more efficiently utilizing the available water is less.

Fixed proportional
A fixed proportional type of water division structure allows permanent water trading. Thus, the incentive to increase the irrigated area by more efficiently utilizing the available water is high.

8.3.7 Flexibility

Ad hoc adjustment
Distributing water by ad hoc adjustment type of structures takes in to account the crop stage, soil type, terrace type and conveyance losses in water distribution. Thus, the irrigation system distributing water by ad hoc adjustment type of structures is flexible.

Open-close
An open-close type of structure does not take into account the crop stage, soil type, terrace type and conveyance losses. However, certain degree of flexibility is achieved by borrowing and shifting the water time of farmers by mutual negotiations. In total, water distribution by open-close type of structures allows less flexibility compared to that by ad hoc adjustment type of structures.

Fixed proportional
Like open-close type, a fixed proportional type of structure also does not take into account the crop stage, soil type, terrace type and conveyance losses. In such system, farmers have no opportunities to take extra water. Thus, the irrigation systems distributing water by fixed proportional type of structures are rigid.

The above discussions are summarized and presented in Table 8.3.

Table 8.3: Operational consequences of different types of water division structures

Types of water division structure	Organizational and institutional support	Transparency of equity	Chances of mismanagement and water related disputes	Devolution of water management tasks to users	Operating cost	Trading of water	Flexibility	Management intensity required for water division	Local organization's primary objective of irrigation management
Ad hoc Adjustment	■	▏	■	▏	■	▏	■	■	Water distribution
Open-close	▮	■	▮	▮	▮	▮	▮	▮	Water distribution and resources mobilization
Fixed Proportional	▏	■	▏	■	▏	■	▏	▏	Resource mobilization

Table 8.3 shows that flexibility in water distribution is high in distributing water by ad hoc adjustment type of division structures. Flexibility decreases with open-close type and becomes minimal with fixed proportional type of division structures. The need for higher flexibility in water distribution has implications for the local organization's primary objective of irrigation management.

The need for higher flexibility in water distribution increases human involvement in flow adjustment and makes the measure of equity subjective. This in turn increases chances of mismanagement and water related disputes. To minimize such disputes, water distribution management is centralized with higher organizational/institutional support and operating cost. As a result, in systems, distributing water by ad hoc adjustment type of division structures, intensity of water distribution management is high, and therefore, water distribution becomes a more important task compared to resources mobilization for maintenance. Thus, water distribution becomes the local organization's primary objective of irrigation management.

In contrast, in systems, distributing water by fixed proportioning type of division structures, the measure of equity is factual and water related disputes are minimal because the flexibility in water distribution is low. In such a system, intensity of water distribution management is low, and resources mobilization task for maintenance becomes more important compared to water distribution tasks for a local irrigation organization.

8.4 Conclusions

Based on the foregoing sections, this study draws following conclusions

- The indigenous proportioning weirs designed by farmers based on their experience conform to the hydraulic boundary conditions as laid down in ISO and hydraulic handbooks. This suggests that farmers are knowledgeable and capable actors, and can develop hydraulically sound water division structures.

- Indigenous proportioning weirs have multiple functions. Minimization of water related disputes by distributing water equitably as per agreed norms, and dispersal of peak flows in branch canals as per their share to avoid the possibility of its concentration at one or two locations, are some of the managerial functions. Maintaining upstream water level, dissipating energy of flow and stabilizing canal bed are some of the hydraulic functions.

- For the relationship of agro-ecology and infrastructure, this study showed the significance of physiographic and spatial factors of land, supply of water and crop choice as agro-ecological conditions. This study also showed that knowledge and practice, labour resources and water rights, power, operational requirements and agricultural livelihood strategies are important socio-cultural conditions in shaping irrigation infrastructure.

- The concept of hydraulic property rights is one of the main social relations integrating the irrigation infrastructure, agro-ecological and socio-cultural conditions in the irrigation systems studied. This study also showed that indigenous irrigation systems do represent as symbolic capital for a group. However, its links with infrastructure configurations are usually indirect, and its values are usually manifested in other practices of water management.

- Choice of water division structure greatly influences irrigation management functions and a local organization's primary objective of irrigation management. In irrigation systems distributing water by ad hoc adjustment type of division structures, water distribution is the primary objective. In distributing water by open-close type of structures, both the water distribution and resource mobilization are equally important objectives. In system distributing water by fixed proportional type of division structure, resource mobilization is the local organization's primary objective of irrigation management.

- Farmer's perception of equity in water distribution and its measure are influenced by agro-ecological conditions.

In sum, in an irrigation system, hydraulic, agro-ecological and socio-cultural conditions determine the choice of water division structures, which in turn shape the irrigation management functions, objective and local organization's primary objective. As the current approach to irrigation development and management considers farmers as the major actor in both turnover of agency-built irrigation system and rehabilitation of farmer managed irrigation system, understanding of these conditions shaping irrigation infrastructure is vital for further developing them in close partnership with local community. Failure to recognize these conditions, while further developing them, can erode the existing management practices and the current and potential contribution of irrigation to local livelihoods. Recognition of these conditions can guide policies for greater use of water resources and to improve livelihoods in the hills of Nepal.

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Nederlandse samenvatting
Dutch summary

Dit proefschrift behandelt de relatie tussen de lokale context (zowel sociaal als agro-ecologisch) van een irrigatie systeem en het irrigatiestelsel (de infrastructuur), met betrekking tot irrigatiewaterbeheer. Deze relatie is onderzocht in irrigatie systemen die beheerd worden door boeren (de zogenaamde FMIS; farmer managed irrigation systems). Deze systemen zijn gekarakteriseerd als inheems, autonoom, zichzelf in stand houdend en een sterke participatie van de gemeenschap.

Een irrigatie systeem bestaat uit verschillende componenten. Dit proefschrift concentreert zich op voornamelijk op één component: de waterleveringswerken, met nadruk op de inheemse proportionele overlaat. Dit systeem, gebruikt door veel FMIS in bergachtige gebieden, is wereldwijd in veel documenten beschreven.

Hoewel veel FMIS opereren met behulp van proportionele ontwerpen, hebben onderzoekers alsnog weinig aandacht besteed aan dit fysische component van het irrigatie systeem. Veel onderzoeken zijn sociologisch van aard en richten zich vooral op organisatorische en institutionele afspraken binnen het onderzochte irrigatie systeem. Een beschrijving van de fysische componenten is in deze studies slechts achtergrondinformatie over het irrigatie systeem.

Veel studies vermelden dat FMIS zeer efficient zijn en goed beheerd worden. Maar er worden geen antwoorden gegeven op de volgende vragen:
- worden deze irrigatie systemen ook goed door de boeren beheerd ten aanzien van de fysische en technische aspecten;
- wat zijn de relaties tot de agro-ecologie en de lokale sociale organisaties;
- welke cultuurtechnische en hydraulische principes worden er toegepast?

Deze studie tracht de bovenstaande vragen te beantwoorden, met als doel de FMIS verder te kunnen ontwikkelen in nauwe samenwerking met de gebruikers, om uiteindelijk de levensstandaard van de huidige en toekomstige generaties te verhogen. Het doel van deze studie is:

> het onderzoeken van de elementen binnen een irrigatiesysteem, die ten grondslag liggen aan de integratie van het irrigatiestelsel (de infrastructuur), de agro-ecologie en de functies en doelen van het irrigatiewaterbeheer.

In dit onderzoek wordt irrigatie beschouwd als een kunstmatig agro-ecologisch systeem, in welke - middels een bepaalde technologie - water naar een bepaalde plek wordt getransporteerd teneinde de landbouwproduktie te verhogen. Deze definitie benadrukt de rol van de technologie binnen een dergelijk agro-ecologisch systeem. Voor het begrip technologie wordt de volgende definitie aangehouden: de capaciteit tot transformatie, gebruik makend van materiële objecten welk ontwerp en gebruik sociaal bepaald worden. De capaciteit tot transformatie is de mogelijkheid van deze kunstwerken om processen te integreren in een dynamisch complex van 'agro-ecologie, mens en samenleving'. Deze kunstwerken zijn echter sociaal bepaald door beheersprincipes en onderhandelingen. Het dynamisch complex bestaat uit twee overlappende sub-complexen van 'agro-ecologie' en 'mens, samenleving en levensonderhoud'. In dit onderzoek wordt naar deze twee sub-complexen gerefereerd als respectievelijk de agro-ecologische en socio-culturele context.

Om deze sub-complexen te kunnen bestuderen, wordt in dit onderzoek gekeken naar kenmerken van het beheer van land, water en vegetatie binnen irrigatie systemen, die gesitueerd zijn in de bergen, en een specifiek irrigatiestelsel gebruiken. Het onderzoek gebruikt concepten als landschapsecologie en bedrijfssysteem (*farming system*). Ook wordt er gekeken naar de irrigatie instituties, de lokale organisaties en de agrarische voorwaarden, die zowel het gebruik van het irrigatiestelsel bepalen als de ontwikkeling van het agro-ecologisch systeem. Tijdens de studie naar het land is speciale aandacht gegeven aan de relatie tussen de fysische, geografische en ruimtelijke factoren, en het irrigatiestelsel. Ook wordt aandacht gegeven aan het menselijk vermogen om een irrigatiestelsel en de verbonden instituties te ontwikkelen en te beheren.

Dit onderzoek bestaat uit een aantal case studies die zijn uitgevoerd in het midden-gebergte van Nepal. Met behulp van verschillende gereedschappen en technieken, zoals survey, metingen, gestructureerde en ongestructureerde interviews en observatie, zijn zowel kwantitatieve als kwalitatieve gegevens verzameld. Op basis van agro-ecologische en infrastructurele verschillen zijn vier FMIS geselecteerd voor gedetailleerd onderzoek: het Julphe irrigatiesysteem (district Nawalparasi), het Bachcha irrigatiesysteem (district Parbat), het Sankhar irrigatiesysteem (district Syangja) en het Patne irrigatiesysteem (district Tanahu). Het veldonderzoek begon in oktober 1995 en duurde tot december 1997. Met behulp van een 'rapid appraisal' studie zin de resultaten van de vier case studies getoetst in 21 andere FMIS, verspreid over vijf districten in dezelfde regio.

Dit proefschrift bestaat uit acht hoofdstukken. Het voorgaande deel van deze samenvatting is gebaseerd op het eerste hoofdstuk. Hoofdstuk twee geeft een beschrijving van Nepal, en definieert de typologie van de irrigatie systemen zoals die te vinden zijn in de bergen van Nepal. In hoofdstuk drie worden de ontwerpen van de inheemse proportionele overlaten omschreven die in veel FMIS in de bergen van Nepal worden gebruikt. De vier bovengenoemde case studies zijn terug te vinden in de hoofstukken vier tot en met zeven. Hoofdstuk acht bevat een samenvatting van de resultaten en de conclusie. Van elk hoofdstuk volgt nu een korte samenvatting.

Nepal bestaat voornamelijk uit bergen met grote verschillen in hoogte over een korte horizontale afstand. Het land kent bijgevolg extreme variaties in de fysische geografie, biodiversiteit en agro-ecologie. Door de eeuwen heen hebben de boeren een groot scala aan irrigatiestelsel ontwikkeld, afhankelijk van de specifieke sociale en agro-ecologische omstandigheden van het gebied. Men schat dat 89 procent van het totaal geïrrigeerde areaal uit FMIS bestaat, die 80 procent van de boeren in de bergen van levensonderhoud voorzien.

Het boerenbedrijfssysteem in de bergen wordt gekarakteriseerd als een gemengd boerenbedrijf, bestaande uit graan produktie (natte rijst, tarwe en maïs), veeteelt en agroforestry, elementen die allemaal sterk onderling verbonden zijn binnen het agro-ecologisch systeem.

De Nepalese irrigatiesystemen kunnen in drie categorieën onderscheiden worden, gebaseerd op de fysisch geografische lokatie van het geïrrigeerde land. De drie lokaties zijn: aan de voet van de berg (middenloop), op de helling (bovenloop) en in de riviervallei. Een middenloop irrigatiesysteem irrigeert terrassen op de middenloop. Deze terrassen liggen in een bergengte langs de oevers van een bergrivier. Een bovenloop irrigatiesysteem irrigeert de bovenloop. Het irrigatie areaal ligt veel hoger dan de bergrivier die door een diepe bergvallei stroomt. Het irrigatiewater wordt derhalve van de zijtakken van de bergrivier afgetapt en vervolgens naar de akkers geleid voor irrigatie. Een irrigatie systeem in een riviervallei bevindt zich op de bodem van deze, meestal wijde, vallei.

De beschikbaarheid van water en de verticale diversiteit in landgebruik variëren aanzienlijk tussen de bovengenoemde drie types irrigatie systemen, en dientengevolge ook de beschikbare produktie inputs. Hierdoor verschillen ook de funkties van de verschillende types verdeelwerken en de irrigatiebeheerspraktijken voor elk type irrigatie systeem.

De FMIS in de bergen maken voornamelijk gebruik van drie verschillende types verdeelwerken, namelijk *ad hoc* instelbare (*ad hoc adjustment*), open-dicht (*open-close*) en proportioneel (*fixed proportional*) verdeelwerken. Een *ad hoc* instelbaar verdeelwerk bestaat uit een open kanaal als zijvertakking van het hoofdkanaal. De toevoer van water in dit secundaire kanaal wordt *ad hoc* geregeld met behulp van stenen en modder. Een open-dicht type is het eenvoudigste verdeelwerk. De watertoevoer is of nul of maximaal, afhankelijk of het verdeelwerk dicht of open is. Bij een proportioneel type stroomt het water door een vaste opening. In de bergen van Nepal zijn de meeste verdeelwerken proportioneel.

Een inheemse proportionele overlaat is een eenvoudige houten kunstwerk met meervoudige functies. De belangrijkste functie is echter de verdeling van het irrigatiewater over de secundaire kanalen, onafhankelijk van het waterniveau in het hoofdkanaal. Dit kunstwerk is loodrecht op de stroomrichting van het water in het hoofdkanaal geplaatst. Om zeker te zijn dat de watertoevoer overeenkomt met de breedte van de inkeping, worden de drempels van elke inkeping op gelijke hoogte gehouden.

Om een overlaat goed te laten functioneren, zijn de volgende hydraulische randvoorwaarden essentieel: vrije stroming door de stuw, uniform verdeelde lage snelheid van het water en een lage h/L verhouding (om effecten van belemmering van de stroming vanwege inkepingen met een grote variatie in breedtes, te minimaliseren). Dit proefschrift geeft aan dat de inheemse proportionele overlaten die de boeren op basis van hun ervaringen ontworpen hebben, overeenkomen met de hydraulische randvoorwaarden zoals vastgelegd in ISO en in hydraulische handboeken. Dit impliceert dat boeren kundige en bekwame actoren zijn en hydraulisch gedegen verdeelwerken kunnen ontwikkelen. De bovengenoemde hydraulische randvoorwaarden worden bij een inheemse proportionele overlaat bereikt door een bassin te maken en de stuw boven de normale kanaalbedding te installeren, aan het eind van een lange en wijder wordende aanvoerkanaal.

Hoe nauwkeurig het irrigatiewater verdeeld moet worden, hangt af van de lokale omstandigheden. Wanneer water relatief schaars is, worden bij operationele en topografische beperkingen ook de hydraulische randvoorwaarden van verdeelwerken in acht genomen. Is er water in overvloed, dan kunnen een aantal hydraulische vereisten genegeerd worden, omdat de nauwkeurigheid van de waterverdeling niet het grootste belang heeft. De verdeelwerken hoeven dan niet perfect te zijn. Het blijft echter een wonderlijke uitvinding, die de boeren in staat stelt om de waterverdeling aan te laten sluiten met de overeengekomen verdeling van watergiften. Wat belangrijker is, de boeren kunnen makkelijk de eigen dorpsmethoden gebruiken om het functioneren van het systeem te controleren.

Alle vier irrigatie systemen die beschreven zijn in de case studies in de hoofdstukken vier tot en met zeven zijn van het zogenaamde *run-of-the-river* type. Dit type is ontworpen voor de teelt van natte rijst gedurende het regenseizoen (juli tot oktober). In elk systeem is een billijke waterverdeling het primaire operationele doel. In elke case studie wordt eerst de agro-ecologische en sociale context van het systeem gegeven, waarna de historische ontwikkeling en de infrastructuur van het systeem worden beschreven. Elk hoofdstuk geeft een gedetailleerd onderzoek van de werking van het systeem weer. Ook wordt de relatie tussen de waterleveringswerken en de omgeving (zowel de sociale als de agro-ecologische omgeving) onderzocht, teneinde het beheer, de controle en het gebruik van het water te begrijpen en waarom bepaalde beheersvormen worden toegepast. Als laatste worden de irrigatie instituties en de lokale organisaties die zich hebben ontwikkeld op het gebied van beheer van het irrigatie systeem, onderzocht.

Het Julphe irrigatie systeem bevindt zich in een rivier vallei en irrigeert ongeveer 200 ha licht glooiend land behorende tot 340 boeren. De rivier de Girwari is de belangrijkste watertoevoer voor dit systeem. Hoewel tijdens het regenseizoen grote hoeveelheden water door de rivier stroomt, is het irrigatiewater toch een kostbaar goed. Door de frequente overstromingen wordt de inlaat vaak beschadigd en moet dus regelmatig onderhouden worden. Het systeem bestaat uit vier niveaus van waterlopen en heeft een groot aantal verdelingsstuwen om het water van het hoofdkanaal volgens de waterrechten van de boeren te verdelen over de andere kanalen. In een deel van het systeem wordt het water continu aangevoerd, terwijl in een ander deel het water bij toerbeurt wordt gedistribueerd. Het systeem is eigenlijk een federatie van drie kleinere, onafhankelijke sub-systemen. Elk sub-systeem functioneert als een autonoom systeem, met haar eigen organisatorische en institutionele afspraken aangaande het beheer en de exploitatie.

Oorspronkelijk werd door het Julphe irrigatie systeem slechts een klein gebied behorend tot één dorp, geïrrigeerd. Het systeem van nu is het resultaat van investeringen van de boeren die, vanaf eind jaren '50, vanuit de nabij gelegen bergen afdaalden en zich in dit gebied gevestigd hebben. Tijdens de uitbreiding van het systeem waren de investeringen van de boeren verschillend. Daarom kregen de boeren in verschillende delen van het systeem verschillende waterrechten toegewezen.

Het Bachcha irrigatie systeem bestaat uit terrassen op een berghelling (de bovenloop). Ook hoort er nog een klein gebied aan de voet van de berg (de middenloop) bij dit systeem. De fysische componenten van het verdelingssysteem en het irrigatiebeheer verschillen aanzienlijk tussen deze twee gebieden. Op de middenloop bestaat het verdelingssysteem slechts uit één niveau aan waterlopen. Hier wordt het *ad hoc* instelbare type gebruikt voor de waterverdeling. Op de bovenloop zijn de waterlopen van het verdelingssysteem over twee niveaus verdeeld. In het bovenste deel van het systeem worden proportionele waterverdeelwerken gebruikt, in het lagere deel de open-dicht types. Dit systeem kent dus zowel de kenmerken van bovenloop irrigatie als van middenloop irrigatie aan de voet van een berg. Binnen dit systeem wordt ongeveer 51 ha glooiend land van 197 boeren geïrrigeerd. Het systeem kent een organisatiestructuur met één niveau die geleid wordt door een invloedrijk persoon. De belangrijkste taak van deze organisatie is om de produktie inputs, met name arbeid, te mobiliseren voor onderhoud van het systeem.

Het Sankhar irrigatie systeem omvat 37 ha glooiend land op een berghelling, behorend tot 112 boeren. Het irrigatiewater wordt onttrokken aan een kleine beek dat langs de helling stroomt. Vergeleken met de andere systemen is hier minder water beschikbaar. De fysische componenten van dit systeem bestaan uit een tijdelijke overlaat die dwars op de stroom is geplaatst, een hoofdkanaal en drie niveau's verdelingskanalen. Maar het meest opvallend van dit systeem zijn de houten inheemse proportionele overlaten. Deze overlaten zijn bij alle vertakkingen van de kanalen geplaatst, zodat voortdurend elke gebruiker zijn of haar deel van het water kan krijgen. De waterlevering van dit systeem is volledig proportioneel, d.w.z. dat het water continu gedistribueerd wordt. Ook dit systeem kent een organisatiestructuur met één niveau, dat door een invloedrijk persoon geleid wordt, en heeft geen uitvoerend comité. De belangrijkste taak van deze organisatie is om produktie inputs, met name arbeid, te mobiliseren voor onderhoud van het systeem.

Het Patne irrigatie systeem bevindt zich op een berghelling en omvat ongeveer 21 ha glooiend land, dat in bezit is van 56 boeren. Het irrigatie water wordt onttrokken aan een natuurlijke bron en aan een kleine beek. De meeste percelen in dit irrigatiegebied liggen aan het hoofdkanaal. De percelen zijn derhalve lang en nauw; het bovenste, korte deel is verbonden aan het kanaal. Een reeks *ad hoc* instelbare verdeelwerken verspreiden het water naar de individuele velden van de boeren. Dit systeem heeft een organisatiestructuur met één niveau, met twee uitvoerende leden. Naast de waterverdeling heeft deze organisatie als taak het onderhoud van het systeem en het oplossen van geschillen met betrekking tot irrigatiewater. Gedurende het teeltseizoen van de natte rijst worden regelmatig, in bijzijn van alle boeren, vergaderingen gehouden om de waterverdeling te beheren.

Na de beschrijving van alle vier irrigatie systemen, wordt in het laatste hoofdstuk (hoofdstuk acht) gekeken hoe de keuze van de verdeelwerken, met name de proportionele overlaat, gerelateerd is aan de socio-culturele en agro-ecologische context van het irrigatie systeem, en welke voorwaarden hun aanvaarding en duurzaamheid bepalen. Hieronder wordt weergegeven hoe de verschillende verdeelwerken de beheersfuncties en de doelen van de lokale organisatie bepalen.

Verscheidene socio-culturele en agro-ecologische factoren bepalen het type irrigatiestelsel. Deze factoren staan in de volgende tabel beschreven.

Socio-culturele context	Agro-ecologische context
1. Kennis en praktijk	1. Fysisch geografische locatie van irrigatie areaal
2. Bronnen van arbeid en waterrechten	2. Ruimtelijke factoren van het land (hoogte, topografie, vorm en grootte van irrigatie areaal)
3. Macht	
4. Operationele vereisten	3. Beschikbaarheid van water
5. Inkomens strategieën	4. Gewas

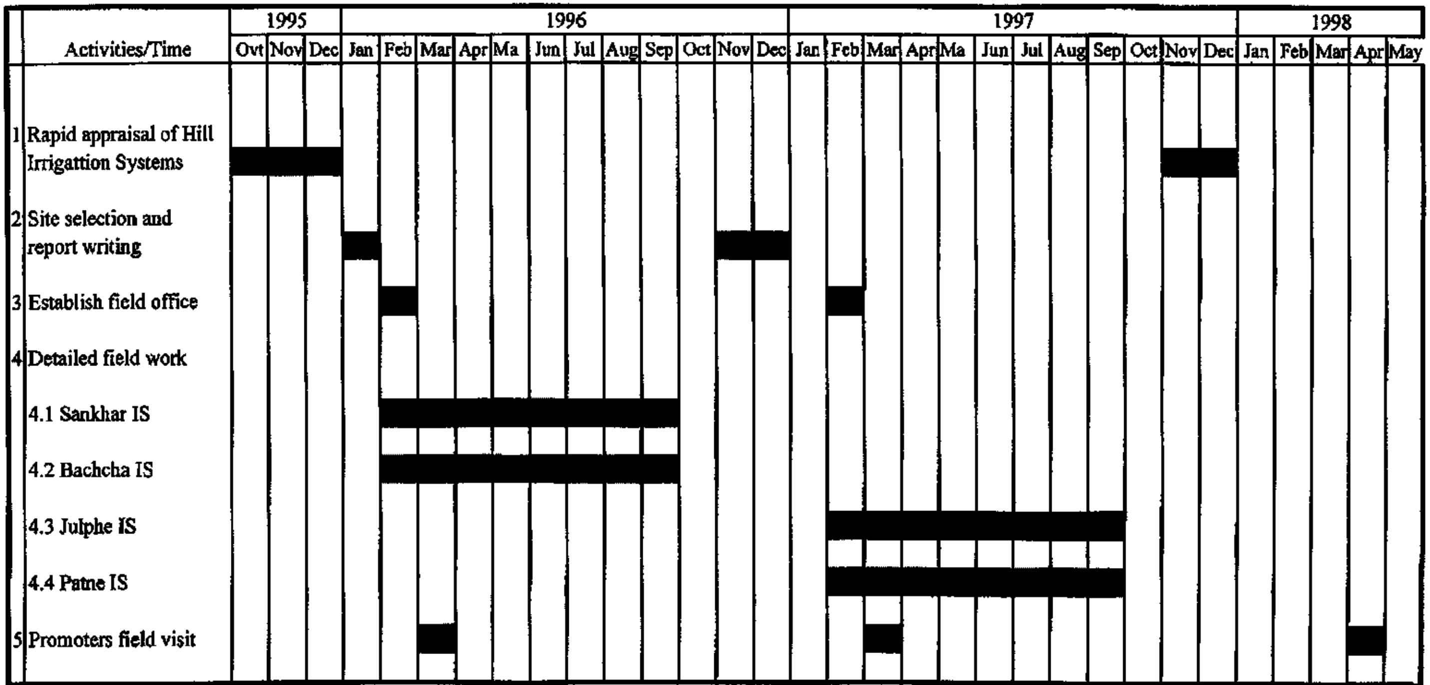
De keuze van het type verdeelwerk beïnvloedt de beheersfuncties en de doelen van de lokale organisatie. In een irrigatie systeem waar het water verdeeld wordt met behulp van het *ad hoc* instelbaar type, is de distributie van het water de belangrijkste taak van de lokale organisatie. Wordt het water verdeeld door een zogenaamd open-dicht systeem, dan is zowel de distributie van water als de mobilisatie van produktie inputs (arbeid) belangrijk. Wanneer in een irrigatie systeem het proportionele verdeelwerk wordt toegepast, is de mobilisatie van produktie inputs (arbeid) de belangrijkste taak binnen de lokale organisatie. De volgende tabel geeft de kenmerken van een aantal beheersfuncties en doelstellingen zoals die ontwikkeld zijn tijdens het beheren van irrigatie systemen met verschillende types waterverdeelwerken.

Type waterverdeelwerk	Organisatorische en institutionele ondersteuning	Doorzichtigheid van rechtvaardigheid	Kans op wanbeheer en geschillen m.b.t. water	Overdracht van waterbeheerstaken naar gebruikers	Operationele kosten	Handel in water	Flexibiliteit	Beheersintensiteit noodzakelijk voor distributie van water	Primaire doelen van waterbeheer van de lokale organisaties
Ad hoc instelbaar	■	ǀ	■	ǀ	■	ǀ	■	■	Water distributie
Open-dicht	▮	■	▮	▮	▮	▮	▮	▮	Water distributie en mobilisatie van produktie inputs
Proportioneel	ǀ	■	ǀ	■	ǀ	■	ǀ	ǀ	Mobilisatie van produktie inputs

Binnen een irrigatie systeem bepalen de hydraulische, de agro-ecologische en de socio-culturele omstandigheden de keuze van het type verdeelwerk, die op hun beurt de beheersfuncties en de belangrijkste taken voor de lokale organisatie bepalen. In de huidige benadering van irrigatie ontwikkeling en beheer worden de boeren als belangrijkste actoren gezien in zowel de decentralisatie van door de overheid beheerde irrigatie systemen als in het herstel van de door boeren beheerde irrigatiesystemen. Het is dus vitaal voor de verdere ontwikkeling van deze systemen, uitgevoerd in nauwe samenwerking met de lokale gemeenschap, om de voorwaarden te begrijpen die het irrigatiestelsel beïnvloeden. Wanneer deze voorwaarden niet worden onderkend bij de ontwikkeling van deze systemen, kunnen de bestaande beheerspraktijken eroderen, als ook de huidige en potentiële bijdrage van irrigatie aan het lokale levensonderhoud. Herkenning van deze voorwaarden in het beleid kan leiden tot efficiënter gebruik van de waterbronnen en een verbetering van de inkomens in de bergen van Nepal.

Appendix I

Schedule of the field reasearch work



Note: IS refers to irrigation system

Appendix II

Systems studied under the Rapid Appraisal Survey

Name of irrigation system	Location (District)	Irrigated area (ha)	Types of water division structure
1. Rogate	Baglung	25	Proportioning weir /open close
2. Ghackowck	Kaski	60	Ad hoc adjustment by a operator
3. Pahare	Kaski	20	Ad hoc adjustment by controlled turnout
4. Upper Dabake	Kaski	18	Ad hoc adjustment by controlled turnout
5. Lower Dabake	Kaski	15	Ad hoc adjustment by controlled turnout
6. Bari Kulo	Nawalparasi	75	Proportioning weir/open close
7. Aagauli	Nawalparasi	160	Proportioning weir/ open close
8. Bejad	Palpa	40	Proportioning weir
9. Kandel	Palpa	18	Proportioning weir
10. Ghimire	Palpa	8	Proportioning weir
11. Tripur	Palpa	13	Proportioning weir
12. Darcha	Palpa	15	Proportioning weir
13. Pangrang	Parbat	30	Proportioning weir/open close
14. Kurga	Parbat	30	Proportioning weir/open close
15. Phalebas	Parbat	140	Proportioning weir/open close
16. Tallo Sankhar	Syangja	18	Proportioning weir/open close
17. Gaire Baguwa	Tanahu	11	Ad hoc adjustment by controlled turnout
18. Satrahasaya	Tanahu	26	Proportioning weir
19. Dhakal Tar	Tanahu	22	Ad hoc adjustment by operator
20. Yampa *Phant*	Tanahu	53	Ad hoc adjustment by operator
21. Satrasaya *Phant*	Tanahu	55	Ad hoc adjustment by operator

Appendix III

Principal physical features of proportioning weirs

(Julphe Irrigation System)

This table should be read as follow:
Each box of the figure represents the notch of a proportioning weir. Values in the upper row of boxes indicate notch widths in cm. Values in the lower row indicate water shares to be distributed through notches. For example, in the proportioning weir, P2, 8, 118 and 85 are the notch widths in cm. It has two branching canals with water shares 20 and 704 *katthas* respectively. This table is to be read with figures 4.5 and 4.11

Weir No.	Physical details of proportioning weirs	Incoming water (*kattha*)	Total notch width (cm)	Notch width per *kathha*	Total weir width (cm)	Notch depth (cm)	Notch length (cm)	Weir height (cm)	Average canal width (cm)	Length of approach canal (m)
P1	↓ Flow direction 52 | 52 | 4 | 51.5 | 51.5 | 45 | 3 40% (845) To P36 | 14.5 | 60%(750.45) 724.0 | 12 (Cement weir)		259		550	39	48	30/DS	170	8
	Julphe Kulo									
P2	8 | 118 | 85 20 704	724	211	0.291	325	20	25	40	150	4
P3	(Shir Ko Bagaicha) 13 | 134 | 132 | 19 31 628 45	704	298	0.423	520	25	32	42	140	5
P4	(Kavra Ko Phed) 8 | 88.5 | 93 | 7 25 585 18	628	197	0.313	450	20	25	52	140	5
P5	(Mudabase Kulo) 13 | 3 | 74.5 | 156 29.5 7 548.5	585	247	0.421	480	21	29	21	140	6
P6	(Khinekumal Ko Dharo) | 73 | 61 5 543.5	548.5	134	0.244	290	25	20	22 u/s 70 d/s	140	
TO1	← 5; ↓ 538.5 (orifice type of turnout) (Pande Ko Muhan)	543.5	The canal bed is above the *khet* on its left side. An orifice of diameter about 10 cm is provided about 15 cm above the canal bed. The orifice is made of hollow timber.							
TO2	← 10; ↓ 528.5 (orifice type of turnout) (Ganga Ko Muhan)	538.5								
		528.5								
	In this sub-system, from P1 down to P7, 20 kattha of water shares is allocated as conveyance losses. It is presumed that this 20 kattha is proportionally distributed from this point onward. For this reason, 528.5 kattha of incoming water is considered as 508.5 kattha.									
P7	(Dabdabe Phed) 117 119 | 103 | 33 445 63.5 (Timber on top of cement weir)	508.5	255	0.501	400	22	35	5 u/s 37 d/s	120	

Weir No.	Physical details of proportioning weirs	Incoming water (*kattha*)	Total notch width (cm)	Notch width per *kathha*	Total weir width (cm)	Notch depth (cm)	Notch length (cm)	Weir height (cm)	Average canal width (cm)	Length of approach canal (m)
	(Ishwori Chowk)									
P8	70 | 120 192.0 253	445	190	0.427			38			
	Dabdabe West Canal									
P9	3.5 | 63 | 42 5.5 186.5	192	109	0.565	300	15	20	30 d/s	150	
P10	63 | 56 | 21 (also works as check) 154 32.5	186.5	140	0.751	300	16	17	46 20	150	
P11	Not noted									
P12	Not noted									
P13	33 | 28 | 102 31 25 98	154	163	1.058	300	14	34	36	80	
P14	13 | 103 11 87	98	116	1.184	170	12	9	34	70	
P15	18 | 94 15 72	87	112	1.287	180	11	18	40	70	
P16	32 | 74 22 50	72	106	1.472	190	8	19	20	70	
P17	62 | 10 42 8	50	72	1.440	170	13	9	30	70	
P18	3.5 | 67 2 40	42	70.5	1.679	140	13	5	21	70	
P19	32 | 69 13.5 26.5	40	101	2.525	160	11	19	12	60	
P20	64 | 5 24.5 2	26.5	69	2.604	130	8	14	22	60	
P21	Tiwari Ko Ghar 5.5 | 58 2 22.5	24.5	63.5	2.592	110	11	7.5	12	60	
	Dabdabe South Canal									
P22	8.5 | 64.5 | 67 15 238.0	253	140	0.553	260	29	18	18	100	3.5
P23	6 | 93 | 61 9 229	238	160	0.672	240	19	19	24	100	3.0
P24	5 | 75 | 75 7 222	229	155	0.677	240	21	22	30	100	3

Weir No.	Physical details of proportioning weirs	Incoming water (*kattha*)	Total notch width (cm)	Notch width per *kathha*	Total weir width (cm)	Notch depth (cm)	Notch length (cm)	Weir height (cm)	Average canal width (cm)	Length of approach canal (m)
P25	3 69 75 4 218	222	147	0.662	240	20	23	19	100	3
P26	Laxmi Ko Ghar 27 51.5 82 35 183	218	161	0.736	240	15	25	7 u/s 43 d/s	100	5
P27	3 128 5 178	183	131	0.716	210	13	16	37	100	
P28	10 59 57 14 164	178	126	0.708	200	15	19	27	90	3
P29	17 8 60 76 16 8 140	164	161	0.982	280	19	24	24	90	5
P30	102 52 101 39 (Timber u/s of cement weir)	140	154	1.100	210	17	25	10 lhs 60 rhs	90	3.5
P31	39 41 16 84 17	101	96	0.950	180	17	22	40	60	3
P32	4.5 5 42 26 8 76	84	77.5	0.923	150	18	19	20	60	
P33	20 22.5 24 47.5 28.5	76	66.5	0.875	150	15	21	27	50	
P34	30 35 22 25.5	47.5	65	1.368	150	14	19	20	50	
	Dabdabe East Canal									
	0.5 ← ⊖ ↓ 63 (orifice type of turnout) (Ishwori Ko Muhan)	63.5								
P35	57 63.5 14 27 36	63	135	2.135	280	16	23	14	70	5
Kolia sub-system										
P36	Hattigaunda Ko Dhara 72 72 20 (cement weir no pond 745 100 upstream)	845	164	0.194	500	26	31	44	150	10
P37	Tulsingh Gurung Ko Dhara 68 54 9.5 92.5 7.5	100	132	1.315	270	19	22	19	100	3
P38	Daraun Khole Sarkee Ko Dhara 52 65.5 3 90 2.5	92.5	121	1.303	230	19	32	25	70	2
P39	45 50 41.5 48.5	90	95	1.056	190	18	15	15	70	2

Weir No.	Physical details of proportioning weirs	Incoming water (*kathha*)	Total notch width (cm)	Notch width per *kathha*	Total weir width (cm)	Notch depth (cm)	Notch length (cm)	Weir height (cm)	Average canal width (cm)	Length of approach canal (m)
P40	5 / 30.5 / 24 3.5 38	41.5	59.5	1.434	190	12	14	10	70	2
P41	8.5 / 43 6.5 31.5	38	51.5	1.355	190	10	13	20	70	2
P42	(Unused weir)									
Basanatpur sub-system										
P43	Pindalu Chowk 63 / 64 / 65 495 250	745	192	0.258	450	23	31	53	120	10
P44	Purano Nambari Ko Dhara 32 / 29 / 23.5 92 158	250	84.5	0.338	220	18	22	10	120	8
P45	Bifale Kumal Ko Ghar Ko Dhara 32 / 36 / 36 105 53	158	104	0.658	290	21	27	21	100	5
P46	Purbetar Ko Dhara 47 / 73 / 72 119 376 (Cement weir)	495	192	0.388	430	28	30	18	150	10
P47	Lamtange Ko Dharo 128 / 17 335.0 41	376	145	0.386	200	13	23	30	90	3
P48	Phulbari Ko Dharo 49 / 122 96.5 238.5	335	171	0.510	250	20	23	32	90	2
P49	Bandhari Ko Dharo 113 / 85 137.5 101	238.5	198	0.828	270	18	30	23	90	5

Note: u/s and d/s refers to weir height up stream and down stream of weir respectively

Appendix IV

Amount of labour mobilized by the Julphe and Basantpur sub-systems for system maintenance

Date	Julphe sub-system		Basantpur sub-system		Activities
	Present	Absent	Present	Absent	
25-May-97			164	7	Main canal cleaning
26-May-97			145	30	"
27-May-97			112	10	Dhick Kulo cleaning
31-May-97	116	16			Main canal cleaning
31-May-97	116	24			"
01-Jun-97	189	26			"
02-Jun-97	130	21	108	39	Intake construction
03-Jun-97	133	18	28	31	"
09-Jul-97	129	22			Julphe Kulo cleaning
10-Jul-97			40	23	Intake maintenance
12-Jul-97	108	43			"
15-Jul-97	61				"
16-Jul-97	127	24	59	16	"
20-Jul-97			39	21	"
25-Jul-97			34	27	"
27-Jul-97			24	24	"
28-Jul-97			39	9	"
31-Jul-97			36	51	"
13-Aug-97			118	27	"
15-Aug-97			49	13	"
16-Aug-97	106	45	48	39	"
20-Aug-97			33	29	"
22-Aug-97			33	55	"
25-Aug-97			31	33	"
06-Sep-97			35	48	"
10-Sep-97			82	58	"
18-Sep-97	121	25	105	47	Maintenance of
19-Sep-97	133	13	158	15	breached main canal
20-Sep-97	146	10	148	29	"
21-Sep-97	126	16	125	42	"
22-Sep-97	130	16	124	38	"
23-Sep-97	132	14	121	50	"
24-Sep-97	128	18			
25-Sep-97	129	17			"
Total	2260	368	2038	811	

Note: Labour mobilized by Julphe is the average of morning and afternoon shifts

Appendix V

Farmer's water shares and landholdings with respect to terminal points of proportioning weirs in Julphe Irrigation System

Terminal points of proportioning weirs	Number of farmers	Water shares (*kattha*)	Flow (lps)	Irrigated area (*bigha*)	Irrigated area (ha)	Flow rate (lps/ha)	Remarks
Julphe sub-system							
P1 (west)	2	14.45	7.23	0.77	0.51	14.12	FP
P1 (east)	1	12.00	6.00	0.75	0.50	12.08	FP
P2 (west)	1	20.00	10.00	2.00	1.32	7.55	FP
P3 (east)	10	45.00	22.50	6.05	4.01	5.62	FP
P3 (west)	2	31.00	15.50	4.10	2.72	5.71	FP
P4 (east)	1	18.00	9.00	1.50	0.99	9.06	FP
P4 (west)	1	25.00	12.50	1.75	1.16	10.79	FP
P5 (west)	4	29.50	14.75	2.64	1.75	8.44	FP
P5 (west)	1	7.00	3.50	0.45	0.30	11.74	FP
P6 (west)	1	5.00	2.50	1.50	0.99	2.52	FP
TO1 (west)	1	5.00	2.50	0.35	0.23	10.79	FP
TO2 (west)	1	10.00	5.00	0.65	0.43	11.62	FP
Dabdabe west canal							
P9 (west)	1	5.50	2.75	0.33	0.22	12.78	FP
P10 (south)	5	32.50	16.25	2.14	1.42	11.47	FP
P13 (west)	4	31.00	15.50	4.00	2.65	5.85	FP
P13 (south)	1	25.00	12.50	1.35	0.89	13.98	FP
P14 (west)	1	11.00	5.50	0.55	0.36	15.10	FP
P15 (west)	1	15.00	7.50	0.65	0.43	17.42	FP
P16 (west)	2	22.00	11.00	1.15	0.76	14.44	FP
P17 (east)	1	8.00	4.00	0.40	0.26	15.10	FP
P18 (west)	1	2.00	1.00	0.35	0.23	4.31	FP
P19 (west)	3	13.50	6.75	0.85	0.56	11.99	FP
P20 (east)	1	2.00	1.00	0.30	0.20	5.03	FP
P21 (west)	1	2.00	1.00	0.50	0.33	3.02	FP
P21 (south)	10	22.50	11.25	8.10	5.36	2.10	PP, Section 1
Dabdabe south canal							
P22 (west)	2	15.00	7.50	1.11	0.73	10.25	FP
P23 (west)	1	9.00	4.50	0.65	0.43	10.45	FP
P24 (west)	2	7.00	3.50	0.70	0.46	7.55	FP
P25 (west)	1	4.00	2.00	0.30	0.20	10.07	FP
P26 (west)	1	35.00	17.50	1.75	1.16	15.10	FP
P27 (west)	1	5.00	2.50	0.30	0.20	12.58	FP
P28 (west)	2	14.00	7.00	1.35	0.89	7.83	FP
P29 (west)	2	8.00	4.00	0.85	0.56	7.11	FP
P29 (south)	1	16.00	8.00	1.25	0.83	9.66	FP
P30 (east)	24	39.00	19.50	9.40	6.23	3.13	PP, Section 2
P31 (east)	4	17.00	8.50	3.30	2.19	3.89	FP
P32 (west)	2	8.00	4.00	1.00	0.66	6.04	FP

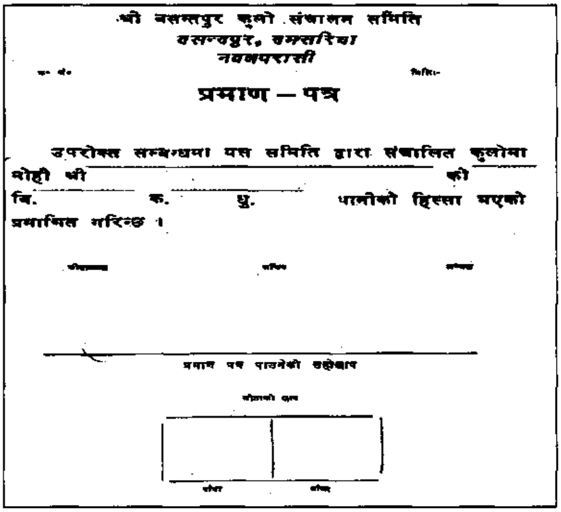
Terminal points of proportioning weirs	Number of Farmers	Water shares (*kattha*)	Flow (lps)	Irrigated area (*bigha*)	(ha)	Flow rate (lps/ha)	Remarks
P33 (east)	17	28.50	14.25	8.80	5.83	2.45	PP, Section 3
P34 (west)	14	22.00	11.00	7.50	4.97	2.21	PP, Section 4
P34 (east)	21	25.50	12.75	11.50	7.62	1.67	PP, Section 5
Dabdabe east canal							
TO3 (south)	1	0.50	0.25	0.15	0.10	2.52	FP
P35 (south)	10	27.00	13.50	4.55	3.01	4.48	PP, Section 6
P35(east)	18	36.00	18.00	7.54	4.99	3.60	PP, Section 7
		730.45			69.65		Total of Julphe
Kolia sub-system							
P37 (east)	1	7.50	2.48	1.75	1.16	2.14	FP
P38 (east)	1	2.50	0.83	0.50	0.33	2.49	FP
P39 (east)	26	48.50	16.01	18.85	12.48	1.28	PP, Section 1
P40 (west)	1	3.50	1.16	0.35	0.23	4.98	FP
P41 (west)	1	6.50	2.15	0.65	0.43	4.98	FP
P41 (south)	10	31.50	10.40	6.00	3.97	2.62	PP, Section 2
		100.00			18.61		Total of Kolia
Basantpur sub-system							
P44 (south)	17	92.00	23.92	33.00	21.85	1.09	PP, Section 1
P45 (east)	27	53.00	13.78	13.75	9.11	1.51	PP, Section 2
P45 (south)	54	105.00	27.30	34.85	23.08	1.18	PP, Section 3
P46 (west)	31	119.00	30.94	20.80	13.77	2.25	PP, Section 4
P47 (east)	18	41.00	10.66	10.25	6.79	1.57	PP, Section 5
P48 (west)	20	96.50	25.09	12.60	8.34	3.01	PP, Section 6
P49 (west)	30	137.50	35.75	20.17	13.36	2.68	PP, Section 7
P49 (east)	39	101.00	26.26	24.40	16.16	1.63	PP, Section 8
		745.00			112.46		Total of Basantpur
					200.72		Total of system

Note:
Flow of each terminal point of the proportioning weir is computed on the basis of measured flows at various points in the system. For this computation, the average flows at the Julphe, Kolia and Basantpur sub-systems are taken as 0.5, 0.33 and 0.26 lps/*kattha* respectively (see Table 4.6 in the main text).

PP refers to partially proportionate
FP refers to fully proportionate

Appendix VI

A copy of water right certificate issued by Basantpur irrigation committee



श्री बसन्तपुर कुलो संचालन समिति
बसन्तपुर, तमसरिया
नवलपरासी

प्रमाण — पत्र

उपरोक्त सम्बन्धमा यस समिति द्वारा संचालित कुलोमा मोही श्री ______ को बि. ____ क. ____ धु. ____ पानीको हिस्सा भएको प्रमाणित गरिन्छ ।

प्रमाण पत्र पाउनेको सहीछाप

English translation of the above certificate:

Basantpur Canal Operation Committee
Basantpur, Tamsariya
Nawalparasi

S No. Date:

Certificate

This is to certify that user Mr...................................own water shares of *bigha* .... *kattha*.........*dhur*............ in the canal operated by this irrigation committee.

(Treasurer)	(Secretary)	(Chairman)

Signature of farmer receiving certificate

Finger prints

Right	Left

Appendix VII

Water distribution in Bikase Khanda

Bikase Khanda is located in the Basantpur sub-system, and receives water through proportioning weir, P45. For cultivating paddy, the section is sub-divided into two sub-sections, A and B. Sub-section B is further sub-divided into two units, C and D. The average incoming flows during and after the period of paddy transplantation are about 48 and 29 lps respectively. Figure A1 and Table A1 show the schematic layout and principal physical features of Bikase Khanda respectively.

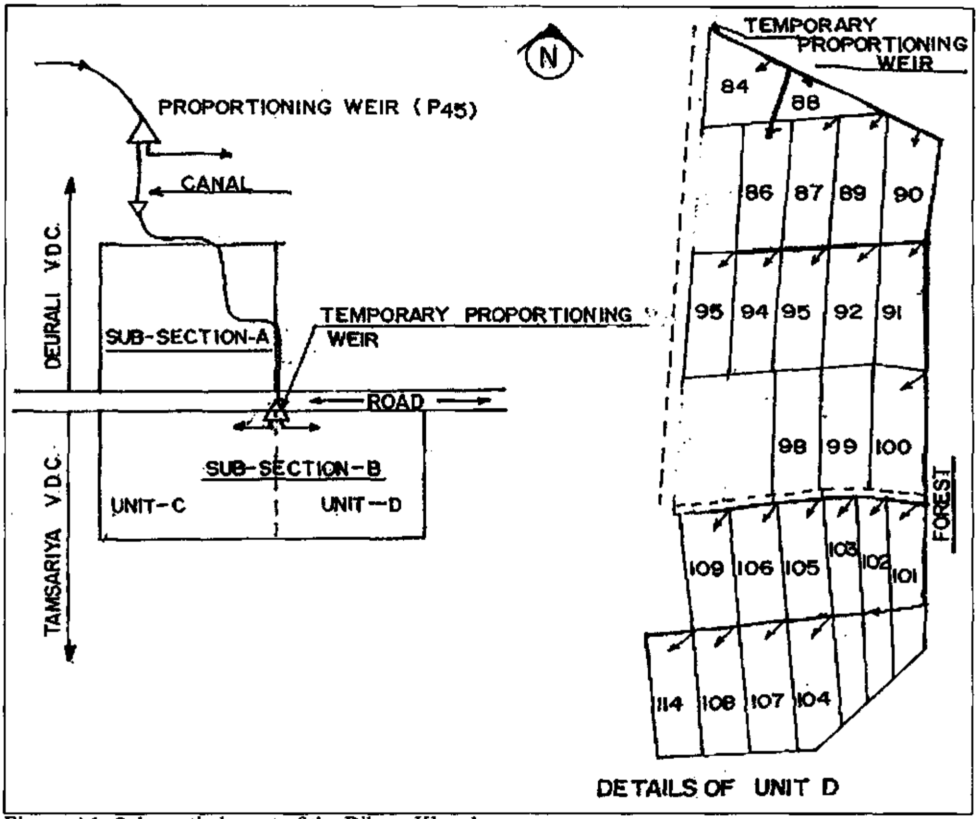


Figure A1: Schematic layout of the Bikase Khanda

Note: Plot numbers 98 and 99 do not have water share

Table A1: The number of farmers, area irrigated and water shares in Bikase Khanda.

Sub-section	Location	Number of farmers	Area irrigated (ha)	Farmer's water shares (*kattha*)
Sub-section A	Deurali VDC	19	10.10	47
Sub-section B	Tamsariya VDC			
Unit C		16	5.6	26
Unit D		20	7.28	32

In this section, the water users' committee (section committee) consists of a chairman, one vice chairman, one treasurer, and five members. Farmers elect the chairman and other committee members every year. Usually it is formed after the start of paddy transplantation and remains active till the paddy cultivation period. Members of this committee are elected in such a way that they represent all three areas of the section. Committee members representing each area manage water distribution in their respective areas. The main tasks of this committee are to manage water distribution among farmers, impose fines on farmers who do not follow rules of water distribution and to resolve minor water related disputes.

Water distribution during paddy transplantation

In this section, once the field is prepared, farmers must complete the paddy transplantation on the same day. For this reason, the water demand to maintain the standing water in the puddled field does not exist. In the daytime, water is distributed exclusively to prepare land for paddy transplantation. At night, it is distributed mainly to irrigate paddy which is already transplanted.

The pattern of water distribution in sub-sections varies during the day and at night. During daytime, sub-sections A and B receive water alternately. At night, sub-section A receives water from 6 p.m. to 11 p.m., and sub-section B receives water from 11 p.m. to 5 a.m. (next day). Within sub-section B, during both the day and at night, the incoming flow is further sub-divided into two parts for units C and D. A temporary wooden proportioning weir is placed at the canal bifurcation point to divide the flow corresponding to their water shares.

During daytime, in each unit, the flow is further divided into two to three parts and distributed to farmers as per their requirements irrespective of their water shares and irrigated area. A farmer requiring water has to inform the committee members well in advance. The committee members allocate turns among farmers.

At night, water is distributed based on the combination of both farmers' water shares and area transplanted. For example, if a farmer having a total water share of 4 *kattha* completes paddy transplantation in 0.2 ha out of his total area of 0.5 ha, his water share for that particular night is counted as (4/0.5X0.2)=1.2 *kattha*. The total available time (6 hours for sub-section B) is then divided by the sum total water shares of farmers for that particular night. This gives the time duration per unit of water shares which is then multiplied by the farmers' share to get the irrigation time for each of them.

In this section, although paddy transplantation started on 14th July, competition to use water increased only in late July. Accordingly, the rotational schedule for both the day and night was enforced only from 26th and 27th July respectively. As the transplanted land area increases with time, a new rotational schedule needs to be prepared every night. Table A.2 shows the rotational schedule used by farmers in unit D of sub-section B.

Since the chairman of the section committee belonged to this unit, in this unit, the chairman and a few other farmers prepare the rotational schedule for night irrigation. Every afternoon the chairman moves around in the area to monitor the progress of paddy transplantation.

Table A.2: Water distribution schedule for night irrigation in unit D, in sub-section B

S.N.	Name of farmer	Plot No	Total area (bigha)	Water share (kathha)	26-Jul		27-Jul		28, 29 Jul		30, 31 Jul		1, 2 Aug		03-Aug		4, 5 Aug		6, 7 Aug	
					Trans. area *bigha*	Total time (min)	Trans. area *bigha*	Total time (min)	Trans. area *bigha*	Total time (min)	Trans. area *bigha*	Total time (min)	Trans. area *bigha*	Total time (min)	Trans. area *bigha*	Total time (min)	Trans. area *bigha*	Total time (min)	Trans. area *bigha*	Total time (min)
1	Soam Bd. Poudel	84	0.5	1	0.25	11	0.25	8	0.25	7	0.25	7	0.5	12	0.5	33	0.5	12	0.5	11
2	Padam Pani Poudel	86	0.5	1	0.5	17	0.5	15	0.5	14	0.5	14	0.5	13	0.5	28	0.5	12	0.5	11
3	Tek Bd. Thapa	88	0.5	1							0.25	10	0.25	7	0.25	14	0.25	7	0.25	6
4	Rudra Narayan	87, 89	1	3	0.33	17	0.5	23	0.5	22	0.5	21	0.5	20	0.65	56	0.65	25	1	36
5	Nathhe Kumal	90	0.5	1	0.5	17	0.5	16	0.5	15	0.5	14	0.5	13	0.5	28	0.5	12	0.5	11
6	Jeet Bd. Thapa	91,92	1	3			0.66	31	0.66	30	0.66	29	0.66	27	0.66	56	0.66	25	0.66	24
7	Dhan Bd. Bayambu	93	0.5	3								0	0.33	26	0.5	56	0.5	37	0.5	36
8	Bishnu Poudel	94	0.5	2	0.5	36	0.5	31	0.5	30	0.5	30	0.5	26	0.5	56	0.5	25	0.5	24
9	Khum Kumari Poudel	95	0.5	2	0.5	36	0.5	31	0.5	30	0.5	29	0.5	27	0.5	56	0.5	25	0.5	24
10	Devu BK	100	0.5	2	0.5	36	0.5	31	0.5	30	0.5	29	0.5	27	0.5	56	0.5	25	0.5	24
11	Gyan Raj Devkota	101, 102	0.66	3	0.66	52	0.66	47	0.66	45	0.66	44	0.66	40	0.66	84	0.66	38	0.66	36
12	Devi Pd.	103	0.5	1					0.125	2	0.125	5	0.125	4	0.125		0.125	4	0.5	13
13	Goam Lal Kumal	105	0.5	1	0.5	17	0.5	16	0.5	15	0.5	14	0.5	13	0.5	28	0.5	13	0.5	12
14	Harsa Ram Kumal	106	0.5	1	0.5	17	0.5	16	0.5	15	0.5	14	0.5	13	0.5	28	0.5	13	0.5	12
15	Man Dhoj Pulami	109	0.5	2	0.5	36	0.5	31	0.5	30	0.5	30	0.5	27	0.5	61	0.5	25	0.5	23
16	Gyan Raj Devkota	101, 102	0.34	1	0.34	17	0.34	16	0.34	15	0.34	14	0.34	13	0.34	28	0.34	13	0.34	12
17	Chure Kumal	104	0.5	1	0.5	17	0.5	16	0.5	15	0.5	14	0.5	13	0.5	28	0.5	13	0.5	12
18	Bale Kumal	107	0.5	1	0.5	17	0.5	16	0.5	15	0.5	14	0.5	13	0.5	28	0.5	12	0.5	11
19	Suite Kumal	108	0.5	1					0.5	15	0.5	14	0.5	13	0.5	28	0.5	12	0.5	11
20	Jeet Bd. Kumal	114	0.5	1	0.5	17	0.5	16	0.5	15	0.5	14	0.5	13	0.5	28	0.5	12	0.5	11
	Total		11	32	7.08	360	7.91	360	8.535	360	8.785	360	9.365	360	9.685	780	9.685	360	10.41	360

Note: Jul refers to July

The following few points explain the above night irrigation schedule used by the farmers in this unit:

- In this method, there is a rule that field does not get irrigation water the following night of the transplantation day. Such field starts getting irrigation water from the next night onwards. For example, a field transplanted on 29th August starts getting turn for night irrigation from 30th August onwards.

- Except in the beginning, the same rotational schedule works for two nights. This is because, transplantation in a sub-section can be performed on alternate days. For example on 28th July, water was diverted to sub-section A. Transplanted area in sub-section B remained the same as that of 27th July. For this reason rotational schedule for the night of 29th July was the same as that of 28th July.

- On 3rd August, it was the day of *aunsi*. In Nepali, *aunsi* is a moonless period. In *aunsi,* since bullocks cannot be used to plough land, water demands to prepare land for paddy transplantation does not exist. Accordingly, the mode of water distribution changes. On that day (3rd August) from 5 a.m. to 4 p.m., sub-section A used water and sub-section B used it from 4 p.m. to 5 a.m. (next day)

In this method, if a farmer wants to use his entire water shares at night, even if some of his land is not transplanted, he can do so. But once he uses all his water shares at night, he would not get water turn during daytime to transplant the remaining land.

By 5th August, 10.41 *bigha* of land had been transplanted. Except a few patches, most of the remaining land was transplanted on 7th August. On 7th August, farmers declared the completion of paddy transplantation in this section.

Water distribution after the completion of paddy transplantation
With the completion of the paddy transplantation, *ghante palo* was started. In *ghante palo,* the entire incoming flow is rotated among farmers within the section strictly on a time-share basis, corresponding to farmers' water shares. The temporary proportioning weir, which was installed during the period of paddy transplantation, does not work any more.

Sub-section A receives irrigation water in the first turn, known as *jetho palo.* Units D and C receive irrigation water in the second and third turns, known as *mailo* and *kancho palo* respectively. Table A3 shows the time allocation to sub-sections based on their water shares.

Table A3: Time allocation to sub-sections in Bikase Khanda.

Sub-sections	Irrigation turn	Water shares (*kattha*)	Time required (hours)	Allocated duration	Allocated time (hours)
Sub-section A	*Jetho palo*	46	15.77	6.00 PM to 9.45 AM	15.75
Sub-section B					
Unit D	*Mailo palo*	33	11.31	9.45 AM to 9.06 PM	11.35
Unit C	*Kancho palo*	26	8.91	9.06 PM to 6.00 AM	8.90

Based on the above irrigation turn, in each sub-section or unit, separate rotational schedule is prepared. Table A4 shows the time allocation to farmers in unit D of sub-section B.

Table A4: Time allocation to farmers in unit D of sub-section B.

Name of farmers	Plot number	Area	Water shares	Allocated time (hours)		Actual time
		(*bigha*)	(*kattha*)	From	To	(minutes)
1 Soam Bd. Poudel	84	0.5	1	21.45.00	22.10.30	25.50
2 Padma Poudel	86	0.5	1	22.10.30	22.31.00	20.50
3 Tek Bd. Thapa	88	0.5	1	22.31.00	22.51.30	20.50
4 Rudra Narayan	87,89	1.0	3	22.51.30	23.53.00	61.50
5 Nathhe Kumal	90	0.5	1	23.53.00	00.13.30	20.50
6 Jeet Bd. Thapa	91,92	1.0	3	00.13.30	01.15.00	61.50
7 Hi Maya Thapa	98	0.5	1	01.15.00	01.35.30	20.50
8 Dhan Bayambu	93	0.5	3	01.35.30	02.36.30	61.00
9 Bishnu Poudel	94	0.5	2	02.36.30	03.17.30	41.00
10 Khum K. Poudel	95	0.5	2	03.17.30	03.58.30	41.00
11 Devu BK	100	0.5	2	03.58.30	04.39.30	41.00
12 Moti Bhandari	99	0.5	1	04.39.30	05.00.00	20.50
13 Gyan R. Devkota	101,102	1.0	3	05.00.00	06.01.30	61.50
14 Devi Pd.	103	0.5	1	06.01.30	06.22.00	20.50
15 Goam Kumari	105	0.5	1	06.22.00	06.42.30	20.50
16 Harsa Kumal	106	0.5	1	06.42.30	07.03.00	20.50
17 Man D. Pulami	109	0.5	2	07.03.00	07.44.00	41.00
18 Chure Kumal	104	0.5	1	07.44.00	08.04.30	20.50
19 Bale Kumal	107	0.5	1	08.04.00	08.25.00	20.50
20 Suite Kumal	106	0.5	1	08.25.00	08.45.30	20.50
21 Jeet Bd. Kumal	114	0.5	1	08.45.30	09.06.00	20.50

Table A4 shows that the time is allocated up to the fraction of a minute. In the past, the section committee used to allocate the time up to a measurable time unit, by allocating 20 minutes per unit of water share. However, by doing so, about 35 minutes is saved, which used to be re-allocated to farmers having land at the tail-end. In 1997, farmers could not agree regarding the re-allocation of this saved time. For this reason, rotational schedule was prepared up to a fraction of a minute. However, in practice farmers count only up to a minute.

The following few points explain the rotational schedule presented in Table A4

- Note that, during the period of paddy transplantation, this area had total water shares of 32 *kattha*. At the end of paddy transplantation period, one farmer (Hi Maya Thapa) bought one *kattha* of water shares in sub-section A, and was transferred here. This made the total water share 33 *kattha*. She used this water in plot number 98, which originally did not have any water shares. Similarly, another farmer (Moti Lal Bhandari) also bought one *kattha* of water shares from a farmer (Gyan Raj Devkota) in the same unit. Mr Moti Lal Bhandari used this water in plot number 99.

- The above water trading was of temporary nature, only for paddy cultivation. Buyers provide 35 *pathi* of paddy to sellers for one *kattha* of water share.

- Note that five minutes extra time is allocated to the first farmer Mr Soam Bd. Poudel. This is because in every turn he had to divert water into this unit from sub-section A. It was his responsibility to divert water within the prescribed time.

Appendix VIII

Principal physical features of proportioning weirs

(Sankhar Irrigation System)

<u>This table should be read as follows</u>
Each box of the figure represents the notch of a proportioning weir.
Values in the upper row of the boxes indicates notch widths in centimetres.
Values in the middle row indicate water shares to be distributed through the notches.
The third row indicates the numbers of the next proportioning weir where the water is diverted for further distribution.

For example, in the proportioning weir number P3, 201, 10, 235 and 6 are the notch widths in cm. 1000, 40, 1170 and 20 are the water shares (*mato muri*) in the branching canals. 1000 and 1170 *mato muri* of water goes to weir number P34 and P4 respectively for further distribution downstream. 40 and 20 *mato muri* of water belongs to the individual farmer. TP means terminal point.

Weir No.	Physical details of proportioning weirs	Incoming water (*mato muri*)	Total notch width (cm)	Notch width per *mato muri*	Total weir width (cm)	Notch depth (cm)	No. of branching canals
Main canal	↓ (Flow direction)						
P1	288 | 5 (with *moko* to smaller notches) 2250 20 P2 TP	2270	293	0.13			2
P2	285 | 5 (with *moko* to smaller notches) 2230 20 P3 TP	2250	290	0.13			2
P3	(Dui Dhare) 201 | 10 | 235 | 6 (with *moko* to smaller notches) 1000 40 1170 20 P34 TP P4 TP	2230	452	0.20	7300	6.7	4
Thado Kulo							
P4	20 | 154 | 158 11 (with *moko* to smaller notches) 60 1080 30 P15 P5 TP	1170	343	0.29	600	5	3
P5	169 | 8 | 111 | 13.5 (with *moko* to smaller notches) 615 20 405 40 P6 TP P17 P16	1080	301.5	0.28	600	3	4
P6	51.5 | 50 | 8 | 61 | 65.5 264 20 331 P26 TP P7	615	236	0.38	400	3	3
P7	8 | 77 | 72 | 10.5 16 295 20 TP P8 TP	331	167.5	0.51	300	4	3
P8	28 | 28 | 40 | 28 | 14.5 265 30 P9 TP	295	138.5	0.47	300	6	2
P9	30 135 100 TP P10 P13	265					3
P10	5 | 15 | 23 | 25 10 30 95 TP TP P11	135	68	0.50	200	4	3
P11	15 60 20 TP P12 TP	95					3

P12 30 30 TP TP	60					2
P13 20 | 16 | 20 | 18 | 20 | 8 20 16 37 27 TP TP TP P14	100	102	1.02	200	3	4
P14 25 2 TP TP	27					2
P15 12 | 12 | 12 20 40 TP TP	60	36	0.60			2
P16 26.7 13.3 TP TP	40					2
P17 21.5 | 14 | 21 | 21 | 21 | 21 | 22.5 | 7 60 345 TP P18	405	149	0.37	360	5	2
P18 15.5 | 18 | 18 | 10 | 15 | 8 | 15 | 15 | 13 | 15 | 18 | 15 30 70 50 75 55 35 30 P22 P23 TP P19 TP P25 TP	345	175.5	0.51			7
P19 16.5 | 18 | 19.5 | 17 17.5 57.5 TP P20	75	71	0.95	150	5	2
P20 14.5 | 12 | 11 40.5 17 P21 TP	57.5	37.5	0.65	140	3	2
P21 8 | 9.5 | 10 | 12 8 10 22.5 TP TP TP	40.5	39.5	0.98	100	4	3
P22 29 | 16 25 5 TP TP	30	45	1.50	150	4	2
P23 12.4 57.7 TP P24	70					2
P24 20 37.7 TP TP	57.7					2
P25 19 | 19 17.5 17.5 TP TP	35	38	1.09	100	6	2
P26 21 | 21 | 17 | 16 | 16 | 16 | 9 | 15 | 12 40 160 15 27.5 21.5 P33 P27 TP TP TP	264	143	0.54	350	7	5
P27 10 150 TP P28	160					2
P28 7 | 14 | 14 | 14 | 13 | 14 | 27 10 140 TP P29	150	103	0.69	175	4	2

P29	| 8 | 16 | 16 | 16 | 16 | 16 | 16 | 8 | 10 80 20 30 TP | P30 | TP | TP		140	112	0.80	350	5	4
P30	|22.5|22.5| 15 | 60 20 P31 TP		80	60	0.75	100	2	2
P31	| 32 | 32 | 32 | 32 | 15 15 15 15 TP | P32 |		60	128	2.13	170	4	2
P32	| 9 | 9 | 11 | 11 | 11 | 11 | 21 | TP TP TP TP TP TP TP			83		200		
P33	|__|__| 20 20 TP TP		40					2
Terso Kulo								
P34	|74.5| 77 | 67 | 66 | 68 | 53 |19 | 350 490 120 40 | P47 | P38 |P36|TP |	(With *moko* to smaller notches)	1000	424.5	0.42			4
P35	| 6.5 | 26 | 15 |12.5| 18 | 10 40 70 TP | TP | P36 |		120	78	0.65			3
P36	| 14 | 21 | 21 | 30 40 TP P37		70	56	0.80			2
P37	|__|__| 20 20 TP TP		40					2
P38	| 5 | 67.5 | 70 | 80 | 7 150 333 TP | TP | P39 |		490	222.5	0.45	350	8	3
P39	| 11 | 66.5 |24.5| 81 | 20 120 45 148 TP P43 TP P40		333	183	0.55	400	5	4
P40	| 35 | 36 | 73 75 P42 P41		148	71	0.48	150	4	2
P41	|24.5|17.5|10.5| 35 25 15 TP TP TP		75	52.5	0.70			3
P42	|__|__|__| 15 24 34 TP TP TP		73					3
P43	|__|____| 20 100 TP P44		120					2
P44	|____|__| 78 22 P45 TP		100					
P45	|__|__| 33 45 TP P46		78					2

P46 30 15 TP TP	45					2
P47 37.5 51 59 13.5 3 315 30 5 P48 TP TP	350	164	0.47			3
P48 (Not installed) 275 40 P59 P59	315					2
P49 65.5 40 39.5 11 255 20 P50 TP	275	156	0.57			2
P50 (not installed during measurement) 178 47 30 P51 P57 TP	255					3
P51 2 14 14 14 14 14 14 4 30 144 TP TP P52	178	86	0.48			3
P52 32 12 4 37 38 36 15 5 88 P60 P61 TP P53	144	123	0.85			4
P53 12 12 12 12 7 20 68 TP P54	88	55	0.63			2
P54 11 11 11 7 60 8 P55 TP	68	40	0.59			2
P55 13 13 13 13 13 13 10 10 20 20 TP TP P56 TP	60	78	1.30			4
P56 10 10 TP TP	20					2
P57 20 27 TP P58	47					2
P58 18 9 18 9 TP TP	27	27	1.00			2
P59 10 30 TP TP	40					2
P60 16 20 TP TP	36					2
P61 5 10 TP TP	15					2

Appendix IX

Written authority given by the farmers to the chairman

(Sankhar Irrigation System)

Written authority in Nepali:

लिखित अख्तीयारी

स्वस्ती श्री सम्बत २०४८ साल आषाढ .....गते.....रोज देखी हाम्रा माथिल्ला कुलाका अधिका स्थिती वमोजिम दिन को १० वजे हामि तपसिलमा लेखिएका मोहि हरू सामेल भई अख्तीयार ले अह्राए वमोजिम मुख नलागी आ-आफ्ना खेत का माटो मुरी का हिसावले माटो मुरी ३०का खेताला १ का दरले रोज रोजै पुरा गरौला। म्व बमोजिम पुरा गर्न नसकेर अपुग भयो भने माथि लेखिए बमोजिम खेताला एक का मोहर रू १५।- का दरले रोज रोजै बुझाऊला। काम मा आल टाल गरी अख्तीयार ले अह्राए वमोजिम काम नगरी मुख लाग्यौं भने हिला पानि ले छेपेमा र अटेर गरे आ-आफ्ना धारा पानि बन्द गरे समेत उजुरू गर्ने छैनौं, गरेछौ भने यसै भर्पाइले वदर गरी लिनु भनि हाम्रा मनोमानि खुसि राजिले अख्तीयार नामाको भरपाई लेखि सहि छाप गरि अख्तीयार मा दियौं।

मोहिहरूको सहिछाप

English translation of the above authority:

Written authority

We, the undersigned farmer and *akhtiyar* of the Uppallo Kulo , who have been gathering at 10 A.M. since....(date),...Asadh (the month in the Nepali Bikram Sambat calendar corresponding to mid June-mid July), Bikram Sambat 2048(19..), commit to undertake and complete the work assigned by the *akhtiyar* without any dispute, by contributing one labour for every 30 *mato muri* a day. If we are unable to complete the work as per the said arrangement, we shall pay a fine at the rate of Rs15/-per labour daily. If we do not undertake the work assigned by the *akhtiyar* and argue with him, or throw water at him, or do not obey him, we shall not file a complaint against him even if he shuts the water inflow (*dhara pani*) of our respective *dhara*. If we do, we sign this authority letter to the effect that this authority letter shall supersede the said complaint.

Signatures of the farmers

Appendix X

Irrigated areas and water shares of a few farmers in the Sankhar Irrigation System

S.N.	Name of farmer	Irrigated area in *ropani*	Water shares in *mato muri*	Water/land ratio *mato muri/ropani*
1	Tirtha Raj Tiwari	23.07	85	3.68
2	Chuda Mani Dhakal	08.78	28	3.18
3	Parbati Uchai	02.95	09	3.05
4	Prem Narayan Dhakal	17.13	45	2.62
5	Bhim Lal Kandel	04.21	10	2.37
6	Medini Lal Bhattarai	06.38	30	4.70
7	Raghu Nath Bhattarai	14.23	50	3.51
8	Dullav Bhattarai	03.89	10	2.57
9	Puspha Raj Adhikari	08.18	20	2.44
10	Pitambar Bhattarai	05.95	16	2.68
11	Ram Chandra Prakash Saha	23.01	56	2.43
12	Bidha Raj Dhakal	11.28	40	3.54
13	Hira Mani Dhakal	09.15	30	3.27
14	Guna Kharkha Gaire	05.73	15	2.61
15	Anirudhra Dotel	04.00	10	2.50
16	Mani Ram Bhattarai	04.44	16	3.60
17	Durga Pd. Gaire	04.76	15	3.15

Appendix XI

Questionnaire for structured interview

Name of irrigation system: ______________________
Date of interview: ______________________

I. Identification

Name of respondent: ______________________
Ward number/Village (house): ______________________

II. Demographic characteristics

1. Total members in the family:

S.N.	Relation with Respondent	Age	Sex		Education*				Occupation **	
			M	F	1	2	3	4	Main	Secondary
1 2 3	Respondent Spouse									

Note: * Educational Code:
- Illiterate = 1
- Just literate = 2
- School literate = 3
- Collage literate = 4

** Occupational Code:
- Agriculture = 1
- Service = 2
- Business = 3
- Agriculture labor = 4
- Wage earner / labor = 5
- Student = 6
- Other (specify) = 7

2. Are you in-migrated? (Yes/ No)
If yes,
From where?....................
When?...........................

3. Is your any family member out-migrated? (seasonal or permanent) (Yes/No)
If yes,
How many members?........
Where? ....
Reasons?.............

III Agricultural aspect

1. Land tenure status:
Area: *ropani/mato muri*

Ownership pattern	*Khet*			*Bari*	*Khar bari*
	Fully irrigated	Partially irrigated	Rainfed		
1. Owner cultivated					
2. Rented-in					
3. Rented-out					
4. Total					

Note: Fully irrigated : Year-round irrigated with canal
Partially irrigated : Irrigated for some part of the year with canal
Rainfed : Totally depending upon rain

2. Are your parcels scattered? (Yes/ No)
If yes,
a) Number of parcels...........
b) Location....................................

3. Do you have lands outside the command area of this irrigation system? (Yes/ No)
If yes,
Where?..............
How much? (*khet* ....*bari*................)

4. Have you rented-in any land? (Yes/ No)
If yes, under what conditions?
....
....

5. Area planted, varieties planted and production of major crops

Crops		*Khet*						*Bari*	
		Fully Irrigated		Partially irrigated		Rainfed			
		A	P	A	P	A	P	A	P
Early paddy	Improved								
	Local								
Late paddy	Improved								
	Local								
Maize	Improved								
	Local								
Wheat	Improved								
	Local								
Others	Improved								
	Local								

Note: A = Area in *mato muri* or *ropani*
P = Production in *muri* or Kg.

6. Do you use chemical fertilizers? (Yes/ No)
If yes, what are the sources of chemical fertilizers?
Sajha ( )
AIC ( )
Market ( )
Others (specify)..........................

6.1 Use of fertilizer for various crops

Crops	Area	*Khet*				*Bari*	
		Irrigated		Rainfed			
		C	CF	C	CF	C	CF
Early paddy							
Late paddy							
Wheat							
Maize							
Others							

Note: C = Compost in *doko*
CF = Chemical fertilizer in Kg.(specify the chemical fertilizer)
Area in *mato muri* or *ropani*.

6.2 If you do not use the chemical fertilizers, why?
Expensive ( )
Not available in the surrounding area ( )
Do not want to use it ( )
Others (specify) ....

7. Do you use insecticides and pesticides to prevent your crops? (Yes/ No)
If yes, what insecticides and pesticides are used and what is the quantity?

Crops	Brand name	Quantity per area	Remarks
1. 2. 3. 4.			

7.1 If no, why?
Expensive ( )
Not available in the surrounding area ( )
Do not want to use it ( )
Others (specify) ....

8. Do you use improved varieties of seeds? (Yes/ No)
If yes, for which crop, quantity and what varieties?

Crops	Varieties	Quantity per area	Remarks
1. 2. 3.			

8.1 What are the sources of improved varieties of seeds?
Sajha ( )
AIC ( )
Relatives ( )
Self ( )
Market ( )
Others (specify) ....

8.2 If you do not use improved varieties of seeds, why?
Expensive ( )
Not available in the surrounding area ( )
Do not want to use it ( )
Others (specify) ....

9. Do you have shortage of agricultural labors? (Yes/ No)
If yes, in which month? ....
And for which crops? ....
How do you meet the required labors?.................................

10. Do you have enough food throughout the year? (Yes/ No)
If no, how many months do you have food shortage?
Less than three months ()
3-6 months ()
6-9 months ()

10.1 In case of food shortage, how do you meet your food needs?
From landlords ()
From relatives ()
From friends ()
Other sources ()

10.2 If you have enough food, what farm produce did you marketed?

Produce	Marketed amount (MT)	Estimated earning in 1995
Late paddy		
Early paddy		
Wheat		
Maize		
Others		

11. Do you have any off-farm activity? Yes / No
If yes, specify

Types of activity	Annual earning (Rs)
a) Salary	
b) Pension	
c) Business (trade)	
d) Wage earning	
e) Others (specify)	
Total	

This earning is .... percentage of the total annual family earning.

12. Livestock detail

12.1 Please specify the number of livestock you have
Cow .... no.
Water buffalo .....no.
Oxen...................no.

12.2 From where do you bring fodder for livestock
Homestead ....%
Forest............. ....% (approximately .... *doko*)
Cultivated land ....%

13. Agriculture extension
Does your village have extension worker? (Yes / No)
If yes what type of extension worker (JT/ JTA/...../.....)
What is the frequency of visit by extension worker (............)
What is the frequency of your visit to extension worker (...............)

14. Is there any change in agricultural practices (new crops, varieties and technologies) in the last 25 years. (Yes/ No)
If yes, specify:
....
....

15. What are the common problems which you commonly encountered in agricultural production activities?
....
....
....

16. Productivity status in last five years

Crops	Productivity			
	Increased	Same	Decreased	No idea
1. Late paddy 2. Wheat 3. Maize 4. Early paddy 5. Others				

IV Irrigation

1. Does the WUA hold general meeting to discuss irrigation problems? (Yes/ No)
1.1 If yes, how many times a year?
Once a year ( ) which month..................
Twice a year ( ) which months................
Thrice a year ( ) which months..............
No definite time ( )

1.2 Who calls the general meeting?

1.3 What are the usual agenda of the general meeting?
Resources mobilization for O&M ( )
Election/selection of executive body ( )
Financial issue ( )
Water allocation ( )
Dispute resolution ( )
Others (specify).......................

1.4 How the resolution passed?
Vote ( )
Consensus ( )

1.5 Are the minutes of the general meeting maintained? (Yes/ No)

2. What is the remuneration of executive body?

3. Are you the executive member of Water User's Association? (Yes/ No)
3.1 If yes, what are your responsibilities?
a) Water distribution ()
b) System strengthening ()
c) Operation and maintenance ()
d) Dispute resolution ()
e) Others, if any (specify)..

3.2 How many meetings of the executive body were held in 1996? ....

3.3 How many times did you attend the meeting? ....

3.4 Were all the decisions minuted? (Yes/ No)

4. Did you participate in irrigation system strengthening, repair and maintenance? (Yes/ No)
If yes,

Participation	Contribution		
	Labor days	Cash (Rs)	Kinds (value in Rs)
Irrigation system strengthening (recent one) year.........			
Repair and maintenance in 1996			

5. What is the frequency of regular maintenance?

6. What was the basis of contribution for system strengthening/ annual repair and maintenance?
Equal to every households ( ), how much, Rs..............
According to land size ( ), rate: Rs.........*mato muri* or *ropani*
According to water share ( ), rate: Rs.............water share

7. Who is responsible for water distribution?
Water user's main committee ()
Water user's field level committee ()
Farmers themselves ()
Others (specify) ....

8. What are the rules for water distribution?
First priority to head portion ( )
First priority to tail portion ( )
No priority ( )
Rotation ( )
Continuous ( )
Others (specify)...
(If differ for various cropping seasons, specify)

9. What is the basis of water allocation?
Equal to all (households) ( )
According to land area ( )
According to water share ( )
Others (specify).....................................

10. How does water allocation change with crops and level of water supply?
....

11. What are the penalties for water steal?
Cash penalty ( ), how much Rs......................
Devoid from irrigation ( ), how many hrs..................
Others (specify)...............................

12. Do you get sufficient water? (Yes/ No)
If no, why (specify)................................
Do you get water in time? (Yes/ No)

13. Is dispute between farmer is common? (Yes/ No)
If yes, frequently ( )
Occasionally ( )
Seldom ( )

13.1. What are the causes of dispute? (list them by priority)
a)...
b)..

13.2 Who is responsible to solve the dispute?
Water User's Association ( )
Farmers themselves ( )
Village Development Committee ( )
Others (specify)..

13.3 What are the dispute resolution mechanisms?
Social pressure ( )
Compensation ( )
Others (specify)..

14. What is the means of communication in the system?
Proclamation by *chaukidar* ( )
Letter issued by WUA ( )
Water user's themselves ( )
Others (specify)............................

15. What are the penalty provisions for following items?

For non-repay of cash (farmers contribution) ....
For not attending O&M activity.......................
Others (specify)..

16. What is the process of decision making?

Local regulation constituted by farmers ( )
Others (specify)....................................

17. What water rights does your household have? (..........*mato muri*), and how were they acquired?

Inheritance ( )
Brought ( )
Others ( )

Has the amount of water rights changed in the last ten years? (Yes/ No)

18. Has your family increased the area of *khet* land in your living memory? (Yes/ No)
If yes, when and how much? (........................)

19. How frequently do you have to check the water level in field during paddy cultivation under continuous and rotational flow regime?
Continuous flow ....
Rotational flow................

20. Is the time of rotation is adequate for irrigation? (Yes/ No).
If not, how do you manage?
....

21. How is rotation of water is supervised within blocks and who performs it?
....

22. How do you balance irrigation and heavy rain? What do you do if you have too much of water in the terraces?

23. How do you irrigate large terraces?
For paddy.......................................
For wheat/ Maize................................

24. Are there any restriction on the irrigation timing, tools use for irrigation and people who perform water distribution from religious point? (Yes/ No)
If yes, what are they......................

25. Do you perform any worship or ceremony as part of your agriculture/ irrigation activities? (yes/ No)
If yes, explain..

26. What is the minimum size of *khet*, which you need to support your families?

Curriculum Vitae

Umesh Nath Parajuli was born on 12 July 1952 in Kathmandu, Nepal. In 1978, he received a Bachelor's degree in Civil Engineering from the Indian Institute of Technology, Kharagpur, India. In 1979, he joined the Department of Irrigation, His Majesty's Government of Nepal, as an Assistant Engineer. Since then he is continuing his service to the development of irrigation in Nepal.

In 1988, he entered a master degree programme at Water Resources Development Training Centre, University of Roorkee, India. In 1989, he obtained his Master's degree in Water Use Management and returned to his home country to resume his work in the Department of Irrigation. During most of his service periods with the Department of Irrigation

Since 1979 till 1994, except during his MSc study period, he worked for the development of Farmer Managed Irrigation Systems in the remote hills of Nepal. In November 1994, he joined the Wageningen Agricultural University for his Ph.D. degree.