LIQUID GOLD
1996 PAPER 1

SCARCITY BY DESIGN

Protective Irrigation in India and Pakistan

M. Jurriens, P.P. Mollinga, P. Wester

Wageningen Agricultural University
Department of Irrigation & Soil & Water Conservation,

INTERNATIONAL INSTITUTE FOR LAND RECLAMATION AND IMPROVEMENT/ILRI

CONTENTS

Page

1 INTRODUCTION 1

2 THE ORIGINS AND MEANINGS OF PROTECTIVE IRRIGATION 3
- 2.1 The First Meaning of Protective Irrigation 3
- 2.2 The Second Meaning of Protective Irrigation 5
- 2.3 The Third Meaning of Protective Irrigation 6

3 THE TECHNICAL DIMENSION: DUTIES AND INTENSITIES 9
- 3.1 The Meaning of Duty, Water Allowance and Intensity 9
- 3.2 Some Examples 11
  - 3.2.1 Northwest India and Pakistan 11
  - 3.2.2 South India 13
  - 3.2.3 Central India 14
  - 3.2.4 Northeast India 14
  - 3.2.5 New Systems 15
- 3.3 Conclusions 16

4 THE OPERATION AND MANAGEMENT DIMENSION: WATER CONTROL CONCEPTS AND WATER DISTRIBUTION PRINCIPLES 17
- 4.1 Northwest India and Pakistan 17
- 4.2 South India 18
- 4.3 Central India 20
- 4.4 Northeast India 22
- 4.5 Checklist for System Analysis 23

5 THE SOCIO-ECONOMIC DIMENSION: CHANGING WATER DEMANDS 25
- 5.1 Agricultural Development and Farmers' Interests 25
- 5.2 Summary of Conflicting Objectives 26

6 PERFORMANCE OF PROTECTIVE IRRIGATION SYSTEMS 29
- 6.1 Northwest India and Pakistan 29
- 6.2 South India 33
- 6.3 Central India 35
- 6.4 Northeast India 36

7 DISCUSSION 37
- 7.1 Shifting to Productive Irrigation 37
- 7.2 Achieving Protective Irrigation Through New Strategies 39

8 CONCLUSIONS 41

REFERENCES

ANNEX 1

1 INTRODUCTION

The dominant design practice in irrigation engineering is to design irrigation systems in such a manner that water supply covers the full crop water requirements, either completely by irrigation or in addition to rainfall. Most large scale irrigation systems in India and Pakistan,.however, are based on an essentially different design logic. These "protective irrigation" systems are designed and operated on the principle that the available water in rivers or reservoirs has to be spread thinly over a large area, in an equitable manner. The idea is to reach as many farmers as possible, and to protect them against crop failure and famine, which would regularly occur without irrigation in regions with low and erratic rainfall. The amount of water a farmer is entitled to receive is insufficient to cover full crop water requirements on all of his land for an average rainfall year. The primary objective of protective irrigation thus has an explicit social dimension.

Protective irrigation is not just an exceptional footnote to normal irrigation engineering. India and Pakistan are among the three developing countries with the largest areas under irrigation: 42 million ha in India[1)] and 16 million ha in Pakistan[2)] (World Bank, 1988). A considerable part of these areas is under protective irrigation. For Pakistan, irrigation is the lifeblood of agriculture, providing more than 90% of agricultural production (World Bank, 1994), whilst in India about two-thirds of agricultural production comes from irrigated areas (Tilak and Rajvanshi, 1991). These facts alone warrant devoting attention to the characteristics of protective irrigation. Moreover, in other parts of the world irrigation schemes are increasingly faced (in design or operation) with growing water scarcity. A discussion on protective irrigation may be relevant to such conditions as well.

Protective irrigation systems are based on scarcity by design. This has important implications for their operation and management. It involves the problem of rationing scarce water in a supply based system, where the objectives of an individual farmer may differ from those of the system management. The past decades it has become apparent that many protective irrigation systems in both India and Pakistan were not performing as expected. Problems have been discussed over the years by many authors, with low efficiencies in water delivery and use, inequitable distribution, unreliable water delivery, widespread vandalism of structures, poor maintenance, waterlogging and salinity and insufficient cost recovery being named as the most pressing (Vohra, 1975; GoAP, 1982; Chambers, 1988; World Bank, 1991; Bandaragoda and Firdousi, 1992; IPTRID, 1993; Navalawala, 1993; World Bank, 1994). India's irrigation policy is now

1) Figures in various sources differ. The official estimate of "irrigation potential created" was 68 million ha in 1985. However, irrigation potential is the gross area which theoretically could be irrigated in one year on the basis of an assumed design cropping pattern, and thus is not the same as the net irrigated area. The net irrigated area was 42 million ha in 1985. The net irrigated area under canals was 16 million ha in 1985. (World Bank, 1991:2,7).

2) The area covered by large scale irrigation schemes in Pakistan is 14 million ha (Sufi, Ahmad and Zuberi, 1993). In China, the third developing country with much irrigation, the area under irrigation is 47 million ha, while in CIS and USA respectively 21 and 19 million ha are under irrigation (Hoffman, Howell and Solomon, 1990).

gradually shifting its emphasis from design and construction of new systems to the functioning of existing ones (GoI/MoWR, 1987; GoI/PC, 1992). In Pakistan, potential sites for new irrigation schemes are nearly nil. The focus of its current irrigation policy is on shifting to productive irrigation through scheme modernization and the progressive privatization of the complete Indus Basin irrigation system (GoP/MoFAC, 1988; Bandaragoda and Badruddin, 1992; World Bank, 1994).

It is our conviction that the performance of protective systems has much to do with their specific design characteristics. A thorough understanding of the essentials and implications of the protective design is therefore indispensable for appreciating their present functioning and for developing programmes for performance improvement. *The main purpose of this paper is to explain the essentials of protective irrigation and to demonstrate their importance with respect to problems of performance and improvement*. Surprisingly, explicit discussion of this issue in the literature on irrigation in India and Pakistan is scarce. There is abundant literature on technical, agricultural, sociological and economic aspects, but very little on the relation between supply and demand of irrigation water and its consequences. Berkoff (1987, 1988, 1991), Jurriëns *et al.* (1987), Jurriëns and Landstra (1989) and Mollinga (1992) were among the first to explicitly raise this issue in recent times.[3] The present lack of information on the actual performance and management of protective irrigation is alarming, in view of the enormous importance of irrigation for the two countries.

After a brief review of the history and meaning of protective irrigation in Chapter 2, the technical and managerial concepts in different parts of India and in Pakistan are discussed in Chapters 3 and 4. Chapter 5 depicts some socio-economic aspects and gives a summary of the conflicts between the protective concept and present farmers' interests. The resulting system performance is then evaluated in Chapter 6. On the basis of that, Chapter 7 presents some reflections on possible lines of action for improvement. It is argued that no real improvements are possible when the consequences of the initial design concept as related to the changed environment, are not taken into account, particularly with respect to water availability and demand. Finally, in Chapter 8, several conclusions are drawn.

---

3) Several times in the paper, we observe that not much is known on the issue under discussion. We emphasize that this is based on the (both formal and grey) literature we know. Any additional information would be welcomed.

2 THE ORIGINS AND MEANINGS OF PROTECTIVE IRRIGATION

The principle of protective irrigation has been applied in India and Pakistan since the previous century, but a clear and explicit definition is difficult to find. In essence, protective irrigation is a specific type of large scale irrigation, in which water is scarce by design, found in the semi-arid, drought prone areas of the Indian subcontinent. As far as can be traced from literature, the term has been used in three different, but overlapping meanings: as a general term denoting protection against famine by irrigation, as a financial-administrative class of works in colonial irrigation policy, and as a specific type of irrigation. This chapter sets out these three different meanings of protective irrigation.

2.1 The First Meaning of Protective Irrigation

The concept of protective irrigation emerged in the context of British colonial rule of the Indian subcontinent. British canal-building activities commenced in India in 1817, with the restoration of a Mughal canal situated near Delhi. This canal came to be known as the Western Yamuna Canal. The little knowledge the British had on irrigation was expanded during the construction of the Ganga Canal, which was undertaken in response to a severe famine in 1837-38. Construction work on this canal started in 1843 and the canal became fully operational in 1857.[1] (Stone, 1984)

With the annexation of the Punjab in 1849, the British gained full control over the Indo-Gangetic plains. They were quick to see the enormous irrigation potential of the area and lost little time in starting the construction of the Bari Doab Canal (BDC, latter renamed Upper Bari Doab Canal), which was completed in 1859. The canal was planned to be 247 miles long and carry a discharge of 3,000 cusecs. Irrigation commenced in 1861 by a system of cuts in the main canal, because distributaries had not yet been provided. (Michel, 1967).

Several motives lay behind the construction of the BDC. The desire of the British to improve the revenue-producing capacity of the lands they annexed was one. A careful calculation of the proceeds of the BDC had been made before it was constructed and the projected returns was one of the reasons it was sanctioned. Another motive was the fear of famine. The famine of 1837-38 was still fresh in the memory of the administration and spurred the development of the BDC. However, the most important objective was to provide employment for Sikh Army veterans. This army had been disbanded in 1849, turning thousands of able-bodied men loose on the countryside. A large number of them took up brigandage and generally disturbed the peace. To solve this problem the British employed them on the construction of the canals and when possible settled them on the wastelands benefited by the canal. (Michel, 1967)

---

1) To fully appreciate the contribution the British made, not only to irrigation in the Indian subcontinent but to irrigation science in general, one must realize that they had virtually no experience in the field of irrigation at the start of the 19th century. Very little was known on hydraulics at the time and few large scale canal irrigation systems existed in the world.

Thus, right at the onset of the development of irrigation, the objectives of the British colonial involvement in irrigation can already be discerned, namely to;

1) Increase the collection of land revenue,
2) Provide a means of famine prevention, and
3) Maintain political and social stability (Michel, 1967; Stone, 1984).

After the Mutiny, or first war of independence, of 1857-58, the Crown took over the rule of India from the East India Company. For a short period, between 1858 and 1866, the government experimented with irrigation development through private irrigation companies (Atchi Reddy, 1990). This was necessary because the cost of irrigation construction, in terms of initial capital outlay, was beyond its means at that time. This experiment proved disastrous.[2] In 1866 the government decided that canal irrigation should be a state activity and it took over the responsibility for irrigation development. Furthermore, it decided that further extension of irrigation works would be financed by loans taken out by the Government of India in London. This was deemed necessary because the earlier system of financing irrigation from the general revenues did not allow a quick expansion of irrigation. To reduce the risks to a minimum, strict conditions were set forth for the application of loan funds. The projected irrigation schemes were not to be undertaken if there was not a reasonable expectation that they would be remunerative, i.e. bring in a profit. As a result, confidence in irrigation was restored and for the first time an adequate and reliable flow of funds went into irrigation development. All government works, including irrigation, were reclassified as either major works (to be financed by loans and labelled as "extraordinary") or minor works (to be financed from revenues and labelled as "ordinary"). (Whitcombe, 1983; Stone, 1984)

In 1867, Strachey was appointed as Inspector-General of Irrigation, and set the task to coordinate the development of irrigation in India. In a fundamental memorandum[3], written in 1867, Strachey set out the principles that shaped the British irrigation policy until it quit India in 1947. In this memorandum he introduced the notion of "irrigation duties", and suggested it be used as the basic criterion for designing irrigation schemes (Whitcombe, 1983). Besides that, he stressed the protective nature of irrigation.

> ***"It appears to me that the Government now having adopted the policy of extending irrigation generally, and so far as is possible in a manner that shall to the utmost guard against the worst effects of severe drought ... in every canal, at the earliest possible period, an allotment of the***

---

2) The Madras Irrigation and Canal Company was established in 1857, and officially existed until 1882. To develop the Mahanadi delta in Orissa, a second company was formed, the East India Irrigation Company. Both these companies were empowered to raise capital of £2 million, and started constructing schemes in 1863. The financial failure of the 'Orissa Undertaking' of the East India Irrigation Company became apparent in 1867, and in 1869 the government bought out the company. In 1882 the Madras Irrigation and Canal Company was bought out. (Whitcombe, 1983; Atchi Reddy, 1990)

3) Strachey, R., 'On the Principles to be Followed in Determining the Capacity of Irrigation Canals in Upper India; in Regulating the Distribution of the Available Water Supply to the Districts Through Which a Canal Passes and to Villages or Individual Cultivators; and in Assessing the Charge Made for Irrigation'. India Public Works Department - Irrigation Proceedings, September 1867. Unfortunately, we did not have access to this memorandum at the time of writing. Gustafson and Reidinger (1971), however, set out the main points.

> *available supply should be made on fixed principles to the districts traversed by it.*" (Strachey, quoted in Gustafson and Reidinger, 1971:A-159)

The question equity that was stressed by Strachey was of primary importance for the British colonial government (Gustafson and Reidinger, 1971). Equity was defined as giving a proportionate share of the available water to each acre of land that could use it.

Thus, in 1867, the general objectives of the British irrigation policy were pretty much in place. At this stage the policy consisted of roughly three elements. The schemes that were to be constructed had to be remunerative because the loans taken out on them had to be repaid and the British wanted to make a profit. Secondly, the schemes were to serve as a protective measure against famine. These first two objectives lead to the formulation of a sub-objective, namely to extend irrigation to the largest possible area at the lowest costs. Thirdly, the available water was to be shared among the cultivators in an equitable manner and on the basis of fixed principles.

The term "protective irrigation" was not explicitly used at this time. There was a general idea that irrigation should provide protection against drought and famine. Discussion was mostly in terms of "area protected", being the area covered by an irrigation system. This was not synonymous with "irrigated area", since an area was considered to be protected when irrigation water could serve a certain percentage of the land surface under command of the irrigation system in that area. In the Punjab in the 1860's, a figure of 42.5% was set in this respect (Stone, 1984) and the Famine Commission of 1880 mentions one-third as the figure which makes an area protected (Famine Commission, 1880). This notion of "area protected" is still used today by many irrigation engineers. In this first and most general meaning of the protective irrigation concept no particular type (canal, tank, well) or scale of irrigation is implied. Rather, all irrigation was seen as providing protection against famine.

2.2 The Second Meaning of Protective Irrigation

In the last quarter of the 19th century the term protective irrigation acquired a second, more explicit meaning. After the flying start of loan-financed irrigation in 1867, things turned sour in 1875, when the government refused to sanction a proposal for the construction of the Chenab Canal. This marked the end of the initial boom in loan-financed irrigation development. The major reason behind this change of atmosphere was the dismal returns of the schemes constructed. The British administration was concerned that the servicing of the loans would become a permanent charge on government revenues and that the irrigation schemes would not pay in the long run.

The government was forced to rethink its policy on irrigation in 1877-8, when a severe famine hit Madras and Mysore, costing the lives of an estimated 1,350,000 people and £9,750,000 in relief funds. In 1879 a Parliamentary Select Committee, the Indian Famine Commission, was appointed to examine the history of famines and to assess the value of famine relief and prevention measures. Its task included examining the ways in which loans raised in London for irrigation might be safeguarded and to recommend a formal criterion for allocating funds among various irrigation projects.

The Commission concluded that irrigation actually yielded a small profit and that the practice of financing the construction of irrigation schemes with loans should be continued. (Whitcombe, 1983; Stone, 1984)

To facilitate decision making on investment in canal irrigation it designed the "productivity test" in 1879, thereby explicitly making a distinction between "protective" and "productive" schemes for the first time (Famine Commission, 1880; GoI/MoIP, 1972). A profitability criterion expressed as the percentage return over total capital outlay was fixed (varying over the years) which was the cut-off point for approving new projects. Projects with direct financial returns lower than that percentage were rejected. Schemes approved were called "productive irrigation" schemes. The Famine Commission recommended to construct schemes with lower returns as well, with the aim to prevent famines and thus depress famine relief costs (in general, the Commission emphasized the indirect benefits of irrigation next to direct financial returns). A Famine Fund was created from which these unproductive schemes could be financed. The schemes that did not pass the productivity test, but were nonetheless constructed with funds from the Famine Fund for reasons of famine prevention were referred to as "protective irrigation" schemes.

After 1880, the confidence in the soundness of irrigation returned and the construction of irrigation schemes throughout India was speeded up. The area irrigated by productive works increased from 1.9 million ha in 1878 to 4.4 million ha in 1900 (IIC, 1903). The investment criterion (productivity test) reinforced the focus of canal development in the Northwest and the deltas of the South, because irrigation development in these areas was relatively cheaper and thus more remunerative. The area covered by protective irrigation grew much slower and covered 0.14 million ha by 1900 (IIC, 1903). It required a series of severe famines, the report of the Indian Irrigation Commission (1901-1903) and the gradual exhaustion of sites for large remunerative schemes, to make protective irrigation a more seriously considered matter. The IIC relaxed the sanctioning criteria for protective irrigation and suggested that investments of up to three times the projected savings in famine relief costs should be considered. From then to independence the area under protective systems gradually rose to 16% (2.2 million ha) of the total canal irrigation (13.6 million ha), excluding the Princely States (GoI/MoIP, 1972). Also, being constructed in the North at first, most protective irrigation schemes constructed after 1900 were located in the Bombay and Madras regions.

This second, administrative-financial meaning of protective irrigation remained in use until 1964. In 1947 the cut-off point was reduced from 6% to 3.75% to stimulate irrigation development. In 1964 the B/C (benefit/cost) ratio was introduced as an investment criterion (GoI/MoIP, 1972). Since then protective irrigation is no longer a formal category in the above sense, though it is still in use in the other two meanings.

2.3 The Third Meaning of Protective Irrigation

The third meaning the term protective irrigation has acquired, is to indicate a specific type of large scale irrigation, with particular technical, organisational and socio-economic characteristics. Protective irrigation schemes can be found in the semi-arid, drought prone regions of the Indian subcontinent, particulary in the Northwest and the Deccan. These systems aim to spread available water thinly over a large area and large number of farmers. That this aim is not only a thing of the past is brought out by various irrigation policy documents. For example, the Irrigation Commission of 1972 states:

> *"In areas other than those with ample water resources (...) our policy should aim at securing the maximum crop production per unit of water. (...) the policy should be to benefit as large a section of the community as possible and at the same time enable farmers to obtain reasonable yields. Surface irrigation systems should be designed to irrigate compact blocks, the blocks being dispersed over a large area to benefit large numbers of farmers. The number of irrigations can be fewer than are required for high yields."* (GoI/MoIP,1972-I:112-113)

Likewise, the recently adopted National Water Policy states that the benefits of irrigation should be extended to as large a number of farm families as possible (GoI/MoWR, 1987).

This general aim of protective irrigation translates into specific technical, organizational and socio-economic characteristics. In a technical sense, protective irrigation implies spreading water thinly, "light crops" (low water demanding) are envisaged to be grown and water is rationed on the basis of available supplies. Thus, in water terms, it is characterized by high duties (low unit water supplies) and low design intensities. In protective irrigation schemes crop water requirements of the full command area are not met nor taken into account in the design of the scheme. Protective systems are completely supply oriented. The fine-tuning of water delivery (supply) to the crop water requirements (demand), necessary for yield maximization, is not aimed at. The supply based nature of the systems, combined with the desire to keep the systems as cheap as possible, has led to an absence of water control structures. The systems are designed for continuous flow and "automatic" water distribution (i.e. very little adjustment of the outlets throughout the season), implying low levels of management intensity.

In an organizational sense protective irrigation implies distributing limited amounts of water over a large number of people. To achieve this, a system of organizational arrangements has to be devised that makes farmers accept less water than is needed for the full growth of their crops, so that other farmers can also have water. Different strategies of protective water control have been devised in different regions, which will be treated in Chapter 4. The low management intensity mentioned above is another organizational characteristic. A third characteristic is that of hierarchy. The supply orientation of the water delivery system fits well with the top-down organizational structure of the Irrigation Department, with an upward flow of information and a downward flow of instructions.

In a socio-economic sense protective irrigation means the maximization of returns per unit of water instead of unit of land (as in productive irrigation), and thereby maximizing total social benefits. From a national economic perspective, protective irrigation makes sense because it maximizes agricultural output given the limited availability of water, generates more employment and spreads the benefits over a large number of producers.

Thus defined, a significant part of the large scale irrigation schemes in India and Pakistan are protective irrigation schemes. In the following discussion we will adhere to the third meaning of protective irrigation.

After independence in 1947, the construction of large irrigation systems received priority attention, primarily to boost food production to meet the needs of the rapidly increasing population. Particularly in the drought prone areas of South India, many new schemes were constructed. Because the use of the terms protective and productive gradually disappeared from irrigation statistics, precise figures cannot be given now. However, throughout the period from 1880 to the present, the design principles of many protective systems have largely remained the same, despite changes in the administrative classification. Therefore it still makes sense to use the term protective irrigation to refer to the essential design characteristics. Our guestimate is that in India has about 12 million hectares of protective irrigation (about 40% of total canal irrigation), whilst about 12.5 million ha in Pakistan are protective irrigation schemes (roughly 85% of large scale canal irrigation, when the cut-off point for protective irrigation is taken as 1.0 l/s.ha water allowance, see annex 1).

We have not come across a comprehensive discussion of protective irrigation. The discussion below therefore has to be based on fragmented evidence and interpretation of texts discussing other issues. In the following three sections we elaborate on its three dimensions: technical, organizational (managerial) and socio-economic. Also, because of the wide variety of irrigation practices and characteristics, a distinction is made between four regions, namely;

1) **Northwest India and Pakistan** (Sind, North West Frontier Province, Punjab (Pak.), Punjab (Ind.), Haryana, North Rajasthan, Uttar Pradesh and North Madhya Pradesh),
2) **South India** (Tamil Nadu, Andhra Pradesh and Karnataka)
3) **Central India** (Gujarat, Maharashtra, South Madhya Pradesh, and South Rajasthan), and
4) **Northeast India** (Bihar).

The states of Kerala, West Bengal and Orissa and other smaller states are not treated, as the irrigation in this states is in addition to substantial rainfall, and thus not protective. Delta irrigation is also not considered because it is not protective in nature (mostly paddy cultivation).

3 THE TECHNICAL DIMENSION: DUTIES AND INTENSITIES

The technical dimension of protective irrigation consists of two elements. The first element are the water related aspects. Protective irrigation systems are designed assuming particular crops with particular crop water requirements, specific irrigation intensities, and water allowances (or duties). The second element are the infrastructure related aspects. Systems have, or lack, particular technologies for regulating canal water levels and distributing water over different canals. In this paper we focus on the first element, the water related aspects. The second element is certainly not less relevant, but would require another long discussion. Infrastructural diversity is substantial across the Indian subcontinent, while at the same time the documentation on this diversity, and its genesis, is very sparse. We leave detailed treatment of this subject to another occasion. For some of the operational aspects of the infrastructure used in protective irrigation, see chapter 4.

3.1 The Meaning of Duty, Water Allowance and Intensity

The objective of protective schemes is to optimize the production per unit of water available, in contrast to productive irrigation, which implies the optimization of production per unit of land. This basic idea is common knowledge to most Indian and Pakistani irrigation engineers, but there are only a few places where it is explicitly written down. Vander Velde writes (on the Bhakra Canal system in Haryana and Punjab):

> *"(...) the implicit goal in the perennial irrigation area of Bhakra project surely was to **protect** agriculture from the effects of the failure of the monsoon rains and subsequent drought, a common occurrence in the Haryana Bagar. The duty of water was set to ensure that a maximum amount of CCA* [Culturable Command Area] *would be established and supplied with water, but the productivity of irrigated lands would not be maximized in these areas."* (Vander Velde, 1980:311; emphasis in the original)

In technical vocabulary this means that protective irrigation can be characterized as having high duties and low irrigation intensities. A "duty" is the inverse of a water allowance and it is given in acres to be irrigated per cusec (cubic foot per second). One cusec equals 28.3 l/s; a duty of 70 acres per cusec equals a water allowance of 1 l/s.ha. Duties commonly used in protective systems in India and Pakistan can be as high as 200 or more, meaning an allocation of about 0.3 l/s.ha or less! The duty concept is mainly used in the irrigation practices of South India. In Northern India and Pakistan the term "water allowance" is more commonly used. It is defined as the number of cusecs of outlet capacity authorised per 1000 acres of cultivable command area. (Mohanakrishnan, 1983; Ahmad and Chaudhry, 1988) A water allowance, therefore, is simply the inverse of duty multiplied by a thousand.

The irrigation intensity indicates what part of the irrigable land is supposed to be irrigated in one agricultural year. An intensity of 200 % for instance in a scheme with two irrigation seasons would mean that the total area is irrigated twice a year. In protective systems, design intensity figures can be as low as 25% in one season, meaning that only 25% of the total command area was supposed to be irrigated.

Complications can arise with these terms in literature and in project- and policy documents, because they are used in different meanings[1)], often without explicit explanation.

- Duties and water allowances can refer to different levels of the system: main canal head, distributary head, outlet head or field level. In terms of water ultimately available for the crop it makes quite a difference which level is meant. The higher in the system, the lower the duties (or the higher the water allowances), because of intermediate losses in the system. Duty at the main canal head is also known as *Gross Quantity*, at the distributary head as *Lateral Quantity*, at the outlet as *Outlet Factor* and at the head of the land to be irrigated as *Net Quantity* (Punmia and Lal, 1992).
- Duties sometimes refer to values actually realized (so much area being irrigated with so much water), instead of design values, sometimes without clearly stating this.
- Intensity often relates to the "Culturable Command Area" (CCA), rather than to the "irrigable command". It is not always clear to what extent the two differ.

This indicates that, when reading papers on this subject, or when talking in the field with irrigation staff, one should be careful in interpreting the figures.

Duties actually imply canal flow sizes and they do not directly indicate the total amount of water to be supplied to a crop. On the Indian subcontinent the latter is given by "delta", usually expressed in acre-foot, here converted to m^3/ha or mm (1 acre-foot equals 1234 m^3/ha or 123 mm). Evidently, the delta can be calculated by taking a constant duty for a given period. A light crop with a growing period of 120 days and a duty of 210 (0.3 l/s.ha) will get (0.3*86400*120)/1000=3110 m^3/ha or 311 mm of irrigation water.

It should be realized that the delta is not a design parameter. Canals and structures are designed on the basis of duties and intensities, not on deltas. Yet, values for deltas are sometimes given for operational purposes in irrigation manuals. This can lead to confusion if realistic delta values are given in the sense that they indicate (an estimate of) actual crop water requirements. With very high duties such deltas can only be realized with corresponding low intensities. The question is whether delta values given in general irrigation manuals are in line with the specific duties and intensities of a particular system.

1) A common mistake is to confuse duty with water allowance, for example by stating that the duty of a certain canal is 0.20 l/s.ha, as Berkoff (1991) and Trimmer (1990) do.

3.2 Some Examples

3.2.1 Northwest India and Pakistan

Initial irrigation development by the British was concentrated in the Indus Basin and the Indo-Gangetic Plain. To date, these areas are still of paramount importance as far as irrigation is concerned. The 14 million ha of large scale irrigation in Pakistan are wholly situated in the Indus Basin and support about 90% of Pakistan's agricultural output (World Bank, 1994). The Indo-Gangetic Plain supports about 40% of India's population and more than 50% of its irrigated area (Berkoff, 1991). The type of irrigation systems dominant in Pakistan and Northwest India are perhaps best known, although still scarcely documented.

In an ODI paper, the case of the Bhakra Canal system, described by Reidinger (1971), is referred to:

> *"(...) the Bhakra system (...) may be taken as a fairly extreme example of the "Punjab" type. (...) the canal system (...) has been designed in a similar manner to other much older systems in the region, with a few control structures and low cropping intensities: planned irrigation intensity was only 62% of the culturable command area, with 23% in kharif and 34% in rabi, based on a factor of 2.4 cusecs per 1000 acres served".*[2] [3] (ODI, 1976:1)

Malhotra (1982) indicates that the water allowance of 2.4 cusecs/1000 acres (equivalent to a duty of 417 acres/cusec) is the value at the watercourse head. Berkoff (1991) mentions a duty of 372 acres/cusec at the main canal head of the Bhakra Canal system. It should be realized that the water allowance mentioned in the quote refers to the entire CCA and should be seen in combination with the (low) design intensity. If only 34% of the CCA is to be irrigated during *rabi* then the duty of 417 acres/cusec for the entire CCA would imply a "real" duty of 0.34*417=142 acres/cusec, or 0.5 l/s.ha. In fact, the water allowance/duty given in the quote does not mean the area to be irrigated by a unit flow size, but rather indicates the water needed for the CCA, taking into account a certain (low) intensity to be achieved. This way of expressing duties seems to be a common practice in Northwest India and Pakistan and is more commonly called the Full Supply Factor (Ahmad and Chaudhry, 1988).

Similar figures seem to be valid for other canal command areas in Punjab, Haryana, Rajasthan, parts of Uttar Pradesh and Northern Madhya Pradesh. Berkoff (1991) indicates that for Northwest India duties are high, ranging from 300 to 400 acres/cusec (water allowance of 0.175-0.23 l/s.ha) at the outlet. In the Sarda Canal system, located in Uttar Pradesh and with a CCA of 1.55 million ha, the duty at the head of the main canal is 337 acres/cusecs (Berkoff, 1991). For the Ganga Canal

---

2) For the same system, Hukmani and Katariya (1982), mention an intensity of 25% in kharif and 37% in rabi.

3) Both the ODI paper as well as the Reidinger research from which it draws, do not elaborate on the nature and implications of intensities and duties. In their discussions, emphasis is on organizational and institutional issues, canal operation, *chak* water management, etc., but not explicitly on the relations of these issues with the protective nature of the systems.

system, also in Uttar Pradesh and commanding about two million ha, Mathur (1982) gives a 40% intensity for *rabi* only. Maheshwari (1993) mentions that Ganga and Agra Canal (also in Uttar Pradesh) systems were initially designed for irrigation of 35%-40% of the CCA, for *rabi* only. Duties are not given in these cases, however. For Gang (Bikaner) Canal, in North Rajasthan, the water allowance is 2.56 cusecs/1000 acres. The canal was originally designed for an irrigation intensity of 60% (24% *kharif*, 36% *rabi*). (Hukmani and Katariya, 1982) Lastly, Gupta (1993) gives a range of water allowances for schemes in Haryana, from 2.25 to 4.5 cusecs/1000 acres.

Another typical aspect of the Northwest systems is that crops are not indicated as a basis for scheme design. Farmers are free to use their water allocation as they see fit. Thus, their cropping patterns are a response to an expected pattern of water supply ("crops to water") (Berkoff, 1991). This is most likely related to the fact that, when the schemes were designed, only wheat and other low water demanding crops were traditionally grown.

For Pakistan, a wide range of data on water allowances (and therefore also duties) was found (see annex 1). Bandaragoda and Badruddin mention that the schemes of the Indus Plains were designed;

> *"(...) for the purpose of opening up new cultivable but sparsely populated lands, both to realize income to the government from the sale of waste crown lands and to alleviate chronic famines by resettling farmers from poorer areas. The physical layout and design of the canal system were evolved empirically to fit into the pattern of water supplies available in the unregulated rivers and to meet the objective of "bringing to maturity the largest area of crop with the minimum consumption of water". (...) Irrigation intensities (...) were designed to be quite low, averaging about 75% (about 50% in kharif and 25% in rabi)."* (Bandaragoda and Badruddin, 1992:4-5)

They give a list with water allowances at outlet head for nine large systems, built between 1859 and 1947, ranging from 2.84 to 6.15 cusecs/1000 acres (0.20 to 0.44 l/s.ha). Wolf (1986) states that 58% of the 14.25 million ha irrigation network can be irrigated perennially and 42% can be irrigated only during *kharif* when rivers are at peak flow. He gives the total canal capacities and command areas for four provinces, showing average allocations from 0.35 to 0.69 l/s.ha at the headworks. Anver (1991) mentions that the Indus systems have been designed "with the objective of bringing to maturity the largest possible cropped area with the minimum consumption of water", and that designs generally are for an annual intensity of 85-100%. Trimmer (1990) finally states: "The average flow rate through a turnout (mogha) to a watercourse in Punjab is less than a third of peak water requirement. As an example, a typical duty (sic) of 3 cu ft/sec per 1,000 acres is a rate of 2 mm day^{-1}" (p.343). An interesting point to note is the difference in water allowances between the Punjab and North West Frontier Province (NWFP).

> *"In case of canals in Peshawar Vale* [NWFP] *the water allowance is quite high varying from 4.6 cusecs to 9.85 cusecs per 1000 acres except in the left and right bank of Upper Swat Canal. In case of Punjab for perennial canals, it is generally equal to 3 to 4 cusecs. Actually it varies*

with each canal. In case of non-perennial canals it is increased to 4 to 6 cusecs per 1000 acres." (Ahmad and Chaudhry, 1988:8.11)

The reason for this difference is unclear. Likewise, in Sind several canals are designed for high water allowances. The Rice, Pinyari, Fuleli, Kalri Baghar, Desert and Begari Canal systems, covering 1.67 million ha, all have allowances that are higher than 1 l/s.ha (14.29 cusecs/1000 acres) at the canal head, and thus are not really protective irrigation schemes.

3.2.2 South India

For South India, particularly Karnataka, Andhra Pradesh and parts of Tamil Nadu, the situation is completely different. Duties are still high, though the figures seem to be generally lower than in the Northwest (meaning higher unit supplies). However, one should take into account that they explicitly apply to the area actually to be irrigated.

For the Tungabhadra Left Bank Canal system (CCA of 244,000 ha) in Karnataka the total annual (target) intensity is 100%, composed of about 40% of the area in *kharif* only, 40% in *rabi* only and 20% under one two-seasonal crop (Jurriëns *et al.*, 1987). Design duties vary from 55 acres/cusec (1.27 l/s.ha) for paddy areas to 150 cres/cusec (0.5 l/s.ha) for areas under "light crops". Berkoff (1988) mentions duties of 50-60 acres/cusec (1.15-1.40 l/s.ha) for paddy and 100-160 for light crops (0.4-0.7 l/s.ha). In the Malaprabha Right Bank Canal system (CCA of 81,000 ha), also in Karnataka, the average design duty is 128 acres/cusec (duty per crop not specified) and the designed cropping intensities is 100% (40% *kharif*, 40% *rabi* and 20% two-seasonals) (Vedula *et al.*, 1986). Sastry (1994) indicates a water allowance of 0.74 l/s.ha for the Nagarjunasagar Left Main Canal system (Andhra Pradesh, CCA = 420,000 ha) and 0.66 l/s.ha for the Nagarjunasagar Right Main Canal system (CCA = 475,000 ha). In the Lower Bhavani Canal system (Tamil Nadu, CCA = 82,000 ha) design duty for light crops is 120 and for paddy 60 acres/cusec (Mohanakrishnan, 1983; Palanisami, 1983). All above values refer to the main canal head level. Information of duties and intensities for other large schemes in Andhra Pradesh, Tamil Nadu and Karnataka was difficult to find.

The foregoing also shows another difference with the Northwest, namely that crops are often explicitly mentioned and different duties for various crops are given. The duties are valid for the area designated for that crop, so that the above confusion about whether or not the intensity is included does not occur. It is noted that sometimes individual crops are indicated (paddy, cotton, sugarcane), sometimes similar crops are taken together under one common name: for instance "garden" or "light". The latter includes many crops with low water demands like grains, oilseeds and pulses. Sometimes, only a distinction is made between "irrigated dry" (ID-crops, low water demanding) and "wet" (more water supply), sometimes "dry-cum-wet" (a mixture) is given.

3.2.3 Central India

For the irrigation schemes in Maharashtra, Gujarat and parts of Madhya Pradesh little information was found on design duties and intensities in the literature. In the Tawa Irrigation project in Madhya Pradesh, we infer that the water allowance of the Left Bank Canal (CCA of 186,200 ha) is 0.57 l/s.ha and of the Right Bank Canal (CCA of 60,700 ha) is 0.44 l/s.ha. The designed irrigation intensity is 138% (67% *kharif*, 67% *rabi* and 4% summer) for the Left Bank Canal and 125% (58% *kharif* and 67% *rabi*) for the Right Bank Canal (Singh and Sharma, 1994). No information on duties and intensities concerning Maharashtra were found.

In the Mahi-Kadana project in Gujarat, the design discharge of the Mahi Right Bank Canal is 7,000 cusecs for a CCA of 212,000 ha (Desai, Gulati and Rathod, 1994). This implies a generous duty of 75 acres/cusec (0.93 l/s.ha) at main canal head. In the Ukai-Kakrapar project, also in Gujarat, the Kakrapar Right Bank Canal has a design discharge of 70.23 m^3/s for a CCA of 58,745 ha, implying a water allowance of 1.20 l/s.ha (duty of 58.3 acres/cusec) at main canal head. The Kakrapar Left Bank Canal has a design discharge of 85.63 m^3/s for a CCA of 145,335 ha, and thus a water allowance of 0.59 l/s.ha (duty of 119 acres/cusec). The Ukai Canal system, part of the Ukai-Kakrapar project, consists of the Ukai Right Bank Canal and the Ukai Left Bank Canal. Water allowances for these two canals are 0.67 and 0.41 l/s.ha (104 and 169 acres/cusec) respectively. (Desai, Bandi and Shah, 1994) Irrigation intensities for these two projects (five schemes in all) are not given. The reason for the variance in the value of the water allowances is unknown to us, as is the underlying design logic.

3.2.4 Northeast India

In Bihar in the Northeast, where rainfall is more plentiful (mean average of 1260 mm), intensities are usually higher and there is a designed cropping pattern. Paddy is planned as well. Berkoff (1991) states: "(...) in Bihar paddy has been normally limited to 60-80% in *kharif* and excluded in *rabi*" (because of the low flows available in rivers). Duties are based on the peak crop water requirements of the design cropping pattern minus the effective rainfall ("water to crops"). For the Gandak Canal system, located in Bihar and with a CCA of 960,000 ha, the designed irrigation intensity is 120% (72% in *kharif*, 24% in *rabi*, 15% in summer and 9% perennial)[4)] and the water allowance is 0.71 l/s.ha (duty of 100 acres/cusec) at the main canal head and 0.37 l/s.ha at outlet level (Berkoff, 1991; Agarwal, 1994). The Sone Canal system, located in Bihar and with a CCA of 740,000 ha, was originally constructed for *rabi* irrigation only. The water allowance at main canal head is 0.56 l/s.ha (duty of 126 acres/cusec). (Berkoff, 1991)

Sinha (1994) gives data on design intensities of seventeen schemes in Bihar. For instance, he indicates that Kamal Irrigation project, covering 36,000 ha (CCA), has a

---

4) Agarwal (1994) indicates that the designed annual cropping intensity is 120% but that no summer crops were envisioned to be grown. Rather, he gives the following breakup: kharif 88%, rabi 23% and perennials 9%.

designed intensity of 90% (70% *kharif*, 20% *rabi*), Sakri Irrigation project (CCA of 37,000 ha) has a designed intensity of 70% during *kharif* only, Chandan Reservoir project (CCA of 89,528 ha) has a designed intensity of 98% (71.5% *kharif*, 26.5% *rabi*) and Badu Reservoir project (CCA of 45,000 ha) has a designed intensity of 100% (83% *kharif*, 17% *rabi*). He also mentions design deltas for most schemes, ranging from 200 to 635 mm in *kharif* and 230 to 410 mm in *rabi*. However, it is not possible to indicate which duties these deltas imply, because the base period (length of cropping season) is not mentioned. For the Durgawate Irrigation project (CCA of 11,000 ha) the design duty at canal head was 66 acres/cusec (Sinha, 1994).

Although the duties in Bihar are still comparatively high (low unit supplies), it can be debated whether the above systems are truly protective systems, because supplies are additional to substantial rainfall. Thus, they are not based on the principles of deficit irrigation and can better be typified as supplementary irrigation schemes.

3.2.5 New Systems

As was noted earlier, many new schemes are still designed on the same principles. To give only a few examples: design of the much discussed 1.9 million ha Sardar Sarovar (Narmada) scheme in Gujarat is still based on a supply of 0.60 l/s.ha (Morse, 1992). The Chasma Right Bank Canal (1987) in Pakistan was designed for 0.53 l/s.ha. Design of the huge 1,149,000 ha Indira Gandhi (Rajasthan) Canal system, in the sandy desert region along the India-Pakistan border, is based on a duty of 260 acres/cusec (0.26 l/s.ha) at main canal head and an intensity of 110%; 47% in *kharif* and 63% *rabi* (Gurjar, 1987).

3.3 Conclusions

Design duties and intensities are important elements in protective systems. Insufficient information on these basic issues often makes it difficult to assess in detail the design, although it is illustrated that assumed duties and intensities differ for the various regions. The general picture is clear, however: in each irrigation season only part of the total scheme area is to be supplied and this with low design supplies per hectare.

Not much is known about actual crop water requirements in India, but estimates indicate that they may commonly be in the order of 0.5-1.2 l/s.ha at crop level (evapotranspiration of roughly 4-8 mm/day), or assuming an efficiency of 40%, some 1.2-3 l/s.ha at main canal head (for 100% intensity). Moreover, rainfall in the wet season is very unreliable. Deviations from the annual or monthly average can be considerable, long dry spells can occur, and rain can fall in a drizzle as well as in a few large showers. The above water allowance figures, usually in the range of 0.3-0.6 l/s.ha, show that duties cover only a small part of the actual requirements and yields will be low when such supplies are realized. It also illustrates that, when a farmer would go for productive irrigation, he needs much more water than he is supposed to get according to the scheme design. Or, as Berkoff states for the Indo-Gangetic plain,

> *"Delivery capacity per hectare is very low, (...) insufficient even if given continuously to meet the theoretical crop water requirements for more than perhaps 20-30% of land in kharif and 35-45% in rabi."* (Berkoff, 1991:72)

4 MANAGEMENT CHARACTERISTICS: WATER CONTROL CONCEPTS AND WATER DISTRIBUTION PRINCIPLES

Going through the vast amount of literature on Indian irrigation, there is amazingly scant detailed information on the actual operation of irrigation systems and the strategies on which operation is to be based. In this chapter, examples of water allocation concepts, water distribution principles and the water control concepts on which these are based will be discussed for the different regions. Although all protective schemes on the subcontinent have to deal with the rationing of scarce water, water allocation concepts and water distribution principles vary, depending on the design and on a number of local traditions and circumstances. All schemes are supply-oriented systems and operation is based on upstream control of discharge and/or water level. The systems do not automatically respond to changes in demand. A quantity of water is released at the source and then distributed throughout the system on the basis of a water delivery schedule. It is important to note that water control is not only a function of the physical infrastructure but as much of management. In the following we focus on the interrelationships between infrastructure and management and how these combinations are used as strategies to realize the rationing of scarce water.

4.1 Northwest India and Pakistan

The rationing of scarce water in Northwest India and Pakistan is controlled through a specific type of infrastructure in combination with the *warabandi* system of water distribution. Extensive discussion of the *warabandi* concept (starting with Malhotra, 1982) has contributed to these systems now being most frequently cited. *Warabandi* is a system of rotational water supply, applying to both the *chak* (tertiary unit) level and the main system level, whose primary objective is to ensure equity in water distribution. The cardinal principle underlying the *warabandi* system is that the irrigation water entering the *chak* is allocated to each and every landowner or plot for a fixed time period. The duration of this period is proportional to the size of the landholding. Usually, a seven-day (both day and night) rotation forms a complete cycle. (Reidinger, 1974, 1980; Malhotra, 1982; Merrey, 1986a, 1986b, 1990)

At main system level all canals are run at full supply level, in principle. However, in periods of water shortage, canals are shut down in rotation if the water levels fall below 75% of full supply level. This is necessary to avoid upsetting the silt regime of the canals and because the proportional distribution of water is only assured at or around full supply level. The command area is divided into a number of groups or blocks and secondary canals (distributaries) in these blocks are in principle operated on a eight day rotation basis. All distributaries under one block run at full supply level for eight days and are then closed for eight days (or multiples of that).[1] The sequence and on-periods of the canals during the season is according to a pre-set schedule, depending on the ratio of available to design quantities of water, with a priority ranking of the blocks (for detailed explanation, see Malhotra, 1982). The running of canals under rotation is mainly practised in Haryana and the Indian Punjab. In Pakistan this is not commonly practised, although Khan (1991) states that officially the canal rotation system is also applied in Punjab, Pakistan.

When a distributary is running, equitable distribution over the outlets is thought to be realized by another characteristic element: the proportional ungated modules used as tertiary inlets/outlets from the distributaries. Most frequently used are the "adjustable proportional modules" (APM)[2] and the "open flume outlet" (for details, see Mahbub and Gulhati, 1951; FAO, 1977; Malhotra, 1982). These structures theoretically guarantee an equitable distribution along the distributary, but they can only work as long as the canal level does not deviate too much from design level. If flows decrease, part of the canals are entirely closed so that others can run at full design level. Water levels in the canal are controlled by the "tail-cluster" (a combination of sill outlets at the canal end; there must be one foot of water on the sills if the canals run at design level) and cross-regulators are therefore absent in the distributaries.

Crops are not prescribed in the Pakistan and Northwest Indian systems. Design duties and intensities are given without any indication of crops. Farmers are free to grow the crop(s) they prefer. Traditionally, wheat and other grain crops were grown in these regions. Gradually, rice and sugarcane have become more important.

The above descriptions are also generally valid for the other Northern states, although modifications may be introduced on one or more of the elements (crops, structures, *chak warabandi*, canal rotation) when going East from Punjab/Haryana. Finally, an important aspect is that additional use of groundwater (shallow wells or deeper tubewells) is widespread in the alluvial plains in the Northwest.

4.2 South India

Together with the different designs, the water allocation concept and the water control strategies in the South are substantially different. The rationing of scarce water in the Southern systems is not by the different rotations and by the nature of the structures as in the North, but is thought to be realized by the system of "localization". The localization system prescribes in detail which crops are to be grown, where and in

---

1) Some people say that warabandi only refers to the tertiary level and they refer to the main system as "canal rotation" or "on-off operation". For discussion of the advantages and disadvantages of the 7 and 8 day periods see Reidinger (1974) and Malhotra (1982).

2) In Pakistan, and we presume also in Northwest India, very few APMs have actually been installed. Rather, most outlets are Adjustable Orifice Semi-Modules (AOSMs). AOSMs are the same type of outlet as APMs but the crest level is set at 0.8 of Full Supply Level (FSL) instead of 0.6 as with the APM. This was necessary because the APMs silt-drawing capacity is very poor. (Mahbub and Gulhati, 1951)

which season. The localization pattern is fixed and generally only minor adaptations are made over the years. It is a form of agricultural land use planning in which the government allows and disallows the cultivation of particular crops on particular pieces of land. Typically, the cultivation of "wet" crops such as sugarcane and rice is only allowed on a small scale. The main idea behind this form of water allocation is that in this way the amount of water used can be controlled. Thus, localization is an effort to regulate water distribution indirectly through controlling the cropping pattern.

Under the localization system certain areas are formally excluded from irrigation in one of the seasons. In areas that are localized, farms are supposed to be irrigated for 100%. In the North, the entire system gets water in both seasons. A 50% intensity there means that the entire area will be supplied, but that every individual farm can be irrigated for about 50%, with a free crop choice for the farmer. In the South, the same intensity for one season means that 50% of the area (precisely indicated where) will not get water at all in the season concerned, in the other 50% of the command farms are supposed to be irrigated fully and the localized crop must be grown.

The operation of the systems as well differs from the Northern practices. Usually, all canals run continuously, although Tilak and Rajvanshi (1991) mention that intermittent canal supply sometimes occurs in the "irrigated dry" areas (10 days on, 10 days off) and Kathpalia (1983) mentions that in schemes where there is a shortage of water a fixed rotation has been introduced. In Andhra Pradesh, the so-called Systematic Canal Operation is implemented on some canals if there is not enough water for the canals to carry their design discharge. This implies that head-end outlets of distributaries and minors are closed to push water to the tails (Rub and Venkat Reddy, 1983). The additional use of groundwater is largely absent in the protective systems in the Southern states.

Tertiary outlets are gated pipes instead of ungated modules, mostly placed at canal bed-level. There are no tail clusters as in the Northern systems. Officially, the outlets are sized in accordance with the area localized in the *chak*, and are intended for on/off operation. However, it is necessary to operate the gates when flow rates or water levels deviate from design values. Cross-regulators are largely absent, although in the often sloping canals, drop structures may act as partial level control. Formal *warabandi* does not exist, although some form of rotational arrangements exist in many *chaks* (Wade, 1982; Jurriëns *et al.*, 1987; Ratnadurai, 1990).

In the Lower Bhavani Canal system (Tamil Nadu, CCA = 82,000 ha) a seasonal turn system, called zonal system, is followed. This implies that in every odd numbered year the odd numbered distributaries (the first distributary on the main canal is number 1, the second is number 2, etc.) are kept open during *kharif* (from 15th of August to 15th of December) and the even numbered distributaries are kept closed. During *rabi* (16th of December to 15th of March) the even numbered distributaries are run and the odd numbered distributaries are closed. In even numbered years the sequence is reversed, and the even numbered distributaries are kept open during kharif. This type of rotation is only occurs in the LBC, as far as we know. (Mohanakrishnan, 1983; Palanisami, 1983; Sivanappan *et al.*, 1983)

4.3 Central India

In Maharashtra and Gujarat water control strategies and water distribution principles are very different from those in South India and Northwest India and Pakistan. Generally somewhat more water is available and the prevalent water distribution practice is called *shejpali* (Gandhi, 1979). In the *shejpali* system farmers request water before the cropping season by presenting the Irrigation Department (ID) with proposed cropping patterns. These proposed cropping patterns are (partly) sanctioned by the ID and the farmers are then entitled to irrigation supplies for these crops. The distribution of the sanctioned water is in rotation, taking into account the requirements of the sanctioned crops. (Saksena, 1982) Concerning water control strategies in Madhya Pradesh nothing was found in the literature.

Shejpali is a form of an arranged water delivery schedule. The rationing of scarce water is thought to be realized through crop zoning, by sanctioning the types and areas of crops which may be grown. It is thus a method of water control in which the demand for water is regulated. *Shejpali* differs from the localization system of South India, for two reasons. Firstly, there is interaction between the farmers and the ID concerning the area to be localized (i.e. sanctioned) as the farmers can indicate which crops they want to cultivate. Also, each year the area sanctioned is revised on the basis of new requests. Secondly, the ID commits itself to realizing a water delivery schedule which is drawn up before the start of the cropping season and thus actively manages water flows.

An important sub-element of the *shejpali* system of water distribution, only practised in Maharashtra, is the "block system". It was introduced in the first decade of the 20th century on canals in the Deccan Plateau as an effort to introduce volumetric water distribution and pricing and to reduce the administrative work involved in receiving and sanctioning crop applications every season. It was an attempt to let the invisible hand of the market control the system. The system quickly evolved into what is now a system for controlling the cropping pattern through six-year period sanctioning of particular crops in certain blocks of land. Sugarcane blocks are mainly sanctioned, and primarily in the head reaches of the canals. Basically, one could see this as a modified *shejpali* with long term sanctioning and large fixed blocks as well as a form of (periodically changed) localization per blocks. Water distribution is the same as under *shejpali*, and the blocks are treated as any other sanctioned crop area. (Dhamdhere, 1983; Attwood, 1987; Bolding, Mollinga and van Straaten, 1995)

How water distribution should be executed under *shejpali* is poorly described in the literature. What follows below it therefore a tentative, and perhaps inaccurate, description of the *shejpali* concept. In the *shejpali* procedure of water distribution an irrigation programme is drawn up by the ID, on the basis of sanctioned block areas and the expected water availability. If water is available over and above the amount needed for the sanctioned blocks, applications are invited from farmers for other crops they want to grow. Areas are then (partly) sanctioned, with proportionate reduction of the areas proposed by the farmers being made if the demand exceeds the available water supply. Once crops are sanctioned, farmers receive an irrigation pass book in which their sanctioned area and the first irrigation date are indicated. (Wade, 1976; Saksena, 1982; Gandhi and Inamdar, 1983; Tilak and Rajvanshi, 1991)

After the area of sanctioned crops has been publicized the ID is responsible for delivering water to them. A rotation schedule, called *shejpali*, is prepared indicating the supplies allotted to different canals and the names of the canals which will be closed down from week to week. Water is supplied to crops in a rotation of 14 days for perennials and 28 days for seasonals. Canals run for about 12 days, and are closed on the other days. The water requirements of the sanctioned areas are worked out on the basis of a uniform water application of 10 cm (4 inches) in the field. This implies that the area that can be irrigated in one day with one cusec is six acres (AI/DC = Area Irrigated / Day-Cusec). Water is allocated to the different canals on the basis of total day-cusecs required for the sanctioned areas, taking into account the rotation of 14 or 28 days. In order to allow for seepage losses in the canals, the AI/DC at distributary head is taken as 4 acres. A measuring device is provided at the head of each distributary so that the quantity of water used during each rotation can be measured. (Wade, 1976; Gandhi, 1979; Gandhi and Dhamdhere, 1982; Saksena, 1982; Gandhi and Inamdar, 1983)

After the quota for each canal is fixed, it is further distributed over the outlets. For each outlet, the Canal Inspector prepares a list of sanction-holders, indicating their sanctions in terms of acreage. On the basis of the AI/DC he calculates the total time for which a particular outlet is required to run and prepares a timetable, known as *pali-patrak*, for each outlet indicating the definite date that a certain sanctioned area is to be irrigated. At a meeting of irrigators before each rotation they are informed of the dates on which water will be supplied. (Gandhi, 1979)

Outlets in *shejpali* schemes are generally gated to enable modification of flows. The discharge capacity of the outlets is not correlated to the irrigable area, as in Northwest India and Pakistan. The pipes are of standard size, generally 30 cm to 40 cm in diameter, and are fixed at bed level of the canal. All the outlets do not discharge simultaneously and are opened and closed in rotation during the period that the canal is running. The canals do not run with a fixed discharge and the supply level in the canals vary in time depending on the requirement of water for irrigation.

More recently, changes have been introduced in the *shejpali* system. Although the ID is committed to supply water to a cultivator on a certain date under *shejpali*, this is not guaranteed in practice as there are no restrictions on the length of time that a cultivator can take for irrigating his sanctioned areas. As a result head-end cultivators in a *chak* take most of the water when their outlet is running and leave little or none for the tail-enders. To curtail this tendency, "rigid *shejpali*" has been introduced, in which, along with the date, the duration of each cultivator's irrigation turn is also recorded in the irrigation timetable issued to the farmers. Thus, a water delivery schedule is prepared at main system level for the sanctioned areas (rotation among distributaries and outlets) and at tertiary level for each interval of irrigation. (Tilak and Rajvanshi, 1991; Saksena, 1982)

4.4 Northeast India

The design and management of irrigation in Northeast India has been strongly influenced by the Bengal Irrigation Act, which covers Bihar, West Bengal and Orissa. Most of the irrigation systems in Bihar are run-of-the river based. During the monsoon the rainfall is good and on average there is no water shortage during this season. Paddy is the main crop, to which supplementary irrigation is provided in case the rains fail during monsoon. Irrigation during the *kharif* has priority over irrigation during the rest of the year. In *rabi*, the area irrigated is normally much lower, due to the low flows in the rivers. (Tilak and Rajvanshi, 1991)

It is difficult to infer from the literature which type of water control strategies are followed in Northeast India. Apparently, variable flows are provided to outlets in response both to demand (strongly influenced by rainfall) and to the supplies available in the river or reservoir. For water distribution through the conveyance system the distributaries are operated under rotation. The dates of "opening"' and "closing" of canals are fixed by the ID and are duly publicized. This is known as the *tatil* system. For example, distributaries in the Sone Canal system are operated on a rotation basis of ten days open and five or ten days closed. The main canal and branch canals are run according to the water requirements of the command area and as such the discharge of these canals is variable. Canals below this level are always run at full supply level, or, if the demand for water exceeds supply, the distributaries are run with full discharge under the *tatil* (rotation) system. (Shina, 1990; Tilak and Rajvanshi, 1991; Dwivedi, 1994)

Irrigation water is distributed to the fields through pipe outlets placed in the banks of main canals, branch canals, distributaries and minors. Most of the outlets are ungated and a number of them are temporary (Roy, 1990; Tilak and Rajvanshi, 1991). According to Berkoff (1991), however, all the outlets in Bihar are gated. He also indicates that they are designed for full discharge at 2/3 flow in the parent canal. Thus, if the flow in the latter is more, the outlet must be regulated (partially closed) or it takes (much) more than its design discharge. In the *chaks* field-to-field irrigation is practised, even for non-ponded crops, and generally water courses and field channels are absent. (Sihna, 1990; World Bank, 1991; Narian, et al. 1994) Within the *chaks*, water is in principle rotated (Berkoff, 1991). It is unclear how this is possible without watercourses and field channels. Apparently, farmers appoint a "Lambardar" of "Sattedar" who looks after the water distribution (Tilak and Rajvanshi, 1991).

There is also a practice of application for supply of water from a single watering to long-term lease (7-10 years) (Tilak and Rajvanshi, 1991). Also according to Berkoff (1991) irrigation was once sanctioned as under *shejpali* in Maharashtra and Gujarat, with long term sanctions of blocks customary. However, he indicates that the system never worked well in Bihar and that it has been abolished.

4.5 Checklist for system analysis

It is clear from the discussion in Chapters 3 and 4 that it is important to understand the basic technical and managerial elements of a protective irrigation system and their interrelationships. But it is also clear that evidence in the literature on these matters is scarce and scattered. On the basis of the previous discussion a number of questions can be formulated that at least need to be answered when investigating a protective irrigation system.

1) What is the design duty of the system?
   a. Is it/are they crop related or not?
   b. To which level do they refer?
   c. Do they include the design intensity or not?
   d. How does the duty relate to the actual crop water requirements (taking into consideration the amount, variation and pattern of rainfall)?
2) What is the design intensity of the system?
   a. What is the intensity in each of the seasons?
   b. Are intensities lower than 100% (for a season) realised by excluding land from irrigation on each farm, or by excluding part of the command area?
3) How is the control of water rationing envisaged?
   a. Through controlling the cropping pattern (localization, *shejpali*, block system)?
   b. Through controlling water distribution (operational control as in *warabandi* or other systems of rotational water supply)?
      i) Which formal and informal rotation systems exist below the tertiary outlet structure?
      ii) Which forms of rotation are found on the secondary and primary canal level?
   c. Through control by the structures?
      i) Are there water level control structures in the primary and secondary canal system, and of which type are they?
      ii) Of what type are the outlet structures from main to secondary canal and from secondary canal to tertiary unit;
   d. Through a combination of these methods?

5 THE SOCIO-ECONOMIC DIMENSION: CHANGING WATER DEMANDS

An implicit assumption of protective irrigation is that farmers will adhere to the objective of maximizing production per unit of water. This adherence can be the result of either: 1) the self interest of the farmer (by making it the most attractive economic proposition), 2) by social control mechanisms in the farmers community (through a water users association with equity objectives for example) and 3) the force of government water control (leaving the farmer no other option). Below, we concentrate on the first element: the farm economy in relation with general agricultural development and crop choice. The third element (government control) has been partly discussed in the previous sections. Social aspects like the organization of farmers at *chak* level or the participation of farmers in the scheme management are not discussed in the context of this paper.

5.1 Agricultural Development and Farmers' Interests

During the first decades of their existence, protective schemes functioned more or less as intended: more in the North and less in the South. In the North the combination of the *warabandi* system of water distribution with the cultivation of wheat, a low water demanding cash and food crop, seems to have led to a relatively stable pattern of agricultural development and a fairly equitable water distribution (Ghose, 1979). In the South there initially was a problem of unwanted water. Farmers took to irrigation only when the rains completely failed. The soils of the area were so moisture retentive that in years of normal rainfall, irrigation had little effect on yield (Attwood, 1987). In modern terminology, the Southern systems were underutilised.

Gradually, however, a number of developments lead to a changing picture in the irrigated areas. Particularly since the 1950's, the rapidly growing population has led to shortages in food and fibre and some droughts during monsoon periods aggravated the situation. There was an increasing need in India and Pakistan for boosting agricultural production, to become self-sufficient in food production. Apart from resulting in a vast program of construction of new irrigation it also induced a growing importance of the agricultural sector as a whole. National programs for improvements of seeds, fertilizer, pesticides, processing and marketing were initiated and had some impact. All this resulted in agriculture gradually becoming more of a commercial, market-oriented undertaking and farmers started trying to increase production. Marketable crops like rice, sugarcane and cotton became more widespread.

The above developments became even more important after the introduction and rapid spread of high yielding varieties after 1965 (for instance for the latter three crops as well as for instance for maize, millet and sorghum). These varieties are often less resistant to moisture stress than traditional varieties, and require the "fine-tuning" of water supply to the demand of the crop.

As a result of these developments, crops like rice and cotton were introduced in areas where they had not been grown before. In some schemes in the interior South for instance, rice was introduced by the people from the Andhra Pradesh coastal plains who resettled in the large new schemes, bringing their crops and irrigation practices with them. Even in the Punjab and Haryana, paddy cultivation gained new ground.

In this changing agricultural situation, four factors contributed to an increasing demand for more and better controlled irrigation supplies.

- Gradually, farmers wanted to irrigate in two seasons instead of in one (additional *kharif* in the North and additional *rabi* in the East), and sometimes in summer as well.
- In contrast to the planned low intensities, farmers wanted to irrigate all their land, or at least more than planned.
- Demands in terms of l/s.ha increased because of HYV's and more productive irrigation. This made the initial high design duties (low supplies) even more inadequate.
- Paddy cultivation increased. Even in the Punjab, where wheat was the common crop, additional paddy cultivation (in the other season) became widespread, while systems were designed for low intensity and low-water demanding "light" crops in that season.

Thus it can be expected that in the present situation the requirements of crops and farmers do no longer correspond with the initial scheme objectives of protective irrigation. Generally, the farmers' interest is nowadays more with productive irrigation.

5.2 Summary of Conflicting Objectives

It has been argued convincingly that protective irrigation makes economic sense from an overall, national economic perspective both in terms of total output and employment generation (Rath and Mitra, 1989; Dhawan, 1989; also see Mollinga, 1992). The model of protective irrigation implicitly assumes that farmers will stick to subsistence production of food crops, when supplementary irrigation is made available to them. It is seen above that this is to a large extent not or no longer valid. The general interest radically conflicts with the individual farmers' propensity to maximise his income per unit of land, through the cultivation of cash crops that happen to be water intensive. With their entrepreneurial nature, the farmers have grasped the opportunities that irrigation offers for growth and accumulation. Maximising output per unit of water is not economically attractive to individual farmers. Farmers opt for maximising output per unit of land, which requires full irrigation: of the full holding, in both seasons, and to full crop water requirements. Major cash crops that are water intensive, like rice and sugarcane, are now widely cultivated. Our discussion of the characteristics of protective irrigation is summarized in Table 1. The contrast with productive irrigation illustrates the differences in terms of irrigation objectives between present farmers and the initial design.

It is not surprising, considering these developments, that Berkoff (1988, p.10) observes: "..duties are often higher than can be achieved in practice", and (p.11) "optimistic duties have been adopted to help justify extending the command". The latter points to the fact that such situations have not only been created by initial designs, but also later on when the scheme already existed. An example is that of the Hemavathi scheme in Karnataka. The command area of this initially productive scheme was expanded by a factor four to five under pressure of downstream areas, and became a protective scheme (Mollinga, 1992). Jurriëns *et al.* (1987) mention that during construction of the Tungabhadra scheme, a Government Committee decided to enlarge the system from 179,400 to 243,900 ha, "to emphasize the protective nature of the project".

The foregoing implies that one can expect many problems in protective irrigation schemes as a result of the above essentials and inherent conflicts between system objectives and farmers wishes. In the next chapter an attempt is made to give an overview of the actual performance and problems in the various regions.

Table 1. Differences (water oriented) between productive and protective irrigation

	PROTECTIVE IRRIGATION	PRODUCTIVE IRRIGATION
TECHNICAL		
Intensity	Low	High
Duty	High (low supply)	Low (crop requirements)
Seasons	One	Two
Crops	Low water demanding	High water demanding
Control	Supply oriented	Demand oriented
Optimization of	Unit of water	Unit of land
MANAGEMENT		
Water	Planned scarcity	Planned sufficiency
Canal supplies	Constant canal flows	Varying flows
Cropping pattern	Prescribed/controlled	Free
SOCIO-ECONOMIC		
Benefits	Spread	Concentrated
Objective	Poverty alleviation	Agricultural growth
Labour	Family	Hired
Orientation	Subsistence	Market

6 PERFORMANCE OF PROTECTIVE IRRIGATION SYSTEMS

In view of the above, one could expect that if part of the farmers would succeed in taking more water than according to the protective principles, this would leave less for other farmers in the system and head-tail differences would be created. It would therefore be useful to have field information on the actual performance of protective systems, to assess if this is so. Data on actual intensities and actual water use, which should then be compared with the design values, could give a first impression. The problem, however, is that very little field information on these issues is available.

In reviews of irrigation in India and Pakistan it is frequently pointed out that the average yields attained are much lower than in other counties and that the large scale irrigation schemes are performing poorly. Paddy yields average 2.5 t/ha in India and 1.7 t/ha in Pakistan, while, for example, they are 5.5 t/ha in China and 4.1 t/ha in Indonesia (GoP/WAPDA, 1990; World Bank, 1991). The label "poor performance" is attached to most of the schemes because it is alleged that water is poorly distributed both spatially and temporally, water charges are too low and hence do not cover working expenses of management and maintenance, cost recovery is weak, scheme maintenance is deplorable, structures are frequently demolished or tampered with by farmers, on-farm water application is poor and farmers are notorious over-irrigators if they can get water. However, the empirical base of these observations is very limited, as very few in-depth studies of irrigation water management practices have been conducted. Moreover, the above sketched poor performance analysis is diagnostic in nature and belittles the benefits that irrigation has brought.

No doubt there are problems in irrigation in India and Pakistan and improvements are necessary. The basis for any improvements, however, should be a profound understanding of the protective irrigation concept and a thorough analysis of current irrigation water management practices. In the following it is attempted to give an overview of the performance of protective irrigation, drawing on the available literature. We concentrate on the performance of the irrigation system and more specifically on water supply performance and not on the agricultural performance. Thus, our main concern is actual irrigation water management practices.

6.1 Northwest India and Pakistan

Generally in India it is said that water distribution problems typically occur in the Southern part of the country, but not in the North. The *warabandi* system is often claimed to be a success (most recently by Berkoff, 1991).[1] Northwest India is heralded for having achieved a good fit between agro-climatic and socio-economic conditions and the irrigation schemes and for showing good to excellent irrigation management performance. It is said that, in large parts of Punjab and Haryana, high intensities and

[1] Warabandi was considered to be so successful by irrigation policy makers, that it was exported wholesale to the South in the 1980's, to be implemented by the Command Area Development Authorities. This effort largely failed, see for instance Jurriëns *et al.* (1989) and Reddy (1989). This is not surprising, where Wade (1982) already labelled it as "planning by slogan".

good yields are realized, in spite of the low design intensities and high duties. The average irrigated cereal yield in Punjab is 3t/ha, which is the highest in India (World Bank, 1991).

Although irrigation in Northwest India is claimed to be successful, little empirical evidence exists for this. Recently there has been an increase in rice cultivation in the canal systems in the north. It is difficult to imagine that rice farmers have reduced their cultivated area proportionally to the higher water demand of rice. One of the few documented examples is the work done by Tyagi (1993) on the Haryana part of the Bhakra system. Based on field measurements it was concluded that:

- The average relative water supply RWS (ratio of actual supply to crop water requirements) on 5 watercourses varied in the rainy season from 0.72 in the head regions to 0.58 in the tail regions and in the dry season from 0.65 to 0.50 respectively;
- Accordingly, IQR values (interquartile ratio, being an indication of inequity) along watercourses varied between 1.5 and 2.5, showing that on the average, upstream ends received about twice as much water as tail-end reaches;

That the relative water supply ratio is less than one is not surprising for protective irrigation schemes. The differences between head and tail are important however. Unfortunately, no intensity figures were given and no information was collected on command areas larger than the watercourse commands, so that nothing is known on realized intensities and water use on entire distributaries and along main canals.

For Adampur and Gohana distributaries in Bhakra and West Yamuna Systems, Tyagi and Mishra (1990) mention recorded seasonal average RWS values of 0.28 and 0.36 respectively. One other figure is from the Gohana area on the Bhalaut distributary on the West Yamuna Canal system (de Jong and Datta, 1994), where the average annual irrigation intensity over five recent years was 72% against a design intensity of 62%. It must be added, however, that this is largely due to a widespread additional use of private tubewells. And moreover, during field visits considerable head-tail differences were observed and problems of waterlogging and salinization are increasing.

Sometimes, more detailed figures are given, as for instance in Kundu (1990), but information is insufficient to compare actual results with design and thus to analyze the above questions. It was measured for instance that supply to outlets on a distributary varied from 80% of design on the canal head to 50% on its tail, but design duties are not given. Also, irrigation intensities for different minors on some distributaries are given as varying between 50-90% (head) to 25-45% (tail), but the definition is not clear and design intensities are not given. In any case, the detailed results show that the design operational targets are certainly not realized. Whatever may be the case, these figures do not give the impression of unqualified success.

Yet, a number of factors may indeed result in fewer problems and better performance in the Northwest, factors which are not valid for all other parts of the country. One factor is the system of rotation in the main system, which makes it difficult for the farmers to interfere with the "automatic" distribution by the proportional outlet structures on the distributary. Another element is that in many cases, over the years, extra water has been made available by additional pumping of groundwater from wells. Tubewells have individualized water management; when canal water is falling short, additional pumping can cope with the situation, rice can be grown and higher intensities can be achieved than according to design. Moreover, in some of these areas over the past decades, the groundwater level has risen considerably (from more than 20 m to less than 1-2 m within 30-40 years), to such extent that crops draw part of their water from groundwater by capillary rise. Thus, there are cases where canal water caters for only half or less of the total crop consumption.[2)]

Concerning the performance of protective irrigation in Pakistan much more is known. Although the irrigation schemes are of the same type as in Northwest India, they are claimed to be unsuccessful (e.g. Merrey, 1986b; Bandaragoda and Badruddin, 1992; World Bank, 1994). Most studies draw attention to the low productivity of protective irrigation in Pakistan, by pointing out that the average yield for rice is 1.7 t/ha and for wheat 2.5 t/ha. However, as Bhatti *et al.* (1991) rightly caution, it can be questioned whether yields in Pakistan should be expressed in terms of yield per unit area. In protective irrigation systems water, and not land, is the constraining factor. If yields are expressed in terms of yield per unit of water it transpires that Pakistan's irrigation systems are not performing so badly, and that average wheat yields lie in the order of 7 kg/mm of water (Bhatti *et al.*, 1991). In India, average yields per unit of water for all crops was found to vary between 2.2 kg/mm of water in Andhra Pradesh and 4.8 kg/mm of water in Uttar Pradesh, with a mean of 3.2 kg/mm of water (Dhawan, 1988). Unfortunately, figures from other countries were not available, making comparison impossible.

Detailed studies of main system management in Pakistan are still few in number, and have mainly been conducted by the International Irrigation Management Institute (e.g. Bhutta *et al.*, 1991; Vander Velde, 1991; Bhutta and Vander Velde, 1992; Kuper and Kijne, 1992). At the most general level it was found that the annual relative water supply ratio (RWS) in most command areas is below one (ranging from 0.47 to 0.70 for six selected command areas), which is to be expected in protective irrigation schemes (Bandaragoda and Badruddin, 1992). Studies on existing water distribution in selected distributaries of the Lower Chenab Canal system (Punjab, CCA of 1,200,000 ha) by Vander Velde (1991), Bhutta *et al.* (1991) and Bhutta and Vander Velde (1992) reveal that discharges at the head of distributaries greatly vary and that water distribution among the outlets is highly inequitable, with head-end outlets taking three to six times more than their design discharge. As a result, large areas in the tails of distributaries receive very little of no water. They attribute the highly inequitable water distribution to outlet tampering (the enlarging of outlets by farmers), frequent distributary operation at less than 70% full supply level, installation of illegal outlets and the changed canal dimensions due to deferred maintenance.

2) At the same time, however, the higher water use in upstream parts and particularly canal seepage lead to increasing waterlogging and salinization in such areas. In many areas there is now a delicate equilibrium between groundwater being high enough to provide extra water to the crop by capillary rise and low enough for the maintenance of an acceptable salt balance. The present danger is that when better drainage is implemented, this may lower the water table to such extent that canal water, which is insufficient already, would have to take a greater share in meeting the crop needs. According to Pakistan officials, this happened already in some systems after introduction of drainage, leading to increased conflicts over water and head-tail differences.

Concerning irrigation water management at tertiary level there is a small, although growing, body of literature which focuses on *warabandi* in practice (e.g. Lowdermilk, Clyma and Early, 1975; Merrey, 1983, 1986a, 1986b, 1986c, 1990; Franks, 1986; Freeman and Shinn, 1989; Garces and Bandaragoda, 1991; Beeker, 1993; Halsema, van and Wester, 1994). In general, these studies point out the disparities between the *warabandi* concept and *warabandi* in practice and suggest that unequal distribution of water is a prominent feature of the system.

The study by Lowdermilk, Clyma and Early (1975) is, to our knowledge, the first study that was conducted on tertiary level irrigation water management. One of their remarkable findings is that in the *chak* they studied, 86 percent of the cultivators reported trading their *warabandi* turns, although the trading of turns is illegal under *warabandi*. According to them trading mainly occurs between relatives. This is significant because the rigidity of the warabandi concept is apparently circumvented, through trading, in practice. A prime example of a fine anthropological study of an irrigation village is Merrey's (1983, 1986a, 1986b, 1986c). He gives a detailed description of one *chak* and goes into changes in the watercourse route and the *warabandi* roster that have occurred. Although the *warabandi* roster had been changed several times between 1961 and 1977, the roster of turns was losing its legitimacy at the time of his fieldwork (1977-1978). According to Merrey this was the result of land fragmentation, land transfers and conflicts between cultivators. He concludes that the formal rotation schedule is impractical and that informal cooperation, i.e. the trading and sharing of water, is needed between cultivators.

Freeman and Shinn (1989) recently reported on irrigation water management at tertiary level. Their primary focus was on the degree of water control by farmers in the Niazbeg system. They conclude that the location of the farm is the dominant factor in determining which farmers have the greatest water control. Their study revealed that farmers located at the tail of the system received less water than their counterparts at the head of the system, independent of land owned or cultivated, education, or caste affiliation. For six outlets, the actual water supply was compared with the sanctioned water supply over one season. The head-end outlets received 171% and 156% of their sanctioned water supply, whilst the tail-end outlets received 73% and 54%. This locational bias existed among and within watercourses. Although the relationship between location and farmer water control was strong, their data also revealed that *warabandi* provides poor water control for all farmers on the Niazbeg system. They indicate that, although the exchange of *warabandi* turns is strictly prohibited, many farmers in their study area (35%) trade water turns to gain more water control. Besides that, farmers reported that the biggest problem encountered in water distribution was controlling the behaviour of influential landlords, who often appropriate water out of their turn. (Freeman and Shinn 1989)

Another class of studies, which discusses irrigation water management practices indirectly, points out that water distribution under *warabandi* is inherently inequitable, because seepage losses in the watercourse are not taken into account in the preparation of the *warabandi* schedule (Chaudry and Young, 1990; Sharma and Oad, 1990; Latif and Sarwar, 1994). Lowdermilk *et al.* (1978) report that seepage losses in watercourses range from 33% to 63% for the forty watercourses they studied (with an average of 47%). Thus, the tail-end farmers of a specific *chak* in theory receive about half of the amount of water that head-end farmers do, under official *warabandi* schedules.

The conclusions reached by the different studies on *warabandi* in practice are neatly summarized by Garces and Bandaragoda (1991)[3)], who state that field observations clearly indicate that *warabandi* as understood in its traditional "image" no longer exists and that in fact there is already a *de facto* move in Pakistan towards (full) irrigation of actually planted crops, not hindered by time/area distribution rules. They indicate that unauthorized outlets exist, authorized outlets have been enlarged, distributaries are obstructed with cross-bunds, farmers' turns are influenced by large landowners, farmers take water out of turn (steal water) and trade and/or sell their water turns, and equity is no longer a shared value among officials, farmers and politicians. Most of the authors that have written on *warabandi* in Pakistan come to the conclusion that *warabandi* in practice is far from ideal.

> *"Most studies emphasize the poor performance of warabandi systems, both in terms of adequacy, reliability, and equity of water deliveries, and in terms of agricultural production. Warabandi is said to be too inflexible to match crop-water requirements; various factors at the main canal level reduce its reliability; and factors at the watercourse level such as high losses from the channels reduce the equity of water supply."*
> (Merrey 1990:12)

A major drawback of the studies discussed above is that, although the link between main system management and tertiary unit water management is often mentioned in passing, this link is not explicitly explored. Nonetheless, they give an impression of how the drawbacks of the warabandi concept are overcome in the field. It can be concluded that cultivators undertake a range of activities to increase the water supply to their chak and to circumvent the rigidity of the *warabandi* concept. The trading of water (irrigation turns) is most important among these. In all, the studies cited above create the impression that an equitable water distribution, as envisioned under protective irrigation, is not realized in the field.

6.2 South India

In the interior South, the localization approach has largely been ineffective. In this region, there has been an enormous increase in the cultivation of rice, cotton and -to a smaller extent- sugarcane and the government has not been able to stop or control this. For various reasons, additional use of groundwater hardly occurs, and fine-tuning depends fully on the operation of the canal system and the gated outlets.

3) Their observations are primarily based on research conducted by IIMI in the Lower Swat Canal and the Chasma Right Bank Canal systems, both in NWFP. Nonetheless, based on the works mentioned above, it can be stated that these observations generally hold true for all of Pakistan.

An example is from Tungabhadra (Left Bank) in Karnataka. Here, it was concluded, based on field measurements (Jurriëns and Landstra, 1989), that:

- Crop water requirements were much higher than unit supplies according to the duties.
- The actual water use (in average l/s.ha for the actually irrigated areas) was also more than according to the duties and in line with the actual crop water requirements;
- Head-tail differences were considerable, along the main canal, along distributaries and within *chaks*; this was the result of the fact that upstream farmers were able to take approximately the water they needed, leaving little or nothing for downstream reaches;
- As a result, overall realized irrigation intensities were less than target. However, on the upstream reaches they were much higher than target, because of irrigation in two seasons, instead of in one season, according to the objectives.

All land in the Tungabhadra Left Bank Canal has been localized, but administrative and legal control of the crops grown is virtually absent. Rice is grown on large areas, also where not localized. The situation is aggravated by the policy of the National Government to promote more productive and "modernized" agriculture, supported by all necessary programs on crop research, inputs, pesticides, processing and marketing, subsidy policies and related training and extension. Thus in many schemes one can observe a simultaneous strive for productive irrigation in protective schemes, with still the initial limited amount of water (and often less, where reservoirs are silting up). In addition, politicians in tail areas or areas not benefitting from irrigation at all, are often pushing hard to get their area included in the irrigation system which is already too large. In this connection Mollinga (1992) talks about a "deadlock", in which "capable actors on all sides" (farmers, officials, politicians) are trapped in the continuous conflict between protective (design) and productive irrigation (which is the actual practice in part of the system). Basically, it is a redistribution problem whereby meeting the rightful wishes of tail-enders would mean pruning the long-established privileges of head-enders. A solution to this problem is hampered by the existing balance of forces between the parties involved.

Similar observations were made during field visits to or from field reports from other schemes in Karnataka, Andhra Pradesh and Tamil Nadu. Generally, problems were less when more water was available and the scheme was of a less protective nature. One example of the latter is the Bhadra system in Karnataka.[4)]

[4)] This scheme was selected for the World Bank supported National Water Management Project (NWMP), which aims to improve the performance of protective irrigation systems. The claim that the NWMP management intervention was successful has to be looked at with some care. It is doubtful whether this system is a real protective system. There is abundant water available in the reservoir and in fact the limited capacity of the main canal was the major problem. Annual intensities of 165%, with widespread paddy, were already realized before NWMP interventions. For discussion, see Kuiper (1993).

6.3 Central India

Not much is known about the actual performance of irrigation schemes in Central India. High level officials usually state that due to *shejpali* and the block system everything is running perfectly. However, the observation made by Wade still holds true.

> *"I suggest that the Maharashtra method of water accounting may have much to recommend it. To be more confident, however, we need studies of how the method works in practice. The same applies more generally: improvements in canal administration will be more successful if based on knowledge of how canals are administered* ***in practice****. The 'in practice' is important, for there are several generalised accounts of how canal administration is designed to work in principle in different parts of India. What is lacking in these accounts is an interest in the divergence between principle and practice (...)."* (Wade, 1976:1438-1439, emphasis in the original)

Unfortunately, after nearly twenty years, accounts treating the divergence between principle and practice are still hardly available.

It seems that in Maharashtra the protective objectives have been undermined by the widespread cultivation of sugar cane, a water intensive crop, because of the related established interests. The sugar cane boom started in the first decades of the twentieth century and continues till today (Attwood, 1993). Dhamdhere (1983) mentions that in the Mula irrigation scheme (irrigated area of 30,000 ha) 10 to 20% of the command area is under sugar cane, while only 4% was sanctioned. He indicates that farmers request water for seasonal crops under the *shejpali* system but use it for growing sugar cane and that they also illegally draw water for irrigating sugar cane. Besides the widespread cultivation of sugarcane and improved varieties of other crops has also led to an increase in the demand for water. As a result the block system is slowly disintegrating and making way for temporary sanctions and cultivators steal water to irrigate areas not sanctioned. (Gandhi and Inamdar, 1983)

The lack of studies on actual irrigation water management practices in Central India has not deterred irrigation experts from claiming that there are substantial performance problems. They state that the management of the *shejpali* system has often proven difficult, due to the stresses of different cropping patterns, unpredictable rainfall, variable topography and soils, weak designs and inadequate seasonal planning (World Bank, 1991). The breakages of structures by frustrated farmers and large head-end tail-end differences both in *chaks* and in schemes are said to be common problems. It is suggested in the National Water Policy that the *shejpali* system should be abandoned because it entails considerable management problems and water inefficiencies (IPTRID, 1993). The empirical basis on which these statements are based is unclear and could not be traced in the literature.

6.4 Northeast India

Irrigation schemes in Bihar are said to be performing very badly and are claimed to be the least productive of India (Berkoff, 1991). Yields and irrigation intensity are low (average crop yield in Bihar is 1.4 t/ha), and the difference between rainfed and irrigated yields is often small (World Bank, 1991). Problems frequently mentioned in the literature are; extensive cultivation of paddy in the head of the schemes, tail-ends largely unirrigated, extensive damage to physical structures and continual farmer interference with water distribution in the main system through the cross-bunding of distributaries, cuts in the canals and the placement of illegal outlets. Thus, providing protective irrigation during dry periods for the *kharif* crop encounters major difficulties and during *rabi* is nearly impossible. (Roy, 1990; Sihna and Srivastava, 1990; Berkoff, 1991; World Bank, 1991) For example, on the Dumraon Branch Canal of the Sone Canal system (Bihar) farmers are not sure of irrigation water and hence head-end farmers interfere with the canal system and draw much more water than needed. This has deprived the farmers of the tail-ends of their due share of water (Dwivedi, 1994). The regular cross-bunding of the distributaries in the upper reaches have caused a severe scarcity of water in the tail-end reaches. Also, there are a large number of unauthorized cuts in the distributaries.

According to Berkoff (1991) the poor performance of the Northeastern schemes can be attributed to several factors, of which the level of rainfall is the most important. He argues that under conditions of higher rainfall (from central Uttar Pradesh eastwards) all farmers, hoping for sufficient rainfall, plant their entire land to a *kharif* crop. As a result, when a dry interval occurs during the monsoon, all farmers need irrigation water on their entire parcels to avoid crop failure. This leads to tremendous stress in the irrigation schemes because head-enders take (much) more water than they are entitled to thereby depriving tail-enders of their water. Conflicts arise and breakages by farmers of irrigation structures are common. Thus rainfed crops and wide variations in demand result in an unstable, uncertain system with endemic farmer intervention. (Berkoff, 1991)

This contrasts with the situation in Northwest India, which is the most productive agricultural region of India. Because of the much lower levels of rainfall farmers plan on irrigation water as their regular water source. They limit water-sensitive crops to perhaps 20-30% of each farm, with the balance under scratch crops, fodder or fallow. (Berkoff, 1991)

> *"Stability in the west and instability in the centre and east reflect the impact of rainfall (...). If irrigation supplies do not meet full farm requirements, and rainfall is sufficient to support a reasonable crop, then rainfed crops will occupy the balance (non-irrigated) area since farmers must plan to use all their scarce land. If rainfall is insufficient to support a rainfed crop, then of course the balance (non-irrigated) land will be left fallow. It is this, more than anything else, which underlies the poor performance in the centre and the east, and the relative success in the west."* (Berkoff, 1991:76)

7 DISCUSSION

The general impression is that in many protective schemes yields on actually irrigated lands are often quite good, but the problem is that many farmers have been deprived from irrigation for many years and that there is, every year again, a constant struggle for water with much unrest in the area, continuous conflicts between farmers and the Irrigation Department and between farmers mutually, regular political upheaval and increasing demands for improvement of the situation. Yet, the result of the above situation may well be that the total scheme production is about the magnitude initially envisaged, because some of the farmers realize high yields per unit area, instead of less production per unit area by more farmers. This is the reason that one can read about good yields and productions in Indian irrigation, while at the same time all kinds of irrigation management problems are observed. Precise figures on this issue are not known. Research would be useful.

It seems evident that more information on protective irrigation should be collected, both on initial design and on performance. To get a first impression, the list of Chapter 4 could be used as a starting point, whereby actual results should be compared with design data. The present lack of material on water control concepts, water delivery schedules, water allocation concepts and actual irrigation management practices and their interrelationships makes it difficult to evaluate protective irrigation. Moreover, it impedes a substantive discussion on the merits of extensive (i.e. protective) irrigation versus intensive (i.e. productive) irrigation and on which water delivery concept (proportional delivery versus volumetric delivery) is to be preferred in conditions of water scarcity.

The present problems encountered in the performance of protective irrigation illustrate one conclusion of this paper: first, before embarking on developing any new remedial measures, a decision has to be taken on the future objective of the irrigation systems. More specifically, detailed attention must be given to water availability and to whether water scarcity by design should be maintained or not. Basically, there are two options:

1) Abandon the protective objectives, and implement productive irrigation in (part of) the command area.
2) Achieve the initial protective objectives through new technical, managerial and socio-economic strategies.

We briefly discuss both options.

7.1 Shifting to Productive Irrigation

Regarding the first option, this is what has basically happened in the Nira Left Bank Canal case described by Attwood (1993). He argues that the economic spin-off effects of intensive sugar cane cultivation (creation of employment, processing industry, services etc.) compensate the inequity effects in agricultural production. Illustrative in this respect also is the fact that some years ago the Tungabhadra system won the second price in the national competition for production, while at the same time this scheme has a reputation for severe head-tail problems and regular social and political upheavals. Officially, these schemes are still protective, but in practice part of their command area is used for productive irrigation (pockets of prosperity) while the remainder receives little or no water. This state of affairs appears to apply to most of the protective irrigation systems in India and Pakistan.

Burns (1993) proposes to formalize this situation by dividing the irrigation systems in a core and an marginal area. The core area will be sure to receive water, making productive irrigation possible, the marginal area only when there is a surplus. He sees this as the only way to control "rent seeking" behaviour, which, in his view, is the principal undermining force of good irrigation management. Another form of shifting to productive irrigation would be an inter-seasonal or over-year rotation whereby every season or year part of the system will be completely excluded from irrigation. The question is whether the situation on the ground should be officially recognized and sanctioned or whether efforts should be undertaken to restore protective irrigation. This is an important issue for debate, and involves political choices on the type of agrarian change one wishes to support, but as of now there is too little empirical data to support such a discussion.

The shift away from protective irrigation is also occurring in Pakistan, but in a different sense. Current government policy is to modernize selected irrigation schemes and to substantially increase their water allowance, water availability permitting. This policy is based on the thought that the mismatch between irrigation water supplies and crop water requirements inherent to protective irrigation is a major constraint adversely affecting the performance of Pakistan's irrigation schemes. The approach adopted at policy level to date has been a cautious one. The National Commission on Agriculture recommended that pilot studies be executed first before the whole of Pakistan's irrigation sector switches to productive irrigation. (Bandaragoda and Badruddin, 1992)

To make productive irrigation possible in Pakistan the existing infrastructure would have to be completely remodelled and major changes would have to be made in the management sphere. In short, it is a complete redefinition of the concept of irrigation. To effectuate the shift to productive irrigation, several schemes, such as the Lower Swat Canal (LSC) system in NWFP, have been modernized with the objective of creating a productive irrigation scheme with an on-request, arranged water delivery schedule. An important element of the remodelling exercise has been the increase in water allowances. In the case of the LSC, the water allowance at the outlet rose from 6.15 to 11.0 cusecs/1,000 acres (0.44 and 0.78 l/s.ha) (Bandaragoda and Badruddin, 1992).

At present, the LSC is still operated as a supply based, protective irrigation scheme. That it is still operated on the basis of full supply levels is to a large extent the result of engrained practice and the lack of a detailed operating schedule. Yet, seeing as there are only two cross regulators in the main canal and no escape structures in the distributaries the only option the ID has is to run the system at full supply level. Thus, the lack of appropriate infrastructure also impedes productive irrigation water management in the LSC in the sense that varying crop water requirements can be met. Water use in the LSC is very inefficient at present, because it is operated at full capacity throughout the year while this is only necessary in one month of the year, and it will probably aggravate existing drainage problems. As a result, the productivity of water and overall system performance are depressed and the benefits from the substantial investments made in the LSC system are only partially being attained.

It may be argued that shifting to productive irrigation is not feasible in India or Pakistan, both politically and technically. For example, in South India localization has formally created water rights, also for tail-enders who receive no water at present. The existence of these rights is a form of political capital both for tail-enders and their political representatives, that will not easily be relinquished. Making unequal distribution official would, we predict, at least in Karnataka, create a political furore of the first order. One might also argue that accepting the present pattern of unequal water distribution is a morally unacceptable approach of "betting on the strong". In Pakistan, there is simply not enough water to remodel all the irrigation schemes. Thus, in the Punjab, which at present is already using its surface water to the full extent[1)], introducing productive irrigation would entail a substantial reduction of the command area. Once again, it is to be strongly doubted whether this is politically feasible.

7.2 Achieving Protective Irrigation Through New Strategies

With regard to the second option, restoring protective irrigation as planned, many people will argue that this will no longer be possible. And indeed, some of the assumptions of protective irrigation, particularly that of subsistence food production, have become very unrealistic now. However, new approaches might be tried to go at least some way towards achieving a more protective distribution of water.

First of all, one should try to make more water available, for instance by re-use of drainage water or additional use of groundwater. If this is not possible, both technical and managerial measures could be thought of. Canal lining, canal rotation, proportional outlets, introduction of *warabandi* and training of farmers are most frequently advocated. Also, balancing reservoirs in the main system could be useful, but there have to be suitable sites. Considering past experience it is doubtful whether these commonly advocated measures are sufficient to solve the existing problems (Jurriëns, 1993).

A complete package of more systematic management, with clear and consistent pre-season planning and operational guidelines, communications, etc. could be of some help; provided it starts with not trying to irrigate much more than the area which is normally irrigated. And moreover, a more precise legislation and effective prosecution of violators should go along with that. In the organizational field the main option seems to be the organisation of tail-end water users to exert pressure on irrigation department officials and head-end farmers to release more water. Some NGO's are undertaking such efforts, and, it seems, with some success (ISARD, 1992).

---

1) Under the Water Apportionment Accord of 1991, Punjab has the right to 68.80 Bm^3 water annually. With flood water included its share is 75.03 Bm^3. Between 1976 and 1985 the mean annual diversion of Punjab was 66.25 Bm^3. (Sufi, Ahmad and Zuberi, 1993)

The main opportunities may, however, lie in the agricultural sphere. Price and market policy are not usually considered to be relevant for water management, but the discussion above suggest they may be. Favourable prices and good market accessibility for "light" crops may influence farmers' crop choice away from water intensive crops, and thereby automatically have a spreading effect on water distribution. One candidate in this respect is sunflower, which has been a remunerative cash crop over the past years, and requires little irrigation. The liberalization of the Indian economy may also have an impact. Liberalising the market for sugar and sugarcane for example could in the long run make sugarcane a less economically attractive crop than it is now. However, these changes are not easily brought about, and particularly in the case of rice, there are other considerations than economic returns for the cultivation of crops as well.

8 CONCLUSIONS

The gist of this paper is to explain a number of essential elements of protective irrigation. Important lessons learned are:

1) More systematic analysis should be done on initial design of the system in terms of design duties and intensities.
2) Studies of irrigation water management are required to assess the actual performance of systems.
3) Actual results should be compared with design and reasons for differences should be identified, with prior attention to possible implications of the protective nature of the system, especially concerning crop water requirements and water-yield relations.

In Chapter 4 we suggested a list of questions that need to be answered in design and performance assessment exercises. Only after such analysis, a start could be made to develop measures for improvement. It is then essential to take into account the conflicts between initial objectives and current farmers' objectives, which inevitably seem to lead to serious performance problems.

To conclude, it is evident that no clear-cut solutions can be given for the problems that beset protective irrigation, because they will vary depending on the specific circumstances. There are no quick-fixes for the ills of the irrigation sectors of India and Pakistan and improving the performance of surface irrigation schemes will be a complex and time-consuming process. It is in any case crucial first to analyze the relation between water demands and availability and to identify the implications of that in terms of scheme productivity and related scheme and national economy, farm budgets and incomes, measures to be taken for areas excluded from irrigation, and the legislative and management consequences of all this.

REFERENCES

Agarwal, S.C. 1994. 'Performance Evaluation of Gandak Project'. *Proceedings of the Fifth National Water Convention.* New Delhi:MoWR(GoI)/NWDA/IWRS. pp.381-387.

Ahmad, N. and G.R. Chaudhry. 1988. *Irrigated Agriculture of Pakistan.* Lahore:Shahzad Nazir Publishers.

Anver, R.K. 1991. 'Operation of Irrigation System'. *Proceedings Special Technical Session Beijing.* New Delhi:International Commission on Irrigation and Drainage. pp.14-38.

Atchi Reddy, M. 1990. 'Travails of an Irrigation Company in South India, 1857-1882'. *Economic and Political Weekly.* March 24:619-628.

Attwood, D.W. 1987. 'Irrigation and Imperialism: The Causes and Consequences of a Shift from Subsistence to Cash Cropping'. *Journal of Development Studies.* 23(3):341-366.

Attwood, D.W. 1993. *Raising Cane. The Political Economy of Sugar in Western India.* Delhi:Oxford University Press.

Bandaragoda, D.J. 1993. *The Role of Research-Supported Irrigation Policy in Sustainable Irrigated Agriculture: An Interpretive Precis of the Case of Pakistan.* (IIMI Country Paper - Pakistan - No. 6). Colombo:International Irrigation Management Institute.

Bandaragoda, D.J. and M. Badruddin. 1992. *Moving Towards Demand-Based Operations in Modernized Irrigation Systems in Pakistan.* (IIMI Country Paper - Pakistan - No 5). Colombo:International Irrigation Management Institute.

Bandaragoda, D.J. and G.R. Firdousi. 1992. *Institutional Factors Affecting Irrigation Performance in Pakistan: Research and Policy Priorities.* (IIMI Country Paper - Pakistan - No.4), Colombo: International Irrigation Management Institute.

Berkoff, D.J.W. 1987. *Matching Crop Water Requirements in Large Systems with a Variable water Supply - Experiments in India.* (ODI/IIMI Irrigation Management Network Paper 87/3d), London:Overseas Development Institute.

Berkoff, D.J.W. 1988. *Irrigation Management in South India: The Approach of the National Water Management Project.* (ODI/IIMI Irrigation Management Network Paper 88/2d), London:Overseas Development Institute.

Berkoff, D.J.W. 1991. 'India - Irrigation Sector Review: Irrigation Management on the Indo-Gangetic Plain'. *Improved Irrigation System Performance for Sustainable Agriculture. Proceedings of the Regional Workshop on Improved Irrigation System Performance for Sustainable Agriculture*. Rome:FAO. pp.67-93.

Bhatti, M.A., F.E. Schulze and G. Levine. 1991. 'Yield Measures of Irrigation Performance in Pakistan'. *Irrigation and Drainage Systems*. 5:183-190.

Bhutta, M.N., M. Latif and J.W. Kijne. 1991. 'A Study of Water Distribution From a Branch to Distributary Canals: A Case Study of Gugera Branch, Punjab, Pakistan'. *Irrigation and Drainage Systems*. 5:229-247.

Bhutta, M.N. and E.J. Vander Velde. 1992. 'Equity of Water Distribution Along Secondary Canals in Punjab, Pakistan'. *Irrigation and Drainage Systems*. 6:161-177.

Bolding, A., P.P. Mollinga and K. van Straaten. 1995. 'Modules for Modernization: Colonial Irrigation and the Technological Dimensions of Agrarian Change'. *Journal of Development Studies*. 36(1):805-844

Burns, R.E. 1993. 'Irrigated Rice Culture in Monsoon Asia: The Search for an Effective Water Control Technology'. *World Development*. 21(5):771-789.

Chambers, R. 1988. *Managing Canal Irrigation. Practical Analysis from South Asia*. New Delhi:Oxford & IBH Publishing Co..

Chaudhry, M.A. and R.A. Young. 1990. 'Economic Impacts of Alternative Irrigation Water Allocation Institutions: Pakistan's Warabandi System'. In: Sampath and Young (eds.). *Social, Economic, and Institutional Issues in Third World Irrigation Management*. Boulder:Westview Press. pp.395-410.

Desai, N.B., M.A. Bandi and J.V. Shah. 1994. 'Performance Overview of Ukai Kakrapar Project'. *Proceedings of the Fifth National Water Convention*. New Delhi: MoWR(GoI)/NWDA/IWRS. pp.117-125.

Desai, N.B., O.T. Gulati and K.G. Rathod. 1994. 'Performance Overview of Mahi-Kadana Project'. *Proceedings of the Fifth National Water Convention*. New Delhi: MoWR(GoI)/NWDA/IWRS. pp.159-167.

Dhamdhere, H.V. 1983. 'A Case Study of Mula Project in Maharashtra'. *Symposium on Water Management: Experiences of the Past and Directions for Future*. New Delhi: Central Board of Irrigation and Power. pp.11-33.

Dhawan, B.D. 1988. *Irrigation in India's Agricultural Development. Productivity, Stability, Equity*. New Delhi:Sage Publications.

Dhawan, B.D. 1989. 'Enhancing Production Through Crop Pattern Changes'. *Artha Vijnana*. 31(2)153-175.
Dwivedi, V.K. 1994. 'Operation Plan for Dumraon Branch Canal'. *Proceedings of National Workshop on Operation Plan for Run of the River Schemes in Irrigation Systems*. Lucknow:Water and Land Management Institute (Uttar Pradesh). pp.XI-1-XI-27.

Famine Commission. 1880. *Report of the Indian Famine Commission. Part I. Famine Relief. Part II. Measures of Protection and Prevention*. London:Eyre and Spottiswood. (reprinted 1989).

FAO. 1975. *Small Hydraulic Structures*. (Irrigation and Drainage Paper 26). Rome: FAO.

Franks, T.R. 1986. 'Water Management on the Rice Canal System, Pakistan'. *Irrigation and Drainage Systems*. 1:5-18.

Freeman, D.M. and E. Shinn. 1989. 'Irrigation Organization on the Niazbeg Distributary in Punjab, Pakistan'. In: Freeman (ed.). *Local Organizations for Social Development. Concepts and Cases of Irrigation Organization*. Boulder:Westview Press. pp.63-132.

Gandhi, P.R. 1979. 'Management of Irrigation in Maharashtra - Shej-Pali System in the South and Waharabandi System in the North'. *Irrigation and Power*. October 1979:395-408.

Gandhi, P.R. and H.V. Dhamdhere. 1982. 'Water Distribution Practices in Maharashtra (India)'. *Proceedings of the Workshop on Water Distribution Practices*. Roorkee:Indian Water Resources Society. pp.70-76.

Gandhi, P.R. and R.K. Inamdar. 1983. 'Evolution of Management System on Deccan Canals'. *Symposium on Water Management: Experiences of the Past and Directions for Future*. New Delhi:Central Board of Irrigation and Power. pp.1-10.

Garces, Carlos and Tissa Bandaragoda. 1991. *Crop Based Irrigation in Pakistan: Prospects and Constraints*. Lahore:International Irrigation Management Institute.

Ghose, A.K. 1979. 'Institutional Structure, Technological Change and Growth in Poor Agrarian Economies: An Analysis with Reference to Bengal and Punjab'. *World Development*. 7:358-396.

GoAP (Government of Andhra Pradesh). 1982. *Report of the Commission on Irrigation Utilisation*. Hyderabad:GoAP.

GoI/MoIP (Government of India, Ministry of Irrigation and Power). 1972. *Report of the Irrigation Commission 1972*. New Delhi:GoI/MoIP.

GoI/MoWR (Government of India, Ministry of Water Resources). 1987. *National Water Policy*. New Delhi:GoI/MoWR.

GoI/PC (Government of India, Planning Commission). 1992. *Eighth Five-Year Plan, 1992-1997; Chapter 3, Volume II. Irrigation, Command Area Development and Flood Control*. New Delhi:GoI/PC.

GoP/MoFAC (Government of Pakistan/Ministry of Food, Agriculture, and Cooperatives). 1988. *The Report of the National Commission on Agriculture*. Islamabad:MoFAC/GoP.

GoP/WAPDA (Government of Pakistan/Water and Power Development Authority). 1990. *Water Sector Investment Planning Study. Volume I: Main Report. Volume IV: Reports Prepared by WAPDA*. Lahore:GoP/WAPDA.

Gupta, J.P. 1993. 'Water Delivery Scheduling in North West India'. In: Tyagi, Kamra, Minhas and Singh (eds.). *Irrigation in Saline Environment: Key Management Issues*. Karnal:Central Soil Salinity Research Institute. pp.30-39.

Gurjar, R.K. 1987. *Irrigation for Agricultural Modernization (A Study of the Indira Gandhi Command Area Stage-1)*. Jodhpur:Scientific Publishers.

Gustafson, W.E. and R.B. Reidinger. 1971. 'Delivery of Canal Water in North India and West Pakistan'. *Economic and Political Weekly*. 6(52):157-162.

Halsema, G.E. van and P. Wester. 1994. *The "Art" of Diverting Water; Irrigation Water Management in the Kabul River Canal System, NWFP, Pakistan*. (Water Management Project/Agricultural University Peshawar Report No. 94/2). Peshawar:Agricultural University Peshawar.

Hoffman, G.J., T.A. Howell and K.H. Solomon. 1990. 'Introduction'. In: Hoffman, Howell and Solomon (eds.), *Management of Farm Irrigation Systems*. (American Society of Agricultural Engineers Monograph # 9). St. Joseph, MI:ASAE, pp.5-10.

Hukmani, C.S. and S.R. Katariya. 1982. 'Water Distribution in Ganga & Bhakra (Raj) Canals'. *Proceedings Workshop on Water Distribution Practices*. Roorkee:Indian Water Resources Society. pp.44-63.

IPTRID. 1993. *India. Proposal for Technology Research in Irrigation and Drainage*. Washington, D.C.:World Bank/UNDP/ICID.

REFERENCES

IIC (Indian Irrigation Commission). 1903. *Report of the Indian Irrigation Commission 1901-1903. Part I-General.* Calcutta:Office of the Superintendent of Government Printing.

ISARD. 1992. *Farmers' Participation in Water Management in the 36/5B Sub-distributary of TB-LBC at Dhadesugur.* Dharwad:ISARD.

Jong, C. de and K.K. Datta. 1994. 'Some Observations on the Effect of Land Drainage on the Agricultural Economy: Social, Economic and Organizational Aspects.' Paper for the National Seminar on Reclamation and Management of Waterlogged Saline Soils. Karnal:Central Soil Salinity Research Institute.

Jurriëns, M. 1993. 'Protective Irrigation: Essentials and Implications'. *Water Management in the Next Century. Transactions of 15th Congress on Irrigation and Drainage. Volume 1-A.* New Delhi:International Commission on Irrigation and Drainage. pp.333-348.

Jurriëns, M., V. Ramaiah and J.G. van Alphen. 1987. 'Irrigation Water Management in the Tungabhadra Scheme, India'. *ILRI Annual Report 1987.* Wageningen:International Institute for Land Reclamation and Improvement. pp.22-32.

Jurriëns, M. and W. Landstra. 1989. 'Water Distribution: Conflicting Objectives of Scheme Management and Farmers'. In: Rydzewski and Ward (eds.). *Irrigation. Theory and Practice. Proceedings of the International Conference held at the University of Southampton.* Southampton:Institute of Irrigation Studies. pp.711-720.

Jurriëns, M., M. Kuper and P. Bokdam. 1989. *Chak Research in Chaks 8L on 36/3 and 44OR on 36/1.* (Tungabhadra Water Management Project. Research Report No. 10). Wageningen:International Institute for Land Reclamation and Improvement.

Jurriëns, M. and W. Wolters, 1993. 'Can Protective Irrigation be More Efficient?'. Paper to the International Conference on Hydrology and Water Resources. Roorkee:National Institute of Hydrology.

Kathpalia, G.N. 1983. 'Management of Canal Supplies and Social Environment'. In: Singh (ed.), *Utilization of Canal Waters: A Multi-Disciplinary Perspective on Irrigation [Workshop on Irrigation Systems Management to Chak (Outlet) Requirements, July 1981].* (Central Board of Irrigation and Power Publication No. 164). New Delhi:CBIP. pp.36-39.

Khan, M.Y. 1991. 'Irrigation Water Management in Indus River System of Pakistan'. *Proceedings Special Technical Session Beijing.* New Delhi:International Commission on Irrigation and Drainage. pp.298-309.

Kuiper, Rutger. 1993. *Bhadra Reservoir Project. Operation, Plans and Practices*. Paper for National Seminar at WALMI-Anand. PMU Indo-Dutch Training Production Management Unit.

Kundu, P.S. 1990. 'Performance of Irrigation System in Respect of Equity, Reliability and Availability of Water'. In: Tyagi, Joshi, Gupta and Singh (eds.). *Management of Irrigation System. Papers from the National Symposium on Management of Irrigation System*. Karnal:Central Soil Salinity Research Institute. pp.41-50.

Kuper, M. and J.W. Kijne. 1992. 'Irrigation Management in the Fordwah Branch Command Area South East Punjab, Pakistan'. Paper prepared for the Internal Programme Review. Colombo:International Irrigation Management Institute.

Latif, M. and S. Sarwar. 1994. 'Proposal for Equitable Water Allocation for Rotational Irrigation in Pakistan'. *Irrigation and Drainage Systems*. 8:35-48.

Lowdermilk, M.K., A.C. Early and D.M. Freeman. 1978. *Farm Irrigation Constraints and Farmers' Responses: Comprehensive Field Survey in Pakistan. Volume I. Summary*. (Water Management Technical Report No. 48-A). Fort Collins:Colorado State University.

Mahbub, S.I. and N.D. Gulhati. 1951. *Irrigation Outlets*. New Delhi:Atma Ram Publishers.

Maheshwari, K.M. 1993. 'Changing Maintenance Requirements as a Result of Irrigation Developments'. In: Jurriëns and Jain (eds.), *Maintenance of Irrigation and Drainage Systems; Practices and Experiences in India and The Netherlands*. Wageningen/ Lucknow:International Institute for Land Reclamation and Improvement/Water and Land Management Institute (Uttar Pradesh). pp.147-154.

Malhotra, S.P. 1982. *The Warabandi System and its Infrastructure*. (Central Board of Irrigation and Power, Publication No. 157). New Delhi:CBIP.

Mathur, S.P. 1982. 'Water Distribution on Ganga Canal System'. *Proceedings Workshop on Water Distribution Practices*. Roorkee:Indian Water Resources Society. pp.64-69.

Merrey, D.J. 1986a. 'The Local Impact of Centralized Irrigation Control in Pakistan: A Socio-Centric Perspective'. In: Wolf and Merrey (eds.). *Irrigation Management in Pakistan: Four Papers*. (IIMI Research Paper No. 4). Colombo:International Irrigation Management Institute. pp.12-25.

Merrey, D.J. 1986b. 'Reorganizing Irrigation: Local Level Management in the Punjab (Pakistan)'. In: Wolf and Merrey (eds.). *Irrigation Management in Pakistan: Four*

Papers. (IIMI Research Paper No. 4). Colombo:International Irrigation Management Institute. pp.26-43.

Merrey, D.J. 1986c. 'The Sociology of Warabandi; A Case Study from Pakistan'. In: Wolf and Merrey (eds.). *Irrigation Management in Pakistan: Four Papers*.(IIMI Research Paper No. 4). Colombo:International Irrigation Management Institute. pp.44-65.

Merrey, D.J. 1990. 'Warabandi in Pakistan'. In: Hoffman, Howell and Solomon (eds.). *Management of Farm Irrigation Systems*. (American Society of Agricultural Engineers Monograph No. 9). St. Joseph, MI:ASAE. pp.945-957.

Michel, A.A. 1967. *The Indus Rivers. A Study of the Effects of Partition*. New Haven and London:Yale University Press.

Mohanakrishnan, A. 1983. 'Operation of the Canal System and Field Requirements: The Southern States'. In: Singh (ed.). *Utilization of Canal Waters: A Multi-Disciplinary Perspective on Irrigation [Workshop on Irrigation Systems Management to Chak (Outlet) Requirements, July 1981]*. (Central Board of Irrigation and Power Publication No. 164). New Delhi:CBIP. pp. 31-35.

Mollinga, P.P. 1992. *Protective Irrigation in South India; Deadlock or Development*. (DPP Working Paper No 24). Milton Keynes:Open University.

Morse, B. 1992. *Sardar Sarovar Projects. Report of the Independent Review*. Resource Futures International.

Narian, K.D., D.K. Thakur and A. Prasad. 1994. 'Sone High Level Canals Project, Bihar - A Success Story'. *Indian Journal of Power & River Valley Development*. March-April 1994:46-51.

Navalawala, B.N. 1993. 'Indian Experience in Irrigation Management and Farmers' Participation. *Water Management in the Next Century. Transactions of 15th Congress on Irrigation and Drainage. Volume 1-E*. New Delhi:International Commission on Irrigation and Drainage. pp.181-200.

ODI (Overseas Development Institute). 1976. *Canal Systems in North West India and Pakistan*. Paper at Workshop on Choices in Irrigation Management. London:ODI.

Palanisami, K. 1983. 'Problems of Water Distribution and Management at Outlet Level-A Case of Lower Bhavani Project, Coimbatore District, South India'. In: Singh (ed.). *Utilization of Canal Waters: A Multi-Disciplinary Perspective on Irrigation [Workshop on Irrigation Systems Management to Chak (Outlet) Requirements, July 1981]*. (Central Board of Irrigation and Power Publication No. 164). New Delhi:CBIP. pp.114-120.

Punmia, B.C. and P.B.B. Lal. 1992. *Irrigation and Water Power Engineering*. New Delhi: Laxmi Publications. (12th edition).

Rath, N. and A.K. Mitra. 1989. 'Economics of Irrigation in Water-Scarce Regions: Study of Maharashtra'. *Artha Vijnana*, 31(1):1-129.

Ratnadurai, M. 1990. 'Equity of Irrigation Water-Tamil Nadu. A Case Study'. *Proceedings of National Workshop on Equity*. Lucknow:Water and Land Management Institute (Uttar Pradesh). pp.138-145.

Reddy, M.V. 1989. 'Theoretically Well-Conceived and Operationally Ill Operated Water Management Systems: A Case Study from India'. In: Rydzewski and Ward (eds.). *Irrigation. Theory and Practice. Proceedings of the International Conference held at the University of Southampton*. Southampton:Institute of Irrigation Studies. pp.742-756.

Reidinger, R.B. 1971. *Canal Irrigation and Institutions in North India*. (PhD thesis). Durham, N.C.:Duke University.

Reidinger, R.B. 1974. 'Institutional Rationing of Canal Water in Northern India: Conflict between Traditional Patterns and Modern Needs'. *Economic Development and Cultural Change*. 23(1):79-104.

Reidinger, R.B. 1980. 'Water Management by Administrative Procedures in an Indian Irrigation System'. In: Coward (ed.). *Irrigation and Agricultural Development in Asia: Perspectives from the Social Sciences*. Ithaca:Cornell University Press. pp.263-288.

Roy, A.S. 1990. 'Distribution of Water in Irrigation Project, West Bengal (Kangsabati Irrigation Project)'. *Proceedings of National Workshop on Equity*. Lucknow:Water and Land Management Institute (Uttar Pradesh). pp.60-66.

Rub, M.A. and P. Venkat Reddy. 1983. 'Case Studies of Experience and Problems of Operations in Water Management of the System in Sriramasagar Project Command'. *Symposium on Water Management: Experiences of the Past and Directions for the Future*. New Delhi:Central Board of Irrigation and Power. pp.265-276.

Saksena, R.S. 1982. 'Distribution and Regulation of Water for Irrigation in India'. *Proceedings of the Workshop on Water Distribution Practices*. Roorkee:Indian Water Resources Society. pp.112-120.

Sarkar, A.K., B.D. Pal, A.K. Mitra and R.N. Bagchi. 1994. 'Development and Functioning of River Valley Projects in West Bengal'. *Indian Journal of Power & River Valley Development*. March-April 1994:33-42.

Sastry, C.L.N. 1994. 'Performance of Public Irrigation Systems - Typical Case Studies of Andhra Pradesh'. *Proceedings of the Fifth National Water Convention*. New Delhi: MoWR(GoI)/NWDA/IWRS. pp.71-82.

Sharma, D.N. and R. Oad. 1990. 'Variable-Time Model for Equitable Irrigation Water Distribution'. *Agricultural Water Management*. 17:367-377.

Singh, B.R. and V.S. Sharma. 1994. 'Overview of Tawa Project M.P.'. *Proceedings of the Fifth National Water Convention*. New Delhi:MoWR(GoI)/NWDA/IWRS. pp.145-151.

Sihna, K.P. and L.P. Srivastava. 1990. 'Equitable Distribution of Canal Water in Paliganj Distributary (Sone Canal System, Bihar): A Case Study'. *Proceedings of National Workshop on Equity*. Lucknow:Water and Land Management Institute (Uttar Pradesh). pp.1-13.

Sinha, S.C. 1994. 'Performance Evaluation of Some Irrigation Projects in Bihar'. *Proceedings of the Fifth National Water Convention*. New Delhi: MoWR(GoI)/NWDA/IWRS. pp.55-69.

Sivanappan, R.K., P. Kandaswamy and K.V. Selvaraj. 1983. 'Irrigation Experiences in River Command Areas and Suggestions for Water Management of Future - Tamil Nadu'. *Symposium on Water Management: Experiences of the Past and Directions for the Future*. New Delhi:Central Board of Irrigation and Power. pp.103-112.

Stone, I. 1984. *Canal Irrigation in British India. Perspectives on Technological Change in a Peasant Economy*. Cambridge:Cambridge University Press.

Sufi, A.B., N. Ahmad and F.A. Zuberi. 1993. 'Improving Irrigation and Drainage of Irrigated Lands of the Punjab in View of Water Apportionment Accord of 1991'. *Water Management in the Next Century. Transactions of the 15th International Congress on Irrigation and Drainage. Volume 1-A*. New Delhi:International Commission on Irrigation and Drainage. pp.387-402.

Tilak, M.G.B. and B.S. Rajvanshi. 1991. 'Operation of Irrigation Systems in India'. *Proceedings of the Special Technical Session Beijing*. New Delhi:International Commission on Irrigation and Drainage. pp.B1-B13.

Tyagi, N.K. 1993. 'Performance Evaluation of an Irrigation System - A Case Study'. Paper to the National Workshop on Sustainable Irrigation. Karnal:Central Soil Salinity Research Institute.

Tyagi, N.K. and A.R. Mishra. 1990. 'Evaluation of Water Delivery System: Some Case Studies from Haryana.' In: Tyagi, Joshi, Gupta and Singh (eds.). *Management of*

Irrigation Systems. Papers from the National Symposium on Management of Irrigation System. Karnal:Central Soil Salinity Research Institute. pp.33-40.

Trimmer, W.L. 1990. 'Applying Partial Irrigation in Pakistan'. *Journal of Irrigation and Drainage Engineering*. 116(3):342-353.

Vander Velde, E.J. 1980. 'Local Consequences of a Large Scale Irrigation System in India'. In: Coward (ed). *Irrigation and Agricultural Development in Asia: Perspectives from the Social Sciences*. Ithaca:Cornell University Press. pp.299-328.

Vander Velde, E.J. 1991. 'Performance Assessment in a Large Irrigation System in Pakistan: Opportunities for Improvement at the Distributary Level'. *Improved Irrigation System Performance for Sustainable Agriculture. Proceedings of the Regional Workshop on Improved Irrigation System Performance for Sustainable Agriculture*. Rome:FAO. pp.93-111.

Vedula, S., K. Sridharan, A. Sundar and P.S. Rao. 1986. *Main Canal System Technical Issues. A Case Study in the 10th Block of Nargund Branch Canal of Malaprabha Project*. Bangalore:Indian Institute of Science.

Vohra, B.B. 1975. *Land and Water Management Problems in India*. New Delhi:Training Division, Cabinet Secretary.

Wade, R. 1976. 'Water Accounting in Irrigation Projets. A Technique from Maharashtra'. *Economic and Political Weekly*. August 28:1436-1439.

Wade, R. 1982. 'The World Bank and India's Irrigation Reform'. *Journal of Development Studies*. 18(2):171-184.

Whitcombe, E. 1983. 'Irrigation'. In: Kumar and Desai (eds.). *The Cambridge Economic History of India. Volume 2: c. 1757 - c. 1970*. Cambridge:Cambridge University Press. pp.677-737.

Wolf, J.M. 1986. 'Cost and Financing of Irrigation System Operations and Maintenance in Pakistan'. In: Wolf and Merrey (eds.). *Irrigation Management in Pakistan: Four Papers*. (IIMI Research Paper No. 4). Colombo:International Irrigation Management Institute. pp.1-11.

World Bank. 1988. *Pakistan. Second Irrigation Systems Rehabilitation Project. Staff Appraisal Report*. (Report No. 6991-PAK). Washington, D.C.:World Bank.

World Bank. 1991. *India; Irrigation Sector Review*. (Report No. 9518-IN). Washington, D.C.:World Bank.

REFERENCES

World Bank. 1994. *Pakistan. Irrigation and Drainage: Issues and Options*. (Report No. 11884-PAK). Washington, D.C.:World Bank.

ANNEX 1: WATER ALLOWANCES AT CANAL HEAD OF ALL LARGE SCALE IRRIGATION SYSTEMS IN PAKISTAN[1)]

Canal System	First Year of Operation	CCA (1000 acres)[2)]	CCA (1000 ha)	Canal Capacity		Water Allowance		Duty (acres/ cusec)
				m^3/s	cusecs	l/s.ha	cusecs/ 1000 acres	
1. Central Bari Doab	1859[a)]	649[b)]	263	73.62	2,600[a)]	0.28	4.01	249
2. Sidhnai	1886[a)]	869[b)]	352	127.43	4,500[a)]	0.36	5.18	193
3. Lower Swat[3)]	1890[a)]	146	59[c)]	23.50	830[c)]	0.40	5.68	176
4. Kabul River	1890[a)]	48[b)]	19	12.74	450[a)]	0.66	9.38	107
5. Lower Chenab	1892[a)]	3,034[b)]	1,228	325.64	11,500[a)]	0.27	3.79	264
6. Lower Jhelum	1901[a)]	1,500[b)]	607	150.08	5,300[a)]	0.25	3.53	283
7. Paharpur	1909[a)]	104[b)]	42	14.16	500[a)]	0.34	4.81	208
8. Upper Chenab	1912[a)]	1,441[b)]	583	116.10	4,100[a)]	0.20	2.85	351
9. Lower Bari Doab	1913[a)]	1,670[b)]	676	198.22	7,000[a)]	0.29	4.19	239
10. Upper Jhelum	1915[a)]	544[b)]	220	53.80	1,900[a)]	0.24	3.49	287
11. Upper Swat	1915[a)]	279[b)]	113	50.97	1,800[a)]	0.45	6.45	155
12. Eastern Sadiqia	1926[a)]	969[b)]	392	138.75	4,900[a)]	0.35	5.06	198
13. Pakpattan	1927[a)]	1,049[b)]	425	186.89	6,600[a)]	0.44	6.29	159
14. Fordwah	1927[a)]	426[b)]	172	96.28	3,400[a)]	0.56	7.98	125
15. Qaimpur	1927[a)]	42[a)]	17	16.99	600[a)]	1.00	14.29	70
16. Bahawal	1927[a)]	605[b)]	245	152.91	5,400[a)]	0.62	8.93	112
17. Upper Dipalpur	1928[a)]	360[b)]	146	65.67	2,319[b)]	0.45	6.44	155
18. Lower Dipalpur	1928[a)]	615[b)]	249	113.74	4,017[b)]	0.46	6.53	153
19. Mailsi	1928[a)]	688[a)]	279	138.75	4,900[a)]	0.50	7.12	140
20. Panjnad	1929[a)]	1,348[b)]	546	254.85	9,000[a)]	0.47	6.68	150
21. Abbasia	1929[a)]	154[b)]	62	31.15	1,100[a)]	0.50	7.14	140
22. North West	1932[a)]	1,215[b)]	492	144.42	5,100[a)]	0.29	4.20	238

1) The water allowances in this table are those at canal head. Losses in canals have been measured and are estimated to range between 30% to 40% (GoP/WAPDA, 1990).

2) The data given in the literature is not always consistent. In those cases that figures differed, the lowest value was chosen.

3) Before modernization. After modernization, canal capacity is 1,940 cusecs and water allowance is 13.3 cusecs/1000 acres (Bandaragoda and Badruddin, 1992).

Canal System	First Year of Operation	CCA (1000 acres)	CCA (1000 ha)	Canal Capacity		Water Allowance		Duty (acres/ cusec)
				m^3/s	cusecs	l/s.ha	cusecs/ 1000 acres	
23. Rice[4]	1932[a]	519[b]	210	288.83	10,200[a]	1.37	19.65	51
24. Dadu	1932[a]	584[b]	236	90.61	3,200[a]	0.38	5.48	182
25. Khairpur West	1932[a]	417[b]	169	53.80	1,900[a]	0.32	4.56	219
26. Rohri	1932[a]	2,561[b]	1,037	317.15	11,200[a]	0.31	4.37	229
27. Khairpur East	1932[a]	373[b]	151	76.46	2,700[a]	0.51	7.24	138
28. Eastern Nara	1932[a]	2,176[b]	881	379.45	13,400[a]	0.43	6.16	162
29. Rangpur	1939[a]	344[b]	139	76.46	2,700[a]	0.55	7.85	127
30. Havali	1939[a]	179[b]	72	19.82	700[a]	0.27	3.91	256
31. Thal	1947[a]	1,641[b]	664	215.12	7,597[b]	0.32	4.63	216
32. Pinyari	1955[a]	758[b]	307	407.76	14,400[a]	1.32	19.00	53
33. Fuleli	1955[a]	923[b]	374	390.77	13,800[a]	1.04	14.95	67
34. Lined Channel	1955[a]	502[b]	203	116.10	4,100[a]	0.57	8.17	122
35. Kalri Baghar	1955[a]	592[b]	240	254.85	9,000[a]	1.06	15.20	66
36. M.R. Link (Int)	1956[a]	158[b]	64	56.63	2,000[a]	0.89	12.66	79
37. D.G. Khan	1958[a]	909[b]	368	249.19	8,800[a]	0.68	9.68	103
38. Muzaffargarh	1958[a]	809[b]	328	206.71	7,300[a]	0.63	9.02	111
39. Pat	1962[a]	747[b]	302	235.03	8,300[a]	0.78	11.11	90
40. Desert	1962[a]	328[b]	133	365.29	5,383[b]	1.15	16.41	61
41. Begari	1962[a]	1,002[b]	406	438.91	15,500[a]	1.08	15.47	65
42. Ghotki	1962[a]	858[b]	347	240.69	8,500[a]	0.69	9.91	101
43. Warsak	1962[a]	119[a]	48	14.16	500[a]	0.29	4.20	238
44. Chasma Right Bank[5]	1986[c]	570[c]	231	138.16	4,879[c]	0.60	8.56	117
Totals		34,720	14,055					

Sources: [a] Ahmad and Chaudhry, 1988; [b] GoP/WAPDA, 1990; [c] Bandaragoda and Badruddin, 1992.

4) Franks (1986) mentions a canal capacity of 300 m^3/s. It is not clear why the Rice Canal system has such a high water allowance, although, as its name suggests, it was specifically designed for rice cultivation.

5) At present, only Stage-I of the project, covering 56,000 ha, has been completed. The Paharpur Canal system has become part of the CRBC system. Within the next ten years the CCA will be expanded to finally cover 230,675 ha. (Bandaragoda and Badruddin, 1992)