The Dilemmas of Water Division

Considerations and Criteria
for
Irrigation System Design

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For INEZ—*I owe this to my wife for bearing with all the inconveniences I caused in the course of writing this book.*—Lucas.

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Cover photograph, by Jop Horst, of work of art by Pino Pascali titled "Ploughed fields with irrigation channels."

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PREFACE

The reason for writing this book is the challenge to address a number of interrelated questions I came across during my work in irrigation.

The first question concerns design and operation of irrigation systems. During the last 15 years it became increasingly clear that in many irrigation schemes a large discrepancy exists between design assumptions and operational reality. Considerable efforts are made to reduce this discrepancy by changing or improving the management environment. The technology however is rarely examined and mostly treated as a black box. Although, admittedly, management aspects are important, one may ask:

> *"Is management really the crux of irrigation problems? Does not the type of technology (the physical canal system with its appurtenant operational requirements) determine the management modalities for use? Do we not apply cosmetic surgery by only trying to improve the management environment without considering the technology? Is it not time to examine the root of the problem: the design of irrigation systems?"*

Generally, irrigation designs are mainly based on physical criteria (hydraulics, agronomy, engineering). When compared with the operational reality they fall short in terms of human and institutional aspects. The following questions arise:

> *"Would it be possible to design irrigation systems taking into account human and institutional aspects? If so, what would be the repercussions on the type of technology?"*

Most irrigation schemes have a persistent shortage of skilled operational staff. Combined with the complicated and opaque water division technology and operational procedures this often leads to poor performance. The present drive for increasing water use efficiencies, in view of increasing shortages of water, will result in even more complicated technology and operation with subsequently poorer performance. This leads to the question:

> *"Are these complicated technologies and operational procedures realistic and really necessary? Would it be possible to achieve better performance by simplifying the technology and operational procedures?"*

In the following chapters I have endeavored to address these questions. This book is not a blueprint type of textbook but is meant to create awareness in designers, planners, and students of irrigation for them to make more balanced design choices for water division structures. I also hope it will contribute to the ongoing debate in irrigation.

I am grateful to the Wageningen Agricultural University for the arrangements made to carry out this study and I am specially thankful to my successor Linden Vincent for taking over the heavy burden of the chair of irrigation.

I am indebted to Ian Makin of the International Water Management Institute (IWMI), Colombo and K. Sanmuganathan of Hydraulic Research, Wallingford, UK for their substantive contribution to the final text. Thanks are also due to Daniel Renault of IWMI, Eugène Dahmen of the International Institute for Hydraulic and Environmental Engineering (IHE) in Delft and Geert Diemer and Bert de Jager of the Department of Irrigation and Soil and Water Conservation in Wageningen. Their valuable comments on the draft manuscript were most welcome.

Finally, I owe thanks to Trudy Freriks for typing this last handwritten book of the department.

Lucas Horst
1998

ABBREVIATIONS

ADB	Asian Development Bank
AOR	Additional Operational Requirements
BIP	Bali Irrigation Project
CHO	Constant Head Orifice
F	Hydraulic Flexibility
FAO	Food and Agriculture Organization
ICID	International Commission on Irrigation and Drainage
IWMI	International Water Management Institute
ILRI	International Institute for Land Reclamation and Improvement
IR	Irrigation Requirements at Farm Level
NIA	National Irrigation Administration (Philippines)
ODI	Overseas Development Institute (UK)
O&M	Operation and Maintenance
S	Sensitivity
tu	Tertiary Unit
USBR	United States Bureau of Reclamation
WAU	Wageningen Agricultural University
WDS	Water Delivery Schedule

PART I

Introduction

To understand today's irrigation problems, it is necessary to go back in history to examine the origin and development of irrigation. In chapter 1 the development through the twentieth century is presented in broad outline.

After this setting, the scope, limitations, and structure of this book are dealt with in chapter 2. Also in this chapter the reasoning for the focus on water division structures is explained.

CHAPTER 1

HISTORICAL AND INTRODUCTORY NOTES

1.1 First Half of the Twentieth Century: A Balanced Development

At the beginning of this century, irrigation design was very much empirically determined, based on previous experiences in other irrigated areas. This was the time when colonial powers (especially the British, Dutch, and French) and the United States started to build large-scale irrigation projects. During the course of the first half of this century irrigation system design became more and more supported by scientifically developed hydraulic principles and theories. Although these basic hydraulic principles became globally accepted and standardized, the actual design of irrigation systems developed differently from country to country. Various technology 'schools' emerged, notably the British, Dutch, French, and American schools. Most of these technologies had in common: firmly disciplined centralized management, open canal systems, and manually or mechanically[1] operated hydraulic structures for flow regulation and measurement.[2] Some typical technology examples of different 'schools' are:

- the British school on the Indian continent: development of the regime theory induced by silt-laden rivers; extensive irrigation to combat famine resulting in division of scarcity by proportional outlets.
- the Dutch school: the development of the Romijn weir meeting the requirements of vested sugar interests.
- the French school: development of an automated system to distribute scarce water in dry areas (N-Africa).
- the American school: development of the Constant Head Orifice as a distribution-cum-measuring structure for large farms.

[1]During the latter part of the colonial period, the French began to develop automatic float actuated water-level control systems in the Mediterranean area.

[2]The need for flow control might possibly be explained by vested interests of colonial powers to assure water supply for export crops (like the sugar cultivation in Indonesia), by engineering perceptions on efficiencies and the urge to control nature as developed in the Industrial Revolution, or by a combination of both.

Whatever the underlying objectives and justification for these technologies might have been, they were developed to be consistent with the physical and socioeconomic environment. This balanced development was made possible because planning, design, construction, operation, and maintenance were concentrated in one ministry, accountability was high, and a direct feedback took place from operation to planning and design. As a result, technology developed in balance with the management capability. It should be noted that during that same period the agricultural design parameters (crop water requirements) remained largely based on empirical figures.

1.2 Mid-Century Disruption

The irrigation environment changed dramatically as a result of the Second World War, wars of independence, and subsequent decolonization of a large number of countries where irrigation is important. These events left many countries with deteriorated irrigation systems, a lack of funds for operation and maintenance, and a shortage of skilled personnel. Training facilities were scarce and, furthermore, trained technical personnel were underpaid and often attracted by the emerging private sector, better salaries, and prospects of jobs in towns instead of in rural areas.

Moreover, urged by the need for increased food production, many countries embarked on large-scale expansion of their irrigable areas. This led to a demand for more and better qualified staff. This demand was often augmented by increasing interventions in the lowest levels of the irrigation systems (e.g., Command Area Development Programmes in India). All these factors contributed, and are *still contributing*, to a situation in which it is extremely difficult to establish a management infrastructure manned by staff sufficient in terms of technical skill as well as of numbers.

Generally, the higher the level of technology adopted, the higher the level of management capability needed to operate the system. As we have seen, during the first half of this century, a balanced development of irrigation technology took place, hand in hand with a compatible management capability. This is sketched in the left part of figure 1.1.[3]

The disruption during the middle of this century resulted in a kink in the management curve. At that point two options lay open (see figure 1.1): adapt the level of technology to the level of management capability (arrow a), or increase the management capability to cope with the given technology (arrow b).

Clearly, during the last 40 years the level of technology has been rigidly maintained. In spite of all efforts, however, the level of management capability has seldom approached the level of technology over the expanded irrigated area, leaving a persistent gap between the level of technology and the level of management capability.

In light of this, when considering the activities of national, international, and bilateral agencies in the field of irrigation development in the third world during the last three to four decades, it is remarkable that technology has seldom been questioned. Activities have been concentrated on new projects employing the same technology, or on rehabilitation of old projects that could better be described as 'restoring' the colonial systems, and on unsuccess-

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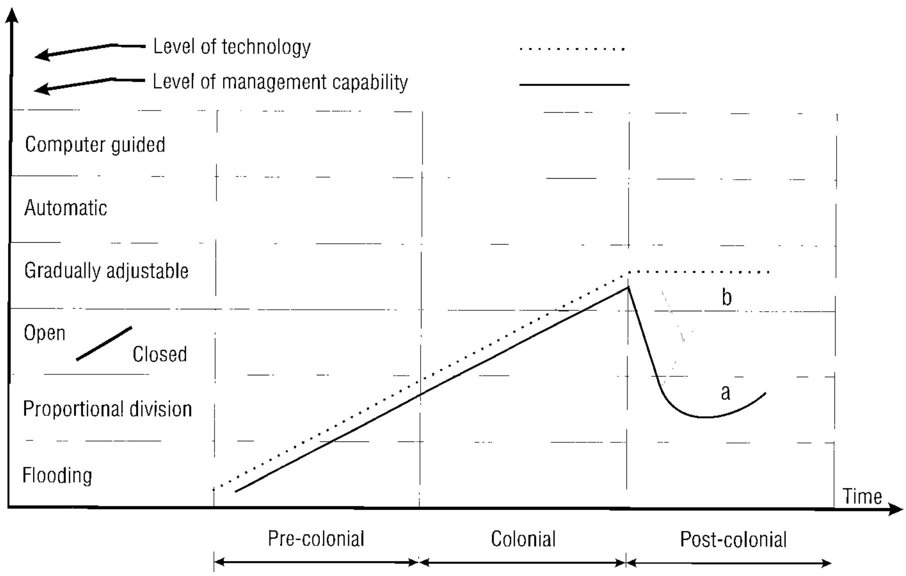
[3]See also Horst 1990.

Figure 1.1. Technology and management capability development (cf. Horst 1990).



ful attempts to upgrade the management capability to the level required for this technology. Also remarkable is the fact that until today irrigation research has continued to focus mainly on increased production and water efficiency. Little has been done on questions arising from a change from one agricultural and social setting (colonial) to another (independent), and the impact of this change on design, management, and the social and organizational aspects of irrigation.

Another problem arose with the rehabilitation of old projects and construction of new ones. Bilateral and multilateral donors and consultants came to the fore to assist in these development efforts. Many donors stipulated that foreign consultants were to be involved in the planning, design, and supervision of construction. These consultants came from different parts of the world with different irrigation technologies and traditions. Each of them was educated and (if old enough) experienced in one of the distinct irrigation schools.[4] Owing to the weak position of the national irrigation departments in terms of experience in planning and design and the dominant role of the donor agencies, the consultants were able to decide on the technology to be adopted, that is to 'sell' or impose their own technology. In other words, the

[4]The British, Dutch, French, and the US schools remained for many years the most important in the international irrigation development scene (cf. Jones 1995). Furthermore, most of the irrigation students from developing countries were trained overseas in one of these schools.

country of origin of the consultant determined the type of technology, and not the compatibility with the local physical and socioeconomic environment.[5]

Furthermore, it should be noted that water division structures as 'invented' in the first half of this century have hardly changed until now.[6]

In spite of efforts to treat these structures universally (e.g., FAO 1975; Bos ed. 1978) consultants from the four earlier-mentioned schools continued to promote 'their' own technology. This situation remained unchanged for many years because there were only a few international donors and a few reputed consulting firms. In such a situation one could not expect critical voices from consultants. Moreover, consultants were seldom confronted with the operational problems of the schemes they designed.

Even in cases where technology was adopted where it came from (e.g., the British in India or the Dutch in Indonesia), the management environment had changed: the centralized control of water distribution by strict discipline made place for a more loose bureaucratic management system. Also social (village) structures changed, creating different relationships between the farmer and the irrigation agency.

Returning to the agricultural parameters of the design, it was only in the middle of this century that scientific research on soil-water-plant relationships started (mainly in the U.S.). This production-driven research was based on the optimization of yields and water use efficiencies and resulted in the ability to determine crop water requirements with greater accuracy at various growth stages and under different climatic and soil conditions (see FAO 1977, 1979). This development enabled designers/planners to better assess required canal capacities, irrigable areas, required reservoir volumes, etc., on the basis of assumed cropping patterns. On the other hand, this more refined determination of crop water requirements led to more refined irrigation scheduling and subsequently to complicated operations and heavy demand on the numbers and skills of personnel. This was augmented by the introduction of high yielding varieties (HYV) of crops requiring a stricter water management than traditional varieties. The increasing knowledge of irrigation agronomy also led to an increased dichotomy between agronomists and engineers. Where a good design should be based on a dialogue between the two, this is seldom the case. Each is focused on his or her own field: the plant at plot level by the agronomist and the main canal system by the engineer. Both assume, however, that once the project is completed, there will be sufficient trained staff for operation and maintenance.

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[5]This situation occured in many developing countries. Extreme examples are Nepal (Pradhan 1996), Indonesia (Horst 1996a), and Senegal (Scheer 1996). The Philippines is an exception due to the dominance of the US in terms of development assistance after the 1960s. Here the USBR (United States Bureau of Reclamation) standards were rigidly adhered to. Also design standards in India remained unaltered due to late donor involvement.

[6]Technology development mainly took place in automation. In recent decades, further advances have been made in automatic systems, and today systems based on automatic and remote control, computer models, advanced communication systems, micro processors, etc., are in use, mainly in the United States and France. This development of automatic systems has drastically reduced the numbers of staff required and at the same time has drastically increased the skill of the staff required to operate and maintain these systems. Introduction of this technology in other countries (e.g., Indonesia, Thailand) has not been very successful.

Summarizing, the disruption in the middle of this century and the large-scale expansion of irrigable area have caused persistent shortages of capable staff. Introduction of technologies incompatible with the local environment, together with the tendency for more complicated operational procedures has led to even greater staffing problems.

1.3 Problems and Solutions

As a result of the situation outlined above, irrigation has been haunted for decades by a multitude of problems: low performance, low water use efficiencies, conflicts between farmers and management, farmers interfering with operation, damaging structures, and making illegal offtakes, and corruption, etc.

Before the end of the seventies, irrigation was considered a technical matter and therefore technical solutions were proposed: for example, improved water application methods, increasing the density of the canal system (tertiary unit development), and technical training of farmers, operators, and extension workers.

During the last 20 years however, a growing awareness has emerged that irrigation should not be looked at as a purely technical matter, but that human and institutional aspects play at least as large a role in the many problems encountered. Irrigation was viewed as a multidisciplinary or interdisciplinary issue,[7] leading to considerable research effort notably by social scientists. New research topics were addressed such as: processes of marginalization and differentiation in irrigation schemes; access to water in relation to power structures; social interfaces between farmers and management; institutional aspects; corruption in water distribution practices; and others. The results of these activities were important in terms of gaining a better understanding of the complex and interdisciplinary nature of irrigation.[8]

From this change of paradigm from a technical to a multidisciplinary and interdisciplinary approach emerged a focus on management which took shape by the establishment of the International Irrigation Management Institute (IIMI) in 1984. Much of IIMI's work comprised institutional reforms, performance studies, organization of farmers (water user groups) and training, while in recent years the transfer of management to farmers came to the fore. Most of these activities have one thing in common: a search for solutions by changing or improving the *management environment.*

In this search the irrigation *technology*, the design, and underlying operational principles of irrigation systems were often treated as a black box and rarely questioned. Seldom was the interrelation between technology and human and institutional aspects considered.[9]

Not surprisingly few of the research results, in themselves important, are reflected in present day design standards and manuals. Indeed, in the meantime, designers continued to

[7]This interdisciplinary nature of irrigation has already been noted by Cornell University in the 1970s, typifying irrigation as a 'socio-technical unit' (Barker, Coward, and Levine 1984).

[8]These results, however, had little impact on actual skewed power relationships where vested interests and political unwillingness prevent change.

[9]Although an Asian Regional Symposium was held in Sri Lanka in 1987 dealing with design-management issues, perusal of the proceedings reveals very little on design issues.

design according to standards often dating back to decades if not to colonial times. Furthermore, designers are seldom confronted with the way in which their designed systems are working in reality. This is because proper monitoring has rarely been carried out and designers have left the country (foreign consultants) or have been transferred. Many of them work with one-sided design standards with little relevance to the operational reality. Not unexpectedly, recent studies (IIMI 1989; Burns 1993; Plusquellec, Burt, and Wolter 1994) reveal the discrepancy between design assumptions and operational reality, especially for the widely used manually or mechanically regulated systems.

Here it is argued that the focus on management and at the same time the neglect of attention to design issues will not reduce this discrepancy. On the contrary, it is surmised that this leads to cosmetic surgery as long as the ingrained design practices and the design-management relationship are left untouched.[10] Furthermore, it will probably not fill the gap between technology levels and management capabilities as discussed in the previous section.[11]

[10]During the last decade two exceptions to the neglect of design issues have been observed: In the first place the concept of "structured irrigation" was introduced in India by the World Bank-funded National Water Management Plan (cf. World Bank 1986; Shanan 1992). This concept, inspired by the irrigation technology used in the Punjab, contains drastic simplifications when compared with usual designs. A second development has been the increasing pressure to search for solutions in terms of modernization and automation. Both concepts relinquish the manually adjustable systems and try to find solutions by technical measures. Both of them will be dealt with in later chapters.

[11]Much of the situation sketched in this section can be explained by what Chambers calls "normal professionalism" *(Normal professionalism is the thinking, values, methods and behaviour dominant in a profession.* Chambers 1988, p. 68.). Ironically where the monodisciplinary technical approach by engineers was (rightly) criticized some 20 years ago, the same professional biases in the social sciences came to the fore afterwards.

CHAPTER 2

DELINEATION OF THE CONTENTS

2.1 *Points of Departure*

Clearly, from the previous chapter it appears there is a need for reconsidering design of irrigation systems in terms of criteria and assumptions. These criteria and assumptions should not only comprise agronomic, hydraulic, and civil engineering parameters but also operational ones: the human and institutional aspects. In this book it is endeavored to review conventional criteria and assumptions for system design and to analyze them in the light of operational use. To this end, the following points of departure are proposed.

- An irrigation system is not a black box, but determines by its design (physical shape and operational requirements) the institutional and human modalities for use.
- An irrigation system therefore should not only be designed on the basis of agronomic, hydraulic, and civil engineering criteria but also on human and institutional ones.
- Design should not be a priori 'modern' but should reflect the local situation.

By broadening the conventional criteria and assumptions with operational aspects, several questions emerge:

- What are the staff requirements for a certain type of system in terms of numbers and skills?
- Are these requirements realistic, given the local situation?
- How transparent is the system for farmers to understand the way water is divided?
- Are the operational procedures needed for that type of technology transparent?
- Is the system hydraulically stable in order to ease operation?
- Are measurements required?
- Does the system render equitable distribution of water?

- Are the structures easy to tamper with and do they give opportunities for corruption?

These and other questions will feature in the following chapters.

2.2 *The Focus on Water Division Technology*

The technical infrastructure of an irrigation scheme comprises a large number of civil engineering works ranging from the actual irrigation and drainage systems to roads, bridges, buildings, etc. Of all these works the irrigation system forms the crux of the scheme: the system of canals and structures to convey, regulate, and divide the water and to deliver it to the users.

Such a system can be divided into two parts (see figure 2.1):

- A *conveyance* part comprising canals and fixed structures such as drops, culverts, and escapes. If well-designed, -constructed, and -maintained, these works will convey the water as planned. They generally do not need to be *operated*.

- An *operational* part: those points in the system where the water is divided, regulated, and measured, i.e., the water division structures.

These water division structures form the crucial component of the irrigation system. Their type and characteristics largely determine the operability and subsequently the manageability of the system. These structures may be simple or complicated to handle, they may be more or less sophisticated, they may be fragile or sturdy, they may be flexible or rigid, they may be user-friendly or user-incompatible. Furthermore, their type and characteristics largely determine whether centralized management is necessary or whether decentralized management and

Figure 2.1 System componens.

Conveyance component

Division component

farmers' participation are possible. The operation and maintenance of these structures account for a very large part of the total management input of a project.[12]

Furthermore, water division has a double connotation: a *physical* as well as a *human* one. The physical connotation is based on flows expressed in l/s related to irrigated areas, cropping calendars, and crop water requirement. The second connotation relates to farmers' perceptions on how water, as a scarce resource, is allocated and distributed. Water division structures are, therefore, points of interface where conflicts of interest between farmers and management and between (groups of) farmers may take place. These structures, therefore, form the core of many of the problems encountered in irrigation.

2.3 *Limitations*

The contents of this book mainly concern the issue of design criteria and assumptions for agency-managed, smallholder, open canal, gravity irrigation systems. This category of systems excludes the typical flat deltaic coastal areas that require a different approach: horizontal canals combining irrigation and drainage, irrigation by pumping, etc., (cf. Burns 1993; Jones 1995).

Details on construction and mechanics are not covered. Important as they are, they hardly influence the choice of structures. Also the issue of maintenance is not pursued specifically.

Drainage systems are not dealt with. They are implicitly assumed to be incorporated in scheme design. They do not need much operation and rarely contribute to conflicts between farmers and management.

2.4 *Structure of the Book*

After this introduction the text is structured into the following parts:

PART II THE PHYSICAL SYSTEM

This part deals with the basic principles of irrigation systems and water division structures. Chapter 3 describes different types of systems, their boundary conditions, layout and components. Chapter 4 presents the most commonly used types of water division structures with their hydraulic and operational characteristics.

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[12]Consequently, the question *How can a system best be managed?* is directly related to the physical/technical irrigation system. It is the planners and designers who determine this irrigation system. Hence, their choice of technology and design largely determines the management options.

PART III DESIGN AND PRACTICE

An important parameter in system design is the Water Delivery Schedule (WDS) or the way water is delivered to the tertiary unit (smallest subunit in a scheme[13]; see Section 3.2). Conventionally this WDS is derived from a number of design choices and assumptions both at field level (cropping calendar, field irrigation methods, farm delivery methods) and at system level (types of allocation and delivery). Different design choices and assumptions lead to different WDSs (chapter 5). Each WDS has its own matching type of system in terms of water division structures (chapter 6).

When analyzing the different types of systems in the light of operational consequences (chapter 7), the shortcomings of the conventional design method are made explicit. These often lay in the omission of human and institutional factors. The resulting discrepancies between design assumptions and operational reality are illustrated in chapter 8. Conclusions are drawn in chapter 9.

PART IV OPTIONS FOR CHANGE

On the basis of the analyses of Part III, possible options for change (changes in design process, management and technology) are discussed in chapter 10. One of the options "simplification of water delivery" is further investigated in chapter 11 and another "intermediate reservoirs" in chapter 12. Finally some concluding remarks and afterthoughts are presented in chapter 13.

[13]Although in some countries (e.g., Indonesia) quartenary units are in use, they have little bearing on the principles of the WDS, and will not be dealt with further.

PART II

The Physical System

This part consists of an introduction to the physical features of the book's main subject: The irrigation system (chapter 3) and its water division structures (chapter 4). These two chapters are included for the sake of completeness. They may be skipped by readers conversant with the subject.

CHAPTER 3

IRRIGATION SYSTEMS

3.1 Introduction

An irrigation system might be defined as the physical infrastructure needed to capture, transport, and distribute water to (groups of) farms. Any irrigation system is conceived within local physical and organizational boundary conditions and is, therefore, situation-specific. Nevertheless, general observations can be made on different types of systems as presented in the following sections.

3.2 Types of Systems

Irrigation systems need to be looked at from physical, operational, and organizational points of view.[14]

The *physical* shape of an irrigation system often depends on topography, availability of water and suitable soils, as well as on project objectives (e.g., intensive or extensive irrigation). The canal system can be in the form of closed conduits (pipes below or above ground surface), elevated flumes or earthen lined or unlined canals. This book deals mainly with open canal systems, representing large parts of the smallholder irrigated areas in the world.

From an *operational* point of view, flows in canals can either be intermittent or continuous. When rotation between canals is practiced the flows are often either Full Supply or zero. In other cases, flows are regulated to accommodate varying demands. Clearly, a wide range of choices is available to the designer, each of them having consequences on the required technology, the operability, and the way in which farmers will receive their water.

Each irrigation system requires some form of *organization* to allocate and distribute the water and to perform the necessary maintenance. The organization can be centralized or decentralized, agency- or farmer-managed or some hybrid form (e.g., joint management). Another classification is (cf. Huppert 1989):

- agency-managed—dictated: water is delivered according to requirements as determined by an irrigation agency

[14]Other typologies such as upstream and downstream control systems, structured and unstructured systems, and flexible and inflexible systems will be discussed later.

- agency-managed—as a service: water is delivered by the agency according to farmers' wishes

- farmer-managed

In terms of management of water, the system can be divided into:

- major system: main and secondary canals up to the tertiary offtake

- minor system: or tertiary unit (*tu*)[15] served by the major system through the tertiary offtake

Usually, the water in the minor system is handled by the farmers and in the major system by the agency. Again the type of organization should be compatible with the technology of the system: its layout, its water division structures, and its operation.

3.3 Layout

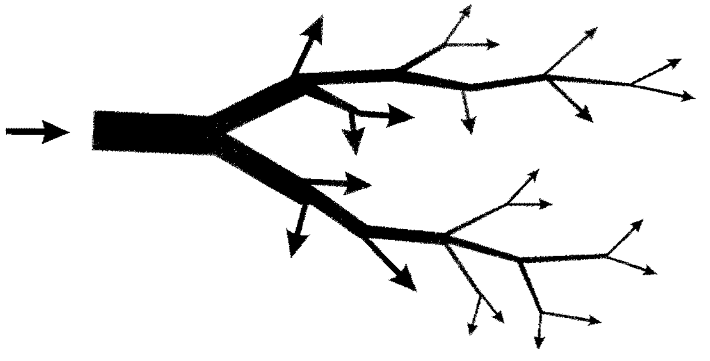
A canal system can be laid out following two different principles:

- bifurcating systems

- hierarchical systems

In a *bifurcating system* the water is divided among two or three large groups of farmers, subdivided again into two to three smaller groups etc. (see figure 3.1).

Figure 3.1 Bifurcating system.



[15]For smallholder irrigation the tertiary unit (sometimes called minor unit; service unit; or *chak*) is the smallest unit in the system comprising several farmers who are supposed to divide the tertiary flow among themselves. This is contrary to large-holder irrigation as for example in the U.S. where the farms are individually connected to the main system.

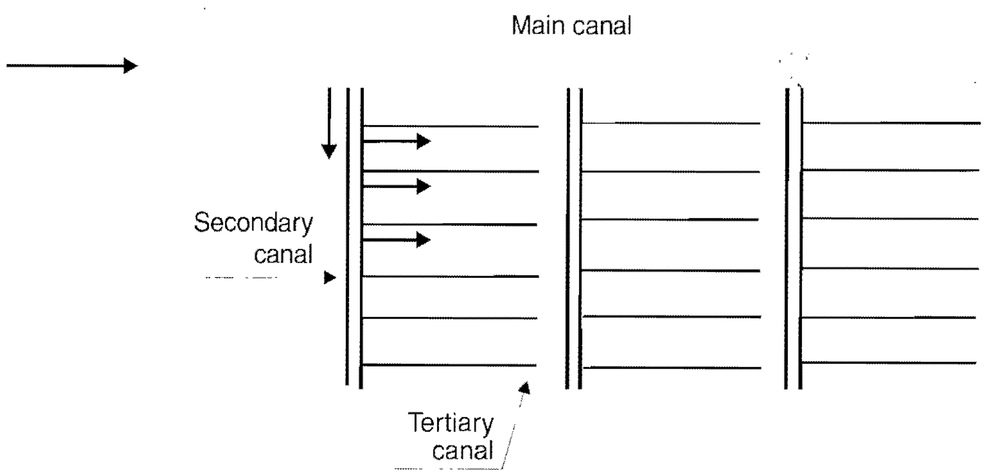
This layout is often followed in traditional irrigation, where the water is divided in fixed proportions. At each bifurcation point the groups served by the divided flows have equal locational positions. A top-tail end differentiation hardly exists.

The *hierarchical system* is mostly adopted in modern irrigation projects. The water is distributed to large (secondary) blocks, and subdivided into smaller (tertiary) units (see figure 3.2.).

Such a compact layout generally results in lower costs per hectare due to shorter lengths of irrigation and drainage canals and roads per unit irrigated area. On the other hand, the large number of offtakes (e.g., along a secondary canal there may be often 10–20 tertiary offtakes), and the large distances between top- and tail-end units may lead to distribution problems. The locational unequal position of these units may render unequal access to water.

Finally, it should be noted that the designer has a large degree of freedom to trace the canals: somewhere between the two extremes of "a plate of spaghetti" by exactly following the contour lines and "chequers" following a grid system.

Figure 3.2 Hierarchical system.



3.4 *Farmers' Dependency on the System*

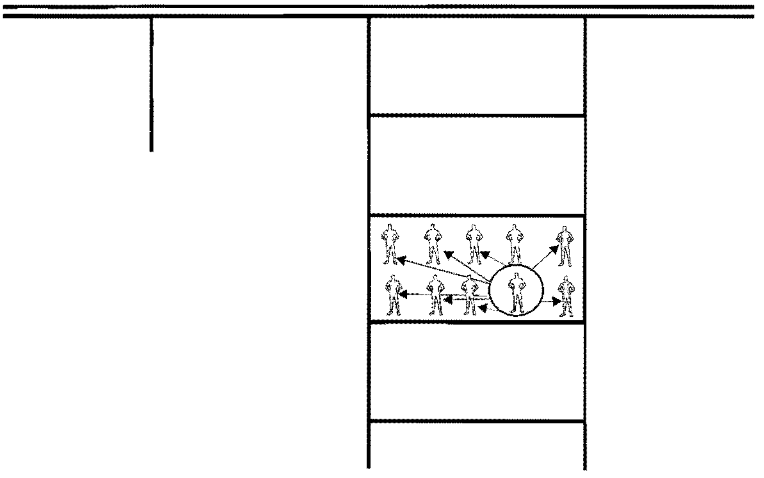
In contrast with other infrastructure systems, irrigation is characterized by the strong dependency of the user on the system. Users of most infrastructure such as drainage, roads, water supply, electricity systems, etc., can make use of the system whenever they like. In most cases, the irrigation user, however, is dependent on the irrigation system in regard to timing and quantity.[16]

[16]Again, contrary to other infrastructure systems, the dependency on irrigation water constitutes often a matter of sheer survival. Furthermore, in many parts of the world farmers are pressured to grow certain crops. In other words, they are not free to use the water as they wish.

This dependency occurs at two levels resulting from subdividing the irrigation system into minor and major systems:

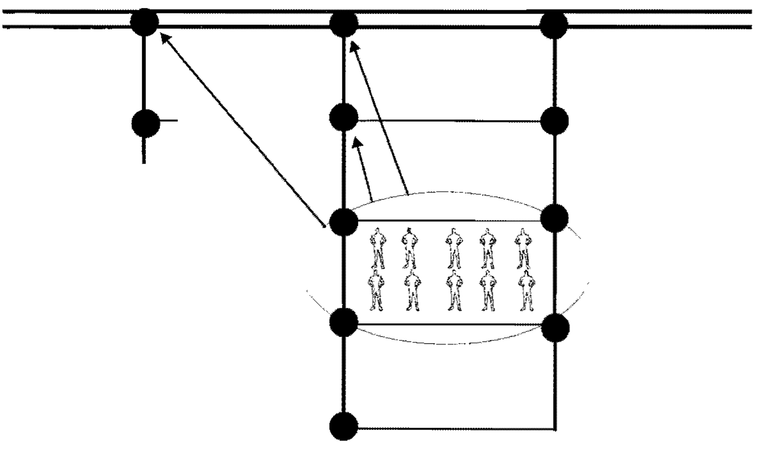
In the minor system (tertiary unit), the group of farmers organizes the water distribution among themselves. Here the individual farmer is dependent on the internal organization of water division and his relationship with the other farmers within the tertiary unit (see figure 3.3). Power structures and collusion might influence accessibility to water.

Figure 3.3. Dependency within the minor system.



On the other hand, the group of farmers as a whole, within the tertiary unit, is dependent on the operation of the major system—that part of the system supplying the water to the tertiary units (see figure 3.4). Access to water might be influenced by the location of the unit in the system (top-tail end) and also by political connections (cf. Mollinga forthcoming; Van der Zaag 1992 a).

Figure 3.4 Dependency on the major system.



CHAPTER 4

WATER DIVISION STRUCTURES

4.1 Introduction

In this chapter, the most common types of water division structures are discussed in terms of general hydraulic characteristics and operational implications. For details on hydraulics and construction the reader is referred to handbooks and design manuals (cf. Bos ed. 1978; FAO 1975).

4.2 Types of Bifurcations

Bifurcations could, in principle, be divided into:

- *Division*: Bifurcating canals with capacities of the same order of magnitude and the same function in the system (e.g., lateral canals bifurcating into two sub-laterals, figure 4.1)

- *Offtakes*: Smaller, lower-order canals branching off from larger ones. Here the function of the offtaking canal differs from the ongoing one (figure 4.2).

Figure 4.1 Division.

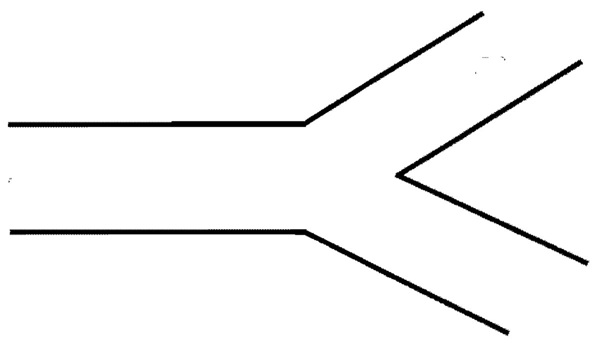
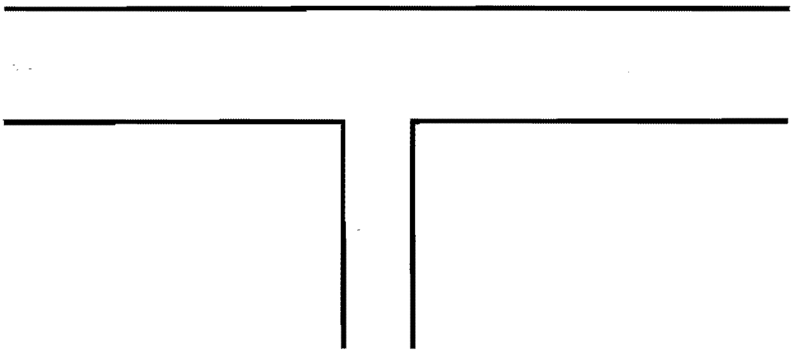
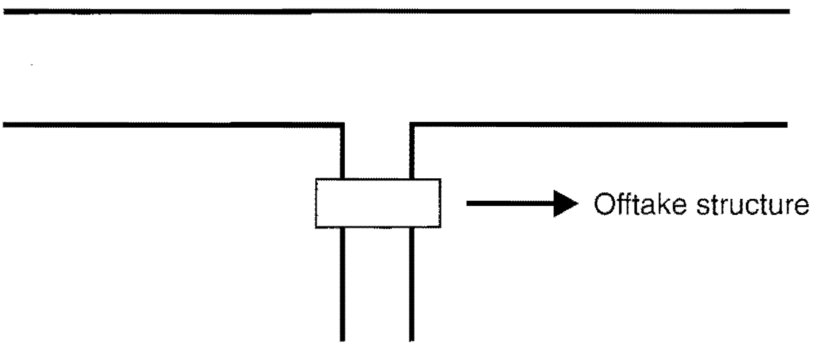


Figure 4.2 Offtake.



At the point of bifurcation the division of water is realized by hydraulic structures. In case of a free offtake (see figure 4.3), the flow through the offtake structure will change with different water levels in the parent canal. As will be discussed later in this chapter, the rate of change depends on the shape of the offtake structure.

Figure 4.3 Free offtake.



A free offtake is usually only acceptable when the upstream water level remains constant. (For instance, in the Punjab systems in North India and Pakistan where the flow in the distributary canals is either Full Supply or zero - see Section 6.3).

With changing flows and subsequently changing water levels in the parent canal, there is often a need for water level control in order to create sufficient head for the offtake structure and to avoid frequent resetting of the offtake gate. This control can be achieved by a check structure or cross regulator in the parent canal (figure 4.4).

To reduce costs for the relatively expensive check structures, the solution of clustered offtakes might be adopted (see figure 4.5).

Figure 4.4. Controlled offtake.

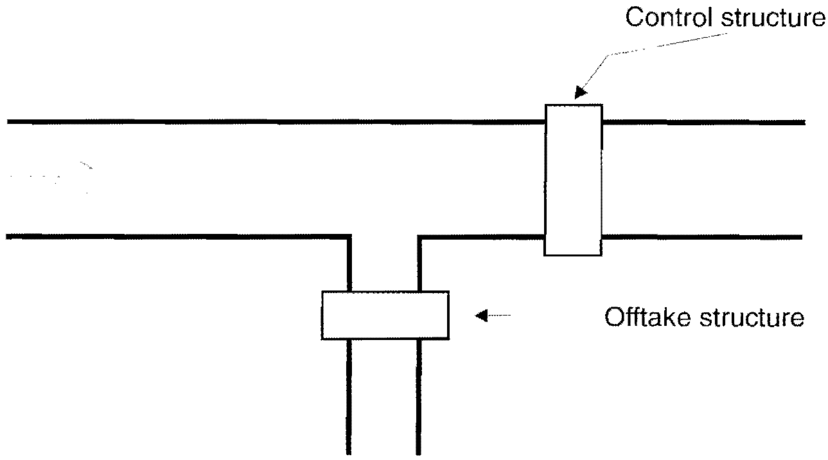


Figure 4.5. Clustered offtakes.

4.3 Types of Structures

A hydraulic structure at a bifurcation point in an irrigation system can be used for one or more of the following purposes:

- flow regulation
- controlling upstream water levels
- controlling downstream water levels
- measuring flows

As will be discussed in the following, the suitability to meet these purposes depends on the hydraulic properties of these structures.

A structure can further be classified by different boundary conditions in terms of upstream and downstream water levels:

- *Modular:* changes in either upstream or downstream water levels do not affect the flow rate. In theory this situation cannot exist. In practice, however, structures have been developed approximating a modular flow within a limited range of upstream water levels: e.g., stepwise distributors such as the "Module à Masque" by Neyrpic, France, and the various types of modular outlets, developed in India.

- *Semi-modular:* the flow is affected only by the upstream water level.

- *Non-modular:* the flow is affected by both upstream and downstream water levels.

Modular structures require no water level measurements. Their discharges are determined by the shape of the structure. The discharges of semi-modular structures can be obtained by measuring the upstream water level. Non-modular structures require measurements of both upstream and downstream water levels. In general, therefore, preference should be given to modular or semi-modular structures.[17] Moreover, downstream users can manipulate the flow in case of a non-modular structure.

Hydraulic structures might also be divided into: (see figure 4.6).

- overflow structures

- undershot structures

Figure 4.6. Overflow and undershot structures (h = head).

[17]In many handbooks structures are divided into either modular or non-modular, reflecting whether the flow at the control section is critical or not. Here the Indian-Pakistani classification (modular, semi-modular, and non-modular) is followed because it better reflects the need for water level measurements which constitute an important part of the operation.

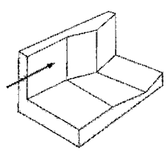
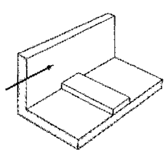
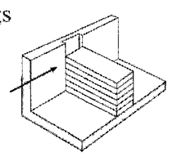
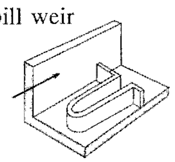
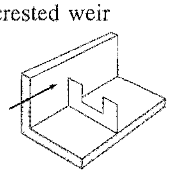
Overflow structures

Overflow structures are normally used under semi-modular conditions. The general formula is:

$Q = c.h^{1.5}$ where Q = flow
c = constant
h = head

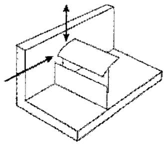
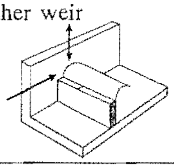
In tables 4.1A and B the most common types of overflow structures are presented with their modular limits,[18] sediment passing capacities, and application.

Table 4.1A. Fixed overflow structures (cf. Bos ed. 1978).

Type of structure	Modular limit	Sediment-passing capacity	Application
Flume 	0.5 - 0.8	Good	Measurements
Broad crested weir 	0.4 - 0.95	Fair	Water level control + Measurements
Stoplogs 	0.4 - 0.95	Poor	Water level control
Duck-bill weir 	0.4 - 0.95	Poor	Water level control
Sharp crested weir 	Head: h + 0.05 m	Very poor	Measurements

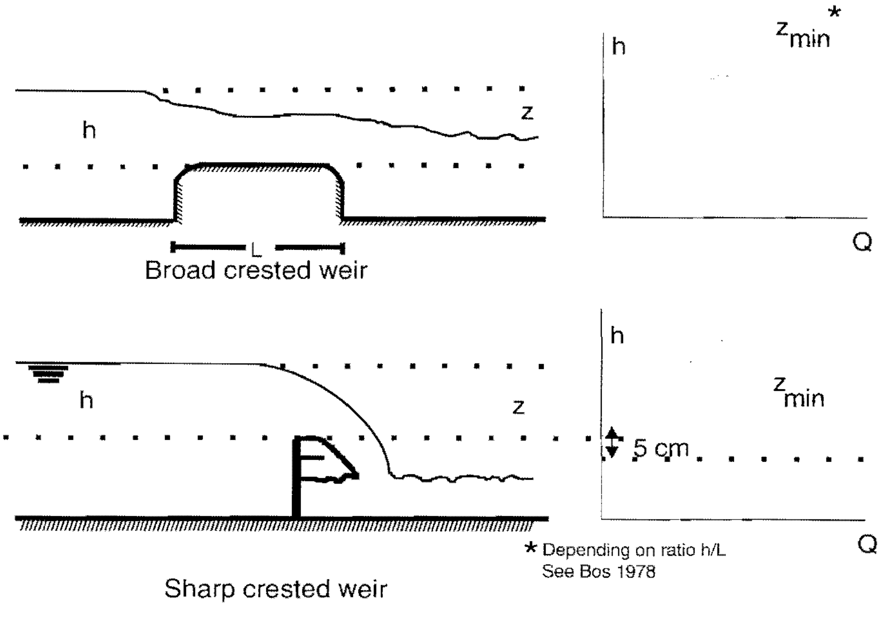
[18]A structure operates at its modular limit, if the submergence ratio is such that the discharge is just on the verge of being reduced because of the tail-water level. The submergence ratio can be expressed as H_2/H_1, where H_2 is the total downstream energy head over crest and H_1 is the total upstream energy head over crest (Bos ed. 1978).

Table 4.1B Adjustable overflow structures (movable weirs [cf. Bos ed. 1978]).

Type of structure	Modular limit	Sediment-passing capacity	Application
Romijn weir 	0.3	Depending on movable or fixed undershot gate	Flow regulation + Measurements
Butcher weir 	0.7	- do -	- do -

Compared with flumes, the weir type structure often has structural advantages (more compact, simpler construction, cheaper). In case of silt-carrying water, however, flumes have the advantage of higher silt-carrying capacities. Rectangular weirs could be broad, short, or sharp crested. The advantage of broad crested weirs (and flumes) is their small head loss (see figure 4.7).

Figure 4.7 Broad and sharp crested weirs.



Undershot structures

These types of structure are generally used in semi-modular as well as non-modular conditions. The orifice can be circular or rectangular and fixed as well as adjustable (gated). The general formula is:

$Q = c.h^{0.5}$ where, Q = flow
c = constant
h = head

In tables 4.2 A, and B, and figure 4.8, the most common undershot structures as used in irrigation are presented.

Table 4.2A. Fixed undershot structures (cf. Bos ed. 1978).

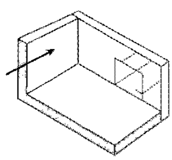
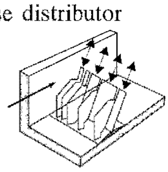
Type of structure	Modular limit	Sediment-passing capacity	Application
Fixed outlet 	Variable	Good	Modular flow within limited range of upstream head (e.g., see Mahbub and Gulhati 1951)
Stepwise distributor 	0.6	Fair	Flow regulation + Measurements

Table 4.2B. Adjustable undershot structures (cf. Bos ed. 1978).

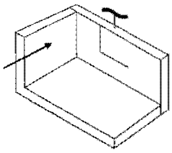
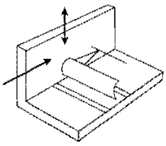
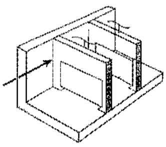
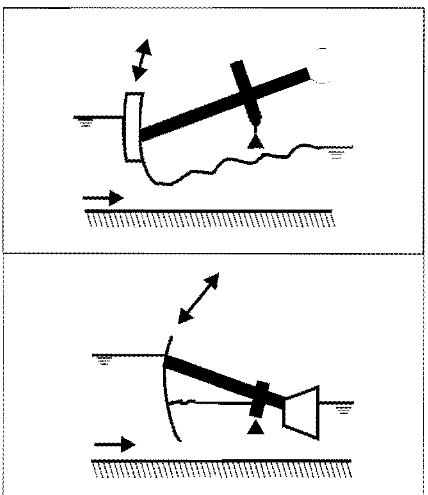
Type of structure	Modular limit	Sediment-passing capacity	Application
Gated offtake 	Variable	Poor	Flow regulation
Radial gate 	Variable	Very good	Flow regulation or water level control
Constant Head Orifice 	Very good	Poor	Flow regulation + Measurements

Figure 4.8. Automatic undershot structures.



Automatic upstream water level control

Automatic downstream water level control

4.4 *Sensitivity and Hydraulic Flexibility*

Two important hydraulic concepts explain the operational implications of selecting a certain type of structure: the *Sensitivity S* and *Hydraulic Flexibility F.*[19]

Sensitivity S

The discharge through a structure is directly related to the upstream head in case of semi-modular flow conditions and with the head loss in case of non-modular conditions. This can generally be expressed as:

$$Q = c.h^u$$

The Sensitivity S of a structure depends on the power u and the head h. It is commonly expressed as the fractional change of discharge caused by the unit rise of the upstream head:[20]

$$S = \frac{\Delta Q}{Q} = \frac{\left(\frac{dQ}{dh}\right).\Delta h}{Q}$$

or with $Q = c.h^u$:

$$S = \frac{c.u.h^{u-1}.\Delta h}{c.h^u} = \frac{u}{h}\Delta h$$

This formula can also be used for canals. The rating curve (stage-discharge relationship) for a canal may be expressed as $Q = c.h^u$, where the power u is dependent on the shape of the canal. In practice, u can be taken between 1.6 and 1.8.

Summarizing, the most common values for u are:

Overflow structures	$u = 1.5$
Undershot structures	$u = 0.5$
Canals	$u = 1.6 - 1.8$

[19]These concepts were developed in Northern India (Punjab) in the beginning of this century (see for example, Mahbub and Gulhati 1951). Remarkably these concepts have in recent years been largely forgotten and are hardly found in current textbooks. They are presented here because they prove a powerful tool to understand system operational characteristics.

[20]Sensitivity can also be related to other indicators (such as flow area, conveyance, gate setting, etc.): See Renault and Hemakumara (forthcoming). It will not be further dealt with here.

The water-level fluctuation Δh caused by a change of flow ΔQ, can also be expressed as:

$$\Delta h = \frac{h}{u} \cdot \frac{\Delta Q}{Q}$$

From this formula the implications of the choice of structure become clear. Take for example an undershot ($u = 0.5$) and an overflow structure ($u = 1.5$) as in figure 4.9. When Q, ΔQ, and h are the same value for each structure, Δh is three times larger for an undershot than for an overflow structure.

Sensitivity requirements depend on the purpose of the structure:

- To minimize upstream head fluctuations, the Sensitivity should be high. In other words, the structure should have the highest possible factor u/h:

  u large: weir or flume ($u = 1.5$).
  h small: weir with long crest (e.g., duck bill weir).

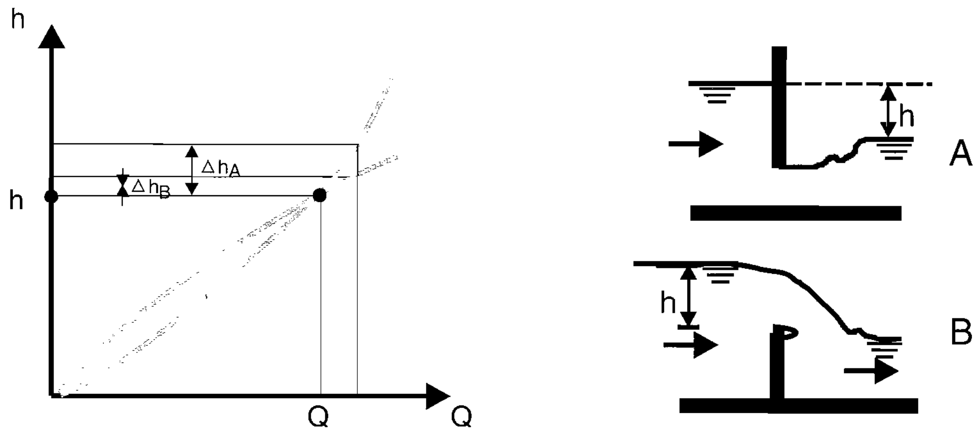
- To minimize fluctuations of discharge through the structure, caused by varying upstream water levels. In this case, the factor u/h should be as small as possible (undershot type: $u = 0.5$ and h as large as possible, entrance as narrow as possible).

- To measure discharges. Here also the Sensitivity should be small (small variation in Q should result in a relatively large variation in h to enable accurate reading).

From the above it becomes clear that the combination for more than one purpose in one structure cannot always be reconciled.

In the above, the requirements for Sensitivities for different purposes are indicated from a hydraulic point of view. In practice, other requirements (e.g., operation or head losses) could lead to the selection of a different type of structure.

Figure 4.9. Different water-level fluctuations of different structures.



Hydraulic Flexibility F[21]

The flow at a bifurcation will be divided by a certain ratio. Changes in oncoming flows will result in changes in the water level at the bifurcation. The relative change in distribution will depend on the hydraulic properties of the structures. This can be defined by the Hydraulic Flexibility F.

The Hydraulic Flexibility is an important tool to visualize generations of flow changes through a system. It is expressed as the ratio between the relative change of offtake flow and the relative change of the ongoing flow (or the ratio between the Sensitivities of offtaking and ongoing structures S_o/S_s) (see figure 4.10).

The Hydraulic Flexibility can be expressed as:

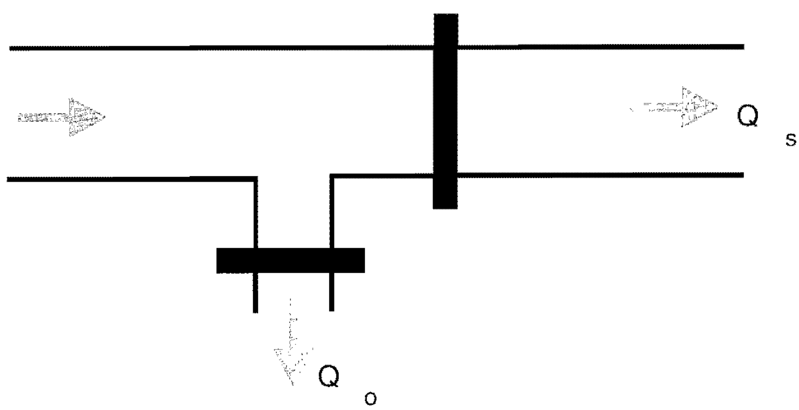
$$F = \frac{S_o}{S_s} = \frac{\frac{u_o}{h_o}.\Delta h}{\frac{u_s}{h_s}.\Delta h} = \frac{u_o\ h_s}{u_s\ h_o}$$

where,

u = power u of Q = $c.h^u$	s = supply (ongoing) flow
h = head	S = Sensitivity
o = offtake	(cf. Bos ed. 1978)

The consequences of Hydraulic Flexibility on the hydraulic behavior of the system will be further discussed in Section 7.2.

Figure 4.10 Bifurcation.



[21]Often the term *flexibility* is used. Here *Hydraulic Flexibility* is used as different from *operational flexibility*. See Section 7.3.

4.5 Measurement Structures

In most irrigation schemes, the quantities of flows through the various parts of the system should be determined. This is generally done at bifurcation points.[22]

Two types of measurement structures can be discerned (see also tables 4.1A and B and 4.2A and B).

- Flow regulation and measurement combined in one structure: Constant Head Orifice (CHO), movable weir, modular distributor.

- Special measurement structures placed behind a bifurcation structure: flumes, broad- and sharp-crested weirs.

Apart from the modular structures, water-level readings and calibration graphs or tables are needed to determine the flow rates. With the exception of the CHO all structures should function in a semi-modular way. Bos ed. (1978) gives their limit of application.

4.6 Operational Characteristics

From an operational point of view five types of structures can be distinguished. In sequence of sophistication, they are:

- *Fixed* (fixed weirs and orifices)

  The flow passing through depends on the shape of the opening and water levels upstream (and downstream when non-modular) of the structure. These structures are often used in systems with proportional fixed distribution of water. No adjustments are possible.

- *On-Off* (shutter gates)

  The structure is normally equipped with a gate which could either be in the open or closed position.

- *Stepwise Adjustable* (stoplogs and stepwise distributors)

  The flow is regulated in steps.

- *Gradually Adjustable* (gated undershot structures and movable weirs)

  The flow can be regulated by changing the opening either by hand or mechanically.

- *Automatic* (automatic upstream and downstream water-level control structures)

  Most of these structures react by floats, on changing water levels.

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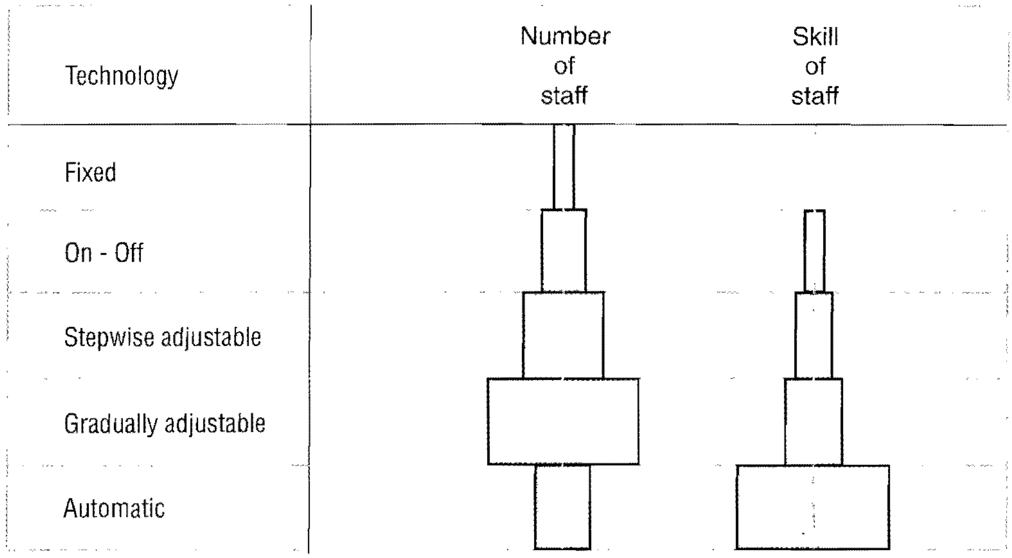
[22]In some systems, calibrated canal sections are used for measurement. The calibration, however, is often disrupted by siltation and weed growth. This method will not be further considered here.

Figure 4.11. Operational characteristics (cf. Horst 1990).



Clearly, the type of structure determines the operability (easy or difficult operation) and the required number and skill of staff. The first four types require increasing numbers of operating staff, while the last type needs fewer, but more highly skilled staff (see figure 4.11). These aspects will be further discussed in Section 7.3.

PART III

Design and Practice

The way in which water is delivered at the tertiary unit—the Water Delivery Schedule (WDS)—might be considered the core of the design of irrigation systems. The WDS is derived from a number of choices and assumptions both at field and system level and it determines the type of system and the mode of operation. The conventional way of deriving the WDS is presented in chapter 5. Various possible types of delivery systems, each of them with its own type of structures, is reviewed in chapter 6. In chapter 7 these systems are analyzed in terms of operational consequences. In this chapter the shortcomings of the conventional choices and assumptions will be laid bare. These shortcomings result in discrepancies between the design assumptions and the operational reality as sketched in chapter 8. Finally, conclusions are drawn in chapter 9.

CHAPTER 5

WATER DELIVERY SCHEDULES—DESIGN CHOICES AND ASSUMPTIONS

5.1 Introduction

The first step in the design of an irrigation system is the delineation of the area to be irrigated and a tentative layout of the canals. The area to be irrigated depends primarily on irrigable soils and available water within the context of project objectives and available financial resources. The layout is mainly determined by the topography of the area. Once the (preliminary) layout of an irrigation system has been defined, two important design questions remain:

- What capacities are needed for the various canal sections?
- What type of structures should be adopted to divide the water to the various parts of the system?

Both these questions are to be answered by determining how, in what quantities, and what time the water has to be delivered at the tertiary unit. For that purpose the Water Delivery Schedule[23] is determined, which should be considered as the agenda for the required water delivery. In the following sections the normal method of determining the Water Delivery Schedule is discussed.

5.2 The Water Delivery Schedule

The conventional derivation of the Water Delivery Schedule is schematically presented in figure 5.1 in which the various boundary conditions, design choices and assumptions, and their derivatives are presented as a flow chart. The upper section of the chart represents the design decisions at farm level. They are, logically, concerned mostly with the agronomic and agro-hydrological aspects of irrigation at field level. The lower section of the chart deals with de-

[23]Distinction should be made between *irrigation scheduling* concerning supply to the plant and *water delivery scheduling* concerning supply to farmers or tertiary units (see FAO 1996). Here a further distinction is made between *water delivery scheduling* concerning demand and supply assumptions during the design phase and *operational plan* needed for the management to distribute the water to farmers and tertiary units.

sign choices at system level. These are primarily related to technological and operational questions. Matching the two sections will result in the Water Delivery Schedule.[24]

In the following sections the flow chart of (figure 5.1) will be discussed by focusing on those points where design decisions (choices and assumptions) have to be made.

Cropping Calendar

Most irrigation projects are based on an assumed cropping calendar. Crop choices are, in the first instance, derived from the suitability of soils and the availability of water and climatic conditions. Economic and political considerations, however, often play a crucial role in the final decisions: national self-sufficiency in food crops or promotion of growing export-earning crops might be decisive factors. In these cases, a standard calendar for all farmers is often adopted. For example, the Mwea irrigation project in Kenya and the Gezira project in the Sudan were developed for compulsory mono-crop growing (for rice and cotton, respectively).

In cases where, for part of the year, water supply falls below the water demand for unrestricted cropping, two approaches are possible:

Restrictions on crops

> Restrictions are issued on growing specific crops (including fallow) during the dry season, to match the irrigation requirements with the available water.

Restrictions on water

> Another possibility to solve this problem is to design irrigation systems which divide the water shortage equally among the farmers or groups of farmers.

The consequences of these two restrictions on the Water Delivery Schedule will be further discussed in Section 5.4.

Once the cropping calendar is established, the irrigation requirements can be determined by working out this calendar with figures for the potential evapotranspiration and effective rainfall.

Potential Evapotranspiration (Ep)

Although many efforts have been made to arrive at global standards (e.g., see FAO 1977, 1979; Jensen ed. 1983), there still remain different methods for estimating potential evapotranspiration (Ep). The difference between the methods can be substantial (cf. Campbell 1995).

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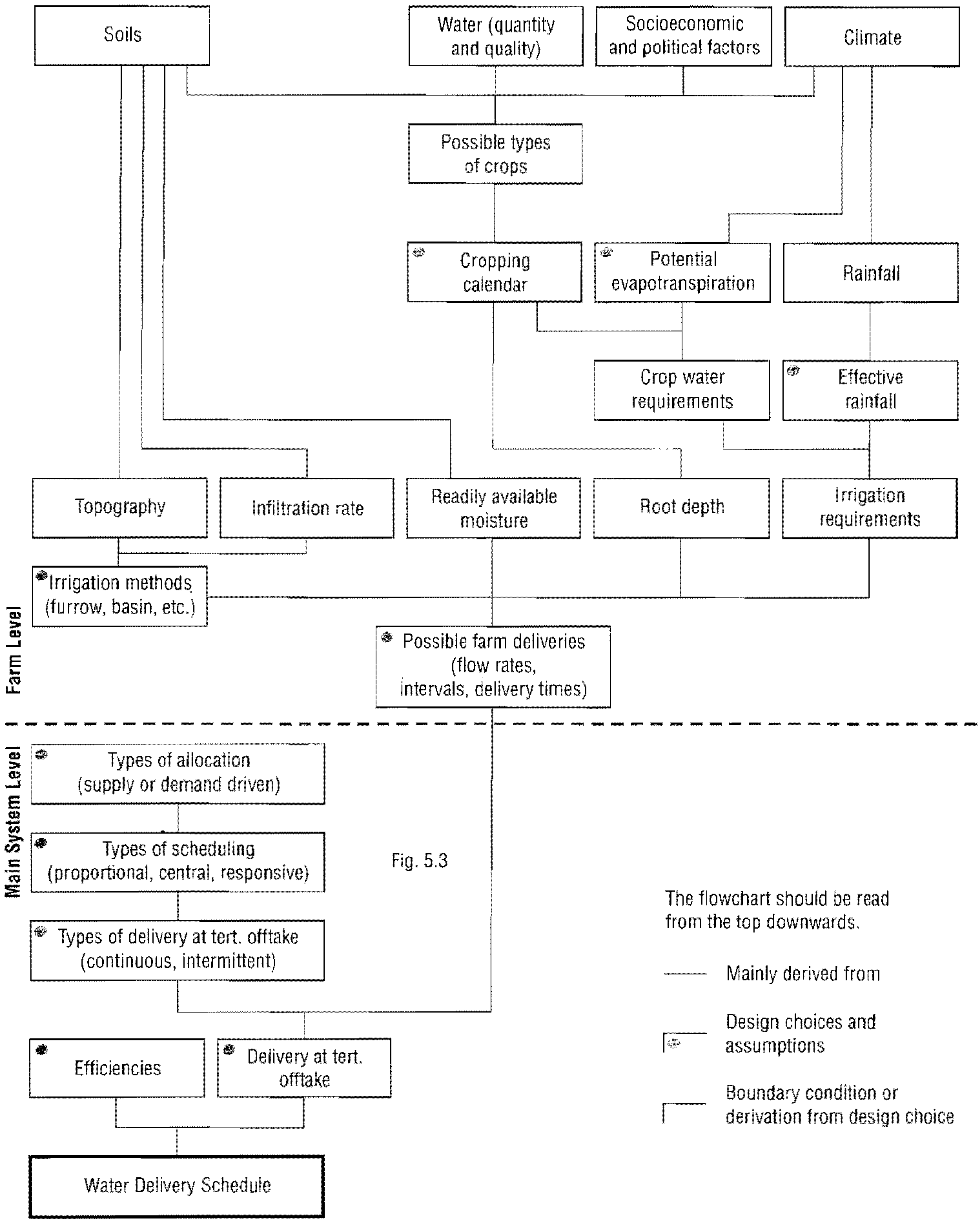
[24] In many designs, the Water Delivery Schedule does not exactly feature as in this chapter. The principles of choices and assumptions, however, remain basically the same.

Figure 5.1. Conventional derivation of the water delivery schedule.



Effective Rainfall

Effective rainfall is based on an analysis of previous rainfall records. An assessment is made of that part of the rainfall which might be expected to be stored in the root zone. That part will then be deducted from the crop water requirements to arrive at the irrigation requirements. In practice, the assessment varies widely from country to country and from designer to designer (see Section 5.3).

The Irrigation Method

A choice has to be made on the method by which the water will be delivered to the plant. The irrigation method is very dependent on the infiltration rate and topography (slopes, the need for leveling, erosion hazard, etc.), and also on the type of crops (row crops, rice or otherwise). Furthermore, socioeconomic reasons like labor availability, play a role.[25] The choice is to be made between surface irrigation (furrow, border or basin), sprinkler, or drip irrigation. (The last two methods imply a different technology from the surface methods requiring pipes, tubes, pressure irrigation, etc., and are not further considered here.)

Possible Farm Delivery

The chosen irrigation method together with the irrigation requirements and the soil and plant characteristics 'Readily Available Moisture' and 'Root depth' determine the possibilities for water delivery to farms. The delivery can either be continuous or intermittent. Continuous delivery is only practical for large farms or for plot to plot irrigation for rice cultivation. In general, however, individual continuous delivery to small farms will result in flows too small to handle and will be subject to large percolation losses. In many smallholder schemes, therefore, the water is delivered to the farm on an intermittent (rotational) basis.

In such a case (see figure 5.2) options are open in terms of flow rate, irrigation intervals, and delivery times.

Qm = unit flow or "main d'eau" (l/s)

h = farm delivery time (hours)

i = irrigation interval (days)

The changing irrigation requirements during the growing season can be met by changing one or more of the above three variables: Qm, h, or i. From a practical point of view, generally only one of the variables should be changed. It should be noted that changing duration of supply (h) leads to odd delivery times and is therefore seldom practiced. That leaves two practical methods of water delivery scheduling: to change either the irrigation interval i or the unit flow Qm.

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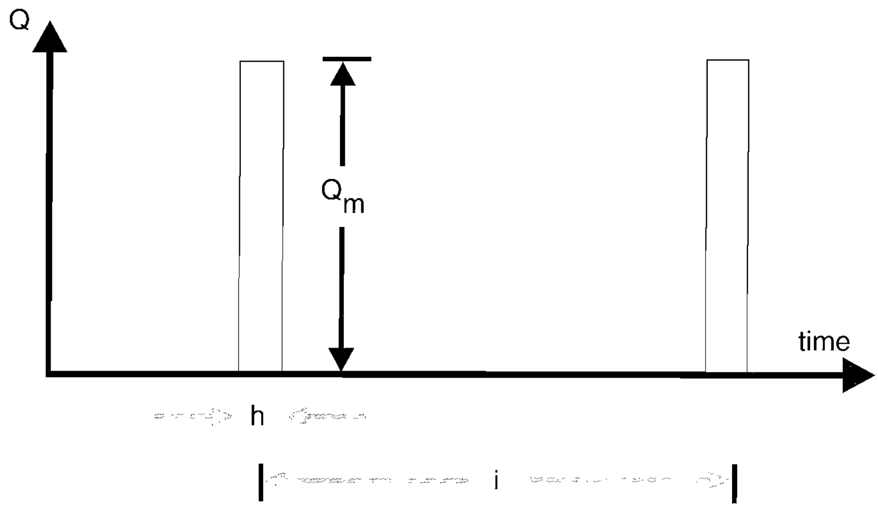
[25]See, for example, Kloezen and Mollinga 1992: Farmers in Southeast Spain appear to choose their type of irrigation method primarily on labor requirement (and not on water saving).

Figure 5.2. Intermittent farm delivery.



From an operational point of view, the first method is preferable: the whole system (or subsystems) can then be adjusted for one Qm. By closing the system (or subsystems) for longer or shorter periods, the variability of irrigation requirements can be met. Also from the point of view of unit flow, being the optimal size of flow to be handled by the farmer, this method should be preferred.

Changing unit flows (Qm) requires readjustment of the structures for every change in Qm. In this case, a more complicated operation results and, therefore, more skilled operators are required.

The consequences of the type of technology required due to changing these variables will be discussed in chapter 6. Further, it should be noted that this design choice is very important in respect of the maneuverability of farmers to develop their own 'style of farming.'[26]

Often, a definite choice of the farm delivery variables, as dictated by agronomic considerations, is made at this stage. However, by doing so the distribution technology of the main system will be more or less determined and few options are left for alternative solutions. Therefore, it is recommended not to finally select the farm delivery variables before the main system options have been assessed. Clearly, a dialogue between agronomists and system design engineers is called for. (Unfortunately this is seldom the case [cf. Section 1.3]).

Having assessed the possible ways by which water can be delivered to farms, the delivery at the tertiary offtake from the main system level should be considered. Here, the first questions to be addressed are on what basis water should be allocated, how water should be divided within the main system, and how deliveries at the tertiary offtakes could take place.

[26]Research on different styles of farming in general has been carried out by van der Ploeg (1991), while van Bentum (1995) specifically researched the evolution of irrigation technology in Spain in relation to styles of farming and to what extent irrigation systems function as production regimes.

Types of Allocation

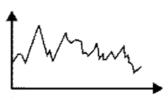
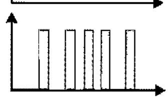
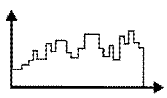
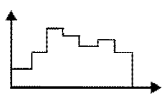
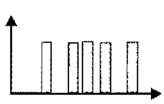
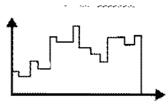
Water allocations to tertiary units can either be supply- or demand-driven (table 5.1). Supply-driven allocation is based on equitable division of water available at the source, over the sub-areas of the scheme. In the case of demand-driven allocation, the actual or estimated crop water requirements form the basis of distribution.

Types of Scheduling and Types of Delivery at Tertiary Offtake

Many different types of water delivery scheduling can be identified (cf. FAO 1982; Repogle and Merriam 1982). In the following the most important categories of delivery schedules are discussed (see table 5.1).

In the case of supply-driven allocation, water division can be based on proportional scheduling. This can be attained either by dividing continuous flows through the system according to areas served (up to the tertiary offtake or even to the farm intake), or by delivering the water intermittently on a proportional time basis. The first type (Schedule 1, table 5.1) is often practiced in traditional farmer-built and -managed schemes (for instance in Nepal, Bali, Yemen). The second type (Schedule 2) is developed in the northern part of India and Pakistan (the Punjab type[27]).

Table 5.1. Types of water allocation and deliveries.

Basis of allocation	Type of scheduling		Type of delivery at tertiary offtake	Type of flow at tertiary offtake
Supply (water source)	Proportional scheduling	Traditional	1. Irregular changing flows	
		'Arranged' Punjab type	2. Intermittent full supply	
		'On request'	3A. Variable flows—short periods	
Demand (crop water requirement)	Central scheduling (agency deciding)	'Arranged'	3B. Variable flows—long periods	
		'Arranged' Rotation	4. Intermittent full supply	
	Responsive scheduling (farmer deciding)	Automatic	5. Stepwise changing flows	

[27]This type is often identified with the way water is divided within the *chak* (tertiary unit): The Warabandi. Because here the main system is dealt with, it is indicated as 'the Punjab type.'

Demand-driven allocation can be divided into:

- Central Scheduling (agency deciding)
- Responsive Scheduling (farmer deciding)

In the case of central scheduling the crop water requirements can either be based on the requests of farmers for water ('on request' schedule) or on an assessment by the central agency of the various crops and their water requirements ('arranged' scheduling)—see Schedule 3A and 3B, table 5.1. In both cases, the modalities of delivery are decided upon by the central agency. In principle the two schedules do not differ. In both cases, the delivery is based on the total of all delivery graphs (figure 5.2) for each individual farm within the tertiary unit. In Schedule 3A the farmers' requests for water will be met by regularly readjusting the flows in the system (typically once every 1 or 2 days). For Schedule 3B readjustments are usually made once every 7, 10, or 14 days.

Another option for 'arranged' scheduling is intermittent delivery at the tertiary offtake by rotation either among tertiary blocks or secondary blocks: Schedule 4.

In the case of responsive scheduling, individual farmers decide when and how much irrigation is needed, while the irrigation system is designed in such a way that each farmer is able to draw water (within certain flow limits) at any time he/she wishes. The only technology to comply with this type of scheduling is some form of automatic control where the system responds automatically to withdrawal of water. The flow at the tertiary offtake is characterized by stepwise changes (Schedule 5, table 5.1).

When reviewing the six types of water delivery schedules at the tertiary offtake (see last column of table 5.1), it should be noted that Schedules 3A and B differ only in the time periods between readjustments. Apart from that, they need the same operational handling and subsequently the same type of technology. Although Schedules 2 and 4 look similar, operation is different. That leaves basically five types of schedules (1 through 5).

Delivery at the Tertiary Offtake[28]

When discussing the way in which the water has to be delivered at the tertiary unit in a smallholder scheme, the distinction has to be recalled (Section 3.4) between the minor and the major system. Clearly, the tertiary offtake is the pivotal point in the system where the responsibility for the flow of water changes from the management into the hands of the farmers. The method of water delivery at the offtake should meet the demands for water by the farmers as well as render division of water among farmers possible. On the other hand, a certain type of delivery (in terms of volume, duration and timing) requires a certain type of technology and operational control.

Here a critical point in the decision process is reached: first at farm level the Possible Farm Deliveries were analyzed and next at main system level the various options (1 through

[28]Although the design of a tertiary unit (size, layout, unit flow) is an important part of system design, it is not discussed here. In this chapter the issue at stake is the typology of scheduling. For tertiary unit design see Meijer 1990.

5) for Delivery at the Tertiary Offtake. At this point a match must be made between the two groups of options. This match has large consequences on:

- opportunities for farmers to develop their own farming system (see footnote 26)
- the technology required
- operation (staff requirements), transparency and, acceptability by farmers (sources of conflicts) of selected technology

A mismatch will lead to conflicts between farmers and management, which in most cases will, not surprisingly, be centered around the flow through the tertiary offtake. The different types of technology will be dealt with in chapter 6 and the consequences in chapter 7.

Efficiencies

To arrive eventually at the Water Delivery Schedule, the water delivery figures have to be corrected by taking into account the efficiencies. These efficiencies relate to losses in conveyance, distribution, and field application (Bos and Nugteren 1974). Figures for these efficiencies can be assessed only on the basis of studies in similar projects (rare) or figures from handbooks and manuals (frequent). The level of optimism of the designer plays a large role.

5.3 The Reliability of Water Delivery Schedules

The conventional derivation of the Water Delivery Schedule as outlined in the flow chart (figure 5.1) is useful in terms of giving an insight into the interrelated factors which play a role in the decision-making process of irrigation design. It also elucidates the substantial number of design decisions to be made which determine the type of technology (further discussed in chapter 6) and also the operability and acceptability by farmers in terms of compatibility with their farming systems (chapters 7 and 8).

On the other hand, in practice working through the flow chart results in concrete values for the required delivery of water at the tertiary offtake expressed as l/s over time. The question arises how accurate these values are. Scrutinizing the various components of the chart a wide variety of assumed values are encountered.

To begin with, in many cases the actual field cropping calendar often deviates strongly from the one assumed in the design. Economic incentives resulting from access to credit, market prices, or labor costs lead farmers to grow crops other than those assumed. Unfortunately, these other crops often require more water (e.g., rice and sugarcane) rendering it impossible to meet water delivery requirements. This can often lead to collusion, water theft, and damage to structures.[29]

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[29]See also Jurriens, Mollinga, and Wester 1996 for the problems encountered with the allocation in India, and IIMI 1989 for the sanctions on rice in Indonesia.

The wide variations in estimates of Effective Rainfall, Crop Water Requirements, and Efficiencies have already been noted in the previous section. Different assumptions made for the various components lead to considerable differences in the resulting Water Delivery Schedules.[30] Values for Water Delivery Scheduling therefore should be handled with the greatest caution and should probably be considered not more than indicative.

5.4 Demand-Supply Considerations[31]

Five types of Water Delivery Schedules were identified (Section 5.2). A selection from these five types however cannot be made freely without testing them in terms of demand-supply considerations. Two different types of water supply sources can be identified:

- static (lakes, reservoirs, groundwater)
- dynamic (unregulated run-of-the-river flows)

If the water is not diverted from the source, in the first case water will remain stored and available for use later, and in the second case it is lost (in the river) and is no longer available at the diversion point.

Another distinction is the adequacy of supply:

- sufficient supply throughout the year
- insufficient supply for unrestricted cropping calendars during part of the year

These distinctions result in the four cases as illustrated in figure 5.3.

In both cases (A and B) the schedule can be simple. As water is sufficient throughout the growing seasons, a responsive type of scheduling might be adopted, accommodating the instantaneous requirements of the farmers. An automated system is an option although the question arises whether this type of sophisticated technology is actually necessary: a system with proportional division structures running at full supply (FS) throughout the year will accom-

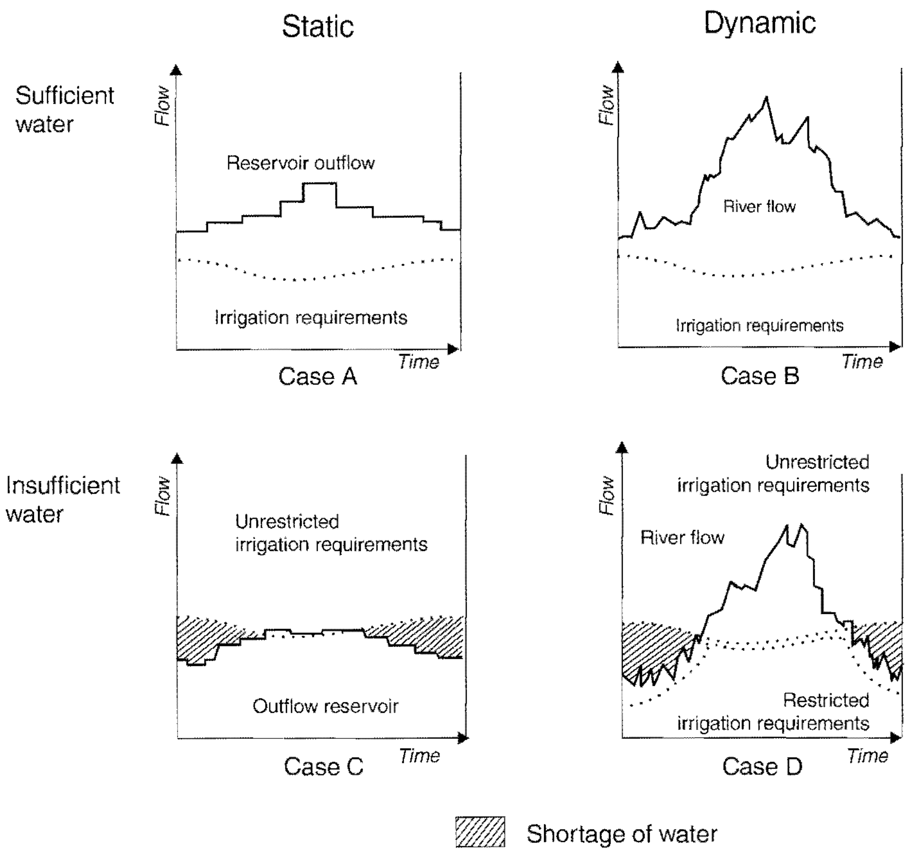
[30]For example, a study of feasibility reports on 15 different projects by 12 different consultants in Java, Indonesia revealed the following (Binnie and Partners 1980): In spite of the fact that the 15 projects were in similar locations regarding climate and soils and were planned for two similar rice crops, the following extremes were noted:

		Lowest	Highest
Crop water requirements	mm	826	2,743
Effective rainfall	mm	268	1,448
Diversion (overall) efficiency	%	40	85
Overall requirements	mm	686	4,020

These ranges of differences might be explained by the use of different formulae (e.g., Penman or Blaney Cridde for crop water requirements), different assumptions on which part of the rainfall can effectively be used, efficiencies based on comparison with other projects with different performances, overoptimistic assumptions inspired by economic reasoning (expanding the irrigable area), etc. It should be realized that, in reality, at plot level these values might show even greater variations taking into account different local soil variations (percolation).

[31]This Section draws on Horst, 1996 b.

Figure 5.3. Supply and demand curves.



modate the same needs. Canals running FS also should be preferred when silt enters the system: at FS, most of the silt will either leave the system or will be deposited in the fields. In either case (automatic and proportional division) a well-developed drainage system is required to return the excess water back to the river system.

With cases C and D, one of the fundamental questions in irrigation emerges: what measures should be taken to address the shortage of water during part of the year? Matching supply to unrestricted demand is possible only by building reservoirs to increase the dry season flows (creation of case A). In many parts of the world, however, this appears rarely feasible and solutions are needed to match demand to the actual limited supply. As shown in Section 5.2, in principle, two types of solutions might be considered: restrictions on crops and restrictions on water.[32]

[32]A third possibility of closing part of the system in case of water shortages is sometimes advocated. For example, Burns (1993) proposes to create a core group of farmers who will get water and a marginal group who will not. Although this solution may sound rational in terms of economics and engineering, it might be considered socially unjust and politically unacceptable.

Restrictions on Crops

During the dry season, to match the irrigation requirements with the water available, restrictions are issued on growing specific crops. Examples are the localization or crop zoning in South India limiting the areas under 'wet' crops like rice and sugarcane, and the sanctions in Indonesia for growing rice in the dry season.

These crop restrictions are based on an assessment of anticipated water availability during the dry season. Localization if based on average reservoir storage (case C) or average river flows (case D) would lead to water shortages during 50 percent of the (drier) years. Therefore, localization is often based on 1:4 or 1:5 dry-year river flows, determined by statistical analyses of hydrological records.

In case C, the reservoir outflow can be regulated to supply the flows required for the given restricted cropping calendar. Case D is more complex due to irregular river flows complicating operation of the system. In tropical rivers, these irregularities can be large and frequent, and consequently, in practice, a considerable volume of water is not used and is therefore 'lost' in the river (see dotted line in figure 5.3).

In both cases, C and D, proportional delivery scheduling is often not applicable because the localized areas are not evenly distributed over tertiary and secondary blocks. In principle therefore, central or responsive schedules (Schedules 3A and B, 4 and 5) have to be adopted. The limitations of these schedules will be discussed in the following chapters.

Restrictions on Water

An alternative solution to the problem of having to restrict cropping during the dry season, is to design irrigation systems that divide any water shortage equally among the farmers or groups of farmers. These systems are based on principles of proportional water division (Schedules 1 and 2 table 5.1).

The advantages of this solution lie in the domains of equity, transparency, and timeliness. Instead of having to determine and impose crop restrictions, here the restrictions are in the form of less water than wished, forced equally upon the (groups of) users. It is at the users' discretion to solve these restrictions either by growing 'dry' crops or leaving part of their land fallow. (This is contrary to restrictions on crops where actual localization is in most cases by sections of the scheme and not by a percentage of each farm.) This principle is the basis for many traditional irrigation schemes as well as in the irrigated areas in Northern India and Pakistan (Punjab) where it is called "protective irrigation." This "scarcity by design" (cf. Jurriens, Mollinga, and Wester 1996) is based on optimization of the production per unit of water available contrary to "productive irrigation" based on optimization of production per unit of land.

The point of departure for restrictions on water is equitable division. Of course collusion, power pressure, etc., will always play a role where farmers try to obtain more water than allocated. However, with fixed structures, the sources of struggles and conflicts are, at least on paper, reduced to the level of the village and tertiary unit.[33] Moreover the fixed struc-

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[33]Whether this is a positive point or not depends on the local social structure. One might expect a higher degree of solidarity at village level than at project level. Merrey's (1982) findings for Pakistan however point out differently.

tures are more understandable and operation is more transparent than in the case of adjustable structures (see further Section 7.4).

Finally, an important advantage of applying restrictions through water can be noted for case D (run-of-the-river schemes) that constitutes a large part of the irrigated areas in the world. Localization is often based on 1:4 or 1:5 dry-year river flows. These flows are much lower than the actual flows (cf. Perry 1993, paragraph 19). In case of proportional division, the actual river flows are diverted constituting a considerable extra volume of water for crop growing. Here an important aspect is the water-holding capacity of the soil rendering a buffer function for irregular supplies.[34]

Summarizing, it can be stated that the choice of Water Delivery Schedule as a basis for the technical design of systems and structures is very much determined by the availability of water. In a situation where sufficient water is available throughout the year for unrestricted crop growth, a choice can be made from any of the five types of schedules delineated in this chapter. However, where periodic water shortages are experienced, a decision has to be made to either restrict crops (localization) or water allocations. This decision has repercussions on the possible choice of schedule and on the matching technology as will be discussed in the next chapter.

5.5 *The Equity Issue*

The term "equitable distribution" features prominently in many irrigation publications. This term, however, is seldom defined and is probably the most misused word in irrigation literature.[35] "Equity" is either confounded with "equality" or related to something vague as "uniform water delivery," "meeting crop water requirements" or an objective to combat head-end tail-end problems.

When examining the equity issue somewhat further, it appears that "equity" as used by design engineers does not pertain to moral or social justice but to production motives: apart from fertilizers, pesticides, labor, etc., irrigated agriculture is largely concerned with land, water, and crops. Land is viewed by the design engineer as a physical boundary condition. Land tenure is seldom questioned even in cases of skewed landholding proportions. It is considered a political question outside of the engineer's competence. About water however, the engineer expresses his opinion in and out of season. The reason is obvious: the objective of the design is to optimize agricultural production. For the designer the land remains a production function whether under smallholders or large holders, and the issue is reduced to water and crops. Furthermore, water has a direct bearing on the type of delivery schedule and system technology.

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[34]In this context, a remarkable feature of irrigation engineering should be noted: where in rain-fed farming the vagaries of rainfall are—from sheer necessity—accepted, irregular supplies are seldom tolerated where irrigation is concerned.

[35]One of the exceptions is the analysis by Levine and Coward (1989).

This becomes clear when considering possible interpretations of the term "equitable distribution:"

1. Each farmer receives an equal share of the water. This applies to (re)settlement schemes with equal farm sizes.

2. Each farmer (or person) receives an equal share of the water irrespective of his or her landholding size (an example is the Pany Panchayat water division principles in Maharastra, India).

3. Each farm receives water according to plot size (same volume of water per hectare; supply-driven; proportional scheduling).

4. Each farm receives water according to irrigation requirements of the crop grown (demand-driven; central or responsive scheduling).

One can speak of equality in cases 1 and 2. From a social perspective cases 3 and 4 are unequal and unjust when skewed landholding proportions exist and water is subsidized. Such cases are predominant in many countries and thus irrigation may reinforce social differentiation; these cases are contrary to measures necessary for poverty alleviation.[36]

In practice, decisions on these socio-political aspects of land and water are made by planners and politicians. Nevertheless, here it is argued that the socio-political consequences of choice of water delivery schedules and technology should at least be understood by engineers.

[36]Chambers (1988) states: *Production and livelihoods are linked, but for poverty alleviation ... the generation and support of livelihoods are a higher priority than production per se.*

CHAPTER 6

TYPES OF DELIVERY AND APPURTENANT TECHNOLOGY

6.1 Introduction

Five basic types of delivery schedules have been identified in chapter 5 (table 5.1). Each requires its own system in terms of canal capacities and water division structures.

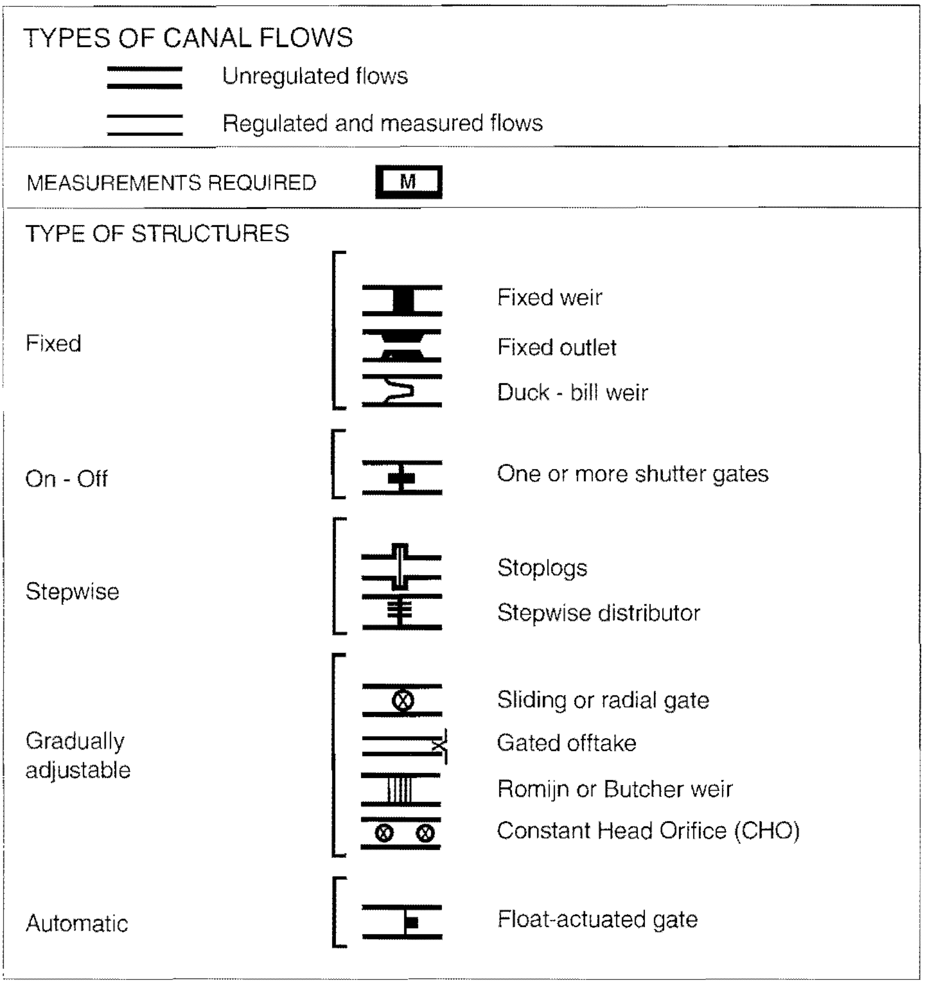
Canal Capacities

- The way the water is to be delivered at the tertiary outlet has a direct bearing on canal capacities. Canal capacities for traditional systems with proportional water division (System1) are mostly determined by local experience on expected river flows on the one hand, and on the intended area to be irrigated on the other. Because of the continuous flows through the system the capacities can be kept limited. The Punjab type (System 2) should have larger dimensions in view of rotation among the distributaries (secondary canals). However, they are generally designed for 'protective irrigation' with low requirements per hectare. In case of central scheduling (Systems 3 and 4) the canal capacities are derived from the water delivery schedule. Finally, canal capacities for responsive scheduling (System 5) comprise the largest in terms of flow per hectare: the chance that during a dry period most farmers will draw maximum water at the same time has to be accounted for. For these canals, capacities can be calculated by statistical methods (e.g., Clement 1965).

Water Division Structures

- In the following sections the different types of systems with possible choices of water division structures are discussed in terms of operation, measurement requirements, farmers' dependency on management, transparency, and operational flexibility. (Operational flexibility can be defined as the capability of the system to comply with changing demands and supplies). The legend for the various figures in this chapter is presented in figure 6.1.

Figure 6.1. Legend for figures 6.2-6.6.

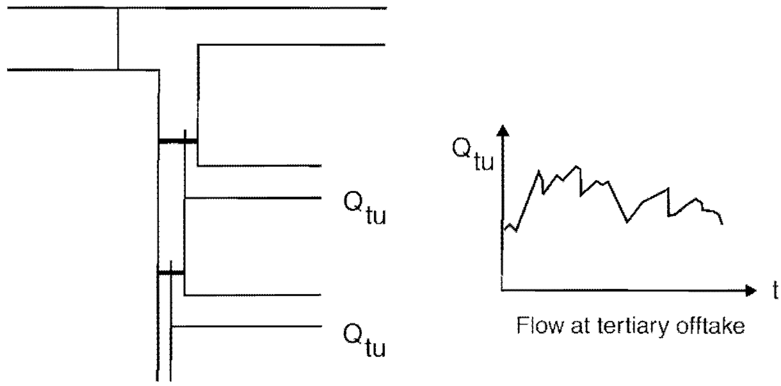


6.2 Schedule 1. Proportional Division—Traditional

The flow entering the system (often from a run-of-the-river source) is divided by means of overflow weirs with equal crest heights and proportional widths. This type of system is widely used in traditional irrigation.[37] The proportions are generally based on irrigated areas but are sometimes adjusted to account for preferential rights, distance of irrigated area from the structure, etc. In rice areas, flows are often subdivided into very small portions serving individual plots. In case of non-rice crops, or in times of low supply, rotation among farmers is often necessary.

[37]The layout of traditional systems is often of the bifurcating type (figure 3.1). The presentation as a hierarchical type in figure 6.2 is made for the sake of comparison with the subsequent figures.

Figure 6.2. System 1.



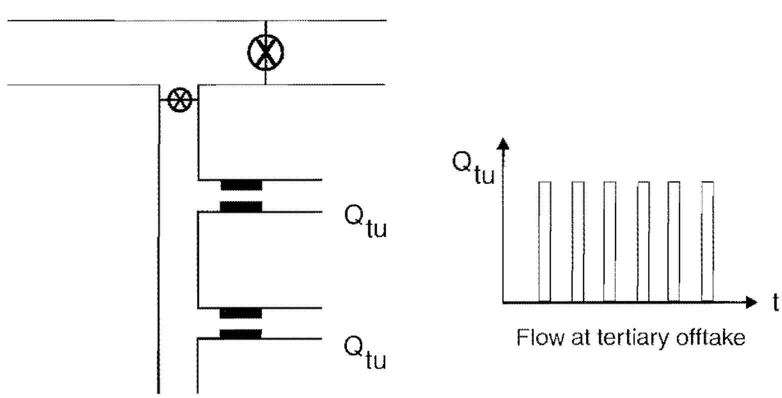
Operation is decentralized and limited to regulation of the head works and overall inspection. Water division, in principle based on equity (volumes of water per unit area), is transparent and renders tampering difficult. No measurements in the system are needed. Operational flexibility is small.

6.3 Schedule 2. Proportional Division - Punjab Type

This system (figure 6.3) is widely used in the Punjab and is based on water division proportional to the areas of the chaks. The secondary canals (distributaries) flow either full supply or zero. There exist a large variety of outlets (cf. Mahbub and Gulhati 1951). Most commonly used are: adjustable proportional modules (APM), open flumes, and pipe outlets (cf. Mahbub and Gulhati 1951).

The system, based on equitable distribution, requires only operation of the main canal: gate setting, and regulation of secondary flows. The transparency is less than for System 1, since most of the modular offtakes are of the undershot type. The flow within the tertiary unit is divided on the basis of a time roster (*warabandi*). The operational flexibility is small.

Figure 6.3. System 2.

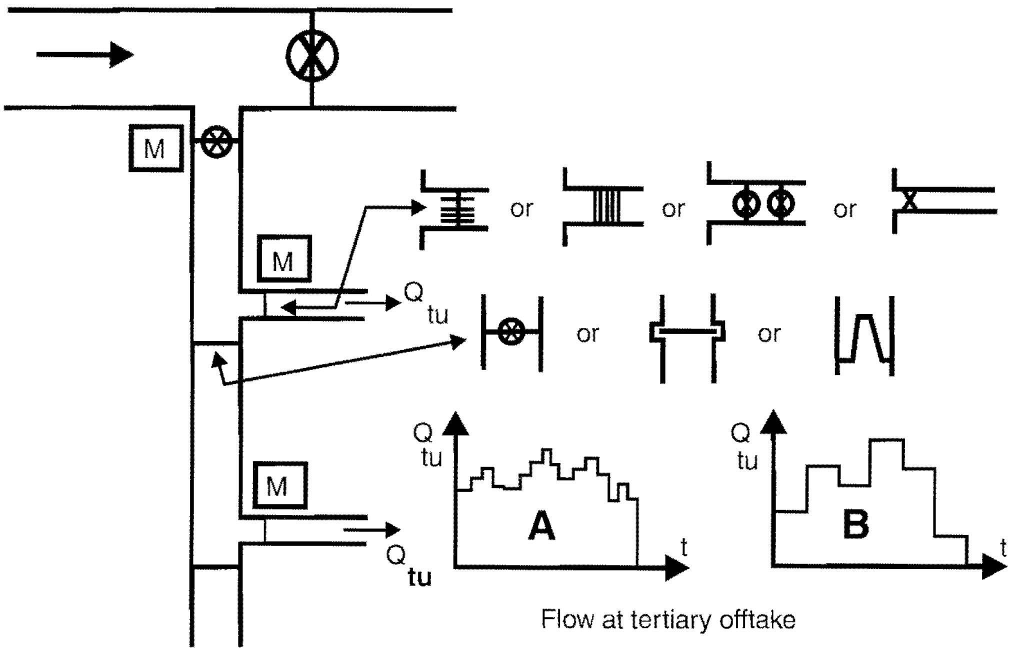


6.4 Schedule 3A and 3B. Variable Flows

The delivery principle for both systems is based on crop water requirements. To accommodate the varying requirements of the different tertiary units, the tertiary as well as the secondary offtakes should be adjustable and flows measurable. Measurements can either be by the structure itself (e.g., stepwise distributor, Romijn weir, or CHO) or by a measuring structure (broad or sharp crested weir or flume) downstream of the offtake. For this widely used type of system, a large number of structures can be adopted (see figure 6.4). We will see in chapter 7 that the selection of combinations of cross regulator and offtake has important impacts on requirements for staffing and hydraulic behavior of the system.

The systems for types A and B do not necessarily differ in terms of technology. They only differ in frequency of operation. Case A requires frequent and often complicated resetting of gates and correspondingly frequent measurements. Farmers are heavily dependent on scheme management. Most structures are not, or only poorly, transparent. The operational flexibility is large.

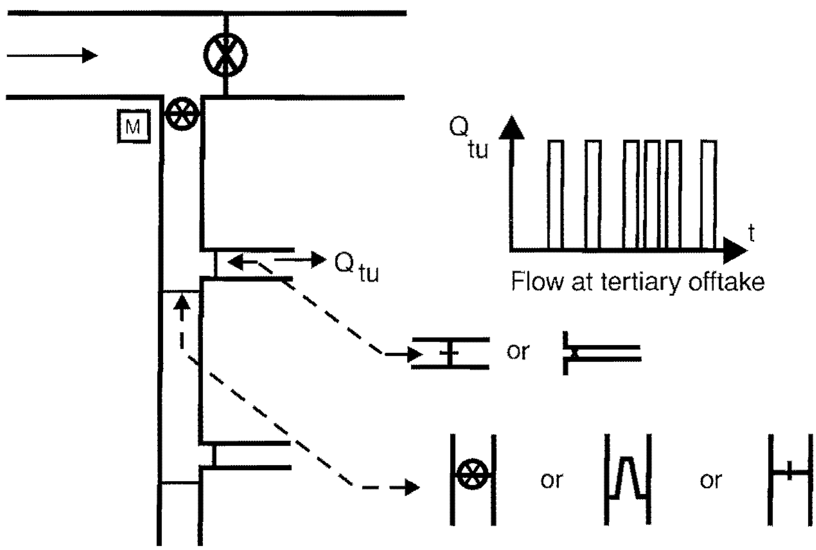
Figure 6.4. Systems 3A and 3B.



6.5 Schedule 4. Intermittent Flows

Rotation can either be practiced among tertiary or secondary canals. For rotation among tertiary canals the unit flow (main d'eau) is fixed and the irrigation interval variable. Thus the tertiary offtake flow is either full supply or zero and on-off gates can be used as offtake struc-

Figure 6.5. System 4.



tures (figure 6.5). (Nevertheless, sliding gates are often used.) For cross regulators in the secondary canal, a duck-bill weir, sliding gate, or a battery of on-off gates[38] might be considered. When rotation among secondary canals with either full supply or zero is practiced the Punjab situation will occur (see System 2). In case of variable secondary canal flows the same type of structures as for System 3 are required for dividing water properly.

Water distribution is on the basis of crop water requirements. For rotation among tertiary canals operation is relatively simple and transparent compared with System 3. Measurements are needed only at the secondary offtakes. Operational flexibility is larger than for Systems 1 and 2 but smaller than for System 3.

6.6 Schedule 5. Automatic Delivery

In this responsive system (figure 6.6), water requirements are, in principle, accommodated instantaneously by handling the stepwise distributors at the tertiary offtake. The induced changes in flow and subsequently in water levels will be transmitted upstream automatically by float-actuated gates, resulting in required changes in the supply. Clearly, this type of system can only work as described when sufficient water is available (stored) to meet the demand during the whole growing season. In cases of shortage, part of the system will run dry: automatic upstream control will produce shortages at the lower end of the system and downstream control at the upper end. Therefore, control gates are often installed at the head end of the tertiary or secondary canals. By doing so, however, the responsiveness is largely nullified, and the scheduling becomes "centrally arranged."

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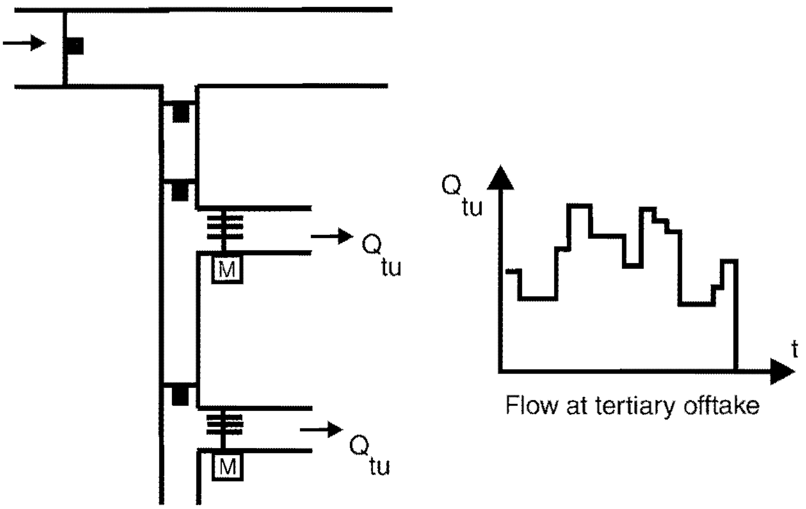
[38]The solution with on-off gates is specially relevant for projects with tertiary units of equal sizes. In such a case one gate serves one tertiary unit and can be standardized.

Figure 6.6. System 5 (downstream control).



Water distribution is based on crop water requirements. System operation is simple and transparent, and the number of measurements limited when compared with System 3. The structures, however, are vulnerable and easy to tamper with. The operational flexibility is large.

6.7 Deviating Choice of Structures

From the previous sections it became clear that the type of system and the choice of structures should be determined by the principles of water allocation and distribution as decided during the earlier planning phase. In practice however, the actual choice of structures is often influenced by a wide range of different motives:

Tradition

Many design standards originated from colonial times. Older designers have been working with them all their lives and younger engineers are educated along the same lines and lack the authority or the insight to change these standards.

Design 'Schools'

As discussed in Section 1.2 foreign consultants have a large influence on irrigation design in many countries where they could introduce and propagate their own design 'school.'[39]

[39]In Indonesia, the only firm standard for government schemes was the 'technical irrigation' requirements: systems where the water can be regulated and measured in each point of the system. Within these requirements all types of 'schools' could find its place. This led to a wide variety of structures (cf. Horst 1996 a). On the other hand, in the Philippines the USBR standards were adopted and strictly adhered to.

Personal Inducements

It is the characteristic of the engineer to invent new technologies. Consequently, the development path of irrigation is strewn with many designs ranging from ingenious to particular.[40]

Urge for Modernization

The present day promotion of modern (automation, computerization, etc.) technology often does not take into account local conditions in terms of trained staff, farmers' acceptance, and sufficient storage requirements.

Ignorance

Unfortunately, in many cases design choices are made without realizing their origin and the consequences on future operation.[41]

Economics

Naturally, different structures have different costs. It should be noted that the smaller structures (at secondary and tertiary level) are cheap individually but constitute a large share of the total project costs due to their large numbers. The cost of a particular structure can differ greatly between one designer and another.[42]

Tampering

The fear that farmers will tamper with the structures sometimes leads to extreme forms of over-dimensioning as shown in Section 7.4.

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[40]Good examples can be found in the Indian literature of the first half of this century e.g., Mahbub and Gulhati 1951.

[41]For example, in early times most projects in India were run-of-the-river supplied and cross regulators were designed as undershot structures for silt evacuation. These types of structures are still built but now for reservoir type of schemes, in spite of the fact that weir type of structures give better water level control (personal communication Satnarayan Singh, Hyderabad).

Another instance is the wrong combination of Romijn Weir as offtake and sliding gate as check structure in Indonesia. See chapter 7, note 45.

[42]For the Bura Irrigation Project in Kenya two design consultants made design specifications for the same project. One consultant proposed twice the volume of concrete and three times the volume of steel compared with the other consultant. One of the arguments was maintenance: the first argued that problematic maintenance requires sturdy structures, the second assumed sufficient maintenance in view of an assumed highly mechanized, well-managed project.

Health Aspects

Special types of structures and operational procedures might be adopted to fight health hazards. Intermittent canal flows can have a positive effect on schistosomiasis.[43] Over-irrigation can lead to breeding grounds for malaria mosquitoes.

[43]For example, in Zimbabwe the Mushandike Irrigation Scheme was specially designed to control schistosomiasis—see various Technical Notes from Hydraulic Research, Wallingford, UK.

CHAPTER 7

CHOOSING STRUCTURES AND THE OPERATIONAL IMPLICATIONS

7.1 *Introduction*

In chapter 6 the five most frequently occurring irrigation systems were defined. Each system is characterized by the type, and combinations of types, of water division structures. In this chapter these structures are examined in terms of hydraulic behavior, operational aspects, and human dimensions. For that purpose the following questions are addressed:

- *Hydraulic behavior:* How does the system react hydraulically upon changes in flow and what are the operational consequences?

- *Operation:* How is the system operated? How flexible is the system? What operational procedures are required? How many staff are needed?

- *Human dimensions:* How understandable are the structures? Is their operation transparent? Does it correspond with the perception of the farmers on intended distribution and equity? How easy can corrupt practices be detected?

As illustrated in the previous chapters, consideration of these issues receives little attention in conventional design choices and assumptions. However, they can be of decisive importance in achieving satisfactory performance as will be discussed in the following sections.

7.2 *Hydraulic Behavior*

In every irrigation system, changes in flow and water levels occur concurrently. These changes may be sudden, caused for example by changes in river water levels at the head gate or by a gate in the system which is opened or closed; or they may also be gradual, with siltation and weed growth in canals influencing the flows in the long run. Each irrigation system reacts differently to these fluctuations depending on the characteristics of water division structures. From an operational point of view four questions are of interest:

- reactions at bifurcation points

- reactions of the system as a whole

- propagation of fluctuations
- reactions to siltation and weed growth

Reactions at Bifurcation Points

At the local level of water division points in the system some general observations can be made on type of structures, on hydraulic characteristics, and subsequently on operational actions required. These observations are based primarily on the Sensitivity S and Hydraulic Flexibility F concepts as discussed in Section 4.4. Figure 7.1 presents six examples of combinations of structures at a bifurcation point. Although not exhaustive, these cases represent frequently occurring combinations and they suffice to illustrate the relationship between type of structure and operational consequences.

Case A

This case is applicable for systems with proportional water divisions (System 1). Changes in flow will be automatically divided proportionally into the two canals (F=1), provided the flows are semi-modular (see Section 4.3). The structures cannot be adjusted and operation is nil. See plate 7.1.

Plate 7.1 Proportional division (Bali).

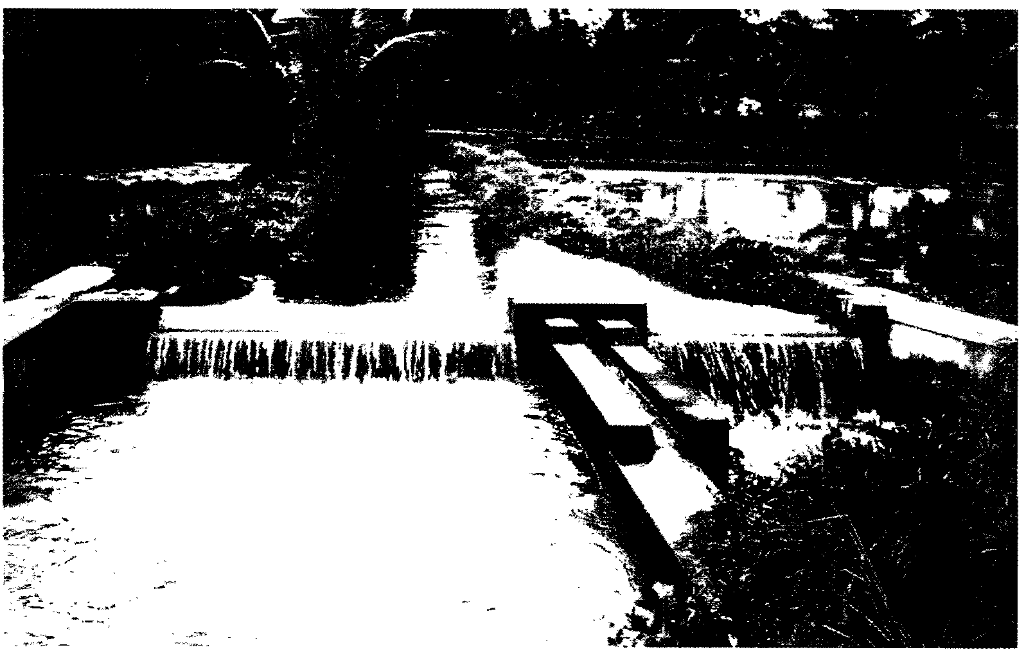
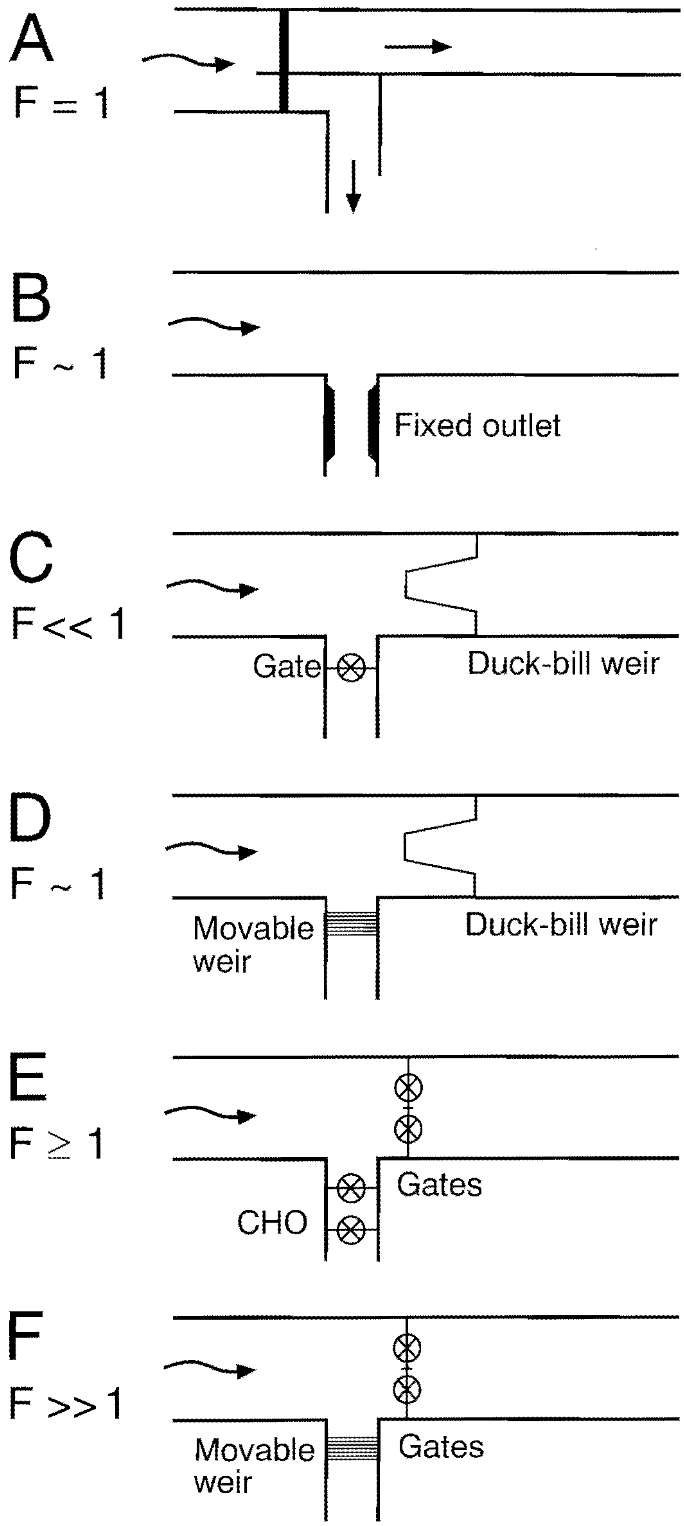


Figure 7.1. Some possible combinations.



Case B

This design (System 2) is applied widely in the Punjab. Proper distribution is dependent on flows in the parent canal being either full supply or zero. The offtakes (fixed orifices or flumes) are dimensioned and placed below full supply level of the parent canal in such a way that the flows are proportional to the areas served. For examples see Mahbub and Gulhati 1951. See plate 7.2.

Case C

In this case water level fluctuations will remain small due to the duck-bill weir as cross regulator (large S), while water-level fluctuations will have little effect on the flow under the offtake gate (small S). This combination, where F is very small, requires few readjustments, if any. See plate 7.3.

Case D

Although similar to case C, more frequent readjustments are required to maintain planned divisions, due to the higher sensitivity (S) of the movable weir in the offtake.

Plate 7.2 Fixed outlet (Punjab).

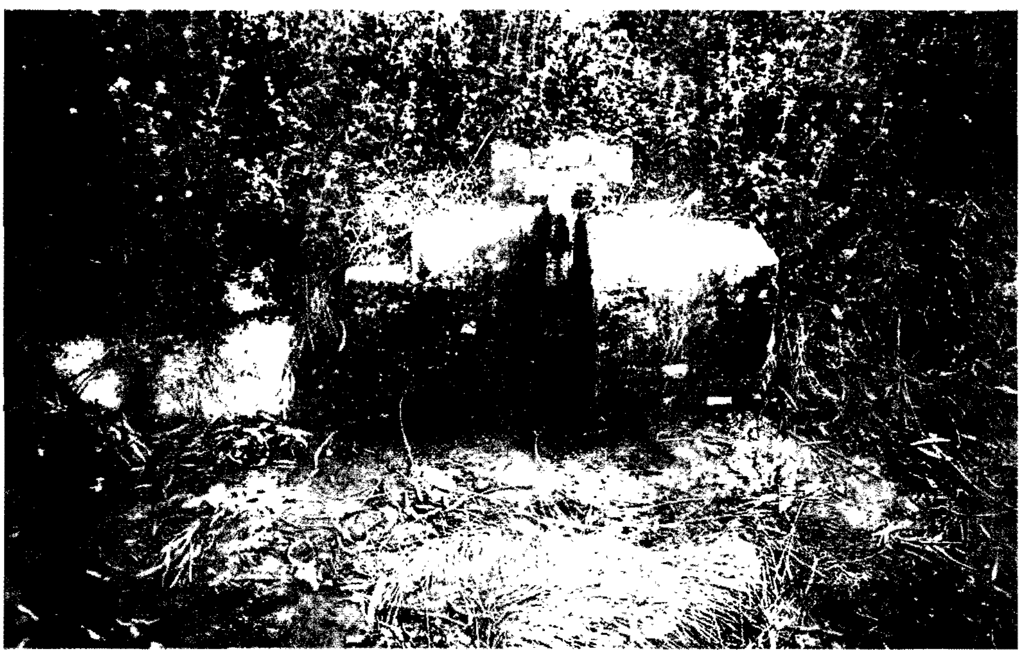


Plate 7.3. Duck-bill weir (Sri Lanka).

Plate 7.4. Gated check structure and CHO offtake (Kenya).

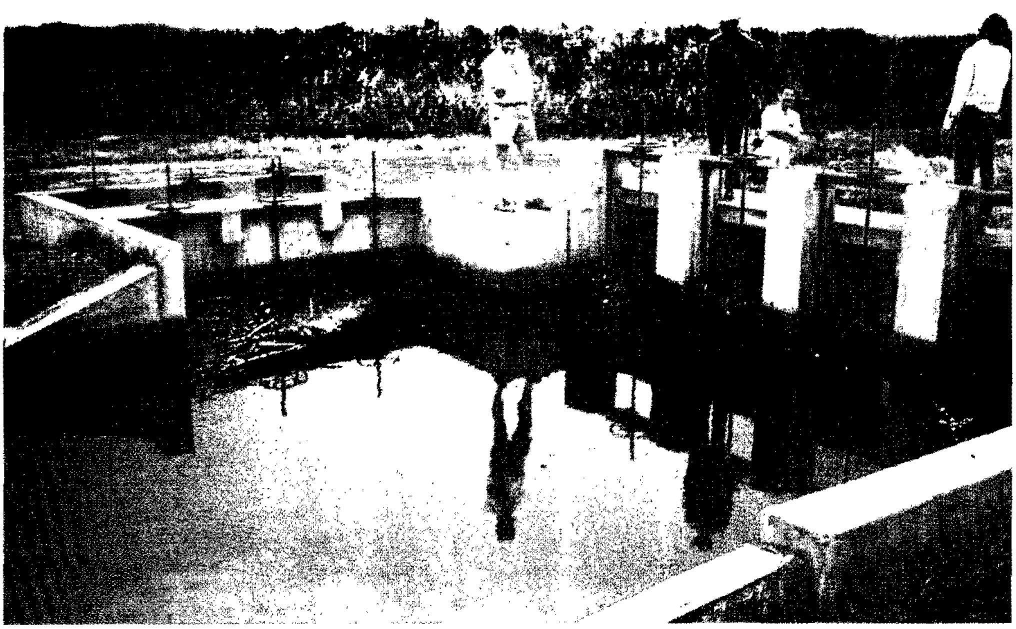
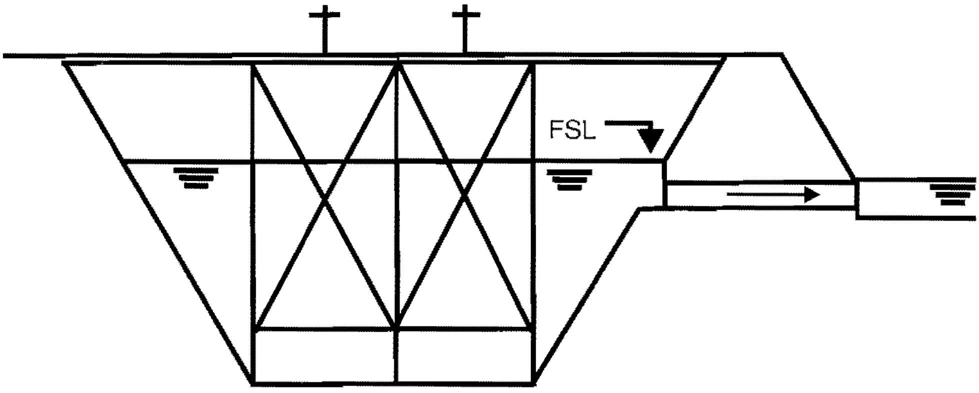


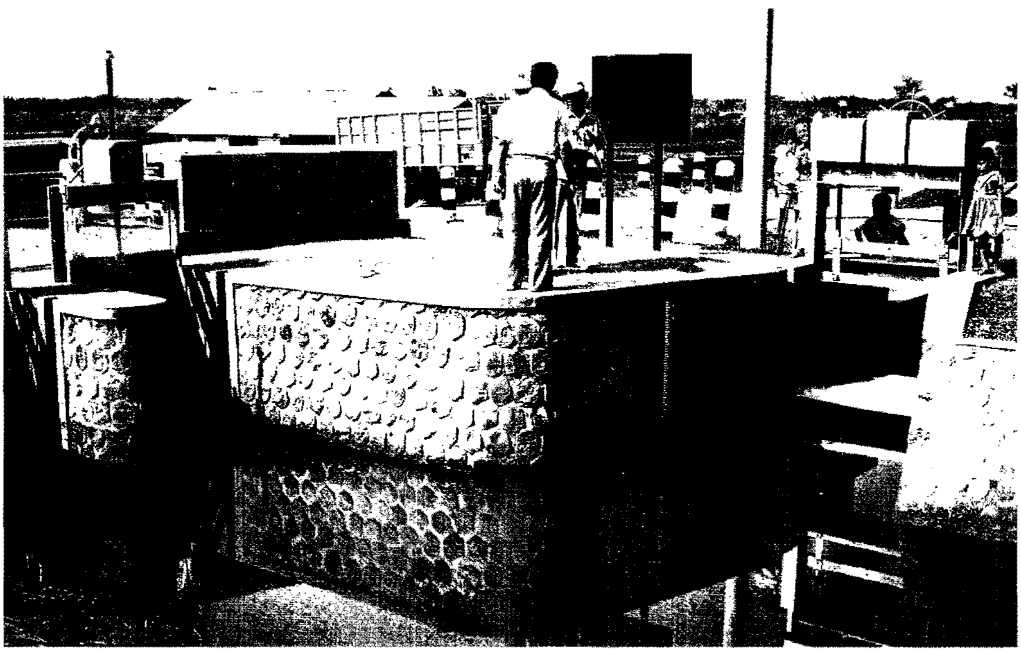
Figure 7.2. Gated check and offtake structures.



Case E

This combination of structures[44] requires more adjustments than the above cases (plate 7.4). In the common arrangement where offtake gates are placed at a higher elevation than the gates of the check structure, figure 7.2, there are large fluctuations in the offtake discharge as a result of water level fluctuations in the parent canal (F>>1).

Plate 7.5. Gated check structure (left) combined with Romijn weir (right).



[44]In the Philippines for example, this combination is often applied. Furthermore, this solution may contain the danger of overtopping in case of sudden unwanted increase of water supply. This danger does not feature in the previous cases.

Case F

This may well be the worst combination for effective operation (see plate 7.5). Small fluctuations in flow result in large variations in water level and subsequently large variations in offtaking flows (F>>1). The proper operation of such a combination is probably impossible.[45]

It should be noted that cases E and F are common to many schemes with central scheduling (Systems 3 and 4) and constitute the core of operational problems.

Reactions of the System as a Whole

The type of structures in an irrigation system will have a considerable bearing on how the system will react to fluctuations in flow. Two interrelated factors are important: the response time and the hydraulic stability of the system.

Ankum (1992) defines the response time as "the time required for the system to transit from the previous steady state into the desired steady state." This time might be quite substantial (possibly a number of days). For example, IIMI describes the hydraulic situation at its Indonesian research sites as follows (IIMI 1989, p. 76):

> *It is .... apparent that canal discharges in many of the systems studied never achieve any form of stability. Operation of a gate has an immediate effect on water conditions at the next structure downstream, and downstream gate keepers have to take action to accommodate this change in upstream discharge. Having done so, however, upstream gates may be readjusted within a day or two, or inflow into the canals system changes, and the temporary equilibrium downstream is lost, etc.*

In this connection IIMI/ADB (1989) noted an important shortcoming in the design and operation of the main systems they studied. Drawing the attention to the two physical functions performed by the main canal—conveyance of water over distance and delivery at a place—they concluded that agency staff tend to perceive the main canal as a distribution system with emphasis placed on delivery aspects. In such cases, situations, as described above by IIMI in Indonesia, will be created at the expense of the conveyance function.

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[45]This combination can be found in many schemes in Indonesia. There, the Romijn weir was developed in the 1930s. This adjustable weir has the advantage of having regulation and measurement combined in one structure and of operation with small head losses. For check structures stop logs were most commonly used. Because both structures were of the overflow type, the Hydraulic Flexibility F approached 1 (unity). Fluctuations in flow were therefore spread more or less proportionally through the system. With the arrival of foreign consultants in the 1960s and 1970s, different structures were promoted (see Horst 1996 a). Many consultants proposed using sliding gates instead of stop logs for check structures, because stop logs were considered to be too outdated for modern management. Retaining the Romijn weir as offtake, due to its supposedly good functioning in the past, led to a situation in which F>>1. Consequently, flow fluctuations are felt most strongly in the head end of the system, resulting in frequent gate adjustments, which may or may not be authorized, and which often eventually result in the entire system becoming unmanageable. Remarkably, none of the consultants assessed their proposals in terms of Sensivity or Hydraulic Flexibility and thus disregarded operational consequences.

Design solutions are proposed which consider inclusion of intermediate storage in the system (see chapter 12) and the use of weirs instead of manually operated gates.

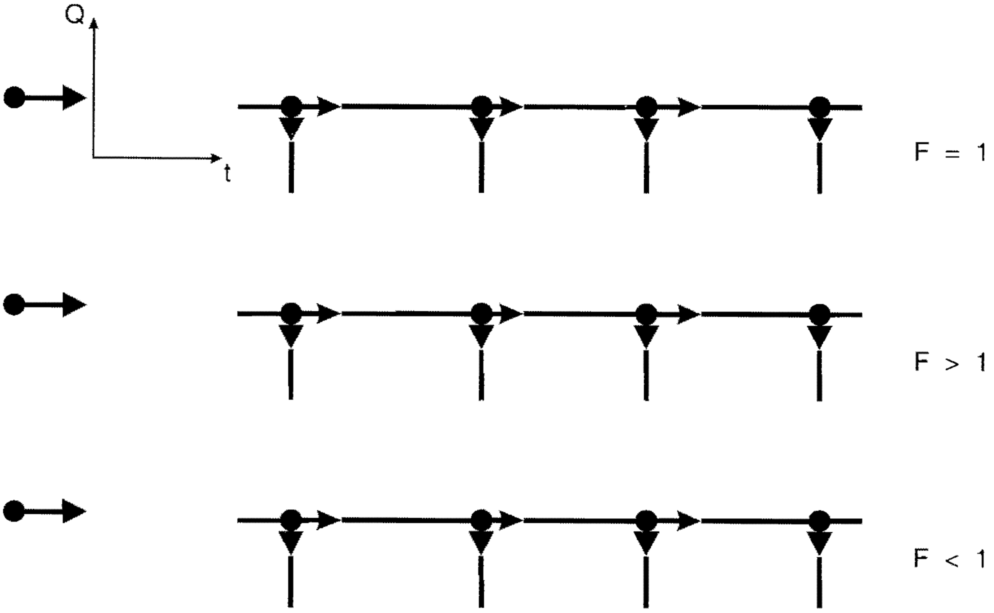
Propagation of Fluctuations

In Section 4.4 the Hydraulic Flexibility F has been introduced as the ratio between the Sensitivity S of the offtaking and ongoing structures. This factor F is a powerful tool to visualize the way in which flow fluctuations are propagated through a system. Figure 7.3 presents three different scenarios.

At F = 1 the fluctuations are propagated proportionally through the system; for F > 1 the fluctuations are mostly propagated to the upper end; and for F < 1 to the lower end of the system. On first sight one is bound to choose for F > 1 since many projects have problems of water shortages at the lower end of the project area. The following arguments could, however, be made against such a choice:

- To shift water shortages from one part of the scheme to another does not basically solve the problem.
- The larger the flexibility, the larger the fluctuations in water levels in the supply canal. This could lead to extra freeboard requirements.

Figure 7.3. Propagation of flow fluctuations through a system (Horst 1983).



- Siltation and weed growth in the canals could result in sufficient water for the head-end offtakes and might still lead to water shortages at the lower end.

- Probably the most important argument is derived from field experience: water shortages are felt most strongly at the head end in case of the supply decreasing below expected levels. Farmers might intervene when the situation is not redressed quickly. Unauthorized handling of gates or even breakage might be the result.

In general therefore, combinations of hydraulic structures providing flexibilities of $F = 1$ or $F < 1$ should be adopted (cases A through D of figure 7.1).

Reactions to Siltation and Weed Growth

In many irrigation schemes siltation of canals is a major problem. Water division structures are generally points of discontinuity in velocity of flow, and decreased velocities such as those caused by weirs, result in silt deposition upstream of the structure. Siltation raises water levels and increases flows through offtake structures. The same effect is observed when weed growth decreases the hydraulic cross section of the canals.

Of course, the best solution to prevent siltation is to divert silt before it enters the system by means of silt traps or excluders at the head works. In case silt entry to the system is inevitable the designer has three options.[46]

To design the system in such a way that silt will be carried through the system to the fields. An example is the design of the Punjab system (System 2, chapter 6) based on the regime theory. The type of structure is determined by the method of water allocation and distribution while they are shaped to pass sediments effectively.

To flush local siltation upstream of structures by special gates (for example in duckbill weirs or the bottom gate of the Romijn weir[47]). The silt, however, will by and large remain in the system and will eventually have to be removed.

To accept deposition of silt in the system and to presume regular excavation of the canals.

7.3 Operational Aspects

Every irrigation system has to be operated. The operation is primarily based on type of scheduling adopted (proportional, central or responsive; see Section 5.1), while the modalities of operation are determined by type of system (System 1 - 5, chapter 6) and the type of structures adopted.

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[46]For example, Plusquellec, Burt, and Wolter 1994. The authors rightly point to the inherent conflict between flexible delivery and maintenance costs in run-of-the-river schemes with high sediment load. Flexible delivery results in unsteady flow conditions resulting in increasing siltation.

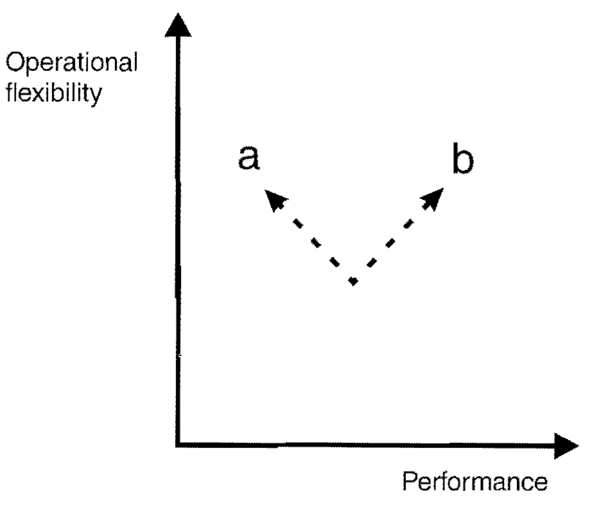
[47]Undershot gates for flushing, however, are prone to mismanagement; see Section 7.4.

Operability

The previous section (7.2) illustrated that the type and combinations of types of structures determine the frequency of operations required when changes in flow occur. Furthermore, operation of some structure types is easier than others (see Section 4.6). Clearly, both the type of structure in itself as well as the combination of structures at points of bifurcation determine the ease or difficulty of system operations.

Here a controversial issue in irrigations is reached: Operational flexibility. Many authors[48] contend that the greater the operational flexibility of the system, the better the matching of demand and supply and eventually the better the obtaining of performance. This might sound reasonable on paper. However, in practice, this reasoning often leads to over-sophisticated structures, cumbersome and time-consuming to operate; and to complicated operational procedures, resulting in sub-optimal operation and consequently water distribution that differs considerably from the intended flows. Also the necessity for measuring and monitoring add to the operational complexity. The end result might well be a much lower performance than in the case where a lower operational flexibility had been adopted in the first place. Or as sketched in figure 7.4 the performance by increasing operational flexibility might follow arrow "a" instead of arrow "b" as expected. This issue will be discussed further in Part IV.

Figure 7.4. Relation between performance and operational flexibility.



Procedures

Operation of a system requires certain procedures. These procedures vary strongly from system to system (see System 1 - 5, chapter 6).

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[48]For example Plusquellec, Burt, and Wolter 1994, p.24. *New irrigation projects are generally built with the stated objective of delivering water according to crop water requirements. This objective implies a delivery schedule with more flexibility than a simple rotation.*

- *System 1 (proportional division - traditional).* These, mostly farmer-managed, systems with fixed proportional weirs, require very little operation apart from occasional inspection for siltation, removal of debris, and detection of possible tampering.

- *System 2 (proportional division - Punjab type).* Operations consist of rotation of full supply among the distributaries (secondary canals) according to the available water at the source. In addition to this relatively simple procedure, inspection is needed along the distributaries as for System 1.

- *Systems 3 and 4 (central scheduling).* These demand-driven, agency-managed systems require comprehensive operational procedures. An operational plan is needed, where on the basis of crop types and cropped areas the irrigation requirements should be met by regulation of the supply.[49]

- *System 5 (responsive scheduling-automated).* This system requires procedures focused on the administration of water use and water charges.

Measurements and Monitoring

Requirements for measurements and monitoring clearly depend on the type of system adopted (as indicated in figures 6.2-6.6). For example System 1 (proportional-traditional) requires no measurements at all apart from possibly at the head works. In System 2 (proportional-Punjab) and System 4 (intermittent flows) measurements along the main canal are needed. In System 3 (variable flows) frequent measurements are necessary at all bifurcation points of the system. Finally, in System 5 (automatic) measurements and monitoring are required at the lowest levels for volumetric accounting.

It should be noted that measuring requires reading and recording, and constitutes sources of error. Measuring therefore should be restricted to the bare minimum (the tendency nowadays of promoting the increase in the number of measuring points to obtain higher irrigation efficiencies should be considered questionable. Not only does this require an impossible increase in number and competence of manpower, but it is also considered contrary to a logical solution for a sound operational system). Wherever possible, quantities of flows should be

[49]It should noted that the operational plan should logically be an operationalized version of the water delivery schedule: where the water delivery schedule is a prognosis for design, the operational plan is based on the actual situation. In reality however, this is seldom the case: very few designs give procedures on how the system is to be operated. Operational procedures are often compiled at a later stage by different consultants and not fully related to design assumptions. Many examples can be found where, based on demand-driven premises, voluminous operational procedures are compiled without any bearings on the original design criteria regarding water delivery scheduling. In Indonesia for example, the so-called Factor-K method, used as a basis for water distribution, has been developed into an extremely elaborate procedure requiring 12 sets of data and 16 steps to plan, implement, and monitor water distribution (see Horst 1996 a). Also in the Philippines, consultants put together an elaborate O&M manual (identifying the need for 46 different types of reports - see NIA 1991). This increasing elaboration of the operational procedures, not surprisingly, leads to an expanding bureaucracy, hand in hand with an increasing alienation from the day-to-day field practice (see chapter 8 for further information).

determined by the characteristics of the structure (e.g., stepwise distributors) or by unit flows on a time basis (rotation).

Staff Requirements

From the previous paragraphs it is clear that the type of system determines the operability, operational procedures required, and the need for measurements. System type also determines staff requirements. Actual numbers of staff employed per unit area in projects vary strongly from project to project and from country to country. A survey on project staffing (Bos and Nugteren 1974) revealed an overall average number of one staff required for 200-300 hectares. This tallies with FAO 1982, which gave a number of one water guard for 500 hectares in semi-demand and rotational systems. Significantly a number of one water guard for 2,500 hectares is given for continuous irrigation.

As no firm numbers of staff required for a given type of technology are available, all these values are indicative only. However, they point strongly to the fact that, compared with System 3 (and 4), considerable reductions in staff can be achieved by adopting a different water division technology. The applicability of these other technologies will be further discussed in Part IV.

Farmer Management

The possibilities for farmers to manage irrigation systems depend largely on the type of system technology and required operational procedures. For example, Systems 3 and 4 are much less suitable for farmer management than System 1 and 2 due to complicated operation and poor transparency. This will be discussed in Section 10.3.

7.4 Human Dimensions

Conflicts

Irrigation structures are technological artefacts which have to be operated by human beings. In general, the designer assumes that trained operators will handle the structures according to standards appropriate to the types. In most cases little attention is given to those at the receiving end: the farmers. How do they perceive the technology in terms of quantity and timing of flows? Here we have to realize that division of water is not only a technical matter expressed in l/s but also a human one: the right and expectation of a certain share of water and the assurance that this share is received in the right quantity and the right time. We have further to realize that these shares of water often constitute a matter of sheer survival. It is not surprising that in case of real or suspected injustice in water division, conflicts will emerge. These conflicts become apparent not only as intervention by farmers in the actual operation of the system but also as damage to structures. Some typical examples are illustrated in the following plates:

Plate 7.6. Unauthorized check structure (Malaysia).

Plate 7.7. Tampering with downstream control gate by placing stones on the float (Senegal).

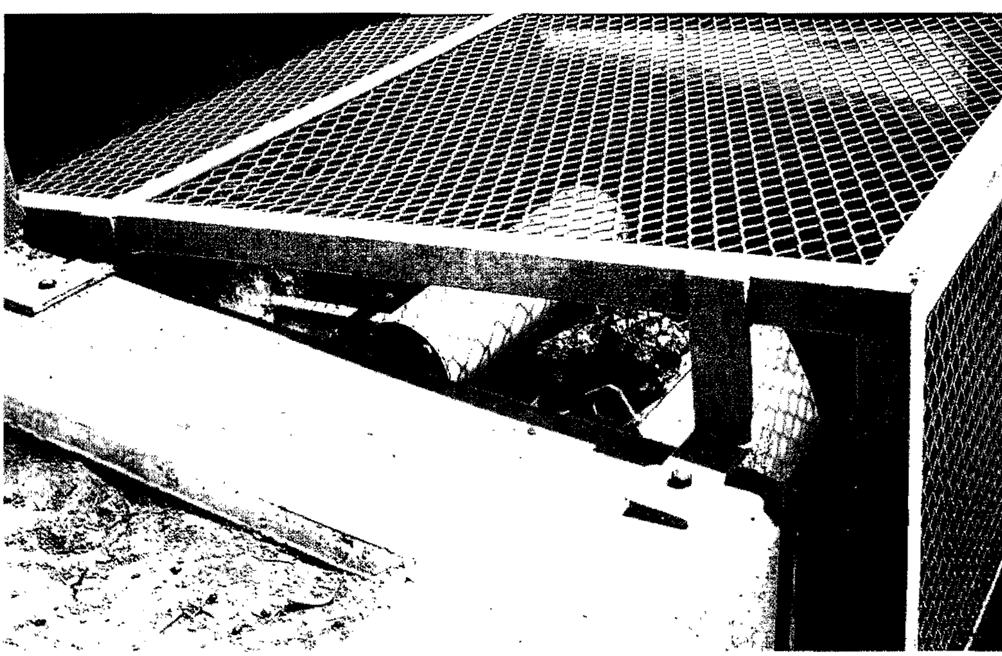


Plate 7.8. Broken gates of check structure (Nepal).

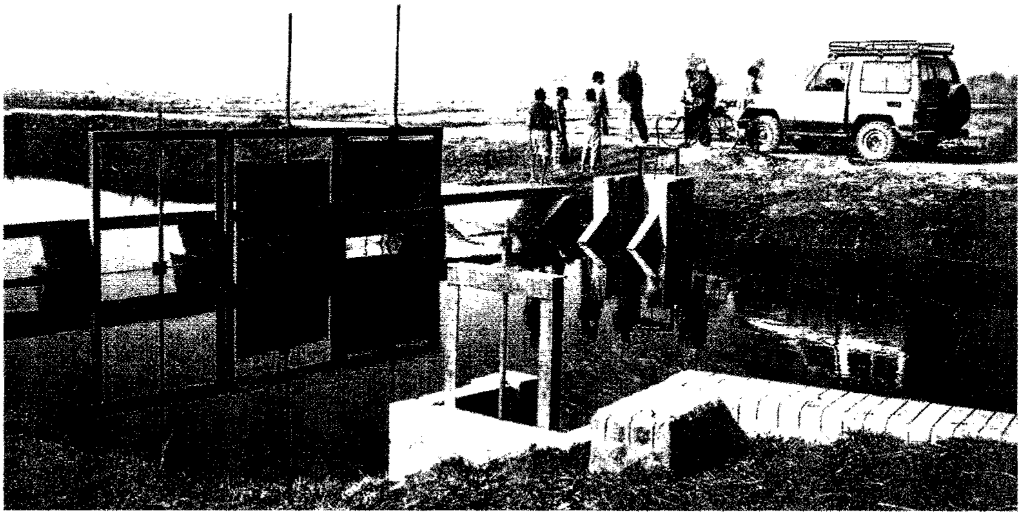
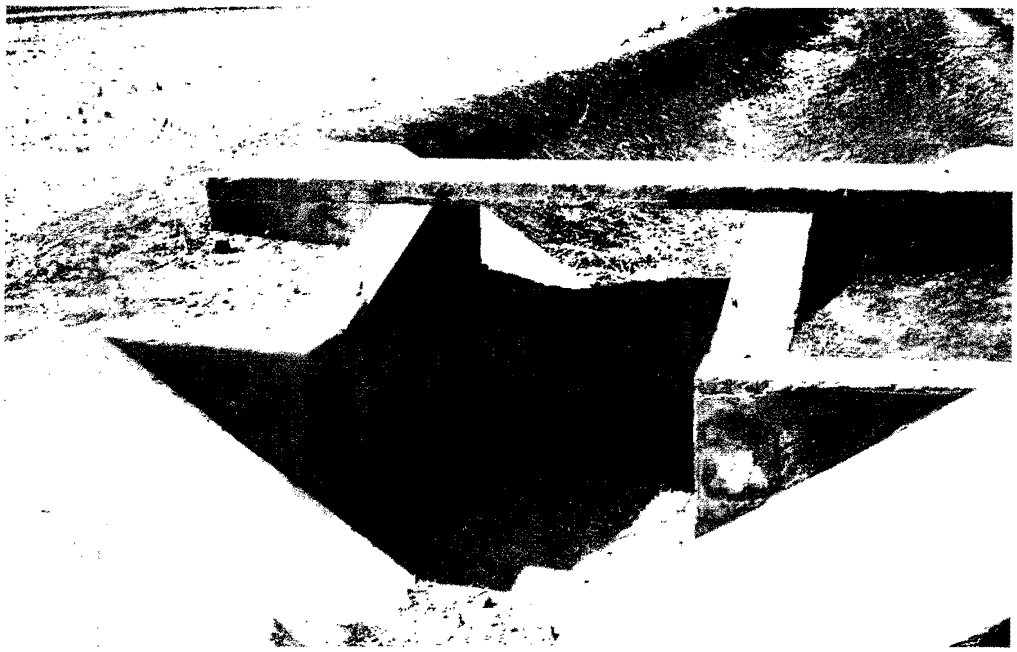


Plate 7.9. Assuring the open position of CHO by bending the lift rods (Philippines).

Plate 7.10. Check structure damaged by downstream farmers (Senegal - cf. Scheer 1996).



In many cases damage distorts water distribution in favor of the damaging party. In some cases however, the infrastructure is reconstructed by the farmers to render it compatible with farmers' perceptions in terms of allocation and distribution. An example is presented in Horst 1996c for the case of Bali.[50] Other cases of incompatibility between engineering designs and farmers perceptions are described by Siy (1986) and Yabes (1989) for the Philippines.

Solutions

The underlying reason for incompatibility between design and farmers' perceptions is the lack of communication and mutual understanding between engineers and farmers. (For an analysis for the Senegal valley see the Ph.D. dissertation of Scheer 1996). Many engineers complain about the ignorance and unreasonable behavior of farmers. Solutions therefore are often sought in technical 'tamperproof' measures instead of trying to understand the reasons why farmers behave the way they do. Some examples are illustrated by the following plates.

[50]In the Bali Irrigation Project (BIP), funded by the Asian Development Bank, and studied and designed by consultants from Italy and Korea, the consultants discarded the local, centuries-old technology and introduced gated structures in systems where formerly the traditional proportional division principles were practiced. In some cases, farmers destroyed these structures or used them to reestablish as fully as possible the original proportional division of flows. In a number of cases, however, they reconstructed the BIP technology by building walls in the canals upstream of division points and by creating proportional overflow weirs, leaving the gates useless. Eventually the BIP conceded and the last schemes were built as proportional division systems without gates (see Horst 1996c).

Plate 7.11. A fortress as offtake. (The continuous struggle between farmers tampering with offtake structures and irrigation officials resulted in the "ultimate solution," cf. Mollinga and Bolding 1996).

Plate 7.12 Padlocks. (In many irrigation projects padlocks are used to prevent unauthorized handling).

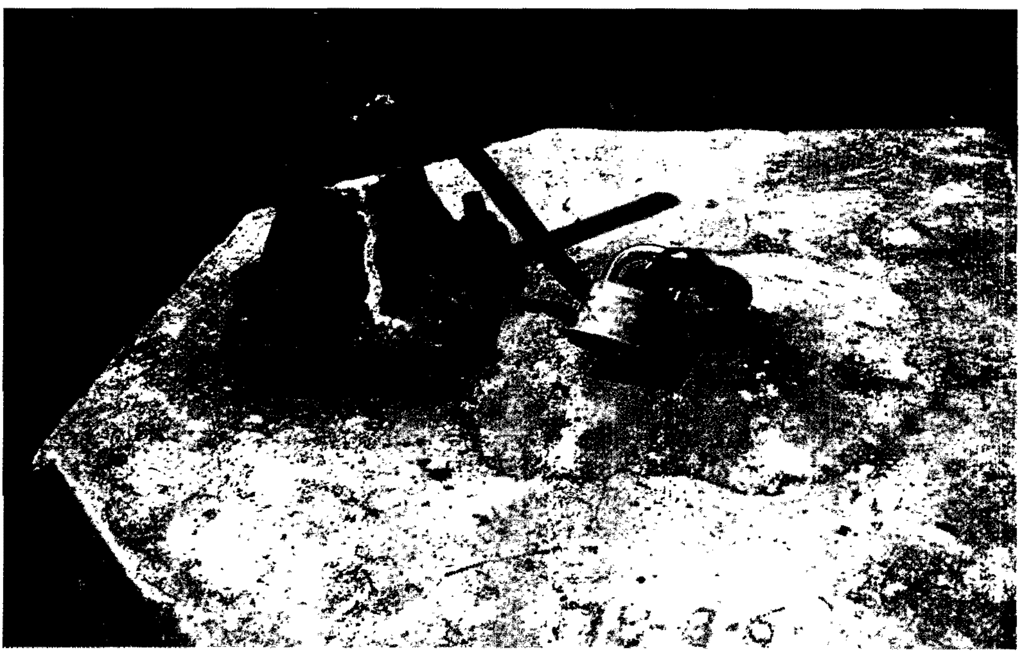


Plate 7.13 The Chinese lock. (In some projects in Nepal an ingenious bolting device requiring special tools is used to fix the gate setting).

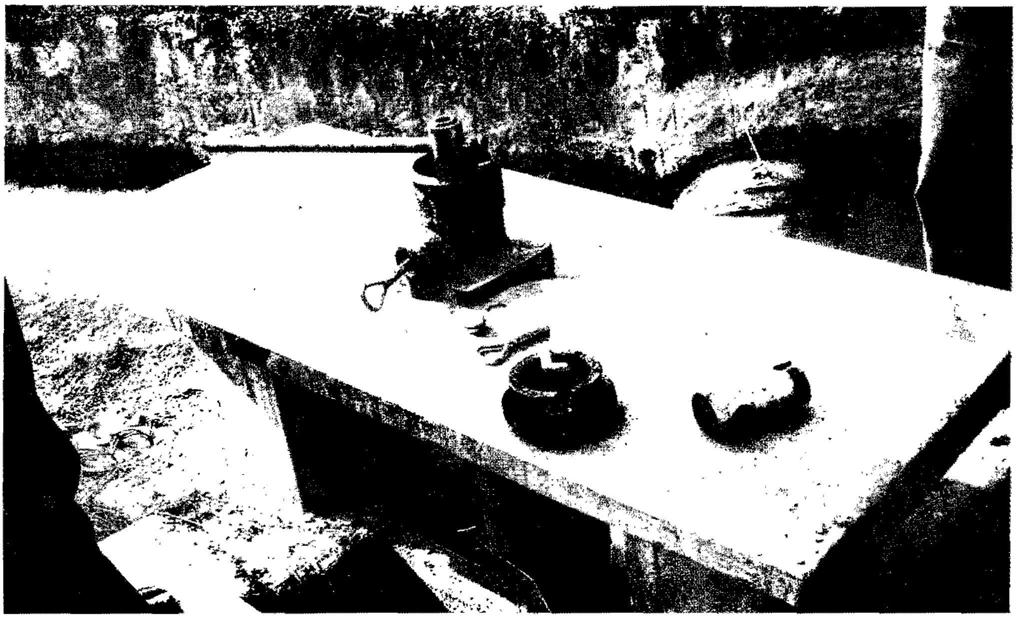


Plate 7.14 One key for all gates. (In the Banganga scheme in Nepal one hand wheel is used for all major offtakes. The wheel remains under the water guard's care).

The Need for Transparent Technology

Although vulnerable structures should be avoided, many of the efforts to prevent tampering prove to be of no avail in practice when farmers are convinced rightly or wrongly that the water is not properly divided. To try to find solutions for tampering by technical measures alone should in general be considered an illusion. Solutions can only be found by a combination of:

- General consensus by farmers and management on the allocation and distribution of water (including during times of scarcity).

- A system of canals and structures which enables farmers to understand the flows of water by their own perceptions.

Transparency of operation differs strongly from structure to structure. For example, the overflow (weir) type of structure gives, by its width and depth of flow, a clear visual picture of the water flow. On the other hand, flows through undershot (gated) structures are difficult to assess. Changes of flows through such structures depend on either changes in gate opening or in upstream and downstream water levels. Assessment is only possible by calibration graphs or tables. A fine example is the constant head orifice (CHO) where it is impossible to estimate the flow without calibration data. (In this context, it is important to realize that water levels and water depths are important parameters for farmers to assess flows.) These undershot structures are also easily mishandled either on purpose (bribery) or because of their intrinsic complexity (e.g., the setting of a CHO is a very cumbersome operation).

Corrupt operations cannot be eradicated simply by introducing a particular type of technology. However some structure types render corrupt practices easier and make detection more difficult. In other types, for example weir types, (plate 7.15) tampering is obvious.

An opposite case might be found in Indonesia: the frequent mishandling of the bottom gate of the Romijn Weir. Opening this bottom gate (designed for flushing of silt) will allow passage of an undetected additional flow of water: see figure 7.5 and plate 7.16.

Figure 7.5. Romijn weir-undershot flow.

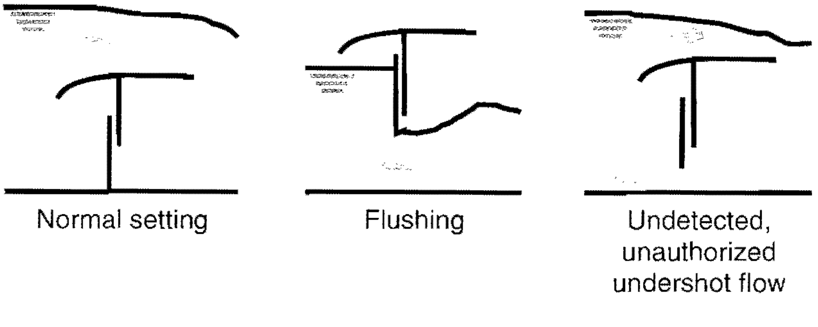


Plate 7.15. Tampering with proportional division.

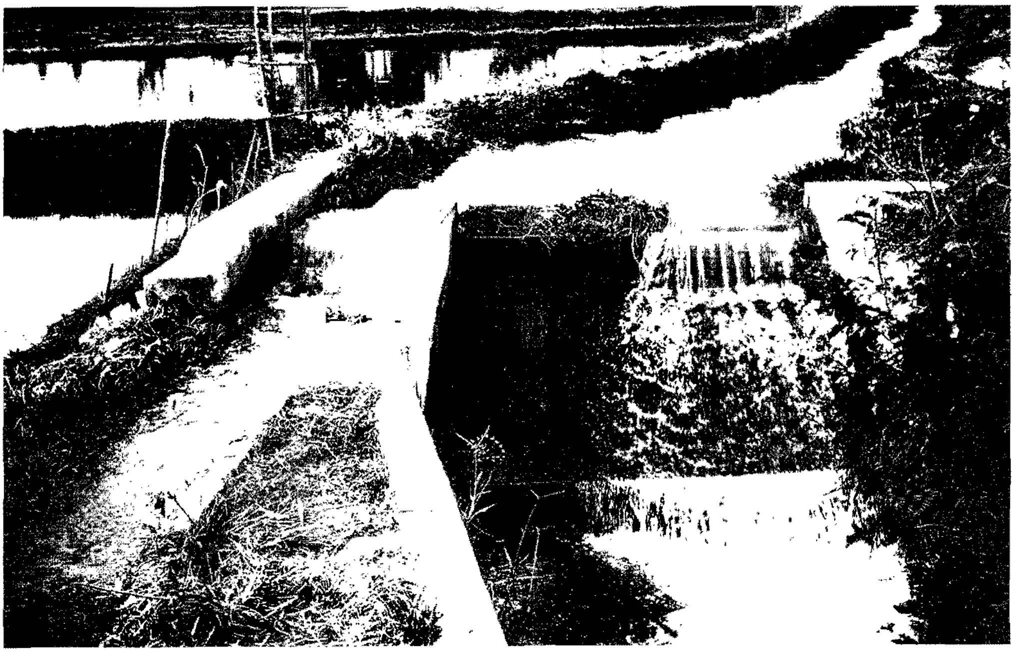


Plate 7.16 Romijn weir-undershot flow.

CHAPTER 8

OPERATIONAL REALITY

8.1 Introduction

The previous chapters show that design of water division structures based on incorrect hydraulic suppositions, while omitting social and institutional criteria can lead to inappropriate technology, resulting in low water efficiencies, conflicts, mismanagement, etc.[51] Although procedures for the regulation, measurements and monitoring of flows are often presented in guidelines and operational manuals, they seldom address the inherent design shortcomings. At project level, managers and farmers 'inherit' systems with hydraulic defects, incompatible with the staff capabilities and hardly understood or accepted by farmers. How these problems manifest themselves, specifically for Systems 3 and 4 (chap. 6[52]), are discussed in this chapter.

8.2 The Actors

To analyze the complex interrelation between design assumptions, water delivery schedules, and operational realities, it is useful to discern the three major parties involved in irrigation practice:

i. Planners/designers (irrigation agency, consultants, donors).

ii. Operational office staff (irrigation agency staff in headquarters, provincial and district offices).

iii. Operational field staff and farmers (at tertiary and secondary level).

Planners/Designers[53]

As discussed in chapter 7, in many cases inappropriate water division structures are selected, leading to hydraulically unstable canal systems which are cumbersome to operate. Furthermore, farmers' understanding or perceptions of the structures are rarely taken into account in the design.

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[51]Admittedly projects with high performances do exist in spite of large discrepancies between design and operation. The issue here however is that a design which is not used as intended should be considered a wrong design. Such a design leads to cumbersome operation requiring extra staff and/or to redundant technology comprising unnecessary extra costs.

[52]These Systems (3 and 4) feature predominantly in irrigation schemes in Asia, Africa, and Latin America.

[53]As we have seen in Section 4.4 this group is far from homogeneous (e.g., the dichotomy between agronomy and civil engineering). Nevertheless, in practice the physical design is primarily determined by the resultant of decisions made within this group as a whole.

Moreover, consideration is seldom given to staff requirements (numbers and skills) in relation to the water division technology chosen.

Operational Office Staff

In general, operational staff in district or provincial offices are mainly concerned with water allocation and distribution scheduling (operational plan). The increasingly refined and supposedly accurate assessments of irrigation requirements have led to increasingly sophisticated and complicated operational procedures. During the last decades, voluminous operation manuals have been compiled in a number of countries in which lengthy stepwise procedures are given to arrive at operational schedules (see Section 7.3).

These procedures require an enormous amount of data collection, processing, and dissemination. Shortage of staff, in combination with little contact with or feedback from the field (especially from the tertiary level) and insufficient or unreliable water measurements because of malfunctioning structures, often results in a situation in which the administrative activities remain largely paper exercises with little relevance outside of the office. Furthermore, such situations often go hand in hand with a lack of incentives and/or accountability.[54]

Operational Field Staff and Farmers

In reality this third party,[55] finally determines how water is actually distributed. The actual distribution of water at field level is the product of a number of circumstantial causes:

- First of all, water distribution which aims to follow the soil-water balance closely, requires varying irrigation intervals and/or varying irrigation applications. In order to accommodate such schedules, complicated operations of regulating and measurement structures are necessary. When combined with hydraulically unstable canal systems with structures cumbersome to operate, the often poorly trained field staff are confronted with an operational task which is effectively impossible.

- In many cases, the real cropping patterns differ from the ones assumed in the operational plan. This might be due to localization influenced by political pressure or unreliable crop data.

- Field staff often live in and originate from the area they have to serve. Their loyalty (genuine or bought) lies primarily with the local farmers and less with the office in

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[54]Engineers in many countries prefer working in construction or maintenance departments (more lucrative) rather than in operation and management departments. For an IIMI research case in Pakistan, Van der Velde and Murray-Rust (1992) reported: *System managers do not know what is going on in their areas of responsibility. They clearly do not care about canal performance.*

[55]Although field staff and farmers are often adversaries, they are here considered as one group since the actual distribution of water at that level is mostly the result of interaction between them.

town. Therefore, when confronted with shortages of water, they will distribute the water at their discretion, on the basis of their experience, ignoring official scheduling instructions. After all they are confronted with the users.

- Finally, the field staff might also ignore instructions when, after many years of experience, they have learned how to better accommodate the various groups of farmers (by taking into account local soil differences and topography) than by strictly following the official schedules. Likewise, water might be distributed differently from official scheduling on the basis of negotiations, power relations, or traditional rights (see, among others, Van der Zaag 1992 a).

8.3 Discrepancies between Assumptions and Reality

As a result of the roles these three groups play in the irrigation scene, two important discontinuities in the chain of events can be discerned:

- As designers seldom leave behind detailed manuals or guidelines on system operation, the operational plan drawn up by the actual management often differs from the design assumptions in regard to water scheduling. Designers are hardly ever confronted with the operational reality at field level. Few opportunities for monitoring and feedback occur resulting in continuous repetition of the same type of design containing the same shortcomings as previously.[56]

- The operational plan is seldom implemented at field level. The difference between the assumptions for the operational plan and the operational reality is illustrated in figure 8.1.

Under such circumstances the assumptions made for the operational plan to distribute and measure water in predetermined quantified flows expressed in liters per second, become irrelevant. They have no bearing on the operational reality where water flows are qualified

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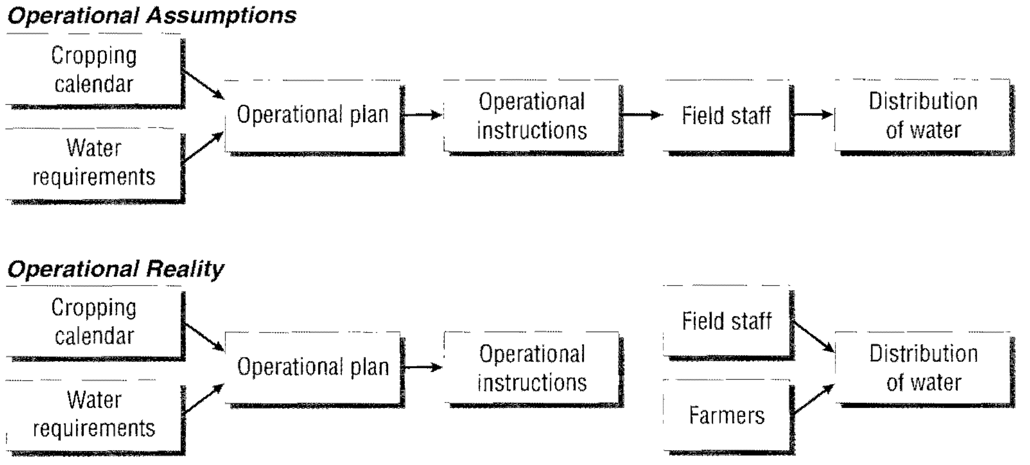
[56]The fact that this situation can exist for decades without change might be explained by the following reasons:

- The universal schism between field and office: most engineers in central offices have no clue of how in reality water is distributed at field level. Inspection visits, whether from HQ or by supervision missions of donor agencies, seldom extend beyond the headgates of the secondary canals.
- Irrigation research by universities and institutes is mostly focused on soil-water-plant relationships, production functions, or pure hydraulics. Water management at field level came only recently to the fore (cf. Van der Zaag 1992a; IIMI 1987, 1989; Pradhan 1996). As yet little of the results has been reflected in handbooks or manuals for design.
- Tenacious adherence to design standards (USBR standards in the Philippines) or principles (pursuance of 'technical irrigation' in Indonesia).

Figure 8.1. Operational assumptions and reality.



from different perceptions such as 'too little,' 'sufficient,' or 'too much.'[57] These perceptions are based on experience, accommodation, negotiations, and rights instead of figures on cropping calendars and irrigation requirements. This situation is illustrated in figure 8.2.

From studies, research, and field observations, it is clear that this discrepancy is apparent in a large number of irrigation projects (e.g., IIMI 1987, 1989; World Bank 1990; Horst 1996a; Van der Zaag 1992 a, etc.).[58]

There is no single answer to the question of how in reality water is divided without measurements, the practice of water division being too situation-specific. In addition, the issue of equitable division of water is difficult to assess without in-depth local research. Conceivably, a number of situations may occur: at one extreme the water guard knows after many years of experience how to accommodate the various groups of farmers he has to serve,[59] or at the other extreme the water is divided on the basis of negotiations, power relations, or traditional

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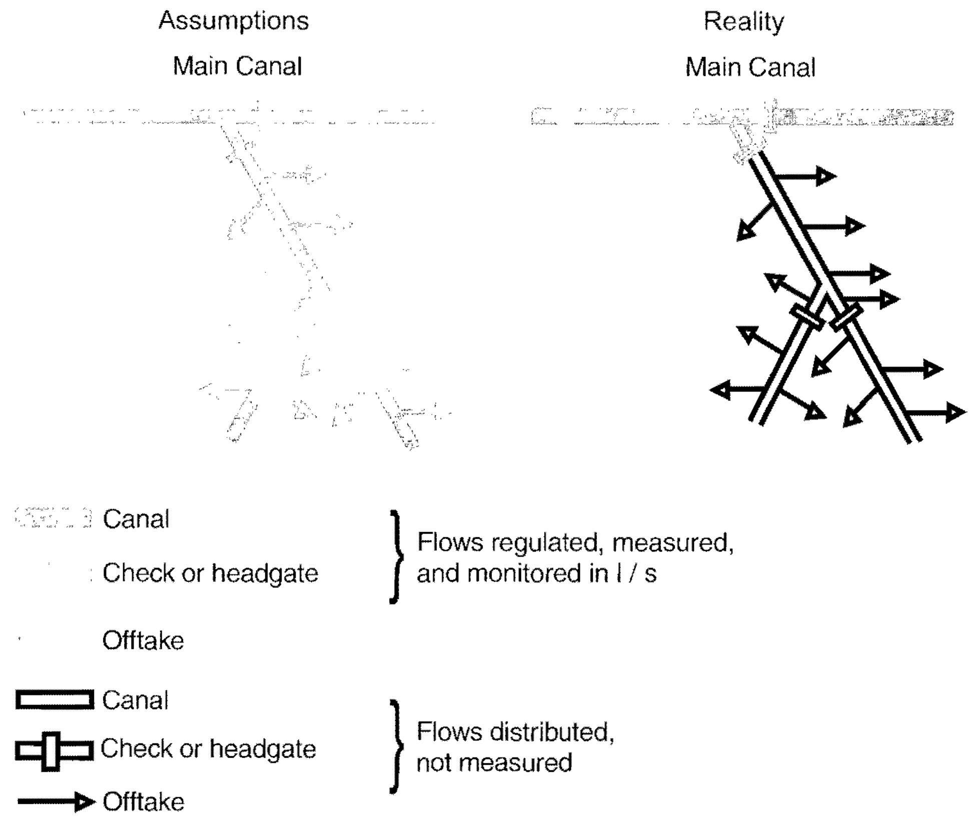
[57]When the management of the Mahaweli Ganga project in Sri Lanka informed farmers about the number of cusecs they were to receive, the farmers replied: *We do not want cusecs we want water* (L. Siriwardene-personal communication).

[58]For example IIMI 1987 states for the Indonesian situation (p. 20): *This divergence (of actual from prescribed practices) seems to be related to such things as: (a) lack of sufficient field operations staff; (b) lack of well-trained and motivated staff; (c) lack of workable measuring structures; (d) decentralized control over water division; (e) a frequent lack of exclusive PRIS (Provincial Irrigation Service) control over offtake structures; (f) considerable diversity in crop types and planting dates within given tertiary locks; (g) prevalence of unmeasured supplemental water supply sources; (h) frequency of having tertiary blocks stretch across more than one village; and (i) the apparent tendency of irrigation inspectors and farmers to sometimes distribute water on the basis of negotiated arrangements rather than hierarchical implementation procedures which have been determined through objective information-gathering and analysis.*

Figure 8.2. Measurements: Assumptions and realities.



rights. One extreme might be reflected in the way the water is handled during the daytime but different realities may hold during the night.[60]

The discrepancy between design assumptions and operational reality will be most prominent in case of water shortages. On the other hand, in case of sufficiency of water, the water guard might accommodate the real needs of water in his own way. Van der Zaag (1992a) describes this situation vividly for a Mexican case:

Once a basic irrigation schedule has been established at the beginning of the irrigation season, the canalero (water guard) can add an extra irrigation turn without reconsidering the whole irrigation plan. From a fairly simple core pattern, a complex schedule of irrigation turns evolves, which is well-structured, and accounts for the differences in water need that exist from plot to plot.

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[59]IIMI/ADB (1989) describes this situation for the Kirindi Oya system in Sri Lanka as follows: *For all practical purposes, the true objectives of the operators are not expressed in terms of a given flow to be delivered at the offtake but as an 'equilibrium' to be reached (i.e., a no-complaints situation).* In some cases, this situation might lead to an even more equitable water division than when strictly adhering to the water schedule procedures, since local conditions (e.g., locally different soil types, high ground, etc.) might be coped with more satisfactorily.

[60]Chambers (1988) rightly drew the attention to the white spot of night irrigation.

Significantly, in this case water delivery to the farms shows variations in irrigation intervals, in delivery times as well as in unit flows.[61]

[61]From this example of good irrigation service by the canalero in spite of the cumbersome inappropriate technology (adjustable undershot gates), it might be deduced that with good operational staff any technology will render good performance (cf. Van der Zaag 1992b; Plusquellec, Burt, and Wolter 1994). It should be noted however that this system is reservoir-supplied with sufficient water. It is surmised that the situation would have been different in case of water shortages where the canalero will be confronted with pressure exertion by the large farmers, political pressure, and possible mishandling of division structures.

CHAPTER 9

SUMMARY AND CONCLUSIONS

- The problems in irrigated agriculture are historically determined: they find their roots in the technology of the colonial era and the lack of adaptation to the new socioeconomic environment of the post-colonial period. During the colonial times, design and operation resided within the same ministry, making interaction and feedback possible. In the post-colonial era, however, design has been carried out mostly by (foreign) consultants, while government agencies have been responsible for operations. This divorce between design and operation has led to discrepancies between design assumptions and operational realities.

- Design assumptions deal partly with policy planning (extensive or intensive irrigation, poverty alleviation or production-driven, type of water allocation, etc.), and partly with agronomic requirements (cropping patterns, water requirements, irrigation methods). These assumptions lead to the assessment of how the water has to be delivered to the tertiary unit: the Water Delivery Schedule (WDS). Once the WDS is determined the system technology follows as a derivative from this schedule. In its turn, the type of system technology determines the mode of operation of the system.

- In the previous chapters alternate types of schedules and subsequent types of systems have been reviewed and analyzed in terms of operational consequences. These consequences pertain to operability, operational procedures required, staff requirements, transparency, corruptibility, social acceptance, and possible farmer management. This is illustrated in figure 9.1 for three different types of structure.

This analysis shows that often, in the design phase, little or no attention is paid to operational aspects. Not surprisingly, by limiting design assumptions to agronomic, engineering, and economic parameters only, without taking into account institutional and human aspects, the outcome of design might well be incompatible with the socio-institutional environment. Therefore, it is argued that all these aspects should not be dealt with as derivatives from the design, but rather should be explicitly included as criteria or considerations in the design (see figure 9.2).

These discrepancies between design and operation are especially apparent in System types 3 and 4 (variable delivery and adjustable structures) where most problems occur. Indeed, examining designs for these systems, it is apparent that the "additional criteria" of figure 9.2 have seldom been taken into account. Part IV will focus on exploring alternatives for these systems.

Figure 9.1. Relation between type of structure and objectives (Horst 1987).

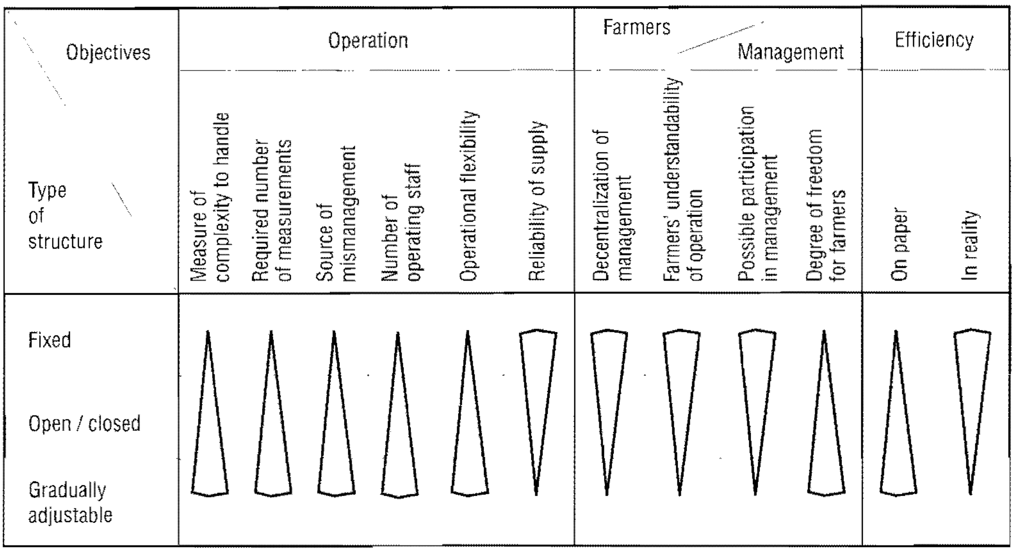
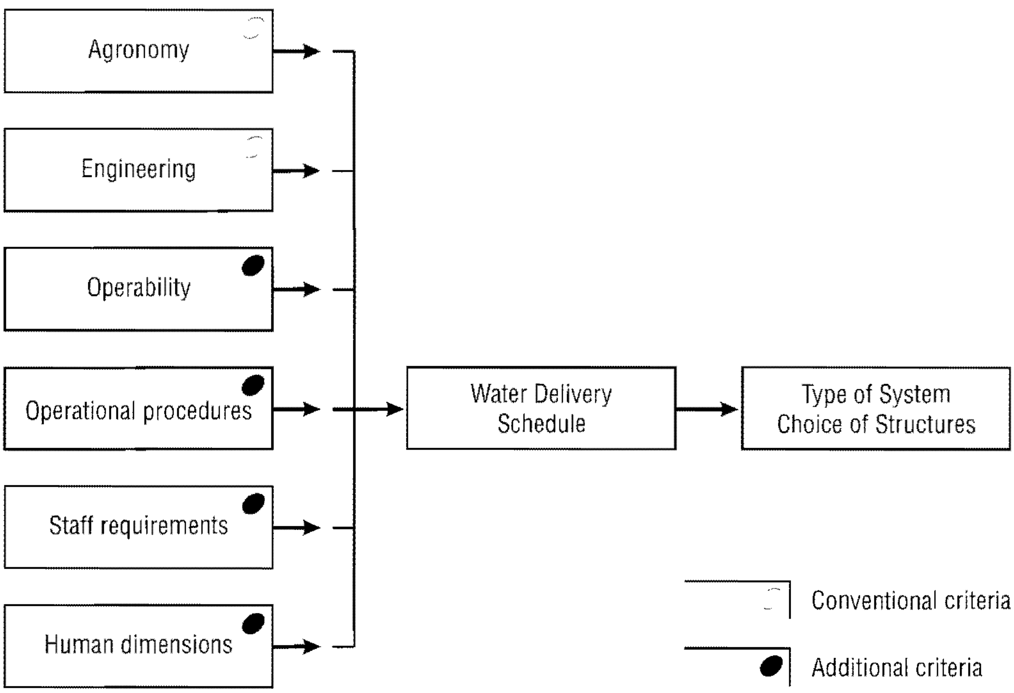


Figure 9.2. Conventional and additional design criteria.



PART IV

Options for Change

Part III (Design and Practice) reveals that types of irrigation systems with manually or mechanically operated water division structures (Systems 3 and 4, Section 6.1), experience serious problems. These types of systems, constitute by far the largest proportion of irrigation in the world. Various remedies for solving these problems as put forward in recent literature, are reviewed in chapter 10. One of the options for change is simplification of operation and technology. A discussion on the applicability of simplification of water delivery and technology is presented in chapter 11. In chapter 12 the potential role of intermediate reservoirs is explored. Finally, in chapter 13 an attempt is made to place the contents of this book in a wider perspective.

CHAPTER 10

IN SEARCH OF SOLUTIONS

10.1 Introduction

In Part III five types of systems based on different water delivery schedules were identified and examined in terms of operational aspects. It appears that systems with manually or mechanically operated structures (Systems 3 and 4) suffer most operational problems. These problems have been recognized by a number of persons working in irrigation planning, design, management, and research.[62] Although there exists a general consensus that the patient is seriously ill, the type of treatment proposed differs from person to person. These differences often reflect the discipline and profession of the person concerned and prove the 'normal professionalism' as identified by Chambers (1988).

The search for solutions can be broadly categorized into three:

- improving the *design process*
- changes in *management*
- changes in *technology*

In the following sections these topics will be briefly discussed with special reference to design of irrigation systems.

10.2 Improving the Design Process

The design choices and assumptions to arrive at a certain water division technology (chapters 5 and 6) are usually made by the planner/designer with no or little interaction with the future users of the system. In practice, for most projects where the social environment and the dialogue and interaction with farmers have been neglected, problems might be encountered in terms of delays, conflicts, and underutilization. During the 1980s, the question arose whether

[62]For example Plusquellec, Burt, and Wolter 1994, p. 5: *Extended gravity irrigation schemes with manually operated gates and control structures rarely work, despite all efforts to improve irrigation management and the capacity of staff;* and Burns 1993, p. 784: *The myth of the efficient and equitable flow of valuable water, by gravity, from source through a large-scale public system of raised earth aqueducts presided over by an honest and competent bureaucracy manipulating thousands of gates continuously for just-on-time delivery to the root zones of plants, needs to be discarded first.*

interactive design involving the farmer and his social environment would be possible. In 1990, a special workshop on that topic was held in Wageningen eventually resulting in a publication (Ubels and Horst 1993) in which an attempt was made to place interactive design into a conceptual framework. Although these and other efforts to get a hold on this subject, rendered a better understanding and awareness of the possible consequences of the design on the social environment of the farmers, it has appeared difficult in practice to convert this awareness into actual design procedures.

Moreover, the willingness of farmers to participate, as a matter of course, in the design process has been questioned by recent research findings. Scheer (1996) made an analysis of the difference between farmers and design engineers in the Senegal Valley in terms of technical knowledge and perceptions. He found that farmers often do not want to participate in the design because *"they may lose the entire project if they do."*

Also van Bentum (1995) noticed in his research the same attitude among farmers in Spain. He questions *the equivalent participation of users and engineers in the design.* On the other hand, he advocates *the creation of a space of autonomous action for the farmer with respect to the use and adaptation of the irrigation system.* Another problem emerges in large projects when it is very difficult to establish participation in design in view of the large number of farmers involved. Moreover, farmers are often more interested in the technology within their direct environment and less in the main system (Scheer 1996). Nevertheless, room should, at least, be made for a sufficient socioeconomic-cultural pre-assessment of the local situation. A blatant example of the consequences when omitting such an assessment is described in Horst 1996 c for the Bali Irrigation Project (see chap. 7, note 50).

10.3 Changes in Management

Focus on Management

At the end of 1970, a general consensus emerged among irrigation professionals that most problems in irrigation found in the broad field of "irrigation management," were of a sociotechnical nature and should be solved by a multidisciplinary or interdisciplinary approach.[63] In 1984, the International Irrigation Management Institute (IIMI) was established with significantly the word "management' explicitly in its name. In fact, the focus of the IIMI program was continuously on management-related subjects (performance, institutional aspects, training, etc.). The irrigation technology only got some occasional attention (e.g., IIMI/ADB study 1989). This is noteworthy when one realizes that the type of technology strongly determines the manageability of irrigation systems (see chap. 7).

Turnover

During recent years, the issue of transfer of management to farmers (turnover) came to the fore. Also here the institutional and organizational aspects are getting significant attention,

[63]Typically for example, Carruthers (1987) stated: *Irrigation development is now primarily a management task, not a design or construction task, ...*

while the technology is largely left out of the discussion (cf. the management transfer conference in China in 1994 and the workshop in Thailand in 1995). At best, rehabilitation of projects is considered for turnover taking the existing technology for granted. This is remarkable since most systems being transferred are of the manually adjustable type (Systems 3 and 4) with all the problems as discussed in Part III. One might pose the question whether transfer to farmers of systems, which even agencies are incapable of operating properly, is ethically justified. It seems that at least a search for an appropriate technology to enable an adequate and transparent distribution of water is called for (see further Section 11.6).

Measuring, Monitoring, and Modeling

Specially in engineering circles more measurements and better monitoring are often advocated.[64] It is surmised however that these measures will be to no avail as long as the operational reality sketched in chapter 8 exists.

Considerable effort is spent to develop computer models both for irrigation delivery scheduling and for canal operation. Although they might increase our knowledge in respect of the irrigation requirements and the hydraulic behavior of canals, they do not address the fundamental problems of water delivery: the human element of canal operation.

Water Charges

A recurrent issue is the need for pricing and charging for water. Repetto (1986), when discussing the political economy of large-scale agency-managed irrigation schemes, drew the attention to the rent[65]-seeking behavior of politicians, administrators, and users, having a shared interest in preserving and expanding the arrangements that benefit them. He came with strong arguments for correcting incentives by placing financial responsibility on the beneficiaries. Unfortunately, he did not elaborate on the consequences of the technology required for volumetric pricing of water. Burns (1993) rightly pointed out that for public, large-scale, gravity-flow schemes, volumetric pricing is simply not feasible (see also Perry 1993 for the sheer impossibility of water charges under conditions of shortage in India).

Crop-Based Irrigation

The recent drive for introducing crop-based, demand-driven irrigation is based on the premise that supply-based irrigation leads to water wastage and low performances. Strosser and Garcés (1993) defined the primary objective of crop-based irrigation as: *to increase the utility of the land by supplying water to a specified system according to crop water requirements.* Its operational success however has still to be reported, which is not surprising in view of the enor-

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[64]Garbrecht and Bos (1980) even promote to increase the number of measuring points *including the farm outlets.*

[65](Economic)rent = the difference between the value of additional water to the farmer and what the system charges for it (Repetto 1986).

mous amount of data collection, processing, and monitoring involved and the requirements for complicated operation of the system. Crop-based irrigation can only be achieved by systems with adjustable gates (type 3 and 4) or by automated systems (type 5). The failure of the first group of systems has been noted above, while automated systems only work when sufficient storage is available (see next Section 10.4). Moreover, as Perry (1993) writes for the Indian context: *Irrigation scheduling to meet the individual needs of thousands of small plots is unrealistic with the infrastructure in any existing Indian irrigation project, and would require much higher infrastructure costs in new or rehabilitated schemes.*

10.4 Changes in Technology

Several solutions proposed to alleviate the problems encountered in irrigated agriculture have been discussed above. Here it is argued that most of these measures will remain cosmetic surgery as long as the fundamental problems are not addressed: too complex irrigation schedules requiring sophisticated water division structures resulting in difficult operation; a shortage of skilled staff; and the different perceptions of water distribution objectives that exist between field operations and farmers on the one hand and the official irrigation schedule on the other (these problems are generally the result of the omission, during design, of an analysis of the institutional and human dimensions of the scheme, see chap. 9). The core of these problems lies for a large part in the given technology: irrigation systems with manually or mechanically adjustable gates (Systems 3 and 4, chap. 6).[66]

When one accepts the failure of this type of technology (see footnote 62), the question emerges what other more appropriate types of technology might be adopted. To answer this question, the different types of systems can be divided into three broad categories:

- adjustable technology (Systems 3 and 4)
- automated technology (System 5)
- simplified technology (Systems 1 and 2)

When discarding adjustable technology, logically two options remain open:

Adjustable[67] → Automation
Adjustable[67] → Simplification

[66]Admittedly, technological improvements might be introduced in some projects, for example by placing duck-bill weirs as cross regulators instead of sliding gates or by changing Romijn weirs with single-gated outlets. The problem created by adjustable gates, however, will not be removed.

[67]These two options are, in broad lines, equivalent to demand- and supply-driven water allocation (see Jones 1995 for a discussion on the two types of advocates).

Automation[68]

During the last decade, a number of experts have advocated the introduction of automation. Automation in terms of automatically controlled systems, hydraulically (by float-operated gates), electronically, or electro-mechanically, or by microprocessors or computers, will generally result in fewer persons required to operate the system. Operational and maintenance staff, however, should be very highly skilled. Knowledge of computers, electronics, and mechanics is often essential.

Apart from this staffing requirement, a more problematic restriction lies in the available water supply. As noted in Section 6.6, automation can, in general, only be adopted for projects for which unrestricted water demand will be covered by sufficient supply *throughout the year.*[69] This technology is therefore excluded for run-of-the-river projects or for projects with restricted reservoir capacities.[70]

Simplification

That leaves us with the second option: "simplification." Simplified technology can be adopted by simplifying the water delivery. This will be discussed in the next chapter. Chapter 12 deals with intermediate reservoirs as another form of simplification. Here the water delivery is not based on instantaneous water requirements but on bulk supply to buffer reservoirs.

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[68]For many people automation and sophisticated technology are synonymous with modernization. Here it is argued that modernization should be based on our present day (modern) knowledge and perception of how irrigation should be planned, designed, constructed, and managed. Depending on the local situation this can be achieved by simplified as well as by sophisticated technologies.

[69]Many authors implicitly assume sufficient supply (upstream storage reservoirs) to render automation possible (significantly the introduction to an important symposium on automation [Zimbelman 1987] states: *The reliability of the supply in its broad sense of the capacity of a major reservoir is not the concern of this symposium*).

[70]Plusquelec, Burt, and Wolter (1994) p. 61: *In such cases (irrigation schemes that are supplied through river diversions without internal storage) there is indeed little need for precise flow and water level control in the main system.... Modern water control concepts are most valuable in schemes that include upstream reservoirs or substantial buffer storage.*

CHAPTER 11

SIMPLIFICATIONS OF WATER DELIVERY AND TECHNOLOGY

11.1 Introduction

Most irrigation projects are designed on the premise that the technology of the system and its operation should be able to accommodate the varying water requirements of an assumed cropping plan. In other words, the cropping plan is the point of departure from design (chapter 5) and the technology and operation should comply with its (water) requirements. As discussed in Part III, a close match of the supply with the demand (water requirements) often leads to complicated technologies and operational procedures, creating situations where mismanagement, conflicts, and inequitable distribution are rampant.

Therefore, in this chapter a different approach is followed, focused on the question:

> *How can the varying water requirement curve be approximated by a simplified delivery curve, enabling simplified technology and subsequently making simplified operations possible, while keeping overall water use efficiencies within acceptable limits?*

11.2 Simplified Technologies

Simplified technologies can have many different forms:

- *Proportional outlets.* The different solutions for the Punjab type of outlet to assure proportionality have been noted before (e.g., Mahbub and Gulati 1951).

- *Proportional division weir-type structures.* Many variations are possible and do occur in practice as illustrated by the following pictures (see also plate 7.1).

- *On-Off gates.* Different types of on-off gates are sketched in figure 11.1.

- *Stepwise distributors.* Although during low flows distribution by on-off gates on a time basis might be preferable, in some cases a more flexible technology might be called for.

Some examples of simplified technologies are shown in the following plates 11.1 to 11.6.

Plate 11.1 Proportional division (Nepal).

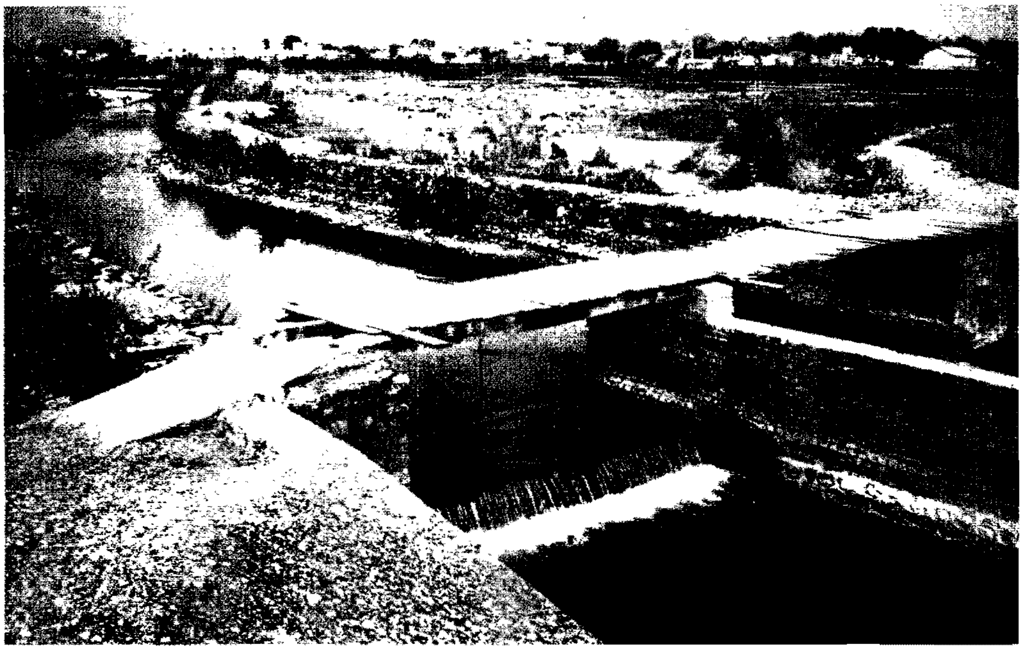


Plate 11.2 Proportional division (Tunisia).

Plate 11.3 Proportional division (Punjab).

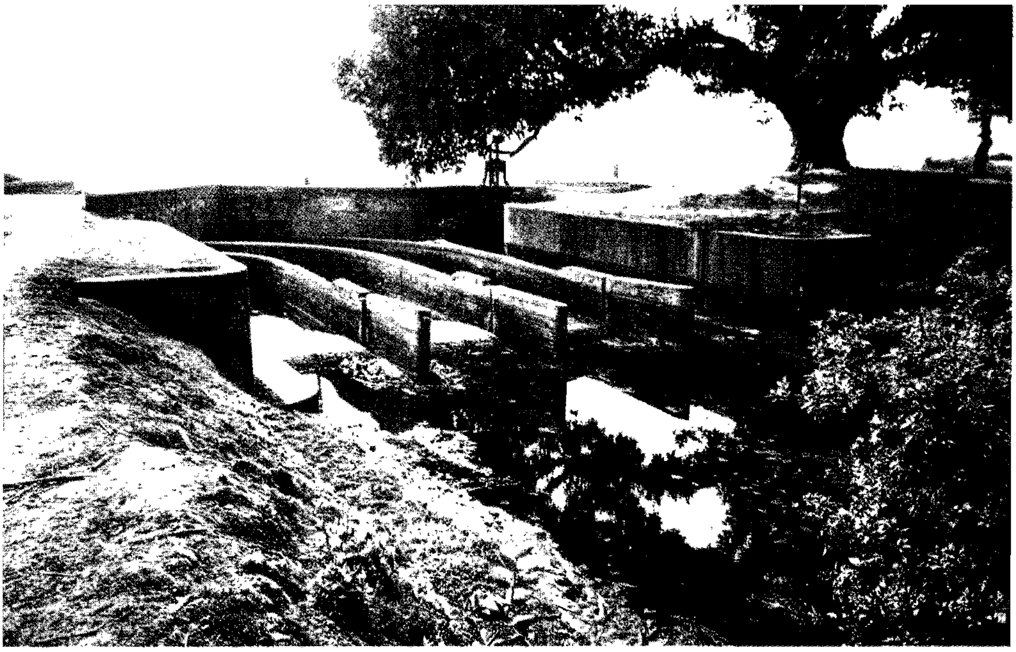


Plate 11.4 Standard on-off gates (Kenya).

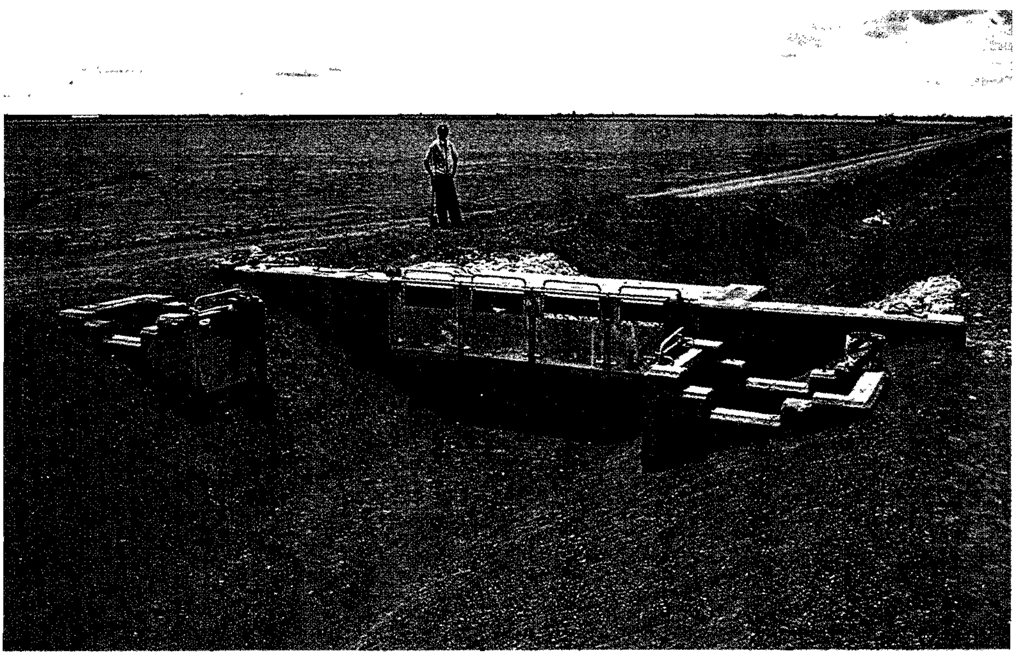


Plate 11.5 Stepwise distribution (Spain).

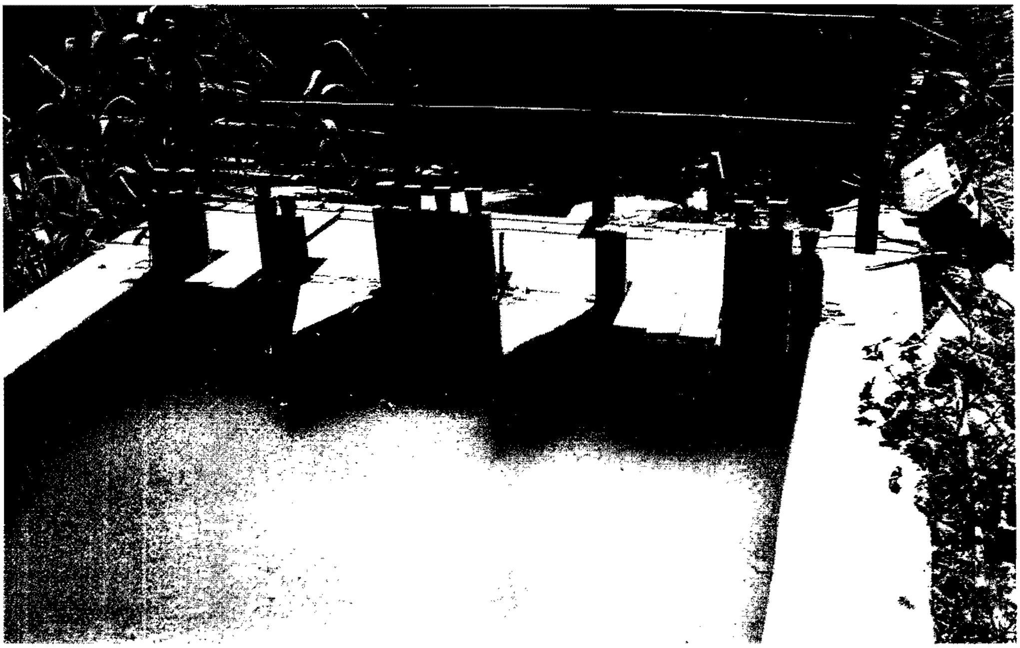


Plate 11.6 Stepwise distribution (Tunisia).

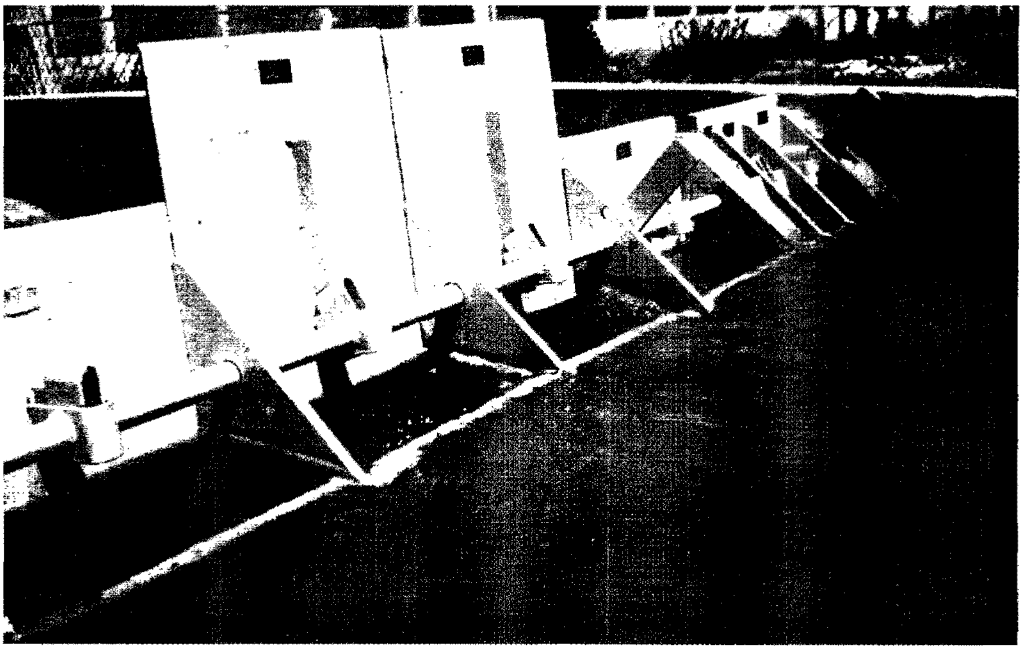
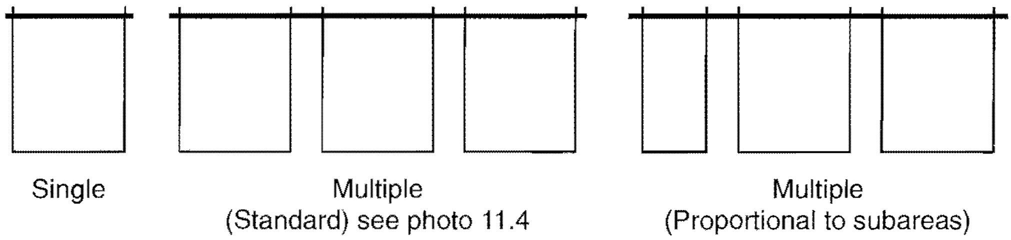


Figure 11.1 On-Off gates.



When considering simplified technology it should be realized that many design engineers find this solution inexpedient. It goes against their perception of the need to control, regulate, and measure the water in the system. For example, engineers in the Philippines described proportional dividers as *structures used by non-technical people* and *they do not give enough control* (see Yabes 1989). Further, ADB (1989) typifies sharing whatever inflow is available in proportion to the planted areas as a *"degraded objective."* Another instance can be found in Horst 1996 c where the condescending attitudes of foreign consultants towards the local technology based on proportional division in Bali are described. Many more examples can be found, all of them pointing to a nonacceptance of simplified technology by engineers.

The aim of this chapter is not to accept *a priori* the simplified technology concept, but to analyze its applicability in the light of frequently occurring cropping patterns in practice. This analysis is required to evaluate simplified technology as one of the possible options for change and to put it in the right perspective.[71]

11.3 Simplified Delivery

A realistic approach to simplifying water delivery has been proposed by Meijer 1992. He states:*....apart from crop requirements, water is needed to facilitate a fair and simple water distribution. If these so-called additional operation requirements (AOR),*[72] *management losses, or intentional losses are ignored or not accepted, water distribution schedules tend to be much too complicated and far too rigid for everyday practice. They will preclude any reasonable water use efficiency beforehand.*

The AOR can be expressed by the ratio (in percentage) of the water volume delivered in excess of requirements to the total water volume supplied during the period considered. The principle of AOR can be applied to all distribution levels in the irrigation system above the tertiary outlet. Below the tertiary outlet the flow is to be divided according to the given cropping patterns and requirements.

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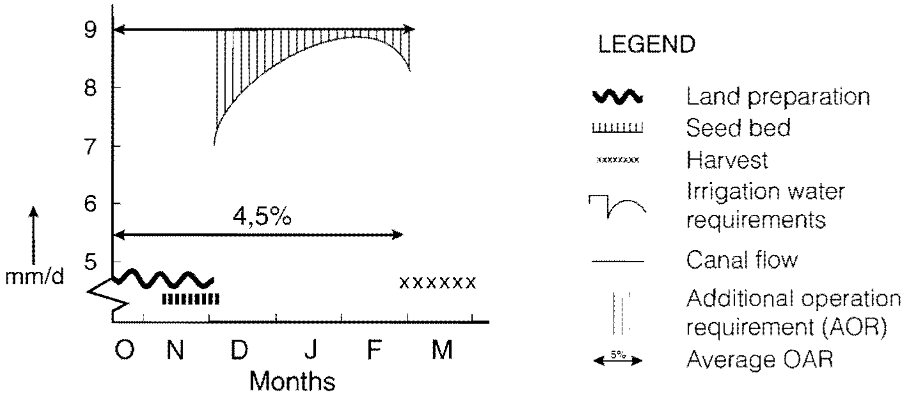
[71]The propagated solution of simplification of scheduling and technology concurs in broad lines with the principle of structured irrigation as developed by the World Bank for the National Water Management Project in India. See World Bank 1986. (The structured level is the level below which the system is proportional.)

[72]It should be noted that the AOR refers to operation and excludes normal expected losses such as seepage, etc.

Figure 11.2 Additional operational requirements for single rice crop (Meijer 1992).



In his paper Meijer discusses a number of examples for a rice area. One example is given in figure 11.2, where for a water supply at constant discharge over the whole growing period, the value of AOR amounts to only 4.5 percent.

This approach certainly has merits for existing schemes where operations are too complicated when attempting a close matching of supply with crop water requirements. The principle of AOR, however, is also valuable when designing for simplicity as will be discussed in the next sections.

11.4 Applicability of Simplified Delivery in Case of Sufficient Water

To examine the applicability of simplified technologies, six commonly recurring cropping patterns are examined:

Rice:
- A. uniform crop stand in all tertiary units (*tu*s)
- B. uniform crop stand in each *tu*; staggered planting among *tu*s
- C. staggered planting within *tu*s

Non-rice:
- D. uniform mono-crop stand in all *tu*s
- E. uniform mono-crop stand in each *tu*; staggered diversified planting among *tu*s
- F. staggered diversified planting within *tu*s

For this analysis one secondary block is considered schematically, comprising four tertiary units of unequal size. Important parameters are:

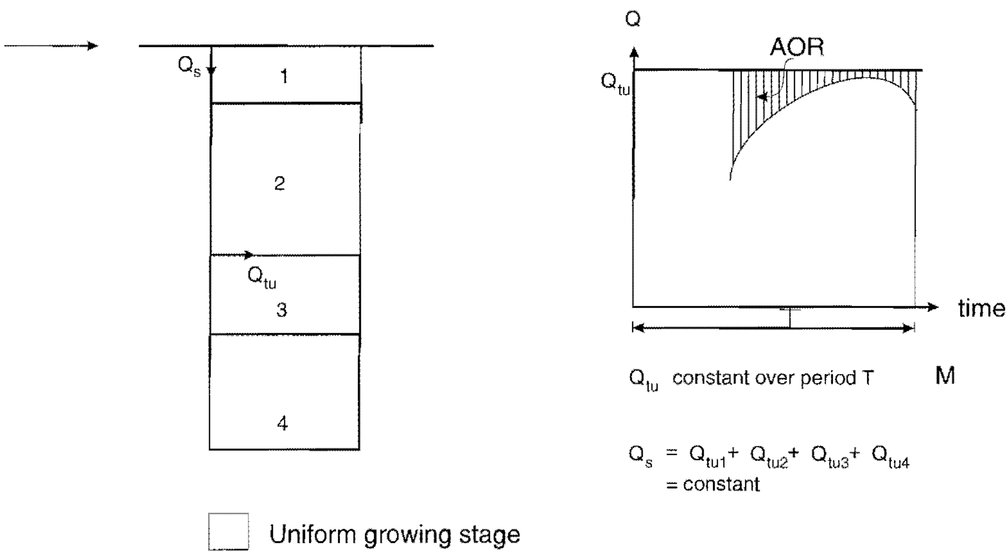
t_o = planting date
IR = irrigation requirements at farm level
Q_{tu} = flow into tertiary unit (*tu*)
Q_s = flow into secondary block
AOR = additional operational requirements

Case A: Rice-uniform crop stand in all tus (see figure 11.3)

This is a common case for projects where rice is the principle crop.

- t_o is the same for all farms
- Q_{tu} and Q_s are constant for the whole growing season (see figure 11.2)
- IR per unit area is the same for the whole secondary block
- delivery to farms is either continuous or on rotation

Figure 11.3 Uniform crop (rice) in all tertiary units.



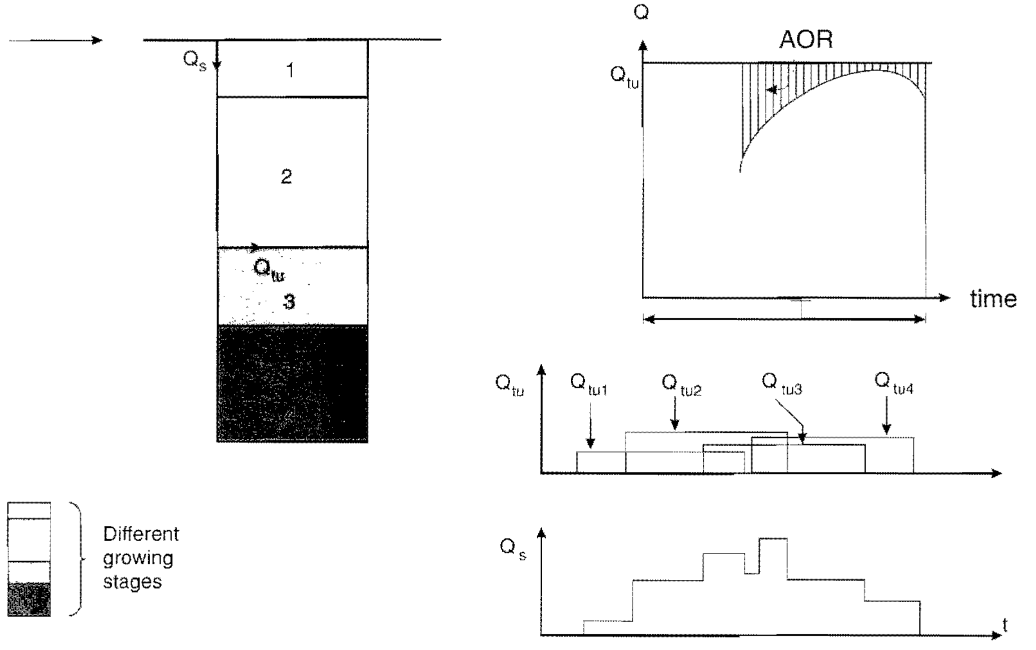
Conclusions

- proportional division is applicable for all structures
- AOR: 4.5 percent (see Section 11.3)

Case B: Rice-uniform crop stand in each tu*; staggered planting among* tus

The prime idea for such a case is to make the best use of the river flows in case of run-of-the-river projects (cf. the *Golongan* system in Indonesia).

Figure 11.4 Uniform crop (rice) in all tertiary units (tus)*, planting staggered between* tus.



- same t_o within and different t_o between *tus*
- IR per unit area is the same for each *tu*
- Q_{tu} constant for the whole growing season
- Q_s changes stepwise
- delivery to farms either continuous or on rotation

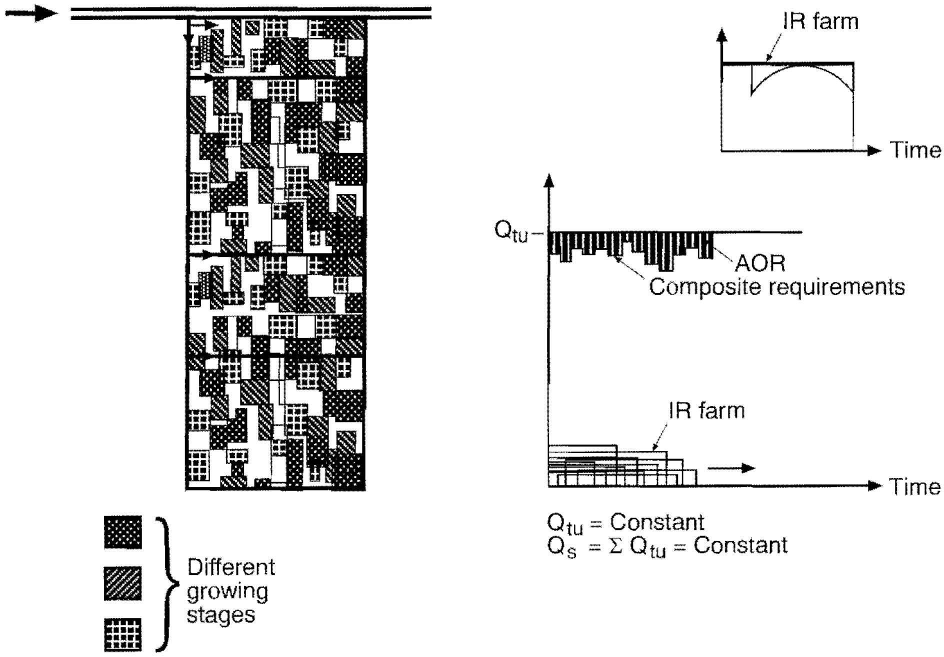
Conclusions

- On-Off proportional gates are applicable for all structures (the required number of gate settings for the example in figure 11.4 are: 8 for Q_s and 2 for Q_{tu}).
- AOR: 4.5 percent (see Section 11.3).
- In case of staggered planting among secondary blocks, proportional division within the secondary block could be applied (see case A).

Case C: Rice-staggered planting within tus

In many areas, farmers' decisions on rice cultivation are not based solely on the climatic cycle but are influenced by other factors (labor availability, credit, marketing, etc.). As a result, within individual tertiary units, plots with rice crops with different growth stages are common. In such cases, a continuous constant flow can be supplied based on the composite curve of all individual water requirement, taking AOR into account (see figure 11.5).

Figure 11.5 Staggered planting (rice) within tertiary units.



- different t_o for each farm
- IR per unit area the same for each farm
- Q_{tu} approximated by a constant value based on the composite curve of all the individual farm water requirement curves
- Q_s (= ΣQ_{tu}) also constant
- delivery to farms on a rotational basis

Conclusions

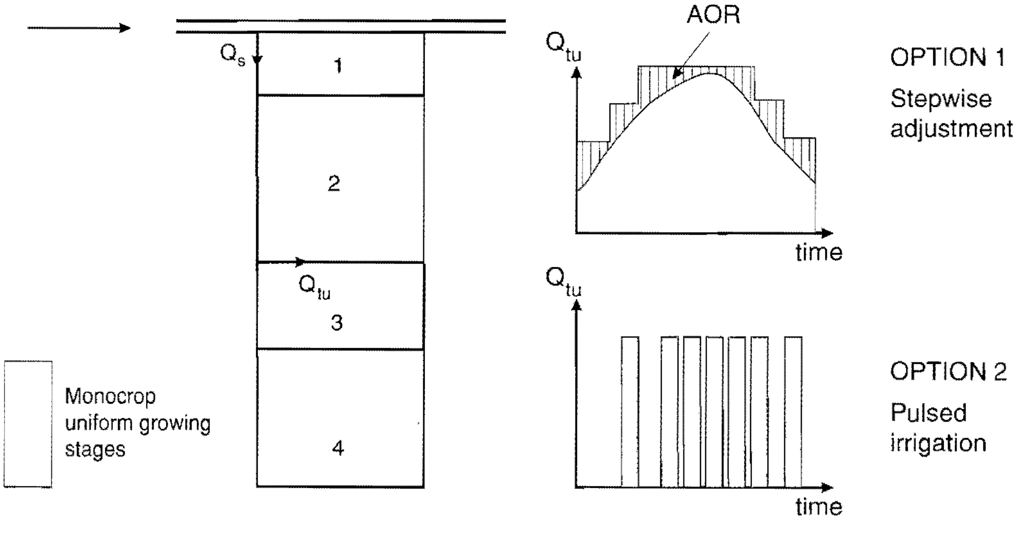
- proportional division applicable for all structures
- AOR: estimated 5-15 percent

Case D: Non-rice-uniform mono-crop stand in all tus

This situation occurs in projects with a mono-cultural cropping pattern: For example, cotton (as originally in the Gezira project in the Sudan) or sugar.

In such a case, adoption of one fixed flow through the crop season will generally result in an unacceptably high figure for AOR (30% or more). In principle, two solutions are possible (see figure 11.6).

Figure 11.6 Uniform mono-crop (non-rice) in all tertiary units.



Option I: Stepwise adjustment of Q_{tu}

- t_o the same for all farms
- IR the same for all crops
- Q_{tu} variable in steps
- rotational delivery to farms

Conclusion

- disadvantage is the change in unit flows (see Section 5.2)
- proportional division in principle possible below the headworks
- AOR depending on number of steps; estimated in the order of 10–20 percent

Option II: 'Pulsed' irrigation[73]

- t_o the same for all farms
- IR the same for all crops
- Q_{tu} either zero of full supply
- rotational supply to farms

Conclusions

- proportional division applicable for *tu* offtakes and on-off gates for secondary offtakes
- AOR low to medium; estimated in the order of 5–15 percent

Case E: Non-rice-uniform mono-crop stand in each **tu***; staggered diversified planting among* **tu***s* (see figure 11.7)

- same t_o within and different t_os between *tu*s
- IR the same within *tu*s
- for Q_{tu} see options I and II of case D

Conclusions

- stepwise distributors for *tu* and secondary offtakes
- operation complicated
- AOR medium to high; estimated in the order of 10–20 percent

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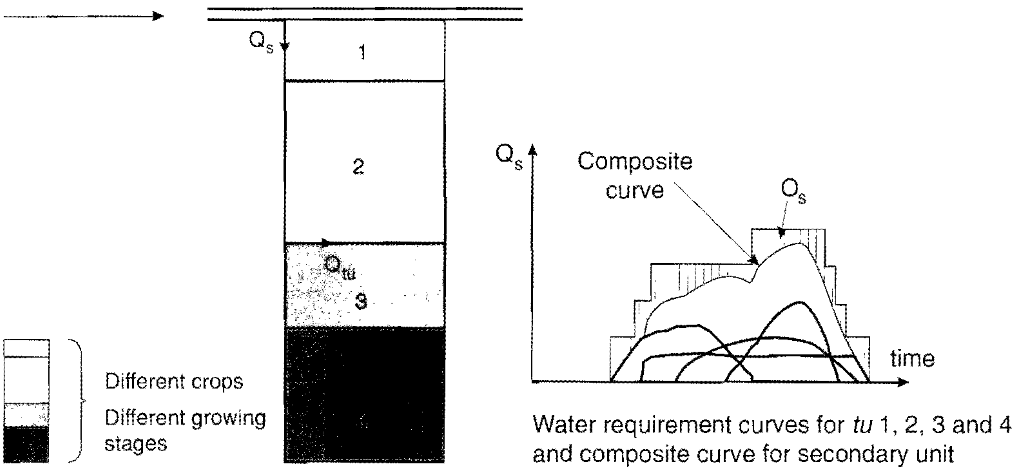
[12]Cf. World Bank 1986.

Figure 11.7 Uniform mono-crop (non-rice) in each tertiary unit (tu); Staggered diversified planting among tus.

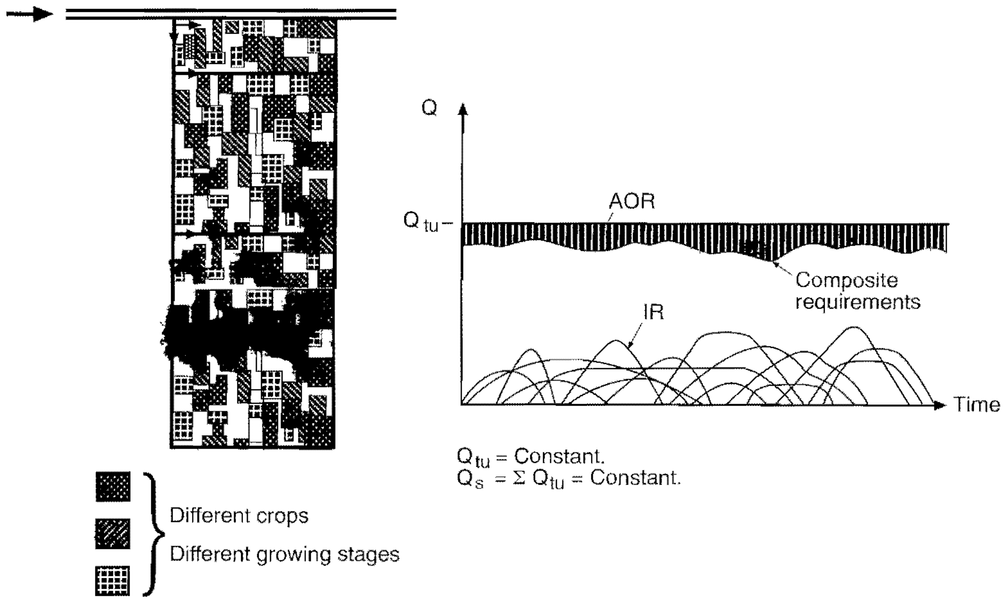


Case F: Non-rice-staggered diversified planting within tus

In many parts of the world irrigated areas are characterized by large numbers of small plots, with different types of crops in different stages of growth. Here a demand-based or crop-based operation becomes unrealistic. It is physically impossible to follow each water requirement curve for each plot through time. If one considers such an area, however, it is possible to assess an overall composite water requirement curve on the basis of the sum of all the individual water requirement curves. This composite curve can then be approximated by a constant supply curve by taking into account the AOR (see figure 11.8).

- different t_o for each farm
- different IR for each farm
- Q_{tu} approximated by a constant value based on the composite curve of all the individual farm water requirement curves
- Q_s (= ΣQ_{tu}) also constant
- delivery to farms on a rotational basis

Figure 11.8 Staggered diversified planting (non-rice) within tertiary units.



Conclusions

- proportional division applicable[74]

- AOR acceptable (especially when considering the great simplicity of operation); estimated in the order of 5–15 percent

The above discussion is summarized in table 11.1. In this table the possible technology is indicated as well as a 'guestimate' of the AOR. From these examples it appears that for many different types of cropping patterns a simplified technology (either proportional division or on-off structures) is applicable, provided additional operational requirements (AORs) are taken into account

On the first sight of it, objections might be raised against the AOR. They contribute to even more losses and low efficiencies. Paradoxically (cf. Horst 1987), although the AOR can be considered as a loss of water, the overall water use efficiencies are expected to increase due to a simpler technology and a simpler operation. This will render a positive effect on the shortage of trained staff and a more transparent water distribution, resulting in a possible de-

[74]This is contrary to a widespread belief that proportional division is not applicable for diversified cropping. For example, Ankum (1992) states: *Proportional flow control cannot be used efficiently for different crops with different water needs, since the flow cannot be regulated.* Also in a consultants' report: *It should be noted that diversification of agriculture is one of the main objectives of the GOI (Government of Indonesia). Therefore, the system should enable the farmers to grow diversified crops. Because of this, fixed proportional flow diversion is not recommended.*

crease of mismanagement and unequal water distribution (or as Meijer 1992 suggested: *you need water to save water*). Furthermore, the "guestimates" in table 11.1 appear to be small when compared with actual overall losses as observed in the field. These losses may easily reach values in the order of 60-80 percent (cf. Bos and Nugteren 1974). Cases with high AOR such as cases D and E might become acceptable when the excess tail water is used for downstream purposes. It is therefore important to view an irrigation system in the context of river basin allocation (see chap. 13). Further consequences of simplified technologies will be discussed in Section 11.6.

Table 11.1. Applicability of simplified technology.

Cropping pattern		Possible technology		Approx.	Remarks
		tu offtake	Secondary offtake	AOR %	
Rice					
A. Uniform in all *tus*		Prop. div.*	Prop. div.	5	
B. Uniform in each *tu* Staggered among *tus*		on-off	on-off	5	
C. Staggered within *tus*		Prop. div.	Prop. div.	5–15	
Non-rice	Option I	Prop. div.	Prop. div.	10–20	Difficult water management within *tu*
D. Uniform monocrop < in all *tus*	Option II	Prop. div.	On-off	5–15	
E. Uniform monocrop in each *tu* Staggered diversified among *tu*		Stepwise distributors	Stepwise distributors	10–20	Difficult operation
F. Staggered diversified within *tus*		Prop. div.	Prop. div	5–15	

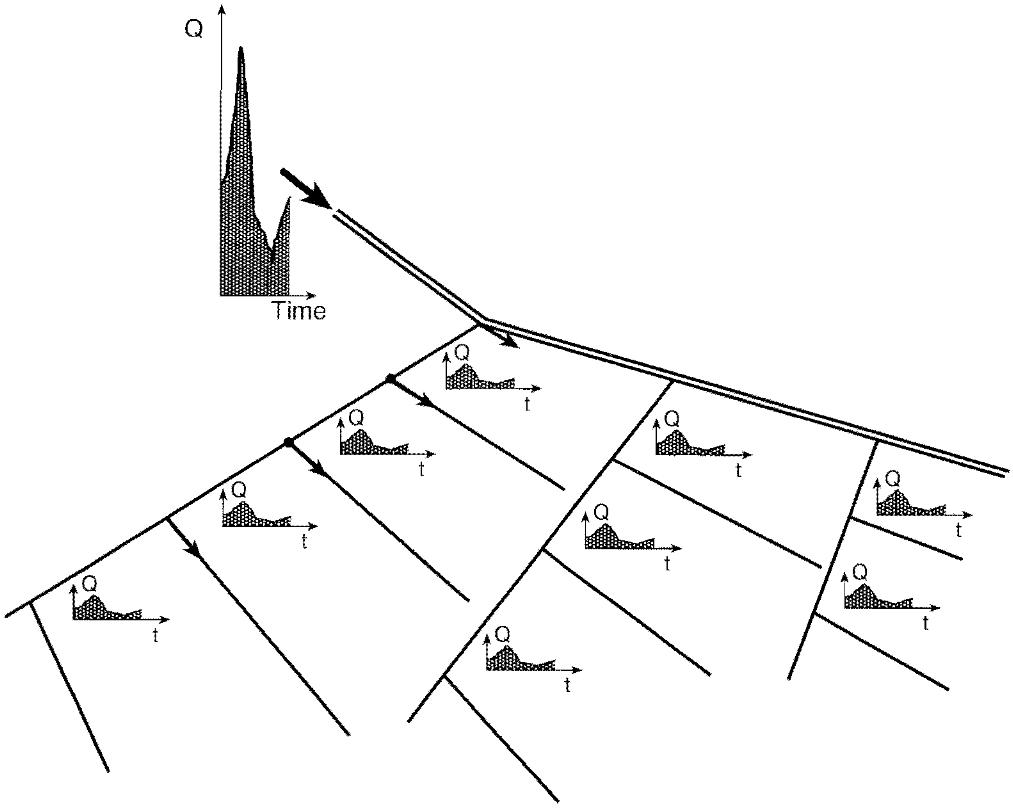
*Prop. div. = Proportional division.

11.5 Applicability of Simplified Delivery in Case of Water Shortages

Until now the applicability of simplified deliveries has been discussed under the assumption that the demands of the various cropping patterns could be met sufficiently by the available supply. This is often not the case and restrictions are necessary for that part of the year when the water supply is *not* sufficient for all farmers to grow what they wish. As discussed in Section 5.4 these restrictions can be in terms of crops (crop allocation) or in terms of water (division of water shortages). With restriction of cropping, provided the restrictions are adhered to strictly, the water distribution situations described in the previous sections apply. Applying restrictions on water lead to proportional division (Section 5.4). In run-of-the-river-schemes, traditional proportional division (System type 1-Section 6.2) in effect subdivides the scheme into small run-of-the-river-schemes each comprising a tertiary unit (figure 11.9).

This results in a minimal operation and a certainty for groups of farmers within a tertiary unit that they will receive an equal share of the (fluctuating) water supply. Proportional division can also be obtained from a Punjab type system (System type 2-Section 6.3). However,

Figure 11.9 Proportional division of river flows.



these systems are more difficult to operate with frequent and widely fluctuating river discharges.

11.6 Consequences of Simplified Technologies

Introduction of simplified deliveries and compatible simplified technologies have consequences on a number of issues.

Staff Requirements

In many countries a chronic deficiency exists in number and competence of operational staff. The required number of staff and level of competence depend on the number of regulating structures and the level of complexity of the structures (cf. Section 7.3). Introducing simplified technologies can result in savings in operating personnel required.[75]

[75]A comparison is made by Horst (1987) for an existing project in Indonesia, between the number of regulating structures when the tertiary offtake structures at the secondary canals are adjustable (existing situation) and what it would have been, had proportional divisions been applied. The number of adjustable structures decreased more than tenfold.

Operational Flexibility

Numerous case studies have shown that flexible demand systems generally operate at low performance levels, with headstream farmers receiving the major share of the water (Shanan 1992). The often-heard objection against proportional division in terms of lack of flexibility might be refuted by its timeliness and dependability.[76]

Turnover

In the last decade, turnover became an important topic in irrigation. Although much attention has been focused on the handing-over procedures, organizational processes, etc., little thought has been given to the technology to be handed over: the water division structures and their operational requirements.[77]

As discussed before, structures for flexible operations are, in many schemes, cumbersome to operate, and in practice the irrigation staff are unable to handle them in accordance with design assumptions and operation manuals. Measurements are seldom taken below the primary canal level (see Section 8.3) and water is not divided in accordance with irrigation schedules in l/s, but in accordance with a completely different set of rules. Under these circumstances, turnover of management implies turnover of an inappropriate technology. It is surmised that the simplification of technology and operation as discussed in this chapter, will lead to the handing-over of an irrigation technology which is more compatible with the capabilities and wishes of the farmers.[78] Turnover can be introduced only if the design results in:

- decentralized water delivery operation (e.g., proportional division and buffer reservoirs at tertiary level-see chap. 12)
- simple operation
- understandable structures (fixed or on-off structures).

Farmers can only 'participate' if the operational procedures and the water division structures are transparent and understood.

Physical Constraints

Proportional division can become problematic in case of widely varying soil types with large differences in percolation rates. Here either the scheme should be subdivided into blocks according to soil types or the proportions of the water division should be adjusted.

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[76]Moreover, in this context it should be realized that irregular (e.g., run-of-the-river schemes) proportional divided flows are still manifoldly more reliable and 'flexible' than rainfall.

[77]It should be noted that nowadays most consultants take technology for granted and spend most of their time on organizational and institutional matters.

[78]It should be noted however, that for large complicated schemes where the agency remains responsible for the larger canals, automation might be considered for these canals.

Another restriction of the applicability of proportional division can be the available heads: Proportional division of the weir type (System 1-Section 6.2) might not be applicable in very flat areas.

Waterlogging and Salinity

Many irrigation schemes suffer from over-irrigation in the head end and under-irrigation in the tail end. Over-irrigation often results in waterlogging and salinity. These head-tail differences occur along main and secondary as well as tertiary canals and result in situations illustrated in figure 11.10A. Due to the fixed position, proportional dividers (if not tampered with), will distribute water entering the system evenly to all tertiary outlets. The head-tail end problem is then carried from project level to the tertiary unit level. Although over-irrigation might be practiced in the head end of the tertiary unit, the buildup of the groundwater table is more evenly distributed and might not reach critical levels (see figure 11.10B). This also might have positive effects on the prevention of breeding sites for disease vectors, for example, malaria mosquitoes.

Figure 11.10A Usual head-tail pattern.

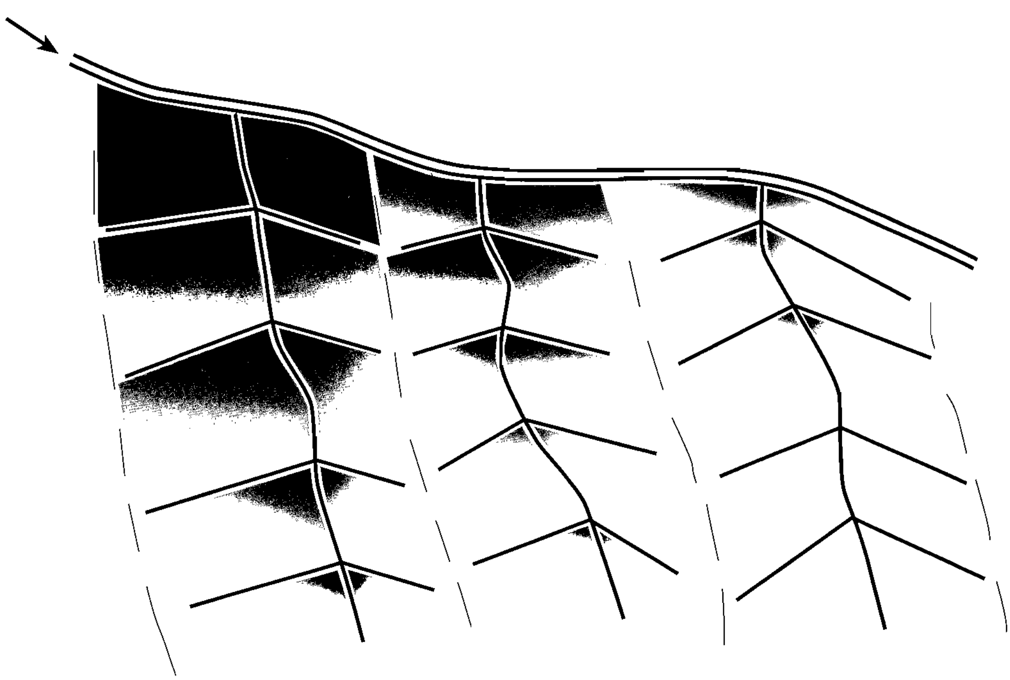
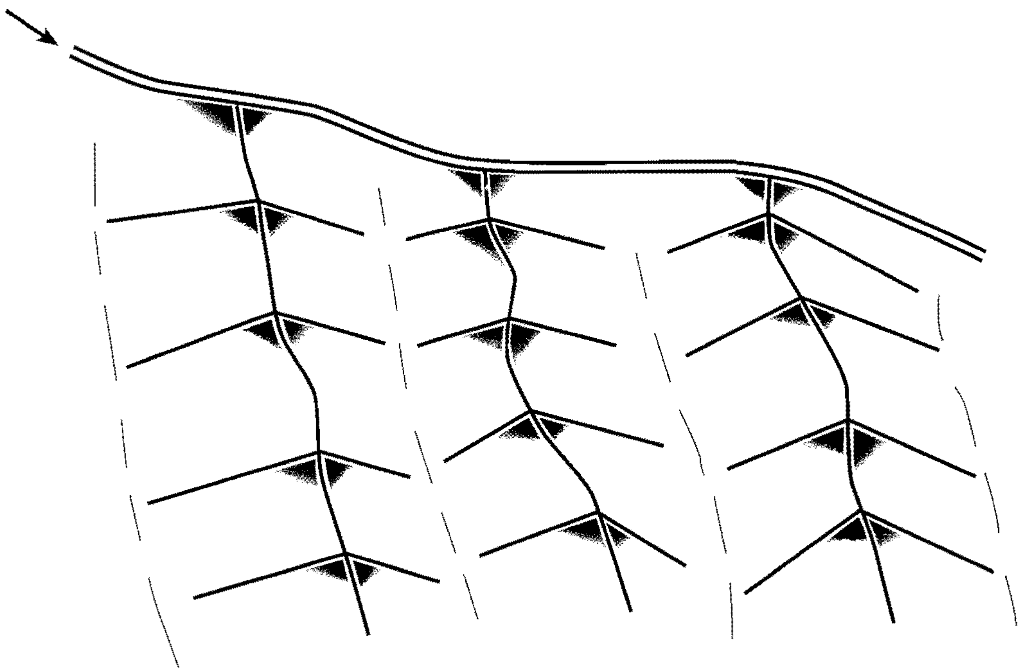


Figure 11.10B Head-tail pattern with proportional division.



Low Flows

During dry periods (particularly with run-of-the-river schemes) flows in the distribution system can become low and hence seepage losses will become proportionately greater. In these situations rotational operation should be implemented by means of on-off regulator gates.

Social Reality

The simplifications of irrigation distribution technology and operations discussed in this chapter will provide more equitable methodologies for division of water. It has to be recognized that these simplifications do not fundamentally change the real world of existing power structures and the social position of farmers. However, it may be surmised that the choice of technology does influence the social domains in which access to water is contained. It may be expected that technologies in which operations are transparent to all will expose blatantly corrupt interference in distribution and misuses of water, and in that way arouse social control.[79]

[79]Striking examples are the gated orifices (specifically the Romijn gate) as incomprehensible structures rendering corruption and collusion easy, versus the transparency of overflow weirs - see Section 7.4.

CHAPTER 12

INTERMEDIATE RESERVOIRS[80]

12.1 Introduction

In chapter 11 solutions to the water division problem were examined by considering simplified delivery schedules and compatible technology. An alternative possibility is to decentralize operation by creating intermediate buffer storages between the main system and the (groups of) farmers. The reasoning for such a technology lies in the following considerations:

- A basic problem in canal irrigation is the fact that once water enters the canal system, it has to continue flowing. The direction, duration, and magnitude of the flow should be according to the operational plan and are determined by setting the various division points of the system. A suboptimal operation of the main system will result in surpluses in one part of the system and shortages in another. These deviations from the intended supply can be corrected by adjusting the appropriate division and offtake structures. However, during the period of suboptimal operation, in the areas of surplus some water will be lost, while correction of shortages is generally difficult to achieve and time-consuming. In many cases, these areas of surpluses and shortages become firmly established as a consequence of faulty irrigation operation, siltation, or corruption. In practice, they often occur in the head and tail end.

- Another problem of canal irrigation (see Section 3.4) is the extreme dependence of the farmer on the operational plan in terms of possible crop choice and the timing, duration, and volumes of irrigation delivery. These operational plans are frequently based on assumptions having little or no relevance to farmers' realities: many site-specific factors might be more important such as soil types, labor, market, etc. As a result, farmers often do not adhere to the operational plan.

- Farmers' non-adherence to the designers' plans is often interpreted as '*ignorance*' or '*uneducated*' resulting in training and extension programs to '*educate the farmer.*' Many of these programs fail because they do not address the underlying motives for farmers to act differently.

The philosophy behind intermediate reservoirs is based on the reversed reasoning: '*farmers know best when and how to irrigate*' (this does not mean that extension on new varieties, use

[80]See also Horst 1983.

of fertilizers, and pesticides, etc., are not called for). To implement this approach a source of water, independent from agency management, near to the farmer (or group of farmers) is required. Farmers can decide when and how to irrigate with that water. By building storage reservoirs at the interface between farmer- and agency-managed systems a buffer is created. This storage capacity, equal to say a few days' irrigation requirements,[81] absorbs possible surpluses and shortages in the system and renders operation more simple and flexible.[82]

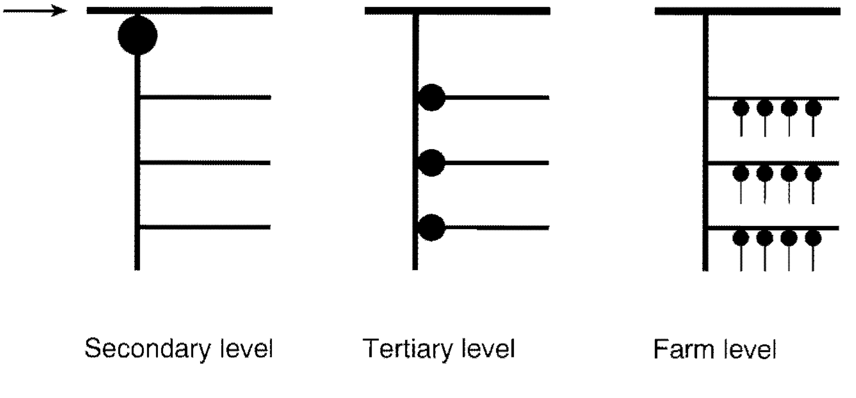
12.2 Location in the System

Intermediate reservoirs can be located at different levels of the system (figure 12.1).

From the above reasoning, it follows that the ideal place for a buffer reservoir is at farm level. In that case, the farmer can determine his own farming system and irrigation methods, crop diversification is more feasible, and when irrigation is a part-time activity the farmer can choose his own application times. Furthermore, there is no need for night irrigation. Many smallholder schemes however do not have sufficient space within the farm. Therefore, from a practical point of view intermediate reservoirs at tertiary level can be considered as the best alternative solution and will be further discussed below.

An important aspect of buffer reservoirs is the operational independence it gives farmers from the irrigation service otherwise imposed by conventional systems. Whilst O&M of main and secondary canals and structures are the responsibility of the management agency, the reservoir and tertiary are the responsibility of the farmers. Owing to their size, the reservoirs can (and from an economic point of view, should) be used for fish farming (Section 12.5).

Figure 12.1 Potential buffer storage location in distribution systems.



[81]It should be noted that these intermediate reservoirs differ from storage reservoirs at scheme level in terms of storage capacities: a few days supply versus a much longer (monthly or over yearly) period. Furthermore, they differ from night reservoirs designed to store the exact total water requirements for one 12-hour period. Here shortages and surpluses cannot be accommodated.

[82]The improved manageability of systems with decentralized storage has been proven by a comparative study by IIMI/ ADB (1989).

12.3 Layout

The main system

Water is conveyed from the source through main and secondary canals to the reservoirs in each tertiary unit. This conveyance system should preferably operate on a continuous basis to minimize canal dimensions. (However, a certain overcapacity is desirable to enable flexible operation.)

The Reservoir

The surface area and water depth of the reservoir depend on local conditions. As an indicative example:

Tertiary unit	:	30 ha
Irrigation requirement	:	8 mm/day
Buffer period	:	5 days
Surface area	:	1 ha
Active storage depth	:	1.20 m
Dead storage depth	:	0.50 m

An example is illustrated in figure 12.2.

12.4 Methods for Deliveries to Tertiary Reservoirs

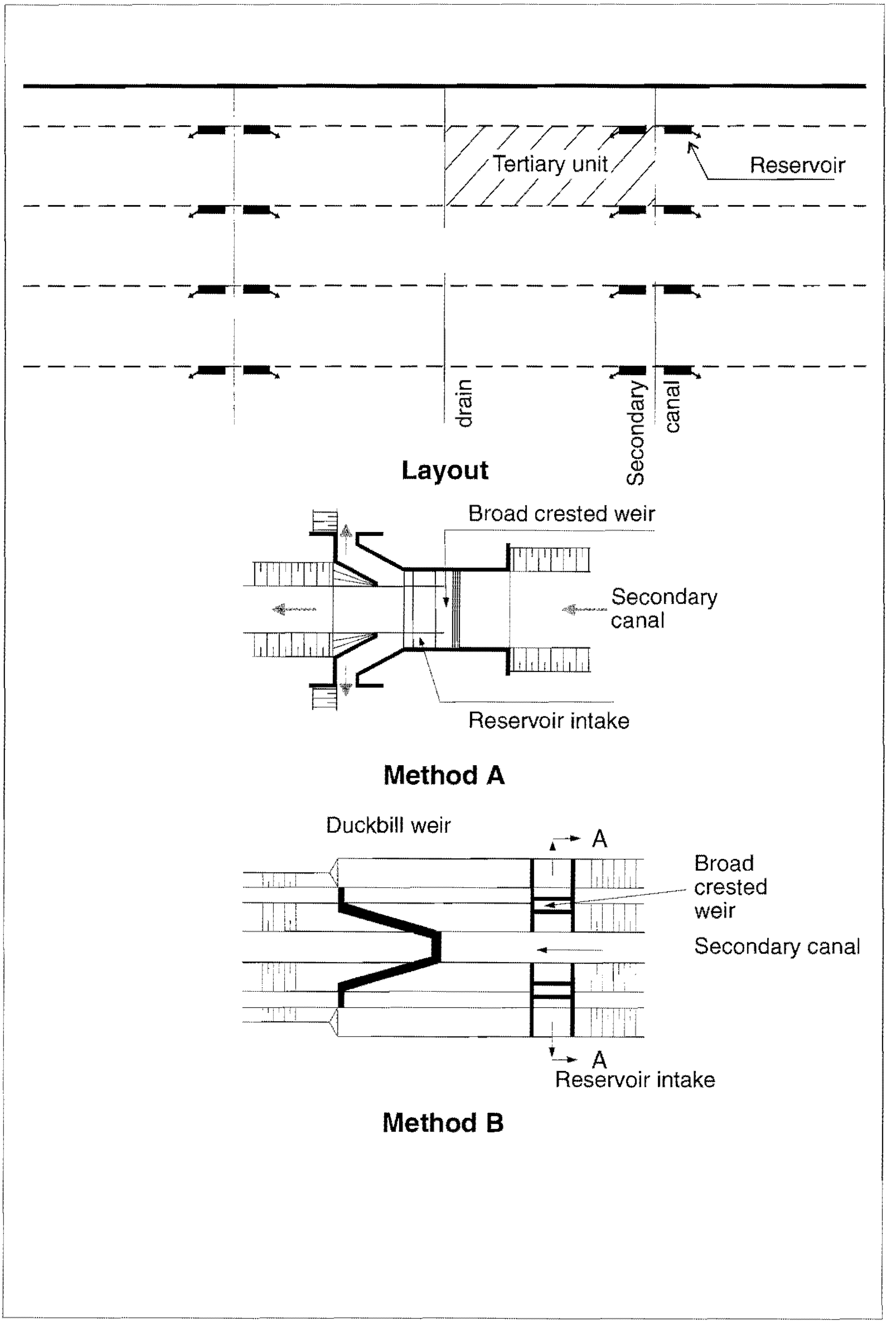
Contrary to conventional systems where water is divided and delivered according to pre-set requirement programs, the operation of systems with buffer reservoirs is reduced maintaining the storage in the reservoirs. This can be done in four ways:

A. *Proportional supply*. At each offtake point of the secondary canal, the offtake flow to the reservoir and the ongoing flow are divided in proportion to the areas commanded, taking into account conveyance losses, if required. This system is the simplest to operate and could well be adopted for areas where cropping is either homogeneous or very diversified (see chap. 11).

B. *Sequential supply*. Each offtake from the secondary canal is by broad-crested weir. The upstream water levels are controlled by duck-bill weirs with higher crest levels than the offtake weirs. When a reservoir is full, the local duck-bill weir will pass all flow to the downstream section with very little increase in the upstream water level (due to the high sensitivity of this structure type).

   Once all reservoirs are filled secondary canal flow will automatically maintain the buffer reservoirs at full supply level, provided the flow equals the gross irrigation requirements including losses. If the secondary canal discharge does not equal the gross requirement, the last reservoir will either empty or overflow.

Figure 12.2 Intermediate reservoirs.



Operation management consists of adjusting the head regulator of the secondary canal in response to the observed levels in the last reservoir. Shortage of water will still be concentrated towards the tail end; however, the buffer capacity of the tail reservoir allows additional time for management response. This system can only be applied successfully when sufficient water is always available at the source.

C. *Rotational supply.* Similar combinations of structures proposed for sequential supply (case B above) can be adopted for rotational supply with the addition of on-off gates at the reservoir intakes. Larger secondary canal capacities are required for rotational filling than methods A and B. This requirement is an important consideration when canals are constructed mainly in fill. Rotational operations also result in larger fluctuations in reservoir levels making operation of the reservoir outlet more difficult (requiring frequent adjustments of gate settings), and may adversely affect fish culture.

D. *Adjustable supply.* This method, requiring adjustable gates at the reservoir intake structures is not recommended since it entails problems similar to those in the conventional systems with variable flows.

From an operational point of view, methods A and B are to be preferred both for simplicity and for reduction of manpower, as no setting of gates is required. From the point of view of misuse and wastage of water within the tertiary units, however, the preference may be different. Over-irrigation in the first units will not be checked with method B, as the reservoirs will automatically fill up. With method A over-irrigation in a tertiary unit will result only in depletion of the reservoir concerned. Methods A and C make it possible to monitor and possibly check over-irrigation. They are preferable if water charges are to be made since the water supply can be measured on a volumetric basis. The overall irrigation efficiency should be higher in method C and A than in method B and therefore in most cases method A would be preferable to method B or C.

The Reservoir Outlets

The outlets from the reservoir to the tertiary canal could be designed as one or more gated outlets. This structure can be operated by the farmers in the tertiary unit and, due to its low sensitivity, will give little variations in discharge (in contrast to night storage reservoirs, readjustment of the gate would not normally be necessary during daytime operation due to relatively small water level fluctuations in the reservoir).

12.5 Feasibility

Systems with buffer reservoirs at tertiary level have clear advantages when compared to conventional systems. Advantages include easy operation of the main and secondary systems; reduced requirements for operations staff; transparent technology; reduced opportunities for mismanagement; and greater operational independence for farmers. Moreover, decentralized management is an appropriate basis for turnover. Finally, in case of run-of-the-river schemes, the buffer storage can damp out some of the fluctuation in supply rates.

However, this system cannot be adopted under all circumstances. In very steep or very flat areas, the volume of earthwork can become prohibitive. In relatively permeable soils, the seepage from the reservoir will be too high, while lining might be too costly. In very densely populated and cultivated areas the loss of 2-4 percent of the land for the reservoirs might be unacceptable. Finally, a disadvantage of these reservoirs may be that they could harbor the vectors of malaria and schistosomiasis.

Fish Culture

The costs of the additional volume of earthwork required for a reservoir system compared with a conventional system might be balanced by the yield and prices for fish. For the example cited previously, costs of earthwork in the order of US$10,000–20,000 and fish production of $2,000–10,000 per year could be achieved, indicating the economic importance of fish culture.[83] For fish culture, a number of requirements should be met:

- A minimum water depth of 0.5 m is required. This could be obtained by utilizing the reservoir area as a borrow pit but which may pose problems when complete emptying is required.
- No frequent or large fluctuations of the water level are allowed. Here operational methods A and B will be preferable.
- In some cases, emptying of the reservoir is required to collect the fish and possibly, to dry out the bottom of the reservoir to prevent diseases. This cycle of emptying and refilling should be compatible with the irrigation cycle within the tertiary unit.
- Provision should be made to prevent fish from entering either the secondary or the tertiary canal.

[83]Production depends on the intensity of management: simple management may yield 800-1,200 kg/ha/year while intensive management can produce up to 5,000 kg/ha/year (information from Mr. H. van Zon, Euroconsult, Sri Lanka).

CHAPTER 13

CONCLUDING REMARKS

13.1 Introduction

At the end of this book, looking back at its contents, it is opportune to return to the questions posed in the preface. It is also expedient to examine the contents in terms of limitations, future trends, and research needs.

13.2 Answering the Questions

In Part III an endeavor has been made to analyze the conventional methodologies by which designs are created. The different types of systems resulting from different design assumptions were reviewed in terms of operation. By doing so, it became clear that the type of technology largely determines the modalities for use of the system (management). It also became evident that in many conventional designs the institutional and human aspects have been neglected. This negligence is especially revealing for those systems with varying flows and manually operated gradually adjustable gates (Systems 3 and 4).

Including institutional and human aspects in the design considerations will lead to systems requiring less manpower (simpler technology and operational procedures) and more easily understood structures (Systems 1 and 2). When examining such systems in terms of supply-demand aspects and efficiencies (Part IV), they appear to be applicable for many practical situations.

13.3 Limitations

The underlying reasons for this book were a combination of the denial of the importance of technology vis-à-vis management, the increasing indifference to system design, the persistent shortage of manpower and the lack of transparency of technology and operational procedures. Admittedly, as a result the contents of this book show biases.

The first lies in the focus on technology. Writing from an engineering design perspective, with the aim to examine the restricted, one-sided design assumptions as handled by conventional designers, the technology might have been overemphasized. Needless to state that, in practice, technology can only work satisfactorily if the users accept it and if it is embedded in a compatible institutional framework.

The second bias is towards simplicity as discussed in chapters 11 and 12. The simplified technologies put forward, however, should not be considered as clear-cut technological answers for all irrigation problems. The aim is to entice a rethinking of system design and to contribute to the debate on the future direction of irrigation developments.

Another limitation is dealing with an irrigation system vis-a-vis the water source as an isolated entity. In practice, such a system forms part of a complex environment, a watershed, with other users requiring coordination of water use, water rights, etc. Although this situation might have consequences on water allocation and subsequently on technology this issue is not pursued.

13.4 Future Trends

When anticipating the future of water resources development in general and irrigation in particular, the following trends might be expected:

- increasing shortage of water
- increasing crop diversification
- increasing management transfer (turnover)
- increasing use of automation, models, and computers

Advocating simplification as discussed in chapters 11 and 12 should be examined in the light of these trends.

Increasing Shortage of Water

Increasing population and industrial expansion (tourist industry included), together with a growing water demand from the irrigation sector will result in increasing competition for water. When considering the various sectors of water users, water supply for households will generally have priority. In many countries, industrial development is an important national objective receiving strong political support. When looking at the varying annual volumes of water available and the demands from the various sectors, one might expect very little elasticity in the curves for water supply and industry (figure 13.1). In many instances, the water available for irrigation will in the long run remain the "*restpost*" in this process of growing water demand.

As a consequence (see figure 13.1), through the years the average total volume of water for irrigation, ½A + B, is expected to decrease, and the variability of supply (A/B) to increase. (A is the difference between maximum and minimum annual volumes of water, and B is the minimum volume available for irrigation.) Therefore, it will become more and more difficult to plan cropping calendars without (over year) storage facilities. As noted before, automation only works fully when sufficient water is assured for the whole growing season. With increasing uncertainties of assured supply, this technology will become vulnerable and simplified technologies should be seriously considered.

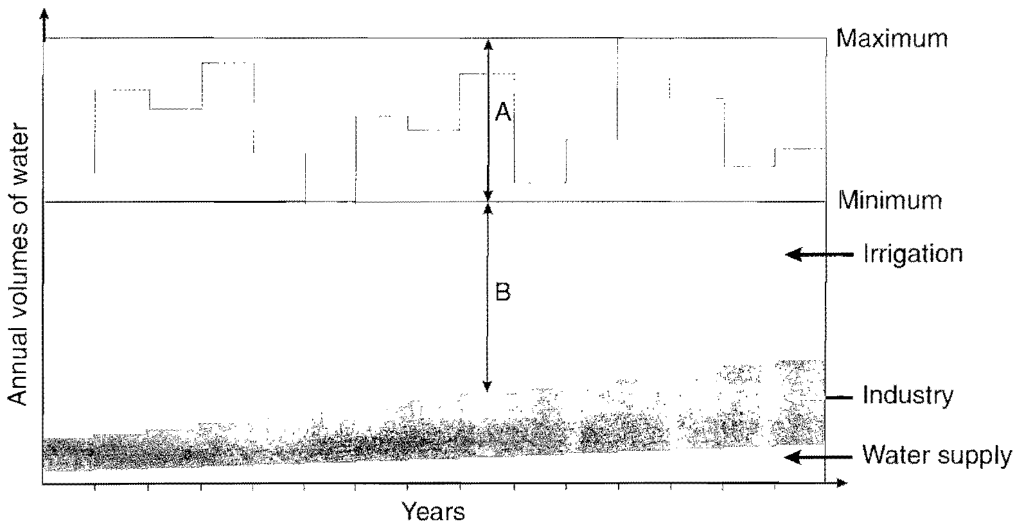
Increasing Crop Diversification

The consequences of this trend are possibly more complicated cropping patterns requiring more flexible water supplies. On the first sight, this might increase calls for on-demand and automated systems. In chapter 11, however, it was demonstrated that even for diversified cropping, simplified systems can be applied. Furthermore, intermediate reservoirs (chap. 12) can create the potential for farmers to irrigate as they wish, thus reducing water supply constraints to crop diversification.

Increasing Management Transfer

Transfer of management responsibility is often accompanied by rehabilitation or reconstruction of infrastructure. Where possible, simplified technologies with transparent operations should be implemented to minimize operational difficulties for the organization accepting the system.

Figure 13.1 Changing water allocation.



Increasing Use of Automation, Models, and Computers

Although pilot projects on automation and computer models appear less successful than expected, it is unrealistic to assume that these modern techniques are not going to be used in future irrigation development. The question however is: "*how far in future?*" Here it is surmised that satisfactory introduction of these techniques in general irrigation practice will not be feasible for many years to come. It is argued that, in the meantime, simplification of system operation through proportional division, on-off structures, and intermediate reservoirs should be seriously considered as potential solutions to the present poor performances of many irrigation projects.

13.5 Research Needs

Most irrigation research has been focused on systems with varying flows and manually adjustable structures. With the growing consensus that these systems do not perform well, other types of systems should be considered. For both alternative technologies (automation and simplification), little research has been carried out to date.

Introduction of both these technologies is called for, supported by comprehensive research programs. These programs should not only study the technical performances but should also address operational, socioeconomical, and institutional aspects. The results of these researches should form the basis for future designs.

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