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IRRIGATION WATER DIVISION TECHNOLOGY IN INDONESIA

a case of ambivalent development

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CONTENTS

1 INTRODUCTION

1.1 Background

Water division structures are a crucially important part of an irrigation system because their hydraulic characteristics determine the system's potential operation. They also determine how many operational staff are required and what skills these must have. Moreover, because of their numerousness, these types of structure account for a considerable part of the project costs. Finally, the type of these structures determines to what extent they are compatible with farmers' perceptions in the case of turnover.

This case study forms part of a more comprehensive study on design issues that covers other Asian and African countries too. Indonesia was chosen as a case because of its specific features regarding former (Dutch) technology[1]), the changes in this technology over the years, the hydraulic and operational consequences of these changes and the increasing discrepancy between design assumption and operational realities. The paper contends that not the changes in the management environment are the major reason for the present state of malfunctioning of the irrigation systems, but the failure of designers to adapt the water division technology to these changes. This paper might furthermore contribute to the debate on irrigation technology, featuring issues as automation, simplification and turnover.

1.2 Methodology

The material for this case study was collected in Indonesia at various times in the period 1992-1994. During these visits, manuals on design and operation, and design reports of specific projects were perused and discussions were held with design engineers of the Directorate General of Water Resources Development (DGWRD) in Jakarta Headquarters and provincial and district offices, and also with consultants. In addition, field visits were made to about twenty irrigation schemes on Java and Bali. During these visits operation of water division structures was observed and operators and farmers were interviewed. Secondary information was gathered in the form of research reports and papers related to water division issues.

1.3 Acknowledgements

First and foremost I would like to thank Mr. Soenarno, Director of Irrigation I and

1. Technology is here defined in its broadest sense, pertaining to material artifacts (structures), as well as to activities related to their use (operation) and related knowledge and skills. In the Indonesian context, the irrigation systems discussed in this paper are classified as 'technical irrigation'. The point of departure for such systems is (as stated in DGWRD, 1986a, p. 2): "For effective management of irrigation water its rate of flow should be measured (and regulated) at the head of the primary canal, at canal bifurcations and at tertiary off-takes".

Mr. Napitupulu, Chief of Subdirectorate Planning and Design for giving permission for this study, the support they provided and the open discussions held at DGWRD Headquarters in Jakarta. Furthermore I wish to thank the many DGWRD staff in the provincial and district offices who gave me their assistance and time and thereby helped to make this study possible. I am grateful for the time and information given by the field personnel and farmers who I met at the water distribution locations.

The useful suggestions on contents and structure of the paper by Messrs Bastiaansen, Diemer and De Jager from the Dept. of Irrigation and Soil and Water Conservation of Wageningen Agricultural University are greatly appreciated.

1.4 Structure of the Paper

The operational implications of selection of water division structures can be assessed on the basis of the hydraulic characteristics of these structures. Two hydraulic concepts "Sensitivity" and "Flexibility" needed for this assessment are reviewed in Section 2. Section 3 deals with changes in water division structures from the pre-colonial era until the present. The operational assumptions underlying the choice of these structures are discussed in Section 4. In Section 5 the operational reality as encountered in the field will be presented. A number of solutions for the operational problems as put forward by international agencies and consultants are reviewed in Section 6. Most of these solutions involve simplifying operations by adopting a water division technology based on some form of proportional distribution of water. In Section 7 the question of the applicability of proportional division is addressed. The paper ends with a resumé and some concluding remarks (Section 8).

2 TYPES OF STRUCTURE AND THEIR OPERATIONAL IMPLICATIONS

2.1 Introduction

Before reviewing the changes in water division structures in Indonesia over the years, it is useful to review two hydraulic concepts that are needed to explain the operational implications of selecting a certain type of structure. These concepts are the "Sensitivity" S of a structure and the "Flexibility" F at canal bifurcation points.

2.2 Hydraulic Criteria

Sensitivity
The sensitivity S can be defined as the proportional change of discharge caused by the unit rise of the upstream head:

$$S = \frac{\Delta Q}{Q}$$

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

$$S = \frac{u}{h} \Delta h$$

(for the derivation of this formula, see Bos et al., 1978).

We can also write: $\Delta h = \frac{h}{u} \cdot \frac{\Delta Q}{Q}$

From this formula the implications of the choice of structure become clear. The value of u is 0.5 for an orifice and 1.5 for a weir. This means that when Q, ΔQ and h are the same value, Δh is three times larger for an orifice than for a weir (see Figure 1).

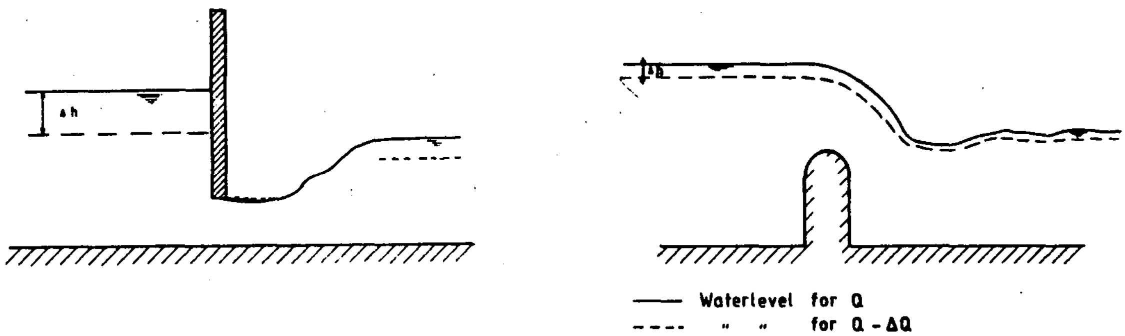

FIGURE 1 Weir type (overflow) and orifice type (undershot) structures.

Flexibility
The flexibility F can be expressed as the ratio of the rate of change of discharge of the off-take or outlet Q_o to the rate of change of the discharge of the continuing supply canal Q_s (Figure 2).

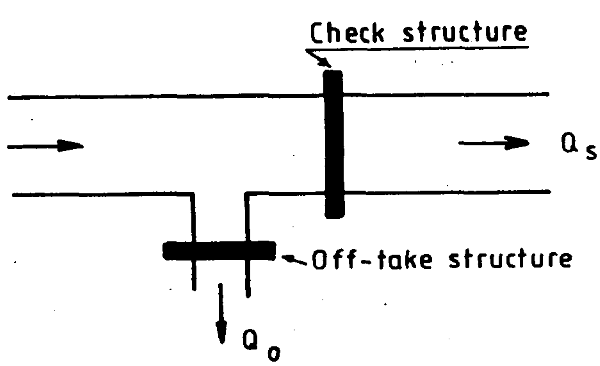

FIGURE 2 Off-taking structure.

F can be expressed as:

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

in which:

u = power u in $Q = c.h^u$
h = head difference
o = off-take
s = supply (ongoing)flow.

For the derivation of this formula, see Bos et al., 1978. The flexibility F is important for visualizing the generation of flow fluctuations in a system: Figure 3.

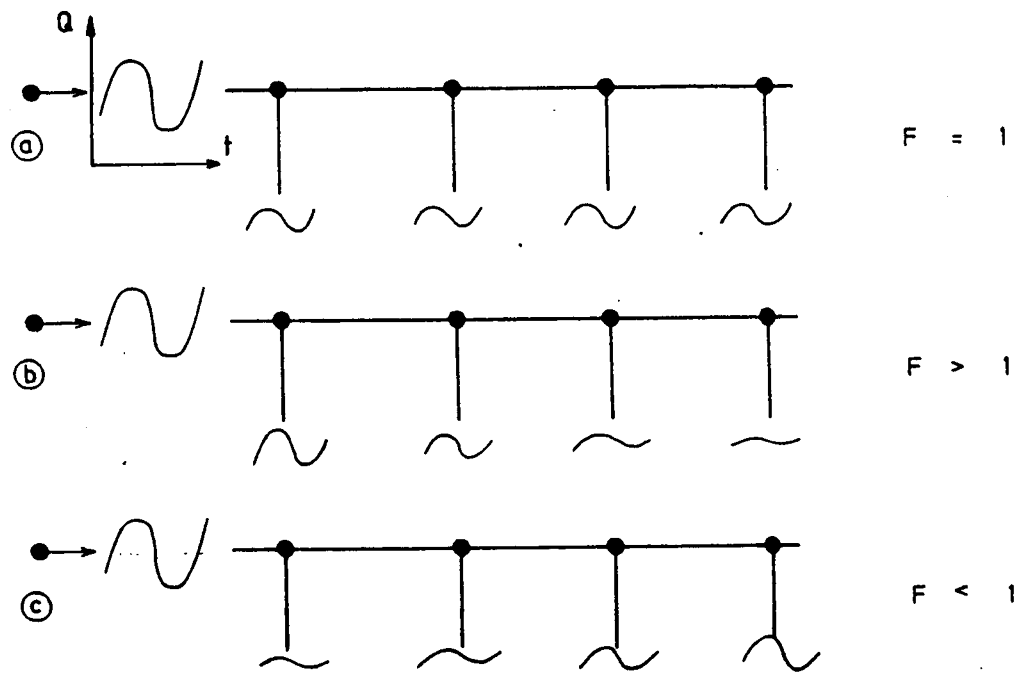

FIGURE 3 Propagation of flow fluctuations.

For F = 1 (case a) water surpluses or shortages will be spread uniformly over the system. This will be possible at the bifurcation points, using proportional dividers. The influence of fluctuations will be felt most strongly at the upper end of the irrigation system for F > 1 (case b) and at the lower end of the system for F < 1 (case c).

2.3 Operational Implications

Bearing in mind the hydraulics explained above, the operational implications of the selected water division structures, can now be assessed.

In every irrigation system, changes in flow occur during the irrigation season. First of all, the irrigation requirements change during the season. Other changes in flows might occur when offtakes are opened to accommodate local water shortage or closed when water is sufficient, and as a result of rotational practices, changing flows at the headworks (in the case of river diversion) or of changes in channel dimension (caused by siltation, vegetation growth or cleaning), or of unauthorized handling of gates etcetera. These changes in flow result in fluctuations of the water levels in the canals. As we have seen in subsection 2.2, the magnitude of these fluctuations depends on the type of structures.

Check structures: In the case of a system with gated orifices as check structures, fluctuations in water level will generally be large (compared with weir-type check structures). This implies frequent resetting of gates at each change of flow. However, the setting of one gate influences the water level throughout the system, requiring adjacent gates to be adjusted and so on. In other words, using gated orifices as check structures is a laborious way of regulating flows in irrigation systems. On the other hand, fluctuations in water level will remain small if the check-structure is a wide (duck-bill) weir. In this case these fluctuations might be tolerable, rendering resetting unnecessary.

Off-takes: From subsection 2.2 it is evident that flows through orifice-type offtakes are less susceptible to fluctuations in water level than weir-type offtakes, resulting in a reduced need for resetting.

The above clearly shows that the type of water division structures has a direct bearing on the number of operating staff required and the skills these people must have. Shortage of staff might lead to infrequent and/or incorrect resetting of gates, and thus to inequitable division of water. This could result in conflicts between farmers and staff, and unauthorized handling or even destruction of gates by farmers.

3 CHANGES IN WATER DIVISION STRUCTURES

3.1 Introduction

Van Bentum (1992) states: "Technology ..... does not appear out of the blue and neither does it evolve from itself. It should not be regarded as socially neutral. Technology is constructed in a social process. It is determined by the relations between the actors involved and their interests in development and technology".

The validity of this statement is borne out when reviewing changes of water division structures in Indonesia through the ages. The changes presented in this section were largely determined by a wide variety of actors, including sugar enterprises, farmers, government officials, donors and consultants.

3.2 Indigenous Structures

Indigenous irrigation existed in Indonesia for centuries prior to the colonial period. It is not clear however what type of technology was in use at that time[1].

Some authors report on the existence of some sort of technology comparable with the *Subak* in Bali. Other sources claim that water division principles were not based on proportionality but on priority rights. No clear picture could be obtained of the appurtenant technology.

If it is surmised that the pre-colonial technology was of the *subak* type, the principle water division was then based on proportional flows over fixed weirs as sketched in figure 4. The proportions are agreed by the water users and regulation of flows is not possible.

These structures, where the available flows (mostly derived from run of the river) is divided proportionally, are easy to understand, and require little operation. Their flexibility equals 1.

[1] Happé (1935) stated: "... that centuries ago the subak structure probably did exist on Java". Sutardjo (1965) claims that at one time the subak was also present on Java, but the Compulsory Cultivation System caused it to disappear (source: Hutapea et al., 1978). Ankum (1993b) contends: "Initially, many systems were based on proportional flow control".

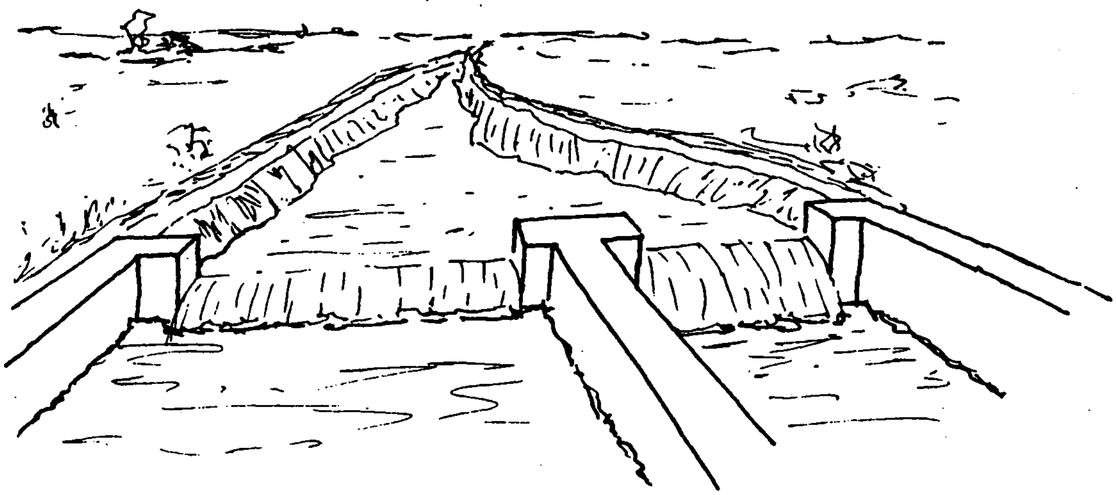

FIGURE 4 Proportional division.

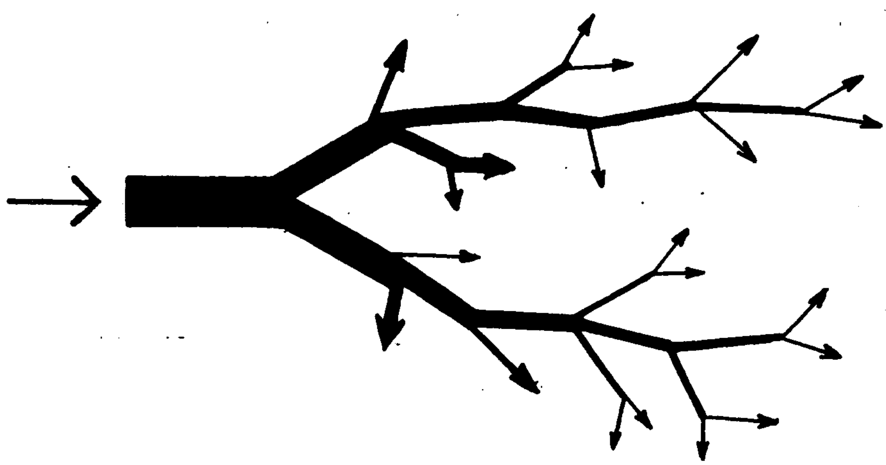

FIGURE 5 Lay-out proportional system.

3.3 Dutch Colonial Structures

In the 1850s, during the period of the "Cultuurstelsel"[2], the sugar industry started to develop in Indonesia and the colonial power became interested in irrigation. From that time onwards large-scale, centrally managed irrigation projects were constructed. Permanent intake works were built (fixed weirs in the river) and the irrigated area was arranged in lay-outs, containing secondary and tertiary blocks - schematically presented in Figure 6.

The compulsory cultivation of sugarcane within traditional rice-based irrigation areas led to the traditional way of irrigation being abandoned and to the introduction of

[2] During the 'Cultuurstelsel' (Compulsory Cultivation System) farmers were forced to grow agricultural products for the European markets. Private (Dutch) enterprise started to expand.

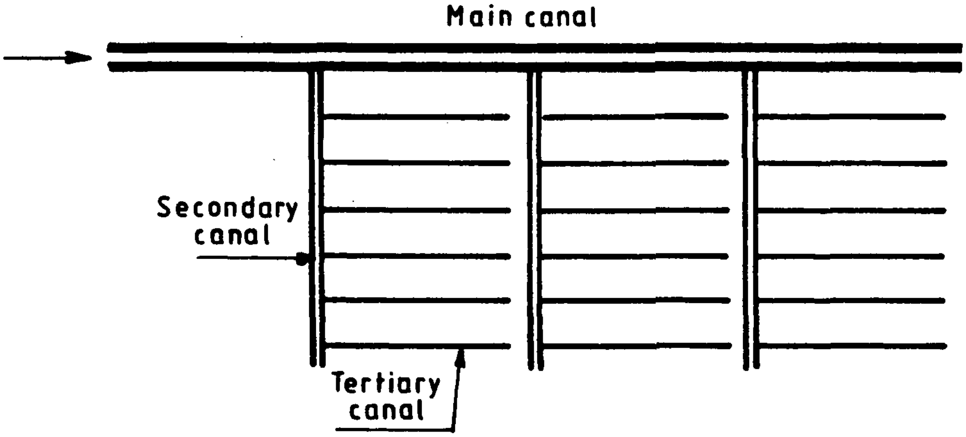

FIGURE 6 Lay-out of secondary and tertiary blocks.

structures that enabled flows to be regulated (controlled) and measured[3].

At the beginning of the 20th century (see also Ankum 1993b and Van Maanen 1924), the water division structures consisted of stop logs used as check structures to control the water levels, with sliding gates in the off- taking canals (Figure 7).

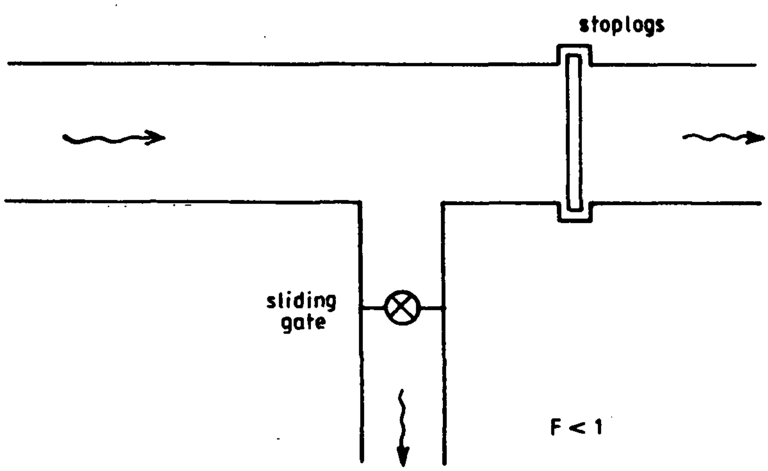

FIGURE 7 Combination stop logs-sliding gates.

The sliding gate was generally constructed in front of a pipe. Where necessary a measuring device consisting of a Cipoletti or Thomson weir was installed below the pipe outlet (Van Maanen, 1924).

Since notions of sensitivity and flexibility were unknown until the 1940s, it can be surmised that this solution resulted from technical convenience: if gated check

[3] For a good analysis - in Dutch - relating the chosen technology with the vested interests of the sugar industry, see Ter Hofstede et al., 1979.

structures had been used instead of stop logs with relatively large openings, complicated and costly solutions would have been required. Furthermore, it is easy to install a gated off-take (pipe outlet). The given combination has a flexibility $F < 1$, resulting in flow fluctuations propagating more near the end of the system (see Figure 3).

In the 1930s, the sliding gates at the offtakes began to be replaced by Romijn weirs. This adjustable weir has the advantage of having regulation and measurement combined in one structure and of operation with small head losses[4]. (The disadvantages of its lack of transparency and of the likelihood that the bottom gate would be handled wrongly will be dealt with in subsection 5.4). One important feature of having the Romijn gate as off-take and using stop logs as check structures is the resulting Flexibility. Because both structures are of the overflow type, the Flexibility approaches 1 (unity). Fluctuations in flows will therefore be spread more or less proportionally over the system (Figure 8)[5].

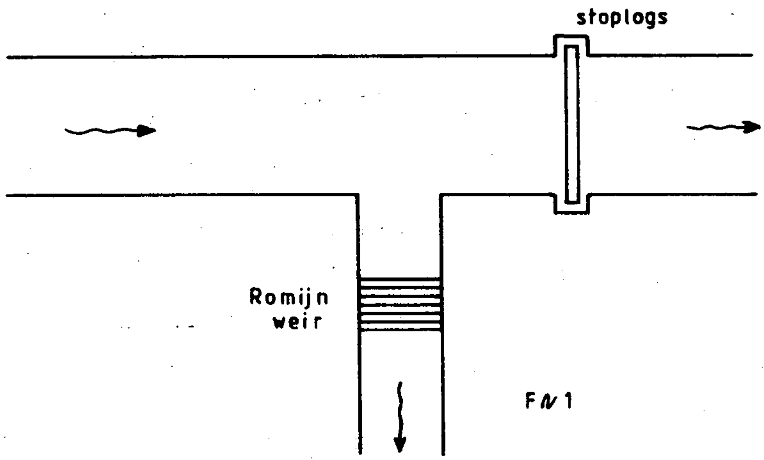

FIGURE 8 Combination stop logs - Romijn weir.

[4] Note that regulating structures were invented in other important irrigation areas in Asia and Africa during colonial rule (French and British colonial technologies). The motives for the invention of adjustable structures might have been political as well as economic. Furthermore, the influence of the development of modern industry, where notions such as efficiencies and control were dominant, certainly played a role.

[5] During that period, numerous discussions took place among others in the 'Ingenieur in Nederlandsch Indië'. The gist of these discussions is reflected in the lecturenotes (mimeograph in Dutch) by Prof. Berkhout in the late fifties.

3.4 Changes During Recent Decades

During and after World War 2, irrigated agriculture experienced a period of stagnation in Indonesia, ended towards the end of the 1960s, when a large programme involving the rehabilitation of irrigation systems started. New irrigation works were also built in the period following. This was the beginning of an impressive development of irrigated agriculture, which has brought Indonesia from being the world's largest importer of rice in the 1970s to its present state of self sufficiency.

The rehabilitation and the construction of new irrigation works were carried out with financial assistance from multilateral (World Bank and later Asian Development Bank) and bilateral donor agencies. Most of these agencies stipulated that foreign consultants were to be involved in the planning, design and supervision of construction. During the first large rehabilitation projects, Dutch, Taiwanese and US consultants were employed, but they were later joined by other consultants, including Australians, British, Korean, Japanese and French. In the last ten years, Indonesian consultants have increasingly become involved, often in association with foreign consultants.

The foreign consultants came from different parts of the world with different irrigation technologies and traditions. Therefore, not surprisingly, they also recommended water division structures that differed from the original Dutch stop logs as check structures and Romijn weirs as offtakes. To give an impression of the large variety of the structures proposed, a random sample of the offtakes and check structures proposed by various consultants is presented in Table 1. Below, some of the changes proposed by these consultants that have important hydraulic and operational implications will be discussed.

TABLE I Structures recommended for Check and Tertiary Off-take.

Name of project	Date design	Origin of consultant	Check					Off-take							Justification for chosen structure given in the design reports
			sliding gate	stoplogs	combination	overflow walls	others	sliding gate + broadcr. weir	sliding gate + Cipoletti	sliding gate + flume	Romijn weir	Crump - de Gruyter	Constant Head Orifice	Others	
Jatiluhur	1972	?					• Duckbill weir							• Neyrpic module	Visual observation no report available
Serayu	1974	Australia	n.a.											•	Current meter at each tertiary offtake
Teluk Lada	1978	Korea	•								•				No reasons given
South Kedu	1978	US	•	• $< 1.4 m^3/s$					•	•					No reasons given
Wonogiri	1978	Japan	•	•		•		• $> 1 m^3/s$	•		• $< 1 m^3/s$				Preference for Cipoletti, depending on discharge and head
Progo	1981	UK	•					•		•					No reasons given
Ular River	1982	Japan	n.a.					• $> 0.7 m^3/s$	•		• $< 0.7 m^3/s$				Preference for Cipoletti if sufficient head. No further explanation
Wawatobi	1982	Netherlands	•	•							•				No reasons given
Jratunseluna (Serang)	1984	Australia Indonesia	•			•					•				Usefulness of Romijn questioned
Jratunseluna (Lusi)	1985	US Indonesia	•										•		Eliminate the need for 2 structures + generally easier to operate
Jratunseluna (Klambukanan)	1986	Indonesia Australia	•								•				No reasons given
Jratunseluna (Sidorejo)	1986	Indonesia France					•							•	Neyrpic system - comparison with upstream controlled systems discussed
Irrigation Design Standards	1986	DGWDR + Dutch & Indonesian consultants	•					•			•	•			Pros and cons discussed
W.Semarang	1987	Korea Indonesia	•							•	•				No explanation
Seputih/way	1987	US Taiwan	•						•	•					Stoplogs not recommended Romijn not recommended (silt + inaccurate)
Jatigede - Group II	1987	Indonesia Taiwan	•	• $< 1.5 m^3/s$	•			•	•						Pros and cons of Romijn weir given
Jatigede - Group I	1989	Indonesia Korea	•	•		•		•	•		•				No explanation
Blender	1992	Indonesia Australia		•				•							Visual observation - no report available
Bapang	1993	?	•								•				-do-

Firstly many consultants proposed using sliding gates instead of stop logs for check structures. This was first proposed in the 1970s, because stop logs were considered to be too out of date for management (Ankum, 1993a).[6] Retaining the Romijn weir as off-take, because of its supposed good functioning in the past led to a situation in which the Flexibility F became > 1 (Figure 9).

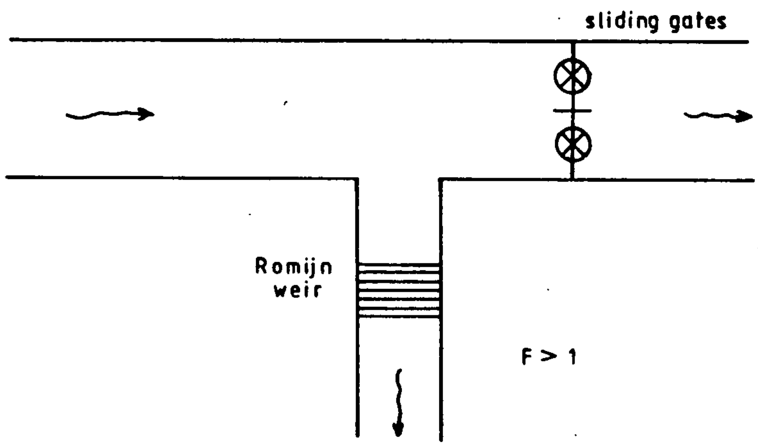

FIGURE 9 Combination sliding gate - Romijn weir.

Consequently (see subsection 2.2 and Figure 3), flow fluctuations will be felt most strongly in the head-end of the system, resulting in frequent gate adjustments, which may or may not be authorized, and often eventually causing the entire system to become unmanageable. Remarkably, none of the consultants assessed their proposals in terms of sensitivity or flexibility and by so doing disregarded operational consequences. World Bank 1990, rightly typified this combination as "... possibly the worst of all combinations from the hydraulic point of view since it is extremely unstable ...".

Secondly, other consultants questioned the adequacy of the Romijn weir as an off-take structure. The arguments against the Romijn weir included inaccuracy, siltation and the likelihood of the mishandling of the bottom gate. Instead, an orifice type of structure combined with a downstream measuring device was proposed (Figure 10).[7] Nevertheless, the Romijn weir remained the most important measuring structure (comprising 70% of all measuring structures according to Sutiyadi, 1991).

Many other solutions and preferences have been given by various consultants

[6] Some engineers prefer the sliding gate because silt easily passes the structure.

[7] As an example, the Romijn weir as off-take structure practically disappeared in the province of Yogyakarta under the influence of British consultants. Instead, sliding gates with broadcrested weir, or Cipoletti or long-throated flumes were installed. In combination with sliding gates as check structure, the result was a hydraulically improved situation by comparison with the former combination (Flexibility approximating 1). However, this solution is still far from ideal, because the strong fluctuations in water level render flow conditions unstable.

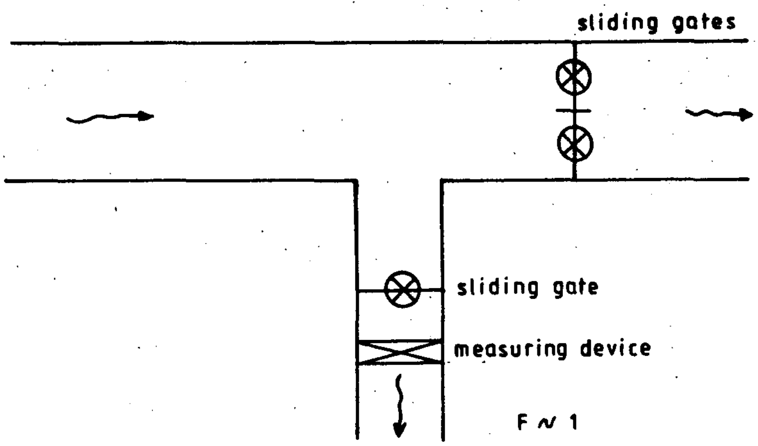

FIGURE 10 Combination of sliding gates.

through the years, based on different technological backgrounds, as can be seen from Table 1. For instance the Constant Head Orifice (CHO) has been recommended as an offtake structure in the Citanduy and Lusi river basins. This American structure rarely works outside the USA (e.g. see Horst 1994, forthcoming). These structures are recommended for their "easy operation", but in reality they are among the most cumbersome ever invented. An extreme proposal to install current meters at each offtake for tertiary units larger then 5 (!) ha was made for the Serayu project. The automatic system (Neyrpic) as proposed for Sidorejo should furthermore be considered as a pilot project. Finally, it should be noted that - remarkably - during the last 20 years none of the consultants listed in Table 1 proposed a duckbill weir as a check structure.

3.5 Design Standards

In 1986 design standards were compiled by DGWRD with assistance from consultants on the basis of an overall assessment of design practices in Indonesia. These standards consist of seven volumes and supporting annexes. Chapter 2 in the supporting volume "Irrigation Design Manual" (DGWRD, 1986b), deals with system design. The *capacity* of the system is derived from an analysis of 1) irrigation requirements (assumed cropping pattern, evapotranspiration, crop coefficients and effective rainfall), 2) assumed *golongan*[8] system and 3) assessment of the available water. These are used to work out the *dimensions* of canals and structures. The *number and location* of the water division structures are determined by the layout of the system: topography (irrigation and drainage canal alignments), administrative and other boundaries, and size of tertiary units.

[8] A system widely used in Indonesia, of staggered planting dates. See further subsection 7.5.

The *types* of water division structures are dealt with in Volume KP-04 of the standards (DGWRD, 1986a). That volume covers "Discharge measurement structures" (pp. 3-29), "Water regulating structures" (pp. 31-44), and "Division structures and offtakes" (pp. 45-53).

Of the six commonly used discharge measurement structures three (Cipoletti weir, Parshall flume and Constant Head Orifice) are not recommended by DGWRD because they have insufficient provision for allowing debris and sediment to pass through, or because of the construction costs involved their inadequate accuracy. The applicability of the three recommended structures (Broadcrested weir, Romijn weir and Crump - De Gruyter Orifice) is discussed in detail in the standards.

The standards appear to be ambiguous with regard to check structures. After finding both the stop-log gates and the flat sliding gate suitable for water level regulations, their pros and cons are discussed (ibid. pp. 43, 44). Rightly the disadvantage of sliding gates in terms of their sensitivity to changes in flows (large fluctuations in water level) are pointed out.[9] The standards note (ibid, p. 44) that when used in combination with the Romijn weir (recommended as offtake structure!), frequent adjustments will be required. This discussion ends with the surprising statement that "Ease of operation and durability make that it is recommended to use undershot gates as regulating gates in spite of the mentioned shortcomings". In other words, the standards recommend "the worst possible combination" (World Bank, 1990) of water division structures.

Resumé

This section reviewed the physical changes in water division structures through the years. It became clear that during recent decades, the type of water division structure has largely been determined by the nationality of the foreign consultants involved in the design. Many of the structures selected depended on technologies developed elsewhere, or on the whims of the consultants concerned. Rarely were those structures adapted to the local physical, social and cultural conditions. Furthermore, it was not until the 1980s that efforts were made to produce a general Indonesian standard for irrigation design.

The operability of the structures was briefly referred in this section. Operational procedures will be dealt with in the next section.

[9] The hydraulic criteria Sensitivity and Flexibility are not dealt with explicitly in the standards.

4 UNDERLYING OPERATIONAL PROCEDURES

4.1 Introduction

IIMI, 1987, pages E2 and E3 states: "The levels of sophistication in Indonesia's irrigation infrastructures (hardware) and Indonesia's underlying principles of irrigation water management are some of the highest to be found in South and Southeast Asia". IIMI continues: "In Indonesia three major methods for determining irrigation requirements in government systems are used: Pasten, Factor-K and Factor-Palawija[1] -Relatif (FPR)". Below the basic principles underlying these methods are presented.

4.2 Water Distribution Principles

In the same volume it is observed that Ibid p. E2: "No matter which method is used, however, the underlying assumptions for effectively using the tool operationally are basically the same. These assumptions are:

1. The actual number of hectares in each block planted by type of crop and growth stage is accurately known;
2. The actual flow at the intake can be, and is, measured on a timely and accurate basis;
3. The exact quantity of water diverted into each canal can be measured and controlled;
4. The rate of losses, or exact magnitude, are known; and
5. Proper gate settings are made as required and the gates are not tampered with between settings.

If any of these assumptions are violated, the operational method used is subject to error" (ibid, p. E2).

On the basis of these assumptions, the operational decisions refer to the allocation and distribution of water and address the following three questions:

a. How much water is required in the tertiary block?
b. Does the water available meet the water requirements?
c. How are distribution losses incorporated into the allocation process?

The standard approach is essentially a continuous flow, "arranged demand", system under which deliveries to the tertiary outlets are controlled to meet the requirements of sanctioned crop areas. Shortfalls in (river) supplies relative to requirements are shared equitably among authorized recipients (World Bank, 1990). For detailed description of the three methods, see IIMI, 1987.

[1] Non-rice food crops.

4.3 Operational Procedures

In the last six years, a number of Operation and Maintenance manuals written by various consultants have appeared. Some are at project scale (e.g. Rentang), others - more comprehensive - are at province scale. Of the latter category, the Guidelines on O&M for Central Java (Mac Donald, 1988) prepared in the framework of the World Bank Irrigation Sub Sector Project will be reviewed as an example:

In Chapter 3 "Operation", the Factor-K is taken as the basis for water distribution planning. For each irrigation system a set of data is required (pp. 3-21) (see Box 1).

Box 1

a. Consumptive use/water requirements of each crop at the various growth stages;
b. Cropping plans;
c. Records of river discharge/other sources (half monthly or monthly) for previous years;
d. An inventory of the command area of each tertiary unit;
e. Estimates of water losses in canals;
f. Water requirements for other users, e.g. factories etc.;
g. Records of additional supplementary discharges for each half month or month in previous years;
h. Previous year's cropping schedule and realization;
i. Reliable records of rainfall;
j. Irrigation Area Schematic Diagram and Irrigation Area Schematic Operation Map;
k. Canal Capacities (maximum and minimum);
l. Discharge tables or curves for each measuring structure in the irrigation system.

A stepwise procedure comprising the following sixteen steps is used to plan, implement and monitor water distribution:

1. Preparation of global cropping plan for each irrigation area.
2. Preparation of authorized detailed cropping plans for each tertiary unit.
3. Routine cropped area reporting (half monthly).
4. Calculation of water requirements at each tertiary gate (half monthly).
5. Calculation of water requirements at secondary and primary intake gate - from step 4 - (half monthly).
6. Water requirement plan for the main system - from step 5 - (half monthly).
7. Estimation of available water at headworks - from previous river discharges - (half monthly).
8. Comparison of water requirements with available water: Factor-K (half monthly).
9. Confirmation of Factor-K and proposed water distribution (half monthly).
10. Completion of operation boards (half monthly).
11. Setting the gates (minimum half monthly, see step 13).
12. Monitoring discharge (half monthly).
13. Revising Factor-K (every 5 days; if changes in water availability exceed 10-15% the K-value and resulting canal discharges should be recalculated, gates reset and new values entered on the operating boards).
14. Collection of supplementary data (on flooding and rainfall).
15. Assessment of operation performance.
16. Summaries of seasonal and annual data.

Most of these sixteen steps require one or more standard forms to be prepared twice a month and sent to a higher level in the irrigation service hierarchy.

From the above it becomes clear that the operational procedures are lengthy and elaborate. In order to arrive at satisfactory allocation and distribution of water and monitoring of operational data, a large well-trained office and field staff are required. Note that the Factor-K method is a modification of the Pasten method, which was developed before the second World War and was used only sporadically at that time, in mixed rice-sugar cane areas, "... dependent on a high level of discipline, notably in the context of well-organized sugar operations" (World Bank, 1990).

The question whether this method is still appropriate in a structurally changed socio-economic environment will be addressed in the next chapter, which deals with the interactions between design and operation.

5 DESIGN ASSUMPTIONS AND OPERATIONAL REALITIES[1]

5.1 Introduction

In order to analyze the complex interrelation between design assumptions, operational procedures and operational realities, it is useful to discern the three major parties involved:

1. Designers (DGWRD, consultants, donors);
2. Operational office staff (DGWRD staff in headquarters, provincial and district offices); and
3. Operational field staff and farmers (at tertiary and secondary level).

5.2 Designers

Designers are supposed to design 'technical irrigation' systems: systems where the waterflows are regulated and measured at each bifurcation point (see Figure 11a).

By adopting a certain technology for the distribution of water, the designer demarcates the boundaries of possible operation. Surprisingly, the way an irrigation system should be operated does not feature in any of the design reports and standards consulted. Significantly, the Factor-K or Pasten methods for water allocation and distribution (Section 4), are unfamiliar to most design engineers. The assumption seems to be that as long as the rate of flow can be measured and regulated the system will fulfil its requirements.

In subsections 3.4 and 3.5 it was shown that choosing an inappropriate water division structure may lead to hydraulically unstable systems and cumbersome operation. Furthermore, farmers' perceptions in terms of the understandability of structures are rarely taken into account in the design. Moreover, no considerations are given to staff requirements (numbers and skills) in relation to the water division technology chosen. (The chronic shortage of trained staff in Central Java is mentioned in MacDonald, !988: for the given technology, around two and a half times the present number of staff are required to operate the systems as envisaged - *ibid*, subsection 6.3.4).

5.3 Operational Office Staff

The DGWRD operational staff in the district and provincial offices are mainly concerned with the allocation and distribution of water following the procedures described above (Section 4). From this description it became clear that these

[1] The following analysis strongly corroborates the findings of IIMI (1987, 1989) and World Bank (1990).

procedures require an enormous amount of data collection, processing and dissemination. In combination with shortage of staff, little contact with or feedback from the field (especially from the tertiary level) and unreliable water measurement capability because of malfunctioning of structures and consequently unreliable data, this results in a situation in which the administrative activities remain largely paper exercises (e.g. IIMI, 1989, p. 223: "In practice it is clear that the Pasten system is rarely implemented as planned, and tends to result in a set of operational plans that are rarely implemented with any degree of precision").

5.4 Operational Field Staff and Farmers

It is generally the case that in Indonesia the irrigation deliveries deviate strongly from demand and show a low degree of stability. At all the sites of IIMI's research projects for instance, irrigation deliveries in the main and secondary canal system show two main characteristics (IIMI, 1989, p. 75):

- "a high degree of variability in daily discharges in main, secondary and tertiary canals, and
- large differences between actual and planned discharges at main, secondary and tertiary level".

This situation is the result of a combination of factors such as shortage of staff, frequently required resetting of gates, difficult and laborious operation of structures, malfunctioning[2] and mishandling of measuring structures and "the apparent tendency of irrigation inspectors and farmers to sometimes distribute water on the basis of negotiated arrangements rather than hierarchically implementation procedures which have been determined through objective information gathering and analysis" (IIMI, 1978, p. 3).

Furthermore, the field staff often live in and originate from the area they have to serve. Their loyalty lies primarily with the local farmers concerned and less with the office in town. Therefore when they are confronted with laborious operation, unstable canal systems, malfunctioning structures and crop areas differing from planned (see IIMI, 1989, p. 171), they will distribute the water on the basis of their experience, ignoring official instructions. Their measure of water flows will be "enough", "too much" or "too little" and not litres/second. This leads to the situation as sketched in Figure 11b.

[2] The underlying reasons for poor quality of construction is not further discussed in this paper.

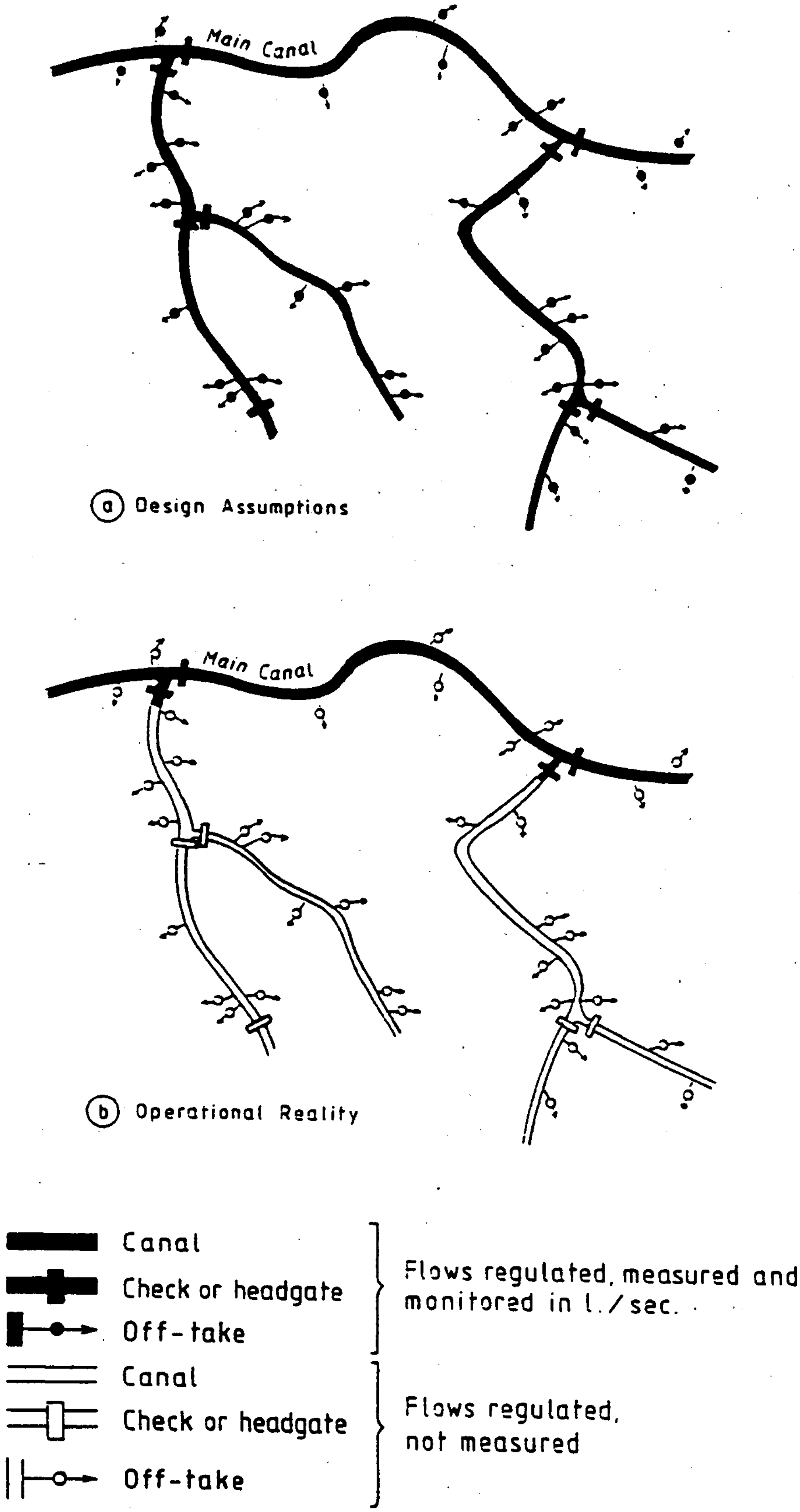

FIGURE 11 Design assumptions (a) and operational reality (b).

5.5 Conclusions

Water distribution and the issue of equitable division is very situation-specific and can only be assessed by in depth research. Speculatively, a number of situations may occur: after many years of experience the gatekeeper has learnt how to accommodate the various groups of farmers he has to serve[3], or the water is divided on the basis of negotiations, power relations or traditional rights. This might be reflected by the way the water is handled during the daytime but might also lead to different activities at night.

Clearly, the design assumption to deliver water through the off-takes in predetermined quantified flows in l/sec has no bearing on reality, where water flows are qualified from a different perception (sufficient, too little or too much) and based on experience, accommodation, negotiations and rights instead of water schedules derived from plant-water requirements. Consequently, the way the given technology is actually used differs from how it is supposed to be used. Gates are not set according to the calibration of structures but to accommodate "sufficient" flows of water. (For that purpose for instance, the bottom gate of the Romijn weir is often used to divert flows.)

[3] In some cases this situation might lead to an even more equitable water division than strictly following of the water schedule procedures, since local conditions (e.g. locally different soil types, high land etc.) might be better addressed.

6 RECENT DISCUSSIONS

6.1 Introduction

The situation regarding irrigation problems in Indonesia outlined above has led to various discussions and recommendations. In this section the various issues will be reviewed.

6.2 IIMI Management Studies

The International Irrigation Management Institute (IIMI) carried out an irrigation management study in collaboration with the DGWRD and the Gadjah Mada University in the period 1985-1989. The first phase of the project comprised system performance and crop diversification, the second phase focused on upgrading system management performance and improved operation. This phase also included the issue of turnover.

The results of the research are described in detail in two reports (IIMI, 1987 and 1989), and reveal a situation concurrent with that sketched in Section 5 of this paper. In order to assess IIMI's recommendations, one has to take into account IIMI's terms of reference (IIMI, 1989, p. 41): "IIMI's main purpose in Indonesia, ..., is to work with the Government (GOI) in identifying, testing and assisting in the adoption and dissemination of irrigation management innovations [emphasis added]". This focus on management, not surprisingly, reflects IIMI's recommendations (summarized by WB, 1990, p. 9) most of which concern improvements to the managerial structure. They do not address the fundamental problem of the incompatibilities between technology, operational procedures (Pasten, Factor-K) and the operational realities in the field. The World Bank rightly concludes "They [IIMI's recommendations] do not, however, directly address the underlying factors which have often made it difficult to sustain improvements". They should therefore be considered as cosmetic surgery.

This failure to "address the underlying factors' is surprising because in the report of IIMI, 1989, section 7 "Alternative Models for System Design and Operation", these incompatibilities are well analyzed. Here the interactions between design and management are addressed and conclusions and recommendations, that are much more far reaching than any in the preceding chapters of IIMI's report are presented.

Two important interrelated conclusions are reached in this section of the IIMI report, regarding management requirements of the Pasten system and the need for proportional division of water. In para 7.2.1 p. 223, it is noted that the Pasten system is rarely implemented as planned, that it is highly improbable that increases in staffing levels would be justified by improved performance and therefore that simpler operational strategies should be sought. Subsequently the three main hydrological conditions at different times of the year are analyzed in the light of the question of whether the Pasten system is required or not. The report says in short (*ibid*, p. 224):

> In the ***wet season*** irrigation deliveries are normally well in excess of the difference between rainfall and actual crop water requirements. There is no need for precise control of water and there is little concern for discharge measurements under these conditions. This operational practice can be most easily implemented using some form of proportional division system that provides a share of water based on total command area.
>
> In the ***dry season*** water availability is well below demand (i.a. Factor-K is less than 0.6 and frequently as low as 0.3-0.4) and rotational measures are enforced. There is little, if any, need to know what precise water demand is, because it cannot be met anyway. After pointing out the unfair sharing of water under the present system, the allocation of water on the basis of irrigation area instead of current cropping patterns, is advocated. A proportional distribution system can achieve this type of water delivery much more easily than under the current system.
>
> IIMI considers the ***intermediate period*** between these two conditions described above, as valid in terms of the Pasten method. (Factor-K between 1.0 and 0.6). This period is relatively short, perhaps one or two months per year. Here, regulation of the flow is required and sliding gates are to be provided to reduce discharges by up to 40 %.

From these deliberations, IIMI concludes that the technology of water division should consist of regulating and measuring structures (in order to cope with the short intermediate period). The proportionality should be achieved by using gate sizes proportional to command areas (*ibid* para 7.3.1).[1] In other words, IIMI proposes adopting a technology consisting of regulating and measuring structures, in order to enable operation according to the Pasten method for one or two months per year. This implies that during the remainder of the year (10-11 months!) fixed proportional distribution would have sufficed.

[1] The precise technology to be adopted remains unclear. IIMI proposes to match gate widths to the irrigable area. This is correct for the Romijn weir but less relevant for sliding gates where the differential head is at least as important or when measurements are taken downstream (by e.g. flume or Cipoletti weir). Furthermore it appears that IIMI's judgement on the Romijn weir is erroneous: "the Romijn gate cannot be used where there is insufficient head difference between the upstream channel and the head of the off-taking channel. Under such conditions the standard design calls for a sliding gate backed up with a downstream flume or weir for water measurement" (ibid para 7.3.2). This should be just the other way around. In ibid subsection 7.5.2 is stated that Romijn weirs are poorly suited for implementing rotation as "they have to be closed upwards". This does not make sense.

The question arises why IIMI did not decide to fundamentally reconsider the technology and operation by opting for fixed proportional distribution with open/closed gates for rotation during low flows. A solution could certainly be found for the intermediate period of one or two months. This question of the need for regulating and measurement structures will be taken up again in Section 7.

6.3 World Bank Discussion on Operational Issues

In 1990 a discussion paper on operational issues was prepared by the Asian Technical Department of the World Bank.[2] The objectives of the paper were to review performance of past projects, to identify lessons learnt to help guide future approaches to design and irrigation management and to describe possible alternative approaches for future projects. The paper draws heavily on the IIMI research results but also brings a perspective which reflects experience in Bank-supported projects elsewhere in Asia.

Reviewing the existing system, the authors of the paper came to roughly the same conclusions reached by IIMI (and also outlined above in Section 5). They further suggest four general reasons to help to explain why it is often difficult to implement the Pasten system in practice:

a. It requires standards of management that are difficult to sustain under the conditions prevailing in Indonesia.

b. Even if implemented correctly, it involves errors that can be significant.

c. Staff and farmers have motives for not implementing it correctly - if water is abundant there is little point in attempting to implement it, if water is scarce, farmers may intervene (in collusion with low-level staff).

d. If not implemented correctly, the physical infrastructure often compounds errors, leading in a vicious circle to further farmer intervention and further instability.

Under the heading "Possible Alternative Approaches" the World Bank paper deals first with further strengthening and improvements to the implementation of the Pasten system. It is contended that the correct implementation of design, construction and operation is essential for such a strategy. The paper concludes that this does not directly address the underlying factors which have often made it difficult to sustain improvements (see points a. - d. above). For this, modifications to the operational system and its associated infrastructure may have to be considered.

Operational Modifications. The paper suggests delegating management below the

[2] Surprisingly there has been no follow-up to this discussion paper.

secondary head to the field staff working with farmers and their representatives, rather than determining management at the level of the scheme. In effect, this means sanctioning the existing situation (*ibid* para 34: "Such an approach would go a long way to recognizing the reality often found in the field, for instance that there is already considerable *ad hoc* adjustment with field staff and farmers "negotiating discharges").

Modifications to the Physical Infrastructure. A number of possible solutions are reviewed, regarding reduction of hydraulic instability and simplification of operation: replacing the Romijn gate by a simple calibrated sliding gate (if required, provided with a measuring device downstream of the gate); matching gate widths and capacities with irrigable areas (see 6.2 above); long-crested or duck-bill weirs as cross-regulators and modular offtakes.

Rightly, the paper states (*ibid* paras 39 and 40) that whatever technological modifications are made, misuse by head-enders remain possible. "If farmers can be organized to take responsibility for water distribution within the secondary command, then these problems might be avoided. However, this requires the farmer organization to maintain discipline and act in a manner equitable to all its members" and further: "... it has yet to be shown that farmers can manage larger sub-commands in major publicly-operated schemes ...". The paper concludes: "If control at this level (secondary command) cannot be assured, then it may be necessary to consider the alternative of proportional distribution".

Proportional Distribution. The paper refers to the Balinese *subak* system as an indigenous example, pointing out that the success of that system is due to discipline based on strong Balinese traditions. Assuming a lack of discipline in areas other than Bali, the paper subsequently advocates the so-called "structured" approach adopted in large systems elsewhere in Asia (World Bank, 1986): "A structured design allows for a variable and controlled discharge to a specified level (the structured level), below which canals run full or not at all, with distribution proportional and free flowing to the outlet (pulsed irrigation, see Figure 12). This reduces flexibility in meeting differential needs but is more manageable since: (i) the number of controls is much reduced (gates below the structured level can be eliminated), (ii) measurement and monitoring are greatly simplified, and (iii) incentives for farmer interference are much reduced" (*ibid* para 43).[3] The paper further notes: "The critical decision is the level at which the system is to be structured".

[3] Two variations on the structured design are discussed in the paper (ibid para 44):

a. To design canals below the structural level to be strictly proportional at two specified discharges.

b. Gated, proportional system along the secondary canal.

These two alternatives will not further be discussed here, since a) has few advantages compared with the *subak* system and b) will inevitably lead to a situation as complicated as at present.

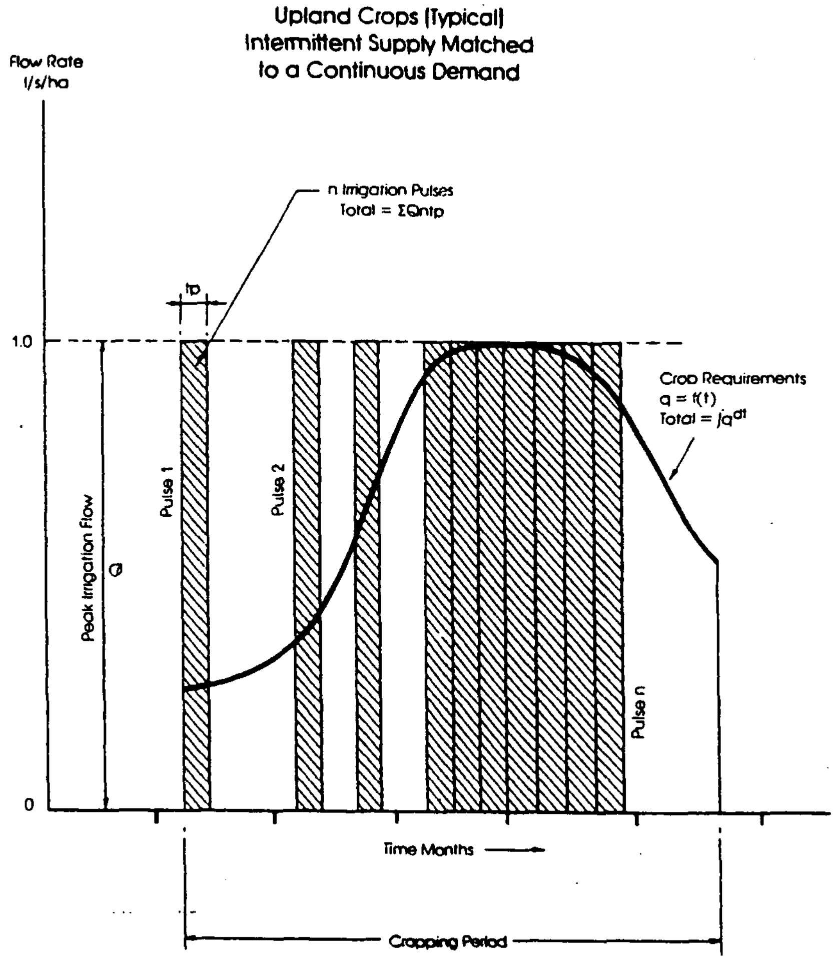

FIGURE 12 **Structured (Pulsed) Irrigation (World Bank, 1986).**

The great value of the structured system consists of point (iii) above: when canals below the structured level run full, few possibilities of tampering with the flows remain since all canals and outlets are operating at maximum capacity. On the other hand, it will be extremely difficult to match the intervals in time between the pulsed irrigation (see Figure 12) with a run-of-the-river hydrograph. These points will be discussed further in Section 7.

6.4 Concept of Semi Proportional Division

The dissatisfaction with the present situation was also discussed by the Indonesian Hydraulic Engineering Association, in 1991. At the 8th annual convention ir. Sutiyadi presented a paper in which the problems of operation of existing systems were discussed. He specifically mentioned the Romijn weir (70% of the measuring structures) in view of the mishandling of the bottom gate. He proposed that at tertiary offtakes sliding gates should be installed with broad crested weirs, whose widths are proportional to the tertiary unit areas and whose crests are at the same level.

In the wet season the sliding gates remain fully opened and the upstream water level is regulated by the check structure to a level consistent with the requirements for rice. In the dry season the sliding gates are used to meet the various demands.

This situation certainly has its merits in simplifying operation during the wet season, although if the check structures consist of sliding gates, it will be laborious to accommodate fluctuations in flow.

6.5 Training

The issue of training has surfaced repeatedly in recent decades. DGWRD staff of different levels have been trained and so have water users. This was done within the framework of various district or provincial irrigation projects. These training efforts are generally based on design assumptions (measurements up to the tertiary offtake) and operational rules (Factor-K or Pasten). They do not take into account the reality in the field as sketched in Section 5. They are therefore unrealistic and naive since they do not reflect the fundamental problems of design assumptions and operational reality.

6.6 Turnover

In the last decade, turnover has become an important topic in Indonesian irrigation. Plans have been drawn up to hand over small (< 500 ha) irrigation systems or subareas from larger projects to the farmers. Projects on Irrigation Service Fees have also been started. Although much attention has 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.

It should be noted that the given technology generally consists of complex structures that are difficult to understand. For instance, farmers often comment on the Romijn weir "having large volumes of water in front of the gate", and find the measuring scales incomprehensible. Clearly, a water division technology compatible with farmers' perceptions is called for when turnover is being considered.

6.7 Automation versus Simplification

Another issue concerns choosing between automation or simplification as alternatives to the present inadequate system of manually adjustable structures. In this context the following questions might be raised (Horst, 1990):

- Is it realistic to stick to a technology of adjustable structures requiring huge numbers of staff, when one can clearly see that these numbers cannot be reached for many years to come?

- Is it not better to adapt technology to the local managerial potential and training facilities, instead of the other way around?

- In other words, is it not better to look at other, more appropriate technologies when starting new projects or rehabilitating old ones?

Let us consider the two options available

SIMPLIFICATION
↗
ADJUSTABLE
↘
AUTOMATION

- *Simplification* of structures, so that they require fewer manual adjustments and fewer measurements, (e.g. proportional division and on/off structures).

- *Automation* in terms of automatic controlled systems, by whatever modern means are appropriate.

In both cases, fewer persons will be required to operate the system. In the first case, the skills required will also be less, because the structures are simpler; operation will be easy, and maintenance and repair will require skills at the level of the local mason and blacksmith. The second case implies an operational and maintenance staff with a very high level of skill and with knowledge of computers, electronics and mechanics.

Whichever system is adopted to deliver water to users, problems arise in the case of water scarcity. In the *simplification* case, the burden of scarcity is divided among the groups of users. The farmers understand the structures. Attempts to tamper with the structures can readily be seen. In the case of automation, the system is opaque, vulnerable and easy to tamper with.

Under Indonesian circumstances where the majority of schemes are run-of-the-river supplied, there seems to be little possibility of applying automation, without first constructing reservoirs.[4] Because of this, the automation option will not be pursued further in this paper.

6.8 Conclusions

The above discussion of issues pertaining to design and operation reveals the need for simplification of operation based on some form of proportional division. The applicability of proportional division will be discussed in the next section.

[4] Plusquellec et al. 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". Accordingly, the Sidorejo pilot scheme is supplied by the Kedung Ombo reservoir.

7 APPLICABILITY OF PROPORTIONAL DIVISION

7.1 Introduction

The present combination of a complicated, often hydraulically unstable, infrastructure and operational procedures based on cumbersome paperwork, was analyzed in Section 5. This analysis corroborates in broad lines the findings of others such as IIMI and World Bank and leads to considerations and recommendations pointing in the same direction (Section 6): simplification of the operation by adopting a water division technology based on proportional distribution. In order to assess the applicability of proportional division, it is necessary to analyze irrigation systems in relation to demand and supply of water.

7.2 The Demand

The demand for water is based on the type of crop grown and timing of the crop cycle. In Indonesia there are in general four crop types: padi, palawija, sugar and fallow, each with its own water requirements in time.

The IIMI study (IIMI, 1987) noted that in Java there is a marked tendency to plant padi during rainy season and palawija during the second planting period of dry season (*ibid*, p. 86). The first planting period in the dry season is more problematic, however, and its success depends largely on the prospects of water availability. Under the prevailing conditions it appears impossible to distribute water according to prepared district plans: "Most planting decisions are made by individual farmers without reference to the plan, but related to actual local weather and water conditions, crop prices, labour availability and so on" (IIMI, 1989, p. 171). An example of the large variation of planting dates is shown in Table 2, and of a crop mix in Table 3. Clearly it is impossible to plan and inventory the cropping patterns of each individual farmer and to translate this into a demand curve. Therefore it is logical to search for another solution for the water allocation. For that, we need to consider the supply.

7.3 The Supply

Two fundamentally different situations exist regarding the supply of irrigation water in Indonesia:
- run-of-the-river
- storage.

Run-of-the-river (r.o.r.). Most of the Indonesian irrigation systems are still supplied by r.o.r. diversions. These diversions are in general able to supply sufficient water for growing padi in the wet season. In the dry season the supply will drop and show

Variation in Planting Dates for Second Dry Season, 1986
East, Central and West Java Study Sites

Province and Block	Maize Planting Date			Soybeans Planting Date			Peanuts Planting Date			Padi Planting Date		
	First	Last	Modal	First	Last	Modal	First	Last	Modal	First	Last	Modal
E. Java												
EJ a99	6/7	27/8	18/7	4/7	22/8	21/7	14/7		14/7	4/7	28/7	24/7
EJ B-13	25/5	28/8	15/7	9/7	27/7	25/7	25/7	20/8	25/7			
EJ B-29	5/8	5/9	5/8	29/6	20/7	1/7	7/8	10/8	10/8	28/6	30/7	4/7
C. Java												
CJ CKG-7	9/7	18/9	14/8							14/9	14/9	14/9
CJ CKG-3	15/4	25/8	21/8				28/6	28/6	28/6	7/5	10/9	17/8
CJ JRT 2	20/7	18/8	18/8	4/7	18/8	23/7	25/6	23/8	29/6	25/7	20/8	10/8
CJ JRT 5	4/6	9/9	19/8	9/8	28/8	10/8	4/6	3/9	7/7			
W. Java												
WJ MRT I	10/8	10/8	10/8				2/8	30/8	16/8			
WJ MRT IIb	3/8	24/8	10/8				20/6	2/9	30/7			
WJ JSM 2	21/7	9/8	9/8	***** Mainly fallow due to severe rat problem ******								
WJ JSM 7	12/8		12/8	***** Mainly fallow due to severe rat problem ******								

TABLE 2 (IIMI, 1987).

Crop Mix for First and Second Dry Seasons, 1986
Jarot 2 and 5, Gung Section, Central Java

Crop	Jarot 2 First Dry Season	Jarot 2 Second Dry Season	Jarot 5 First Dry Season	Jarot 5 Second Dry Season
Rice	XX	XX	XX	
Soybeans	XX	XX	XX	XX
Sugarcane	XX	XX	XX	XX
Maize	XX	XX	XX	XX
Peanuts	XX	XX	XX	XX
Long Beans		XX	XX	XX
Cassava	XX	XX	XX	XX
Sweet Potatoes	XX	XX	XX	
Mungbeans	XX	XX	XX	XX
Chilies	XX	XX		
Tomatoes			XX	
Intercropped			XX	XX
Squash			XX	XX

XX indicates present in the block that season.

TABLE 3 (IIMI, 1989).

frequent fluctuations. During this period, water supply is generally too short for all farmers to grow padi.

In spite of the attractiveness of padi growing, only those farmers who have access to water are able to do so, sanctioned or otherwise. Area-wise this often results in a skewed situation, where padi is grown in the head-end of irrigated areas and the tail-end farmers may be forced to leave land fallow.

Regarding operation, it should be noted that no operational plan can be made to match the r.o.r. supply, without re-adjusting the plan every one or two days (see Figure 13). This will inevitably enhance uncertainty among farmers. But without frequent re-adjustments, either water is wasted or farmers will experience shortages. In this context, the solution of structuring proposed by the World Bank (World Bank, 1990) should also be questioned: for the pulses (see Figure 12) to be synchronous with the fluctuations of the r.o.r., a repeated change of irrigation intervals is required.

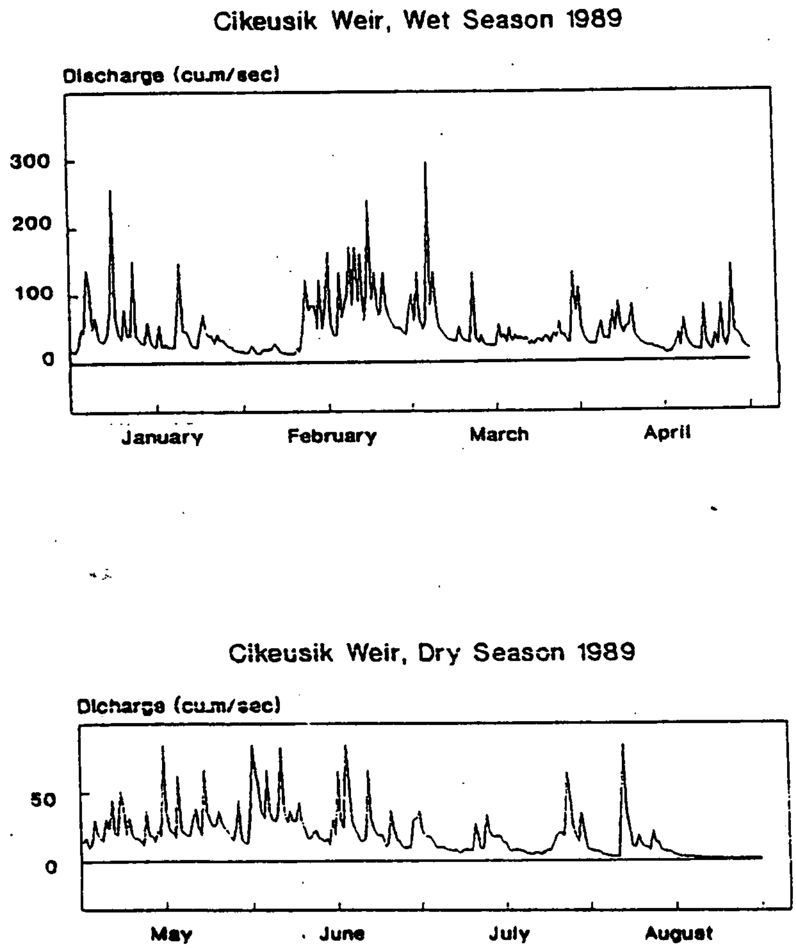

FIGURE 13 River Discharges (IIMI, 1989).

The only solution here remains to opt for proportional division where the incoming flow of water is divided *up to* tertiary offtake (*subak* system). The advantages and disadvantages will be discussed further in subsection 7.6.

Storage. In the case of storage of irrigation water, the allocation of water becomes more predictable: the uncertainty of the expected dry season flow volume is partly balanced by the water stored at the end of the wet season. Moreover, the reservoir outlet is controlled and the fluctuation of the river flow is reduced by the reservoir. In such a case the solution of structuring as described in World Bank 1990, is applicable.[1]

7.4 The Structured Level

The structured level (below which the system is proportional) can be adopted for r.o.r. projects at the river diversion point, since there is no scope for pulsed irrigation supply (see subsection 7.3). In the case of storage, the structured level logically should be at the head of the secondary canals (above the tertiary and below the primary levels).

7.5 The *Golongan* System

IIMI, 1987, p. 84, states: "In Indonesia, the *golongan* system is used as a procedure for scheduling cropping patterns and planting dates for given secondary or tertiary blocks of irrigation systems. The practice of minimizing water demand through staggering planting dates preceded the Dutch period, but the Dutch elaborated on the *golongan* system, particularly with regard to scheduling cropping patterns to permit sugarcane and padi rotations under the Culture System". In most systems a *golongan* includes more than one tertiary block, while the size of a *golongan* is a function of the number of *golongans* established for the system (*ibid*, p. 84). The staggered (14 days) planting dates are based on previous records of water supply.

It is clear, as shown in Figure 14 that the reduction of peak water demand only becomes apparent if there are many *golongans*. It is therefore amazing that this system has been maintained until today, in view of the shift in priority from growing sugarcane to growing padi. Moreover, the fixed *golongan* schedule rarely matches the uncertain r.o.r. hydrograph, resulting in a loss of irrigation water when rains start early and in unplanted areas (in the first *golongan(s)*) if the rains fall late. Proportional division of the early flows to the tertiary blocks and a *golongan* arrangement **within** the tertiary block seems to be the appropriate solution for r.o.r. situations: the early flows are fully utilized, while farmers within the tertiary block can, by mutual agreement, organize their planting activities. If sugar is grown, the

[1] Note that this method was developed in India where most irrigation schemes are supplied by reservoir storage. Shanan (1992) states that one of the characteristics of a structured system is: "A cropping system designed to match the available water as *routed through available storage*" (my emphasis).

sugar area might in such a case be equally divided among tertiary units in order to make proportional division possible.

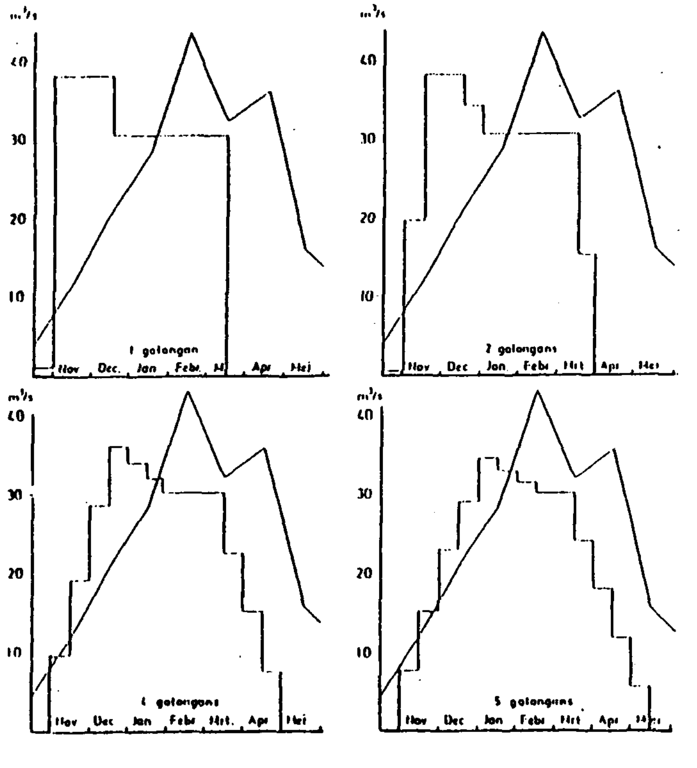

FIGURE 14 : Water Requirements and River Discharges for different numbers of Golongans. Source: Ter Hofstede et al., 1979.

If it is decided to maintain the *golongan* arrangement in the case of storage with a structured system, the areas below the structured level should logically be one *golongan* (e.g. secondary block).

7.6 Technology and Farmers' Acceptance

Proportional division can, in principle, be attained by either orifices (pipes, undershot gates) or by weirs (broad or sharp crested). Although the irrigation systems in North India and Pakistan are of the orifice type, the weir type might be preferable if flows fluctuate. Ankum (1993a) noted that if discharges fluctuate, systems (with orifice type structures) will not function proportionally.

The main advantage of the weir type flow divider is its transparency: the division is clear and no measuring is required. This brings us to the discussion of the applicability of proportional division. The contention of some engineers in Java that the

Subak works satisfactorily in Bali "because of a different religion", appears to be questionable, since both Hindu and Moslem groups practise the *Subak* system in Bali. The World Bank discussion paper 1990, states: "Without strict farmer discipline, it is a simple matter for headenders to draw more than their fair share either by heading up water in the parent channel with a few stones or a cross bund, or by blocking the outlet to the tail-end". The advantage of the weir type divider, however, is that any tampering is clearly visible; in other structures such as gated orifices or regulating weirs, tampering can be concealed (e.g. Romijn bottom gate).

7.7 Final Considerations

For most of the r.o.r. projects it appears impossible to match water demand with water supply. Even in the improbable case of the authorized cropping patterns being adhered to, it remains difficult to translate the water requirements for each individual plot with its own specific crop and specific planting dates into a realistic demand curve. Nevertheless, assuming that this might be achieved, the demand curve will never satisfactorily match the erratic flows in the river. Under these circumstances, the only way to utilize the available water as optimally as possible is to divide the water proportionally to the irrigable areas. The assumption is that the group of farmers in a tertiary unit will use this erratic flow best, because they have field-level knowledge.

Proportional division throughout the year might be problematic if there are very low flows during the dry season. In such a case rotation (*giliran*) is called for and the openings could be fitted with on/off gates.

Finally, an often-heard objection to proportional division is its lack of flexibility (in its broadest sense). Numerous case studies, however, have shown that flexible demand systems generally operate at low performance levels, with headstream farmers receiving the major share of water (Shanan, 1992).

8 RESUME AND CONCLUDING REMARKS

This paper has endeavoured to analyze the development of water division technology in Indonesia. As pointed out, during the 1930s two important components of irrigation technology evolved: the invention of the Romijn weir for measuring and distributing water to groups of farmers (in secondary and tertiary blocks) and the introduction of the Pasten method to plan and allocate water to those groups. Both developments should be considered in the context of well-organized sugar operation, requiring a high degree of discipline.

At the end of the 1960s Indonesia embarked on a massive development of irrigated agriculture with financial assistance from World Bank, ADB and bilateral donor agencies. Most of these agencies stipulated that foreign consultants be involved in planning, design and supervision of construction. Consequently, irrigation technology became influenced by a large variety of views from different consultants, each with their own differing technological background.

In the first place a wide variety of water division structures was proposed in new and rehabilitation projects. Some of these proposals were appropriate; many, however, resulted in hydraulically unsound designs (such as Romijn weir offtakes combined with gated check structures). Overall it could be observed that the principles of controlling and measuring flows as prescribed in the 1930s are still valid.

In the second place, operational procedures were developed based on the principles of the Pasten method (Factor-K method used at present). This method was elaborated by various consultants and contains lengthy procedures requiring large numbers of trained staff. It further assumes strict discipline.

In view of the above, it can be concluded that in spite of some modifications, the present water division technology is still rooted in the colonial irrigation of the 1930s. In retrospect it is remarkable that whereas the agricultural, social and economic environment changed drastically after independence, the irrigation technology (design and operation) did not. This might be the underlying cause of the incompatibility between assumptions on design and operation on the one hand, and the operational reality on the other.

This paper does not claim to present tailor-made solutions. Irrigation is too situation-specific for this to be possible, and furthermore a good design can only be achieved if the water users are involved in the design process. The attention given in this paper to proportional division and on/off structures should therefore be considered in the light of possible alternatives, away from the ingrained "technical" systems and Pasten operation.

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