TYPOLOGY AND PARTITION FOR IRRIGATION SYSTEM OPERATION APPLICATION IN SRI LANKA

by

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Abstract

This paper presents a generic typology and partition GRID, developed for canal operation. It is based on four levels of analysis: Technology (Factory & machines)- Hydraulic (Networks) - Hydrology (Water context) - Policy (Service to consumers). This GRID is then applied for manually operated irrigation systems in Sri Lanka. It focuses mainly on the NETWORKS level, as technology and service are mainly similar in most irrigation systems found in Sri Lanka.

The criteria of this typology are the main physical characteristics of irrigation systems and sub-systems, viz. presence of return flow (Yes/No), source of supply (Reservoir or Diversion), canal topography (Storage/No storage). The study, identifies four main types of irrigation systems in Sri Lanka and presents hydraulic and other management considerations relevant to canal operation.

1. GENERIC TYPOLOGY FOR IRRIGATION SYSTEM OPERATION

A typology is a set of pertinent criteria and partition rules to describe irrigation systems and sub-systems. Its practical objective, is to facilitate the understanding of a specific domain and promote accordingly some improved management rules. To be effective, a typology must be activity oriented. Here, the typology, focuses on canal operation. It is planned to use it, in four ways:

- **Evaluation of irrigation system properties for canal operation** to facilitate the day-to-day decision making of irrigation managers (local management);
- **Partition of irrigation systems** into more homogeneous sub-systems to define consistent units of operation. The goal here, is to improve the allocation of means for operation (local management);
- **Comparison between different irrigation systems** with the goal to improve allocation of means among schemes, on the basis of the difficulty of operation (national/regional level);
- **Assessment of irrigation schemes performance** with regard to the physical, agricultural and institutional set-up (policy makers, research and development institutes).

This paper will not discussed the above listed uses of the typology, which are still under investigation. It will present **the methodology** used in designing a generic typology of irrigation systems and the first attempt made, to classify irrigation systems under the Sri Lanka Irrigation Department.

1.1 Framework

Canal operation can be defined as an industrial process by which INPUTS is transformed into OUTPUTS. This applies for single structure or the entire irrigation system. The performance of this process relies on the skill of the staff, the properties of machines, and the characteristics of INPUTS. The achievements should be compared with the targeted service of water. The latter is dependent on the opportunities and constraints of the hydrological and policy contexts.

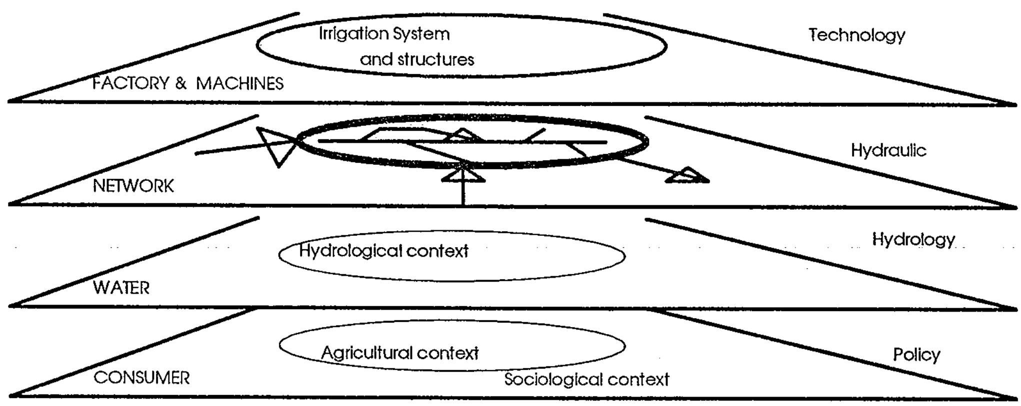
Accordingly, the typology for canal operation is organized in four levels (Figure 1). The first level, FACTORY looks at the different MACHINES composing the system. It encompasses what is often called 'hardware' and focuses on the physical characterization of the irrigation machines, in fulfilling their functions: conveyance (canals), storage (canal - reservoirs), water control (cross-structures) and deliveries (offtakes and outlets). Safety structures are not addressed in this study.

The second, is the level of NETWORKS. It deals with the perturbations in inputs that irrigation systems are likely to face. It considers perturbations related to the nature of water flows at the boundaries of the system or subsystem. The features in that regard, are related to the different networks within the scheme, i.e., source, irrigation, drainage, runoff, return-flow,....

The third level, WATER, consists of opportunities and constraints on the availability, quality and impacts of water in the hydrological context.

The fourth level, CONSUMERS, focuses on the service of water for users/clients, based on policy and quality of distribution. Sociological and institutional setups, are also taken into account in the fourth level.

Figure 1. Framework for canal operation approach



1.2 Considerations on conveyance, delivery and control processes in canal operation

Conceptually, the canal operation process, at least for the more common type, can be split into three components:

- **Balancing the discharge.** It means adjusting the supply to offtake discharges and losses or adjusting the deliveries to the available discharge. Flexibility in the balance, can come from ***storage variation.***

- **Controlling the water depth along the canal.** It is made to maintain water level upstream each offtake, within a limited range of fluctuations.

- **Controlling the settings at the offtakes.** It consists of adjusting discharge deliveries to new targets and to the new water profile.

1.3 The Level of FACTORY & MACHINES

The matrix of criteria and partition rules is displayed in tables 1.a and 1.b.

a. Control technology: Discharge and volume control:

Discharge control (via water depth), is the more common type. However, more and more considerations are given to systems based on the control of volumes. Dynamic regulation (Rogier D. et al, 1988) is one example of volume controlled technology applied to irrigation canals without reservoirs. This technique is not necessarily based on high technology. The well-known Gezira scheme in Sudan, was designed on this technique, in 1926 (Plusquellec, 1990). It stores water in the tertiary canals during the night when no irrigation is undertaken.

b. Downstream and upstream control:

Most of the irrigation gravity networks, worldwide, are upstream controlled. However, downstream control as an alternative technique, has received much attention from engineers and irrigation managers because of its potential advantages, Burt (1987), Plusquellec (1988, 1994), Malaterre (1995).

Table 1a. Matrix of criteria: Level of FACTORY

Criterion of characterization	***Related Properties for operation***	***Partition criteria***		
Controlled variable	• Flexibility in deliveries • Regulation of water balance	Discharge	Volume	Composite
Type of control	• Supply/demand driven	Upstream	Downstream	
Degree of operation	• Amounts of efforts • hydraulic stability	Fully operated • Manual	Low operated system • Automatic • Semi-fixed	No operation • Structured

c. Degree of operation:

Clearly, the amounts of effort that the agency has to put in operating a system, and the performance achieved, depend highly on the degree of operation.

- **Fully operated systems:** These are systems for which every machine, i.e., offtake and cross-regulator, requires gradual adjustment devices. They have to be operated by the irrigation staff when a change in the flow regime is to take place or in response to any unscheduled deviation. The difficulty in operating these types of systems, is related to the numerous number of structures to be adjusted at the same time. A high number of structures, implies the mobilization of large amount of resources from the agency (human, transport means). It also complicates the process by creating large interactions among reaches.

- **No operated system:** These systems have been largely developed in India and Pakistan (Shanan, 1992) and Nepal (Pradhan 1996). Water delivery is organized around pulses of constant discharge with a varied frequency. Distribution is proportional and structures are fixed and set once and for all at the construction stage (no movable parts). Although, structured systems, are limited to minor canals and the upper canals remain fully operated, still, the savings of efforts in manipulating the structures, are enormous.

- **Low operated system:** Hydraulic automatic systems are based on machines controlling the water level in canals in a wide range of discharge variation. They are either downstream or upstream

operated. The control of water level, is achieved by mechanical moves of the gate, driven by hydraulic forces, without any external source of energy or human intervention. This type of gates, includes AMIL and AVIS/AVIO gates, Goussard (1987), DACL, Clemmens and Replogle (1987), and Danaidean gates (Burt and Plusquellec, 1990). To minimize the impact of unavoidable fluctuations of water level, automatic cross-structures are often associated with constant discharge distributors such as baffles.

d. <u>Physical characteristics of irrigation machines</u>:

The irrigation machines in a system can be divided into few categories; machines for conveyance and storage (*Canal Reach*), machines for control of water depth and for delivery (*Structure*). The behavior of irrigation systems should be analyzed first according to the original design of irrigation machines and second by incorporating on top of that, the present physical status, i.e., deviation from original design. Matrix of criteria for this level is given in table 1.b.

Control and delivery machines: Structure

Water depth control along the canal and delivery adjustment at offtakes, relies on physical structures that transform *Inputs* into *Outputs.* Physical assessment of control structures is essential to understand the performance that managers can expect from them. The related properties for operation of machines proposed here for consideration, are the freedom and the precision in the output adjustment, then the amounts of efforts for manipulation and control, last the hydraulic stability based on sensitivity. These properties lead to identify criteria for typology.

<u>Adjustment</u>: The related properties of this criterion are freedom and precision of control. The partition can be based on the classification of structure proposed by Horst (1983):

1. Fixed:	no adjustment is possible, e.g., weirs , orifices, dividers,...
2. Open/closed:	generally gates for minor canal either fully open or closed
3. Stepwise adjustment:	regulation by steps, modules or stoplogs
4. Gradual adjustment:	gated orifices, movable weirs.
5. Automatic:	hydraulically moved gates.

- For fixed structures, freedom is nil, since output is directly imposed by on-going discharge (input), and precision is meaningless.

- For open/closed structures; freedom, and precision are not relevant.

- For stepwise adjustment, freedom and precision are limited by the number of discrete steps between zero and full capacity.

- For gradual adjustment structure, the degree of freedom is usually high. It is always possible to choose any setting between zero and the maximum value. However, the real setting will be imposed by the *Input* value. Precision, will depend on the increment of the mechanical adjustment.

- For hydraulic automatic structures, flow conditions are the governing factors. These structures, cannot be adjusted. Freedom in this case, is also nil, but the output is normally constant by objective. Precision is related to the range of variation of output as a result of variation of input.

<u>Manipulation and control</u>: The related property targeted by the *manipulation and control* criteria is the amount of efforts needed to operate the adjustable machines along the canal. For this property, the criterion on manipulation leads to distinguish manually, hydraulically, and motorized operated machines. The criterion on control separates in situ and remotely controlled machines.

Sensitivity: The *sensitivity* criterion is related to the hydraulic stability of the machines. For delivery, overshot structures are more sensitive than undershot structures (assuming head losses are equal). Actually, they are three times more sensitive. The difference is due to the exponent of head losses variable in discharge equation, $\frac{3}{2}$ and $\frac{1}{2}$, respectively. Due to a feedback effect from the downstream side of the machine, the sensitivity of an offtake is not always simply related to the current head losses (Renault and Hemakumara, submitted).

For control, overshot structures are less sensitive than undershot structures. The same perturbation in the discharge, will be reflected in water depth, three times less for overshot structure (weir type) than for undershot structure (orifice type).

Physical condition: The current physical condition of machines influences greatly the adjustment, the manipulation and control, and the sensitivity of the machines irrespective of their properties at design stage.

These properties are site specific, and largely dependent on the maintenance of the system, as well as on the discipline of the users. The physical condition of the structure is a typical criterion for which the degree of consistency is variable. Despite its high variability, this criterion is retained in the typology because of its importance in canal operation and because it can sometimes provide strong and reliable criteria for partitioning the system.

Table 1b. Matrix of criteria: Level of MACHINES

Type	*Criterion of Character-zation*	*Related Properties for Operation*	*Partition of Criterion*			
Structure	Adjustment	• Freedom and precision of control	Fixed	Open or Closed	Stepwise	Gradual
	Manipulation	• Amount of efforts	Manual	Hydraulically automatic	Motorized	
	Control	• Amount of efforts	In situ controlled	Remotely controlled		
	Sensitivity	• Accuracy in control	Low	Medium	High	
	Physical condition	• Deviation from design	Low	Medium	High	
Reach	Storage	• Responsiveness • Regulation of water balance	No Storage (DBK)	Distributed Storage (SBK)	Localized Storage (Intermediate Reservoir)	
	Control	• Depth control	Under back-water effect	Under normal depth	Under freeflow	
	Bed material	• Seepage losses • Roughness	Lined	Unlined		

Conveyance and storage machines: Reach

Reach is taken here as a machine that can store and/or convey water. Criteria linked to 'reach' are: storage, control, and bed material.

Storage: The first property related to this criterion is the reach responsiveness. The response of reach for any known or unknown perturbation of inputs, is related to the topography of the reach. *Double Bank Canal (DBK), Single Bank Canal (SBK)* and reaches with *Intermediate Reservoir,* behave differently in such perturbations. Furthermore, on-line storages act in two contradictory fashion that are important for time lag. On the one hand, it increases time lag between issue and delivery by lowering the velocity and damping the wave. On the other, it allows to issue additional water in advance of the wave, reducing considerably the time-lag. The second property related to this criterion is the regulation of water balance

at subsystem level. An intermediate storage along a canal can be utilized as a partition point for different units of operation as it mitigates fluctuations coming from the upstream water balance.

Control: The water depth along canals is controlled by backwater effects from regulators. Depth decreases with distance, and reaches a constant depth when regime reaches normal flow. The control is interrupted whenever super critical flow occurs. The latter is commonly found at cross-regulators having downstream free-flow conditions. Therefore the partition for this criterion consider three situations: under backwater effect, under normal depth, and under free-flow.

Bed material: This criterion is integrated in the typology with respect to one main property, the seepage losses. It separates unlined canals having high and fluctuating seepage losses and lined canals having low and almost constant losses. However, the bed material criterion interact with control criterion through the roughness property of the reach.

1.4 The Level of NETWORKS

This level expands on the perturbations of inputs in irrigation systems. It considers perturbations related to the nature of fluxes at the boundaries of the system or sub-system. Features in this regard, are related to the network lay-out and its properties at boundaries.

a. Characterization criteria: main supply Q(t,0):

The degree of control on the main supply Q(t,0) expresses the possibility of adjusting its value through the entrance structure between zero and maximum. This is accomplished by modifying the structure setting (w) (discrete or gradual control). Systems fed by **Reservoir,** have a high degree of control. Those fed by **River Diversion,** have a low degree of control. Furthermore, it is worthwhile to consider two types of canal diversion. For **Canal Series Diversion**, the supply is dependent on the upstream sub-system management and the degree of discharge control is low if not nil. For a **Canal Branch Diversion**, the degree of control is not nil. Discharge can be set within a reasonable range so that, it does not jeopardize the other sub-units downstream the main canal.

b. On-line discharge balance Q(t,x):

Discharge distribution along the canal is a top-down process **governed by a continuity equation.** Controlling discharge can be defective for many reasons:

- uncontrolled inflow;
- unscheduled reduction in withdrawal;
- unscheduled outflow (illicit taping, etc.);
- difference between expected and actual canal losses;
- difference between expected and actual offtakes discharge.

c. Lateral flows:

- the **Return-Flow (RF),** from drainage or from overflow at the tail end of irrigated fields.
- the **Run-off** in a **single-bank canal (SBK)** or in cases of **ditches** connected to canals. Discharge can reach high peaks during heavy rains.
- Unexpected **Reduction of the withdrawals** can also cause perturbations in irrigation canals (after a rainfall event). It is related to the **flexibility** allowed to the users and the **discipline** within the system.
- **On-line seepage.** Variation occurs when a significant change in water depth, modifies the wetted perimeter and leaks of **un-lined canals.** It also happens for a small change of discharge when water depth is already close to the top of the canal (by spilling or by losses through holes in the upper part of the banks). **Lined canals** are much less sensitive in that regard.
- **Unexpected outflow** (illicit tapping). This factor is related to **discipline.**

Table 2. Matrix of criteria: Level of NETWORK

Criterion of characterization	*Related Properties for operation*	*Partition of criterion*			
Source Supply	• Variability • Degree of control	Reservoir	River Diversion	Canal Branch Diversion	Canal Series Diversion
Layout Lateral flows	• Variability of on-line discharge	Return Flow (RF)		Non Return Flow (NRF)	
		Single Bank Canal (SBK) with runoff		Double Bank Canal (DBK) without runoff	
		Runoff ditches		No ditches	

d. Delivered discharge:

Accuracy in controlling deliveries is very important for the critical discharge balance. **Freedom** in adjustment (see above) and **physical condition** of the offtake are the properties to consider here. Furthermore, the behaviour of the canal will rely highly on the **sensitivity** of the delivery machines. This dependency is in two ways. Perturbation of water depth in a reach with highly sensitive offtakes, creates large deviations in the on-going discharge in the main canal. Inversely, perturbations of discharge entering such a reach, are likely to be attenuated by the sensitive offtakes. At global level, relative deviation of discharge amplifies along the canal in case of low sensitive offtakes (Horst, 1983).

1.5 The Level of WATER

The availability of water resource. Abundance or shortage, makes a big difference in terms of performance levels that managers should achieve. Where water is abundant (compared to demand) targets in delivery distribution can include a safety coefficient. Operation allows overflow losses, to some extent, depending on the downstream abilities to accommodate them. Where water is insufficient, operation has to be more precise. Targets have to be defined in more accurate ways and implementation should follow.

Quality of water: Solid transport and sedimentation are serious problems affecting physical characteristics of irrigation machines. Impacts of sedimentation are often taken into consideration as part of the maintenance activity. However some systems already include this problem at design stage and within the operation rules.

Recycling of water: The reuse of water drained from irrigated areas, is an important asset in water management where water shortage occurs.

Conjunctive use of water: Groundwater use, is something more and more popular as technology of pumping becomes more accessible (O'Mara, 1988). Most of the time groundwater pumping is used to compensate rigidity or low performance of surface delivery system. In Punjab, Pakistan, density of wells is inversely related to the quality of surface water (Strosser and Kuper, 1994). Areas lacking in additional supply from groundwater, because of the high pumping cost or the low quality of water, should receive more attention than areas where pumping facilities can compensate inadequacy.

Soil and water salinity and water logging: These are environmental hazards tremendously important in arid regions. They represent a severe threat to irrigation schemes. It is clear that operation of irrigation systems have to take into considerations the spatial distribution of these issues in order to provide a selective and adapted service of water.

Health: This is the last aspect to consider for water service. It is a well known fact that irrigation, despite its positive effects on the economy and incomes of farmers, also has some adverse impacts on health through vector-borne diseases. Maintaining water in canals during a long period of time, modifies the cycle of reproduction and spreading of vector of diseases. The link between irrigation and health can be strong. Fluctuations of water flows, in this instance, is considered by many as highly positive for health. Recommendations from health experts are somewhat converging towards more variability of the flow regime to prevent the breeding of mosquitoes (Hunter et a,1993).

Table 3. Matrix of criteria: Level of WATER

Criterion of characterization	***Related properties for operation***	***Partition of criterion***		
Upstream Source (hydrological context)	• Water availability	Abundance	Shortage	Varying (seasonally)
	• Water quality	Sedimentation Saline	No sedimentation Not saline	
Downstream Source	• Additional water availability	Recycling systems	No recycling	
		Conjunctive use	No Conjunctive use	
Impacts	• Environmental impacts	Salinity hazard Yes	Salinity hazard No	
		Logging hazard Yes	Logging hazard No	
	• Health impacts	Stable Flow	Fluctuating Flow	

1.6 The Level of CONSUMERS

The identification of **water consumers** and the estimation of their specific needs (table 4), are of great importance to define the service of water.

Multiple uses of water in irrigation schemes are included more and more, in the management policy. Domestic water use, environmental use, fisheries, perennial vegetation, hydro-power are some of the main important ones. Operation and delivery rules have to take into consideration not only the primary satisfaction of crop needs, but also the other uses of water.

Distribution policy for agriculture is one important aspect to consider for the quality of service. High variabilities in cropping pattern and climatic conditions or any important agricultural properties, require more flexibility in the delivery pattern. For farmers, the most desirable is a fully flexible pattern. It is the more costly as well. A compromise has to be reached between rigidity and flexibility. For the managers, the distribution pattern influences the amount of effort in operating the system. Flexibility without automatic facilities, necessitates numerous manipulations.

Quality of distribution, is important to operate a system. Although it is desirable to have a good quality of service over the entire system, this goal is out of reach in some cases. Priorities should then be defined on a fixed or a rotational basis. These priorities often correspond to systems with insufficient water. They specify the policy to channel the limited available amount of water. Priorities can be defined on the basis of the values of crops (high /low), the water holding capacity of the soil and the

climate. Lastly, the agreed equity policy in the distribution of water, whatever the rationale behind, is a criterion to consider for defining priorities.

Sociological context brings additional aspects that have to be considered. Discipline of the users with regard to illicit operation, is important. Communication between managers and users, is the key point of the mutual understanding about management activities.

Institutional aspect of water management has also to be taken into account for operation. Several levels of organizations are involved in the water management from the main reservoirs to the fields. The recent transfer of management to farmers organization, is a strong aspect to be considered in the organization and the set up for operation.

Table 4. Matrix of criteria: Level of CONSUMER

Criterion of characterization	*Related Properties for operation*	*Partition of criterion*		
Use of water	Priorities and sharing between users	Single use	Multiple use	
Distribution policy	Distribution mode	Supply-based	On request (arranged)	Free-access
Performance of distribution	Performance of operation	High	Medium	Low
Sociological aspect	Hydraulic stability	Discipline	No discipline	
Institutional aspect	Management setup	Headworks	Main system	Distribution system

1.7 Application

Application of the typology and of the partition grid, can be seen as a Geographical Information System (GIS) approach. For each criterion, a layer of information displays the distribution of the variable within the considered domain. Some criteria lead to spatial units like command areas, drained basins, etc., whereas some others are points along the irrigation network, e.g., a breaking point in the water depth control. Homogeneous units for operation, can be created from an overlay of criteria, with weighting factors.

2. A NETWORK TYPOLOGY FOR SRI-LANKAN IRRIGATION SYSTEMS

This specific application refers to existing irrigation systems within the Sri Lankan Irrigation Department. The typology focuses on the NETWORK Plane. In Sri Lanka the types of structure are mostly standard types, undershot gated regulators with side weirs and undershot gated offtakes with downstream weirs. Information on sensitivity of irrigation machines requires intense data collection. Hence, it is not addressed by this preliminary survey. Therefore, the plane of MACHINES is not included in this analysis. The plane of WATER is essentially based on the criterion of water availability (abundant or shortage). The service of water is still basically monolithic as it is supply based, mainly for agriculture and paddy cultivation. However, changes are underway and this plane has to be addressed in future.

Four criteria are used a priori, in this first analysis: the supply condition (Reservoir/ Diversion) - the topography (Single Bank - Double Bank) - the storage (with/without storage) - the return flow (with/without). The results of the typology applied on a sample of 64 major systems above 1000 ha, are given in Table 5.

Table 5. Network plane of the typology for 64 Sri Lankan major irrigation systems

Type	*Physical characteristics*			*No. of schemes*
1	R	SBKS	NRF	19
2	R	SBK0	NRF	18
3	D	SBK0	NRF	8
4	R	SBKS	RF	4
5	D	SBKS	NRF	4
6	D	SBK0	RF	3
7	R	SBK0	RF	2
8	R	DBK0	NRF	2
8	R	DBK0	RF	1
10	D	DBK0	RF	1
11	D	DBK0	NRF	1

R/D = Reservoir/Diversion
DBK0=Double Bank no storage
SBK0= Single Bank no storage
SBKS= Single Bank with storage
RF/NRF = Return-Flow/No return-flow

Findings from this survey and main considerations for further typology developments, are:

- Double-Bank canal are not common in Sri Lanka as only 5 cases are recorded (8%). Hence this criteria, has been dropped in the further development by considering Single Bank canal only. Systems falling previously in Double-Bank category, had been regrouped with similar Single-Bank classes.

- Return-Flow systems, are split into several small categories. As a whole, however, they amount for 12 cases (19%). Furthermore, the impact of Return-Flow is permanent. Accordingly, Return-Flow has been selected as the main criteria of a specific category of systems, which are variable for the other criteria.

- River-Diversion type system represents 17 cases (27%).

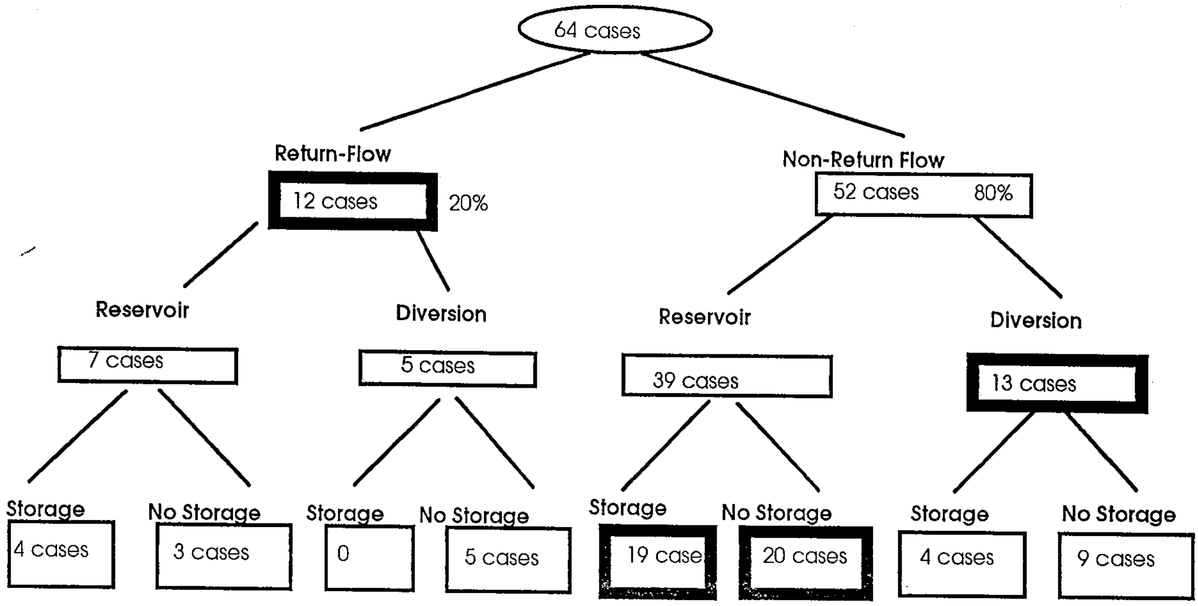
- Intermediate storage are found in 27 systems (42%).

The three criteria retained at the final stage, namely, Return-Flow, Supply and Storage, defines 12 potential types of systems identified. They are displayed in Figure 2 on a hierarchical tree. Some classes, have limited number of cases. Four categories have been extracted for further consideration:

- Systems having Return flows, whatever the other feature are.
- Non return-flow systems using Diversion on the river, with or without storage.
- Non return-flow systems, supplied by a Reservoir without online storage
- Non return-flow systems, supplied by a Reservoir with intermediate storage

For the four main types of systems, Table 6 provides the main hydraulic features that are of interest for canal operation. The table, also identifies the main problems and opportunities. It provides some specific hydraulic and management considerations. General conclusions derived from this typology will be analyzed in depth in subsequent papers.

Figure 2. Tree display of system types of Sri Lanka Irrigation Department



3. PERSPECTIVES

The authors advocate the use of typology to define consistent and effective Plan for Operation and Maintenance (P.O.M.) which are currently being updated by the Irrigation Department of Sri Lanka.

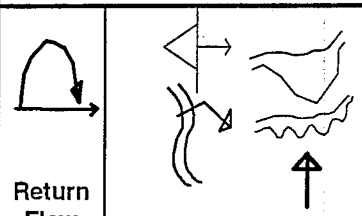
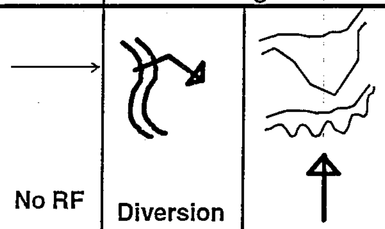
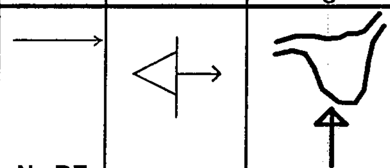
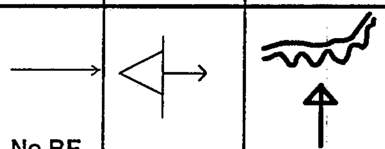
However, in depth investigations, have to be made. Further developments will focus on:

⇒ In depth analysis of the most common types of the typology with respect to planes not yet covered;

⇒ Simulations of operational rules to improve water management for the most common types;

⇒ Application of the partition grid to enhance operation within an irrigation system presenting a great variety of situations.

Table 6. Hydraulic, canal operation & management considerations for the five main types of systems.

Type	System Features	Inputs Features	Main constraints/ Opportunities for Canal Operation	Main Hydraulic Considerations	Other Management Considerations
RF 12 cases	 Return Flow; Res. or Div. Storage/NS	• variable lateral inflow	• difficulty to forecast on-line discharge • flooding during rainfall period	• deviations of discharge propagates downwards on the main canal or through the return-flow	• increased efficiency due to loop system • return flows, requires higher canal capacity at tail reaches • difficulty to maintain targeted water depth under low flow conditions (without return flow) at tail reaches
D 13 cases	 No RF; Diversion; Storage/NS	• unpredicted main supply • unpredicted lateral inflow limited to rainfall period	• difficulty in controlling main supply discharge • presence of online storage, can alleviate fluctuations	• high unsteady flow conditions	• requires highly efficient canal operation techniques both during rainfall and non-rainfall periods • silting from river and run-off
RS 19 cases	 No RF; Reservoir; Storage	• fixed and known supply • unpredicted lateral inflow limited to rainfall period • online operational storage	• good control of main discharge to match with deliveries • easier canal operation • management of reservoir levels to harvest more rainfall	• damping of unsteady flow conditions • control of lag-time: between high value due to damping to low value using releases from intermediate storages	• silting from run-off • requires improved techniques in canal operation during rainfall periods
R0 20 cases	 No RF; Reservoir; No Storage	• fixed and known supply • unpredicted lateral inflow limited to rainfall period • no online operational storage	• good control of main discharge to match with deliveries • unable to store run-off	• unsteady flow conditions • no alternative to overcome lag time in delivery	• requires efficient canal operation techniques both during rainfall and non-rainfall periods • silting from run-off

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