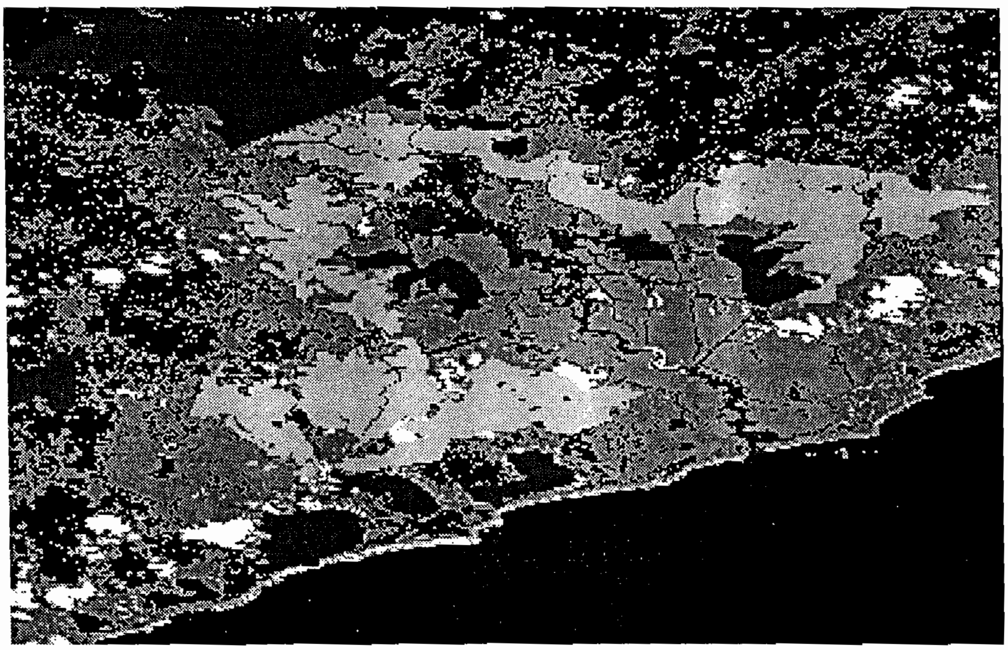
ECOLE NATIONALE DU GENIE DE L'EAU ET DE L'ENVIRONNEMENT DE STRASBOURG

INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE

IRRIGATION DEPARTMENT OF SRI LANKA

Geographical Information System for Water Management in a Cascade System

Kirindi Oya - Sri Lanka



Final Report

Thibaut MALLET

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Without forgeting Peekay... of SACEP.

Résumé

Le périmètre de Kirindi Oya est une zone de développement agricole de plusieurs milliers d'hectares, située au Sud-Est du Sri Lanka en bordure d'Océan Indien. La culture pratiquée est le riz. Un réservoir principal alimente des zones nouvellement mises en irrigation ainsi que les réservoirs d'un périmètre existant.

En saison des pluies, les problèmes d'abondance en eau dans les réservoirs se manifestent par une surirrigation des secteurs dominés et des débordements directs vers la mer. Cette abondance en eau est en partie le résultat d'une contribution en eau importante des drainages amonts. Parallélement, il est fréquent de voir ces mêmes réservoirs pratiquement vides en fin de saison des pluies. Il en résulte inévitablement un manque d'eau au démarrage de la saison sèche, limitant de fait l'irrigation.

Ces problèmes peuvent être imputés à une gestion éclatée et incomplète de l'information au sein du périmètre. Depuis 1991, un système d'information pour la gestion du canal principal rive droite est en place et fonctionne correctement. Il apparait cependant nécessaire d'élargir ce type d'intervention à l'échelle régionale. L'étude présente, s'est efforcée de répondre à ce besoin en s'appuyant sur l'outil Système d'Information Géographique pour établir un tableau de bord, synoptique des principaux indicateurs de gestion.

En seconde partie, une étude de terrain a été menée pour cerner, l'amélioration potentielle de la gestion de l'eau et développer des stratégies spécifiques. L'étude simultanée du drainage et de la performance de distribution amont a montré la nécessité d'un control efficace de la distribution amont pour réduire les pertes à la mer. Une typologie des zones de contribution a été également définie. Le diagnostique des saisons a conclu sur la nécessité d'améliorer la programmation saisonnière (phasage entre irrigation amont / aval).

L'étude a conclu sur la nécessité d'unifier l'information pour faciliter l'efficacité de la gestion régionale.

Abstract

Kirindi Oya Scheme is an agriculture based development project, located in Southern Sri Lanka. Main irrigated crop is rice. Build in 1986, a main reservoir supplies newly developed areas as well as five tanks of an old system existing prior to the construction of the main dam.

During rainy season, the consequences of water abundance in the system are the overspill in the tanks combined with an overdistribution within old areas, directly open to the Ocean. These both problems are essentially due to the incapacity of tanks to store drainage return flow coming from new areas. Parallel, it is usual to observe tanks that are only half full at the end of rainy season. It unavoidably implies a water stress at the beginning of the dry season, limiting irrigation to the old system.

These diagnosed problems are partly due to a divided and incomplete management of information within the system. Since 1991, an information system is set up to manage operations along the Right Bank Main Canal and functions well. However, it appears necessary to enlarge this kind of intervention to the whole system.

Present Study has attempted to meet this need, by using Geographical Information System to build a dashboard, displaying indicators of water management.

In a second part, a field investigation has been conducted to improve the water behavior knowledge within the system as well as to define water management flexibility. The simultaneous study of drainage and upstream distribution performance has shown the necessity of an efficient control of irrigation to limit system water losses to the Ocean. A typology of contribution zones has been defined with specific recommendations of management strategy. Diagnostics of rainy and dry season have concluded on the necessity of a seasonal planning for irrigation upstream and downstream from intermediate tanks to increase their storage capacity.

Study has concluded with the indispensability to unify information to facilitate the efficiency of the system management.

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List of Abbreviations

CEMAGREF	: French research center for agricultural and environmental engineering
CRE	: Chief Resident Engineer
DEM	: Digital Elevation Model
DSS	: Decision Support System
ENGEES	: Water and environmental engineering school of strasbourg
FAO	: Food and Agriculture Organization of the United Nations
FSL	: Full Supply Level
GIS	: Geographical Information System
IIMI	: International Irrigation Management Institute
IMIS	: Irrigation Management Information System
ITIS	: Irrigation Techniques Information System
KOGIS	: Kirindi Oya Geographical Information System
KOISP	: Kirindi Oya Irrigation and Settlement Project
LBMC	: Left Bank Main Canal
LHG	: Low Humic Gley
ML	: Maintenance Laborer
MOL	: Minimum Operation Level
RBE	: Red Brown Earth
RBMC	: Right Bank Main Canal
RE	: Resident Engineer
SIC	: Simulation of Irrigation Canals
TA	: Technical Assistant
WS	: Work Supervisor

Conversion of Units

1 foot (ft) = 0.3048 m

1 acre (Ac) = 0.4047 ha

1 acre foot (Ac.ft) = 1233.3 m3

1 cusecs = 28.3 l/s

INTRODUCTION

The study has been carried out as a part of the research program of the Irrigation Techniques Information System (ITIS) Unit on Geographical Information Systems (GIS) of the International Irrigation Management Institute (IIMI). It was completed during my final year of water and environment engineering study at Ecole Nationale du Génie de l'Eau et de l'Environnement de Strasbourg (ENGEES).

Because of the complexity of cascade irrigation systems, and the social and political tensions that exist, most managers have abandoned system piloting with a policy of dynamic management for system improvement [Rey J. 1996]. The consequences are heavy and invariably lead to an inefficiency of water management, that manifests itself in inefficient use of available water during the rainy season and unrelenting water stress during periods of drought.

Since the scientific management of irrigation systems demands the handling of large amounts of data, collecting and processing of this data is a tedious task for irrigation managers. Also, the data they collect cannot be used in decision making at an optimum level unless the proper tools are used.

For the past five years, the IIMI-ITIS team has focused on Information Techniques for Irrigation Management. It has already developed a Decision Support System (DSS) for daily canal operations, combining information system with a hydraulic simulation model (Simulation of Irrigation Canal (SIC)).

This study attempts to enlarge the scope of water management to system level, with the aim of centralizing control. The use of GIS has been proposed.

A gap exists between researchers, who build data-intensive DSS tools, and managers, who, in many cases, have to deal with poor data collection networks, poor processing means and have to base their decisions on empirical expertise, This survey therefore, has included a field intervention in which related methods have been implemented, adjusted, developed and tested according to needs of managers.

The present survey has been implemented on a pilot basis at Kirindi Oya Irrigation and Settlement Project (KOISP), located in southern Sri Lanka.

Chapter 1: Presentation and Methodology

1 SRI LANKA

1.1 General Presentation

Sri Lanka, known as "Ceylon" until 1972, is an island of 65,000 km^2, located at the southern tip of India. Successively, Sri Lanka was colonized by the Portuguese, the Dutch and the British, before gaining independence in 1948. Since then, this small democracy has had to manage problem that arise due to ethnic diversity (between Sinhalese, Tamil, Burghers (descendants of European colonists) Arabs, Malays and Veddhas) and a wide range of religions (Buddhists, Hindus, Christians and Muslims).

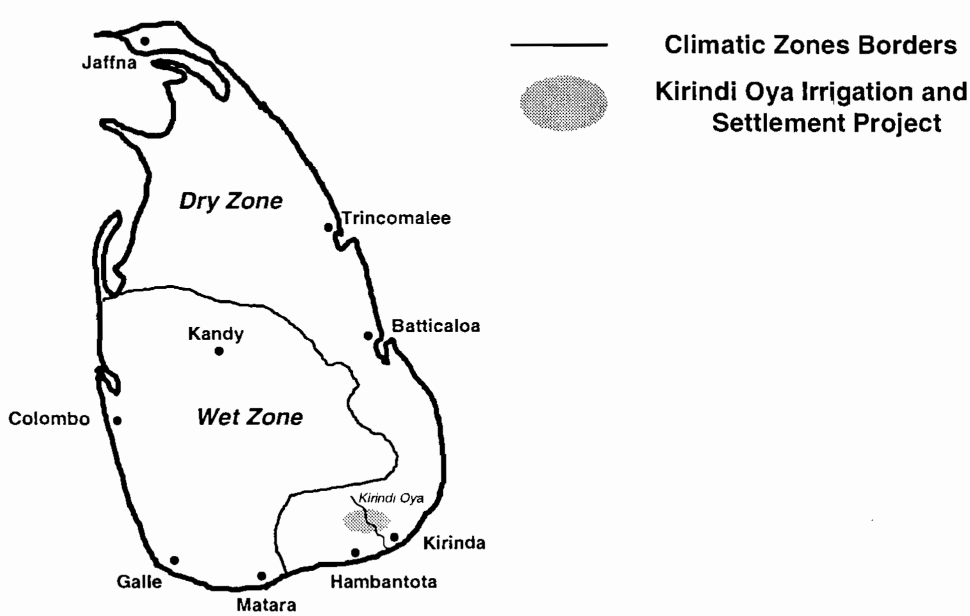
Since 1983, successive governments, have had to contend with a separatist war waged by a group of militant Tamils, seeking independence for the Northern and Eastern Provinces. On the economic front, Sri Lanka has embarked on a free enterprise economy with a view to attracting foreign investors.

1.2 Climate

The agro-climate of Sri Lanka is divided into the wet zone and the dry zone. (See Fig.1). The annual rainfall distribution in both climatic zones follows a bimodal pattern with the wet zone receiving more than 2,500 mm of rainfall and the dry zone around 1,500 mm [Sakthivadivel et Al. 1996]

In the dry zone, the main rainfall season is from October to January and is referred to as the Maha (great) season with a rainfall expectancy value of 650 mm (Probability of occurrence of 75% [Panabokke C.R., Walgama A. 1974]). The short rainfall season during April-May, which is referred to as the Yala (secondary) season, has a rainfall expectancy of 150 mm (Probability of occurrence of 75 %). During the period late May to September, the dry zone falls within the rain shadow of the major regional Southwest Monsoon and thus experiences a four-to-five month dry season with strong desiccating winds. Evaporation rates during this period are around 7.0 mm per day and the total annual evaporation is approximately 1,800 mm and thus exceeds the average annual rainfall, implying water stress during certain periods of the year [Sakthtivadivel et Al. 1996].

Figure 1. Sri Lanka: Climatic zones and location of KOISP



1.3 A Great Hydraulic Society

Because of the highly variable nature of rainfall both between seasons and within seasons coupled with the high evaporation rates for more than one third of the years, as early as 2 500 years ago, people of the dry zone to have stable settlements, had to resort to storage of water in tanks. Thus, was born 'The Great Hydraulic Society". In the 12^{th} century, King Parakramabahu the first, said *"In my kingdom are many paddy fields cultivated by means of rainwater, some cultivated by means of perennial streams, and some by means of tanks both small and big. By rocks and by many thick forests is the land covered. In such a country, not even a single drop of water obtained from rain should be permitted to flow to the ocean without having given its full benefit to man."* [Moormann F.R., Van Bremen N. 1978]. This famous pronouncement has since become the IIMI watchword, and shows us that, as early as 900 years ago, there was a profound understanding of crop ecology and of important factors guiding agriculture production.

1.4 Agriculture

Despite its diversity in climates and reliefs, Sri Lanka has developed its agriculture, by promoting only four main crops: coconut, rubber, tea and rice. The last one is either soaked by rain in wet zone or partially or totally irrigated in dry zone. Paddy[1] fields take up more than one third of cultivated area and represent the main seasonal crop in Sri Lanka. As the staple diet, rice provides approximately 45 % calories and 40 % proteins of total requirements to Sri Lankans [Rougeau V. 1989].

[1] Paddy fields are designed so that leveling and bunding has been carried out to retain or pond the water.

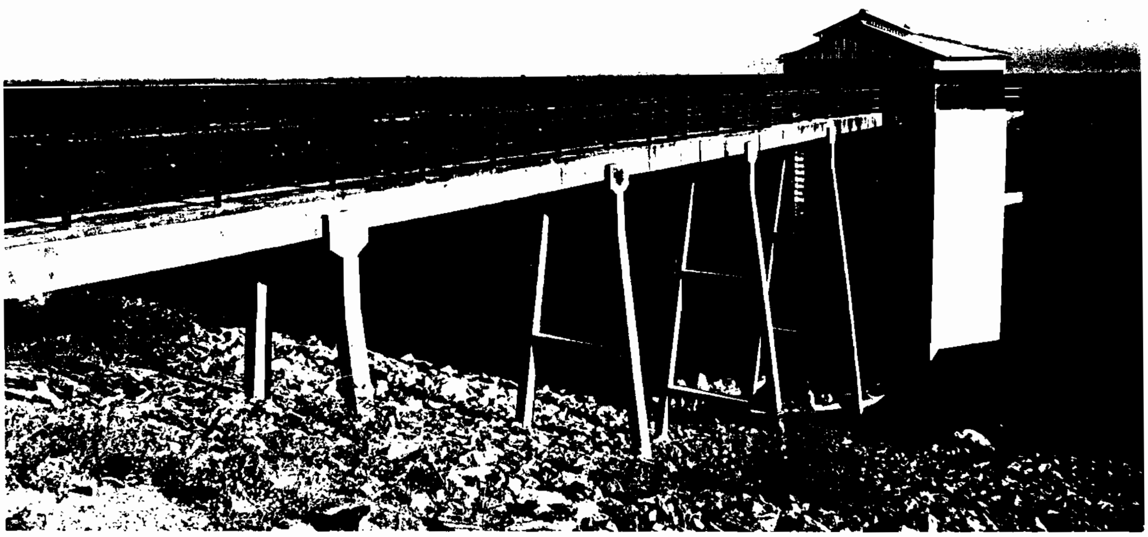
2 KOISP PRESENTATION

The study has been conducted on a pilot basis at KOISP in the Kirindi Oya River Basin (See Fig.1) in Hambantota District of Southern Province about 260 km by the coastal highway from Colombo. The study area is entirely located in the dry zone. The climate is tropical and characterized by nearly constant year round temperatures (26 °C to 28 °C). Evaporation is uniform throughout the year with an annual average approximating 1,500 mm. Mean annual rainfall is around 1,000 mm.

2.1 KOISP Objectives

The KOISP, in the southern part of the island, which was commissioned in 1986, is one of the largest agriculture based development project of the government of Sri Lanka. The total project area covers about 20,000 ha. The project envisaged the augmentation of irrigation water supply for the existing systems in Ellegala and Bandagiriya, and the provision of irrigation facilities to new areas of approximately 8,400 ha through the newly constructed Lunugamwehera Reservoir (See Picture1).

Picture 1: Lunugamwehera Reservoir



Agricultural Objectives [IIMI 1995] were for:

Lowlands (Ellegala) : One rice crop during the wet season and 50 % paddy (Rice) and 50 % subsidiary crops during the dry season.

Intermediate lands (New Areas) : paddy during the wet season and subsidiary crops during the dry season.

Uplands (New Areas) : 80 % paddy and 20 % subsidiary crops during the wet season and 100 % subsidiary crops during the dry season.

2.2 Ten years after ?

Because water supply has been initially overestimated by 30 % [IIMI 1995] and Kirindi Oya has turned out to be a short water system, only 66 % of the proposed irrigable area has been developed during both phases of the project, i.e. 5550 ha of new lands.

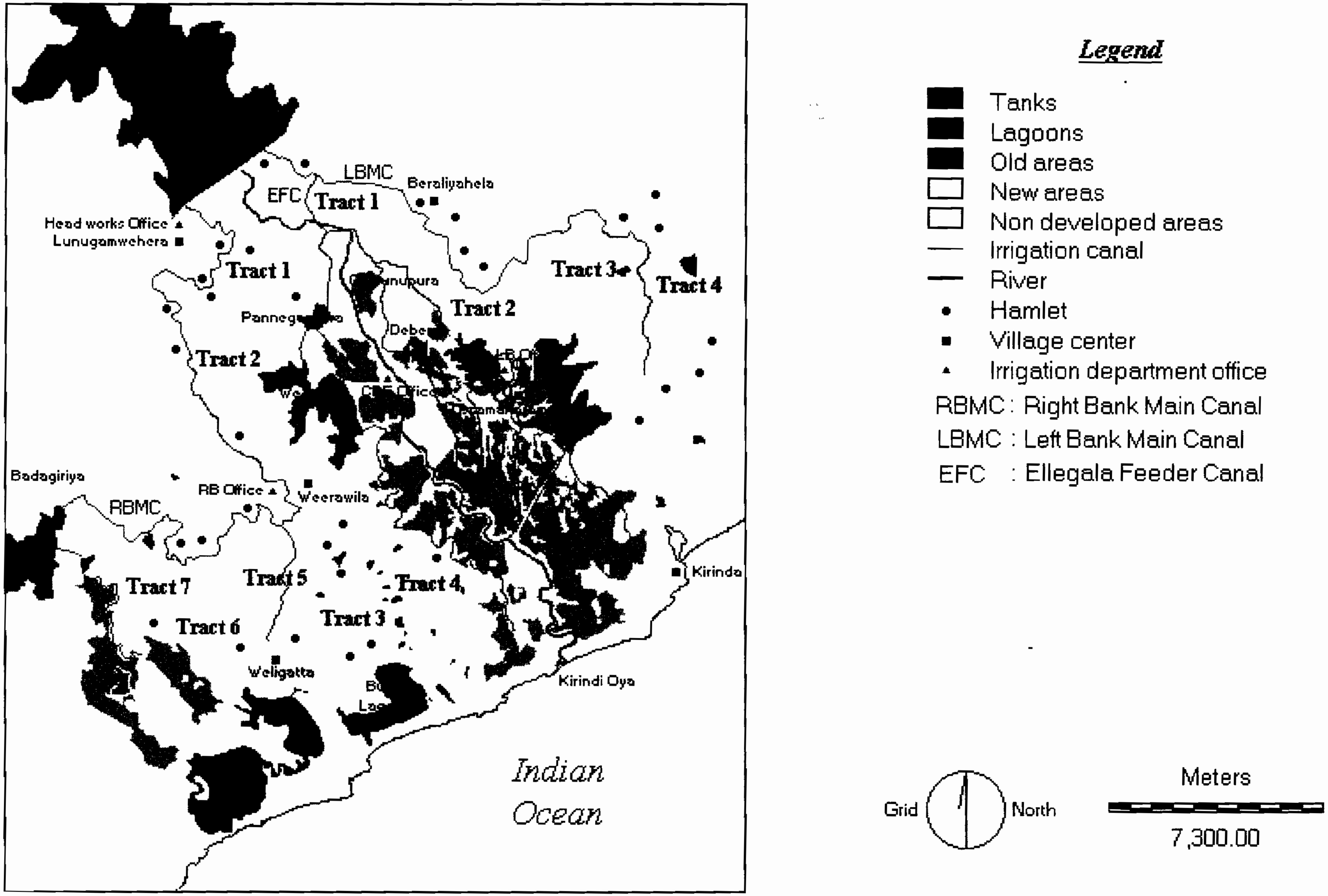
In addition, despite crop diversification policies, farmers have always preferred to grow paddy, even though current attempts towards crop diversification are noticed. This insistence on paddy results in high water consumption.

But the main problem has come from the Old areas. Due to their historical rights and the free water policy in Sri Lanka, farmers have always claimed their water priority. Also, even though the Irrigation Department has identified signs of poor service within new areas, its attempt to reequilibrate allocation priorities in aid of these farmers has failed, due to political and social pressure.

The consequences are that Ellegala farmers currently enjoy priority of allocation in both seasons, cultivating two paddy crops with a cropping intensity of 200 % versus 120 % for the new areas.

These political and social pressures have led to the two systems operating differently. Most of the farmers within the new areas do not have certain basic facilities yet.

Figure 2: Kirindi Oya Irrigation and Settlement Project Map



2.3 KOISP : Two Systems

2.3.1 Old Areas

The Ellegala System, which is one of the oldest settlement schemes, receives its water supply through inter-connected tanks system, diverted from the Ellegala Anicut or diversion structure of the Kirindi Oya which existed prior to the construction of the Lunugamwehera Reservoir. The original diversion structure was constructed during 1874-78. The Ellegala System consists of a cascade of five tanks, namely: Pannegamuwa Wewa, Weerawila Wewa, Yoda Wewa (Original tank built by King Maha Naga in the second century), Tissa Wewa (Built by King Ilanga 35-44 AD) and Debera Wewa. North of this last tank, a small scheme about 180 ha called Gamunupura, also belongs to Ellegala.

With the new project, a feeder canal has been constructed from the Left Bank Main Canal (LBMC) to the Ellegala diversion structure to meet water requirements of the Old System (See Fig.2). Besides this, the Old system also receives water from two main other sources: runoff from its own catchments and drainage return flow from the newly developed areas. The total command area under Old System is about 4,110 ha. Old areas are characterized by lowlands, where dominant soils are Low Humic Gley (LHG) soils which are poorly drained soils. Deep percolation relating to these soils is assumed around to 3 mm/day [IIMI 1995].

Land tenure in old areas varies from 0.2 ha to 50 ha.

The Bandagiriya Subsystem is located in Malala ara Basin (another basin, along the right side of the Kirindi Oya river. The existing system covers 740 ha and was constructed about 36 years ago. Although this subsystem is supplied from its own catchment inflow, in the short water period, it can be also supplied from Lunugamwehera Reservoir through the Right Bank Main Canal (RBMC).

Main tanks characteristics are described below (See Tab.1):

Table 1: KOISP tanks and main reservoir characteristics

Tank Name	Capacity at FSL[2] (m^3)	Catchment area (ha)	Command area[3] (ha)	Supply Days[4]
Lunugamwehera	200,000,000	91,400	All System on demand	
Pannegamuwa Wewa	762,000	82	224	19
Weerawila Wewa	12,941,000	7,256	920	72
Yoda Wewa	9,750,000	5,948	1,307	45
Tissa Wewa	3,868,000	1,959	1,100	19
Debera Wewa	863 000	269	380	8
Badagiriya Wewa	7 338,000		740	

[2] FSL: Full Supply Level

[3] Command area: Irrigated surface under main management

[4] Supply days gives the number of irrigation days which could be made with reservoir at its maximum level. It has been computed from Active Capacity and table 4.

2.3.2 New Areas

New Areas are irrigated by two main canals: RBMC and LBMC, themselves supplied by Lunugamwehera Reservoir.

The RBMC, about 35.2 km long, supplies tracts[5] 1, 2, 5, 6 and 7. Irrigated surfaces for each tract are mentioned below (See Tab.2) and totalizes 3,620 ha.

Along RBMC, 42 offtakes supply 42 subcommand areas

Table 2: RBMC irrigated area

Right Bank Main Canal	Surface irrigated area (ha)
Tract 1	851
Tract 2	868
Tract 5	1 005
Tract 6	662
Tract 7	234

The LBMC, with a length of 17.6 km, supplies three tracts. Their corresponding irrigated surfaces appear below (See Tab.3). They total 1,926 ha.

Along LBMC, 23 offtakes supply respectively 23 subcommand areas

Table 3: LBMC irrigated area

Left Bank Main Canal	Surface irrigated area (ha)
Tract 1	719
Tract 2	903
Tract 3 (partially developed)	304

New areas are essentially characterized by intermediate and uplands where dominant soils are Reddish Brown Earth (RBE) soils, which are well drained soils. Deep percolation relating to these soil types is assumed around to 6mm/day [IIMI 1995].

[5] Smallest management unit (project level)

2.4 Water Management

Water Management within the system is carried out by Irrigation Department of Ministry of Lands, Irrigation and Mahaweli Development, represented by a Chief Resident Engineer (CRE). CRE is in charge of system management and of releases from both main sluices of Lunugamwehera Reservoir. Under him, there are three Resident Engineers (RE):

- Right Bank RE deals with RBMC operations and Bandagiriya scheme.
- Left Bank RE is in charge of LBMC operations and of Ellegala System management, including tank operations.
- The third engineer is attached to the CRE's Office.

In addition, operation and management staff, consist of: technical assistants (TA), work supervisors (WS) and maintenance laborers (ML).

TA are in charge of operation at tract or tank level, but because of lack of staff, most of the time they have to deal with several tracts or tanks. Under Technical Assistants, Work Supervisors manage data collection at tract level, carried out by maintenance laborers.

2.5 Data Collection

In the past, IIMI-ITIS Unit in collaboration with CEMAGREF has focused on "daily canal operations" component of the management process. A DSS: Irrigation Management Information System (IMIS) has been developed. It aims to ease data entry, storage and process as well as facilitating the link with a simulation tool - Simulation of Irrigation Canal (SIC) developed by Cemagref.

This intervention has allowed the organization of a data collection system through the RBMC to monitor performance and make it sustainable.

Thus, along RBMC, gate settings and relative water levels of 19 regulators and 42 offtakes are collected and recorded twice a day by maintenance laborers. Recordings are registered by work supervisors and brought to the RE office, where a draughtsman enters the data in a computer using IMIS. Discharges are computed and visualized on a display board. Decision to modify gates setting can be conducted by engineer.

In the same manner, a similar data collection is carried out along LBMC and for Ellegala tanks. However, data processing has not been implemented so far.

On his side, CRE computes on a daily basis, the main reservoir water level, discharges from both main sluices, as well as releases to old areas.

Five climatic stations are maintained within project area. All provide rainfall records. Two stations are well equipped and provide data on: maximum and minimum temperature, relative humidity, sunshine hours and wind velocity.

2.6 Seasonal Allocation and Decision to start the season

2.6.1 Seasonal Allocation

Seasonal allocation is decided during the Kanna[6] meeting between farmers and the project management committee, composed of representatives from the Irrigation Department, other line agencies and farmer leaders.

The Irrigation manager, in charge of seasonal allocation, presents data on current storage in tanks and main reservoir, as well as expected inflow for next season (probability of exceedance retained is 80 %, but computing is conducted on a monthly basis which contributes to decrease the risk for a seasonal decision of allocation).

The expected inflow consists in: Lunugamwehera inflow, direct rain on the tank spread areas and on irrigated areas, runoff in Ellegala tanks and upstream from Ellegala Anicut. Evaporation on tank spread areas and drinking water demand are taken into account.

If the total water demand for the rainy season (See Appendix 1) equals the allocation for the entire system, water supply during Yala season does not allow a full irrigation of the system and depends mostly on the water savings stored at the end of two seasons.

During the meeting, irrigated surface area is decided by committee, but farmers keep the final decision concerning choice of irrigated zones. This choice takes into account priorities of previous years. The four zones considered for allocation are:

- Zone 1 : Tract 1 and 2 of RBMC
- Zone 2 : Tract 5, 6 and 7 of RBMC
- Zone 3 : Tract 1, 2 and 3 of LBMC
- Zone 4 : Ellegala System

As said earlier, Ellegala Farmers enjoy priority of allocation.

Although currently, seasonal allocation does not create any major problems, farmer's concerns about Irrigation Department modalities has been a reason for debate in the past few years. Issues arose over crop failure of Yala 92 [IIMI 1994]. Despite the Irrigation Department's warning that water in the reservoir was not sufficient for cultivating paddy crop in the whole of the Ellegala, some prominent farmer representatives mislead farmers into thinking there was sufficient water for a Yala paddy crop. Pressure by these farmers compelled the Irrigation Department to release irrigation water to the whole Ellegala System. It resulted in a severe crop failure.

2.6.2 Decision to start the season

Decision to start the season is made most of the time after a cumulative rain of 100 mm or when capacity in main reservoir has reached 43 mcm. Then, cultivation starts zone by zone. According to climatic behavior of the season and crop progress within first irrigated zones, readjustment of allocation can be conducted.

Usually Maha Season starts mid-September and Yala Season starts mid-April

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[6] Cultivation meeting

2.7 One Irrigated Crop: Paddy

Despite moves towards crop diversification, paddy remains by far the main irrigated crop. Its cultivation season is divided into three main phases with respect to on-farm management, namely: Land soaking and land preparation, crop establishment and crop development [Murty V.V.N., Koga K. 1992].

Specific irrigation objectives relative to the cultural and physical water requirements of paddy cultivation are associated with each of these phases (See Tab.4). The basic requirement, that soil saturation be established early and maintained throughout the season underlies water management objectives for paddy cultivation. Kirindi Oya System provides a continuous irrigation delivery during all phases of paddy cultivation.

2.7.1 Land Soaking and Land Preparation

The land soaking consists of five days of full irrigation. Then, the flow is normally reduced to a lesser but continuous one, sufficient for maintaining shallow pounding. This flow reduction is called the land preparation cut back. Thus, starts the land preparation phase, which lasts approximately ten days until paddy planting begins.

Targeted issues relating to these stage has to satisfy deep percolation, evaporation requirements, and application losses. Water requirements are computed as if the paddy crop was planted with a crop coefficient held constant at 1.0 (Evaporation from the shallow pounded water).

2.7.2 Crop establishment

In Kirindi Oya, this phase begins with sowing (Transplanting is not practiced). This period, called *Initial growth stage*, lasts 20 days for the 105 days paddy variety. Targeted issues satisfies evapotranspiration, percolation and conveyance losses in distributors and field canals. A crop coefficient is held constant at 1.0. Sensitivity to water shortage is high during seedling.

2.7.3 Crop Development

The Crop Development phase begins immediately after the Crop Establishment and lasts until paddy completes its growth cycle. It consists of three main plant growth stages.

The *Development stage* lasts 30 days. It is tillering which starts this phase. The crop coefficient is taken as 1.15. Sensitivity to water shortage is moderate.

The *Mid stage* lasts 30 days with a crop coefficient held constant at 1.2. It corresponds to vegetative stage, starts by panicle initiation and finishes by flowering. Sensitivity to water shortage is high and becomes gradually very high until flowering.

The last stage called: *Late stage*, lasts 25 days and corresponds to ripening stage. Sensitivity to water shortage is moderate and decreases until plant maturity. Crop coefficient equal to 0.9. In the paddy field, depth of water has to gradually withdraw until harvest.

2.7.4 Targeted Issues for new and old areas

Targeted issues[7] relating to five mentioned stages appears below (See Tab.4)

Table 4: Kirindi Oya main system targeted issues (l/s/ha)

Stage Name	Old Areas	New Areas	Duration
Land Preparation	1.93	2.6	15/21 days
Initial	1.22	2.0	20 days
Development	1.32	2.14	30 days
Mid	1.37	2.18	30 days
Late	1.14	1.91	25 days

We can observe a significant difference between targeted issues of old and new areas. It is due to their soil properties. In addition, we can mention that drainage water is significantly reused in old areas and contributes to decrease the demand from reservoirs.

[7] Targeted issues are for old areas: at head of tank sluices. And for new areas: at head of distributors along main canal

2.8 Hydrological Characteristics within KOISP

2.8.1 Hydrological Characteristics

Two characteristics of KOISP are fundamental to understanding hydrological behavior in the area:

- **A cascade system** - This common feature in Sri Lanka implies that runoff, overflow and drainage coming from upstream areas, are more likely collected and stored in downstream reservoirs.

- **A basin open to the sea** - The KOISP is the last water user before the ocean. Hence water savings in this area are "true" savings, since drainage of zones open to the sea can not be useful for a downstream system.

2.8.2 Hydrological Levels

To analyze hydrological behavior, four levels can be considered (See Fig.3).

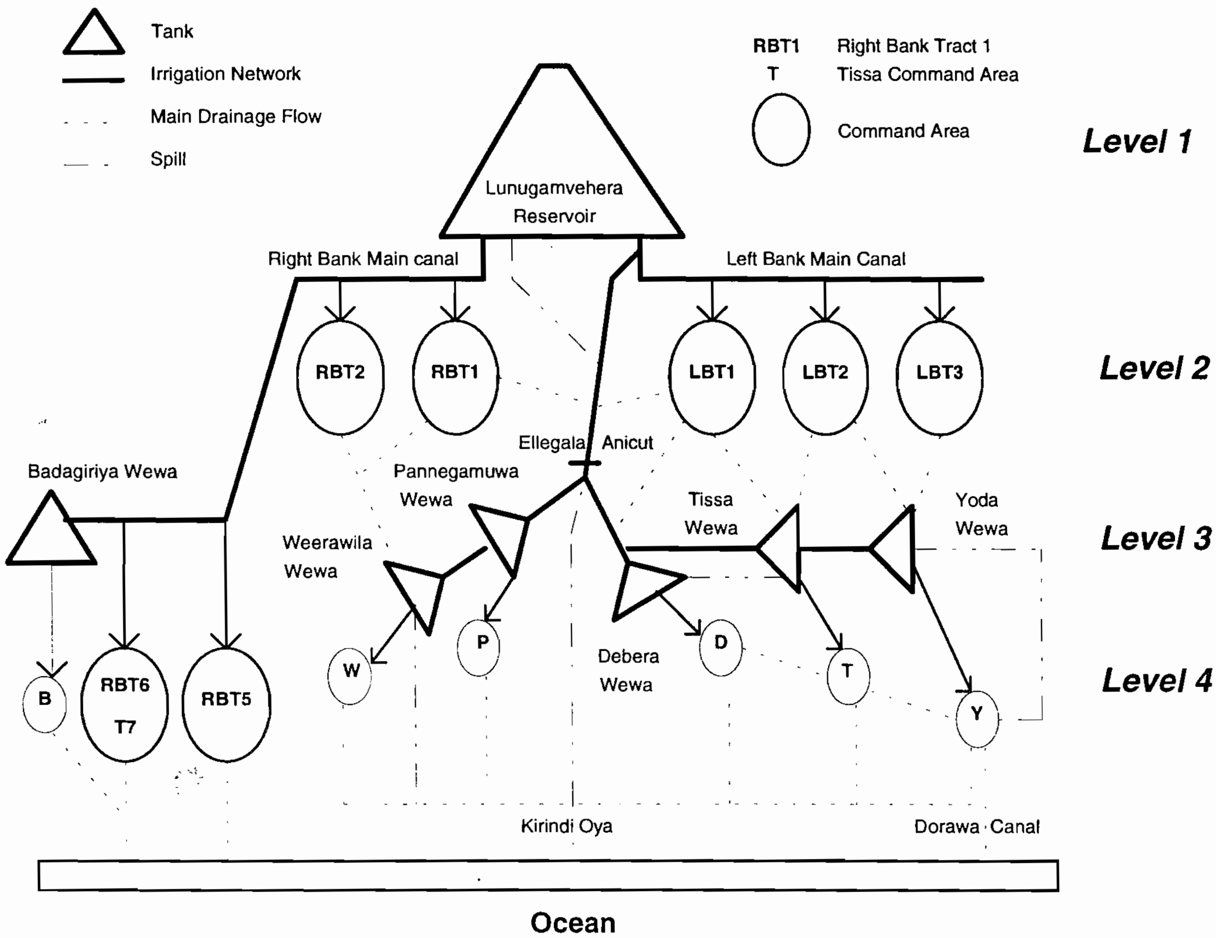
- Upstream level is the main system feeder: Lunugamwehera Reservoir.

- A second level supplied by level 1, it consists in tracts 1 and 2 of RBMC and tract 1, 2 and 3 of LBMC. Its drainage return flow does not represent a real lost for the system, since it is stored by Ellegala tanks.

- The third level includes Ellegala tanks and Badagiriya Wewa. They are supplied by their own catchments and drainage flow return from level 2 (except for Badagiriya).

- The last level concerns command areas open to the sea, for instance Ellegala, and Bandagiriya System as well as Tract 5, 6 and 7. Their drainage return flow runs to the sea, except for the Left Bank of Ellegala, where a process of water reuse is developed.

Figure 3: Kirindi Oya and Badagiriya system flow



2.8.3 Outlets to the sea

Outlets to the sea consist of four main drainage streams. Two of them evacuate drainage return flow coming from Ellegala System, they are: Kirindi Oya and Dorawa Drainage Canal. Two others collect drainage coming from Tract 5, 6 and 7 on the RBMC.

2.9 Management Issues within the System

Since IIMI-Cemagref intervention, major management problems have been eliminated in the RBMC. However, it represents only a small component of the global management of system, and other issues of water management occur at system level.

Related problems by CRE are classified into two kinds: Quantity and quality.

2.9.1 Quantity Problems

→ During rainy season, the consequences of water abundance in the system are the overspill in the Ellegala tanks combined with an overdistribution within old areas. Both these problems are essentially due to the incapacity of tanks to store drainage return flow coming from new areas. Besides, it is usual to observe tanks that are only half full at the end of Maha, when they should be filled to capacity.

→ Commencing the dry season with a low water level in their tanks, Ellegala farmers find themselves supplied by Lunugamwehera Reservoir, so depriving farmers of new areas a second irrigated cultivation (See Paragraph 2.2).

2.9.2 Quality [8] Problems

Salinity problems are not new within the area and it is no coincidence that Lunugamwehera, the name accepted to designate the main dam, means in Sinhalese "Temple of the Villages of Salt".

These problems are due to:

→ Salt leaching from new areas soils, which supply Ellegala tanks. Monthly analyses of tank salinity is monitored by Department of Agriculture. When quality decreases, dilution with water of Lunugamwehera is performed.

→ Drainage congestion in the Tissa and Yoda Wewa command areas and the poor drainage in micro-depressions and lower topographical locations. Water issued for irrigation is evacuated with difficulty and causes agglomeration of salt, hampering paddy field cultivation.

[8] Even though quality problems will not be studied in present study, it is worth to evoke them to take them into consideration in our future reflections. (According to CRE, no complain has been made this year)

2.9.3 Chief Resident Engineer's Requirements

→ Parallel to related problems, CRE's requirement would be to have a better understanding of the spatial distribution of rainfall. The significant disparity, which can be observed and recorded, is essentially due to location of system at the borders of two agroecological zones [Ponrajah, A.J.P. 1982].

→ Given the large amount of information collected along RBMC, data interpretation is currently not operated at its optimum. Hence, the CRE would like tools to be able to analyze the data and make the information more meaningful .

2.9.4 Consequences of these Water Management Problems

As consequences of quantity problems identified earlier, heavy water losses to the sea can be observed (Boxes of Figure 4).

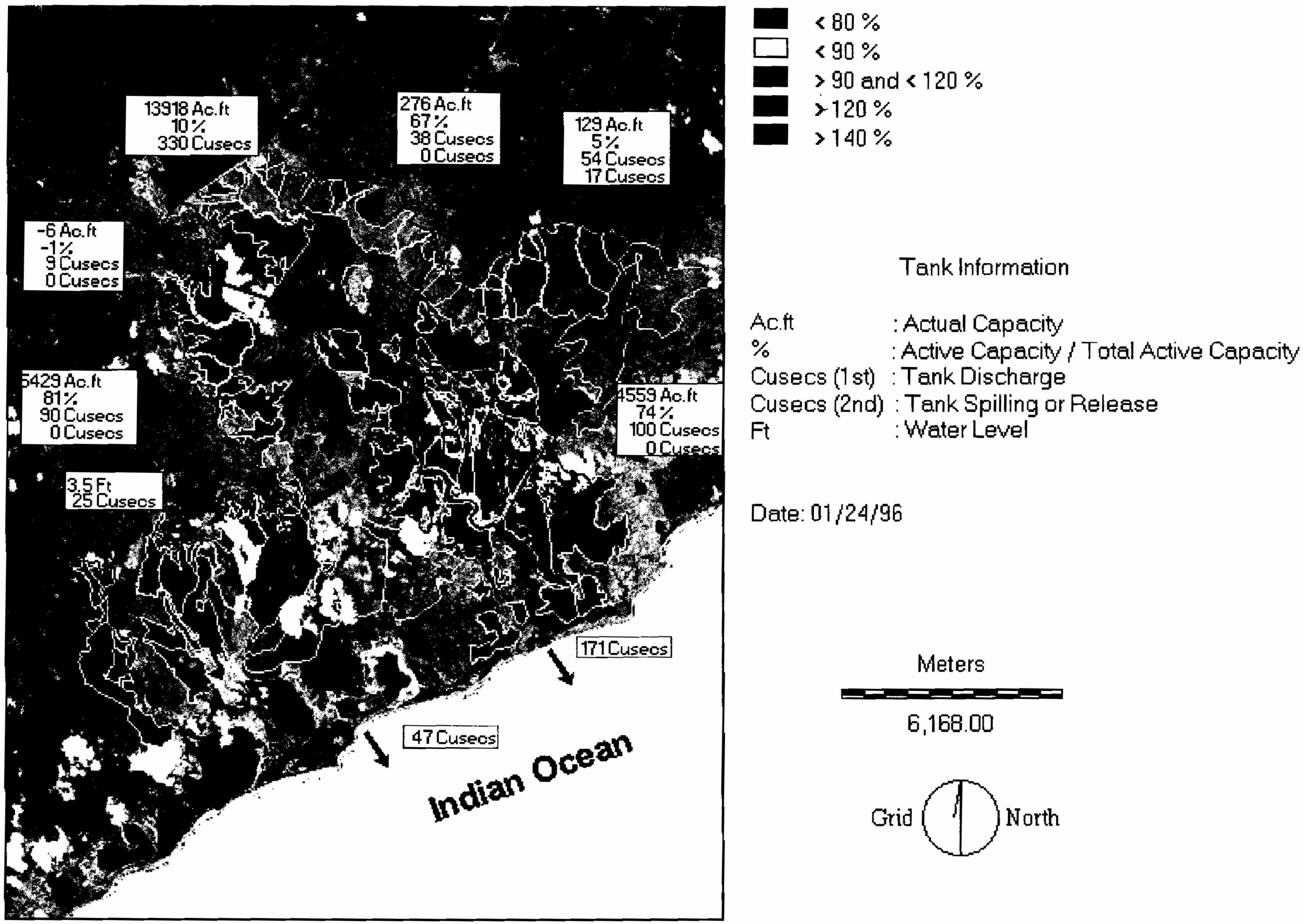
This picture (See Fig.4) displays all available information within the system (For units, see conversion table). Data for the RBMC is currently computed and analyzed while data for the LBMC is not. This processing has had to be conducted.

In addition to available information, specific measurements been carried out to evaluate water losses to the sea.

According to Figure 4, this particular day displays the important flow recorded in Kirindi Oya, Dorawa and both drainages downstream from new areas (See 2.8.3). 6.2 m^3/s are definitively lost by system, while system input though Lunugamwehera is 9.3 m^3/s. It is more likely that the losses to the Ocean are related to overdistribution occurring throughout the command areas of the old system (ratio $r = \frac{Issue}{Target} > 140$ %) with a peak of 240 % for Weerawila and 200 % for Yoda Wewa.

This picture shows the need to have a more intensive information network within the system through control of available data at the Left Bank Office. In addition, controlling of losses to the sea could appear interesting as a feedback for upstream management and water savings.

Figure 4: Dashboard displaying spatial pattern of targets deviation and tank water status



3 INTERVENTION PROPOSAL

3.1 Diagnostic

Diagnosed problems are essentially due to a lack of a *real command capability by CRE for the whole system.* Kirindi Oya System is currently managed as two systems in two different ways: On the one hand, Ellegala system, which enjoys priority of allocation and for which control is more or less transferred to farmers and on other hand, new areas, whose allocation depends on management efficiency and on climatic hazards. However, on a hydrological viewpoint, both systems are linked and tank spilling or overdistribution directly ensue from upstream distribution.

On field, four engineers work in three different offices. It results in a divided information network, preventing CRE from making real-time decisions.

It has also been observed that data relating to tanks discharges, releases, and spillings were no longer processed, explaining in part, the lack of control of distribution within old areas.

3.2 Intervention Proposal

Different types of intervention strategies can be envisaged to "reinject" control into system management. One implies the provision of better information to managers, which leads to a better understanding of their system and, ultimately, to better decisions. However, it is important to emphasize, if data cannot be received and analyzed quickly, even important data or information may prove useless [Rey J., Hemakumara H.M. 1994]. Thus, implementation of an information system has to be accompanied by a efficient communication network.

The subsequent intervention strategy can be so proposed through identification of a *Performance Objective*, choice of *Management Critical Activities*, and *Performance Drivers* [Rey J. 1996].

3.2.1 Identification of a Performance Objective

It appears clear that a *Performance Objective* in Kirindi Oya is the need for an efficient management of tanks, system and water transfer during rainy season to end the Maha with tanks at their maximum water level.

At present, Ellegala tanks start dry season at their full supply level, water demand from Lunugamwehera by Ellegala farmers will be less important and enlargement of irrigation supply to new areas will be able to be conducted.

3.2.2 Identification of Critical Activities

As soon as a *Performance Objective* is defined, *Tank and System Operation* obviously become *Critical Activities* in the process leading to improved performance.

3.2.3 Identification of Performance Drivers

To improve Tank and System Operation, *Performance Drivers* need to be identified **around** three following questions:

Adequacy of messages: Are system management decisions based on reality ? It appears clear that currently, information needed by CRE to coordinate efficiently both RE does not convey in real time. (Only Lunugamwehera status is known daily). Hence, intervention strategy will have to define the **communication** flow to set between different offices to *unify information* network.

Adequacy of system memory: Are system management decisions based on performance analysis ? Currently, CRE does not have access to tools to make adequate decisions at system level. Hence, choice of *DSS* will have to be identified. It will have to allow entrying, processing and storing of **data** conveyed.

Adequacy of technical knowledge: Is system hydrology known ? Main hydrological flow are well known by CRE. However, a *better knowledge of water behavior* is required to define **tasks** to be carried out between downstream and upstream output.

3.3 Choice of a Geographical Information System as Decision Support System

During the last decade, a multitude of information systems have been developed for irrigation system management (IMIS, INCA[9] ...) through use of databases, spreadsheets... [Makin I.W., Cornish G.A. 1996].

Geographical Information Systems (GIS) have been widely used in environmental studies but their application in irrigation have been so far limited. However, their ability to use simultaneous strata of data from a variety of sources appears to be worthy for analyzing complex spatial patterns, usually met in irrigated agriculture.

Idrisi for windows v.1.1 has been proposed for the study. Its friendliness (Windows Interface), quality-price ratio (450 $) and capabilities to process spatial information (In aim to link it with a future model), has been judged adequate to develop a DSS for system and tank operations.

Digitizing of basic maps has been made with software Arc-Info.

[9] INCA: Irrigation Control Network Analysis (Developed by H.R.Wallingford)

3.3 Methodology of the study

From diagnosed problems to targeted performance objective and choice of GIS to support critical activities, we have developed the following methodology (See Fig.5) for the study:

- **Homogenization of data processing within the system in aim to unify information.** Building of a small database computing Ellegala tank discharges, releases and spillings. This study has included a field intervention aim to calibrate gates of five tanks

- **Development of data visualization tool: a dashboard.** A dashboard, using GIS as interface, has been combined with RBMC information system (IMIS) and the upgraded database of Ellegala tanks. Status of the main tanks as well as spatial variations of water distribution can be so displayed.

- **Improving the water behavior knowledge within the watershed**: Identifying subsurface and surface water fluxes and defining typology of catchments present in Kirindi Oya (water reused or running directly to the ocean).

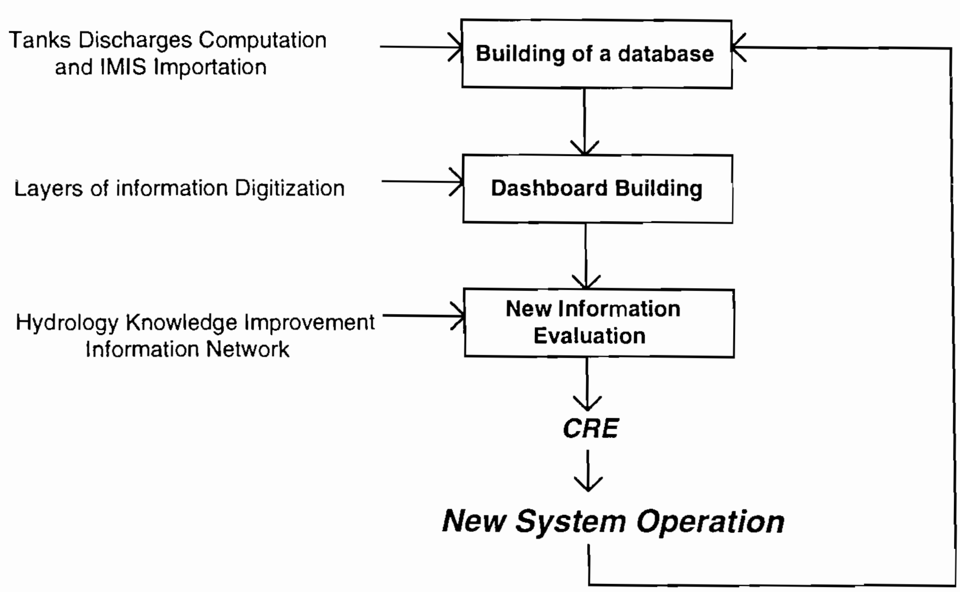
- **Defining the water management flexibility** from water behavior knowledge and from diagnostic of rainy and dry seasons. Operational rules for a given level (See Fig.3) as a function of visualized information on downstream levels will be evoked.

- **Designing an information network** has been the next step of the methodology. Based on the previous step, data collection network has been be optimized.

- **Developing of a performance indicator** for system management will allow observation of improvement along years.

To facilitate the implementation and acceptation of Kirindi Oya Geographical System (KOGIS), the above methodology has been developed in close collaboration with the CRE.

Figure 5: Flow chart: KOGIS methodology



Chapter 2: Information System Design

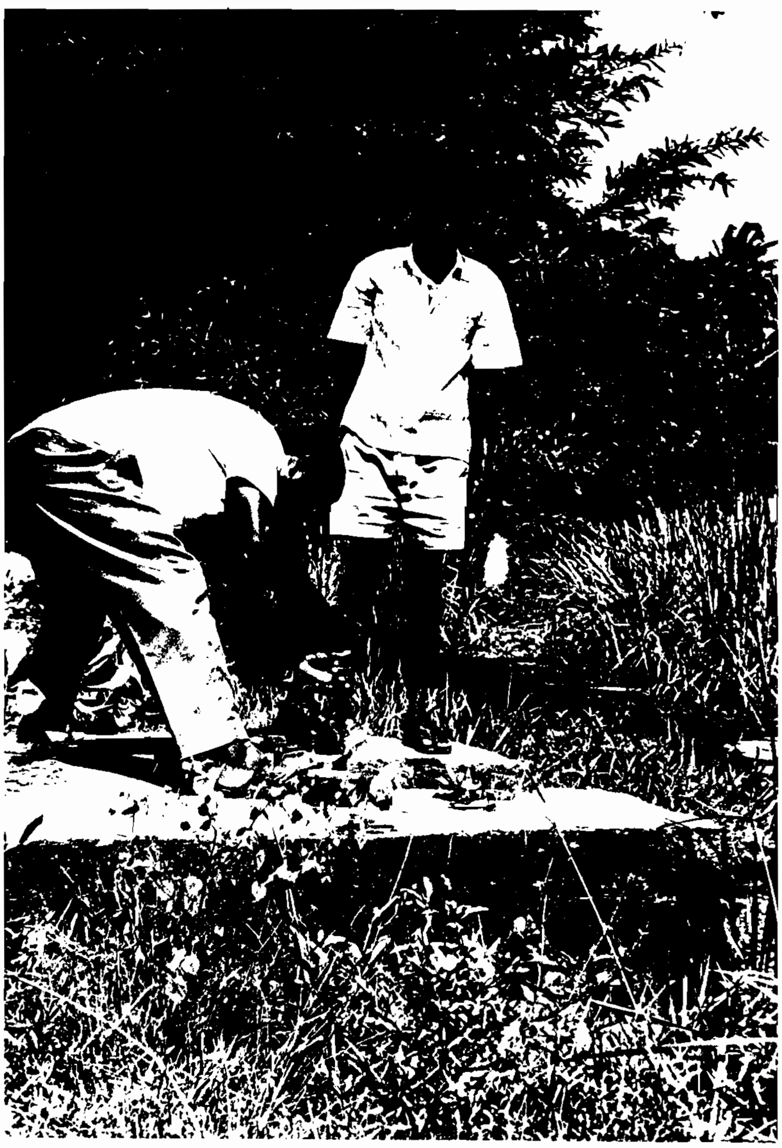
1 DATA PROCESSING HOMOGENIZATION

1.1 Introduction

Currently, only data relating to RBMC are computed. Therefore, homogenization of data processing within the system should be carried out before envisaging the collection of unified information. This part intends to equip the CRE Office with a small database computing tank discharges, releases and spillings from available information at the Left Bank Office. It has been accompanied by field investigation, where gate parameters have been checked and gates calibrated by current metering measurements.

In this manner, a book of tables, computing tanks discharges as a function of data recorded at each structure has been developed. It aims to reinstate control in gate operations (See Picture 2) carried out by maintenance laborers.

Picture 2: Gate operation

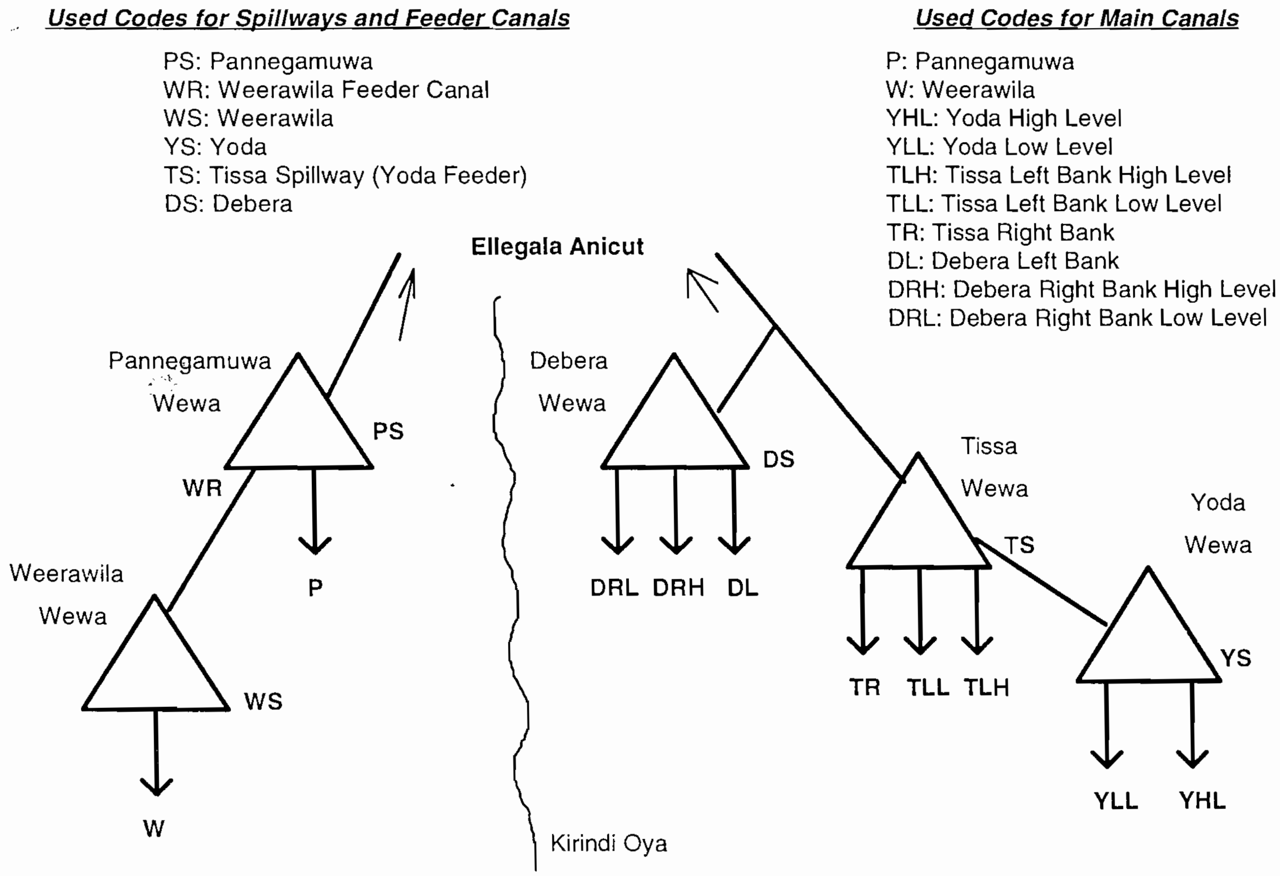


1.2 Ellegala System

Ellegala System consists of a cascade of five tanks linked each other by feeder canals, themselves supplied by Ellegala Anicut. No data is available for computation of discharges issued from anicut. The projected database will consequently focus on computation of tank discharges, spillings and releases from tank to tank.

Main and feeder canals as well as spillways, where computations have been set up are presented below (See Fig.6)

Figure 6: Ellegala system irrigation network



- Weerawila Wewa is supplied by Pannegamuwa Wewa through four gates.

- Yoda Wewa is supplied by Tissa Wewa through one gate.

- Each tank has a spillway. On the Left Bank of Ellegala System, Debera Wewa spilling is accounted as an inflow for Tissa Wewa. and Tissa Wewa spilling as an inflow for Yoda Wewa. On the Right Bank of Kirindi Oya. Pannegamuwa spilling is accounted as an inflow for Weerawila.

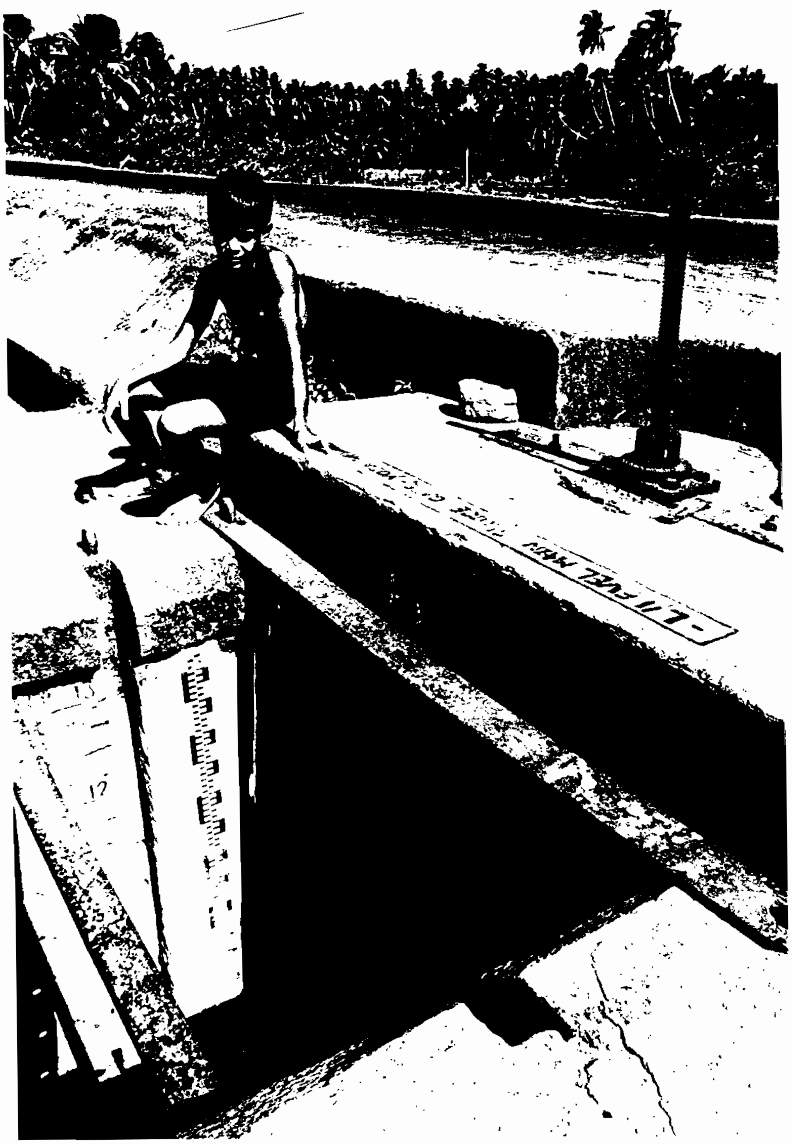
- Only spillings issued from Weerawila and Yoda Wewa run to Kirindi Oya and are then lost to the system.

1.3 Data collection

Data collection is carried out by maintenance laborers of Irrigation Department twice a day. Each record has the following information (See Appendix 2):

- Gate Code allowing gate identification
- Spindle length (in cm), which characterizes gate opening.
- Relative upstream water level (in cm) (one record per tank) (See Picture 3)
- Relative downstream water level (in cm).

Picture 3: Yoda Wewa upstream gauge



1.4 Data Collection on Structures

1.4.1 Undershot Gate Structure

→ Physical description of all gates, already available at RE and CRE Office, has been checked and corrected on site (See Appendix 3).

→ Three types of gate are found:

- Circular orifice with circular gate (1)
- Circular orifice with rectangular gate (2)
- Rectangular orifice with rectangular gate (3)

→ For (1), pipe and gate diameters have been collected. For (2), only pipe diameter has been collected and for (3) width and height.

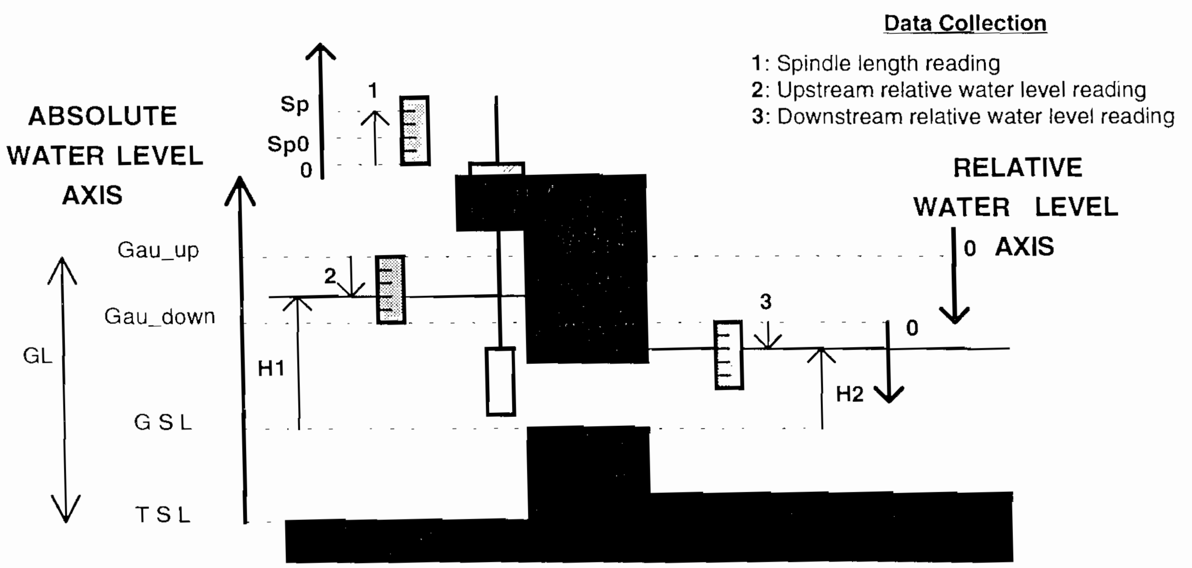
→ Recorded spindle length not being equal to orifice opening, spindle length at gate closed Sp0 (See Fig.7) have been measured thanks to gate operators. They are defined as spindle length just before water starts to flow out

→ Upstream and downstream water level reading being in relative measurement, gate and tank sill levels (m above sea level) as well as gauge length, where relative upstream is recorded, have been collected in the CRE Office. During Yala season, attempts to check them have been made. However, tank depth was too great to allow for accurate measurement. Hence, measurements taken at the CRE Office have been kept for further computations

→ Level difference between top of downstream and upstream gauge have been measured using a a theodolite.

A typical undershot gate appears below (See Fig.7)

Figure 7: Tank undershot gate structure



1.4.2 Permanent Information identifying each Undershot Gate

Permanent data identifying each gate are:

TSL: Tank sill level (in m above sea level)
GSL: Gate sill level (in m above sea level)
GL: Upstream gauge length from tank sill level to top
Gau_up - Gau_down: Difference between top of upstream and downstream gauge.
Sp0: spindle length at gate closed

1.4.3 Update Information at each Structure

Readings carried out and recorded daily by maintenance labors are mentioned in paragraph 1.3. They appear in figure 7.

1.4.4 Computation of Heads and Orifice Opening

Computation of downstream and upstream head, as well as orifice opening is as follows:

$H_1 = TSL + GL - GSL - \textit{Upstream Reading}$
$H_2 = TSL + GL - GSL - (\textit{Gau\_Up-Gau\_down}) - \textit{Downstream Reading}$
$W = Sp - Sp0$

H_1 and H_2 are respectively upstream and downstream head.
W is the orifice opening.

To minimize computation, only terms equal to *TSL + GL - GSL* and *TSL + GL - GSL - (Gau_Up-Gau_down)* have been computed and captured for each structure.

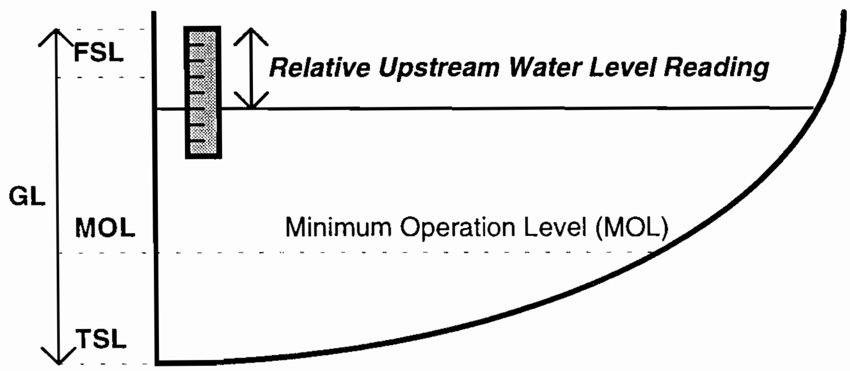
1.4.5 Tank Structure

Each tank has a gauge (GL identifies gauge length in Figure 8) at its sill level (TSL). It allows tank water level computation. Equations compute tank capacity and spread area on the tank as a function of tank water level (See Appendix 4) [IIMI 1994]. Each tank has a full supply level (FSL) and a minimum operation level (MOL). MOL is defined as level relating to capacity in tank supplying the whole command area under tank during 15 days (See Appendix 4).

Likewise, MOL is necessary to maintain water table close to the ground (environment), to maintain a sufficient head in tank (hydraulic) and to supply drinking water.

A typical tank structure appears below (See Fig.8):

Figure 8: Typical tank structure

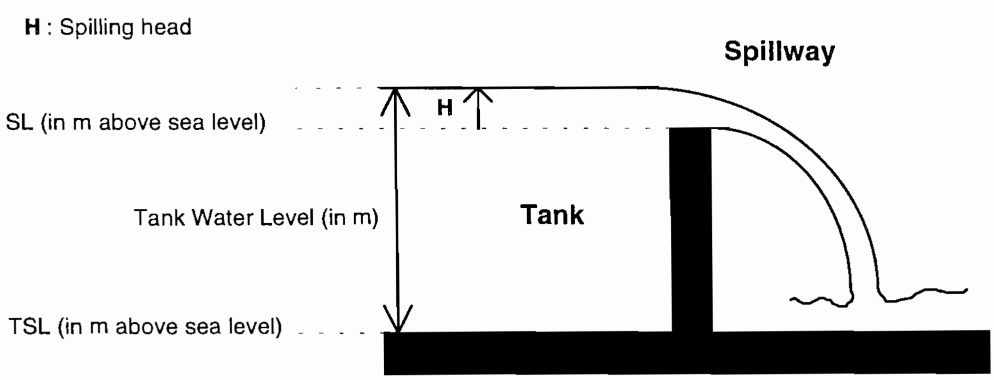


1.4.6 Spillway Structure

Tank spilling occurs through a spillway. Their length and absolute spill levels (m above sea level) have been collected at CRE Office.

A typical spillway structure appears below:

Figure 9: Spillway structure



1.4.7 Permanent Information identifying each Spillway

Permanent information identifying each tank spillway is

SL: Spill level (SL) (m above sea level)
TSL: Tank sill level (m above sea level)
SLe: Spillway length (m)
GL: Gauge length

1.4.8 Computation of Spilling Head

Reading of upstream relative water level carried out allows to know spilling head.

It is equal to $H = TSL + GL - SL - \textit{Upstream Relative Water Level Reading}$

Whether H is lower than 0, it is reclassified to 0

1.5 Computation

1.5.1 Tank Water Level

Tank Water level is computed according to the following formula :

Water Level = Gauge Length - Relative Upstream Water Level Reading

1.5.2 Tank Discharge and Release

For computation of tank discharge and release, we have considered same equation as those equations used in SIC model (See Appendix 5), developed by Cemagref of Montpellier [CEMAGREF 1993]. Each gate has been considered having a small sill elevation. Computational variables are (See Fig.7):

Q : Discharge (m^3/s)
W : Orifice opening (m)
L : Width of rectangular orifice
h_1 : Upstream head
h_2 : Downstream head
g : acceleration due to gravity (m/s^2).

SIC formulas distinguishes whether the opening is hydraulically performing as a weir structure or an orifice.

When opening performs as weir, submerged and free-flow conditions are considered.

When opening performs as an orifice, three conditions are considered. They are respectively, free-flow, partially and totally submerged flow.

1.5.3 Width equivalent for circular orifice

SIC formulas are made for rectangular orifice, while some gates have circular orifices with either a circular or rectangular gate. Also, according to different types of circular structures, types of surface equations have been developed (See Appendix 6).

Each surface S(W) can be written with the following formula.

$$S(W) = K*D*W$$

Where D : Orifice diameter
K : Coefficient of correction depending on W.

Thus, $K*D$ can be assimilated as an equivalent width for rectangular orifice.

As a function of W, Idrisi capabilities have been used to multiply discharge by the coefficient of correction K (See Appendix 7)

1.5.4 Tank Spilling

Tank spillings are under free-flow conditions. SIC formula for high sill elevation [CEMAGREF 1993] have been used for computation (See Appendix 8)

1.6 Database Organization

1.6.1 Database Organization

Tanks Management Information System structure is very simple and consists of:

- One Idrisi table (See Appendix 13) to input raw data recorded by maintenance laborers.
- Values files containing permanent information relating to each gate, spillway and tank. They are called *S_files* (See Appendix 9).
- Values file and Reclass files containing requested information to compute hydraulic coefficients and to test whether the gate is performing as a weir or as an orifice under free-flow or submerged conditions. They are referred as *E_files* (See Appendix 9).
- Modules (See Appendix 10) computing different coefficients and consequently tank discharges, releases and spillings according to previous conditions (*E_files*). Module computing all tank characteristics is called *C_tank.*

Thus, any permanent data revision or correction can be realized by modifying *S_files.*

1.6.2 Program Language

Modules used to test whether canal is under free-flow/submerged conditions and discharges use Idrisi Macro Language. Though, this language is basically meant for manipulating information layers, it has been used as computational programming language without major problems. Used Idrisi modules are described in Appendix 14. To speed up data processing, layers specifying type of discharges (issue, release, spilling) instead of geographical layers have been used in computations. Their structure is explained in Appendix 14.

1.6.3 Gate Identifiers

In database, four numbers identifies each gate:

- First one identifies subsystem within KOISP (Here, we will take 0 as Ellegala System Identifier).
- Second number identifies number of the tank anticlockwise (1 for Pannegamuwa and 5 for Debera).
- Third number designs number of gate for each tank anticlockwise (Figure 5).

Thus, **0310** identifies first gate of anticlockwise of Yoda Wewa, for instance first gate of Yoda High Level Main Canal (See Appendix 13).

1.6.4 Input Messages in "Ellegala" Table

Idrisi Database Workshop is not strictly speaking a database but rather a table with a limited number of functions. One of its limitation is to not allow a proper data storage. Hence, it will have to be carried out through a spreadsheet or a real database, which is usually accomplished by manager.

Table organization consists of six fields (three permanent and three daily updated):

- Field 1 contains gate identifiers
- Field 2 contains name of canal under the gate (e.g. Debera Left Bank Main Canal)
- Field 3 contains gate code (e.g. DL)
- Field 4 Relative Upstream Water Level Reading(in cm)
- Field 5 Relative Downstream Water Level Reading (in cm)
- Field 6 Spindle Length Reading (in cm)

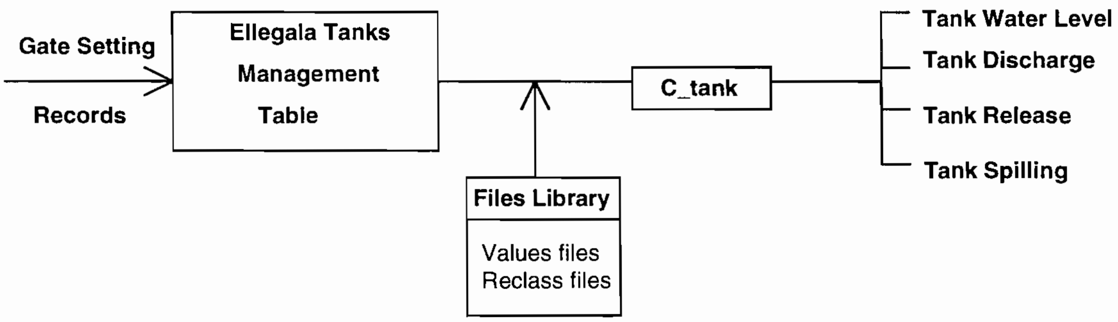
1.6.5 Output messages

Output messages computed from input messages are from four types (Units are those used by manager):

- Files containing tank water levels (in feet).
- Files containing tank discharges (in cusecs).
- Files containing water issues under each gate (in cusecs).
- Files containing tank spilling and releases (in cusecs).

Thus information flow within Ellegala Tanks Management Information System is summarized by following diagram.

Figure 10: Ellegala tanks database structure



1.7 Main Canals Calibration

In order to calibrate each gate by assigning a reference discharge coefficient μ_0 (See Appendix 5), current metering measurements have been realized. Methodology and results, basically correct, appears in Appendix 11

1.8 Conclusion

To account for the lack of a computer in the Left Bank Office, a book of tables computing discharges, releases and spillings as a function of relative upstream water level and spindle length has been developed.

Since canals with tanks' gates are most of the time under free-flow conditions (except during very drought seasons like this year where tank level can fall sometimes very low), tables can be used most of the time to determine different types of discharge (A typical table appears in Appendix 12). Units used, mixes sometimes metric and imperial system. They have been adapted according to units given at structure in question.

Tables have been considered by manager as very simple to use and have the advantage of being used without computers. Likewise, they only require a simple training to be put to use by staff of Irrigation Department.

2 KIRINDI OYA GEOGRAPHICAL INFORMATION SYSTEM DESIGN

Now, we address the building of Kirindi Oya Geographical Information System (KOGIS) to support system and tank operations.

2.1 Introduction

Having homogenized information on the Right Bank and Ellegala System (Left Bank data processing will have to be addressed in a further study), we are in position to compute discharges throughout main system.

Also, this part relates delicate phase of design of KOGIS and information unification. This design has been carried out according to methodology described in [Rey J. and Hemakumara M. 1994] for generic design of DSS for water distribution management.

A careful but simple analysis of the ***decision making process within main system*** has been initially conducted to represent piloting structure of main system. Having defined a frame for decision making process, ***functions supporting decision making at CRE level*** have been identified.

Decisions Oriented Analysis accomplished, an Information Oriented Analysis has been carried out to describe information flow to set up to perform decisions in real time. It covers ***communication flow, tasks to carry out, and data organization.***

The last part introduces the dashboard itself, and indicators selected to support decision.

2.2 Decisions Oriented Analysis

This part describes managerial context relating to the main system and define three functions to support decision at main system level [Rey J. and Hemakumara M. 1994].

2.2.1 Managerial Context relating to the Main System

In the decision making process, four main levels can be distinguished to represent the managerial context of the main system. They are:

$\mathbf{L_1}$: People (CRE) in charge of decision making and data analysis at main system level.

$\mathbf{L_2}$: People (RE) in charge of decision making and data analysis at main subsystem level (canal and tank operation)

$\mathbf{L_3}$: People in charge of data collection

$\mathbf{L_4}$: The physical system encompassing the main reservoir, tanks and command areas under main management (L_1 and L_2).

Farmers are also influential in the decision making (seasonal allocation, operation....) and on going project of Irrigation Department restructuring clearly envisages to transfer water management entirely to farmers delegations in future years. Hence, it is proper to define a corresponding level. So far, transfer of responsibility has not been carried out fully, also farmers influence can be put in level L_1, L_2 and L_3.

Thus, we can distinguish two levels of decision making for main system. Each one depends on the other one. At the beginning of the week, CRE coordinates both RE on objectives to fulfill in term of water distribution, upstream and downstream from tanks (See Fig.11). Then, these ones are in charge of decision making on canal and tanks operation, trying to match management objectives. At the end of the week, data analysis is performed for each subsystem (RE) and for the whole system (CRE). A new decision can be so made by CRE to RE.

2.2.2 Functions supporting Decision Making

Three functions can be identified for decision levels: *Command*, *Observation* and *Evaluation*.

Command Function:

$\mathbf{C_1}$: Decision making regarding operational strategies within system (*Water scheduling*, including targets setting as well as recommendations to RE concerning water transfer and distribution upstream from tanks and in command areas open to the sea (in order to limit losses to the sea)).

$\mathbf{C_2}$: Decision making to fulfill recommendations of CRE and develop canal operational strategies to meet objectives (*Operations*).

$\mathbf{C_3}$: Routine implementation of instructions and local control.

Observation Function:

O_1 : Observation of tank water status and spatial water deliveries pattern within the system according to decisions made by C_2 in order to fulfill C_1 (Project KOGIS).

O_2 : Observation of the hydraulic state and behavior of the system in order to fulfill the activity C_2 (IMIS).

O_3 : Collection of data (water levels, gate settings).

Evaluation Function:

E_1 : Analysis of water delivery performance (Issue/Target) and tank performance to take good decisions (tactic). Study of system functioning improve the decision making process C_1 (strategic).

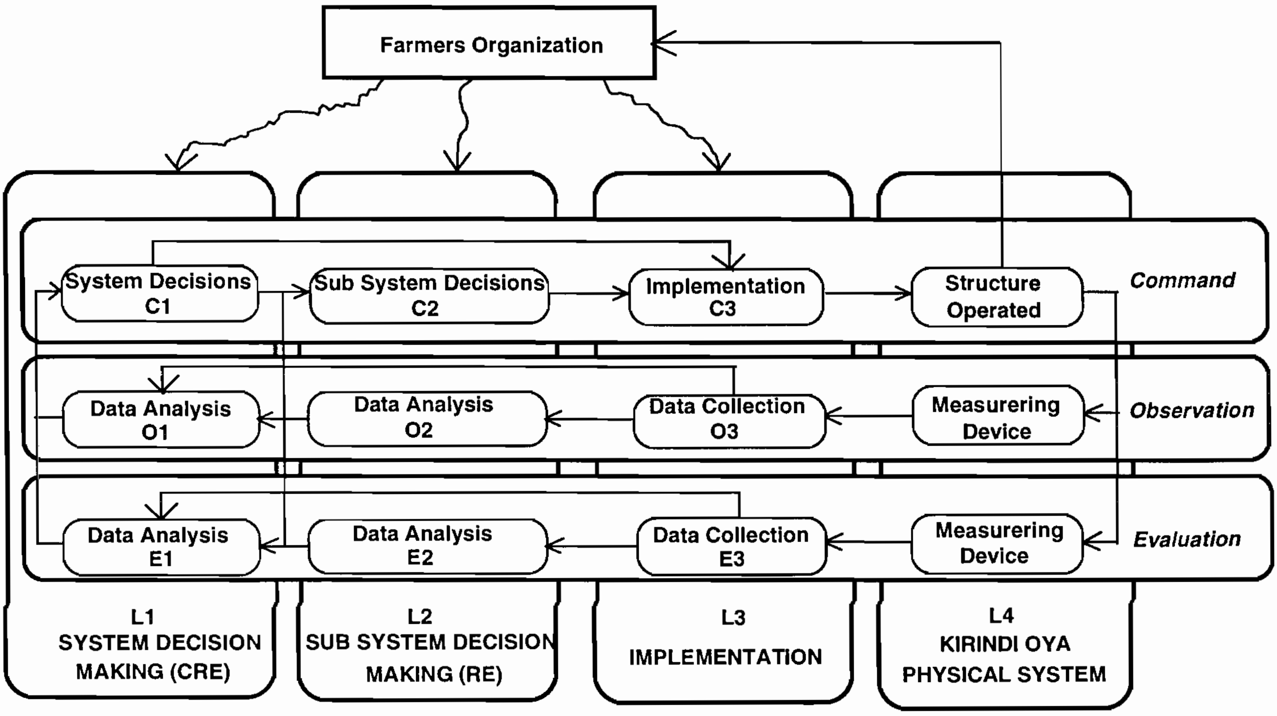
E_2 : Analysis of water delivery performance along canal. Study of system functioning in order to improve the activity C_2.

E_3 : Collection of data (time and magnitude of operations implemented).

Activities under L_2 level have been implemented through past interventions of IIMI by installation of IMIS and are documented in literature [Rey J, Hemakumara H.M. 1993]. Also, feedback coming from O_2 and E_2 to C_2 will not be tackled. KOGIS will focus exclusively on activities under level L_1.

Functional representation of the main system management appears below (See Fig.11)

Figure 11: Functional representation of the main system management



Adapted from Rey J. and Hemakumara H.M 1994

2.3 Information Oriented Analysis

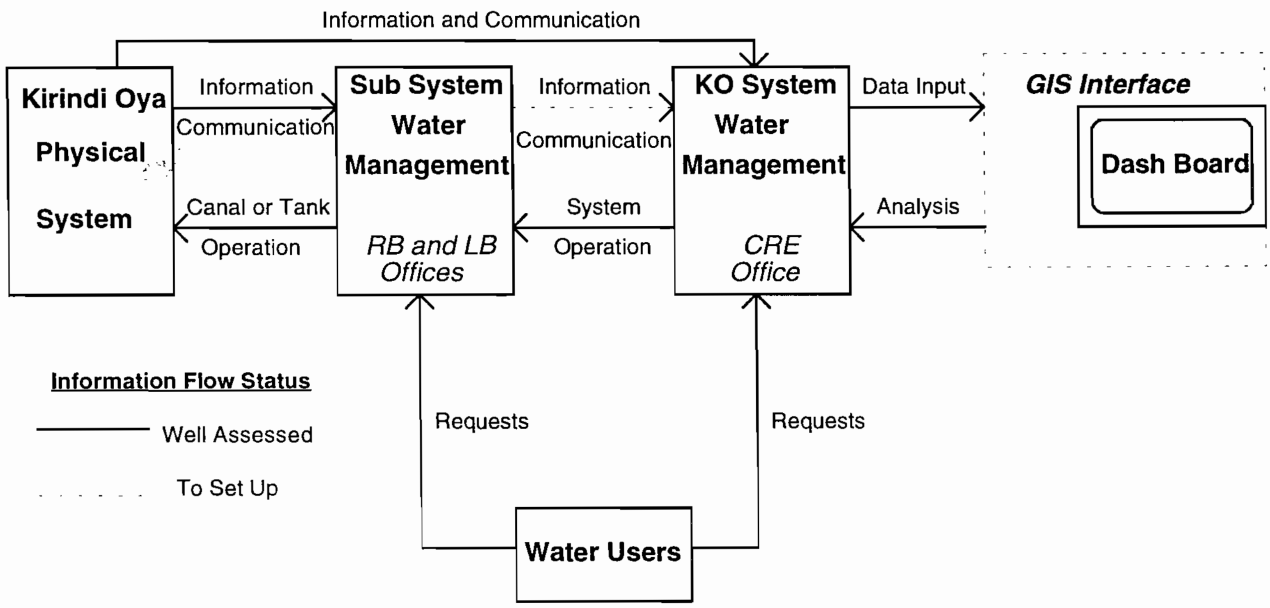
After having defined in a first part, decision making process for management of the main system, this second analysis identifies the corresponding information flow to set up.

2.3.1 Communication Flow to set up

Currently, we can consider that communication flow between levels L_2 and L_3 as well as levels L_1 and L_3 is well established. However, information between levels L_2 and L_3 concerning results of data processing under L_2 needs to be conveyed properly to L_3 (See Fig.12).

Also, a system of repatriation of processed data (IMIS at RB Office) or non processed data (LB Office) to CRE Office need to be set up to perform CRE decisions in real time.

Figure 12: Information flows in system operation in KOISP



Having assessed communication flow set up to facilitate adequate decisions, we can define the input messages that have to reach CRE Office either from field or from RE Offices. They are:

2.3.2 Input messages

Data Flow

- Discharges computed (new and old areas through existing tools).
- Tank water level.
- Rainfall measurements (recorded at 5 KOISP stations).
- Irrigated surface (per block).
- Water losses to the sea measurements.

Human Flow

- Information needed to define targets (Water scheduling (See Tab.4). It can be revised according to rainfall or requests from users)
- Requests from users.

From these input messages, we can define the following output messages:

2.3.3 Output Messages

Data Flow

- Tank Water status (Active capacity[10], spilling, discharge, reserve)
- Water duty distribution (Spatial visualization)
- Spatial distribution performance (Issue/Target)
- Rainfall Spatial Distribution
- Weekly water losses to the sea
- Tank evolution (Graphics)

Interpretation flow

- Understanding of water behavior. Connection between upstream and downstream distribution

Decision Flow

- Emergency decision (spilling, adequacy of supply not met)
- New operation and new targets

[10] Active capacity is defined as tank capacity above minimum operation level (See Fig.8)

2.3.4 Management Clock

In order to describe the whole dynamic of management activities, another type of input, the "management clock" has to be considered. CRE has routine activities of *Command*, *Observation* and *Evaluation* to fulfill at regular intervals as illustrated below (See Tab.5).

Table 5: Management clock

Management Clock		
Frequency	**Management Function**	**Description**
Daily	Observe tanks and system operations	Visualization on dashboard of water deliveries spatial pattern within system, detection of deviations from targets and tank status.
Weekly	Command tank and system operations	Operation to be implemented within RBMC, LBMC and Ellegala for next week taking into account past week and evaluation. recommendations to RE.
Weekly	Evaluation Operations	Visualization on dashboard of timely aggregated indicators.
Seasonally	Evaluation Management	Tanks reserves and expectations

2.3.5 Tasks to carry out

A number of tasks are required in KOGIS to generate output messages from input messages on a daily basis (observation) or weekly basis (evaluation). Output messages are displayed on a dashboard using GIS as interface.

Tasks are :

- Update current date (weekly) to draw targets from the water issue scheduling (See Tab.4) or targets revision according to past week evaluation.
- Update tank water level (daily and weekly)
- Update new areas and old areas discharges, tank releases and tank spillings (daily or weekly)
- Update rainfall records (weekly or factual)
- Update irrigated surface and crop starting date (seasonaly input)

This updating is carried out through tables. To support manager in tasks, a Help menu has been realized on Idrisi (See Appendix 15). By clicking on purposed title, a menu is displayed to help data entry.

Having update tables, five modules support CRE in three functions of decision making.

2.3.6 Database maintenance and links to layers of information

The data obtained by analyzing the information, conveyed through the different messages received by CRE are organized in an efficient and systematic way by aggregating them in different objects.

Idrisi Database Workshop is a database, not really developped yet. Hence, organization of database has been adapted with its limitations of functions. One of these limitations, is not being able to perform a proper data storage. Hence, the latter is carried out in exported values files according to a format described later.

An object in KOGIS is spatial. It can be a command area, a tank or rainfall station. It is characterized by an identifier, which links it to a layer of information, and is described by a given set of data (Field).

Permanent data relating to three objects are stored in values files. Data required for computations are stored in values and reclass files.

2.4 KOGIS Database

Idrisi Database Workshop is the support to entry results coming from IMIS and Ellegala Tanks Management Table. Data entry is carried out through three tables. One concerns command areas management, a second one: tank management, and the last one: rainfall stations.

2.4.1 Command Area Table :

Table managing command area is described below (See Tab.6).

Fields *Surf (ha)* and *St Date* contains respectively irrigated surface under each offtake, whose discharge is computed and crop starting date (See paragraph 2.6).

Each week starts by updating field *Date*. Then, a module defines targets to fulfill in field *Targets (cu)* (See Tab.4). Nevertheless, any revision in field can be performed according to last evaluation and requests of farmers. This task relates *to the Command Function.*

Each day, discharges computed from IMIS or Ellegala are imported in field *Discharge (cu)*. a SQL statement allows to accumulate daily discharges since beginning of the week in field *Acc Dis (cu)*. To store data recorded each day in table, exportation of field *Discharge (cu)* in values file has to be carried according to the following format: *DIdate* (for discharges of 24th of January 96, values files will be called *DI960124*). For weekly record, values files are called *WIdate*.

At the end of the week, field *Wdis (cu)* and fields containing seasonal accumulated data and indicators are updated according to an identical process.

Field *Wrain (mm)* is imported from rain interpolation image.

Table 6: Command areas table

Field Name	Field Description	Field Status	Activity
Identifier	Command Identifier	Permanent	
Canal Name	Canal supplying command	Permanent	
Surf (ha)	Irrigated Surface (ha)	Entry	Seasonally Command
St Date	Crop Starting Date	Entry	Seasonally Command
Date	Current Date to fix Targets	Entry	Weekly Command
Targets (cu)	Targeted Discharge (Cusecs)	Computed	Weekly Command
Discharge (cu)	Measured Discharge (Cusecs)	Entry	Observation
Acc Dis (cu)	Accumulated Daily Discharge since the beginning of the week.	Computed	Observation
Wdis (cu)	Weekly discharge (Cusecs)	Entry	Evaluation
Als (mm)	Allocation supply (in mm/week)	Computed	Evaluation
WI/T (%)	Weekly Actual Issue / Targets (%)	Computed	Evaluation
Wrain (mm)	Weekly Rain (mm)	Computed	Evaluation
Acc Als (mm)	Seasonal Accumulated Allocation Supply	Computed	Data Storage
Acc Rain (mm)	Seasonal Accumulated Rain	Computed	Data Storage

2.4.2 Tank Table

Tank Table allowing data entry relating to tanks is described below. Each day, fields *Wlevel, Discharge, Release, Spilling* are updated by importing data from Ellegala Table. Fields, storing accumulated data, are updated thanks to SQL statements. Data storage is carried out according to a similar process as described earlier. (*Wlevel, Discharge, Release, Spilling* are stored in values fields called respectively *DLdate, DDdate, DRdate, DSdate* for daily records and *WLdate, WDdate, WRdate, WSdate* for weekly records)

Each week, a similar process is carried out with corresponding fields.

Table 7: Tanks table

Field Name	Field Description	Field Status	Activity
Identifier	Tank and Drainage flow Identifier	Permanent	
Tank Name	Tank or Reservoir Name	Permanent	
Wlevel	Tank Water Level (ft)	Entry	Observation
Discharge	Tank Discharge (Cusecs)	Entry	Observation
Release	Tank Release (Cusecs)	Entry	Observation
Spilling	Tank Spilling (Cusecs)	Entry	Observation
Acc Dis	Accumulated Discharge	Computed	Observation
Acc Relea	Accumulated Release	Computed	Observation
Acc Spil	Accumulated Spilling	Computed	Observation
WlevelJ-7	Last Week Tank Water Level	Entry	Evaluation
WlevelJ-8	Current Tank Water Level	Entry	Evaluation
Wdis	Weekly Discharge (Cusecs)	Entry	Evaluation
Wrel	Weekly Release (Cusecs)	Entry	Evaluation
Wspi	Weekly Spilling (Cusecs)	Entry	Evaluation
Acc Dis (Acft)	Accumulated Delivered Volume	Computed	Data Storage
Acc Rel (Acft)	Accumulated Transfered Volume	Computed	Data Storage
Acc Spi (Acft)	Accumulated Spilled Volume	Computed	Data Storage

2.4.3 Rainfall Table

Rainfall Table is destined to entry rain recorded at 5 KOISP rainfall stations. It contains five records but any addition of station can only be an advantage, if it is reliable. Stations are : Lunugamwehera, Weerawila, Tissamaharama, Badagiriya and Debera.

Weekly rain is updated and a module allows to interpolate local measurements to derive the spatial distribution. From rainfall pattern, an average corresponding to each entity of system is stored in field *Wrain (mm)* of Command Areas Table. Data Storage is carried out in values files called *WMdate*.

Table 8: Rainfall table

Field Name	Field Description	Field Status	Activity
Identifier	Rainfall Station Identifier	Permanent	
Station Name	Rainfall Station Name	Permanent	
Weekly Rain	Weekly Rain (mm)	Entry	Evaluation
Accumulated Rain	Seasonal Accumulated Rain (mm)	Computed	Data Storage

2.5 Files Structures

Structure of files (See Appendix 19) has been kept as simple as possible to allow an outside user, the understanding and modifying file contents.

For dashboard building, files are of three types :

- Values files containing permanent information relating to object (e.g. maximum active capacity, MOL etc..).
- Values and Reclass File used for dashboard computations.

Both previous are identified by labelling ***[D_name].*** Third type is:

- Values files containing information to be imported in table, in particular from Ellegala Information System and later from Right and Left Bank. Their identification is done by ***[I_name]***.

For rainfall spatial pattern modelling, files consist of :

- Values files used for further data computations, named ***[R_name]***.
- Values files as intermediate files for data storage and processing, named ***[I_name]***.

For Graphics showing tank or system evolution, files consists of

- Time series files, named ***[P_name]***.

2.6 Layers of Information

From input messages, captured in tables, modules relating to functions supporting CRE decision making (See paragraph 2.8), organizes different dashboards. Dashboards displays water deliveries or deviation between actual and targeted issues (See Fig.4). Similarly, from rainfall table, a module displays spatial distribution of rain and extract average rain by entity of system.

Dashboards are organized from different layers of information, described in the next paragraph.

2.5.1 Layers of Information

Two types of layers of information are present in KOGIS. One type contains permanent information and represent the system. The other type is daily or weekly updated.

Thus, canals and drainage streams layers are just depicted to support managers to interpret results but does not contain any information.

Likewise, boxes to display simultaneously several synthetic tank information have been specially created.

Layers containing command areas and tanks are daily or weekly updated.

List of layers of information appears below (Detailed list: See Appendix 16)

- Soil layer (for hydrology study)
- Tank layer
- Command Area layer
- Rainfall Station layer
- Irrigation Network layer (main and secondary canals layer)
- Drainage (artificial and natural) network layer

They have been digitized from various maps, which appears below:

1. Kirindi Oya Scheme Soil Map (Published by Land Use Division, Irrigation Department (ID), 1976)
2. KOISP Project Map (Published by Irrigation Department, 1986)
3. Tissamaharama Land Use Map (Published by the Survey Department, 1983)
4. Irrigation and Drainage Network-Ellegala RB and LB Schemes (Old areas)
5. KOISP Satellite Image (Landsat Image, 1986)
6. Right Bank Tract 1 Block Out Plan (BOP)
7. Right Bank Tract 2 BOP
8. Right Bank Tract 5 BOP
9. Right Bank Tract 6&7 BOP
10. Left Bank Tract 1 BOP
11. Left Bank Tract 2 BOP
12. Left Bank Tract 3 BOP
13. Bandagiriya Scheme BOP

2.5.2 Digitization

Maps listed contain information mainly at block level but not for the whole system. Hence, a process of aggregation was necessary to generate layers of information representing the whole system.

One satellite map was available (See Appendix 16). It covered the entire system and its scale was accurately known. Hence, it was chosen as reference map to adjust the other maps and aggregate block out plans.

The methodology to aggregate was as follows:

Accurate coordinates for four control points, relating to extremities of the satellite image were assigned. Our reference system was chosen, taking into consideration that the required accuracy was not so important and earth curvature could be ignored at this scale.

So a minimum of four common control points between our reference map and each map were found totaling 44 points (See Appendix 17). Control points of BOP or other available maps were found the closest possible of the extremities in aim to reduce errors. Their coordinates being deduced from our reference map, map overlaps were easily performed.

Overlapping between digitized maps and satellite image revealed a allowable Root-Mean-Square Error (See Appendix 18) equal to 85 for the soil map and to 5 for the other ones. It means respectively an error on the ground of 85 m and 5 m.

2.6 Identifiers Choice

In order to identify different entities of the system and to facilitate link with database, identifiers have been assigned to different types of entities (polygons, lines or points).

2.6.1 Polygon Layer Identifier

Polygon layer concerns command areas, tanks, soil maps, and contribution zones.

Identification of command areas under main management and tanks is made with four number.

- First represents Kirindi Oya Sub-system (Ellegala, RBMC or LBMC).
- Second: tract (for new areas) or command areas relating to tanks (old areas).
- Third and fourth number design subcommand area under secondary canals along main canal (for new areas) or subcommand areas under main canals of the tanks (for Ellegala system).

Identification of tank is carried out by a similar way (except for Lunugamwehera, for which identifier 1000 has been chosen as main feeder of system).

Thus,

First Number :

- Ellegala System :	0
- RBMC System :	1
- LBMC System :	2
- Lagoon :	3

Second Number :

- No identification	0
- Tract 1 to 7 :	1 to 7
- Badagiriya :	8 (assumed to belong RBMC System)
- Pannegamuwa :	1
- Weerawila :	2
- Yoda :	3
- Tissa :	4
- Debera	5
- Gamunupura	6

Third and fourth Number (for new areas):

- Command under DC1 to13: 1 to 13
- Command under FC27 : 27 (except when in a tract DC and FC have the same number. In this case, closest number is assigned).

Third and fourth Number (for old areas):

Third number identifies number of the tank gate (0 is assigned when it is tank). Fourth number is 0.

- Tank :	00
- Yoda Command area under second main canal	20

Thus, a polygon **1513** identifier designs **Right Bank Main Canal Tract 5, command under DC13**, and polygon **0430** identifier designs **Ellegala System Command area under third main canal of Tissa Tank**.

Concerning soil map, number of 1 to 7 identifies seven types of soils.

Concerning contribution (representation layer), 1 identifies zones, where drainage is stored and reused, 2 identifies zones open to the sea, where drainage is reused but not stored. Number 3 identifies zones open to the sea, where drainage is not reused.

2.6.2 Line Layer Identifier

It is made with two numbers.

For network layer:

- First represents Kirindi Oya Sub-system (Ellegala, RBMC or LBMC).
- Second: irrigation canal class.

For drainage layer:

- First number represents if drainage stream is located on Right Bank or Left Bank of Kirindi Oya.
- Second, if drainage flow is reused (Cascade) or runs directly to the sea (Sea Losses).

First Number :

Network Layer		*Drainage Layer*
- Ellegala System :	0	Kirindi Oya Right Bank : 1
- RBMC System :	1	Kirindi Oya Left Bank : 2
- LBMC System :	2	

2.8 KOGIS Modules

Modules supporting CRE decisions appears below (See Appendix 20). They cover phases: *Command*, *Observation* and *Evaluation*. Module relating to command phase defines targets in command areas table. Modules relating to observation phase organizes daily dashboards and displays evolution of tank water level. Modules relating to evaluation phase, organizes weekly dashboards and rainfall spatial pattern.

Table 9: KOGIS modules

Module Name	Description	Activity
C_target	Define targets from schedule	Command
C_observ	Build daily dashboards	Observation
C_eval	Build weekly dashboards	Evaluation
C_rain	Interpolate rain from stations	Evaluation
C_graph	Describe tank water level evolution	Observation

These modules are written in Idrisi macro languages (See Appendix 14), which is able to manipulate layers. One problem faced was data processing speed due to redundancy of computation. It has been solved by creating virtual images, which have a very limited numbers of pixel (See Appendix 14)

2.9 Dashboards Library

A menu under Idrisi allows selection among four dashboards in library. This library is made up with two dashboards for daily observation and two for weekly evaluation.

2.9.1 First Dashboard: DALS "Delivered Amount"

The first dashboard deals with daily water deliveries spatial pattern within the system, as well as tank water status and water losses to the sea.

Allocation supply within Command Area

Water issues in water depth expressed in mm, are used as hydraulic indicators of water distribution [Rey J. et Al.1993]. Five classes have been preferred to display this parameter (0-9 mm, 10-16 mm, 17-21 mm, 22-26 mm and > 26 mm).

This indicator is mostly preferred by managers in Sri Lanka to evaluate management performance and efficiency. It is more expressive as a discharge in Cusecs, since it takes into consideration size of command area.

Tank Water Status

It consists of four sets of information:

- Tank capacity (in Ac.ft)
- Tank reserve status defined by indicator $\dfrac{\textit{Actual Active Capacity}}{\textit{Active Capacity at full supply level}}$ in %
- Tank discharges (in cusecs)
- Tank spillings or release from tanks to tanks (in cusecs)

Tank spilling and release are not separated, since spilling of upstream tanks is accounted as a release for downstream tanks. Concerning the last two tanks before the sea, they have no release. Hence, spilling represents losses to the sea

First information is computed from available equations, developed by IIMI previous studies (See Appendix 4), They compute tank capacity as a function of water level.

Second information used is active capacity divided by active capacity at full supply level in %. Since active capacity is defined as available capacity above capacity at minimum operation level (MOL), a negative ratio does not mean that tanks is empty but that we are under MOL and emergency decision has to be made.

This indicator is essential to assess **"storage capacity"** of tank. A ratio close to 0, will mean that tank is ready to receive inflow. Subsequent control of management efficiency upstream from tanks will be so able to flexible. On the contrary, a ratio close to 100 will mean an imminent spilling and will lead to a severe control of upstream efficiency.

Third information is tank discharge.

Fourth information is principally necessary for tanks directly open to the sea, for which spillings directly run to the sea.

Sea losses

Two boxes relates water losses to the sea. One concern losses occurring from Ellegala system (Kirindi Oya River and Dorawa drainage canal) and second one represents losses running from Bandagiriya scheme, tract 5, 6 and 7 of RBMC. They are destined to allow a feedback in management. Their settings will be discussed later.

2.9.2 Second Dashboard DDEV "Targets deviation"

The second dashboard displays deviation between actual and targeted issues per command area. It is expressed by $\frac{Actual\,Water\,Issue}{Targeted\,Issue}$ in %.

Adapted from indicators of Molden and Gates [Molden D.J., Gates T.K. 1990], it reveals if adequacy of supply is met (enough water) with efficiency (no waste). Its spatialization allows to introduce to managers equity of water distribution within command areas.

Targeted issue depends on spatial character within command area (soil properties, conveyance losses, surface, slope, drainage reused, type of crops...) and on temporal character (crop growth stage). The latter is computed by the module C_target (Paragraph 2.9).

Five performance classes have been defined according to requirements of CRE as regard management and performance classes described in [Molden D.J., Gates T.K. 1990]. They appear below:

Table 10: Water distribution performance classes

Performance Classes	Idrisi Color	Water Management
0-80 %	Red	Poor
80-90 %	Yellow	Fair
90-120 %	Green	Good
120-140 %	Purple	Fair
>140 %	Blue	Poor

2.9.3 Dashboards used for weekly evaluation

Two dashboards, namely WALS and WDEV, display same information within command areas on a weekly basis, which gives more coherence to results by attenuating the high variability of daily operations.

Concerning tanks, evaluation is performed by displaying of weekly delivered amount in Ac.ft. to command areas and volumes of release and spilling.

In addition, weekly variation of tank capacity is registered to detect its tendency to fill or empty .

2.10 Rainfall Evaluation

Kirindi Oya System lies within the borders of two climatic sub-zones [Ponrajah, A.J.P. 1982]. Thus, north of the system (Lunugamwehera) is already under inland influence while south (Weerawila) is directly open to sea influence, meaning a little drier climate. Also, a disparity in seasonally rain is significantly recorded and a high spatial variation is experienced when it comes to daily rain.

In Kirindi Oya, gate operators partially or totally close the gate in case of rain without waiting for managers' decision in order to speed up water management efficiency. On CRE side, it is very important to assess how the system respond to rainfall (local operation) on the ground of a better understanding of rainfall spatial distribution. Hence, using rain recorded in KOISP and Idrisi capabilities to interpolate values, a rainfall spatialization model has been implemented.

This parts relates choice of model.

2.10.1 Rainfall Interpolation Model

Among methods of interpolation available in Idrisi, the model preferred has been the **Distance Weighted** method.

In this method, the estimation of the attribute in any given location (or pixel in a raster image) is the result of a weighted mean of values at surrounding points [Renault D. 1995]. The weight relative to each data is a decreasing function of the distance between the observed rain R at a point m_i and the estimated rain at a point $m_{(x,y)}$, for instance :

$$R(m_{(x,y)}) = \sum_{i=1}^{3} \lambda_i R(m_i) \qquad (1)$$

The coefficient λ_i respect the following equation :

$$\sum \lambda_i = 1 \qquad (2)$$

This interpolators honors the data if λ_i goes towards infinite as distance m_i goes to zero. Also in respect of relation (2), the following λ_i coefficient will be taken equal to :

$$\lambda_i = \frac{1 / \sum \frac{1}{d_i}}{d_i} \qquad (3)$$

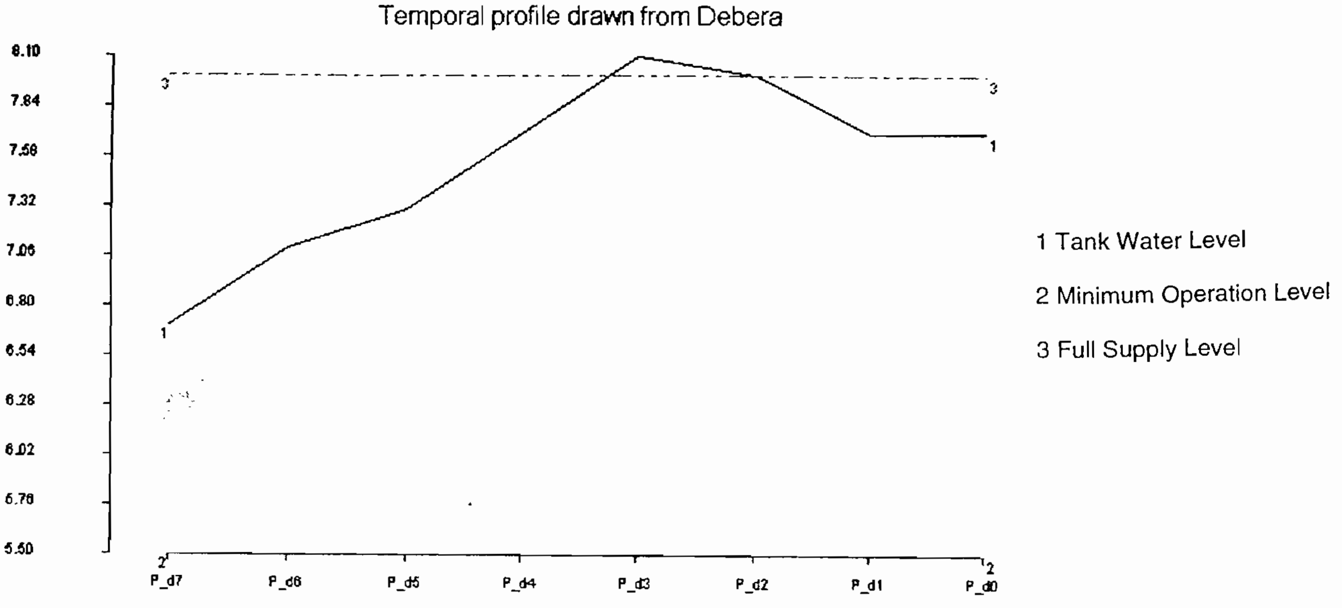
Where d_i is distance between estimated and observed location.

Disadvantages of this method are that, the weighted function choice is arbitrary, and implicitly supposes the spatial autocorrelation of the rain is known. a square distance could have been retained but would have reduced too much influence of surrounding stations.

2.11 Graphics

Graphics displays tank water levels evolution in comparison with their minimum operation level and full supply level. Example of graphics given by module C_graph is given below (See Fig.13).

Figure 13: KOGIS graphics module



2.12 KOGIS Procedure

Pilot of KOGIS is carried out through three functions *Command*, *Observation*, *Evaluation*.

2.12.1 Command Phase

Beginning of the week starts by command phase and defining of targets (*C_target* module).

2.12.2 Observation Phase

Each day, discharges computed from IMIS or Ellegala tanks database are seized in Command Table. In the same matter, tank water level, discharge, release and spilling, computed from Ellegala tanks table are imported in Tank table.

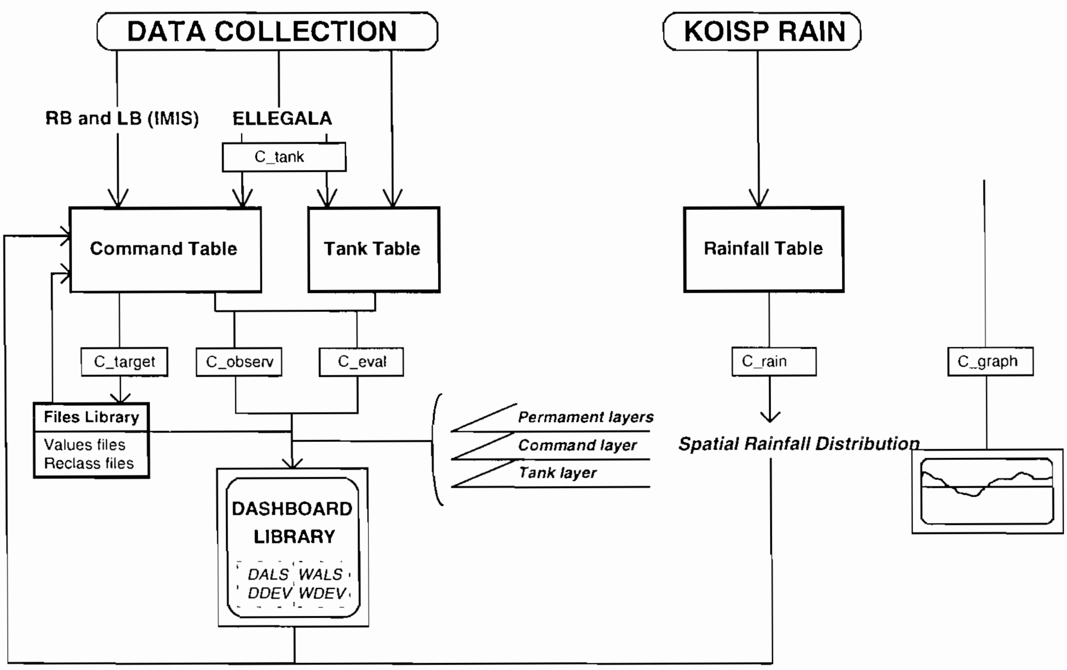
A module (*C_observ*) computes daily dashboards: DALS and DDEV (See Fig.4). An other one (*C_graph*) allows to observe tank evolution (See paragraph 2.11).

2.12.3 Evaluation Phase

At end of the week, a similar procedure (*C_eval*) is carried out to organize weekly dashboards: WALS and WDEV. Likewise, rainfall table is updated and module (*C_rain*) build a rainfall spatial distribution. Average rain relating to command area is extracted in command table as well as allocation supply and targets deviation indicators. Appraisal is conducted in the table of command areas and a new operation and new target are fixed to RE.

Navigation within KOGIS is described below:

Figure 14: KOGIS navigator



2.13 Conclusions

After completion of KOGIS and its main functions, it is important to improve knowledge of water behavior within the system with the goal of better defining water management flexibility and to advice a relevant information network. Thus, the next part relates to a field investigation which was conducted during the dry season in order to develop strategies for next rainy season, as well as management rules.

Chapter 3: Field Investigation

1 IMPROVEMENT IN THE KNOWLEDGE OF WATER FLOWS

1.1 Introduction

This chapter discusses the next step in the methodology of improvement in the knowledge of water behavior within the system. It has been achieved by means of a field intervention, conducted during Yala 96.

In a first approach, we have defined a typology of catchments within the watershed by using GIS and field observations. Then, a management strategy has been proposed taking into account specifications of identified catchments.

For zones open to the sea, with a high drainage discharge, sources of water excess and possibilities of recycling have been studied.

This selective management approach has then been applied to diagnose Ellegala system during rainy and dry seasons 95/96. Preliminary recommendations have then been derived from the latter.

1.2 Catchments Typology

A logical way of seeking for micro-catchments[11] , would have been using a map arranging of contours. Capabilities of GIS to interpolate digital contours would have allowed to build a Digital Elevation Model (DEM) and define micro-catchment areas within the system.

However, due to the civil war prevailing in the country, accurate maps are not available. Hence, an alternative has been proposed, which, though less accurate, is nevertheless interesting. It is the use of the soil map combined with drainage and irrigation layers.

1.2.1 Soil Map of KOISP

During its development by the Land Use Division of the Irrigation Department, the soil map has been accompanied by complementary surveys [Jayasooriya S.E. 1976]. One concerns landforms classification, and gives for each soil types, information concerning : slope, depth and composition of the mantle of the unconsolidated material overlying the bed rock. An other one focuses on soils properties.

The following table (See Tab.11) summarizes information relating to Kirindi Oya soil groups.

[11] Micro-Catchment is restricted to the immediate catchment of each tank within a tank cascade [C.R. Panabokke, 1995]

Table 11: Properties of KOISP soil types

Soil type	Mantle Depth Range	Hydraulic Properties	Slope range
Ranna Series	1-2 m	Well to moderately well drained	2-8 %
Nonagama Series	1-2 m	Well to moderately well drained	2-8 %
Rocky Phase of previous series	1-2 m	Well drained	2-8 %
Siyambala Series	1.2-2.5 m	Poorly to very poorly drained	0-2 %
Ellegala Association	1.2-2.5 m	Imperfectly to poorly drained	0-2 %
Tissa Association	1.2-2.5 m	Imperfectly to very poorly drained	0-3 %
Non Classified Soils	1.2-2.5 m	Excessively Drained	0-8 %

1.2.2 Correspondence between Subsurface and Surface Flow

For surface flow, we can make the following assumption: Surface flow occurs due to gravity and consequently runs from high slope to be harvested in lands with low slope. Hence, the fourth, fifth, sixth and seventh soil types (See Tab.11) can be identified as soils collecting surface runoff.

For subsurface flow, the assumption that subsurface flow occurs from well drained soils to be harvested in poorly drained soils can be made. Similarly to surface flow, we can deduce that the fourth, fifth, sixth and seventh soil types (See Tab.11) collect subsurface flow.

Thus, in the absence of a detailed study, we can draw conclusions on the correspondence of subsurface and surface flows.

1.2.3 Identification of Micro-Catchments within system

Using both previous assumptions as well as overlapping with drainage layer, it is possible then to define micro-catchments relating to tanks, outlets or Ellegala Anicut.

Similarly, overlapping with the command area layer determines contribution zones[12] relating to Ellegala tanks, Anicut or outlets open to the sea (See Fig.15).

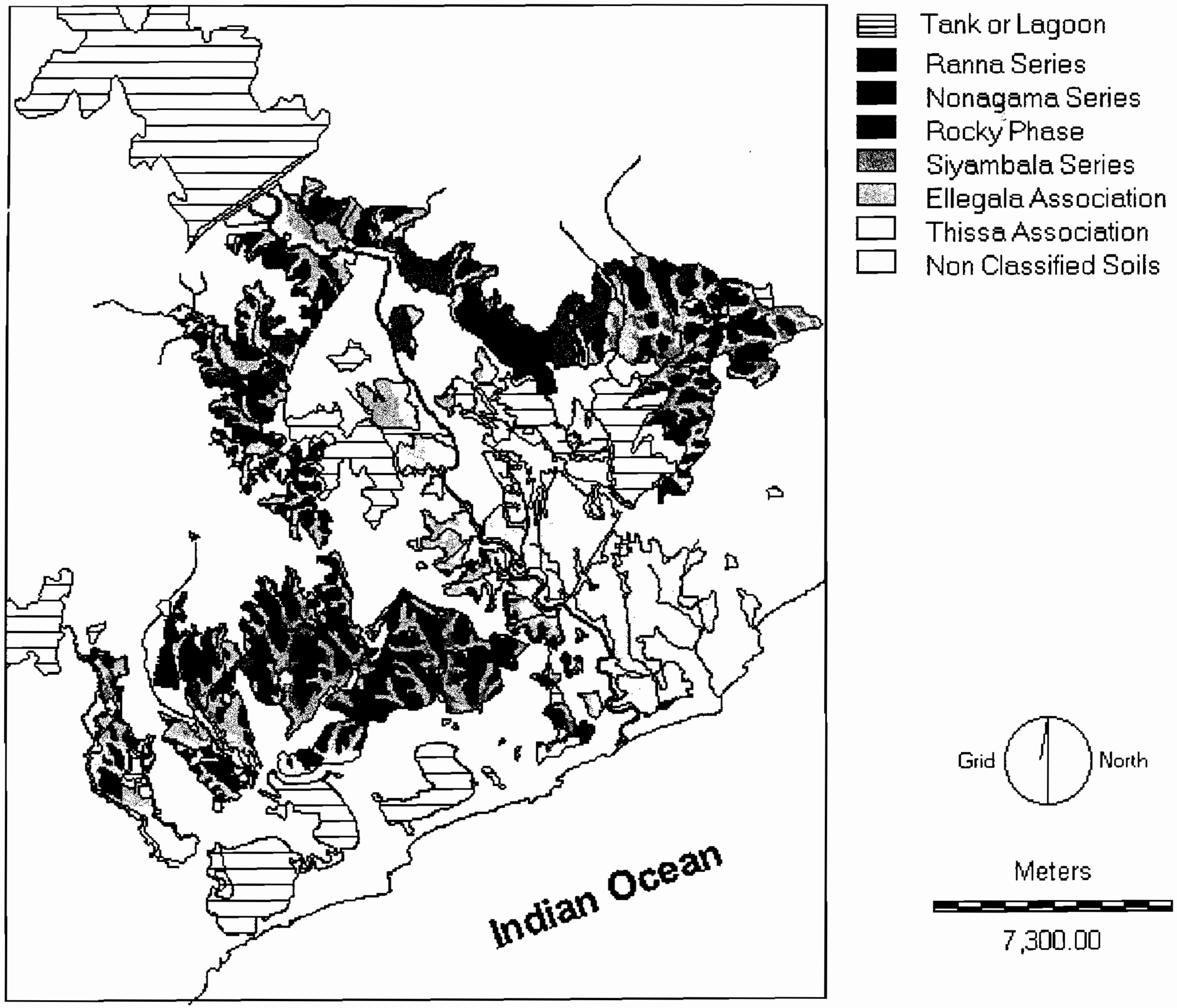
Knowing that these contribution zones are under main management, intervention of CRE on a upstream issue will have a direct incidence on a downstream storage (for zones draining to tanks or anicut) or on a downstream discharge for an outlet (zones open to the sea).

Limitations of this method are: For Ellegala System, only one soil type identifies the area, which represents however 4000 ha of flat irrigated surfaces open to the ocean and is located downstream from Ellegala tanks, for which an efficient management has to be imperatively led during rainy season

Hence, a better knowledge of water behavior within the area is required to define typology of micro-catchments open to the sea. It is the purpose of the next part

[12] Contribution Zone designs the entire command areas under main management located in a micro-catchment

Figure 15: Overlapping between soil, command and drainage layers



1.3 Field Investigation to improve Hydrology Knowledge

Field investigation has been conducted during Yala season. Due to a severe drought during Maha 95-96 (Lunugamwehera inflow during this Maha has had a low water volume about a period of return equal to 14 years), only 2570 ha of paddy and approximately 400 ha of other field crops have been irrigated. The command area upstream from Dorawa channel has not been under cultivation during season. Hence, we have considered the main system outlet as Kirindi Oya, although a "flow" in Dorawa has been observed.

To improve our typology within the old system and determine causes of significant flow in Kirindi Oya, the following methodology has been developed:

- Define all locations of drainage outlets running to Kirindi Oya.
- Define contribution zones upstream from these drainage streams.
- Define for each contribution zone, origin of water (surface runoff or groundwater contribution).
- Determine contribution part of these drainage in a water balance study at Kirindi Oya level.
- Determine proportions of water flow within the system during part of the dry season.

1.3.1 Drainage Outlets Location

Locations of outlets draining to Kirindi Oya have been determined from site observations from Indian Ocean up to Ellegala Anicut. Respectively 11 and 12 points could have been localized on the Right and Left Bank of Ellegala System.

1.3.2 Identification of Contribution Zones and Origin of Water

Each drainage channel has been walked up to define borders of its contribution zone as well as origin of water running in channels.

To define each irrigated surface contributing to the drainage in stream, no accurate maps being available, Issues Trees (See Appendix 21) have been provided by CRE. They give irrigated area under each main, branch, distributor and field canals. They have been the main help to find one's way around paddy fields.

General Conclusions are:

Four types of drainage running to Kirindi Oya can be defined:

- Drainage covering a "micro-catchment". (1)
- Drainage located along a paddy field and collecting paddy spilling. (2)
- Drainage at the end of an irrigation canal. (3)
- Drainage collecting spilling from a canal. (4)

The type (2) flow occurs when there is a water spilling over paddy field bund. In type (4), spilling occurs when canal capacity is full and in the type (3), when there is more distribution than required.

In the drainages of type (2), (3) and (4), **there is no significant flow except during rainy days, or in case of overdistribution in the irrigation network**. Hence, these three types of drainage can be defined as reliable indicators of overdistribution in dry periods. They do not, strictly speaking, cover a catchment and origin of their drainage water has been visually identified as surface runoff.

In type (1), we are in presence of real channels harvesting drainage water coming from a micro-catchment and whose origin is due to deep percolation and surface runoff. Also, it becomes very difficult to separate the proportions coming from surface and ground.

Typology of these micro-catchments is very different, whether we are on the Left or Right Bank of Kirindi Oya. It is described below:

1.3.3 Ellegala System Right Bank

On the Right Bank of Kirindi Oya, irrigated surfaces are supplied by Weerawila and Pannegamuwa Wewa. In Weerawila Wewa command area, relief is intermediate between lowlands and uplands. The morphology of this landscape (slope between 1.5 and 2.5 percent [Jayasooriya S.E. 1976]) determines the location of the main canal, distributors, field channels as well as drainage ways. Thus, borders of contribution zones can be easily defined. A high drainage density is self evident in this type of landscape. However, main drainage channels are mostly identified in the deeper valleys. They are shallow upstream and becomes little by little deeper when we arrive at outlet. Most of the water is not reused and directly runs to the river. Its origin is mainly from groundwater but significant paddy spillings can be observed.

For Pannegamuwa, land is flat, drainage is sometimes reused. All drainage canals are harvested in one main channel, itself partially diverted to additional paddy fields. However the main part directly runs to Kirindi Oya. Nevertheless, possibility to divert it to distributor canal 1 of Weerawila main canal is existing.

1.3.4 Ellegala System Left Bank

In contrast, the Left Bank of Kirindi Oya is located in a very flat alluvial plain with an average 0.5 percent slope [Jayasooriya 1976]. Natural drainage in this type of landscape is comparatively sluggish but benefits from the incised nature of the Kirindi Oya around its lower reaches, where the bed level is around 5 meters below the land surface. Drainage density in this area is very much lower than in Weerawila Command area. Drainage pattern is deranged and has a braided stream. Understanding of water behavior is more complex and depends on external factors such as:

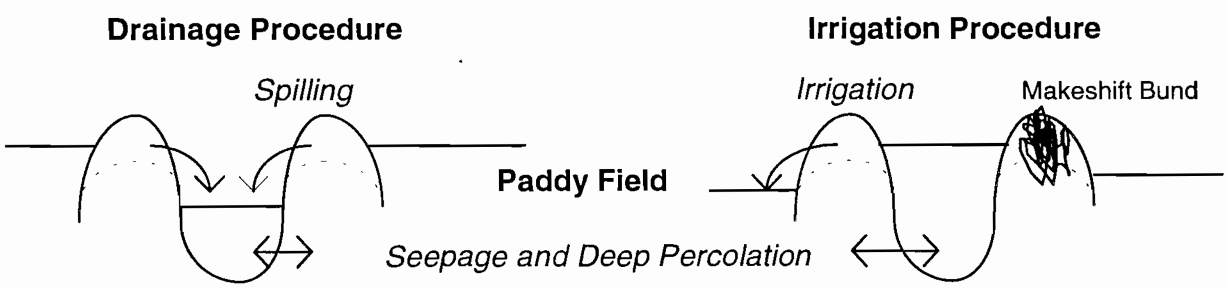
- Farmers
- Flow in drainage channels

Drainage Water Reuse

According to water levels in channels (lower or higher than paddy fields bunds), drainage streams can irrigate again and behaves as a water feeder (See Fig.16).

In the same manner, reused drainage water can drain to a main canal, meaning that water can be diverted water from its source to several outlets.

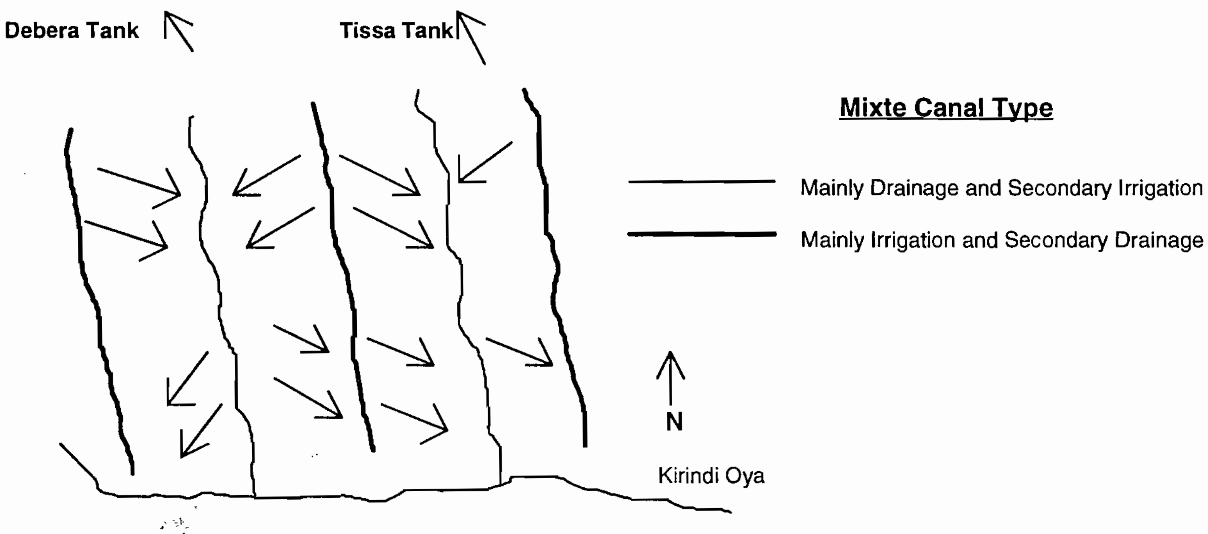
Figure 16: Mixed channels (irrigation and drainage in Kirindi Oya Left Bank)



Drainage Water Lateral Diversion through the System

On field, it means that water issued from upstream tanks (Debera Wewa and Tissa Wewa on Fig.2) can be useful for farmers of command areas of downstream tanks (Tissa and Yoda Wewa) and runs out of system through several outlets (See Fig.17).

Figure 17: Drainage water diversion



A lateral gradient Northwest-Southeast of drainage reuse can be identified. That means that, the more drainage stream is located at east, the broader its contribution zone is. It is needed to mention the significant attenuation of contribution of zones located upstream from a main irrigation canal, since it less common to detect paddy fields supplying irrigation canals.

Close-End-Channels

Likewise, we can observe sometimes artificial or makeshift dams upstream from outlets of drainage channels. They allow to rise upstream water level and divert drainage water to additional paddy fields (See Picture 4)

Picture 4: Dam diverting drainage water

Return Flow Channel

Within Tissa Wewa command area, some drainage channels are entirely diverted at their end, either to supply Yoda Wewa low level main canal and be useful again for irrigation or to irrigate additional paddy fields within Yoda Wewa command area (See Picture 5). Continuation of irrigation is carry out so from a command area to an other one. Drainage water is evacuated at an outlet close to Kirindi Oya Mouth.

Picture 5: Return flow channel

1.3.5 Typology of Drainage Streams running to the sea

Figure 18 specifies for each drainage, their type and if drainage is reused or not. Number used gives the drainage rank from Ellegala Anicut to Kirindi Oya Mouth.

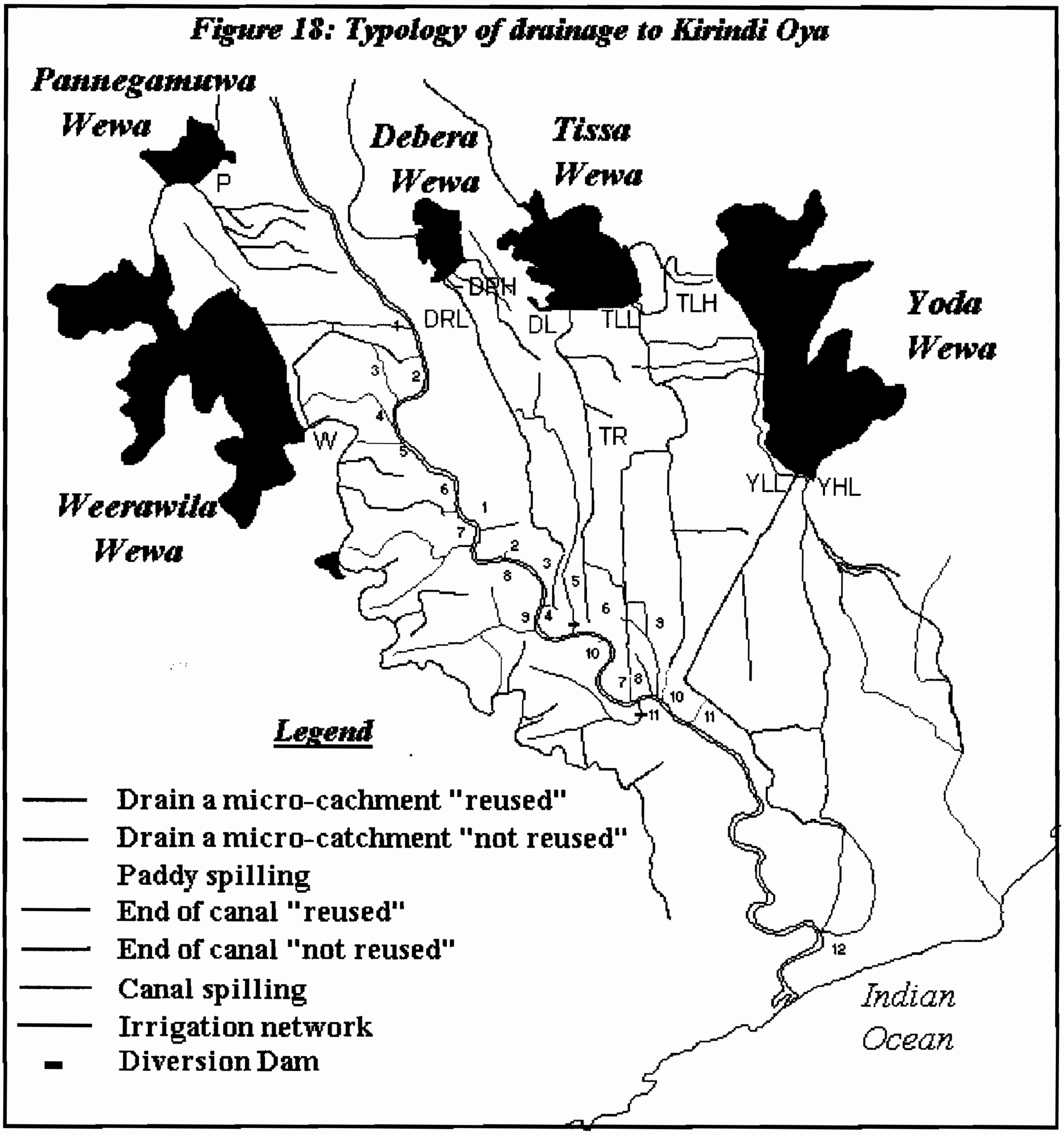


Figure 18: Typology of drainage to Kirindi Oya
Pannegamuwa Wewa
P
Debera Wewa
Tissa Wewa
Yoda Wewa
DRH
DRL
DL
TLL
TLH
TR
W
YLL
YHL
Weerawila Wewa
Indian Ocean
Legend
Drain a micro-cachment "reused"
Drain a micro-catchment "not reused"
Paddy spilling
End of canal "reused"
End of canal "not reused"
Canal spilling
Irrigation network
Diversion Dam

The entire contribution zone to Kirindi Oya covers 3 400 ha out of 4 100 ha of Ellegala System. This difference is explained, because the end of Weerawila main canal (See Fig.18) does not drain to Kirindi Oya and its drainage is lost in the coastal plains. On its side drainage water issued from Yoda Wewa high level main canal (See Fig.18) is also lost in coastal plains. It is found again at outlet of Dorawa channel. No durable solution can be proposed to save these water losses, except a control of the upstream discharge.

We can observe (See Fig.18), on the Right Bank of Kirindi Oya, drainage is essentially not reused while on Left Bank, reuse is widely met.

It is possible to delimit six well defined contribution zones on the Ellegala System Right Bank. On the Left Bank, we can also define four contribution zones, assuming that part of reused drainage water draining into irrigation canals is attenuated (See Fig.17).

1.3.6 Typology of Contribution Zones of Kirindi Oya System

In conclusion of GIS and field investigation approaches, we can define within the Kirindi Oya system, three main types of contribution zones.

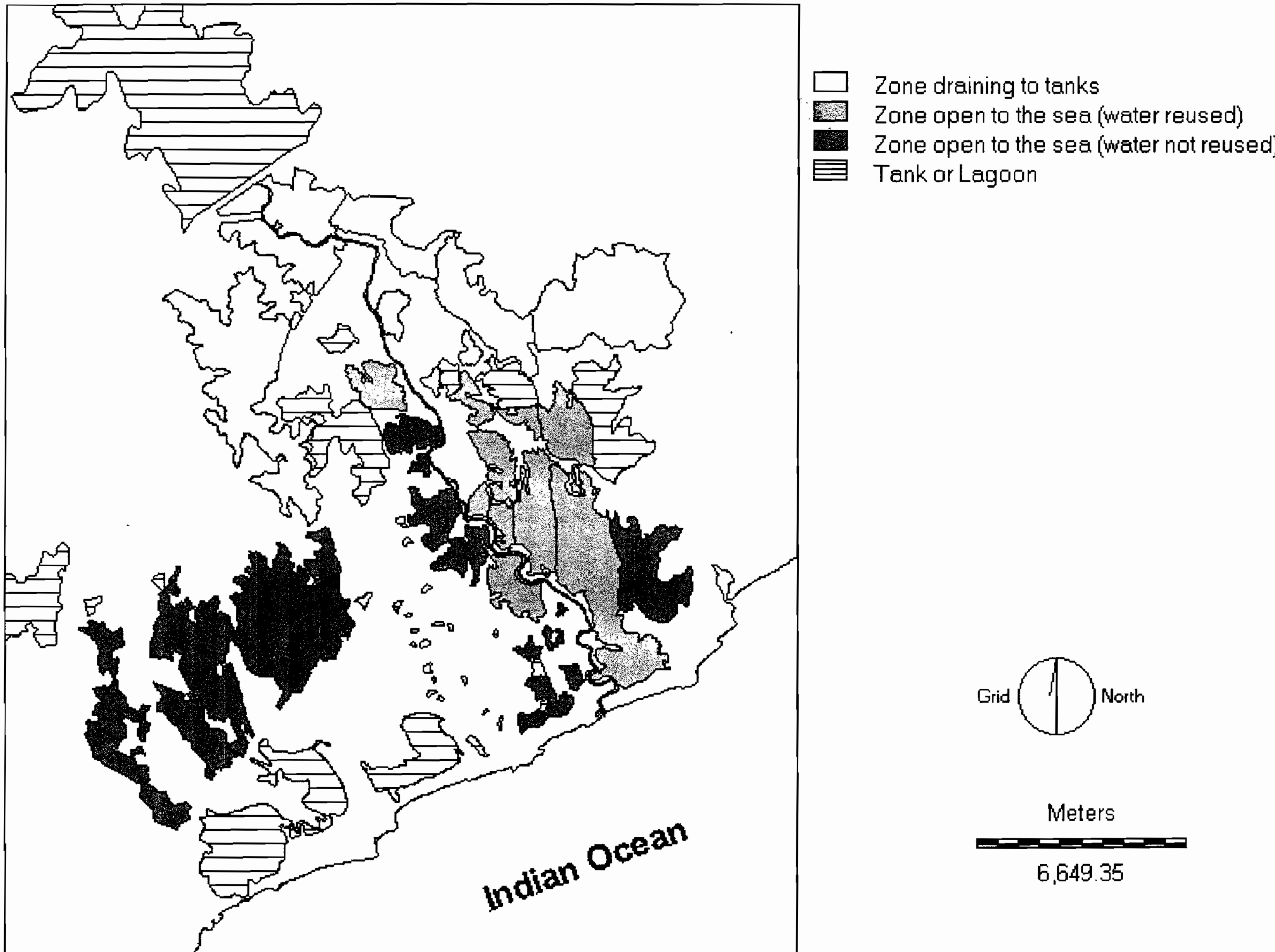
The first type covers zones where drainage water is stored in a reservoir and reused. The second one identifies zones normally open to the sea, but where drainage water is reused by diversion without being stored. The last type concerns zone open to the sea where drainage water is not reused (See Fig.19).

This typology induces different management objectives as shown in table 12.

Table 12: Management objectives according to typology of contribution zones

Contribution Zone Type	Management Quality Requirement	Action
Drainage + Storage + Reuse	Medium	Upstream control depending on downstream storage
Drainage + Diversion + Reuse	High	Upstream control to avoid spillings
Drainage to the sea	Very High	Upstream control induces $Q_{drainage} = 0$

Figure 19: Typology of contribution zones

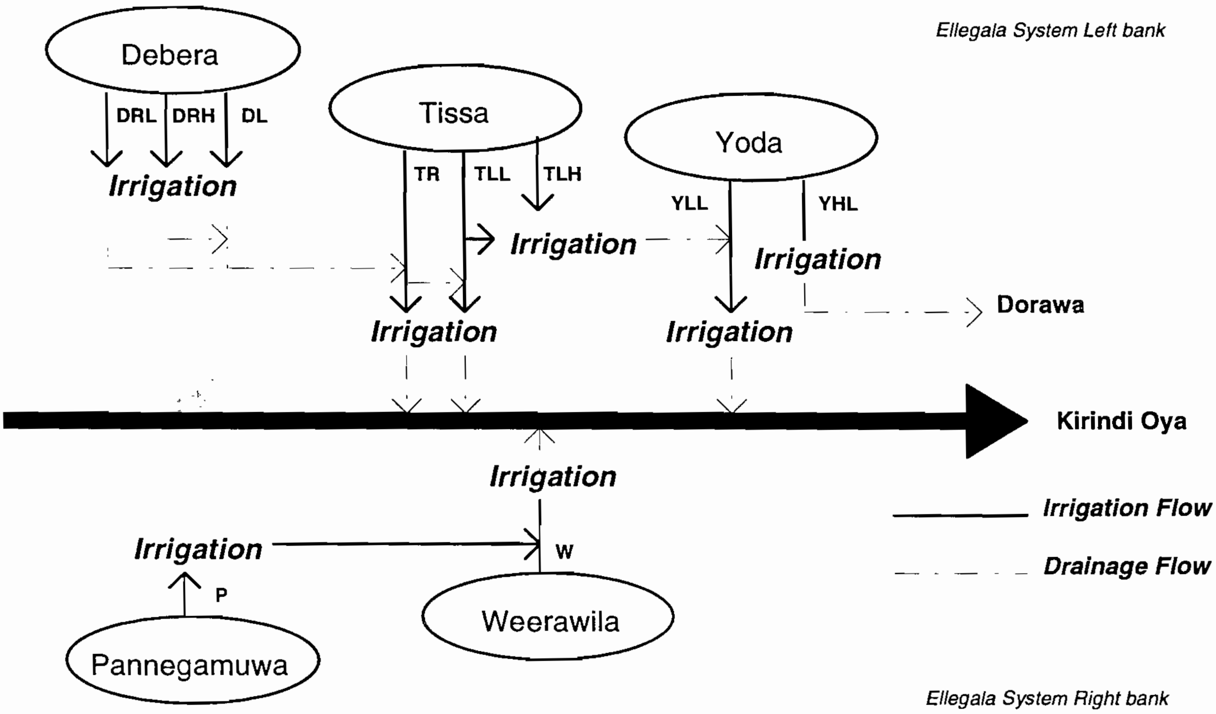


1.3.7 Conclusion on Typology of Contribution Zones

Observations made during the field investigation lead us to conclude on the following fact:

Evaluation of water management cannot be led on command area basis, as it is often recommended in literature, but on a more broader scale, taking into consideration hydrological connection. We propose to base hydrology within Ellegala System on the following schema (See Fig.20).

Figure 20: Schematization of drainage fluxes within Ellegala System



As we go downstream from Kirindi Oya, drainage channels cover a broader area and complexity increases. However, It is necessary to emphasize that upstream influence decreases with distance. Also, it is proper to improve weekly management evaluation to aggregate issues and compare them with their targeted issues, according to the following ***processes of aggregation drainage oriented.***

On the Left Bank

- Sum of issues coming from DRL, DRH, DL and TR with sum of their targeted issues.
- Sum of issues coming from DRL, DRH, DL, TR and TLL with their targeted issues.
- Sum of issues coming from TLH, TLL and YLL with targeted issues.
- Sum of the Left Bank issue with targeted issue for a global analysis

On the Right Bank

- Weerawila issue with its targeted issue.
- Sum of the Right Bank issue with targeted issue for a global analysis

1.4 Water Drainage Reuse Feasibility

For drainage streams covering an "important" micro-catchment and having usual observed flows significant, possibilities of reuse have been studied.

Possibilities of diversion or implementation of a dam to rise water level in drainage canal and to allow further irrigation have been analyzed according to the following characteristics :

- Depth of the drainage stream at its outlet with Kirindi Oya (diversion possibilities)
- Relief surrounding to outlet (diversion possibilities or building of a dam)

As mentioned earlier, significant flows on the Left Bank of Kirindi Oya are already reused.

On the Right Bank, it appears clearly that drainage coming from Pannegamuwa could be easily diverted into DC1 of Weerawila Main Canal.

For drainages of Weerawila command areas, steep banks and relief at the surrounding of outlets have shown that an improvement of water reuse can be dropped.

1.5 Contribution of Drainage Streams to Kirindi Oya

After having defined four main types of drainage, it was important to assess the order of magnitude of their quantitative contribution to Kirindi Oya. It is the purpose of this part

1.5.1 Methodology

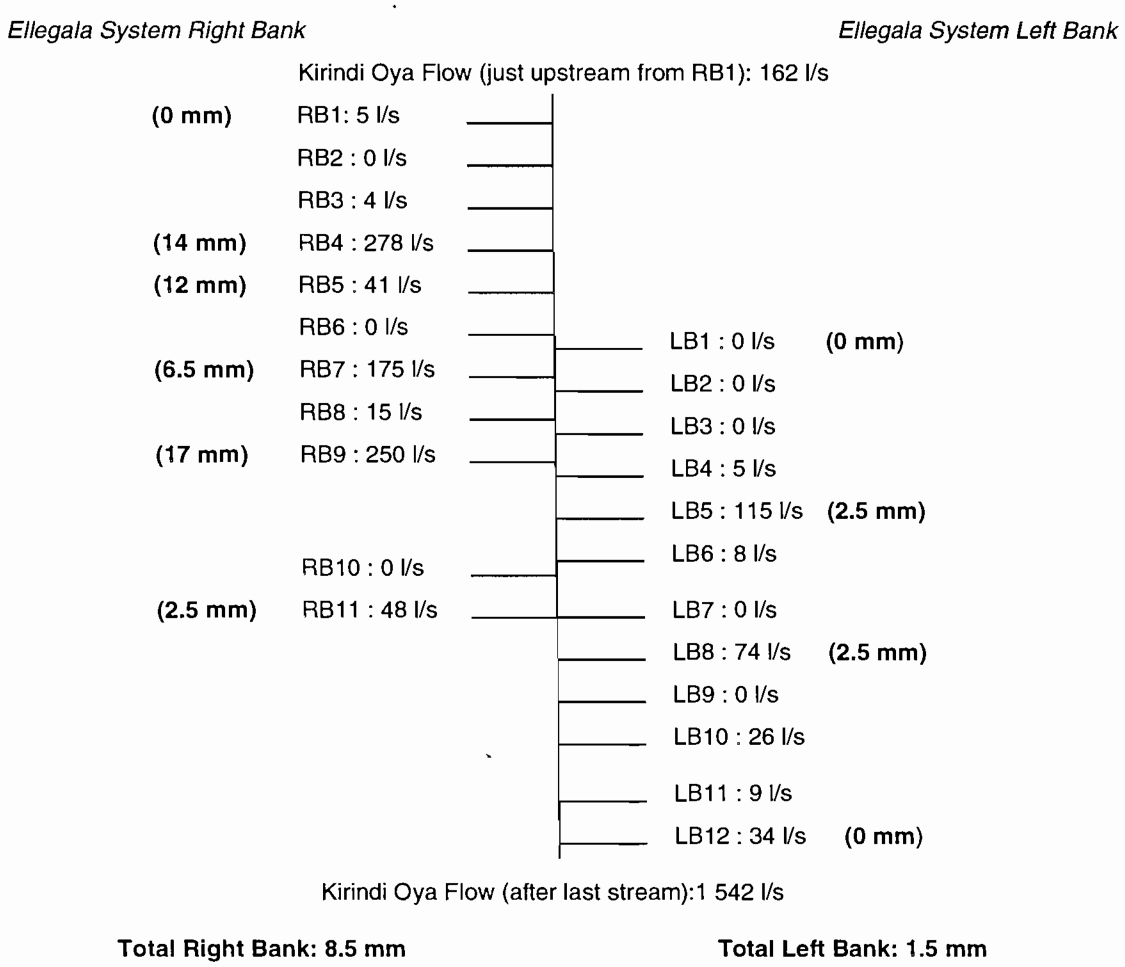
Having only a visual assessment of flow of these streams to Kirindi Oya and with no arrangement of staff to set up regular measurements, a set of discharges measurements has been carried out during a "representative" day. Our "representative" day has been selected as a day with no rain since the previous week and with "usual" observed flows.

Drainage discharges have been measured with a current meter and for small flow with a bucket.

1.5.2 Results

Results appears below (See Fig.21): For streams covering a micro-catchment on the Right and Left Bank, bold characters gives as a function their contributive irrigated area: equivalent water depth draining in mm/day.

Figure 21: Contribution of drainage to Kirindi Oya (22 th of June 1996)



1.5.3 Interpretation

Display of these results allows us to conclude on the following points

- Addition of all streams explains 80 % of the difference of Kirindi Oya flow measured just before the first drainage and just after the last one. We can assume, that missing 20 % are issued from very small surface drainages, which have not been observed or from direct deep percolation. Likewise, missing 20 % can be also explained by uncertainty of measurements. However, we can conclude that Kirindi Oya flow mainly depends on drainage and consequently, any action on upstream management will allow to save water for the system.

- Drainage water essentially comes from the Right Bank of Kirindi Oya: 816 l/s versus 271 l/s for the Left Bank, while their respective irrigated surfaces are 835 ha and 1620 ha. Results can be seen as a performance indicator of the recycling system in the Left Bank. We can conclude that 60 % of Kirindi Oya flow is explained by Weerawila drainage.

- Flows recorded in RB11 and LB5 during campaign were more significant than usually, because their dams were unusually opened. Their opening can be seen as an overdistribution of the system

- LB12 flow varies considerably in time. During the measurements, it was low, but it can sometimes reach 100 l/s. It can be explained by the broad area of its contribution zone, and the long process of drainage water reuse.

- RB1 is the drainage canal of Pannegamuwa. The low recorded discharge is explained by intervention of Irrigation Department and concerned farmers to divert this drainage into DC1 of Weerawila main canal (See Chapter 4, Paragraph 1.2).

- Cumulative drainage RB4, RB7 and RB9 coming from Weerawila represents more than 50 % of Kirindi Oya flow. In addition, equivalent water depth drained is between 6 and 17 mm/day, when deep percolation rate relating to soils of their command areas is assumed around to 3 mm/day [IIMI 1995]. Even though, Weerawila drainage is not reused, it seems that recorded drainages shows an apparent overdistribution coming from Weerawila.

Figure 21 clearly shows that important flow, usually observed in Kirindi Oya, is essentially due to drainage coming from Weerawila command area. Hence, a logical step was to identify causes, for which special attention was given in the next part.

1.5.4 Causes of Kirindi Oya Flow

A logical way to identify sources of water excess in drainage is to observe upstream issues. To maintain consistency in interpretation of upstream and downstream flows, it is better to compare drainage measurements with mean discharges of seven days preceding drainage observation. In addition, we can consider targeted issues. Tank issues appear below (See Tab. 13):

Table 13: Right Bank Ellegala tanks distribution performance

Canal Code	Targets (l/s)	Water Issue (l/s)	Ratio (%)	Downstream Drainage (l/s)
P	252	226	89	5
W	855	1576	184	812

For Pannegamuwa, a ratio of 89 % is sufficient, since its command area benefits from seepage of Weerawila.

For Weerawila, the table 13 is clear. There is significant recorded overdistribution, which is consistent with drainage measured. Thus, a better control of discharge from Weerawila Wewa would have perhaps avoided such water wastage.

On the Left Bank side, results are the following :

Table 14: Left Bank Ellegala tanks distribution performance

Canal Code	Targets (l/s)	Water Issue (l/s)	Ratio (%)	Downstream Drainage (l/s)
DRL	158	385	243	
DRH	34	69	203	
DL	167	331	198	
TR	461	243	52	
Sub Total 1	**820**	**1028**	**125**	**LB 5: 115**
TLL	303	228	75	
Sub Total 2	**1123**	**1256**	**112**	**LB 8: 74**

TLL	303	228	75	
TLH	125	245	196	
YLL	923	829	90	
Sub Total 3	**1351**	**1302**	**96**	**LB 12: 34**

Subtotal corresponds to sum recommended to make pertinent evaluation (Paragraph 1.3.7).

Concerning LB5 drainage, even though overdistribution by DRL, DRH is partially used to meet adequacy of TR (ratio = 52%), ratio of the sum is an important factor and explains the high discharge recorded in LB5 (Dam to divert water was opened).

Concerning LB8, a similar situation can be evoked. The lower ratio explains also the subsequent lower flow recorded in drainage canal. LB5 and LB8 are very close and have a strong relationship.

Concerning LB12, TLH supplies 245 % of its targeted issue, but drains in TLL and YLL command areas. Hence, drainage water generated by its overdistribution is used to meet adequacy of supply within both areas. It results a low discharge in drainage canal.

We can notice that, the closer ratio is to 100 %, the lesser important the flow is.

1.6 Water Balance within Ellegala System

The goal of this step is to better understand proportions of water flux within old areas to provide a representative figure of the seasonal water balance. System analyzed is downstream from tanks. Study was conducted during Yala 96 on a period of 35 days.

Water inputs of analyzed system are irrigation and rain. Water outputs are: Crop water consumption, through evapotranspiration in atmosphere, flow in Kirindi Oya to the sea and losses through evapotranspiration from non irrigated crops and natural vegetation as well as users consumption. Be that as it may, it represents the part of water losses on which we cannot intervene.

Study occurs after land preparation. Hence, we can consider that the whole soil capacity was already filled. In addition, we can assume that contribution zones to Kirindi Oya corresponds to the entire Ellegala System given that paddy fields draining to the coastal plains were not irrigated this season.

Hence, water balance can be written with the following equation

Irrigation + Rain = Crop Evapotranspiration + Kirindi Oya Flow + Other Losses

1.6.1 Crop Evapotranspiration Evaluation

Using climatic data available at Lunugamwehera Station, reference crop evapotranspiration has been computed with software CROPWAT [Doorendos J., Pruitt W.O. 1984]. Thus, arranging of irrigated area under each tanks and crop starting date, we have been able to know consumption by crop evapotranspiration for studied period. For instance :

$$\text{Crop evapotranspiration } (m^3) = \sum_{T=1}^{n} \sum_{i=1}^{9} 70 S_i \, K_c^i \, Et_o^T$$

Where S_i : Irrigated surface (ha) under tank gate i

$K_c{}^i$: Crop coefficient depending on cultural stage of S_i. It varies also as a function of time.

$Et_o{}^T$: Weekly crop reference evapotranspiration in mm/day for week T

n : number of weeks

1.6.2 Irrigation Supply

From typology defined in previous paragraph and irrigated surfaces under cultivation during Yala season, we can assume that all area irrigated by five tanks drain to Kirindi Oya. Hence, irrigation supply is

$$\text{Irrigation } (m^3) = \sum_{j=1}^{n} \sum_{i=1}^{9} D_i^j$$

Where Dij : Weekly discharge for gate i of week j computed by Ellegala database (m^3).

n : number of weeks

1.6.3 Rain Supply

Rain input can be expressed by

$$Rain\ (m^3) = 10 \sum_{i=1}^{n} S\, R_i$$

Where S : total irrigated surface (ha)

R_i : Rain in mm for week i

n : number of weeks

1.6.4 Kirindi Oya Flow Evaluation

Kirindi Oya flow to the Ocean has not been measured so far. To get an estimation, during the campaign, a cross section, where straight flow occurs, has been selected downstream from all drainage streams, described earlier (except LB12). Then, current metering measurements have been made, when important deviation of water level was recorded at cross section. Otherwise, only water level was recorded.

Four current metering (See Appendix 22) relating to four water levels [34-55 cm] has allowed to cover a flow range [1217-1896 l/s]. Using these four data, a simple regression has been carried out to give the flow F in Kirindi Oya as a function of water level H. F is given by the following equation $F = a\ H^b$ [Skogerboe G.V. 1992], where a and b are given by regression analysis. (correlation coefficient was equal to 0.91).

For the drainage (LB 12) not included by the cross section, a similar procedure has been realized.

Thus, twice a week, Kirindi Oya flow has been directly measured or evaluated.

1.6.5 Results of Water Balance

On considered period, results appear below:

Table 15: Ellegala System water balance (results in millions of m^3 during 35 days)

Irrigation	Rain	Kirindi Oya Flow	Crop Evapotranspiration	Users and Losses
11.5	0.6	4.8	3.8	3.5
95 %	5 %	39 %	32 %	29 %

Water supply has been essentially made through irrigation, which is obvious during dry season. On output side, we can notice that 40 % are definitively lost by system through Kirindi Oya. Knowing that nearly 60 % of this flow is due to an overdistribution of Weerawila, we can conclude on the large room to manoeuvre to save water within the system during Yala and on the necessity to set an improvement of Weerawila distribution.

1.6.6 Conclusion about Field Investigation

Study of water behavior within old areas has allowed for conclusions on the following points:

1: On the Left Bank, drainage water being sufficiently reused through diversion, it is not necessary to improve system structure.

2: On the Right Bank, the possibility of diverting Pannegamuwa drainage water to Weerawila DC1 has been performed during Yala by farmers. Also, it seems that currently the Right Bank has reached its optimum of water reuse.

3: The important flow in Kirindi Oya (40 % of irrigation) has been principally identified as an overconsumption of Weerawila Wewa.

4: Hence, setting the right conditions in which to improve tank water distribution has emerged as an important factor and early feedback to upstream management on the control of water losses to the sea.

5: On the Left Bank, it seems rudimentary to efficiently evaluate weekly water distribution to take into account hydrological link between command areas.

6: Typology of contribution zones has revealed three types of irrigated zones, for which subsequent management has to be differentiated.

2 SEASONAL ANALYSIS OF ELLEGALA TANKS

This part diagnoses water management of Ellegala system for the rainy and dry season. It uses the results of the field investigation.

2.1 Maha 95-96 Diagnostic

The whole Kirindi Oya System was under cultivation during Maha 95/96.

Ellegala Tanks discharges as well as spillings have been computed for Maha 95-96 using data collected and recorded at the Left Bank Office. Results appears below (See Tab.16):

Table 16: Maha 95/96 results for Ellegala tanks

	Kirindi Oya Right Bank		**Kirindi Oya Left Bank**							
Tank Name	**Pannegamuwa**	**Weerawila**	**Debera**			**Tissa**			**Yoda**	
Cultivation Period	129 days	127 days	137 days			128 days			138 days	
Gate Code	P	W	DRL	DRH	DL	TR	TLL	TLH	YLL	YHL
Command (ha)	224	920	232	24	122	336	655	90	700	607
Duty for paddy (m)	1.1	2.9	1.9	2.6	2.2	0.9	1.1	2.5	1.8	1.2
Target (m)	1.4									
Release (10^3m^3)	750		5500			8800				
Spilling (10^3m^3)									5600	
Spilling days									38	
Rain (m)	0.6									

Duty as well as target is expressed for the whole season.

Rain is recorded at Lunugamwehera station and totaled from October to January.

2.1.1 Left Bank Water Distribution Performance Analysis

Methodology of Evaluation Drainage Oriented, described in chapter 3 paragraph 1.3.7, has been used to analyze distribution performance of the Ellegala System Left Bank.

For contribution zones upstream from LB5, duty is 1.5 m, which is higher than target. Nevertheless, it can be explained by the difficulty to control distribution along DRL, which is a very long main canal (duty 1.9 m). Globally, distribution is correct but can be improved.

Concerning LB8, duty relating to upstream contribution zones is equal to 1.3 m, which is better.

Problem seems coming from Yoda Wewa distribution. In addition to drainage return flow of Tissa to Yoda command area, duty relating to YLL is abnormally high.

This deliberate overdistribution is essentially explained by a permanent high level in the tank during the season (See Fig.22). Hence, tank overdistribution or spilling unavoidably have occurred.

2.1.2 Left Bank Tanks Management Analysis

Fig.22 below displays evolution of Yoda water level.

2.1.2 Left Bank Tanks Management Analysis

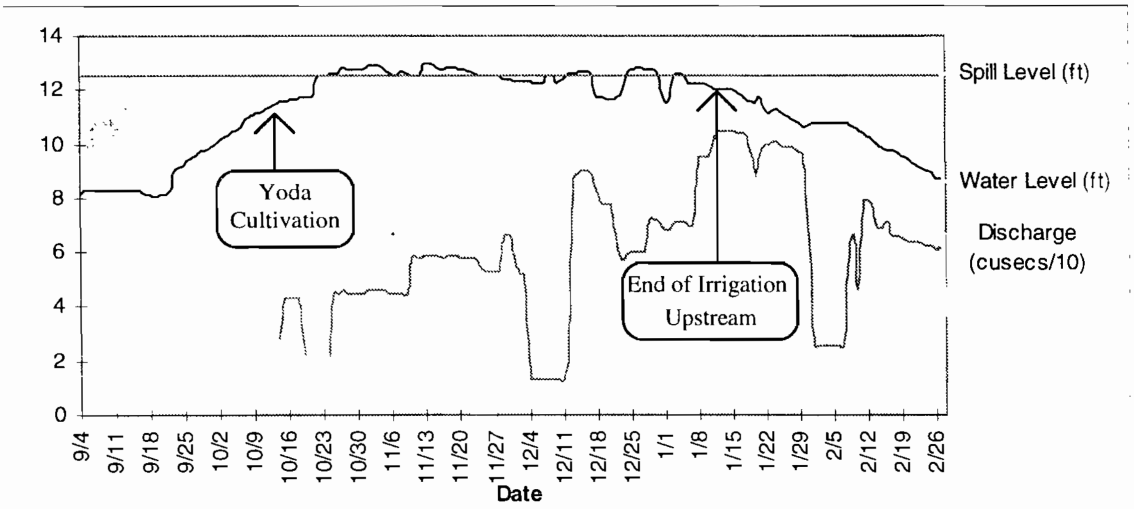
Fig.22 below displays evolution of Yoda water level.

Yoda Wewa has two main sources of inflow: upstream drainage (drainage return flow and runoff) and water supply by Tissa Wewa (feeder canal).

New areas above Yoda Wewa have started their cultivation the 9th of September 95. Hence, the drainage return flow coming from new areas partially induces the rise of water level in the tank. When Yoda Wewa starts its cultivation (15th of October 95)(See Fig.22), it is already at its full supply level. Incapacity of tank to store the on going inflow has heavy consequences (spilling and overdistribution). Yoda Wewa being the last tank before the sea, excess of water runs directly to the sea and represents an important lost for the system.

When, irrigation along the LBMC, stops the 9th of January 96 (See Fig.22), tank water level starts going down. Consequences are: Yoda finishes its cultivation one month after with a low level. Hence, it can not undertake a second paddy cultivation without water supply by Lunugamwehera.

Figure 22: Yoda Wewa water level and discharge (maha 95/96)



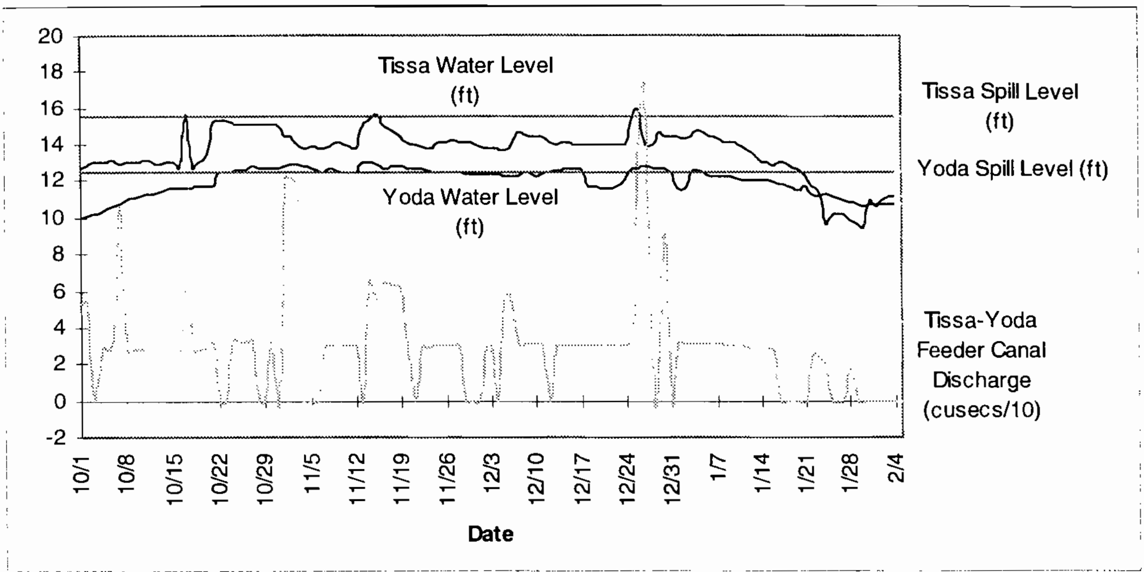
Two main reasons can be evoked to explain these management problems and the potential improvement. One concerns the timing of the decision to start season and the other is the operations of the tanks.

Concerning decision to start the season, the delay of cultivation between command areas upstream and downstream from tanks has consequence: Tank incapacity to store the inflow during the season and to see inexorably its level going down at the end.

Whether, Yoda Wewa had started its irrigation at the same time as new areas above, the slope of tank water level evolution would have been attenuated, storage saved at the end of the season would have been more important.

Concerning tank operation, we can take note of the release of water from Tissa to Yoda (See Fig.23). It can be seen that the release has not stopped, despite tank spilling. This could easily have been done, given that Tissa Wewa at this time was not at its full supply level.

Figure 23: Yoda and Tissa Wewa water status evolution (maha 95/96)



Yoda Wewa management show us that a potential improvement can be led for the water storage during rainy period and starts the dry season at a higher level.

2.1.3 Right Bank Water Distribution Performance Analysis

Pannegamuwa Wewa duty is low. It is mainly due to the location of its command area. Some parts can benefit from seepage water from Weerawila Tank. Other reasons for the low duty include the short canal system and efficient water control.

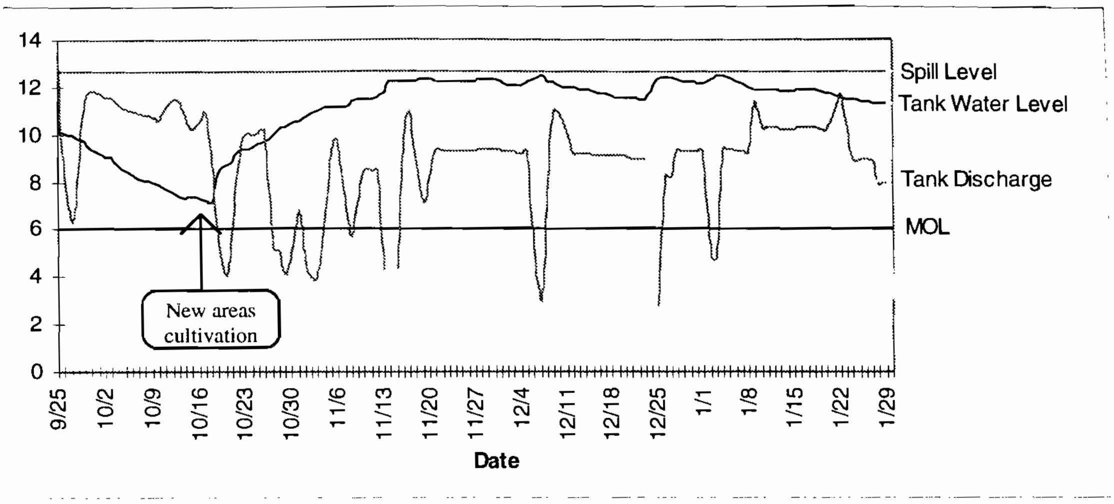
Particular case of Weerawila

Weerawila duty is usually the most important of the five tanks. Several reasons can be evoked:

- Drainage water is not reused
- Main canal is very long. It induces a less efficient control
- Weerawila command area is located close to intermediate lands. Deep percolation rate is quite higher.

However, despite all these constraints, duty is too much higher, and shows the large room for improvement of water management. To understand such a duty, we can see tank water level evolution below (See Fig.24).

Figure 24: Weerawila Wewa water level (ft) and discharge (cusecs/10) (maha 95/96)



Given that Weerawila Wewa has been scarcely fed by Pannegamuwa, we can assume that its inflow has only derived from drainage return flow (new areas above) and run-off (catchment area).

Weerawila cultivation starts the 25th of September 1995. Inevitably, its water level decreases close to its minimum operation level (MOL)(See Fig.24). So, decision to start season within new areas above is made, which explains the rise of its water level. Water level reaches then its full supply level and explains the overdistribution of the tank.

Decision to start the season has been made efficiently, since managers have wait for water level reaches its MOL to start cultivation in the new areas. Since, Weerawila finishes its season with its full supply level, we can conclude that management strategy could not be much better. Weerawila Wewa appears as a water abundant system.

Hence, the potential improvement seems to turn towards a better control of upstream issues in aim to limit drainage return flow.

1.2.4 Conclusion about Tank Management

Concerning Yoda Wewa, it appears clear that improvement can obtained in:

- Decision to start the season (Phasage between new and old areas distribution to store a maximum of water)
- Improve tank operations
- Improve the control of upstream issues.

Concerning abundance of water within Weerawila system, only a better control of upstream issues (RBMC tract 1 and 2) can be suggested.

2.2 Yala 96 Diagnostic

Due to a severe drought, during Maha 95/96, which also continued during Yala 96, only 70 % of Ellegala System was cultivated, for instance, hardly 30 % of the whole system.

For Yala season, results appears below (See Tab.17):

Pannegamuwa and Yoda Wewa haven't finished their cultivation at end of study. Also target is computed with respect to cultivation stage of 1st of August 1996.

Table 17: Yala 96 results for Ellegala tanks

Tank Name	**Pannegamuwa**	**Weerawila**	**Debera**			**Tissa**			**Yoda**	
Cultivation Period	98 days	120 days	121 days			116 days			91 days	
Gate Code	P	W	DRL	DRH	DL	TR	TLL	TLH	YLL	YHL
Surface (ha)	190	645	116	24	122	336	230	90	700	0
Surface (%)	85	70	50	100	100	100	35	100	100	0
Duty for paddy (m)	1.18	2.25	3.67	2	2.37	0.97	1.01	2.44	1.04	0
Target (m)	1.2	1.4	1.4			1.4	1.5	1.4	1.1	
Release ($10^3 m^3$)	4 200					3800			915	
Rain (m)	0.15	0.1	0.15							

From this table, we can see that rainfall has been very low during cultivation period, which explains quite important duties.

2.2.1 Ellegala System Left Bank Water Distribution

Identically to 2.1.1, we can compute duty relating to command areas under DRL, DRH, DL TR. It is equal to 1.8 m, which is important in comparison with Maha. However, we must keep a critical sense. During the cultivation meeting, decision has been made to cultivate only 50 % of paddy under DRL, but it is very unlikely that decision has been really respected and more paddy fields have been cultivated.

Duty relating to same command areas plus TLL is equal to 1.6 m. Taking into account rain and previous assumption, results are rather correct.

Concerning command areas draining in LB12, the global ratio $\frac{Issue}{Target}$ is equal to 101 %, which is optimum.

The Left Bank global management performance can be assimilated as very correct according to low rainfall recorded. It reveals a dynamic during dry period to save water as well as good knowledge of the system.

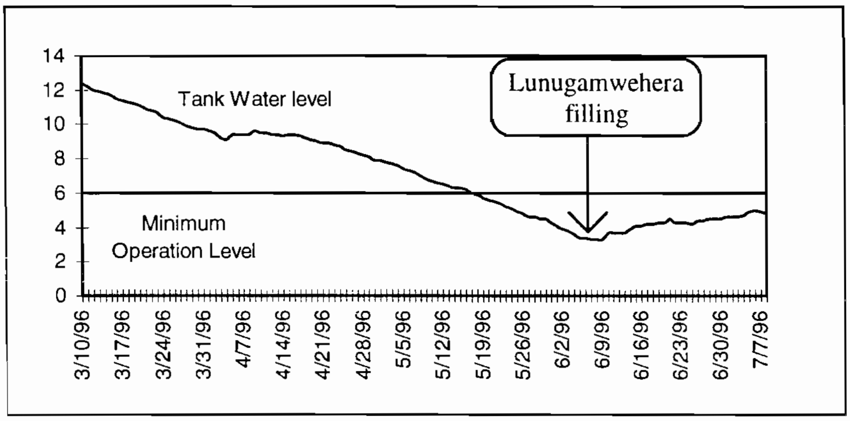
2.2.2 Ellegala System Right Bank Water Distribution

Pannegamuwa Wewa results are similar to Left Bank tanks. However, Weerawila Wewa assessment is less optimistic. Identically to Maha season, duty is very high. Except, that tank management has not been confronted to problems of water abundance.

In addition to high duty, we can add that tank water level having reached a so low level, emergency decision was made to fill Weerawila with Lunugamwehera water.

This water wastage can be explained by character of water abundant system of Weerawila. Water abundance during the rainy season has for consequences to get used to overdistributions and to start dry season with harmful habits.

Figure 25: Weerawila Wewa water level evolution (yala 96)



Chapter 4: Conclusion and Perspectives

1 WATER MANAGEMENT FLEXIBILITY

1.1 Conclusion about Water Management

Observation of both season as well as study of water behavior within Ellegala System leads to the following conclusions:

1.1.1 For the Rainy Season

Performance Objective to end Maha season with Ellegala tanks with their maximum level must be led according to three following concepts:

- **Decision to start the season**. Given that Ellegala tanks capacity appears limited to store upstream drainage return flow, it is proper to phase upstream and downstream issues (See Tab. 18). Whether, at the beginning of rainy season, water level is above MOL, it is proper to anticipate downstream irrigation to decrease water level and increase storage capacity and when water level has reached MOL, to start upstream irrigation. Whether tank water level is below MOL, decision to start upstream irrigation can be made, followed by downstream irrigation, when MOL is reached. In conclusion, it is proper to set an equilibrium between irrigation upstream and downstream from tanks. From results relating to Maha 95/96, storage capacity seems to be able to be only carried out through a downstream release.

Table 18: Recommendations to phase upstream and downstream irrigation

Tank Water Level Status	Irrigation Phasage
Below Minimum Operation Level (MOL)	Anticipate Upstream Irrigation until MOL
Above Minimum Operation Level (MOL)	Anticipate Downstream Irrigation until MOL

- **Tanks Operations** has to be conducted to maintain the lowest possible water level in tanks (Close to MOL) open directly to the sea (Weerawila and Yoda), although it seems difficult, given the low tank storage capacity
- **Control of Upstream Issues**. For a water abundant system as Weerawila, it seems primordial to set an efficient upstream distribution.

1.1.2 For the Dry Season

If tanks management and distribution does not set problems for four of five tanks, discharges recorded in Kirindi Oya has shown necessity to control gate operations and consequent distribution. It is particularly true for Weerawila, whose water abundance during the rainy season, lead to harmful habits in period of drought.

1.2 Drainage Water Reuse: Farmers Intervention during Yala 96

Drainage water reuse system seems to be at its optimum. Last possibilities to reuse drainage water have been conducted during Yala 96 by Ellegala farmers at their own expenses. It concerns Pannegamuwa drainage channel. It was diverted to distributor canal 1 of Weerawila main canal (See Picture 6).

This motivation to reuse water was essentially due to monsoon not coming. Water level in Weerawila Tank was gone so low that during one day, there was no more flow in main canal. Emergency decision was made to supply tank with Lunugamwehera Water. It has revealed on one hand dynamism of farmers to save water in period of drought and on other hand, concern of Irrigation Department to improve water management.

Picture 6: Works undertaken by Ellegala farmers (Yala 96)

1.3 Impact of Intervention

Study of water behavior within Ellegala System has shown the necessity to CRE to reestablish control in tank operations, which had more or less dropped in the last three years.

In addition, it has revealed a methodology drainage oriented to evaluate water distribution within the Left Bank of Kirindi Oya, taking into consideration hydrological connections

It has been concluded, that setting of control of Kirindi Oya seemed too early, and not adequate, given to lack of staff to collect current data. However, control of water losses to the sea will be able to be carried out by next student for zones open to the sea, where drainage water is not reused (Weerawila)

1.4 Operational Rules

Dashboard displays tank water status and spatialization of indicator of deviation. It is proper to conduct evaluation according to type of concerned contribution zone (Typology). Hence, operational Rules to save water within system are:

As a first approach, to improve efficiency, the following recommendations are made..

<u>Distribution within the command areas</u>

- *Zones open to the sea without water reuse.* Ratio Issue/Target has to be imperatively equal to 100 %.

- *Zones open to the sea with water reuse.* It concerns essentially Ellegala system Left Bank. Evaluation has to be conducted according method drainage oriented.

- *Zones upstream from tanks.* It seems that tank storage capacity is not sufficient to lead a management too flexible. Hence, efficiency of management upstream Weerawila has to be considered.

<u>Tank Management</u>

The management constraint being only to be above the minimum operation level, it is proper to maintain tank water level close to its MOL [IIMI 1994], even though, it seems difficulty possible.

<u>Adequacy of supply</u>

In a second approach, in the command area, where supply is inadequate, it is proper to control rainfall (distribution) to see whether rain has supplemented available water.

2 INFORMATION SYSTEM

2.1 Setting up of a Unified Information Network

This intervention has clearly convinced the Chief Resident Engineer that an efficient policy of water management improvement is necessary in order to unify information, which so far has been divided into three sources.

Consequently, for next rainy season, it has been concluded that IMIS results will be imported from Right Bank to CRE Office. At the same time, Ellegala tanks gate setting will be imported by phone on sheets prepared in presence of CRE (See Appendix 24). This unification of information will be all the easier since Projects of restructuring of Irrigation Department have already been aware of centralizing water management within one office and foresee to group four current offices around one main office for next year.

Due to a lack of staff to collect data, and the multitude of data on RBMC, CRE envisages reducing information on the Right Bank at five pertinent points, which it will be proper to select.

In the same manner, three locations along LBMC will be chosen to process the information.

Information reduction but the extension of its process to the whole system, will be the next step.

2.2 KOGIS Implementation

Dashboard, using GIS as an interface, has been accepted by irrigation managers. However, the setup procedures have not been user-friendly. It is essentially due to the fact that Idrisi for windows is a still new product and does not utilize of visual basic language yet.

However, the choice of Idrisi for Windows has been made because of its capabilities to process spatial information. This is an adequate interface to develop a future model. Whether it appears that after Maha 96/97, dashboard serves to save water and a model is not necessary, it will be proper to change the software to develop a final product.

In the price range higher than Idrisi, MapInfo and its Map Basic Language will be eventually studied to envisage the final product.

2.3 Tables Implementation

Having noticed on-field that durability of software depends on too many factors (computers, managers motivation, staff, IIMI follow-up), tables, using results of tank calibration and SIC formulas for undershot gate under free-flow conditions have been developed, to accompany KOGIS as tool of decision support.

They allows the computing of the gate discharge as a function of data collected by operators. A book gathering the entire tables as well as tables computing spilling discharge as a function of tank water level has been produced and given to LB engineer, CRE and TA. Tables destined to gate operators have been laminated to avoid being destroyed by water.

Thus, managers will give targeted discharges to operators each week. According to farmers request, CRE and RE decisions as well as tank water level, gate operators will be able to know spindle length to operate.

These tables allow to speed up process of decision making between managers and operators. They are simple of use and have been perceived as very well by manager. A sample appears in Appendix 12 (without plastic).

3 COMMUNICATION NETWORK DESIGN

The recommended information network design for the next season will be to:

- Repatriate raw data relating to Ellegala Tanks to CRE office on sheet prepared in his presence (See Appendix 24). Data repatriation will be operated by phone.
- It is also recommended that results of IMIS from RB to CRE Office are collected on a daily basis and if it appears too difficult on a weekly basis.
- Setting of sea losses control appears to be premature and inadequate. This is due to a lack of staff to collect current data. Likewise, the study has shown that a large amount of data collected is broadly sufficient to lead an efficient management.

Nevertheless, drainage coming from Weerawila will have to be be considered in the next study to define the improvement.

4 DEFINING A PERFORMANCE INDICATOR

To appreciate the global system management in successive years as well as impact of information unification, defining a simple performance indicator seems necessary for a manager. This part relates to its choice. It will be needed to improve this choice

One interesting point is impact of water management on extension of irrigated surfaces since the beginning of KOISP.

Extension of irrigated area, for both cultivation seasons, depends, on one hand, on climate and on the other hand, on management efficiency for general operations as well as decision making for seasonal allocation. Also, it becomes interesting to appreciate the global water management within the system to define an indicator using climatic data and seasonal irrigated surface.

4.1 Preliminary Studies

We have seen, that seasonal allocation decision is essentially made according to current storage in tanks and reservoir and expected inflow. Also, since in our seasonal evaluation of water supply (See Appendix 1), it has been concluded that main expected inflow derives from Lunugamwehera, we can draw a first assumption:

- Irrigated surface allocation essentially depends on Lunugamwehera storage realized during previous season and on its expected inflow.

Thus, we can assume that allocated surface is a function of two variables: Current storage and Expected inflow, for instance :

$$Irrigated\ Surface = f(Current\ Storage,\ Expected\ Inflow)$$

By the same way, water supply evaluation has shown :

For, *Expected Inflow* (75 %) allowed to irrigate the entire system while for Yala, *Irrigated Surface* depended on *Expected Inflow* and *Storage* realized during Maha

Thus, Yala inflow has a negligible incidence on Maha allocation, when Maha inflow will have an important incidence on Yala allocation.

We can also add, during Yala season, allocation decision is made very carefully. In concrete term, that means that, extension of irrigated surface is decided according to Lunugamwehera inflow and Yala behavior. Thus, we can assume that Yala inflow is essentially used to irrigate and not to be stored.

These results allow us to make two more assumptions:

- Maha Inflow is used to satisfy Maha allocation and a part of Yala allocation.
- Yala Inflow is essentially used to meet Yala requirement.

However, we need to emphasize that *Current Storage* variable at the beginning of Maha will play a significant role on Yala allocation, since Yala inflow does not allow a full irrigation. Consequently, the fourth assumption is:

- Current Storage at the beginning of Maha is a significant factor in next Yala allocation

4.2 Performance Indicator

From four assumptions made in previous paragraph, we can define the following performance indicator for the global system management:

$$System\ Performance = \frac{Storage\ at\ the\ beginning\ of\ Maha + Maha\ Inflow + Yala\ Inflow}{Maha\ Irrigated\ Surface + Yala\ Irrigated\ Surface}$$

It is expressed in m. A low indicator will characterize a high efficiency of system management in term of decision and operation, while a high indicator will mean a poor management. It is needed to emphasize that *Maha Irrigated Surface + Yala Irrigated Surface* can be maximized. Since beginning of the project, it has been made only during Maha 94/95 and Yala 95.

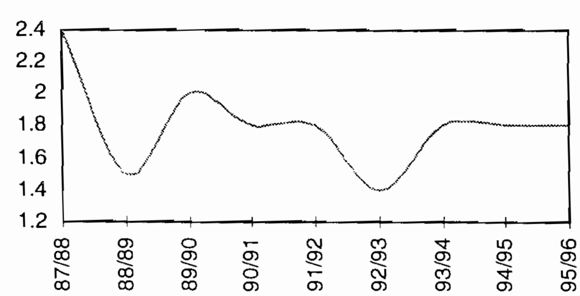
4.3 Global System Management Evaluation

For a pertinent evaluation and because OFC does not consume an big amount of water, it agrees to use paddy surface in the indicator instead of total surface, which is approximately is the same.

4.3.1Performance Evolution

Now, observe evolution of performance indicator along years in figure below

Figure 26: Kirindi Oya system performance (87/96)



General trend is downward with a light stagnation since three last years, which means an global improvement of system management. Indicator is in the region of 1.8 m, except for four years. For years 87/88 and 89/90, it is higher and for years 88/89 and 92/93 lower. To understand evolution, we can observe in table 18, separate evolution of different variables used in indicator.

Table 19: Irrigated area and Lunugamwehera inflow and active storage since 1987

Year	Paddy Surface (ha)					Lunugamwehera (unit in mcm)				
	Maha		Yala		Total	Inflow		Beginning Storage		Total
	Old areas	New areas	Old areas	New areas		Maha	Yala	Maha	Yala	
87/88	4050	4293	4050	2430	14823	212	129	8	82	349
88/89	4050	4293	4050	1903	14296	120	18	81	94	219
89/90	4050	2430	4050	0	10530	107	98	8	22	213
90/91	4050	4293	4050	0	12393	123	83	14	63	220
91/92	4050	5062	101	0	9213	80	25	57	18	162
92/93	4050	4293	1620	0	9963	111	40	-9	27	142
93/94	4050	3146	4050	4814	16060	220	72	-4	155	288
94/95	4050	5516	4050	5516	19132	149	158	44	108	351
95/96	4050	5516	2570	0	12136	75	58	80	14	213

4.3.2 Peaks Interpretation

The significant peak during year 87/88 is essentially due a slight allocation for new areas during both cultivation seasons despite a big water abundance. This explains a high indicator. We can evoke the careful setting of new system and lack of seasonal plan at the beginning of the project.

The light peak of year 89/90 is due to similar reasons. By the same way, we can observe, storage has not been undertaken, despite a significant inflow during Maha 89/90 and a low irrigated surface for new areas for the same period. Hence, it explains lack of irrigation for new areas during Yala 90 and a high indicator for the year.

The low indicator of year 88/89 can be explained by the inverse phenomenon. At the beginning of season, storage was high. Hence, decision to irrigate was made without taking into account season behavior. Also, the severe and unpredictable drought of Yala 89 shows the concern to save water to finish cultivation and consequently a downswing of consumption. This year shows us concern to save water in drought periods.

The low indicator during Maha 92/93 is explained by the lesson of crop failure of Yala 92 and concern to save water during this second consecutive "drought".

4.3.3 Improvement in Seasonal Allocation Decision

Globally, from the evolution of this indicator, we can see an improvement in decisions regarding allocation. If KOISP missed a seasonal allocation plan at the beginning, and decision was based more on current storage than climatic behavior, it seems that currently, decisions to manage irrigation of the entire system, involve less risk.

Whether graph stagnation means a performance stagnation, its attenuation attests to a better decision in term of seasonal allocation.

4.3.4 Stagnation in Resource Conservation

It is necessary to mention that for years 93/94 and 94/95, all new areas were irrigated. Consequently, tanks were benefiting from their drainage return flow. Also, the indicator should have been lower.

This constant indicator reveals that conservation of water resource during period of water abundance is not efficiently conducted, while in period of drought, concern to save water is very efficient.

4.4 Conclusion

This indicator reveals the improvement of decision making and a slight stagnation in terms of conservation of water resource and extension of irrigated surface. It attests an improvement in decisions of managers, which makes us think about the potentiel dynamic to conserve water resource, which is so scarce and beneficial (See picture below) for people of the dry zone area in their daily life...

REFERENCES

BOCCO, G.; DE BROUWER, H.; KARANGA, F.
Modelling water resources and water demand in semi-arid areas: Data integration and analysis using a Geographic Information System: A case study in Samburu District, northwestern Kenya, using the Integrated Land and Water Information System (ILWIS). A demonstration program prepared for the Unesco-ITC programme "Geo-information for the environmentally sound management of natural resources."
Paris, France: UNESCO, 1994, 62p.

CEMAGREF
"SIC: Users guide software documentation"
Montpellier, France: CEMAGREF, 1993.

DASTANE, N. G.
Effective rainfall in irrigated agriculture (FAO irrigation and drainage paper no. 25).
Rome, Italy: FAO, 1982, 62 p.

DOORENBOS, J.; PRUITT, W. O.
Guidelines for predicting crop water requirements (FAO irrigation and drainage paper no. 24).
Rome, Italy: FAO, 1984, 144 p.

EASTMAN R.J.
Idrisi for windows user's guide. Version 1.0.
Worcester, USA: Clark University, 1995

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE INC.
Understanding GIS. The arc/info method.
Redlands, USA: Environmental Systems Research Institute Inc, 1990.

IIMI.
Kirindi Oya Irrigation and Settlement Project: Project impact evaluation study: Draft final report. Vol.II: Annexes.
Colombo, Sri Lanka: International Irrigation Management Institute, 1994, 326p.

IIMI.
Kirindi Oya Irrigation Settlement Project: Project impact evaluation Study. Vol.I: Main report
Colombo, Sri Lanka: International Irrigation Management Institute, 1995, 118p.

IIMI.
Kirindi Oya Irrigation Settlement Project: Project impact evaluation study. Vol.II: Annexes
Colombo, Sri Lanka: International Irrigation Management Institute, 1995, 355p.

JAYASOORIYA S.E.
Kirindi Oya Scheme landforms classification
Colombo, Sri Lanka: Irrigation Department, Land Use Division, 1976.

MAKIN I.W. CORNISH G.A.
Information systems for operational management of irrigation distribution
Cairo, Egypt: International Commission on Irrigation and Drainage, 16 th Congress, Symposium R.4, 1996.

MOLDEN D.J. AND GATES T.K.
Performance measures for evaluation of irrigation water delivery systems.
Journal of Irrigation and Drainage Engineering, Vol 116, No 6, 1990.

MOORMAN F.R., VAN BREMEN N.
Rice: Soil, Water, Land
Philippines, Los Banos: International Rice Research Institute, 1978, pp 1-5.

MURTY, V. V. N.; KOGA, K.
Soil and water engineering for paddy field management: Proceedings of the international workshop on soil and water engineering for paddy field management
Bangkok, Thailand, 1992, 448p.

PANABOKKE, C.R.; AND WALGAMA, A.
The application of rainfall confidence limits to agriculture in the dry zone of Sri Lanka.
Colombo, Sri Lanka, Journal of the National Science Council of Sri Lanka, 1974.

PONRAJAH A.J.P
Designs of irrigation works for small catchments (up to 20 square miles)
Colombo, Sri Lanka : Irrigation Department, 1982.

RENAULT D.
Technical reference guide in GIS: Spatial approaches with GIS, process, model, statistics
Colombo, Sri Lanka: International Irrigation Management Institute, 1995.

REY J.
Apport de la gestion industrielle au management des périmetres irrigués : Comment mieux piloter la production ?
Paris, France, 1996, 178p.

REY J. AND HEMAKUMARA M.
Decision Support System (DSS) for water distribution management: Theory and practice
Working paper no 31.
Colombo, Sri Lanka: International Irrigation Management Institute, 1994, 44p.

REY J. AND HEMAKUMARA M.
IMIS user's guide.
Colombo. Sri Lanka: IIMI, 1994

REY J., HEMAKUMARA M., MOHANRAJAH S., JUNAID M.H.
Introduction of monitoring activities at the main-canal levels: A study of the Kirindi Oya Right Bank main canal-maha 1991/92. Working paper no 23.
Colombo, Sri Lanka: International Irrigation Management Institute, 1993, 66p.

ROUGEAU V.
Amélioration de la gestion de l'eau d'un réseau d'irrigation gravitaire de taille moyenne au Sri Lanka: Simulation des besoins en irrigation et étude de terrain
ENITRTS: HR Wallingford, 1989. 93p

SAKTHIVADIVEL R., FERNANDO N., PANABOKKE C.R., WIJAYARATNA C.M.
Nature of small tank cascade systems and a framework for rehabilitation of tanks within them.
Colombo, Sri Lanka: International Irrigation Management Institute, 1996, 54p.

SKOGERBOE G.V., MERKEY G.P., SHAFIQUE M.S., GANDARILLAS C.A.
Field calibration of irrigation flow control structures
Logan, Utah, USA: International Irrigation Center, Department of Agricultural and Irrigation Engineering, Utah State University, 1992. pp 15-30.

TE CHOW V., MAIDMENT D.R., MAYS L.W.
Applied hydrology.
Mc Graw-Hill International Editions Civil Engineering editions, 1988.

Synthèse en Francais

Table des matières

INTRODUCTION

Cette étude entre dans le cadre du programme de recherche lancé par l'unité ITIS[1]-IIMI[2] sur l'utilisation des Systèmes d'Information Géographique (SIG) comme outil d'Aide à la Décision sur périmètres irrigués. Elle a été réalisée durant ma dernière d'année d'étude à l'Ecole Nationale du Génie de l'Eau et de l'Environnement de Strasbourg (ENGEES) en vue de l'obtention de mon diplôme d'Ingénieur des Techniques de l'Equipement Rural.

De part la complexité des périmètres irrigués (Système en cascade) à laquelle s'ajoutent problèmes sociaux et politiques, la plupart des gestionnaires ont cessé de gérer leur système avec une politique de dynamisme et d'amélioration [Rey. J. 1996]. Les conséquences se manifestent le plus souvent par un manque d'efficacité de la gestion pendant la saison des pluies, aboutissant inévitablement à un manque d'eau pendant la saison sèche.

C'est pourquoi depuis cinq ans, l'unité ITIS-IIMI s'intéresse au développement de systèmes d'information comme outil d'aide à la décision sur périmètres irrigués. Un premier produit baptisé IMIS[3] a été développé sur le périmètre de Kirindi Oya dans le Sud-Est du Sri Lanka. Son but est de gérer les opérations sur le Canal Principal Rive Droite.

Suite, à la demande de l'Ingénieur Résident en Chef de ce périmètre d'élargir ce type d'intervention à l'échelle régionale, l'étude présente, s'est efforcée de répondre à ce besoin en s'appuyant sur l'outil Système d'Information Géographique. Le traitement de l'information a été réorganisé à cette échelle et la première application: un tableau de bord synoptique des principaux indicateurs de gestion, a été réalisée.

Dans le souci de mieux prendre en compte les préoccupations du gestionnaire et la disponibilité réelle en moyens (humains, financiers et techniques) pour gérer le système, l'étude a été développée en étroite collaboration avec le gestionnaire.

[1] Irrigation Techniques Information System

[2] International Irrigation Management Institute

[3] Irrigation Management Information System

1 PRESENTATION ET METHODOLOGIE

1.1 Présentation du Périmètre

1.1.1 Présentation Générale

Le périmètre de Kirindi Oya est une zone de plusieurs milliers d'hectares de champs cultivés (environ 10000 ha), situé au Sud-Est du Sri Lanka (cf. mémoire en anglais page 5). Le climat y est tropical avec des températures avoisinant les 26-28°C tout le long de l'année. L'évaporation uniforme avoisine les 1500 mm. La pluviométrie de la région est régie par la mousson du Nord-Est (d'Octobre à Janvier) et la mousson du Sud-Ouest (Avril-Juin). La mousson du Nord-Est correspond à la saison humide de culture, appelé saison de *maha*, qui fournit 570 mm de précipitation[4]. La mousson du Sud-Est correspond à la saison sèche de culture, appelé saison de *yala*, qui en fournit trois fois moins (220 mm).

1.1.2 Le Projet

Construit en 1986, le réservoir de Lunugamwehera et ses deux canaux principaux (cf. page 9) devaient conforter l'alimentation en eau des périmètres déjà existants (Ellegala et Badagiriya) et permettre l'installation de 8000 familles d'agriculteurs sur des terres nouvellement destinées à l'irrigation.

Cependant, détectée après la construction du barrage, la surestimation initiale de la ressource en eau mobilisable (à peu près 30 % [IIMI 1995]) a conduit à une réduction significative de la superficie à développer pour l'irrigation (8000 à 5500 ha) entrainant de fait une réduction dans les mêmes proportions de celle du nombre d'agriculteurs pouvant venir s'installer sur le périmètre.

A ceci, s'ajoutent, les difficultés à satisfaire sur la surface réduite la demande en eau des nouveaux arrivants et, ce faisant l'instauration de tensions de plus en plus ouvertes entre ces derniers et les agriculteurs des zones anciennes bénéficiant d'un approvisionnement garanti [IIMI. 1994]. Ainsi, depuis 10 ans, Kirindi Oya connaît une gestion à risque.

1.1.3 Présentation du Périmètre

Le périmètre est composé principalement de deux systèmes fonctionnant en cascade :

L'ancien périmètre, appelé périmètre d'Ellegala, est alimenté par une série de cinq réservoirs (cf. page 11). Un barrage de diversion situé en amont de la Kirindi Oya et construit il y a plus d'un siècle pour alimenter les cinq réservoirs, a été relié avec le projet au canal principal rive gauche. Il permet d'alimenter directement le périmètre d'Ellegala avec l'eau de Lunugamwehera (cf. page 9). Parralélement à cette source, les réservoirs bénéficient du ruissellement de leurs bassins versants respectifs ainsi que de l'apport en drainage, généré par l'irrigation des nouvelles surfaces situées en amont.

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[4] Probabilité de dépassement égale à 75 %.

De leur côté, les nouvelles surfaces sont alimentées par les deux canaux récemment construits. Le long du canal principal rive droite (cf. page 12), 43 prises d'eau alimentent 3500 ha de champs irrigués. Le long du canal rive gauche (cf. page 12), 21 prises irriguent près de 2000 ha. Une partie de ces nouvelles surfaces drainent dans les réservoirs de l'Ellegala, l'autre partie drainant vers l'Océan Indien (cf. page 18)

1.1.4 Gestion de l'Eau

La gestion de la ressource et de la distribution d'eau est effectuée par le Départment d'Irrigation représenté un Ingénieur Résident Chef (IRC). Sous son autorité, 3 ingénieurs résidents, répartis dans trois bureaux distants de quelques kilomètres, sont en charge de la gestion des deux canaux principaux et des réservoirs de l'Ellegala.

Les interventions, passées de l'IIMI, se sont efforcées d'organiser la collecte et le traitement des données. Ainsi chaque jour, l'information, le long du canal principal rive droite est relevée, transmise et calculée sur IMIS. Un système de collecte des donnés est également présent sur le canal rive gauche et pour les réservoirs de l'Ellegala mais le traitement de l'information n'y est pas encore effectué.

1.2 Les Problèmes de Gestion

Les problèmes de gestion rencontrés sur le périmètre sont essentiellement d'ordre quantitatif et lié au caractère évenementiel de la mousson.

Ainsi, en saison des pluies, l'abondance en eau dans les réservoirs conduit le gestionnaire à, soit suralimenter les secteurs dominés, soit provoquer le débordement des réservoirs. L'abondance en eau est en partie le résultat de la contribution en eau importante des drainages amonts. Parallélement , il arrive de voir en fin de saison, ces mêmes réservoirs à moitié plein quand ils ne sont pas complétement vides.

Il en résulte inévitablement un manque d'eau au démarrage de la saison sèche, limitant la plupart du temps l'irrigation aux anciennes surfaces.

En outre, d'importantes pertes à la mer peuvent être observée durant les deux saisons dans la Kirindi Oya (cf. page 21).

1.3 Diagnostique

Ces problèmes peuvent être imputés essentiellement à une gestion éclatée et incomplète de l'information au sein du périmètre ainsi qu'à l'absence d'outil de gestion pour l'ensemble du système.

Kirindi Oya est actuellement géré comme deux périmètres. D'un coté, l'Ellegala, qui jouit de la priorité d'allocation et pour lequel, la gestion est plus ou moins laissée aux fermiers (débits non calculés). Et de l'autre, les nouvelles surfaces, dont l'allocation en *yala* dépend du stockage réalisé dans les réservoirs en *maha*. Cependant, d'un point de vue hydrologique, ces deux systèmes sont étroitement liés et les problèmes de gestion des réservoirs en *maha* découlent directement de l'efficacité de la distribution amont. A ceci, s'ajoute l'absence de réseau d'information unifié entre ingénieurs, empêchant l'IRC de prendre des décisions adéquates et en temps réel.

1.4 Proposition d'intervention

Différentes types de stratégies peuvent être envisagés pour réinjecter du control dans la gestion d'un système. [Rey. J. 1996] conseille d'utiliser, dans les interventions visant à améliorer le fonctionnement des systèmes irrigués, la méthode "management par activités", qui consiste à définir un *Objectif de performance*, des *Activités Critiques* et des *Inducteurs de Performance*.

Dès lors, notre *Objectif de performance* peut être défini comme le besoin d'une gestion efficace en *maha*, pour terminer la saison des pluies avec les réservoirs de l'Ellegala à leur niveau maximum et de fait diminuer la demande en eau de Lunugamwehera lors de la saison de *yala*.

La gestion globale du périmètre et des réservoirs apparaissent clairement comme les *Activités critiques* devant mener à l'objectif fixé.

Les *Inducteurs de performance* au sens [Rey J. 1996] du terme ont été identifiés comme :

- La Désignation d'un réseau de communication permettant de faire véhiculer les données nécessaires à la gestion des activités critiques.

- La Construction d'un système d'information géographique en vue de permettre le traitement, le stockage et l'analyse des données nécessaires à la prise de décisions.

- L'Amélioration de la connaissance le l'hydrologie du système pour cerner l'amélioration potentiel de gestion ainsi que pour dégager des régles de gestion du système.

1.5 Methodologie de l'étude

La méthodologie développée dans le projet s'articule autour de trois approches: *l'Approche Décisionelle, l'Approche Information et l'Approche Hydrologique.*

Elle a comporté les phases suivantes:

- **Homogénéisation de l'information au sein du périmètre**. Elargissement du traitement de l'information au périmètre de l'Ellegala. Mise en place d'une base de données simplifiée permettant le calcul des débits de distribution, de transfer et de débordement des réservoirs de l'Ellegala.

- **Développement d'un tableau de bord** sur SIG (Logiciel Idrisi). Il utilise la visualisation spatiale d'indicateurs de distribution, de performance ainsi que le statut des réservoirs. Il est combiné avec IMIS et la base de donnée précédente.

- **Amélioration de la connaissance du comportement de l'eau** au sein du périmètre. Définition d'une typologie de bassins en vue de développer des approches de gestion appropriées.

- **Définition de l'amélioration potentielle de la gestion**. A partir de l'étude de terrain, et du diagnostique des deux saisons (humide et sèche), les points faibles de la gestion de l'eau ont été analysés. Des règles de gestion appliquées à la gestion en amont et aval des réservoirs ont été recherchées.

- **Définition d'un réseau d'information** pour rappatrier les données nécessaires à une gestion efficace du système. Perpectives de gestion.

- **Définition d'un indicateur de performance** pour la gestion globale du système en vue d'observer l'impact de l'intervention au long des années.

Durant l'étude, l'accent a porté essentiellement sur les trois premières phases.

2 HOMOGENEISATION DE L'INFORMATION

Cette phase de l'intervention a eu pour objet d'élargir le traitement de l'information aux zones anciennes.

Les différentes étapes ont été:

A partir des données collectées et enregistrées au bureau de l'ingénieur résident de la rive gauche (cf. annexe 2), une base de données simplifié, permettant le calcul des débits de distribution, de débordement ainsi que des transfers d'eau a été mise en place.

Une étude de terrain a permis de vérifier et corriger les données physiques des vannes des réservoirs (cf. page 32) ainsi que de leur déversoirs d'orage (cf. page 34). De la même manière, les donnés manquantes et nécessaires aux calculs des débits ont été mesurées en présence du personnel du Département d'Irrigation (cf. annexe 3).

Pour le calcul des débits, les formules utilisées dans le logiciel SIC (Simulation of Irrigation Canals) ont été considérées (cf. annexe 5 et 8). Afin de calibrer chaque structure, en leur attribuant un coefficient de débit correspondant, des mesures de courant au moulinet ont été effectuées (cf. annexe 11). Ces mesures ont permis, en outre, de détecter les vannes endommagées (coefficient de débit anormalement fort).

La base de données a été réalisée sous le système de gestion de base de données du logiciel Idrisi.

L'absence d'ordinateur au bureau de l'ingénieur résident rive gauche a amené au développement de tables (cf. annexe 12).

Les tables permettent de calculer tous les types de débit sortant des réservoirs. Elles ont deux entrées: L'ouverture relative et le niveau d'eau amont relatif.

Ayant homogénéisé le traitement de l'information collectée au périmètre de l'Ellegala, la prochaine étape a été de construire un tableau de bord, permettant la gestion globale du système de Kirindi Oya.

3 ÉLABORATION DU SYSTEME D'INFORMATION GEOGRAPHIQUE

L'élaboration du système d'information géographique comme outil d'aide à la décision pour la gestion du périmètre et des réservoirs a été conduit en s'inspirant de la méthodologie décrite dans [Rey J., Hemakumara H.M. 1994].

3.1 Analyse Orientée "décisions"

En premier lieu, une représentation du système de pilotage du périmètre a été formalisée (cf. page 43).

Quatre niveaux ont été distingués:

N_1 : un niveau de pilote pour l'ensemble du périmètre (Ingénieur Résident en Chef).

N_2 : un niveau de pilote pour les trois sous systèmes : canaux principaux rive gauche et droite ainsi que le périmètre de l'Ellegala (Ingénieur Résidents).

N_3 : un niveau de pilote pour le personnel en charge de la réalisation des décisions.

N_4: le système physique, le périmètre.

Trois fonctions ont été spécifiées, auxquelles ont été affiliés tous les traitements mis en oeuvre par le pilote N_1. Les fonctions associés aux autres niveaux n'ont pas été explicitement développées dans l'étude, ayant été mise en place dans le passé. Elles sont dans [Rey J., Hemakumara H.M. 1994].

Au niveau N_1, trois fonctions, respectivement *Commande*, *Observation* et *Evaluation,* ont été identifiées.

- La fonction de **Commande** définie les objectifs de gestion: l'ingénieur en chef coordonne le niveau N_2 pour les activités suivantes: Distribution en amont et aval des réservoirs en vue de limiter les pertes à la mer.

- La fonction d'**Observation** porte sur la distribution, l'écart enregistré par rapport aux objectifs ainsi que sur le statut des réservoirs.

- La fonction d'**Evaluation**, comprend l'analyse de performance du système, grâce à la visualisation d'indicateurs sur le tableau de bord. Compréhension de l'hydrologie, tendance... Analyse de la distribution spatiale de la pluviométrie au sein du bassin. L'évaluation doit permettre de nourrir la fonction **Commande** en modifiant les débits ciblés par le calendrier des cultures.

3.2 Analyse orientée "information"

3.2.1 Flux de Communication à établir

L'analyse précédente a défini l'architecture de pilotage au sein du réseau d'irrigation. La seconde analyse décrit les flux d'information correspondants (cf. page 44).

Actuellement, l'information circule bien entre les niveaux N_1 et N_3 (Lunugamwehera statut) et N_2 et N_3 (IMIS intervention sur la rive droite). Par contre, le flux d'information entre les niveaux N_1 et N_2 reste limité. Les conséquences sont lourdes et empêchent, par manque de données pertinentes, le gestionnaire principal de prendre des décisions adéquates et en temps réel. Aussi, il apparait nécessaire d'établir un système de rapatriement des données collectées et enregistrées au niveau N_2 jusqu'au niveau N_1.

3.2.2 Messages d'Entrée et de Sortie pour le Pilote du Système Principal

Après l'examen des recommendations visant à s'intéresser au réseau de communication, cette partie a défini les messages d'entrée devant parvenir au bureau de l'Ingénieur Résident en Chef. De la même facon, des messages de sortie pertinents ont été définis.

Une horloge interne a été considérée pour établir la fréquence des traitements à effectuer (cf. page 46).

3.2.3 Phase de Traitements

Les traitements effectués à la réception des messages d'entrés et au déclenchement de l'horloge interne pour générer les messages de sortie sont:

- Mise à jour de la base de données (entrée des données)
- Lancement des modules de traitements correspondants aux trois fonctions de N_1 (cf. page 56).

3.2.4 Base de Données et Couches d'Information

La base de données du SIG est constituée de trois tables et de nombreux fichiers de valeurs. Les tables sont destinées à l'entrée des données des objets réservoirs, secteurs dominés et stations climatiques. De leur côté, les fichiers de valeurs contiennent l'information permanente relative aux trois objets et permettent la construction du tableau de bord.

La base de donnée est reliée à des couches d'information, préalablement digitalisées (cf. annexe 16) et permet la visualisation d'un tableau de bord (cf. page 21), rassemblant les principaux indicateurs de gestion du périmètre.

3.2.4 Messages de Sortie

Cinq modules ont été crées pour générer les messages de sortie (cf. page 56).

Le premier correspond à la phase de ***Commande***. Il conseille des débits objectifs en fonction du calendrier des cultures et du sous système considéré (cf. page 16). Les débits peuvent s'en écarter selon l'évaluation de la semaine passée ou les requêtes des usagers.

Deux modules concernent la phase d'***Observation***. Le premier organise deux tableaux de bord visualisant respectivement la spatialisation de la distribution (épaisseur d'eau délivrée)et le rapport débits calculés / débits visés (cf. page 21). Le statut des réservoirs (capacité active, pouvoir de stockage, débits de distribution, débordement et transfer) est également représenté. Les pertes d'eau vers la mer sont aussi visualisables, quoique pour l'instant, aucune mesure de routine ne soit prévue. Le second module visualise l'évolution du niveau d'eau dans les réservoirs en fonction du niveau maximum et du niveau minimum d'opération (cf. page 60).

- Deux modules concernent la phase d'***Evaluation***. Le premier organise des tableaux de bords, identiques à ceux de la phase observation mais génère des indicateurs hebdomadaires, ce qui donne plus de cohérence aux résultats en atténuant les fluctuations des operations journalières. Pour les indicateurs de distribution et d'écart, cinq classes (cf. page 58) ont été à chaque fois représentées, tenant compte des exigences de gestion de la part de l'Ingénieur Résident en Chef. Le second module génère un modèle de distribution spatiale de la pluviométrie en interpolant les mesures locales de pluie au sein du système. En outre, il extrait du modèle, une pluie moyenne, pour chaque secteur dominé.

4 AMELIORATION DE LA CONNAISSANCE DU COMPORTEMENT HYDROLOGIQUE AU SEIN DU PERIMETRE

Disposant d'outil informatique aidant à la décision, cette phase a été effectuée sur la base d'une meilleure connaissance des flux hydrologiques au sein du périmètre, pour de cerner l'amélioration potentielle de gestion et mettre en oeuvre des stratégies.

4.1 Méthodologie

La méthodologie suivante a été développée:

- Définition d'une typologie de zones de contribution[5]. Développement de stratégies de gestion suivant le type de zones considérés.
- Etude des possibilités de recyclage des eaux de drainage débouchant directement dans la Kirindi Oya (Océan Indien).
- Evaluation de la contribution des drainages au débit de la Kirindi Oya.
- Evaluation du bilan hydrologique et répartition des flux au sein du périmètre de l'Ellegala.

4.2 Typologie de Bassins Versants

4.2.1 Utilisation du SIG

Ne disposant pas de carte précise du relief de la région (rendu non disponible par le Ministère de la Défense, étant donné la situation de guerre civile), la carte des sols a été utilisée pour identifier les grands bassins versants du périmètre.

Lors de son développement, cette carte a été accompagnée d'études complémentaires [Jayasooriya S.E. 1976]. Ainsi, pour chaque type de sols, il a été possible de connaitre un ordre de grandeur de la pente du terrain, ainsi que leurs propriétés hydrauliques.

Ayant pris comme hypothèses que les flux surfaciques ont lieu des terrains de fortes pentes vers les terrains de faibles pentes et que les flux subsurfaciques s'effectuent des sols bien drainés vers les sols mal drainés, il a été possible de:

- Conclure sur la correspondance entre le bassin surfacique et subsurfacique (cf. page 66).
- De définir, à partir de chaque réservoir ou éxutoire, le bassin correspondant.

La superposition de la carte des bassins identifiés et de la carte des secteurs dominés, a permis en outre de classer les zones irriguées drainant dans les réservoirs, au niveau du barrage de diversion de l'Ellegala ainsi que celles drainant vers la mer (cf. page 67).

Cette méthode a été efficace pour les nouvelles surfaces, dont le relief est légèrement modelé, mais s'est avérée insuffisante pour le périmètre de l'Ellegala, qui ne comprend qu'un type de sol, et est quasiment plat.

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[5] La Zone de Contribution est définicomme le secteur dominé drainant vers un réservoir ou vers un éxutoire.

Les drainages de l'Ellegala étant directement exposés vers la mer, il a semblé capital de mener une étude de terrain en saison sèche, pour identifier le type de bassins rencontrés au sein des anciennes surfaces, de mieux comprendre le comportement des flux d'eau ainsi qu'étudier les possibilités de recyclage des eaux.

4.2.2 Etude de Terrain

Une typologie des drainages évacuant dans la Kirindi Oya a précédé la typologie de zones de contribution de l'Ellegala. Quatre types de canaux drainant directement dans la Kirindi Oya, ont été identifiés (cf. page 75):

- Les drainages de bassins versants. (1)
- Les drainages collectant les débordements latéraux de rizière. (2)
- Les drainages aux extrémités des canaux d'irrigation. (3)
- Les drainages récoltant les débordements de canaux d'irrigation (4)

Dans les drainages de type (2), (3) et (4), un débit d'origine surfacique a été visuellement observé en cas de surdistribution dans le réseau ou lors des jours de pluie.

Dans le type (1), nous sommes en présence de véritables canaux drainant un bassin, où l'origine de l'eau est soit surfacique, soit souterraine.

La typologie de ces derniers bassins est très différente suivant que l'on se trouve sur la rive gauche ou droite de la Kirindi Oya.

Sur la rive droite, le relief, légèrement modelé, détermine la localisation des canaux d'irrigation et de drainage. Le relief, trop encaissé aux abords des éxutoires, ne permet pas un recyclage des eaux de drainage sauf pour Pannegamuwa. Cette possibilité, signalée à l'Ingénieur Résident en Chef, a donné lieu à des travaux pour détourner ce drainage vers un canal distributeur de Weerawila (cf. page 100). Ce recyclage a permis de mobiliser une quantité supplémentaire d'eau par les fermiers de Weerawila, et de fait diminuer la demande en eau du réservoir de Weerawila. Ces travaux ont été fortement motivés par la sécheresse qui a sévi dans tout le pays de Décembre 95 à Octobre 96.

Sur la rive gauche, le comportement du drainage est totalement différent. Le relief, [illegible] permet en fonction du niveau d'eau dans les canaux de drainage d'irriguer à nouveau (cf. page 71). Cette eau recyclé, peut de la même manière drainer dans les canaux d'irrigation et [illegible] dérivée des champs irrigués amonts vers les champs irrigués avals (cf. page 72). Il [illegible] une baisse de la demande en eau des réservoirs au fur à mesure que l'on se déplace [illegible]. Il a été observé en outre, à la fin des drainages, des petits barrages de béton (cf. [illegible] ou de fortune permettant de redresser la ligne d'eau dans le canal et permettre un [illegible] des eaux de drainage par dérivation latérale. De la même manière, on peut observer [illegible]es, déversant totalement dans les canaux principaux des réservoirs situés en aval [illegible], ou entièrement dérivés vers d'autres rizières (cf. page 74).

4.2.3 Conclusion

Ces observations de terrains ont permis de classer au sein du périmètre: trois types de zones de contribution (cf. page 79).

- Des zones drainant dans les réservoirs de l'Ellegala. L'eau de drainage est alors stockée et redistribuée vers les zones anciennes (une partie des nouvelles surfaces).
- Des zones ouvertes vers l'Océan, où un procédé de recyclage des eaux de drainage est en place.
- Les zones ouvertes vers l'Océan, où le recyclage des eaux de drainage n'est pas effectué.

Il a été conclut que la gestion de l'eau devait être d'autant plus efficace que l'on se trouvait dans une zone où le drainage était évacué directement à la mer sans recyclage (cf. page 77).

Etant donné la forte connection hydrologique entre les zones irriguées de la rive gauche, il convient d'évaluer la performance de distribution en raisonnant globalement sur chaque bassin de drainage et non individuellement par secteur dominé. Pour cela, une "méthode d'évaluation orienté drainage" a été proposée. Elle tient compte que le surplus d'irrigation dans les zones amonts sert à rencontrer l'adéquation des zones avals (cf. page 81).

4.3 Contribution des drainages

Une campagne de mesures ponctuelles a permis d'évaluer la contribution des drainages dans la Kirindi Oya.. Un jour représentatif (flux habituellement observés et sans pluie depuis une semaine) a été choisi pour effectuer des mesures au moulinet.

Les débits de chaque drainage ont été mesurés. De la même manière, le débit de la Kirindi Oya a été évalué, juste en amont du premier drainage et juste en aval du dernier. Ainsi un bilan hydrique (cf. page 83) nous a permis de conclure sur les constats suivants:

- 80 % du débit de la Kirindi Oya est généré par les drainages.
- 60 % du débit de la Kirindi Oya vient du secteur dominé de Weerawila
- L'analyse de performance de la distribution de Weerawila a montré que le débit calculé était égal à 184 % du débit visé (cf. page 85).

Cette analyse a révélé clairement la correspondance entre performance de distribution amont orienté drainage et les débits de drainage observés en aval. En outre, il a révélé l'importante marge d'amélioration dans la gestion de l'eau en saison sèche.

4.4 Bilan Hydrique au sein du périmètre l'Ellegala

L'objectif de cette phase a été d'avoir une idée plus précise concernant la proportion des flux d'eau au sein du périmètre et de fournir une figure représentative du bilan hydrique saisonnier.

4.5.1 Méthodologie

La zone considérée a été prise en aval des réservoirs de l'Ellegala. L'apport en eau sur le système a été supposé uniquement égal à l'irrigation et la pluie, le périmètre étant fermé par les canaux principaux des réservoirs (cf. page 75). La sortie du système se fait par la Kirindi Oya et par un éxutoire proche du village de Kirinda ainsi que par évapotranspiration des rizières et consommation en eau des usagers ou de la végétation non irriguée.

Le bilan hydrique au sein du périmètre peut donc s'écrire (le stockage a été négligé, étant donné que le sol était déjà saturé lors des mesures):

Irrigation + Pluie = Evapotranspiration (Riz) + Kirindi Oya + Autres Consommations

Où *Autres Consommations* représente la part sur laquelle on ne peut pas agir. *Evapotranspiration* dépend des conditions climatiques et du stade de culture de la plante.

Le terme *Kirindi Oya* constitue la part sur laquelle, l'amélioration de la distribution amont, peut amener à une réduction significative.

Le terme *Irrigation* a été calculé grâce à la base de donnée, la *Pluie* a été evaluée avec la pluviométrie enregistrée à Lunugamwehera. De la même manière, l'*Evapotranspiration* a été calculée à partir des données climatiques de la station de Lunugamwehera (CROPWAT) et de la date de plantaison. Le débit dans la Kirindi Oya a été mesuré directement ou évalué deux fois par semaines à la suite d'une calibration (cf. annexe 23).

La campagne de mesure s'est étalée sur une période 35 jours.

4.5.2 Conclusion

Les résultats (cf. page 88) ont montré que 39 % de l'apport en eau s'était écoulé dans la Kirindi Oya, 32 % ont été perdus par évapotranspiration des cultures irriguées. L'autre part (29 %) significative, nous donne un ordre idée des autres consommations.

Sachant qu'une grande partie des 39 % enregistrés dans la Kirindi Oya peut être imputée à une surirrigation de Weerawila, le potentiel d'amélioration pour conserver la ressource en saison sèche devient encourageant et témoigne de la nécessité de mettre en oeuvre une politique de gestion des réservoirs.

5 DIAGNOSTIQUE SAISONNIER DE LA GESTION DES RESERVOIRS DE L'ELLEGALA

Les résultats de notre étude terrain, ainsi que la méthode d'évaluation orienté drainage développée, a permis d'analyser la gestion et la distribution des réservoirs de l'Ellegala en saison sèche et humide.

La distribution des trois réservoirs situés en amont du périmètre (Pannegamuwa, Debera et Tissa) a été percue comme correcte en saison sèche (cf. page 95) comme en saison humide (cf. page 91). Par contre, une surconsommation significative a été enregistrée pour Yoda durant la saison humide. Elle résulte de l'incapacité du réservoir à pouvoir stocker les flux amonts et ce faisant à libérer en aval plus d'eau que requis.

Cette incapacité à stocker le flux amont a trois origines:

- L'alimentation permanente du réservoir situé juste en amont (Tissa) (cf. page 93). Cela aurait pu être évité, étant donné que Tissa n'était pas plein à ce moment.
- Absence d'information dans les zones irrigués amonts, drainant dans Yoda.
- Retard entre l'irrigation en amont et en aval des réservoirs (cf. page 92).

L'irrigation des zones amonts, ayant débuté 1 mois et demi avant l'irrigation des zones avals, a eu pour conséquence de remplir le réservoir à son niveau maximum avant même que celui-ci commence son irrigation (cf. page 92). Il en a résulté une incapacité à stocker la réserve durant toute la saison. Les conséquences se sont par manifestées par des débordements fréquents et une surirrigation constante. De plus l'irrigation amont ayant été stoppée 1 mois et demi avant l'irrigation aval, le niveau de Yoda, privé sa source principale, a inévitablement décru jusqu'à un niveau très faible en fin de saison.

Weerawila a enregistré des distributions anormalement fortes durant les deux saisons (cf. page 91 et 95). Pendant la saison humide, la surdistribution ne peut s'expliquer que par l'abondance en eau alimentant le réservoir. En effet, Weerawila n'a pas été alimenté par le réservoir amont. De plus, il a commencé saison à son niveau minimum d'opération (cf. page 94), et fini à son niveau maximum. Par conséquent, l'amélioration potentiel de sa gestion se situe exclusivement au niveau d'une meilleur efficacité de la distribution en amont du réservoir. Weerawila est apparu comme un système abondant en eau. Cela crée des mauvaises habitudes de gestion pendant la saison des pluies (manque d'efficacité de la gestion et perte de control) qui se répercute inévitablement sur la saison sèche et explique partiellemet la forte distribution enregistrée.

CONCLUSION

Gestion de l'eau

L'étude du comportement de l'eau au sein du système et les diagnostiques saisonniers ont permis de conclure sur:

- L'origine des pertes d'eau dans la Kirindi Oya. Les drainages, dont la grande partie provient du réservoir de Weerawila (surirrigation), sont apparus comme étant la cause du débit observé dans la Kirindi Oya.
- L'optimisation du recyclage des eaux de drainage. L'intervention des fermiers sur le drainage de Pannegamuwa. a montré qu'un optimum de recyclage des eaux avait certainement été atteint cette saison. L'amélioration potentielle résidait désormais sur une meilleure gestion des réservoirs et du système en saison humide.
- La nécessité d'un phasage entre l'irrigation en amont et en aval des réservoirs pour pallier le faible pouvoir de stockage des réservoirs en saison humide.
- Définition de règles spécifiques de gestion et d'évaluation à partir de la typologie de bassin versants, (cf. page 81)

Système d'Information

L'intervention développé en 95/96 a convaincu l'Ingénieur Résident en Chef qu'une amélioration de la gestion nécessitait l'unification de l'information au sein du périmètre. Par conséquent, il a été décidé que les données relatives au canal principal rive droite et aux réservoirs de l'Ellegala seront rapatriées à son bureau pour la prochaine saison des pluies sur des feuilles préparées en sa présence (cf. annexe 24) ou sur disquettes pour les résultats d'IMIS. Ce rapatriement sera d'autant plus facilité, que les projets de restructuration du Département d'Irrigation avait déjà percu la nécessité d'unifier la gestion au sein du système et ont prévu de fusionner en début d'année prochaine, les quatre bureaux d'ingénieurs en un bureau central.

La quantité de donnés actuellement collectée, ayant été jugé comme trop importante par l'Ingénieur Résident en Chef, sa réduction est prévue à cinq endroits sur la rive droite qu'il conviendra de choisir. A côté de cela, trois locations devront être également choisies sur le canal rive gauche pour permettre le traitement de l'information, encore non abordée, sur cette partie du système. Ainsi, la politique d'information pour les prochaines saisons sera la réduction de la collecte des données mais l'extension de son traitement à l'ensemble du système.

Concernant l'installation du SIG, si le tableau de bord est apparu comme synthétique par le gestionnaire, la procédure de mise en place ne l'a pas été. Ceci est due aux limitations du logiciel Idrisi, qui ne contient pas de macro-language dans son système de gestion de base de donnée. Aussi, il conviendra après le diagnostique de la saison prochaine de changer de logiciel pour permettre le développement d'un produit fini. Dans la gamme de prix supérieur, MapInfo et son language de développement peut s'avérer intéressant.

Ayant constaté sur le terrain, que la gestion par ordinateurs était parfois une tâche contraignante pour certain ingénieurs, et que leur utilisation dépendait principalement du suivi des interventions, il a été proposé de développer des tables (cf. annexe 12).

Ces tables permettent le calcul des débits des réservoirs en fonction des données enregistrées aux structures. Pour chaque vanne, un exemplaire plastifié a été remis à chaque opérateurs pour permettre d'accélerer le processus de décisions. Il convient en outre, pour la

durabilité de l'intervention d'envisager le retour à un tableau de bord "géographique", fonctionnant sans l'aide d'ordinateurs.

L'étude a été conclut par le développement d'un indicateur de performance pour évaluer la gestion globale du système au cours des années.

Appendix 1 : Evaluation of Water Supply and Water Demand

1 Introduction

This annex study attempts to evaluate water supply and demand within system for both cultivation seasons.

So, water supply can be evaluated as coming from three main sources:

- Inflow to Lunugamwehera Reservoir (Catchment Yield)
- Inflow to Ellegala tanks and Ellegala Anicut (Catchment Yield)
- Direct Rainfall within system

On its hand, water demand concerns:

- Evaporation from tanks and reservoir
- Drinking water demand by population
- Irrigation requirement for the whole system.

Ellegala Tanks Drainage will be subtracted to irrigation requirement, since it is not strictly speaking an inflow but more accurately a drainage water reuse.

Maha season usually stops at end of February and Yala season end of August. Consequently, we will assume that all water stored or evaporated after end of one season is respectively an excedent or a deficit for the next season. Thus, for Yala season we will take into consideration period of six months between beginning of March and end of August and for Maha the other part of the year.

2 Water Supply

To determine water supply, we arrange of two long term rain samples recorded at Weerawila and Tissamaharama stations and a sample of Kirindi Oya discharge recorded by Irrigation Department (See paragraph 5).

2.1 Methodology

In tropical regions, it has been clearly demonstrated that the mean seasonal rainfall, even when derived from a large number of years, is at best an unreliable guide to the variation in rainfall with which the agriculturist must contend. Indeed, the arithmetic mean that is usually calculated directly from figures, which does not take into account the inherent skewness of the raw data that results from a disproportionately large amount of the rain falling in heavy tropical downpours thereby raising the level of the mean much above the normal amount of rain received or expected. The real need in agriculture or water management is for a precise estimate not merely of the average expected rainfall but the limits within which this expected rain inflow will occur. These limits can be calculated for any level of probability from the transformed data and are known as fiducial or confidence limits. For agricultural purposes, the limits within which rainfall may be expected to lie in 3 years out of 4, namely 75 % fiducial probability are considered adequate [Panabokke C.R. and Walgama A. 1974].

In our evaluation, the variable for which we want to determine occurrence is not merely rainfall but the entire water supply within system. Also, methodology will be the following one:

For each season and each year, we will evaluate water supply coming from three sources defined earlier.

Having assessed this supply, we will fit our both long term sample with distribution functions to determine for any level of probability, the corresponding probable water supply.

In past, IIMI has advised to take 75 % in normal Maha season. If season appears as wet, probability of 70 % seems correct and in case of dry Maha season 80 % probability seems a well adapted value for forecasting. For Yala season, distinction is not taken into consideration, indeed, season is always considered as normal with 75 % probable inflow [IIMI 1994].

2.2 Samples' Comparison

Arranging of two long term rainfall samples, (42 and 50 years for respectively Tissamaharama and Weerawila climatic stations), we set out to determine by interpolating both rains, a rain for system.

However, sample issued from Weerawila village has two origins :

From 1945 to 1988, data were recorded at Weerawila farm, and from 1989 to 1994, at Weerawila Agricultural Research Station. Records at Weerawila Farm having been realized for private cases, also their reliability can be questioned.

Consequently, problem we are faced with is : "Is difference between both samples due to chance, or are samples significantly different ?"

For this, we are going to compare their average and standard deviation,

Comparison between averages:

From both samples (long term and short term), we can evaluate variance of raw population σ^2 by:

$$\sigma^2 = \frac{(n_1 - 1)\sigma_1^2 + (n_2 - 1)\sigma_2^2}{n_1 + n_2 - 2}$$

Then, variable defined by $t = \frac{\overline{x_1} - \overline{x_2}}{\sigma\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$ follows a Student Distribution with $\upsilon = n_1 + n_2 - 2$ freedom degrees [Laborde J.P. 1989].

Where n_1 : number of data for long term sample

n_2 : number of data for short term sample

σ_1 : standard deviation for long term sample

σ_2 : standard deviation for short term sample

$\overline{x_1}$: average for long term sample

$\overline{x_2}$: average for short term data

Let t_{fixed}, a Student variable relating to a certain threshold of probability α. Consequently, if we have $t > t_{fixed}$, there is a probability α for difference between samples is due to chance.

In our case, Student variable is equal respectively for Yala and Maha to 0.67 and 0.90, which means that for both seasons, we have respectively a probability lower than 50 and 37 %, for difference between both samples is due to chance, which is low.

If we divide Tissamaharama sample into same date borders and carry out the same procedure, we have for Yala and Maha, respectively probability lower than 84 and 77 %, for difference is due to chance, which is higher than probabilities relating to Weerawila. Now compare standard deviations.

Comparison between standard deviations

Let, variable $F = \frac{\sigma_1^2}{\sigma_2^2} \quad (si\,\sigma_1^2 > \sigma_2^2)$

It follows a Fischer-Snedecor Distribution with $\upsilon_1 = n_1\text{-}1$ and $\upsilon_2 = n_2\text{-}1$ freedom degrees [Laborde J.P. 1989]. Thus, for each seasons F is computed and associated Fischer-Snedecor probability computed. For Weerawila station, for Yala and Maha seasons, we have respectively a probability lower than 16 and 69 % for difference is due to chance.

On Tissamaharama side, probabilities are respectively 15 and 85 %. Thus, for Yala, we have for both stations less than 15 % chance that difference is due to chance. For Maha, this chance reaches respectively for Weerawila and Tissamaharama, 69 and 85 %

2.3 Conclusion about samples comparison

If we take an interest about comparison between standard deviations, we can see, for both samples, results are similar, and does not allow us to conclude.

However, in our comparison between averages, we can see for Tissamaharama, difference between samples can be explained by chance with a threshold of 84 and 77 %, respectively for Yala and Maha seasons, when for Weerawila station, the same difference due to chance can be explained by probabilities equal hardly to 50 and 37 %.

Also, if we take an interest in mean rainfall recorded at Weerawila Farm, we can see that it is too low to be considered as chance, even though our sample taken in Weerawila Agricultural Research Station is short in years. In addition, if it was question of a modification of hydrological behavior within watershed, similar results would have been observed for Tissamaharama. Consequently, it seems more probable that low rain has not been recorded at Weerawila Farm and consequently it will be more careful for statistical analysis to drop rain sample relating to Weerawila.

Thus, in water supply deduced from rain, we will use exclusively rain recored at Tissamaharama station.

2.4 Lunugamwehera Inflow

Kirindi Oya discharge is computed by hourly records at Kitulkotte Irrigation Department. Sum of this hourly records gives us seasonal volume flowing into Lunugamwehera Reservoir.

2.5 Runoff in Ellegala Tanks and Ellegala Anicut

In the absence of direct stream flows measurements running to the tanks, some assumptions were retained to quantify runoff in tanks. It is obvious that these assumptions can't replace direct measurements and need further studies. Also to evaluate this amount, different runoff estimate models are available and have been suggested by a number of recent research studies. [Sakthivadivel R. and Al 1996] mentions the studies of Somarisiri (1992) and Dharmasena (1991) as an alternative approach for estimating runoff and seasonal catchment yield.

Thus, Dharmasena shows, the catchment area of a tank absorbs a significant amount of rainfall for initial soil saturation before it generates any productive or useful runoff and that, on an average, around 150 mm of rainfall. This value is in conformity with the moisture-holding capacity of the Reddish Brown Earth Soils of Ellegala tanks catchments areas that requires around 150 mm of rain to moisten a 1.5 m depth of the soil profile to the field capacity moisture level.

On his hand, Somasiri reports, the catchment runoff from a normal dry zone forest, a scrub jungle and an abandoned chena are all very similar and around 2 percent of the Maha Rainfall and that run-off is generated only after the soil saturation requirement is met. In contrast, the run-off generated from newly cleared chena land is around 25 percent of the Maha Rainfall. Furthermore, if the catchment consists of a significant area of rock-knob plain and erosion remnants, the runoff from such land forms is in excess of 90 percent of the incident rainfall.

Land Use of tanks catchment areas can be classed as a new cleared chena. Consequently a 0.25 runoff coefficient can be retained for computations as well as rain at Tissamaharama, with a presaturation requirement of 150 mm deducted, except for the new areas above each tanks and Pannegamuwa and Debera catchment areas (entirely located in Kirindi Oya System), for which we can assume that the soils is initially moistened by irrigation.

By the same way, catchment area relating to Ellegala Anicut is not known. Also, we will suppose it equal to the surface of new areas draining in Ellegala Anicut, which is approximately true.

Thus, run-off computation for each tank can be written with following equation.

$$Runoff = (0.25*NA*P+0.25*(C-NA)*(P-150))*10$$

Where *Runoff* : Seasonal tank catchment yield in m^3

NA : Surface of new areas above tank (ha).

C : Surface of tank catchment area (ha).

P : Seasonal rain (mm).

2.6 Direct Rainfall

Rain falling directly within system is from two sources:

- Rain falling in tanks and reservoir, which will be stored and redistributed

- Rain falling in paddy fields. One part will be usable in any phase of crop production and is referred as effective rainfall [Dastane N.G. 1974], other part will run downstream and is referred as runoff part. Since, in previous paragraph, we have assumed that 25 % of rain fallen within paddy flows, we indirectly assume that 75 % rain is considered as effective.

Rain falling directly in tanks can be estimated by the following equation:

*Direct Rainfall in tank (m3) = Tank Spread Area (ha)*Seasonal probable rainfall(mm)*10*

Rain falling in paddy fields and which contributes to meet crop water demand is:

*Direct Rainfall in paddy (m3) = Irrigated Surface (ha)*Seasonal probable rainfall(mm)*10*0.75*

Tank spread area varying along season, it is difficult to give a value. So due to water abundance during Maha season, we can assume that tanks water level varies between their minimum operation levels[1] (MOL) [IIMI 1994] and their levels at full supply (FSL). During Yala season, it is common to see tank water level going below their MOL.

Consequently, we will retain spread area relating to MOL for Dry season and average spread area between MOL and FSL for Rainy season (See Appendix 4).

[1] MOL is minimum operation level recommended by IIMI during its past intervention. It allows to tank to supply its whole command area during two weeks, in case of severe drought. It allows also to maintain a sufficient head in tank for its supply as maintain water table sufficiently close to ground for environmmental impact. In case of drought, it has to supply drinking water to surrounding villages

2.7 Probable Analysis

For each seasons, seasonal records were arranged in order of magnitude with the smallest number first and their cumulative frequency was worked out by using the Hazen equation [Dastane N.G. 1974].

$$F_{th.} = \frac{i - 0.5}{n}$$

Where n is the number of seasons of records keeping.
i the rank number.
$F_{th.}$, the empirical probability of non exceedance.

So mean and standard deviation were computed and a normal distribution was fitted to our both samples. Indeed, for each record, knowing mean and standard deviation of our sample, the probability of non exceedance following normal distribution was computed according to formula below:

$$F_n = \int_0^{\frac{R-\mu}{\sigma}} \frac{1}{\sqrt{2\Pi\sigma}} e^{-\left[\frac{(R-\mu)^2}{2\sigma^2}\right]}$$

Where μ : sample mean.
σ : sample standard deviation.
R : value of the record.
F_n : associated normal probability of non exceedance.

To test conformity of fitting, Anderson's test was used. Indeed, it is more effective than Ki_2. For this, Anderson Coefficient was computed with the following formula :

$$W_n^2 = -n - \frac{1}{n} \sum_{i=1}^{n} \left[(2i-1)Ln(Fn) + (2n+1-2i)Ln(1-Fn)\right]$$

Where n : total records number.
i : rank number.
F_n : the normal probability of non exceedance associated with corresponding rainfall record.

Anderson variable u defined from W^2_n allowed to characterize fitting quality.

$$u = \frac{Ln(W_n^2 - \frac{0.18}{n^{0.25}}) + 0.8 + \frac{1}{\sqrt{n}}}{0.65} \qquad n > 10$$

Let $u_{threshold} = 0.84$. Assuming that seasonal rain is a Gauss rain. If u computed is higher than 0.84, we can admit seasonal rain does not follow a Gauss distribution with a probability of erroneously of 20 %.

For Maha season, our u is equal to 1.62. Consequently, we can reject our fitting with a probability of errouneously lower than 10 %. For Yala, our u is equal to 1.19. Consequently, our probability of errouneously to consider that water supply does not follow a Gauss Distribution is lower than 20 %.

Change of the *rain* variable in *Ln(water supply)* or $\sqrt{water\,supply}$, respectively for Maha and Yala season gives us very good results. Indeed, our respective u are equal to -2.41 and -0.27. Thus, we can admit that variables *Ln(water supply)* and $\sqrt{water\,supply}$ follow Gauss distribution respectively during Maha and Yala seasons. By the same way, we will be able to see that in our considered probability range (probability of non exceedance between 0.2 and 0.3), Gauss distribution fit very well to variables mentionned earlier.

2.8 Seasonal Water Supply Results

Thus, water supply relating to different types of seasons are:

Probable Water Supply for both cultivation seasons

Maha Type and Probable Water Supply (in million of m^3)			Yala Water Supply
Wet (70 %)	**Normal (75 %)**	**Dry (80 %)**	**Normal (75 %)**
216	202	188	105

Thus, we can remark that a normal Yala approximately supplies two times less water than a normal Yala

2.9 Parameters Variation

Having assumed in our runoff estimation a runoff coefficient equal to 0.25 as well as a presaturation equal to 150 mm, we can see if their variation significantly influences water supply estimation. Thus, for a fixed presaturation equal to 150 mm, we can vary runoff coefficient from 0.2 to 0.4. Results appears in table below:

Water Supply within system according to runoff coefficient variation

Runoff Coefficient	Maha Season			Yala Season
	(70 %)	(75 %)	(80 %)	(75 %)
0.2	216	202	188	105
0.25	216	202	188	105
0.3	218	204	190	104
0.35	218	204	190	104
0.4	220	206	192	105

Depth of soil profile of Ellegala tanks catchment areas is between 1 and 2 m. Also, even though we have retained the mean value for the initial presaturation (1.5 m), it is interesting to see that a variation of this presaturation does not vary much results (see table below). We assume that runoff coefficient is equal to 0.25.

3 Water Demand

Water demand is from three kinds (See introduction). This part attempts to evaluate it for both seasons, give a rough idea for both season.

3.1 Drinking Water Demand

According to CRE, in decision making for seasonal allocation, as safety coefficient, the maximum daily drinking water consumption is retained. It is equal for whole system to Q_{DW} where

$$Q_{DW} = 4\ 000\ m^3/day = 732\ \text{thousands of}\ m^3/season$$

3.2 Irrigation Duty for whole system

According to irrigation requirement relating to different paddy growth stages and duration of these stages (See Tab.4 in main report), we are able to compute irrigation water duty for both systems (old and new areas). They are equal to 14 000 m^3/ha for old areas and to 24 400 m^3/ha for new areas (at head of Lunugamwehera main sluice). New areas taking up a irrigated area of 5 550 ha and old areas 4 110 ha, irrigation requirement Q_{IR} for a season of paddy cultivation for whole system is consequently equal to:

$$Q_{IR} = 193\ 000\ \text{thousands of}\ m3/season.$$

However, we can consider that 25 % of water issued to new areas above tanks or Anicut will be reused according to Chief Resident Engineer, this surface covering an area of 3645 ha, irrigation requirement Q_{IR} becomes :

$$Q_{IR} = 171\ 000\ \text{thousands of}\ m^3/season.$$

3.3 Evaporation from tank spread areas

This water demand concern evaporation from tanks spread area. Also in aim to quantify evaporated amount during both seasons, monthly climatic data recorded at Lunugamwehera station for six years were used. They are mean minimum and maximum temperature(Celsius), mean wind velocity (km/day),mean sunshine hours and relative humidity (%). Using Cropwat Software [FAO 1984], monthly average Penman Evaporation was computed for twelve months (See paragraph 6). Indeed, number of recorded years being too short to envisage a probable analysis, so averages were retained, which is relatively correct according to similar behavior of evaporation through years and even in KOISP though months.

Using tanks spread areas equation (See Appendix 4), volume lost by evaporation was evaluated for Maha and Yala Season following this equations.

$$Q_{EVP} = Tank\ Spread\ Areas * Et_o/100$$

Where Q_{EVP} is exprimed in thousand of m^3

Tank Spread Area in ha

E_{to} in mm per season

Tank spread areas we taken as identical at those retained for direct rainfall. Total E_{to} for Maha season is equal to 683 mm and for Yala season 787 mm. So evaporation losses from the tank spread areas are equal for Maha and Yala respectively to **20 995** thousand of m^3 and **11 687** thousand of m^3 (See appendice 2.8).

4 Water supply and water demand for both season

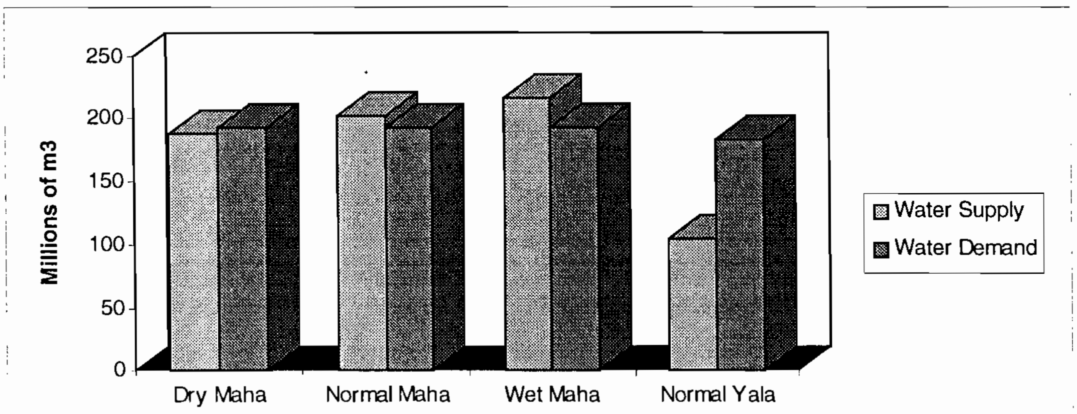
By summing all water demands (See figure below), we arrive at following result: For a wet and normal Maha water supply exceeds slightly water demand, when a dry Maha (4 years out of 5) can not supply water for whole system. Thus, 3 years out of 4, supply meets demand, but just slightly, which insists to the fact to lead an efficient management during rainy season to store maximum of water for dry season. By the same way, it agrees to use rain with a maximum of efficiency.

For Yala Season, expected inflow is very low in comparison with water demand (hardly 50 %) to envisage the irrigation of whole system. Consequently, necessity to finish Maha with Ellegala tanks at their maximum capacity appears as a key issue of performance.

Since building of Lunugamwehera, cultivation was complete during Yala 1995 and nearly complete during Yala 94.

Kirindi Oya is a water short system where water management has to be imperatively very minutious to extend cultivation to new areas during Yala.

Water Demand and Water Supply during both seasons for a complete cultivation



5 Data used (1945-1994)

YEAR	KIRINDI OYA INFLOW (Millions M3) Yala	KIRINDI OYA INFLOW (Millions M3) Maha	TISSAMAHARAMA RAINFALL (MM) Yala	TISSAMAHARAMA RAINFALL (MM) Maha	WEERAWILA RAINFALL (MM) Yala	WEERAWILA RAINFALL (MM) Maha
1945					300	533
1946					313	727
1947		104		586	651	542
1948	56.7	228.8	304	891	135	826
1949	94.9	117.3	275	718	367	511
1950	49.8	123.7	169	845	184	864
1951	69.3	209.9	254	855	229	689
1952	255.5	44.4	394	515	352	467
1953	113.6	192.1	449	1048	424	889
1954	154.8	130.8	338	1150	447	911
1955	164.2	92.3	300	611	356	498
1956	16.2	112.5	324	739	184	757
1957	97.6	418.2	200	1127	149	1117
1958	192.1	93.4	334	560	220	503
1959	126.6	162.1	469	894	326	766
1960	154.5	204.5	267	739	322	701
1961	196.7	187.6	417	842	469	880
1962	131.8	162.5	306	735	202	821
1963	163.6	270.1	276	1184	351	943
1964	172.7	63.7	256	290	359	377
1965	171.9	287.4	202	864	223	819
1966	149.1	454.2	322	1014	250	905
1967	126.5	127.4	146	713	262	650
1968	84.3	242.9	204	448	239	325
1969	242.1	549.5	331	1091	326	936
1970	485	295.3	362	365	231	389
1971	244.4	162.1	254	440	126	424
1972	116.3	293.9	107	783	174	1016
1973	149.7	386.7	274	982	294	1083
1974	167.7	157.3	289	578	257	801
1975	191.2	173.4	543	598	575	506
1976	83.1	123	238	908	234	722
1977	76.6	383.4	173	791	229	354
1978	145.3	224.9	292	612	169	442
1979	92.1	121.3	136	501	286	257
1980	98	107	No data	425	155	170
1981	98	107	210	256	127	166
1982	98	107	553	935	165	262
1983	98	107	99	910	79	371
1984	98	107	270	592	123	221
1985	98	107	325	760	68	358
1986	98	107	409	370	93	160
1987	35.8	211.9	199	628	65	220
1988	128.5	120.1	354	577	408	627
1989	18.3	106.6	290	291	322	346
1990	98.3	122.8	302	874	352	932
1991	83.3	80	365	674	383	626
1992	24.7	111.4	195	686	202	644
1993	44.2	255.2	266	997	289	928
1994	48.7	195	270	650	237	752

6 Monthly Penman Reference Crop Evapotranspiration

Monthly Penman Reference Crop Evapotranspiration

Date	ETo (mm)
January	110
February	119
March	142
April	129
May	131
June	125
July	128
August	132
September	133
October	118
November	100
December	103

Appendix 2: Sheet on which Tank data is collected

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ගේට්ටුව	වේලාව	[illegible]	ඉහළ	ජල මට්ටම
TLL	16-00	20	14-10 ඉහළ	විය
TLH	16-5	5		
TR	16-10	10		
TS	16-20	20		
TLL	7-00	20	14'-6"	
TLH	7-5	5		
TR	7-10	10		
TS	7-20	20		

Appendix 3: Ellegala Tanks' Gates and Spillways Parameters

Tanks' Gates Parameters

Gate Name	Gate Sill Level (m MSL)	Gau_up-Gau_down (m)	Orifice	Gate	Width (m)	Height (m)	Diameter (m)	Spindle 0 (m)	µ0	
P	25.72	1.7	Rectangular	Rectangular	0.762	0.6096		0.096	0.433	
W	21.14	2.5	Rectangular	Rectangular	1.2192	1.143		0	0.427	
YHL	11.08	2.09	Rectangular	Rectangular	0.5715	0.5715		0	0.4	assumed
YLL	10.09	2.58	Rectangular	Rectangular	0.762	0.9144		0.15	0.407	
TLH	17.22	no	Rectangular	Rectangular	0.6858	0.2286		0	0.38	
TLL	15.7	no	Rectangular	Rectangular	0.6858	0.9144		0	0.373	
TR	16.95	no	Circular	Circular			0.6096	0	0.413	
DL	21.35	2.05	Rectangular	Rectangular	0.6096	0.381		0.14	0.373	
DRH	21.77	1.606	Circular	Rectangular			0.3048	0.4	0.26	
DRL	20.88	no	Circular	Circular			0.6858	0.4	0.373	
WR 1	26.29	no	Rectangular	Rectangular	1	1.1		0.31	0.407	
WR 2	26.29	no	Rectangular	Rectangular	0.98	1.1		0.25	0.407	
WR 3	26.29	no	Rectangular	Rectangular	0.96	1.1		0.29	0.407	
WR 4	26.29	no	Rectangular	Rectangular	1	1.1		0.29	0.407	
TS	17.98	no	Rectangular	Rectangular	4.57	2.44		0	0.4	assumed

Spillways' Parameters

Tank Name	Tank Sill Level (m MSL)	Gauge Length (m)	Spill Level (m MSL)	Spillway Length (m)
Pannegamuwa	25.72	2.5	28.19	91.44
Weerawila	21.14	4	24.99	16.764
Yoda	9.91	4	13.72	50.05
Yoda (2nd Spill)	9.91	4	14.02	121.92
Tissa	15.7	5	20.42	60.96
Debera	20.88	3	23.29	18.9

Appendix 4 : KOISP Tanks Parameters

Tank Spread Area and Capacity at MOL[1] and FSL[2]

Tank or Reservoir Name	Tank Water level (Ft[3]) at MOL	FSL	Capacity (Acft[4]) at MOL	FSL	Spread Area at MOL	F
Lunugamwehera Reservoir	156	191	20 362	166 584	1 710	7
Pannegamuwa Wewa	5	8.1	72	618	107	2
Weerawila Wewa	6	12.5	3 811	10 493	869	1
Yoda Wewa	7	12.3	1 735	7 906	693	1
Tissa Wewa	9	15.5	468	3 137	200	6
Debera Wewa	5.5	8	287	700	131	1

Tank Spread Area and Capacity Equations

Tank or Reservoir Name	Spread Area (Ac)	Capacity (Ac.ft)
Lunugamwehera Reservoir	$0.739(H-120)^{2.1618}$	$0.3115(H-120)^{3.0914}$
Pannegamuwa Wewa	$-102.87 + 41.89H$	$0.056H^{4.45}$
Weerawila Wewa	$268.59 + 100.01H$	$321.48H^{1.38}$
Yoda Wewa	$65.79H^{1.21}$	$9.25H^{2.69}$
Tissa Wewa	$1.85H^{2.13}$	$0.214H^{3.5}$
Debera Wewa	$-19.06 + 27.23H$	$4.96H^{2.38}$

H is in feet

[1] MOL : Minimum Operationnal Level
[2] FSL : Full Supply Level
[3] 1 Ft = 0.3048 m
[4] 1 Ac.ft = 1 233.3 m^3
[5] 1 Ac = 4046 m^2

Appendix 5: SIC Formulas (Small Sill Elevation)

Used Variables:

Q : Discharge (m^3/s)
W : Orifice opening (m)
L : Width of rectangular orifice
h_1 : Upstream head
h_2 : Downstream head
g : acceleration due to gravity (m/s^2).

If $h_1 < W$, the opening is hydraulically performing as a weir structure and following weir formula has been used:

Weir - Free Flow

$$Q = \mu_F L\sqrt{2g}h_1^{\frac{3}{2}}$$

Weir- Submerged

$$Q = k_F \mu_F L\sqrt{2g}h_1^{\frac{3}{2}}$$

With k_F = coefficient of reduction for submerged flow

The flow reduction coefficient k_F is a function of the ratio $\frac{h_2}{h_1}$ and the value α of this ratio at the instant of the free flow/submerged transition. The submerged conditions are obtained when $\frac{h_2}{h_1} > \alpha$. The law of variation of the k_F coefficient has been derived from experimental results carried out by CEMAGREF.

Let

$$x = \sqrt{1 - \frac{h_2}{h_1}}$$

If $x > 0.2$ then $k_F = 1-(1-\frac{x}{\sqrt{1-\alpha}})^{\beta}$

If $x < 0.2$ then $k_F = 5x(1-(1-\frac{0.2}{\sqrt{1-\alpha}})^{\beta})$

$\beta = -2\alpha + 2.6$

If $h_1 > W$, then the opening is referred to as an orifice and following formula were used:

Undershot Gate - Free flow

$$Q = L\sqrt{2g}(\mu\ h_1^{\frac{3}{2}} - \mu_1(h_1 - W)^{\frac{3}{2}})$$

It has been established experimentally that the undershot gate discharge coefficient increases with $\frac{h_1}{W}$. A law of variation of μ of the following form is adopted.

$\mu = \mu_0 - \frac{0.08}{h_1/W}$ with μ_0 which will be calibrated by current metering measurement

Hence, $\mu_1 = \mu_0 - \frac{0.08}{h_1/W - 1}$

In order to ensure the continuity with the open channel free flow conditions for $\frac{h_1}{W} = 1$ it must have $\mu_F = \mu_0 - 0.08$

Undershot Gate - Submerged

Partially submerged flow

$$Q = L\sqrt{2g}(k_F\mu\ h_1^{\frac{3}{2}} - \mu_1(h_1 - W)^{\frac{3}{2}})$$

k_F being the same as for open channel flow

The following free flow/submerged transition law has been derived on the basis of experimental results carried out by CEMAGREF. Thus submerged conditions are obtained when $\frac{h_1}{h_2} > \alpha$

With $\alpha = 1 - 0.14\frac{h_2}{W}$ and $0.4 \leq \alpha \leq 0.75$

In order to ensure continuity with the open-channel flow conditions, the free flow/submerged transition under open-channel conditions has to be realized for $\alpha = 0.75$ instead of 2/3 in the usual weir/orifice formulation.

Totally submerged flow

$$Q = L\sqrt{2g}\,(k_F \mu\, h_1^{\frac{3}{2}} - k_{F1}\, \mu_1 (h_1 - W)^{\frac{3}{2}})$$

The k_{F1} equation is the same as the one for k_F where h_2 is replaced by h_2-W (and h_1 by h_1-W) for the calculation of the x coefficient and therefore for the calculation of k_{F1}

The transition to totally submerged flow occurs for:

$$\frac{h_1 - W}{h_2 - W} > \alpha_1$$

With $\alpha_1 = 1\text{-}0.14\dfrac{h_2 - W}{W}$

Appendix 6: Surface Equations of Circular Orifice

Used Variables

Where W : Orifice opening (m)

R_o : Orifice radius (m)

R_g : Gate radius (m)

$$a = \left(\frac{(R_g + W)^2 - R_g^2}{2(R_g + W - R_o)} \right) \text{ and a' } = \left(\frac{R_o^2 - (R_o - W)^2}{2(R_g + W - R_o)} \right)$$

Circular Orifice and Circular Gate

$$S(W)=R_0^2\, Acos\left(\frac{R_o - a}{R_o} \right) - (R_o - a)\sqrt{a(2R_o - a} - R_g^2\, Acos\left(\frac{R_g - a'}{R_g} \right) + (R_g - a')\sqrt{a'(2R_g - a'}$$

Circular Orifice and Rectangular Gate

$$S(W) = R_o^2\, Acos\left(\frac{R_o - W}{R_o} \right) - (R_o - W)\sqrt{W(2R_o - W)}$$

Appendix 7: K Equivalence Coefficient for Circular Pipe as a function of Orifice Opening

DRL Gate
Diameter = 0.6858 m

W[1] (m)	k[2]
0.01	0.46
0.02	0.59
0.03	0.67
0.04	0.73
0.05	0.77
0.06	0.80
0.07	0.82
0.08	0.84
0.09	0.86
0.10	0.87
0.11	0.89
0.13	0.90
0.14	0.91
0.15	0.92
0.17	0.93
0.21	0.94
0.37	0.93
0.42	0.92
0.45	0.91
0.49	0.90
0.51	0.89
0.54	0.88
0.56	0.87
0.58	0.86
0.60	0.85
0.61	0.84
0.63	0.83
0.65	0.82
0.66	0.81
0.67	0.80
0.68	0.79

TR Gate
Diameter - 0.6096 m

W (m)	k
0.01	0.41
0.02	0.53
0.03	0.60
0.04	0.65
0.05	0.69
0.06	0.72
0.07	0.74
0.08	0.75
0.09	0.77
0.10	0.78
0.11	0.79
0.12	0.80
0.13	0.81
0.15	0.82
0.18	0.83
0.24	0.84
0.28	0.83
0.36	0.82
0.40	0.81
0.43	0.80
0.46	0.79
0.48	0.78
0.50	0.77
0.52	0.76
0.54	0.75
0.55	0.74
0.57	0.73
0.58	0.72
0.60	0.71

DRH Gate
Diameter - 0.3048 m

W (m)	k
0.01	0.24
0.02	0.33
0.03	0.41
0.04	0.46
0.05	0.51
0.06	0.56
0.07	0.59
0.08	0.63
0.09	0.66
0.10	0.68
0.11	0.71
0.12	0.73
0.13	0.75
0.14	0.77
0.15	0.78
0.16	0.80
0.17	0.81
0.18	0.82
0.19	0.83
0.21	0.84
0.27	0.83
0.28	0.82
0.29	0.81
0.30	0.80

[1] W : Orifice Opening.
[2] k : Equivalence Coefficient for circular pipe

Appendix 8: SIC Formulas (High Sill Elevation)

Spilling can be computed by the following formula.

$$Q = \mu_F L\sqrt{2g(H-p)^3}$$

Where μ_F : Spillway discharge coefficient, it has been taken equal to 0.4

L : Spillway length (m)

H : Tank water level (m)

p : Threshold height (in m) equal to Spill level - Tank sill level (in m MSL)

Appendix 9: Ellegala Tanks Values Files

Database Values Files

S_Dcoef "Discharge Coefficient"	S_spindl "Spindle at Gate Closed"	S_gau_up "Upstream Level Difference"	S_width "Gate Width"	S_heigth "Gate heigth"
110 0.65	110 0.096	110 2.5	110 0.6096	110 0.762
120 0.61	120 0.31	120 1.93	120 1	120 1.1
130 0.61	130 0.25	130 1.93	130 0.98	130 1.1
140 0.61	140 0.25	140 1.93	140 0.96	140 1.1
150 0.61	150 0.29	150 1.93	150 1	150 1.1
210 0.64	210 0	210 4	210 1.2192	210 1.143
310 0.60	310 0	310 2.83	310 0.5715	310 0.5715
320 0.6	320 0.47	320 2.83	320 0.5715	320 0.5715
330 0.57	330 0.15	330 3.82	330 0.762	330 0.9144
410 0.57	410 0	410 3.48	410 0.6858	410 0.2286
420 0.56	420 0	420 5	420 0.6858	420 0.9144
430 0.55	430 0	430 3.75	430 0.6096	430 0.6096
440 0.6	440 0	440 2.72	440 4.572	440 2.438
510 0.56	510 0.14	510 2.53	510 0.6096	510 0.381
520 0.39	520 0.40	520 2.11	520 0.3048	520 0.3048
530 0.56	530 0.40	530 3	530 0.6858	530 0.6858

S_Spillh "Spillway Heigth"	S_spilll "Spillway Length"	S_gau_do "Downstream Level Difference"	S_gauge "Tank Gauge"
100 2.48	100 91.44	110 0.8	110 2.5
200 3.85	200 16.76	210 1.5	210 4
300 3.63	300 38.40	310 0.74	330 4
310 3.63	310 11.77	320 0.74	420 5
320 3.93	320 121.92	330 1.24	530 3
400 4.73	400 60.96	510 0.48	
500 2.42	500 18.89	520 0.5	

Computing Values Files

E_disch1 "extract Gate of distribution"	E_disch2 "extract Tank Discharge"	E_disch3 "extract Release"	E_down "Isolate gate with a downstream gauge"	E_DRH "Compute coefficient K as a function of opening"	
110 110	110 100	120 100	110 1		
210 210	210 200	130 100	210 1	1	24
310 310	310 300	140 100	310 1	2	33
320 310	320 300	150 100	320 1	3	41
330 320	330 300	440 400	330 1	4	46
410 410	410 400		510 1	5	51
420 420	420 400		520 1	6	56
430 430	430 400			7	59
510 510	510 500			....	
520 520	520 500			....	
530 530	530 500			....	

E_DRHISO	**E_DRL**	**E_DRLISO**	**E_TR**	**E_TRISO**
"Isolate DRH gate"				
520 1	Similar to E_DRH	Similar to E_DRHISO	Similar to E_DRH	Similar to E_DRHISO

E_free	**E_spill1**	**E_spill3**	**E_wlevel**	**E_spill2**
"Isolate gate under free-flow conditions"	"Isolate second spillway of Yoda"	"extract tank spilling"	"Isolate tank water level"	"Isolate third spillway of Yoda"
120 1 130 1 140 1 150 1 410 1 420 1 430 1 440 1 530 1	300 310	100 100 200 200 300 300 310 300 320 300 400 400 500 500	110 100 210 200 330 300 420 400 530 500	300 320

Output Values Files

I_Wissue : Contains Gate Discharge
I_Discha : Contains Tank Discharge
I_Wlevel : Contains Tank Water Level
I_Releas : Contains Tank Release
I_Spill : Contains Tank Spilling

Reclass Files

E_alpha	**E_kf1**	**E_kf2**	**E_kf3**	**E_mu**
"If α > 0.75 then α = 0.75 and if α <0.4 then α=0.4"	"if x>0.2 then x=0.2"	"if x<0.2 then x=0.2"	" If x<0 then x =0"	"If x > 100 then x = 100"
40 -32767 40 75 75 32767 -9999	200 201 32767 -9999	200 0 200 -9999	0 -32767 0 -9999	100 100 32767 -9999

E_mxtest	**E_sptest**
"if W>0 then W=0"	"if W<0 then W=0"
0 0 32767 -9999	0 -32767 0 -9999

Appendix 10: Idrisi Programs to compute tanks discharges

C_Tank "Module computing tank discharges, releases and spilling"

Branch E_gateop
Branch E_head
Branch E_kf
Branch E_kf1
Branch E_mu
Branch E_discha
Branch E_wlevel
Branch E_spill

E_gateop "submodule computing orifice opening"

ASSIGN x Tank i1 **S_spindl** 2
SCALAR x i1 i4 3 1000
SCALAR x Spindle i2 3 10
OVERLAY x 2 i2 i4 i1
RECLASS x i i1 i3 3 **e_sptest**
ASSIGN x tank i2 **S_height** 2
SCALAR x i2 i1 3 1000
OVERLAY x 2 i3 i1 i2
RECLASS x i i2 i3 3 **e_mxtest**
OVERLAY x 1 i3 i1 i2
CONVERT x i2 i2 i 1 2
SCALAR x i2 Gateopen 3 0.001
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img
DELETE x i3.doc
DELETE x i3.img
DELETE x i4.doc
DELETE x i4.img

E_head "submodule computing upstream and downstream head"

ASSIGN x Tank i1 **s_gau_up** 2
ASSIGN x Tank i2 **s_gau_do** 2
SCALAR x i1 i3 3 100
SCALAR x i2 i1 3 100
OVERLAY x 2 i3 Gau_up i2
OVERLAY x 2 i1 Gau_down i3
SCALAR x i2 Head1 3 0.01
SCALAR x i3 Head2 3 0.01
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img
DELETE x i3.doc
DELETE x i3.img

E_kf "submodule computing coefficient kf of SIC formulas"

OVERLAY x 3 Head2 Gateopen i2
OVERLAY x 3 Gateopen Gateopen i3
OVERLAY x 4 i2 i3 i1
SCALAR x i1 i2 3 -0.14
SCALAR x i2 i1 1 1
ASSIGN x Tank down **e_down** 1
OVERLAY x 3 i1 down i3
SCALAR x i3 i1 3 100
RECLASS x i i1 alpha 3 **e_alpha**
SCALAR x alpha i1 3 -0.01
SCALAR x i1 i2 1 1
TRANSFOR x i2 i1 5
OVERLAY x 4 Head2 Head1 i2
SCALAR x i2 i3 3 -1
SCALAR x i3 i2 1 1
SCALAR x i2 i3 3 1000
RECLASS x i i3 i4 3 **e_kf3**
SCALAR x i4 i2 3 0.001
TRANSFOR x i2 i3 5
SCALAR x i3 i4 3 1000
SCALAR x i3 i2 3 0.001
SCALAR x i4 i3 3 0.001
OVERLAY x 4 i3 i1 i4
OVERLAY x 2 down i4 i3
SCALAR x i3 i1 3 100
RECLASS x i i1 i3 3 **e_kf3**
SCALAR x i3 i1 3 0.01
SCALAR x alpha i3 3 -0.02
SCALAR x i3 i4 1 2.6
OVERLAY x 6 i1 i4 i3
OVERLAY x 2 down i3 i1
OVERLAY x 3 i1 i2 i3
SCALAR x i3 i4 3 5
OVERLAY x 3 i4 down i1
ASSIGN x Tank i2 **e_free** 1
OVERLAY x 1 i1 i2 kf
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img
DELETE x i3.doc

OVERLAY x 3 down i4 i2
RECLASS x i i2 i3 3 **e_kf1**
RECLASS x i i2 i4 3 **e_kf2**
DELETE x i3.img
DELETE x i4.doc
DELETE x i4.img

E_kf 1"submodule computing coefficient kf1of SIC formulas"

OVERLAY x 2 Head2 Gateopen i2
OVERLAY x 3 i2 Gateopen i3
OVERLAY x 3 Gateopen Gateopen i2
OVERLAY x 4 i3 i2 i1
SCALAR x i1 i2 3 -0.14
SCALAR x i2 i1 1 1
ASSIGN x Tank down **e_down** 1
OVERLAY x 3 i1 down i3
SCALAR x i3 i1 3 100
RECLASS x i i1 alpha1 3 **e_alpha**
SCALAR x alpha1 i1 3 -0.01
SCALAR x i1 i2 1 1
TRANSFOR x i2 i1 5
OVERLAY x 2 Head1 Gateopen i3
OVERLAY x 2 Head2 Gateopen i4
OVERLAY x 4 i4 i3 i2
SCALAR x i2 i3 3 -1
SCALAR x i3 i2 1 1
SCALAR x i2 i3 3 1000
RECLASS x i i3 i2 3 **e_kf3**
SCALAR x i2 i3 3 0.001
TRANSFOR x i3 x 5
SCALAR x x i4 3 1000
OVERLAY x 3 down i4 i2
RECLASS x i i2 i3 3 **e_kf1**
RECLASS x i i2 i4 3 **e_kf2**
SCALAR x i3 i2 3 0.001
SCALAR x i4 i3 3 0.001
OVERLAY x 4 i3 i1 i4
OVERLAY x 2 down i4 i3
SCALAR x i3 i1 3 1000
RECLASS x i i1 i3 3 **e_kf3**
SCALAR x i3 i1 3 0.001
SCALAR x alpha1 i3 3 -0.02
SCALAR x i3 i4 1 2.6
OVERLAY x 6 i1 i4 i3
OVERLAY x 2 down i3 i1
OVERLAY x 3 i1 i2 i3
SCALAR x i3 i4 3 5
OVERLAY x 3 down i4 i2
ASSIGN x Tank i1 **e_free** 1
OVERLAY x 1 i1 i2 kf1
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img
DELETE x i3.doc
DELETE x i3.img
DELETE x i4.doc
DELETE x i4.img
DELETE x alpha1.doc
DELETE x alpha1.img

E_mu "submodule computing coefficient μ "

ASSIGN x Tank i1 **S_dcoef** 2
SCALAR x i1 i2 3 0.667
OVERLAY x 3 Gateopen Gateopen i5
OVERLAY x 3 Gateopen Head1 i4
OVERLAY x 4 i5 i4 i3
SCALAR x i3 i4 3 100
RECLASS x i i4 i3 3 **e_mu**
SCALAR x i3 i1 3 0.0008
OVERLAY x 2 i2 i1 mu
OVERLAY x 3 Gateopen Gateopen i3
OVERLAY x 2 Head1 gateopen i4
SCALAR x i4 i5 3 100
RECLASS x i i5 i4 3 **e_kf3**
SCALAR x i4 i5 3 0.01
OVERLAY x 3 i3 i5 i4
OVERLAY x 3 i5 i5 i3
OVERLAY x 3 Gateopen i3 i5
OVERLAY x 4 i4 i5 i3
SCALAR x i3 i4 3 0.08
OVERLAY x 2 i2 i4 mu1
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img
DELETE x i3.doc
DELETE x i3.img
DELETE x i4.doc
DELETE x i4.img
DELETE x i5.doc
DELETE x i5.img

E_discha "submodule computing tank discharge and release"

OVERLAY x 2 Head1 Gateopen i1
SCALAR x i1 i2 3 100
RECLASS x i i2 i1 3 **e_kf3**
CONVERT x i2 i2 i 1 2
SCALAR x i2 i3 3 0.1
ASSIGN x Tank i1 **e_disch1** 1

SCALAR x **i1** i2 3 0.01
SCALAR x i2 i1 5 1.5
OVERLAY x 3 i1 mu1 i2
OVERLAY x 3 i2 kf1 i1
SCALAR x head1 i2 5 1.5
OVERLAY x 3 mu i2 i3
OVERLAY x 3 i3 kf i2
OVERLAY x 2 i2 i1 i3
SCALAR x i3 i2 3 4.429
ASSIGN x Tank i1 **S_width** 2
OVERLAY x 3 i1 i2 i4
ASSIGN x Tank i1 **e_drhiso** 1
OVERLAY x 3 Gateopen i1 i2
SCALAR x i2 i1 3 100
CONVERT x i1 i1 i 1 2
ASSIGN x i1 drh **e_drh** 2
ASSIGN x Tank i1 **e_drliso** 1
OVERLAY x 3 Gateopen i1 i2
SCALAR x i2 i1 3 100
CONVERT x i1 i1 i 1 2
ASSIGN x i1 drl **e_drl** 2
ASSIGN x Tank i1 **e_triso** 1
OVERLAY x 3 Gateopen i1 i2
SCALAR x i2 i1 3 100
CONVERT x i1 i1 i 1 2
ASSIGN x i1 tr **e_tr** 2
OVERLAY x 7 tr drl i1
DELETE x i2.doc
DELETE x i2.img
OVERLAY x 7 drh i1 i2
SCALAR x i2 i1 3 0.01
OVERLAY x 3 i1 i4 i2
OVERLAY x 7 i2 i4 i1
SCALAR x i1 i2 3 353.3
EXTRACT x i1 i3 1 3 **i_wissue**
ASSIGN x Tank i1 **e_disch2** 1
EXTRACT x i1 i3 1 3 **i_discha**
ASSIGN x Tank i1 **e_disch3** 1
EXTRACT x i1 i3 1 3 **i_releas**
ASSIGN x command Wissue i_wissue 2
ASSIGN x Tank Discharg i_discha 2
ASSIGN x Tank Release i_releas 2
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img
DELETE x i4.doc
DELETE x i4.img
DELETE x down.doc
DELETE x down.img
DELETE x kf.doc
DELETE x kf.img
DELETE x kf1.doc
DELETE x kf1.img
DELETE x mu1.doc
DELETE x mu1.img
DELETE x mu.doc
DELETE x mu.img
DELETE x alpha.doc
DELETE x alpha.img
DELETE x x.doc
DELETE x x.img
DELETE x drl.img
DELETE x drl.doc
DELETE x drh.doc
DELETE x drh.img
DELETE x tr.doc
DELETE x tr.img

E_wlevel "submodule computing tank water level"

ASSIGN x Tank i1 **s_gauge** 2
SCALAR x i1 i2 3 100
OVERLAY x 2 i2 gau_up i1
SCALAR x i1 Wlevel 3 0.328
CONVERT x Wlevel i1 i 1 2
SCALAR x i1 Wlevel 3 0.1
ASSIGN x Tank i1 e_**wlevel**
EXTRACT x i1 Wlevel 1 4 **i_wlevel**
ASSIGN x Tank Wlevel i_wlevel 2
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img

E_spill "submodule computing tank spilling"

SCALAR x Wlevel Slevel 3 0.3048
ASSIGN x Tank i1 **s_spillh** 2
ASSIGN x Tank i2 **e_spill1** 1
EXTRACT x i2 Slevel 1 4 i1
ASSIGN x Tank i2 i1 2
ASSIGN x Tank i3 **e_spill2** 1
EXTRACT x i3 Slevel 1 4 i1
ASSIGN x Tank i3 i1 2
OVERLAY x 7 i2 i3 i4
OVERLAY x 7 i4 Slevel i2
ASSIGN x Tank Spilling **i_Spill** 2
CONVERT x Spilling Spilling i 1 2
DELETE x Slevel.doc
DELETE x Slevel.img
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img
DELETE x i3.doc
DELETE x i3.img

OVERLAY x 2 i2 i1 i3
SCALAR x i3 i1 3 100
RECLASS x i i1 i2 3 **e_kf3**
SCALAR x i2 i1 3 0.01
SCALAR x i1 i2 5 1.5
SCALAR x i2 i1 3 1.77
ASSIGN x Tank i2 **s_spilll** 2
OVERLAY x 3 i1 i2 i3
SCALAR x i3 i1 3 35.33
ASSIGN x Tank i2 **e_spill3** 1
EXTRACT x i2 i1 1 3 **i_spill**

DELETE x i4.doc
DELETE x i4.img
DELETE x i1.val
DELETE x i1.dvl
DELETE x Head1.doc
DELETE x Head1.img
DELETE x Head2.doc
DELETE x Head2.img
DELETE x gateopen.doc
DELETE x gateopen.img

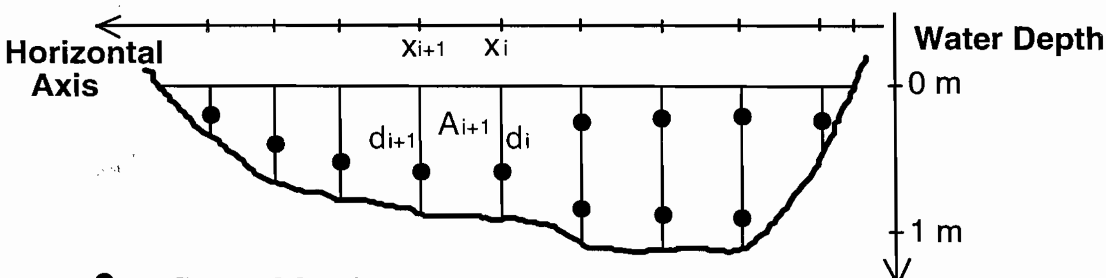
Appendix 11: Ellegala Tanks Main Gate Calibration

Appendix 11.1: Current Metering Methodology

Methodology for current metering is the one described in [Te Chow 1988]:

- Cross section, where a straight flow occurs, is selected.
- According to section width, river bed shape and flow distribution, some measurement intervals are chosen dividing so main section into several sections.
- For each measurement point, depth is measured. When it is below 1m, the flow velocity is measured at a depth of 0.6 times the section depth. At this depth, recorded velocity is assumed as representing average velocity. When depth is above 1m, two depths are retained, one at 0.2 and another at 0.8 of the total depth (see Figure below). Average of both is then accepted as average velocity of the section.

Figure: Current Metering Measurement Shematization



● Current Metering
A_{i+1} Subsection delimiting measurement i and i+1
d_i Depth at measurement i
x_i Distance from the bank at measurement i

For each subsection, discharge flowing out is written as:

$$\text{Discharge at section } i+1 = A_{i+1}\,\frac{Cm(x_i)+Cm(x_{i+1})}{2}$$

Where $Cm(xi)$: Current metering at abcisse xi

$$A_{i+1}=(x_{i+1}-x_i)\left(\frac{d_{i+1}+d_i}{2}\right)$$

Section discharge is sum of subsection discharges.

Gate Calibration

Every undershot gate has been under free-flow conditions during current metering, consequently coefficient μ_0 is deduced from following equation:

$$\mu_0 = \frac{\dfrac{Qcm}{KL\sqrt{2g}} + 0.08\,W\,(h_1^{\frac{1}{2}} - (h_1 - W)^{\frac{1}{2}})}{h_1^{\frac{3}{2}} - (h_1 - W)^{\frac{3}{2}}}$$

Where *Qcm* is results of current metering measurements and *K* the coefficient of reduction used for circular orifice. Others symbols are identical to those used in SIC formula.

By multiplying μ_0 by 3/2, we retrieve the classic free-flow discharge coefficient C_g. If we compare with C_d computed from the classic free flow equation $Q = C_d S\sqrt{2g(h_1 - \frac{W}{2})}$, we can see that sometimes $C_g \neq C_d$. This is due to the fact that the discharge coefficient increases with the h_1 / W ratio in SIC formula.

Results

All *Cg* are between 0.56 and 0.65, which is range of usual discharge coefficient (see annex 3.6). This is not correct for Debera Wewa right bank high level main canal, for which discharge coefficient is equal to 0.39. It is low but explained by the fact that orifice is very small (diameter equal to 30 cm) and circular with rectangular gate. This fact can influence on gate behavior.

However, Pannegamuwa main gate has registered a discharge coefficient *Cg* equal to 0.85. Cause of this high value has quickly been identified by the damaged gate. Even closed, a significant flow was occurring. For this, several current metering have been realized and by solving a two equations system with two unknown values, an equivalent spindle at gate closed as discharge coefficient have been assigned to structure. The third current metering has been carried out to check equivalent values.

Appendix 11.2: Ellegala Tanks' Gates Calibration Results

Equations

N (s-1)	V (ms-1)
0.07-0.32	V=0.013+0.2512N
0.32-11.28	V=0.008+0.2667N

DRL Main Canal - Gate setting (Upstream = 100 cm and Spindle = 61 cm)

Distance (m)	0.85	1.1	1.5	2	2.5	3	3.5	4	4.5	5.2	6
Depth (m)	0	0.14	0.65	0.68	0.67	0.57	0.5	0.48	0.25	0.2	0
Area (m2)	0.02	0.16	0.33	0.34	0.31	0.27	0.25	0.18	0.16	0.08	
N (60s)	0	59.5	50.5	58	53	52.5	52	54	27	22	
N (s-1)		0.99	0.84	0.97	0.88	0.88	0.87	0.90	0.45	0.37	
V (ms-1)		0.27	0.23	0.27	0.24	0.24	0.24	0.25	0.13	0.11	
Q (Cusecs)	0.08	1.41	2.93	3.04	2.66	2.27	2.11	1.21	0.65	0.15	

Discharge : 16.36 cusecs

DRH Main Canal - Gate Setting (Upstream = 100 cm and Spindle = 11 cm)

Distance (m)	0.35	0.42	0.84	1.25	1.32
Depth (m)	0.3	0.3	0.31	0.3	0.3
Area (m2)	0.02	0.13	0.13	0.02	
N1 (60s)	51	51	58.5	52	52
N (s-1)	0.85	0.85	0.98	0.87	0.87
V (ms-1)	0.23	0.23	0.27	0.24	0.24
Q (Cusecs)	0.17	1.14	1.12	0.18	

Discharge : 2.61 cusecs

DL Main Canal - Gate Setting (Usptream = 100 cm and Spindle = 31 cm)

Distance	0.42	0.7	1	1.5	2	2.5	3	3.17
Depth (m)	0.48	0.48	0.45	0.49	0.4	0.4	0.48	0.48
Area (m2)	0.13	0.14	0.24	0.22	0.20	0.22	0.08	
N1 (60s)	23.5	23.5	51	57	65.5	63.5	54.5	
N (s-1)	0.39	0.39	0.85	0.95	1.09	1.06	0.91	0.00
V (ms-1)	0.11	0.11	0.23	0.26	0.30	0.29	0.25	0.25
Q (Cusecs)	0.53	0.86	2.06	2.20	2.08	2.10	0.72	

Discharge : 10.56 cusecs

P Main Canal - Gate Setting (Upstream = 30 cm and Spindle = 22 cm)

Distance (m)	0.5	0.6	1	1.4	2.25	2.7	3.1	3.4	3.8	3.95	4.05
Depth (m)	0.36	0.36	0.38	0.38	0.38	0.38	0.38	0.4	0.42	0.32	0.32
Area (m2)	0.04	0.15	0.15	0.32	0.17	0.15	0.12	0.16	0.06	0.03	
N (60s)		38	46	50	56	62	65	64	49	44	
N (s-1)		0.63	0.77	0.83	0.93	1.03	1.08	1.07	0.82	0.73	
V (ms-1)		0.18	0.21	0.23	0.26	0.28	0.30	0.29	0.23	0.20	
Q (Cusecs)	0.11	1.02	1.19	2.78	1.63	1.56	1.22	1.50	0.42	0.12	

Discharge: 11.55 cusecs

P Main Canal - Gate Setting (Upstream = 30 cm and Spindle = 17 cm)

Distance (m)	0.25	0.3	0.7	1.15	2	2.85	3.3	3.7	3.8
Depth (m)	0.31	0.31	0.31	0.33	0.33	0.33	0.34	0.29	0.29
Area (m2)	0.02	0.12	0.14	0.28	0.28	0.15	0.13	0.03	
N (60s)		23.5	33	39	41	40	38	26	
N (s-1)		0.39	0.55	0.65	0.68	0.67	0.63	0.43	
V (ms-1)		0.11	0.15	0.18	0.19	0.19	0.18	0.12	
Q (Cusecs)	0.03	0.59	0.85	1.84	1.86	0.97	0.67	0.06	

Discharge: 6.87 cusecs

Weerawila Feeder Canal - Gate Setting (upstream = 43 cm, WR1 = 77 cm and WR4 = 38 cm)

Distance (m)	0.2	0.3	1	2	3	3.8	4
Depth (m)	0.58	0.58	0.58	0.58	0.56	0.56	0.56
Area (m2)	0.06	0.41	0.58	0.57	0.45	0.11	
N (60s)	102	102	189	219	218	165	165
N (s-1)	1.70	1.70	3.15	3.65	3.63	2.75	2.75
V (ms-1)	0.44	0.44	0.80	0.93	0.93	0.70	0.70
Q (Cusecs)	0.90	8.93	17.77	18.69	12.90	2.79	

Discharge : 61.97 cusecs

YLL Main Canal - Gate Setting (Upstream 191 cm and Spindle = 55 cm)

Distance	0.3	0.55	1.15	2	2.45	2.7	2.9	3.5	3.9
Depth (m)	0	0.2	0.81	0.81	0.81	0.81	0.8	0.3	0
Area (m2)	0.03	0.30	0.69	0.36	0.20	0.16	0.33	0.06	0.00
N (60s)		63	121	126	123	116	101	80	
N (s-1)		1.05	2.02	2.10	2.05	1.93	1.68	1.33	
V (ms-1)		0.29	0.55	0.57	0.55	0.52	0.46	0.36	
Q (Cusecs)	0.13	4.46	13.55	7.23	3.86	2.79	4.78	0.39	0.00

Discharge : 37.19 cusecs

TR Main Canal - Gate Setting (WL = 9.25 Ft and Spindle = 24 cm)

Distance (m)	0.9	1.2	2.05	2.9	3.75	4.6	4.85
Depth (m)	0	0.35	0.36	0.38	0.34	0.36	0
Area (m2)	0.05	0.30	0.31	0.31	0.30	0.05	
N (60s)		53	64	78.5	79.5	65.5	
N (s-1)		0.88	1.07	1.31	1.33	1.09	
V (ms-1)		0.24	0.29	0.36	0.36	0.30	
Q (Cusecs)	0.23	2.86	3.61	3.88	3.47	0.24	

Discharge : 14.29 cusecs

TLH Main Canal - Gate Setting (WL = 9.25 Ft and Spindle = 11 cm)

Distance (m)	0.2	0.5	1	1.25	1.6	2	2.1
Depth (m)	0	0.23	0.28	0.3	0.26	0.23	0
Area (m2)	0.03	0.13	0.07	0.10	0.10	0.01	
N (60s)		111	132	127.5	125	108	
N (s-1)		1.85	2.20	2.13	2.08	1.80	
V (ms-1)		0.50	0.59	0.57	0.56	0.49	
Q (Cusecs)	0.31	2.47	1.50	1.97	1.82	0.10	0.00

Discharge : 8.16 cusecs

TLL Main Canal - Gate Setting (WL = 11.25 Ft and Spindle = 7.5 cm)

Distance (m)	0.58	0.65	1.1	1.6	2.1	2.6	2.85	3.1	3.5	3.6
Depth (m)	0.32	0.32	0.33	0.35	0.35	0.37	0.38	0.38	0.38	0.38
Area (m2)	0.02	0.15	0.17	0.18	0.18	0.09	0.10	0.15	0.04	
N (60s)	26	26	45	64	74	56.5	43.5	29	12.5	12.5
N (s-1)	0.43	0.43	0.75	1.07	1.23	0.94	0.73	0.48	0.21	0.21
V (ms-1)	0.12	0.12	0.21	0.29	0.34	0.26	0.20	0.14	0.07	0.07
Q (Cusecs)	0.10	0.86	1.50	1.95	1.90	0.76	0.57	0.54	0.09	

Discharge : 8.26 cusecs

P Main Canal - Gate Setting (Upstream = 28 cm and Spindle = 12 cm)

Distance (m)	0.57	0.84	1.6	2.3	2.57
Depth (m)	0	0.47	0.45	0.45	0
Area (m2)	0.06	0.35	0.32	0.06	
N (60s)		15	19	17	
N (s-1)		0.25	0.32	0.28	
V (ms-1)		0.08	0.09	0.08	
Q (Cusecs)	0.08	1.04	0.98	0.09	

Discharge : 2.20 cusecs

W Main Canal - Gate Setting (Upstream = 123 cm and Spindle = 20.3 cm)

Distance	0.5	0.8	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	5.95	6.1
Depth (m)	0	0.36	0.74	0.8	0.8	0.79	0.79	0.8	0.81	0.8	0.86	0.76	0.26	0
Area (m2)	0.05	0.11	0.39	0.40	0.40	0.40	0.40	0.40	0.40	0.42	0.41	0.23	0.02	
N (60s)	0	20	26	49.5	60	60	70	84	77	71	87.5	48	18	0
N (s-1)	0	0.33	0.43	0.83	1.00	1.00	1.17	1.40	1.28	1.18	1.46	0.80	0.30	0.00
V (ms-1)	0.01	0.10	0.12	0.23	0.27	0.27	0.32	0.38	0.35	0.32	0.40	0.22	0.09	0.01
Q (cusecs)	0.10	0.43	2.39	3.55	3.86	4.14	4.92	5.20	4.79	5.28	4.42	1.26	0.03	0.00

Discharge : 40.39 cusecs

Appendix 11.3 : Ellegala Tanks Gates Discharge Coefficient

Canal Code	Spindle (cm)	Upstream (cm)	H1[1] (m)	W[2] (m)	L[3] (m)	CM[4] (cusecs)	$\mu 0$[5]	Cg[6]	Cd[7]
DRL	61	100	2.00	0.21	0.69	16.35	**0.38**	**0.57**	**0.56**
DRH	58	107	1.04	0.18	0.30	2.61	**0.26**	**0.39**	**0.38**
DL	31	107	1.46	0.17	0.61	10.56	**0.37**	**0.56**	**0.56**
W	20.3	123	2.77	0.20	1.22	40.39	**0.43**	**0.64**	**0.64**
TR	24	218	1.57	0.24	0.61	14.29	**0.42**	**0.62**	**0.62**
TLH	12	218	1.30	0.12	0.69	8.16	**0.38**	**0.57**	**0.57**
TLL	7.5	157	3.43	0.08	0.69	8.26	**0.37**	**0.56**	**0.56**
P	12	28	2.22	0.02	0.61	2.2	**0.43**	**0.65**	**0.65**
YLL	55	191	1.91	0.4	0.76	37.19	**0.4**	**0.6**	**0.61**

[1] H1 : Upstream Head
[2] W : Orifice Opening
[3] L : Width of Rectangular Gate or Equivalent Width for Circular Gate
[4] CM : Current Metering Measurement
[5] mu0 : Coefficient used in SIC Formula, defined in Appendix 5
[6] Cg = 3/2mu0
[7] Cd : Discharge Coefficient computed from classical equation for the free-flow undershot gate

Appendix 12: Tables computing Tanks gates Discharge as a function of Spindle and Relative Upstream Water Level

TABLES COMPUTING

ELLEGALA TANKS

DISCHARGES

(Distribution, Release, Spilling)

(UNDERSHOT GATE UNDER FREE-FLOW CONDITIONS)

"Sample"

International Irrigation Management Institute

Weerawila Main Canal

Discharge (cusecs) ***as a function of Spindle Length and Upstream Water Level***

(Code W)	Spindle (in inches)																			
Upstream (cm)	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
0	12	25	37	49	61	73	84	96	107	119	130	141	152	163	174	185	196	206	217	227
10	12	24	36	48	60	72	83	95	106	117	128	139	150	161	172	182	193	203	214	224
20	12	24	36	47	59	71	82	93	104	116	127	137	148	159	169	180	190	200	210	220
30	12	24	35	47	58	70	81	92	103	114	125	135	146	156	167	177	187	197	207	217
40	12	23	35	46	57	69	80	91	101	112	123	133	144	154	164	174	184	194	204	213
50	12	23	34	45	57	68	78	89	100	110	121	131	141	151	161	171	181	191	200	209
60	11	23	34	45	56	67	77	88	98	109	119	129	139	149	159	168	178	187	197	206
70	11	22	33	44	55	66	76	86	97	107	117	127	137	146	156	165	175	184	193	202
80	11	22	33	43	54	64	75	85	95	105	115	125	134	144	153	162	172	181	189	198
90	11	22	32	43	53	63	74	84	93	103	113	122	132	141	150	159	168	177	186	194
100	11	21	32	42	52	62	72	82	92	101	111	120	129	139	147	156	165	174	182	190
110	10	21	31	41	51	61	71	81	90	99	109	118	127	136	145	153	162	170	178	186
120	10	20	31	41	50	60	70	79	88	98	107	116	124	133	141	150	158	166	174	182
130	10	20	30	40	49	59	68	77	87	96	104	113	122	130	138	147	155	162	170	178
140	10	20	29	39	48	58	67	76	85	94	102	111	119	127	135	143	151	158	166	173
150	10	19	29	38	47	56	65	74	83	91	100	108	116	124	132	140	147	155	162	169
160	10	19	28	37	46	55	64	73	81	89	98	106	113	121	129	136	143	150	157	164
170	9	19	28	37	45	54	62	71	79	87	95	103	110	118	125	132	139	146	153	159
180	9	18	27	36	44	53	61	69	77	85	93	100	108	115	122	129	135	142	148	154
190	9	18	26	35	43	51	59	67	75	83	90	97	104	111	118	125	131	137	143	149
200	9	17	26	34	42	50	58	65	73	80	87	94	101	108	114	121	127	133	138	144
210	8	17	25	33	41	49	56	64	71	78	85	91	98	104	111	117	122	128	133	139
220	8	16	24	32	40	47	54	62	69	75	82	88	95	101	107	112	118	123	128	133
230	8	16	24	31	38	46	53	60	66	73	79	85	91	97	102	108	113	118	122	127
240	8	15	23	30	37	44	51	57	64	70	76	82	87	93	98	103	108	112	116	120
250	8	15	22	29	36	43	49	55	61	67	73	78	84	89	94	98	102	106	110	114
260	7	14	21	28	34	41	47	53	59	64	70	75	80	84	89	93	97	100	104	107
270	7	14	20	27	33	39	45	51	56	61	66	71	75	80	84	87	91	94	96	99
280	7	13	20	26	32	37	43	48	53	58	63	67	71	75	78	81	84	87	89	90
290	6	13	19	24	30	35	41	45	50	55	59	63	66	69	72	75	77	79	80	80
300	6	12	18	23	28	33	38	43	47	51	55	58	61	64	66	68	69	69	69	

Appendix 13: Table to input Ellegala Tank Gate Settings

Gate_Id	Gate Name	Gate Code	Gau_up (cm)	Gau_down (cm)	Spindle (cm)
110	Pannegamuwa	P			
120	Weerawila Feeder G1	WR1			
130	Weerawila Feeder G2	WR2			
140	Weerawila Feeder G3	WR3			
150	Weerawila Feeder G4	WR4			
210	Weerawila	W			
310	Yoda High Level G1	YHL 1			
320	Yoda High Level G2	YHL 2			
330	Yoda Low Level	YLL			
410	Tissa Left Bank High Level	TLH			
420	Tissa Left Bank Low Level	TLL			
430	Tissa Right Bank	TR			
440	Yoda Feeder	TS			
510	Debera Left Bank	DL			
520	Debera Right Bank High Level	DRH			
530	Debera Right Bank Low Level	DRL			

Appendix 14: Idrisi manual handed over to IIMI-ITIS Unit

Main Lines to build under Idrisi for windows an Information System in Water Management of a Cascade System

Introduction

Idrisi for windows being a Geographical Information System, it has capability to process spatial information. But being a new product and not particularly destined to be used in water management, some tricks need to be known. Hence, this succinct manual attempts to explain Idrisi modules frequently used in KOGIS.

In a first part, we will describe macro commands used in KOGIS, in a second one: procedures often used in KOGIS. The third part will deal with virtual images used in KOGIS to speed up the process. A fourth part will present digitalization under Idrisi and last part will evoke Dashboard set up.

1 IDRISI Macro Commands used in KOGIS

1.1 Modules used in KOGIS

1.1.1 OVERLAY

Overlay produces a new image from the data of the two input images. New values results from applying one of the nine possible operations (see below) to the two input images.

In batch mode five parameters required are

1 : x (to indicate that batch mode is being used)
2 : Operation number (1: Add, 2: Subtract, 3: Multiply, 4: Divide, 5: Normalized ratio ((First-Second)/(First+Second)), 6: Exponentiate, 7: First covers second unless zero, 8: Minimum, 9: Maximum)
3 : First input image
4 : Second input image
5 : Output image name

1.1.2 TRANSFOR

TRANSFOR undertakes attribute transformations on images (such as converting the data values in an image to the natural logarithms of those values

In batch mode, four parameters required are

1: x (to indicate that batch mode is being used)
2: Input file name
3: Output file name
4: Transformation type (the number code of the transformation desired, see below)

1 : 1/x	6 : sqr(x)	11 : arccos(x)
2 : ln(x)	7 : sin(x)	12 : arctan(x)
3 : exp(x)	8 : cos(x)	13 : radians(x)
4 : logit(x)	9 : tan(x)	14 : degrees(x)
5 : sqrt(x)	10 : arcsin(x)	15 : abs(x)

1.1.3 SCALAR

SCALAR does scalar arithmetic on images by adding, subtracting, multiplying, dividing or exponentiating the pixels in the input image by a constant value. In KOGIS, except for usual operations, SCALAR is often used before reclassifying an image. Indeed, RECLASS reclassifying integers, when it is a matter to reclassify a ratio image, SCALAR is used to multiply image by one hundred, so reclassification is carried out and SCALAR is carried out again (multiplication by 0.01) to get the final reclassified ratio image (see example in part 3).

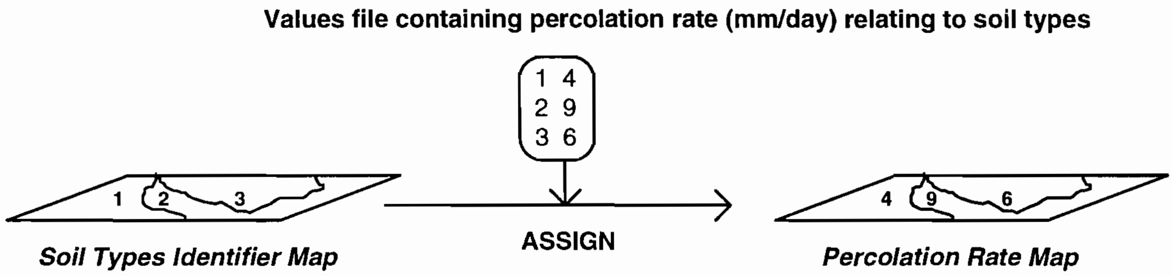
In batch mode, five parameters required are :

1 : x (to indicate that batch mode is being used)
2 : Input image
3 : Output image
4 : Operation number (1: Add, 2: Subtract, 3: Multiply, 4: Divide, 5: Exponentiate)
5 : The scalar value (the value to be used in that operation)

1.1.4 ASSIGN

ASSIGN creates new images by linking the geography of features defined in an image file with attributes defined in an attribute values file. A values file is a 2-column space-delimited ASCII file. The first columns contains feature identifiers (integers within the range of 0-32767) that are used to link the attribute values file to an image or vector file. The second column contains the attributes associated with the features. Note also that ASSIGN may be used as a fast reclassification module whenever it is known that the image data are integers.

A example appears below



Above, we can see the process to carry out to assign to a image containing soil types identifiers of a defined area, a percolation rate proper to each soils.

In batch mode, four parameters required are

1 : x (to indicate that batch mode is being used)

2 : feature definition (the image which defines the features)

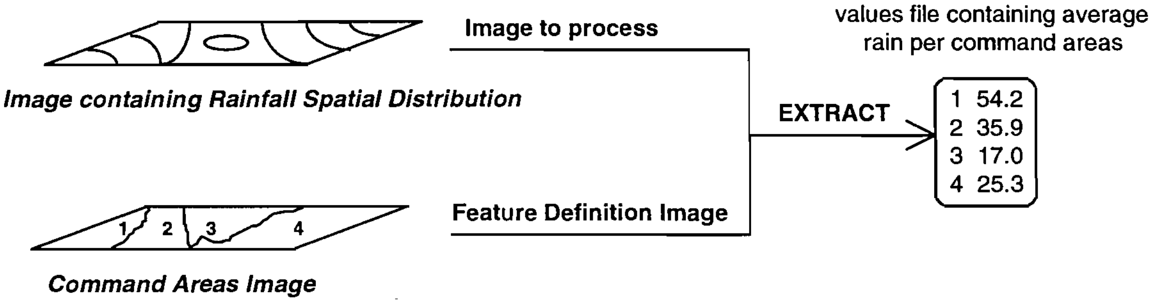
3 : output image name

4 : assignments val file (ASCII file with two columns, first one containing values of features, second one containing the assignments).

1.1.5 EXTRACT

EXTRACT extracts summary statistics to either a table or an attribute values file from an existing image file. It uses two files, an image file and a feature definition file. The summary statistics in the values file can indicate the minimum, maximum, total, average, range or standard deviation of all cells on the analyzed image within each region defined on the feature definition image.

An example appears below. It shows how to extract from an image containing rainfall spatial pattern, the average rain fallen in each command area of an irrigated system.



In batch mode, five parameters required are

1 : x (to indicate that batch mode is being used)

2 : Feature definition file (the image which describes the features)

3 : Image to be processed (the image from which summaries will be extracted)

4 : Output type (1=values file / 2= table on screen / 3=printed table)

5 : Summary type (1: minimum, 2: maximum, 3: total, 4: average, 5: range, 6: population SD, 7 :sample SD)

6 : Values file name

1.1.6 RECLASS

RECLASS classifies or reclassifies the data stored in images or attribute values files into new integer categories. Classification or reclassification is by equal intervals division of the data range, or by the application of the user-defined limits.

Since RECLASS reclassifies integers, a real value will become the rounded integers. Also, when it is matter to reclassify for example, ratio with values lower than 0.6 equal to 0.6, results will be the following ones:

- A ratio equal to 0.3 will become 1, one equal to 0.75 will become 1.

Also to remedy this problem, it is necessary, before a reclassification consisted of real values and whose we don't want to loose accuracy, to multiply initially image by required accuracy (e.g. by 100, if standard accuracy of 1/100 is required). So reclassification can be carried out and multiplication by inverse of initial used number can be done to have the final result. Reclassification file (*.rcl) are tree-columns space-delimited ASCII file. File content is the new and old values of the reclassification, according to following type:

- Assign a new value of : (first column)
- to old values ranging from : (second column)
- to those just less than : (third column)

The file is terminated with a line containing the value -9999

e.g. 0 - 32767 0
-9999

File reclassifying all values ranging from -32767 to 0 by assigning them a new value of 0.

In batch mode, five parameters required are

1 : x (to indicate that batch mode is being used)
2 : File type ("i"=image / "a"=values file)
3 : Input file name (the file to be reclassified)
4 : Output file name (the new file to be created)
5 : Classification type (1=equal interval / 2=user defined / 3=file mode)

1.1.7 CONVERT

CONVERT converts files between all possible combinations of data and file types supported for image and vector files. In KOGIS, this function is very often used in aim not to have too many useless numbers after comma.

In batch mode, at least four parameters are required

1 : x (to indicate that batch mode is being used)
2 : Input file name (the image to be converted)
3 : Output file name (the result)
4 : Graphic type ("i"=image / "v"=vector)
5 : Output data type (1=integer / 2=real / 3=byte)
6 : Output file type (1=ASCII / 2=binary / 3=packed binary)
7 : Integer conversion type (1=truncation / 2=rouding)

1.2 Module used to interpol rainfall

1.2.1 POINTVECT

POINTVEC converts raster points (e.g. Image containing in KOGIS, location of rainfall stations) into a vector point file. All non-zero cells are considered points and will become vector points with identifiers equal to the data value in the cell.

In batch mode, three parameters are required

1 : x (to indicate that batch mode is being used)
2 : Image name (name of the image to be processed)
3 : Output vector file (name of the output vector file)

1.2.2 INTERPOL

INTERPOL interpolates a full surface from point data issued from a vector file. The interpolation procedure can be either a distance-weighted average (used in KOGIS) or a potential model.

In batch mode, twelve or thirteen parameters are required

1 : x (to indicate that batch mode is being used)
2 : data entry options (1=vector point file using id's as heights / 2=vector point file using values file for heights)
3 : input vector file (name of vector file containing the point data)
4 : Output image name (the new image file to be created)
5 : Values units
6 : Choose option (1=interpolation DEM / 2=calculate Potential Surface)
7 : Distance weight exp. (value of the distance weight exponent to be used)
8 : 6-pt search radius ? (Y/N)
9 : Data type desired (1=integer / 2=real / 3=byte)
10 : File type desired (1=ASCII / 2=Binary)
11 : Columns Number (Number of columns that will span the region)
12 : Rows Number (Number of rows that will span the region)

1.3 Module used to draw graphics

1.3.1 PROFILE

PROFILE creates profiles over time or over space. In KOGIS, only profile over time are used. A profile over time shows the values of pixels at up to 15 sites defined by mask. Thus, methodology to show a profile over time of locations is to create an points image (up to 15) defining sample spots where we want to have profile over time. This one carried out, a time series file has to be created. It contains images of witch we want analyze evolution over time. To create image containing sample spots, and update it with points location, INITIAL and UPDATE modules are preliminary used. Image containing sample spots has to have the same structure as images making time series.

In batch mode, seven parameters are required

1 : x (to indicate that batch mode is being used)
2 : Profile type (1=over space, 2=over time, 3=redisplay existing profile)
3 : image with profile areas (image defining the profile sample spots)
4 : Times series file (name of the time series file to be used)
5 : Summary type (1=mean, 2=minimum, 3=maximum, 4=range, 5=total, 6=standard deviation)
6 : Save as values file ? (Y/N)
7 : Values file name

1.3.2 INITIAL

INITIAL creates new images with a constant value.

In batch mode, eight parameters are required

1 : x (to indicate that batch mode is being used)
2 : Output image name (the new image file to be created)
3 : Output data type (1=integer / 2=real / 3=type)
4 : Output file type (1=binary / 2=ASCII)
5 : Initial value (the value each cell will have)
6 : How parameters defined (1=copy from existing image / 2=define individually)
7 : defining image file (name of image file to copy parameters from) (for 1)
8 : Value units

1.3.3 UPDATE

UPDATE corrects cell value on an existing image

In batch mode, at least seven parameters are required

1 : x (to indicate that batch mode is being used)
2 : Input image name
3 : Value to be inserted
4 : First row to be updated
5 : Last row
6 : First column
7 : Last column

1.4 Module used before overlapping between two images with different reference systems

1.4.1 RESAMPLE

RESAMPLE registers the data in one grid system to a different grid system covering the same area. RESAMPLE is necessary before any overlapping between maps having different grid system. Thus, in KOGIS Dashboard, our background image is Kirindi Oya Satellite Image, which has been scannerized with a given grid system. During digitalization, we 've assigned to maps a different coordinates system. Also before proceeding any overlapping, it is necessary to assign an identical reference system. For this, a minimum of three common control points has to be found on both maps. So a correspondence file is created. It contains old coordinates and new coordinates. RESAMPLE process uses polynomial adjustments. Resampling options include a nearest neighbor option in which the new grid value is the same as that in the nearest cell in the old grid, and a bilinear interpolation option in which the new value is a distance weighted average of the four nearest neighbors in the old grid.

2 Procedures often used in KOGIS

2.1 Transfer of Information

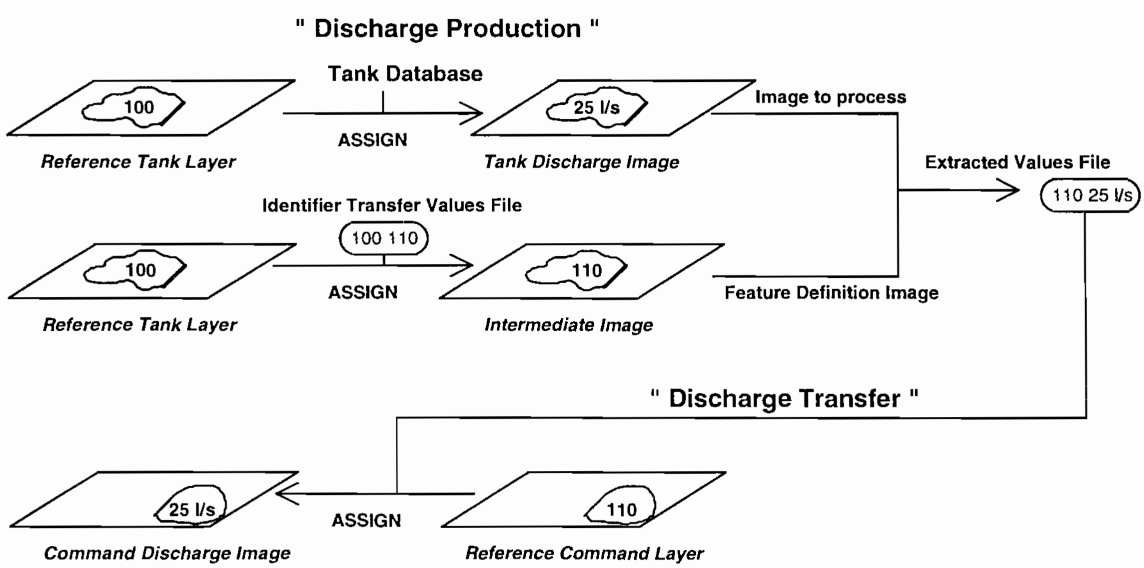
We have seen previously, that production within a cell can be carried out using IDRISI modules as ASSIGN, RECLASS, OVERLAY, TRANSFOR, SCALAR, but no module allows transfer of information from a polygon to another. Also, this part explains how to realize this transfer ?

In a cascade system, hydrological transfers are common and represent dynamic of irrigated systems in Sri Lanka. Also in KOGIS, it is frequent to transfer, information contained in a tank to command area associated with this tank or vice versa. For example, a tank has one gate, and consequently a certain discharge. This last one occurs within a command areas. Also to transfer this discharges from tank to command, process is the following one :

- Assignment of reference tank layer with associated command area identifier.
- Average extraction is proceeded with last image as new feature definition image and tanks discharge as image to process.
-Extracted values file is then assigned to reference command layer.

Figure below visually explains this transfer :

Process to transfer discharge from a tank to its command area



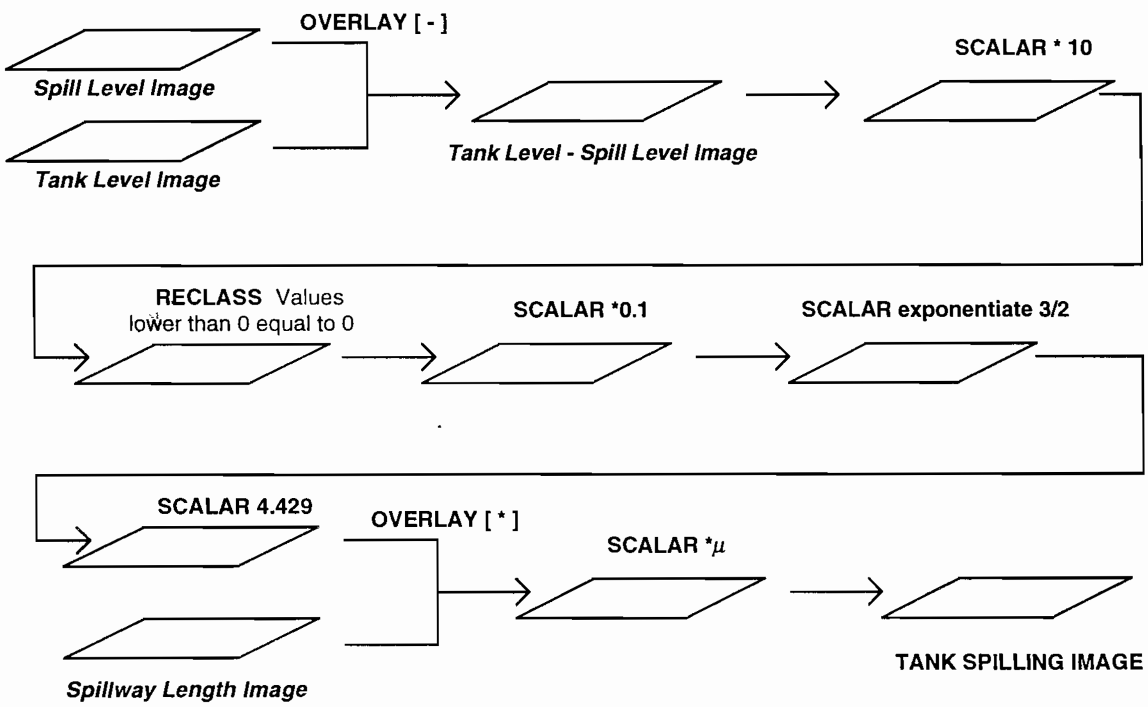
2.2 Condition law

Condition process is realized through RECLASS module. For example, an image contains tanks water level and we want to know which tanks are spilling and how many Cusecs (28.3 l/s) are spilling ?

So used condition is :

- If Tank Level < Spill Level Then $Q_{spilling} = 0$
- If Tank Level > Spill Level Then $Q_{spilling} = \mu L\sqrt{2g(Tank\ Level - Spill\ Level)^3}$

Procedure to process this condition will be the following one :



By a similar process, discharges from tanks are computed using SIC formula.

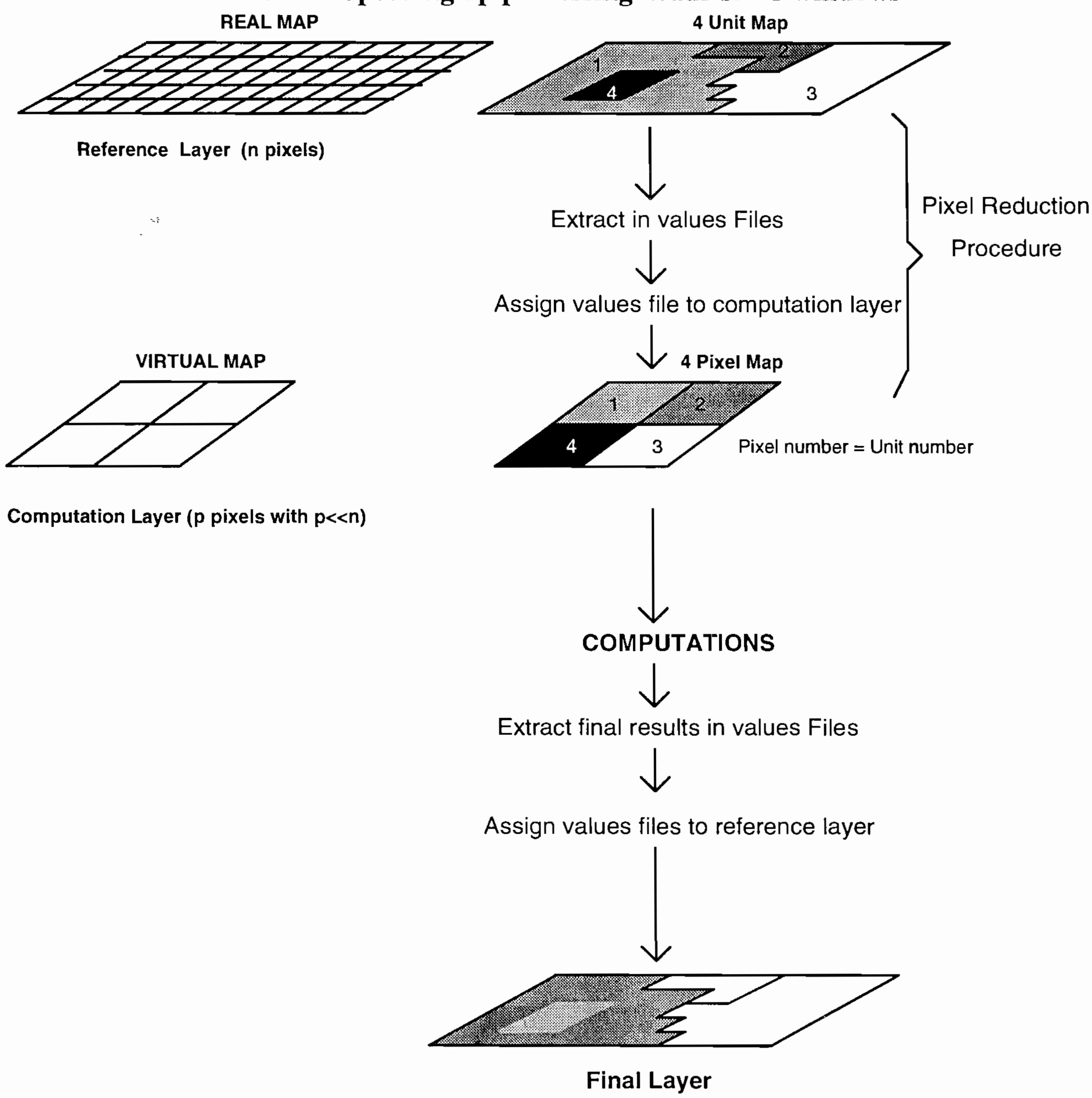
3 Computation Mode (Speeding up processing)

Idrisi uses rasterized images for processing. Each image contains most of the time a great number of pixels. Hence, speed problems quickly occur when it comes to computation between layers.

Indeed, a spatial unit (e.g. tank or command area) contains an important number of pixels and processing often requires ten, twenty or more successive steps. Hence, computation time becomes too high to envisage friendliness of a GIS as tool of decision support.

To remedy this problem, intermediate virtual maps are used. The maps are made with the same identifiers as the reference image, but each of them covers only one pixel. Thus, overlap between maps or any computation processes only one pixel for each polygon, which considerably speeds up procedures. A diagram describing a typical procedure appears below:

Procedure Speeding up processing in Idrisi for windows



4 digitalization under IDRISI

This one concerns digitalization of vector and raster files. Two ways are possible and explained in this paragraph.

4.1 Idrisi digitizer

Digitalization can be realized directly by clicking DIGITIZER toolbar. This type of digitalization concerns only vector digitization. It is carried out by displaying beforehand an image as support of digitalization.

4.2 Creation of ASCII File

Images and Vectors are made up with two files. A file containing the content (coordinate of polygons, lines, and point) and a file containing information about this content (data type, legend, number of columns....). When images and vectors are imported from external source, they are usually in a binary format. Also, they can be converted in ASCII form using CONVERT module.

Also, instead of directly digitizing, polygons, lines and points can be created through an ASCII file. Structure for a polygon is the following one :

```
e.g.    1000 5
        12 15
        12 22
        7  22
        7  15
        12 15
```

1000 is polygon identifier, 5 number of points defining polygons and so appear coordinate of points defining polygon. The last point is identical to first one and allows to close polygons.

Lines and Points structures are similar. Thus, one coordinates couple is needed to identify a point location. Lines follows the same structure as polygons except they are not closed.

When your ASCII file is finished, you have to name it (*.vec for vector, *.img for image), and create a document file (*.dvc for vector, *.doc for image) containing the information about your file. You can use existing document file to see how it is organized. Since a binary format take less memory than an ASCII format, CONVERT to binary format is advised at the end of the process.

5 Dashboard organization

In KOGIS, different dashboards consists of an image added with several vector layers allowing Irrigation Manager to have a clear picture of spatial deliveries pattern within its system and make adequate decision in an appropriate time.

Thus, Dashboard consists in :

- A satellite image as background support.
- An image overlaid on previous one and displaying either targets deviation (1) (Ratio "Actual Issue / Targeted Issue" in %) or water issues in water depth (2) (in mm).
- Tank and boxes containing water losses to the sea (giving respectively tank water status and sea losses)
- Tank narrows vector layer (linking tank boxes and tank locations)
- Tank text vector layer (giving tank capacity, reserve status, discharge and release or spilling)
- Tank unit text vector layer (giving units of previous information)
- Network and Kirindi Oya vector layer

To support dashboard a title, a legend, a text as north narrow and a scale bar are displayed.

5.1 Choice of an appropriate legend for a raster image

Idrisi has capability to display a legend. This legend can be either automatically ordered or created by user. In first case there is nothing to do, 256 categories will be selected by software. But if you want to build your own categories, some tricks are necessary to be known.

Thus, 256 categories are possible relating to available 256 colors. Also, in aim to keep coherence between value and color within a polygon and legend classes, it is necessary to have **integer value in polygon in a range of 0-255. Also, for this, appropriate units are required in aim to cover maximum this range without losing accuracy**. By the same way, **image autoscaling has to be disabled** or some incoherence between your legend and values within polygons can appear. If autoscale is disabled, all values higher than 256 will be assigned in the last class.

Choice of labelization of legend is carried out in IDRISI Menu File/Document. Possibility for image and vector to have colorful and written legend is different and explained in the following paragraphs.

5.1.1. IMAGE LEGEND

Steps to carry out to build a legend for a raster image are:

- In IDRISI Menu, choose File/Document and select image for which you want to put a legend. So select Legend Categories and Labelize your image by filling boxes with legend text. (e.g. for a range 0-6 mm, put the text only in the box 0).
- In IDRISI Menu choose Palette Workshop, define color boxes relating to your legend labelization (e.g. for range 0-6 mm defined by red color, put red color in each box from 0 to 6)
- In IDRISI Menu choose Display/Image and select Use Legend.

It is obviously that color classes chosen in Palette Workshop has to fit with labels input in Document/Legend categories.

In KOGIS Dashboard, 16 colors are used for the black and white background image (cells values of satellite image are assigned in a range of 240-255). Consequently, 240 values stay available to describe water status within command areas (integers). Also choice of appropriate units to keep displayed values in this range has had to be imperatively well chosen. In KOGIS, depth of delivered water in mm as well as % are used.

5.1.2 PRECAUTIONS TO TAKE

When a values file or an image is modified, automatically its document file is initialized, which means that legend categories are deleted. That means that each day you have to create again legend categories. To avoid this, you need to have a permanent document file containing all required information of your values file or your image. Thus, at the end of the process, you can copy your permanent document file as the new document file relating to the final values file or image.

5.2 Title and Text Addition

Addition of a title and text to accompany dashboard is carried out in IDRISI in Display Menu by selecting MODIFY MAP COMPONENTS.

5.3 Text layer

Raster and Vector layers can only store one information by feature. Also when it is matter to display several informations relating to one polygon, problems occurs. This is the case in KOGIS Dashboard for tanks. For this text vector layer are used.

So steps to carry out are:

- Initially, create a point layer defining text location, either with IDRISI Digitizer or with a vector ASCII file (see 5.4).
- In Menu Database Workshop/File select *create text vector layer*. As input layer, input point layer beforehand defined. In output, it depends on user. Thus, a text point layer is defined, accompanied by a database to input required text.
- Input your text in present database.

Thus, when an image is displayed, text vector layer can be added. It will display all content of relating database.

5.4 Representation Permanent Layers

In dashboard, they are tank boxes and narrow linking last ones with polygons representing tanks.

These imposition layer can be created either by digitalization or by creating a ASCII vector file.

5.5 Dashboard Composition

It is realized by adding vectors on one image and saving as a map composition file.

Appendix 15: KOGIS Help Menu

Ellegala Tanks Management Procedure

1 Open Database Workshop
2 Open **Ellegala.mdb**
3 Update field **[Gau_Up], [Gau_down], [Spindle]**
4 Open Link/Assign values field to image
5 Choose as Feature Definition Image: **Tank**, as Output Image: **Gau_Up**, as Feature Definition Field: **Identifier**, As data Field from Current Database: **Gau_Up**.
6 Choose as Feature Definition Image: **Tank**, as Output Image: **Gau_Down**, as Feature Definition Field: **Identifier**, As data Field from Current Database: **Gau_Down**.
7 Choose as Feature Definition Image: **Tank**, as Output Image: **Spindle**, as Feature Definition Field: **Identifier**, As data Field from Current Database: **Spindle**.
8 Run Macro **C_tank**

Targets Fixing Procedure (*Command Function*)

1 Open Database Workshop
2 Open **T_comman.mdb**
3 Update field **[Date]** with SQL Statement **Date**
4 Open Link/Assign values field to image
5 Choose as Feature Definition Image: **Command**, as Output Image: **Date**, as Feature Definition Field: **Identifier**, As data Field from Current Database: **Date**
6 Run Macro **C_target**
7 Open File/Import Idrisi Values file
8 Import in field [Targets (cu)] values file called i_target (*.val).

Graphics Procedure (*Observation Function*)

1 To display evoluation of all tanks, run macro **C_tank**
2 To display particular tank evolution, run macro **P_tank name**

System Observation (*Observation Function*)

1 Open Database Workshop
2 Open **T_tank.mdb**
3 Open file/import Idrisi values and import following values files (*.val): file **i_wlevel** in field **Wlevel, i_discha** in field **Discharge, i_releas** in field **Release, i_spill** in field **Spilling**
4 Update Lunugamwehera and Badagiriya data
5 Open Link/Assign values field to image
6 Choose as Feature Definition Image: **Tank**, as Output Image respectively: **Wlevel, Discharg,,** as Feature Definition Field: **Identifier**, As data Field from Current Database: **Wlevel, Discharge**.
7 Execute all SQL Statement Ob_* corresponding to field containing accumulated data
8 Open **T_comman**.mdb
9 Import values field **i_wissue** in field **Disch (cu)** and data from IMIS in the same field
10 Assign field **Disch (cu)** to output image Wissue
11 Execute all SQL Statement Ob_* corresponding to field containing accumulated data
12 Run Macro **C_observ**
13 Open **Tank.mdb**
14 Import Values file **i_tank** in field **Tank_text**
15 Open Display/Map Composition file
16 Choose Dashboards **DDev** or **DAls** to observe system

System Evaluation (*Evaluation Function*)

1 Open Database Workshop
2 Open **T_tank.mdb**
3 Update field **Wlevel J-7, Wlevel J-0, Wdis, Wrel, Wspi**
4 Execute SQL statements **Ev_*** relating to fields containing accumulated seasonaly data
5 Select Link/Assign values field to image
6 Choose as Feature Definition Image: **Tank**, as Output Image respectively: **WlevelJ7, WlevelJ0, WDis, Wrel, Wspi**, as Feature Definition Field: **Identifier**, As data Field from Current Database: **Wlevel J-0, Wlevel J-7, Wdischa, Wrelease, Wspill**.
7 Open **T_comman**.mdb
8 Update and Assign field **WDisch (cu)** to output image WWissue
9 Run Macro **C_eval**
10 Open **Wtank.mdb**
11 Import Values file **i_wtank** in field **Wtank_text**
12 Open Display/Map Composition file
13 Choose Dashboards **WDev** or **WAls** to evaluate system
14 **To evaluate Rain**
15 Open **T_rain.mdb**
16 Update **Wrain** field and assign it to output image **rain**
17 Run Macro **C_rain**
18 Open **T_comman.mdb** and import respectively in fields **Als, WI/T and Wrain** values fields **i_wals, i_dev, i_rain** to store data
19 Execute SQL Statement all **Ev_*** corresponding to fields containing accumulated seasonaly data

Appendix 16: Layers List

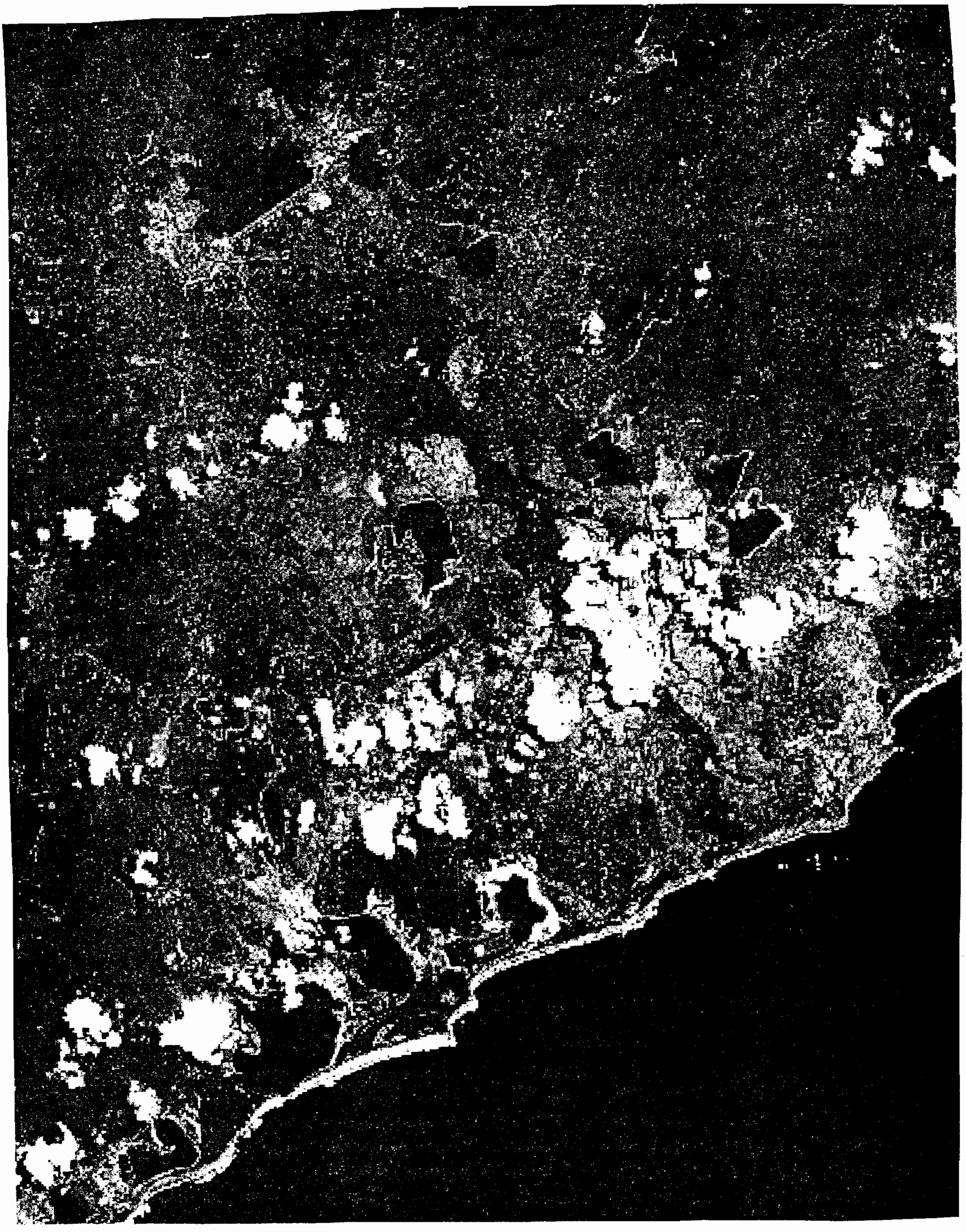
Vector File

Vector Layer Name	*Vector Layer Description*
Command	Command Areas Layer
Watbod	Tanks and Reservoir Layer
Soil	KOISP Soil Types Layer
Mcanal	Main Canals Layer
Dcanal	Secondary Canals Layer
Drainage	Drainages Layer
Lake	Lagoon Layer
Frame	Tank Boxes Layer
Frame2	Tank Boxes Layer
Narrow	Tank Narrow Layer
Tank	Tank Information Layer
Tanktext	Daily Information Units Layer
Wtext	Weekly Information Units Layer

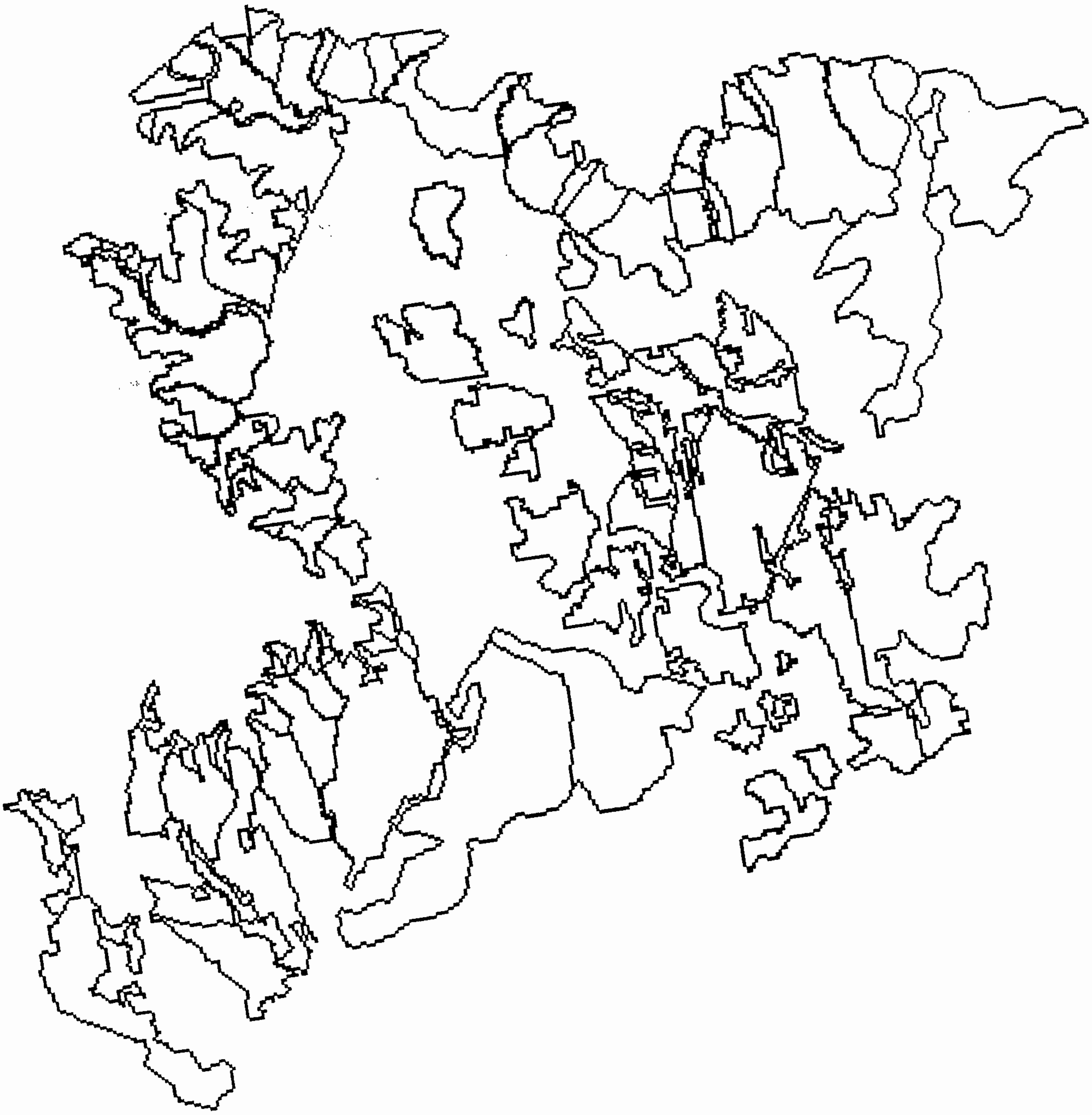
Image File

Raster Image Name	**Raster Image Descriptiom**
Koisp	KOISP Tanks, Command Areas Image
Komap	KOISP Satellite Image
Command	Virtual Image Containing Command Identifiers
Tank	Virtual Image Containing Tank Identifiers
Rainstat	KOISP Rainfall Stations

Kirindi Oya Satellite Image

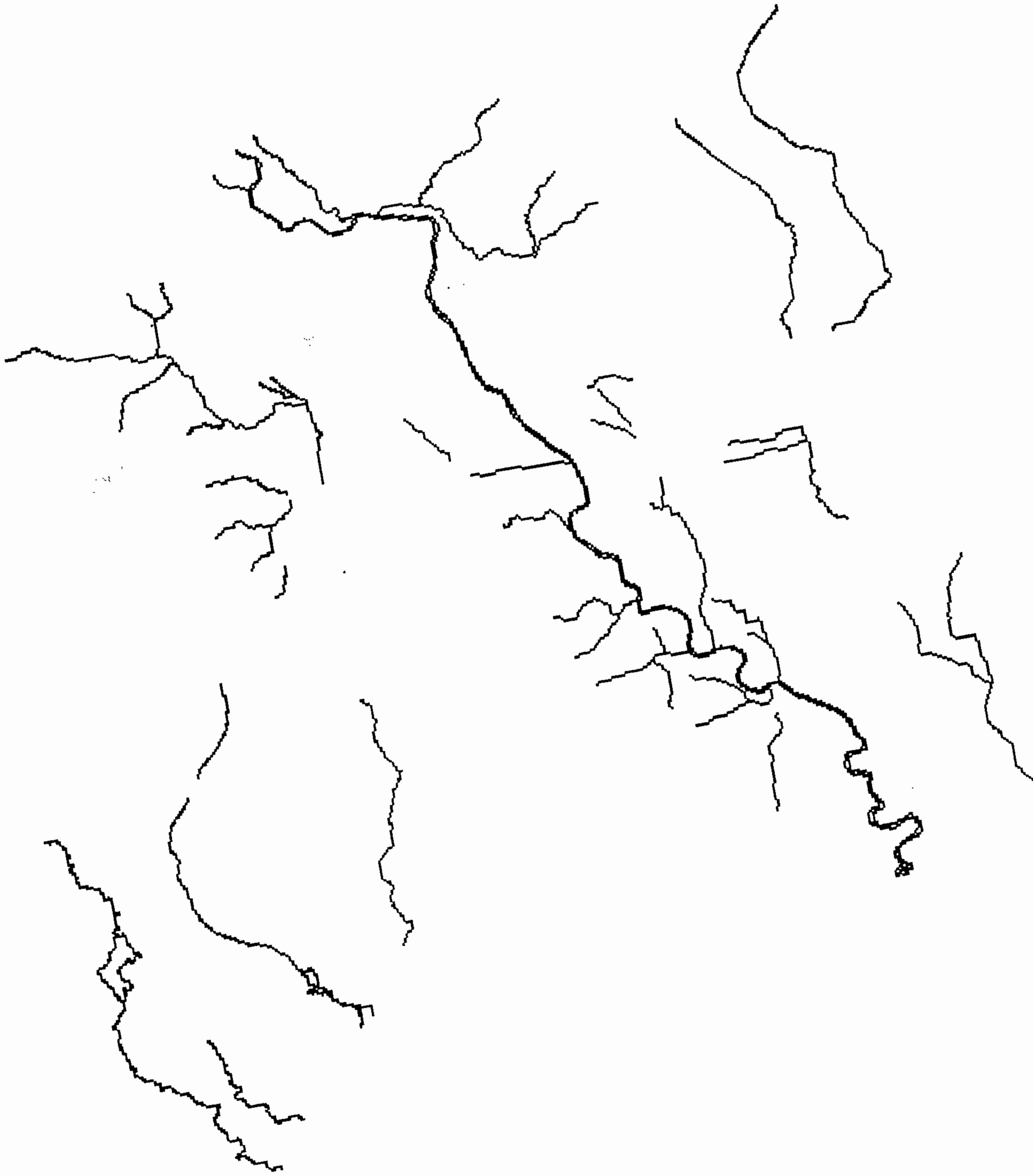


Kirindi Oya Command Areas under Main Management

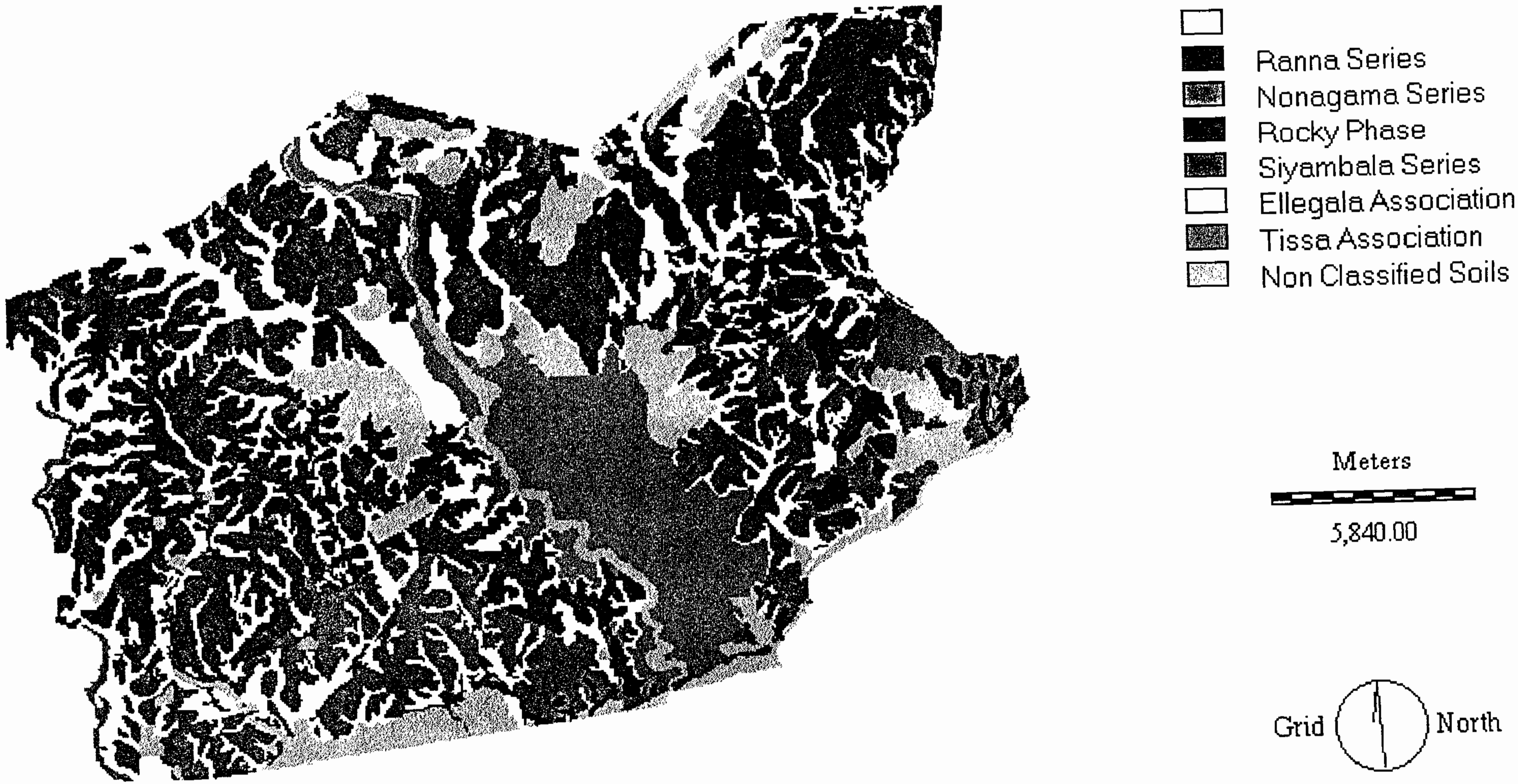


Kirindi Oya Tanks and Irrigation Network

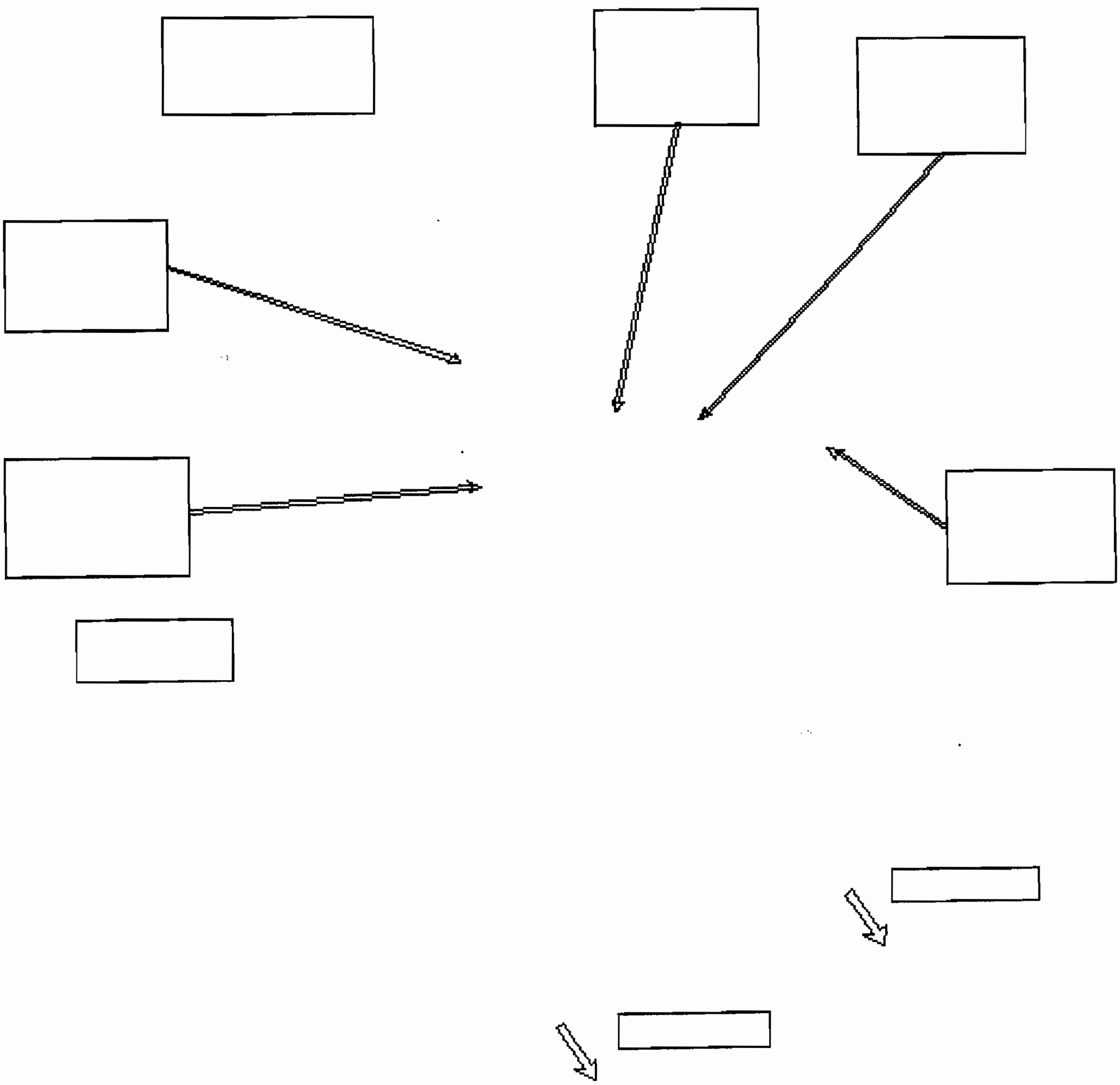
Kirindi Oya Main Drainages and Kirindi Oya



Kirindi Oya Irrigation and Settlement Project Soil Map



Dashboard Representation Layers



Appendix 17: Control Points List

Control Point Id	Name	X	Y	Soil Map	Land Use Map	KOISP	BOP	Ellegala Map
1	Reference Extremity	0	0					
2	Reference Extremity	467	0					
3	Reference Extremity	467	562					
4	Reference Extremity	0	562					
5	Lunugamwehera Control Tower South Extremity	182.9316	444.1668			X		
6	Debera Junction Clock Tower	269.1075	312.3187	X	X	X		X
7	Bridge before Debera Junction on Hambantota Road	266.4419	281.0984	X				X
8	Weerawila Airport South East Extremity	237.4307	257.1451					
9	Weerawila Airport North East Extremity	232.5255	265.0552	X	X			
10	Yoda Wewa Bund South Extremity	350.0212	282.1483	X	X	X		X
11	Kirinda Lewaya West Extremity	386.3648	193.1505		X			
12	Weerawila Junction	209.2113	252.4421					X
13	RBMC and Badagiriya Road Junction	79.4568	251.8618			X		
14	RB Tract1 DC2 Offtake	158.5405	403.4056				RB T1	
15	RB Tract1 DC4 Offtake	167.2965	389.5389				RB T1	
16	**RB Tract 1 FC54 End**	152.9171	367.9288				RB T1	
17	**RB Tract1 FC58 West Turn**	125.2595	373.7884				RB T1	
18	**RB Tract 2 Canal Extremity**	132.6995	362.2751				RB T2	
19	RB Tract2 DC3 OffTake	147.6996	322.8976				RB T2	
20	RB Tract2 DC7 Offtake	167.3926	282.6963				RB T2	
21	RB Tract2 DC9 Offtake	196.6387	260.107				RB T5	
22	RB Tract 5 BC2 Offtake	194.2943	241.2265				RB T5	
23	Tract 5 RBMC Turn Between DC1 and DC1B	200.2723	247.497				RB T5	
24	RB Tract 5 DC3 and Hambantota Junction	208.5493	203.117				RB T5	
25	RB Tract 5 BC2 Last Turn at East of Parcel 376	186.5894	179.785				RB T67	
26	RB Tract 7 FC13 Offtake	132.8067	233.0515				RB T67	
27	RB Tract6 DC2 Offtake	145.0505	219.5206				RB T67	
28	RB Tract6 Parcel 133 North East Extremity	159.374	171.3259				RB T67	
29	RB Tract6 Parcel 177 Center	161.9544	217.0079				RB T67	
30	LB Tract 1 DC3 Offtake	205.8598	427.9751				LB T1	
31	LB Tract 1 DC7 Offtake	264.3525	409.4893				LB T1	
32	LB Tract 1 Parcel 13 South Extremity	173.0029	419.1954				LB T1	
33	LB Tract 1 Parcel 658 South East Extremity	260.6296	381.7896				LB T1 & T2	
34	LB Tract 2 DC1 Offtake	271.278	399.9654				LB T2	
35	LB Tract 2 DC7 Offtake	310.0382	370.6559				LB T2	
36	LB Tract 2 Parcel 552 South East Extremity	322.1569	348.5122				LB T2	
37	LB Tract 3 North West Parcel 83	344.2444	376.1079				LB T3	
38	LB Tract 3 South West Parcel 95	340.5994	354.6822				LB T3	
39	LB Tract 3 DC2 Offtake	344.2771	397.8837				LB T3	
40	LB Tract 3 DC3 Offtake	369.3317	396.0154				LB T3	
41	Weliyawalava North West Extremity	85.8565	223.0028				Banda	
42	Divulgama Tank South West Extremity	104.0492	149.2124				Banda	
43	Bandagiriya Wewa Main Channel at Parcel 82 Level	103.4221	186.62				Banda	
44	Bandagiriya North East Parcel 423	135.8365	175.7485				Banda	

Appendix 18: Root-Mean-Square Error Definition
(RMS Error)

Definition [Idrisi 1995]

The root-mean-square error - a measure of the variability of measurements about their true values. The RMS error is estimated by taking a sample of measurements and comparing them to their true values. These differences are then squared and summed. The sum is then divided by the number of measurements to achieve a mean square deviation. The square root of the mean square deviation is then taken to produce a characteristic error measure in the same units as the original measurements. The RMS error is directly comparable to the concept of standard deviation.

Calculating Allowable RMS

In our case there is no well-defined application, also the allowable RMS error is computed with the following assumptions (IDRISI for Windows Users' Guide),

A common assumption is that a cartographer can plot positions on a map with typical error of 0.25 mm. In this case, the degree of error on the ground must be calculated, based on the map scale, for instance,

*Acceptable error on the ground = Error on the map * Scale conversion * unit conversion*

In case of our Reference Satellite Image for digitizing, the scale is 1:63,360. Then acceptable error on the ground is:

= 0.25 * 63,360 * 0.001 m/mm
= 15.84 meters

Since the allowable RMS is a function of the error on the ground and the z score probability of occurrence, we need to make one final assumption about the RMS. Also, we assume that the acceptable error on the ground represents 1 RMS. Therefore,

Allowable RMS = (Acceptable error on the ground / z score probability of occurrence)

= (15.84 meters / 1)
= 15.84 meters

This lead us to conclude that in each map resampling, the RMS error given by Idrisi for Windows will be assumed as the error on the ground.

Appendix 19: KOGIS Values Files

Database and Computing Values Files

D_cap0
"Capacity Equations"

100 0
200 0
300 0
400 0
500 0
1000 -120

D_cap1
"Capacity Equations"

100 4.45
200 1.38
300 2.69
400 3.5
500 2.38
1000 3.0941

D_cap2
"Capacity Equations"

100 0.056
200 321.48
300 9.25
400 0.21
500 4.96
1000 0.3115

D_cap3
"Capacity Equations"

140 1
240 1
340 1
440 1
540 1
1040 0.1

D_cap4
"Capacity Equations"

140 1
240 1
340 1
440 1
540 1
1040 10

D_cap5
"Capacity at MOL"

140 72
240 3811
340 1735
440 468
540 287
1040 20362

D_capaci
"Transfer to text Layer"

100 140
200 240
300 340
400 440
500 540
1000 1040

D_captot
"Active Capacity at FSL"

140 546
240 6682
340 6171
440 2669
540 413
1040 146222

D_outflo
"Transfer to text layer"

100 160
200 260
300 360
400 460
500 560
1000 1060
1800 1860
3000 3000
3100 3100

D_schedo
"Schedule Converting"

0 0
101 1
102 2
103 3
104 4
105 5
106 6
107 7
....
....

D_spill
"Transfer to text layer"

100 170
200 270
300 370
400 470
500 570

D_status
"Ratio"

140 150
240 250
340 350
440 450
540 550
1040 1050

P_fsl
"Contain FSL"

140 8.1
240 12.5
340 12.3
440 15.5
540 8
1040 191

P_mol
"Contain MOL"

180 5
280 6
380 7
480 9
580 5.5
1080 156

KOGIS Reclass Files

D_adjust

0 100 100
-9999

D_sat

239 239 32767
-9999

D_als

0 2445 2446
-9999

D_targe1

0 -365 0
-9999

D_targe2

0 0 365
-9999

D_targe3

0 365 365
-9999

D_targe4

1 0 1000
0 1000 32767
-9999

D_targe5

0 0 1000
1 1000 2304
-9999

D_targe6
"New Areas Schedule"

0 -365 0
1668 1 15
1054 15 35
1140 35 65
1184 65 95
985 95 365
-9999

D_targe7
"Old Areas Schedule

0 -365 0
2246 1 21
1728 21 41
1849 41 71
1884 71 101
1650 101 365
-9999

Appendix 20 : Modules computing Dashboard

C_Observ (Observation Dashboards)

Branch Ob_capa
Branch Ob_ratio
Branch Ob_disc
Branch Ob_spill
Branch Ob_setup

Ob_capa "Compute Tank Capacity as a function of Water Level"

EXTRACT x Tank wlevel 1 4 i_wlevel
ASSIGN x command wlevel2 i_wlevel 2
ASSIGN x Command i1 **d_cap0** 2
OVERLAY x 1 Wlevel2 i1 i2
SCALAR x i2 i3 3 10
RECLASS x i i3 i2 3 **d_cap6**
SCALAR x i2 i1 3 0.1
ASSIGN x Command i2 **d_cap1** 1
OVERLAY x 6 i1 i2 i3
ASSIGN x Command i1 **d_cap2** 2
OVERLAY x 3 i3 i1 i2
ASSIGN x Command i1 **d_capaci** 1
EXTRACT x i1 i2 1 4 i1
ASSIGN x Command i1 i1 2
ASSIGN x Command i2 **d_cap3** 2
OVERLAY x 3 i1 i2 i3
CONVERT x i3 i3 i 1 2
ASSIGN x Command i1 **d_cap4** 1
ASSIGN x Command i2 **d_cap5** 1
OVERLAY x 3 i3 i1 i4
OVERLAY x 2 i4 i2 Capacity

Ob_ratio "Compute Tank Reserve Ratio"

ASSIGN x Command i1 **d_captot** 2
OVERLAY x 4 Capacity i1 i2
SCALAR x i2 i1 3 100
CONVERT x i1 i1 i 1 2
ASSIGN x Command i2 **d_status** 1
EXTRACT x i2 i1 1 4 i1
ASSIGN x Command Resource i1 1

Ob_disch "Compute Tank Discharges"

ASSIGN x command i1 **d_outflo** 1
EXTRACT x Tank discharg 1 4 i_discha
ASSIGN x Command i2 **i_discha** 2
EXTRACT x i1 i2 1 4 i1
ASSIGN x command Cusecs i1 2
CONVERT x Cusecs Cusecs i 1 2 2
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img

Ob_spill " Compute Tank Spilling and Release"

OVERLAY x 1 Release Spilling i2
ASSIGN x command i1 **d_spill** 1
EXTRACT x Tank i2 1 4 i1
ASSIGN x Command i2 i1 2
EXTRACT x i1 i2 1 4 i1
ASSIGN x command i1 i1 2
CONVERT x i1 spill i 1 2 2
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img
DELETE x i1.val
DELETE x i1.dvl

Ob_setup "Set Up the Dashboards"

OVERLAY x 7 Cusecs Resource i1
DELETE x Cusecs.doc
DELETE x Cusecs.img
DELETE x Resource.doc
DELETE x Resource.img
OVERLAY x 7 i1 Capacity i2
DELETE x Capacity.doc
DELETE x Capacity.img
OVERLAY x 7 i2 Wlevel2 i1
OVERLAY x 7 i1 spill i2
OVERLAY x 4 Wissue Surface i1
SCALAR x i1 i3 3 2445
RECLASS x i i3 I1 3 **d_als**
SCALAR x i1 Als 3 0.1
OVERLAY x 7 Als i2 Watermgt
EXTRACT x Command watermgt 1 4 **i_tank**
OVERLAY x 4 Wissue Target i1
SCALAR x i1 i2 3 100
RECLASS x i i2 i1 3 **d_adjust**
EXTRACT x Command i1 1 4 i1
RECLASS x a i1 i2 3 **d_sat**
ASSIGN x Koisp i1 i2 1
CONVERT x i1 i1 i 1 2 2
OVERLAY x 7 i1 Komap Deviation
COPY x Pindic.doc Deviation.doc
EXTRACT x Command Als 1 4 i1
RECLASS x a i1 i2 3 **d_sat**
ASSIGN x Koisp i1 i2 2
CONVERT x i1 i1 i 1 2 2
OVERLAY x 7 i1 Komap Als
COPY x i_tankd6.val i_Tankd7.val
COPY x i_Tankd6.dvl i_Tankd7.dvl
COPY x i_tankd5.val i_Tankd6.val
COPY X i_Tankd5.dvl i_Tankd6.dvl
COPY x i_tankd4.val i_Tankd5.val
COPY X i_Tankd4.dvl i_Tankd5.dvl
COPY x i_tankd3.val i_Tankd4.val
COPY X i_Tankd3.dvl i_Tankd4.dvl
COPY x i_tankd2.val i_Tankd3.val
COPY X i_Tankd2.dvl i_Tankd3.dvl
COPY x i_Tankd1.val i_Tankd2.val
COPY x i_Tankd1.dvl i_Tankd2.dvl
COPY x i_Tankd0.val i_Tankd1.val
COPY x i_Tankd0.dvl i_Tankd1.dvl
COPY x i_tank.val i_Tankd0.val
COPY x i_tank.dvl i_Tankd0.dvl
DELETE x Watermgt.doc
DELETE x Watermgt.img
DELETE x Wlevel2.doc
DELETE x Wlevel2.img
DELETE x Spill.doc
DELETE x Spill.img
DELETE x i1.img
DELETE x i1.doc
DELETE x i2.img
DELETE x i2.doc
DELETE x i3.img
DELETE x i3.doc
DELETE x i4.img
DELETE x i4.doc
DELETE x i1.val
DELETE x i1.dvl
DELETE x i2.val
DELETE x i2.dvl

C_eval "Evalauation Dashboards"

Branch Ev_capac
Branch Ev_disch
Branch Ev_spill
Branch Ev_setup

Ev_capac "Compute Capacity Difference"

EXTRACT x Tank wlevelJ7 1 4 i1
ASSIGN x command i3 i1 2
ASSIGN x Command i1 **d_cap0** 2
OVERLAY x 1 i3 i1 i2
SCALAR x i2 i3 3 10
RECLASS x i i3 i2 3 **d_cap6**
SCALAR x i2 i1 3 0.1
ASSIGN x Command i2 **d_cap1** 1
OVERLAY x 6 i1 i2 i3
ASSIGN x Command i1 **d_cap2** 2
OVERLAY x 3 i3 i1 i2
ASSIGN x Command i1 **d_capaci** 1
EXTRACT x i1 i2 1 4 i1
ASSIGN x Command i1 i1 2
SCALAR x i2 i3 3 10
RECLASS x i i3 i2 3 **d_cap6**
SCALAR x i2 i1 3 0.1
ASSIGN x Command i2 **d_cap1** 1
OVERLAY x 6 i1 i2 i3
ASSIGN x Command i1 **d_cap2** 2
OVERLAY x 3 i3 i1 i2
ASSIGN x Command i1 **d_capaci** 1
EXTRACT x i1 i2 1 4 i1
ASSIGN x Command i1 i1 2
ASSIGN x Command i2 **d_cap3** 2
OVERLAY x 3 i1 i2 i3
CONVERT x i3 i3 i 1 2
ASSIGN x Command i1 **d_cap4** 1

```
ASSIGN x Command i2 d_cap3 2
OVERLAY x 3 i1 i2 i3
CONVERT x i3 i3 i 1 2
ASSIGN x Command i1 d_cap4 1
ASSIGN x Command i2 d_cap5 1
OVERLAY x 3 i3 i1 i4
OVERLAY x 2 i4 i2 CapaJ7
EXTRACT x Tank wlevelJ0 1 4 i1
ASSIGN x command i3 i1 2
ASSIGN x Command i1 d_cap0 2
OVERLAY x 1 i3 i1 i2
ASSIGN x Command i2 d_cap5 1
OVERLAY x 3 i3 i1 i4
OVERLAY x 2 i4 i2 CapaJ0
OVERLAY x 2 CapaJ0 CapaJ7 WeekCapa
DELETE x CapaJ0.doc
DELETE x CapaJ0.img
DELETE x CapaJ7.doc
DELETE x CapaJ7.img
```

Ev_disch "Compute Tank Discharges"

```
ASSIGN x command i1 d_outflo 1
EXTRACT x Tank wdis 1 4 i1
ASSIGN x Command i2 i1 2
EXTRACT x i1 i2 1 4 i1
ASSIGN x command i1 i1 2
CONVERT x i1 Weekdisc i 1 2 2
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img
```

Ev_spill "Compute Tank Spilling"

```
OVERLAY x 1 wRel wSpi i2
ASSIGN x command i1 d_spill 1
EXTRACT x Tank i2 1 4 i1
ASSIGN x Command i2 i1 2
EXTRACT x i1 i2 1 4 i1
ASSIGN x command i1 i1 2
CONVERT x i1 weekspil i 1 2 2
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img
DELETE x i1.val
DELETE x i1.dvl
```

Ev_setup "Compute Evaluation Dashboards"

```
OVERLAY x 7 Weekdisc Weekspil i2
SCALAR x i2 i1 3 1.982
DELETE x Weekdisc.doc
DELETE x Weekdisc.img
DELETE x Weekspil.doc
DELETE x Weekspil.img
CONVERT x i1 i1 i 1 2
OVERLAY x 7 WeekCapa i1 i2
EXTRACT x Command i2 1 4 i_wtank
DELETE x Weekcapa.doc
DELETE x Weekcapa.img
OVERLAY x 4 wWissue Surface i1
SCALAR x i1 i3 3 2445
RECLASS x i i3 I1 3 d_als
SCALAR x i1 WAls 3 0.1
SCALAR x Target i2 3 7
OVERLAY x 4 WWissue i2 i1
SCALAR x i1 i2 3 100
RECLASS x i i2 i1 3 d_adjust
EXTRACT x Command i1 1 4 i_wdev
RECLASS x a i_wdev i2 3 d_sat
ASSIGN x Koisp i1 i2 1
CONVERT x i1 i1 i 1 2 2
OVERLAY x 7 i1 Komap WDev
EXTRACT x Command wAls 1 4 i_wals
RECLASS x a i_wals i2 3 d_sat
ASSIGN x Koisp i1 i2 2
CONVERT x i1 i1 i 1 2 2
OVERLAY x 7 i1 Komap wAls
COPY x pwals.doc wals.doc
COPY x pwdev.doc wdev.doc
DELETE x i1.img
DELETE x i1.doc
DELETE x i2.img
DELETE x i2.doc
DELETE x i3.img
DELETE x i3.doc
DELETE x i4.img
DELETE x i4.doc
DELETE x i1.val
DELETE x i1.dvl
DELETE x i2.val
DELETE x i2.dvl
```

C_graph "Tank Graphics"

```
BRANCH P_panneg
BRANCH P_weera
BRANCH P_yoda
BRANCH P_Tissa
BRANCH P_debera
BRANCH P_lunuga
```

P_panneg "Pannegamuwa Graphics"

```
ASSIGN x Command i1 i_tankd7 2
ASSIGN x Command i2 P_mol 2
ASSIGN x Command i5 P_fsl 2
OVERLAY x 7 i2 i1 i4
OVERLAY x 7 i5 i4 i3
INITIAL x pannegam 1 1 0 1 Command 0
UPDATE x pannegam 1 0 0 0 0 2 0 0 6 6 3 0 0 2 2
EXTRACT x pannegam i3 1 3 i1
ASSIGN x pannegam P_d7 i1 2
ASSIGN x Command i1 i_tankd6 2
ASSIGN x Command i2 P_mol 2
ASSIGN x Command i5 P_fsl 2
OVERLAY x 7 i2 i1 i4
OVERLAY x 7 i5 i4 i3
INITIAL x pannegam 1 1 0 1 Command 0
UPDATE x pannegam 1 0 0 0 0 2 0 0 6 6 3 0 0 2 2
EXTRACT x pannegam i3 1 3 i1
ASSIGN x pannegam P_d6 i1 2
ASSIGN x Command i1 i_tankd5 2
ASSIGN x Command i2 P_mol 2
ASSIGN x Command i5 P_fsl 2
OVERLAY x 7 i2 i1 i4
OVERLAY x 7 i5 i4 i3
INITIAL x pannegam 1 1 0 1 Command 0
UPDATE x pannegam 1 0 0 0 0 2 0 0 6 6 3 0 0 2 2
EXTRACT x pannegam i3 1 3 i1
ASSIGN x pannegam P_d5 i1 2
ASSIGN x Command i1 i_tankd4 2
ASSIGN x Command i2 P_mol 2
ASSIGN x Command i5 P_fsl 2
OVERLAY x 7 i2 i1 i4
OVERLAY x 7 i5 i4 i3
INITIAL x pannegam 1 1 0 1 Command 0
UPDATE x pannegam 1 0 0 0 0 2 0 0 6 6 3 0 0 2 2
EXTRACT x pannegam i3 1 3 i1
ASSIGN x pannegam P_d4 i1 2
ASSIGN x Command i1 i_tankd3 2
ASSIGN x Command i2 P_mol 2
ASSIGN x Command i5 P_fsl 2
OVERLAY x 7 i2 i1 i4
OVERLAY x 7 i5 i4 i3
INITIAL x pannegam 1 1 0 1 Command 0
UPDATE x pannegam 1 0 0 0 0 2 0 0 6 6 3 0 0 2 2
EXTRACT x pannegam i3 1 3 i1
ASSIGN x pannegam P_d3 i1 2
ASSIGN x Command i1 i_tankd2 2
ASSIGN x Command i2 P_mol 2
ASSIGN x Command i5 P_fsl 2
OVERLAY x 7 i2 i1 i4
OVERLAY x 7 i5 i4 i3
INITIAL x pannegam 1 1 0 1 Command 0
UPDATE x pannegam 1 0 0 0 0 2 0 0 6 6 3 0 0 2 2
EXTRACT x pannegam i3 1 3 i1
ASSIGN x pannegam P_d2 i1 2
ASSIGN x Command i1 i_tankd1 2
ASSIGN x Command i2 P_mol 2
ASSIGN x Command i5 P_fsl 2
OVERLAY x 7 i2 i1 i4
OVERLAY x 7 i5 i4 i3
INITIAL x pannegam 1 1 0 1 Command 0
UPDATE x pannegam 1 0 0 0 0 2 0 0 6 6 3 0 0 2 2
EXTRACT x pannegam i3 1 3 i1
ASSIGN x pannegam P_d1 i1 2
ASSIGN x Command i1 i_tankd0 2
ASSIGN x Command i2 P_mol 2
ASSIGN x Command i5 P_fsl 2
OVERLAY x 7 i2 i1 i4
OVERLAY x 7 i5 i4 i3
INITIAL x pannegam 1 1 0 1 Command 0
UPDATE x pannegam 1 0 0 0 0 2 0 0 6 6 3 0 0 2 2
EXTRACT x pannegam i3 1 3 i1
ASSIGN x pannegam P_d0 i1 2
PROFILE x 2 pannegam pannegam 1 n
DELETE x i1.img
DELETE x i1.doc
DELETE x i2.img
DELETE x i2.doc
DELETE x i3.img
DELETE x i3.doc
DELETE x i4.doc
DELETE x i4.img
DELETE x i5.doc
DELETE x i5.img
DELETE x i1.val
DELETE x i1.dvl
DELETE x pannegam.doc
DELETE x pannegam.img
```

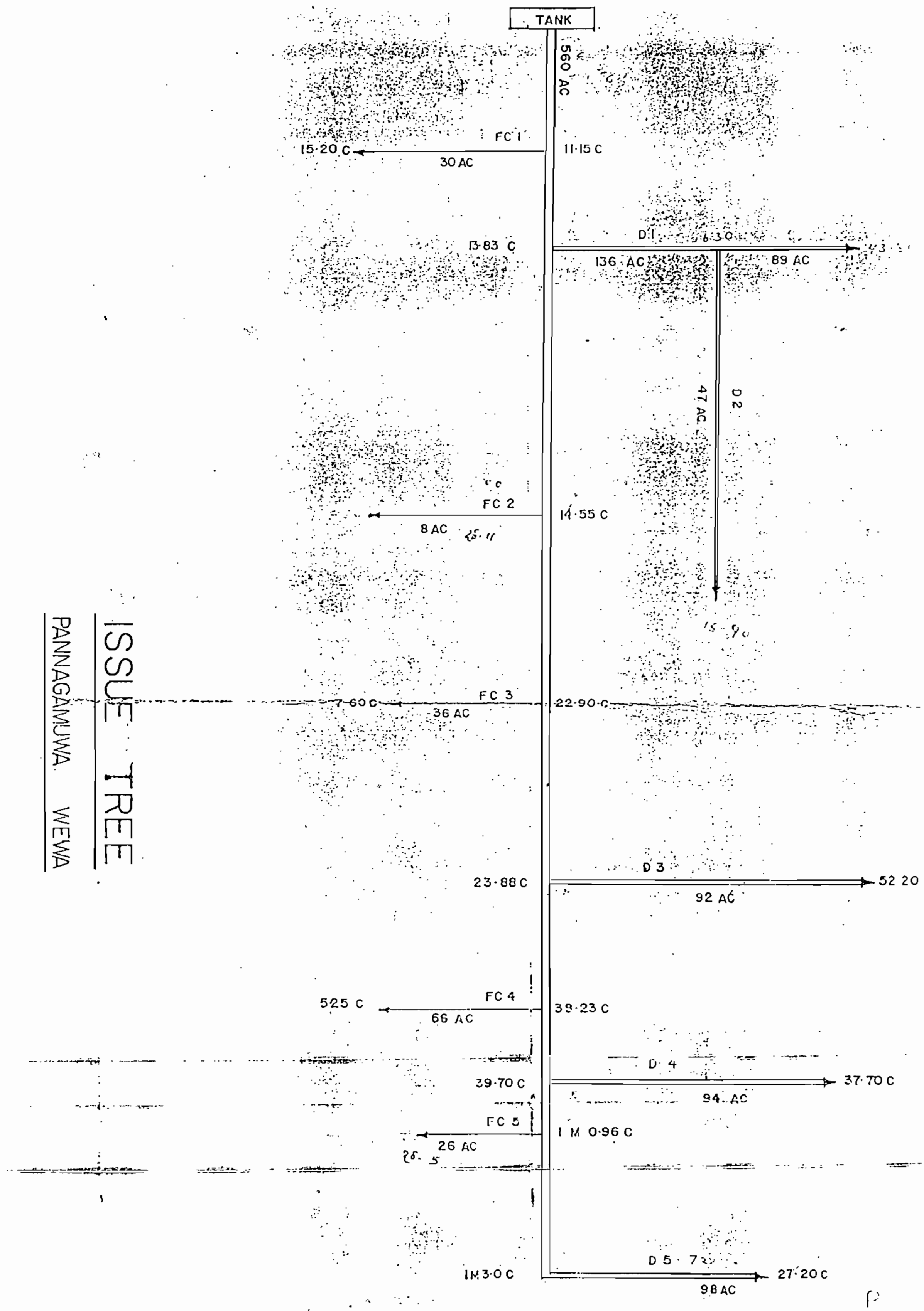
C_target "Define Targets" (*Command Function*)

ASSIGN x CROPDATE i1 **D_Scheco** 1
ASSIGN x DATE i2 **D_Scheco** 1
OVERLAY x 2 i2 i1 i3
RECLASS x i i3 i1 3 **D_targe1**
RECLASS x i i3 i2 3 **D_targe2**
SCALAR x i2 i3 1 365
RECLASS x i i3 i2 3 **D_targe3**
OVERLAY x 7 i1 i2 i3
RECLASS x i Command i1 3 **D_targe4**
OVERLAY x 3 i3 i1 i2
RECLASS x i Command i4 3 **D_targe5**
OVERLAY x 3 i4 i3 i1
RECLASS x i i2 i3 3 **D_targe6**
RECLASS x i i1 i4 3 **D_targe7**
OVERLAY x 7 i3 i4 i1
SCALAR x i1 i2 3 0.01
OVERLAY x 3 i2 Surface i1
SCALAR x i1 i2 3 0.0409
CONVERT x i2 i2 i 1 2
SCALAR x i2 Target 3 0.1
EXTRACT x Command Target 1 4 **i_target**
DELETE x i1.doc
DELETE x i1.img
DELETE x i2.doc
DELETE x i2.img
DELETE x i3.doc
DELETE x i3.img
DELETE x i4.doc
DELETE x i4.img

C_rain "Interpol Rain"

POINTVEC x Rain Rainvec
INTERPOL x 1 Rainvec Rain m 1 1 N 2 2 419 534
DELETE x Rainvec.vec
DELETE x Rainvec.dvc
EXTRACT x Koisp Rain 1 4 **i_rain**
DISPLAY x a Rain Idris16 n x 1 0 418 0 533 Command x x Command

Appendix 21: Issues Tree Relating Pannegamuwa Wewa



Appendix 22:Kirindi Oya Calibration Yala 1996

Regression Equation deduced from four espaced current metering measurements : Q=53.77H^0.873 (Q in l/s and H in cm)

Current Metering (96/05/22 at 12h00)

Distance (m)	0.85	1.05	1.5	2	2.5	3	3.5	4	4.5	5	5.5	5.9	6.6
Depth (m)	0	0.14	0.19	0.31	0.35	**0.35**	0.43	0.45	0.42	0.36	0.26	0.16	0
Area (m2)	0.01	0.07	0.13	0.17	0.18	0.2	0.22	0.22	0.2	0.16	0.08	0.06	
N (60s)		119	125	138	170	199	207	201	178	144	109	105	
N (s-1)		1.98	2.08	2.30	2.83	3.32	3.45	3.35	2.97	2.40	1.82	1.75	
V (ms-1)		0.54	0.56	0.62	0.76	0.89	0.93	0.90	0.80	0.65	0.49	0.47	
Q (m3s-1)	0	0.04	0.07	0.11	0.14	0.18	0.2	0.18	0.14	0.09	0.04	0.01	
Q (Cusecs)	0.13	1.44	2.62	4.04	5.12	6.27	7.11	6.54	4.99	3.12	1.44	0.47	
											Cusecs		43.29

Current Metering (96/05/25 at 7h00)

Distance (m)	0.85	1.25	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.2	6.8
Depth (m)	0	0.19	0.22	0.3	0.4	**0.43**	0.44	0.44	0.47	0.4	0.35	0.24	0.17	0
Area (m2)	0.04	0.05	0.13	0.18	0.21	0.22	0.22	0.23	0.22	0.19	0.15	0.04	0.05	
N (60s)		99	109	136	160	184	208	215	198	166	138	106	107	
N (s-1)		1.65	1.82	2.27	2.67	3.07	3.47	3.58	3.30	2.77	2.30	1.77	1.78	
V (ms-1)		0.45	0.49	0.61	0.72	0.83	0.93	0.96	0.89	0.75	0.62	0.48	0.48	
Q (m3s-1)	0.01	0.02	0.07	0.12	0.16	0.19	0.21	0.21	0.18	0.13	0.08	0.02	0.01	
Q (Cusecs)	0.30	0.85	2.54	4.12	5.66	6.76	7.37	7.44	6.28	4.53	2.87	0.70	0.44	
												Cusecs		49.85

Current Metering (96/05/28 at 13h00)

Distance (m)	0.5	0.55	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.3
Depth (m)	0.16	0.16	0.32	0.36	0.47	0.52	**0.55**	0.54	0.52	0.52	0.41	0.32	0.17	0
Area (m2)	0.01	0.11	0.17	0.21	0.25	0.27	0.27	0.27	0.26	0.23	0.18	0.12	0.03	
N (60s)		110	115	170	205	219	212	208	198	173	151	120	105	
N (s-1)		1.83	1.91	2.83	3.42	3.64	3.53	3.47	3.30	2.88	2.52	2.00	1.75	
V (ms-1)		0.50	0.52	0.76	0.92	0.98	0.95	0.93	0.89	0.78	0.68	0.54	0.47	
Q (m3s-1)	0	0.05	0.11	0.17	0.23	0.26	0.26	0.24	0.22	0.17	0.11	0.06	0.01	
Q (Cusecs)	0.07	1.93	3.85	6.17	8.30	9.11	9.05	8.52	7.65	5.98	3.94	2.20	0.21	
												Cusecs		66.99

Current Metering (96/06/04 at 9h00)

Distance (m)	0.2	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5.2	5.8
Depth (m)	0	0.19	0.26	0.34	0.44	**0.49**	0.47	0.49	0.49	0.46	0.24	0.07
Area (m2)	0.03	0.11	0.15	0.2	0.23	0.24	0.24	0.25	0.24	0.25	0.09	
N (60s)		104	125	153	168	180	194	208	194	172	127	
N (s-1)		1.73	2.08	2.55	2.80	3.00	3.23	3.47	3.23	2.87	2.12	
V (ms-1)		0.47	0.56	0.69	0.75	0.81	0.87	0.93	0.87	0.77	0.57	
Q (m3s-1)	0.01	0.06	0.09	0.14	0.18	0.2	0.22	0.22	0.2	0.16	0.03	
Q (Cusecs)	0.24	2.06	3.32	4.97	6.42	7.12	7.64	7.80	6.89	5.82	0.94	
										Cusecs		53.22

Yoda Wewa Drainage Canal Measurement

Big 96/06/02

Distance (m)	0	0.22	0.45	0.67	0.9
Depth (m)	0	0.33	**0.4**	0.31	0
Area (m2)	0.04	0.08	0.08	0.04	0
N (60s)	0	60	66	64	0
N (s-1)		1.00	1.10	1.07	
V (ms-1)		0.27	0.30	0.29	
Q (m3s-1)	0	0.02	0.02	0.01	
Q (Cusecs)	0.18	0.85	0.82	0.18	
			Cusecs		**2.03**

Small 96/06/02

Distan	0.25	0.4	0.7	0.9	1.15
Depth	0.08	0.26	**0.24**	0.21	0.1
Area (	0.03	0.08	0.05	0.04	
N (60s	0	86	78	58	0
N (s-1)		1.43	1.30	0.97	
V (ms-1)		0.39	0.35	0.27	
Q (m3	0	0.03	0.01	0.01	
Q (Cu	0.18	0.99	0.49	0.18	
			Cusecs		1.84

96/06/04 big

Distance (m)	0	0.22	0.45	0.67	0.89
Depth (m)	0	0.41	**0.48**	0.39	0
Area (m2)	0.05	0.1	0.1	0.04	0
N (60s)	0	81	86	79	0
N (s-1)		1.35	1.43	1.32	
V (ms-1)		0.37	0.39	0.36	
Q (m3s-1)	0.01	0.04	0.04	0.01	
Q (Cusecs)	0.29	1.37	1.27	0.27	
			Cusecs		**3.20**

96/06/ small

Distan	0.25	0.45	0.8	1.15	1.35
Depth	0	0.26	**0.38**	0.27	0.17
Area (	0.03	0.11	0.11	0.04	
N (60s	0	114	127	101	0
N (s-1)		1.90	2.12	1.68	
V (ms-1)		0.51	0.57	0.46	
Q (m3	0.01	0.06	0.06	0.01	
Q (Cu	0.24	2.15	2.07	0.36	
			Cusecs		4.81

Big 96/06/07

Distance (m)	0	0.2	0.4	0.61	0.83
Depth (m)	0	0.23	**0.31**	0.21	0
Area (m2)	0.02	0.05	0.05	0.02	0
N (60s)	0	137	122	106	0
N (s-1)		2.28	2.03	1.77	
V (ms-1)		0.62	0.55	0.48	
Q (m3s-1)	0.01	0.03	0.03	0.01	
Q (Cusecs)	0.25	1.11	0.99	0.20	
			Cusecs		**2.55**

small 96/06/04

h=16 cm

Q =0

date 96/06/14

Big1

Distance (m)	0	0.25	0.5	0.65	0.9
Depth (m)	0	0.5	**0.54**	0.49	0
Area (m2)	0.06	0.13	0.08	0.06	0
N (60s)	0	41	48	44	0
N (s-1)		0.68	0.80	0.73	
V (ms-1)		0.19	0.22	0.20	
Q (m3s-1)	0.01	0.03	0.02	0.01	
Q (Cusecs)	0.21	0.95	0.58	0.22	
			Cusecs		**1.96**

Small 96/06/14

Distance (m)	0	0.3	0.65	1.07	1.35
Depth (m)	0	0.22	**0.46**	0.33	0.23
Area (m2)	0.03	0.12	0.17	0.08	
N (60s)	0	80	84	35	0
N (s-1)		1.33	1.40	0.58	
V (ms-1)		0.36	0.38	0.16	
Q (m3s-1)	0.01	0.04	0.05	0.01	
Q (Cusecs)	0.21	1.57	1.60	0.23	
			Cusecs		3.60

Big2

Distance (m)	1.85	2	2.3	2.6	2.75
Depth (m)	0	0.45	**0.45**	0.39	0
Area (m2)	0.03	0.14	0.13	0.03	0
N (60s)	0	15	16	17	0
N (s-1)		0.25	0.27	0.28	
V (ms-1)		0.08	0.08	0.08	
Q (m3s-1)	0	0.01	0.01	0	
Q (Cusecs)	0.05	0.37	0.37	0.04	
			Cusecs		0.83

downstream 96/06/14

Distance (m)	0.1	0.4	1	1.3	1.7
Depth (m)	0	0.6	**0.68**	0.63	0
Area (m2)	0.09	0.38	0.2	0.13	
N (60s)	0	62	63	47	0
N (s-1)		1.03	1.05	0.78	
V (ms-1)		0.28	0.29	0.22	
Q (m3s-1)	0.01	0.11	0.05	0.01	
Q (Cusecs)	0.45	3.88	1.75	0.48	
			Cusecs		6.57

Appendix 23: Ellegala System Water Balance Results

Kirindi Oya Flow and Irrigation Volume

Date	Kirindi Oya Output Discharge Weekly Average	Kirindi Oya Output Weekly Volume	Irrigation Deliveries Weekly Volume
	(l/s)	(m3)	(m3)
5/22-5/28	1538	930182	2472422
5/29-6/4	1556	941069	2076883
6/5-6/11	1550	937440	2127082
6/12-6/18	1674	1012435	1963786
6/19-6/25	1635	988848	2838931

Tanks Discharges

Tank Gates Weekly Mean Discharge (l/s)								
P	W	YLL	TLH	TLL	TR	DL	DRH	DRL
223	1461	822	228	306	306	275	54	413
272	921	814	221	250	191	310	46	409
247	896	957	220	241	250	311	55	340
151	1081	676	234	295	237	213	39	321
269	1750	1024	249	232	250	365	64	491

Losses by Evapotranspiration

		5/22-5/28		5/29-6/4		6/5-6/11		6/12-6/18		6/19-6/25	
		Eto	4.7	Eto	4.54	Eto	2.96	Eto	3.43	Eto	4.04
Gate	Surface	Kc	Volume	Kc	Volume	Kc	Volume	Kc	Volume	Kc	Volume
	(ha)		(m3)		(m3)		(m3)		(m3)		(m3)
P	191	1	62839	1	60700	1.15	45511	1.15	52738	1.15	62117
W	645	1.2	254646	1.2	245977	1.2	160373	1.2	185837	0.9	164165
YLL	700	1	230300	1	222460	1	145040	1.15	193281	1.15	227654
TLH	90	1.15	34052	1.15	32892	1.15	21445	1.2	25931	1.2	30542
TLL	230	1	75670	1	73094	1.15	54804	1.15	63506	1.15	74801
TR	336	1.15	127126	1.15	122798	1.15	80062	1.2	96808	1.2	114025
DL	122	1.15	46159	1.15	44587	1.15	29070	1.2	35151	1.2	41402
DRH	24	1.15	9080	1.15	8771	1.15	5719	1.2	6915	1.2	8145
DRL	116	1.15	43889	1.15	42395	1.15	27640	1.2	33422	1.2	39366
	Total (m3)		883760		853674		569665		693589		762217

Lunugamwehera Rain

	5/22-5/28		5/29-6/4		6/5-6/11		6/12-6/18		6/19-6/25	
Total Surface	Weekly Rain		Weekly Rain		Weekly Rain		Weekly Rain		Weekly Rain	
(ha)	(mm)	(m3)	(mm)	(m3)	(mm)	(m3)	(mm)	(m3)	(mm)	(m3)
2570	0.7	17990	0.9	23130	1.2	30840	19.6	503370	0	0

Final Results

	Output		Input		Losses
	Kirindi Oya	Evapotranspiration	Irrigation	Rain	
Date	(m3)	(m3)	(m3)	(m3)	(m3)
5/22-5/28	930182	883760	2472422	17990	676470
5/29-6/4	941069	853674	2076883	23130	305270
6/5-6/11	937440	569665	2127082	30840	650816
6/12-6/18	1012435	693589	1963786	503370	761132
6/19-6/25	988848	762217	2838931	0	1087867

Total	(10^6 m3)	4.8	3.8	11.5	0.6	3.5

Appendix 24: Sheet to Import Collected Data From Left Bank Office

Daily Water Levels and Gate Openings

Month	Tissa Wewa 15'-6"					Debera Wewa 8'-0"				Yoda Wewa 12'-4"			Weerawila 12'-4"		Pannegamuwa 8'-1"						Gamunupura			Ellegala RB					Ellegala Bifurcation							Rain (mm)
																														Deberawewa			Tissa Wewa			
		Gate Opening (cm)					Spindle Length (cm)				Spindle Length (cm)					Spindle (cm)					WL	WL		WL	Spindle (cm)				WL			WL			WL	
Day	Water Level	TLH	TLL	TR	TS	Water Level	DL	DRL	DRH	Water Level	YHL	YLL	Water Level	W (opening ")	Water Level	P	WR1	WR2	WR3	WR4	Upstream (cm)	Downstream (cm)	Spindle (cm)	Upstream (cm)	RB1	RB2	RB3	RB4	Upstream (cm)	Gate 1(cm)	Gate 2 (cm)	Downstream (cm)	Gate 1(cm)	Gate 2 (cm)	Downstream (cm)	Tissamaharama
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