NATIONAL WATER CONFERENCE
Nov. 4-6, 1998
BMICH, Colombo Sri Lanka

RESEARCH PAPERS PRESENTED

Session No.22 6 November 1998 *11:00 a.m.*

Groundwater

Paper No.48
Indrapala, W.C.K.
Ground Water Do We Treat Correctly?

Paper No.50
Wijesekera, R.S.
The Importance Of Managing The Groundwater Source In Koggala Free Trade Zone Area In Order To Prevent The Environmental Hazards

Paper No.70
Panabokke, C.R.
A Rational Approach To The Use Of Limited Shallow Groundwater Supplies Within The Small Tank Cascades Systems Of The North Central Province Of Sri Lanka

Ground water - Do we treat correctly ?

Throughout the country there are lot of garment factories which have been working from mid-eighties. Most of these have low pressure boilers working below 10 bars and gives about 500 kg/steam per day. Also there are larger boilers in Sri Lanka operating at higher pressures and capable of giving high capacity.

The quality of the water used for such systems can be defined by following major parameters.

a) Alkalinity
b) Hardness
c) Total Dissolved Solids (TDS)
d) Silica

Though there are some other important parameters involves in defining water quality this research revolves around hardness and TDS which are premier conserns in industrial water usage.

A sample of feed water obtained from one of the boiler at Koggala EPZ gave the following test results.

pH 8.0 at 28.9 C
TDS 720 mg/L
Total hardness as CaCO 280 mg/L
Total alkalinity as CaCO 374 mg/L

This water supply is from ground water and samples taken from other ares including Kalutara, Matara and Hambantota showed some what lower result values but not very different. But the water taken from the general distribution systems (pipe borne) showed much lower test result values. For those systems total hardness was around 50 and TDS around 200 mg/L.

Analyzing above results we can see that ground water in this areas not very suitable to use as boiler feed water or for cooling systems.

The normal methods adopted by the around these areas are use of chemical treatment to convert the hardness in to soft sludge, finally removed by blow down and use of Sodium form Cation exchangers. On the occasions where we have to use well water of this quality as industrial supply, this treatment methods are not seems to be ideal.

Though the total hardness can be removed by the above methods successfully the Total Dissolved Solids can not be decreased upto required levels. The normal recomended value of TDS should be less than 2500 mg/L for a low pressure boiler. High pressure boilers demand much lower TDS values. It is easily seen that non TDS removing methods can lead to exeed the recomended values creating lot of problems for the systems.

Basically Total Dissolved Solids includes inorgnic salts which have a particle size of diameter less than 10^{-6} millimeters. High TDS levels cause several disastrous problems. It improve formation of scales inside the boilers and cooling systems. These scales as we know mainly contains Calcium and Magnisium Carbonates reduse heat transfer causing over heating of heating elements. Higher levels of TDS also cause foaming and results boiler water to be carried with steam. The final end result will be depositions in steam lines and user points and errosion. The mechanical devices such as steam purifiers and seperates are used for preventing carry over. These are not employed with some low pressure boilers. With high carry over these apperatus can also get clogged even when they are used.

The carrying over was clearly evident in the garment factories on which basically the research concentrated. Some scales had come out from metal joints of steam irons indicating that there may be scales inside the irons and there is a high carry over. These scales reacted with diluted acid giving a gasous product giving an indication that it may be a Carbonate of Ca^{2+} or Mg.

According to the above finding outs it is seen that for treatment of well water in Sri Lanka (Mainly in coastal areas) demineralizers are the most suited method. Strongly acidic cation exchanger (H^+ form) will serve this purpose.

By using H^+ form ion exchangers where Ca^{+2}, Mg^{+2}, Na^+ and other catioas of metals can be exchanged for H^+. This will not increase the TDS simultaneously will remove the hardness. By using this type of ion exchangers (H^+) pure steam can be obtained and lesser problems will occur in boiler systems. Though the initial cost for the demineralizers is high enery saving and protection of heating elements will compensate for the initial cost. Moreover the water want be a culprit that creates deep concerns in you.

THE IMPORTANCE OF MANAGING THE GROUNDWATER SOURCES IN KOGGALA FREE TRADE ZONE AREA IN ORDER TO PREVENT THE ENVIRONMENTAL HAZARDS.

R.S. WIJESEKERA, WATER RESOURCES BOARD.

Abstract

The Koggala free trade zone is located at the Southern province of Sri Lanka. This is one of the major BOI projects in the country, initiated in the year 1990. The project area is bounded by the sea to the south, Koggala lake to the north, Poloya outfall to the east and connecting the Koggala area to the main land by a narrow land section on the western boundary. As per the request made by the BOI, Water Resources Board has undertaken this project. The main purpose of the project was to supply adequate amount of water for the factories established in the project area.

Reconnaissance surveys were conducted and all the hydrogeological data relevant for the study was collected. Geological, Geophysical and detailed hydrogeological investigations were conducted along with test drilling and pumping test program.

Five number of wells were selected for the water supply project and since 1992 the pumping was continued. The wells are still functioning smoothly. However, a groundwater level and water quality monitoring network has been introduced by the WRB in order to monitor the possible groundwater fluctuations and groundwater quality changes that might taken place during the course of pumping.

Two major environmental problems can be expected in the future with the expansion of this industrial zone. The 1 st problem would be the salinization and the 2 nd problem would be the groundwater quality changes due to activities of the factories.

Therefore, the paper will discuss the groundwater investigation criteria adopted during the study period and the findings related to groundwater occurrences in the project area and also the environmental problems that might happen in the future and the remedials that can be taken to overcome those environmental problems in order to run the project smoothly.

Introduction

The Koggala free trade zone which is one of the major BOI projects in Sri Lanka, initiated in the year 1990. under this project 12 numbers of factories were established and the supply of water was the one of the major problems encountered during the implementation of this project. During the design period it was thought to carry water from the surface water bodies through several miles long supply lines. However finally it was decided to conduct feasibility study in order to develop the groundwater potential within the free trade zone area.

Location of the project

The Koggala free trade zone is located at the Southern province of Sri Lanka (fig 1) is having an area extent of 246 km^2. It covers the coastal stretch of Koggala area, bounded by the sea to the South, Koggala lake to the North, Poloya outfall to the East and connecting the Koggala area to the mainland by a narrow land section on the Western boundary (fig 2)
.

Geomorphological and Geological features

The land mass of the project area predominantly covered by coastal sand, beach sand, lake sand and dunesand more than 3 meters above mean sea level, except the lateritic ridges of higher elevation. The South Western part of the area composed of lateritic hillocks rising over 15 meters above mean sea level. The depth to the basement floor in the region varies within the range of 15 - 20 meters. Specially in the Northern area the coastal stretch massive sand dunes, old sand dunes and terraces are clearly visible. The soils in the coastal lowlands are predominantly recent sands deposited along the shore line. In few places of the off shore area coral reefs are also visible.

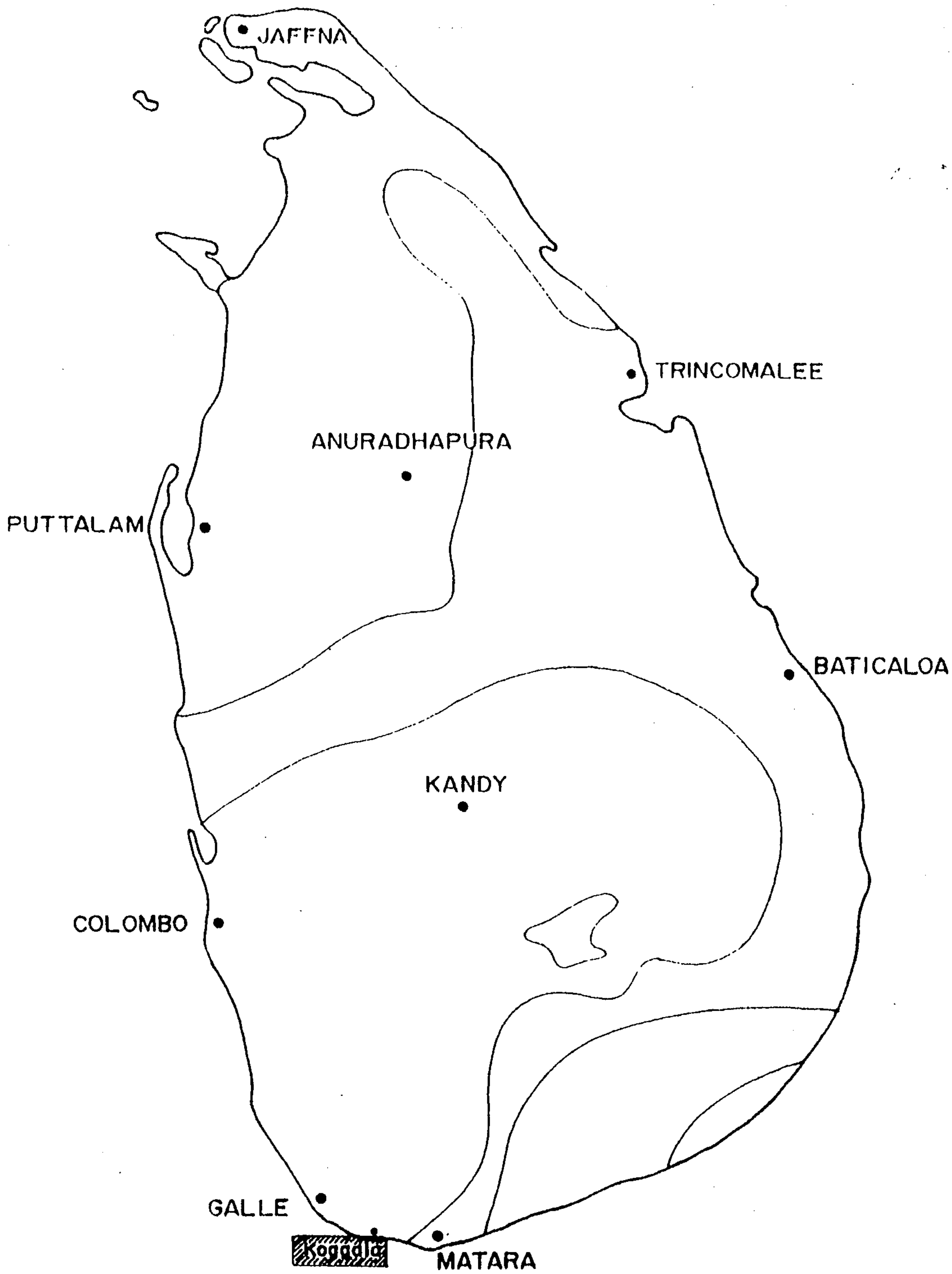
Charnockite exposures are located in some areas of the southern boarder. The sand dunes secure the regions of the project area is about 100 metres wide. Beach sands ridges are gently across the project area covering nearly 0.4 km and a prominently rising sand ridge is found along the edge of the Koggalalake(fig 3). The relief of inland areas are marked by narrow lateritic hills.

Climate

The climate of Sri Lanka is characterized by two monsoonal periods namely the South West monsoon prevailing from about April to September and the North Eastern monsoon from October to March. The project area is subjected to most of the rainfall of both monsoonal periods. The annual figures of the rainfall data for ten years (1979 - 1988) have been analyzed and it was found that the lowest rainfall experienced in the year 1983 amounting to 1572 mm . Except 1983 and 1986 the annual rainfall of rest of the years are reported well over 2000 mm.

SRI LANKA

Fig: 1



KOGGALA PROJECT AREA

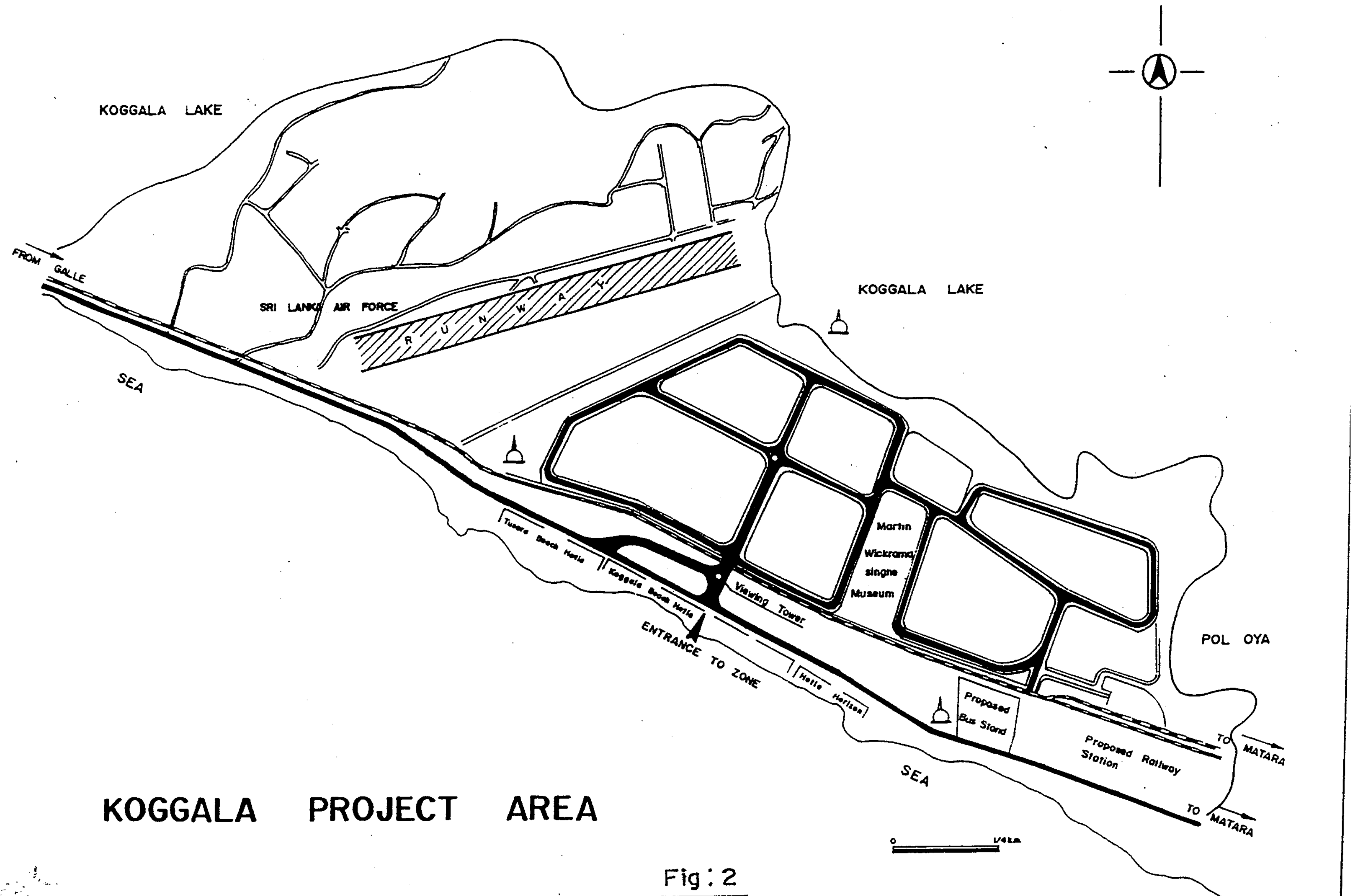


Fig : 2

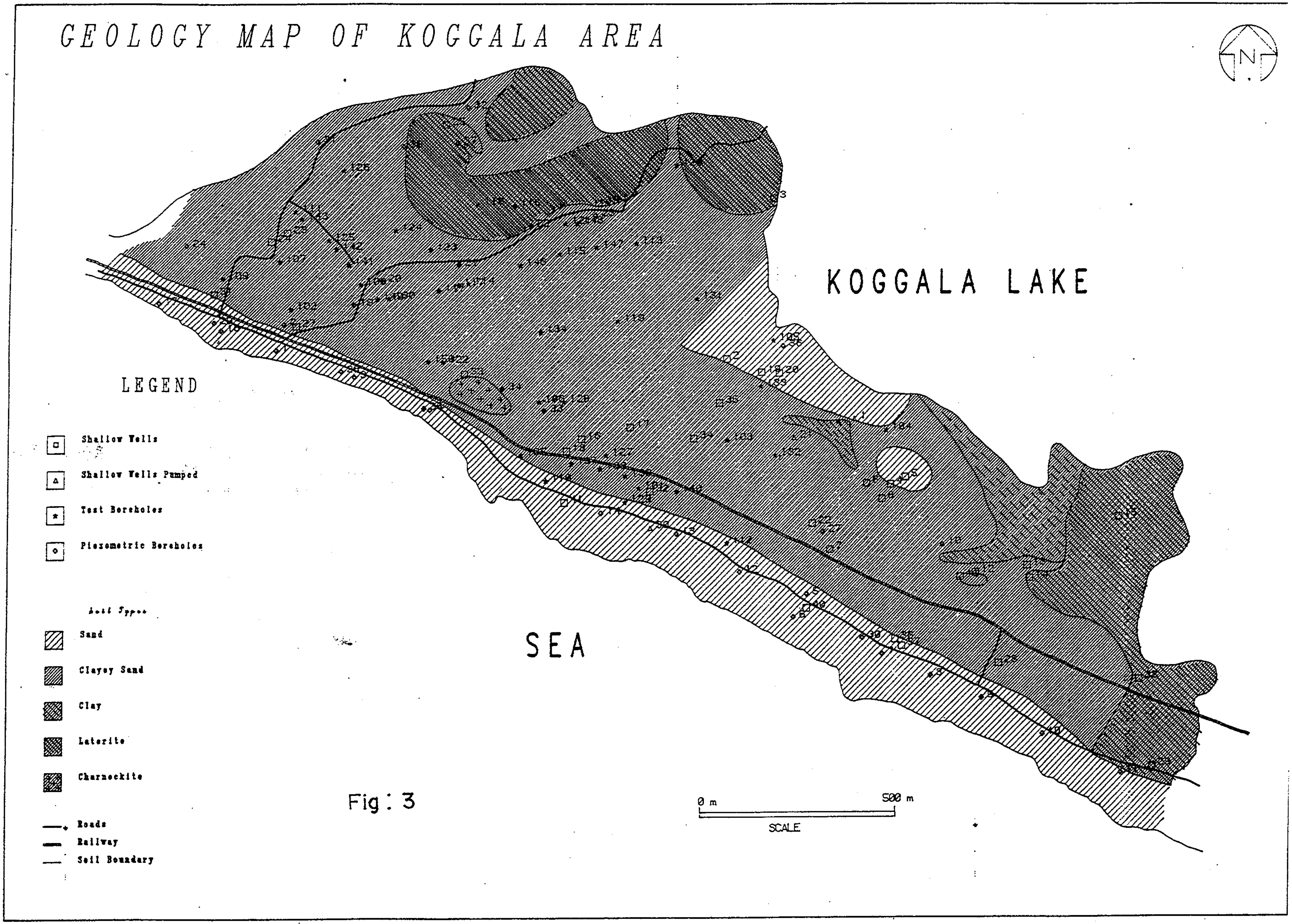

GEOLOGY MAP OF KOGGALA AREA
KOGGALA LAKE
SEA
LEGEND
Shallow Wells
Shallow Wells Pumped
Test Boreholes
Piezometric Boreholes
Soil Types
Sand
Clayey Sand
Clay
Laterite
Charnockite
Roads
Railway
Soil Boundary
0 m
500 m
SCALE
N

Fig: 3

Methodology

Prior to the surveys conducted, all the existing Geological and Hydrogeological data were collected and reviewed. The available Geological maps, Structural maps and Aerial Photographs were collected and studied in order to determine the potential areas. Once the areas are identified, Geophysical investigations were carried out adopting resistivity method. Profiling traverses were made along several directions. Based on the results of the profiling, vertical electrical soundings were conducted on selected points. All the sounding curves were analyzed.

Geophysical survey techniques

The resistivity survey method is one of the most prominent method in Geophysical survey techniques was applied for the Koggala studies. The terrameter (SAS 300) comprises a battery powered, deep penetration resistivity meter. It measures signal voltages created by the terrameter signal current.

Under the vertical electrical sounding method, a series of apparent resistivity measurements were made with expanding electrode distances.

Pumping tests were conducted on the test bore holes constructed in the project area in order to evaluate the aquifer parameters and also to determine the long term safe pumping limits of the existing aquifer system.

Water of all the bore holes were chemically tested for 17 physical and chemical parameters. Based on the analytical results chemical maps were prepared.

Results of the study

The Geophysical survey results indicated that in Koggala free trade zone area the fresh groundwater occur at shallow depth. Therefore it was suggested to drill 35 number of test bore holes and 40 piezometers for monitoring purposes. The diameter of the test bore hole was 8 inches and the diameter of the piezometer was 2 inches. During the construction period of test bore holes, perforated pvc casings were used within the water bearing zones to collect water into the bore hole.

It was observed that the electrical conductivity of water in those test bore holes were drastically changed with the depth of respective bore holes (fig 4).

Hardness and the presence of chlorides were reported within the permissible levels of the drinking water standards. However water with high concentration of iron was reported specially in the central part of the project area.

According to the survey results it was concluded that the fresh water in the Koggala free trade zone area occur at 10 metre depth, and beyond that level water is saline. It was also

Fig: 4

WATER RESOURCES BOARD

KOGGALA GROUNDWATER INVESTIGATION PROJECT

BOREHOLE No - X. 101

LOCATION - KOGGALA

GROUND LEVEL - 3.592 m

DATE - 1990.05.08

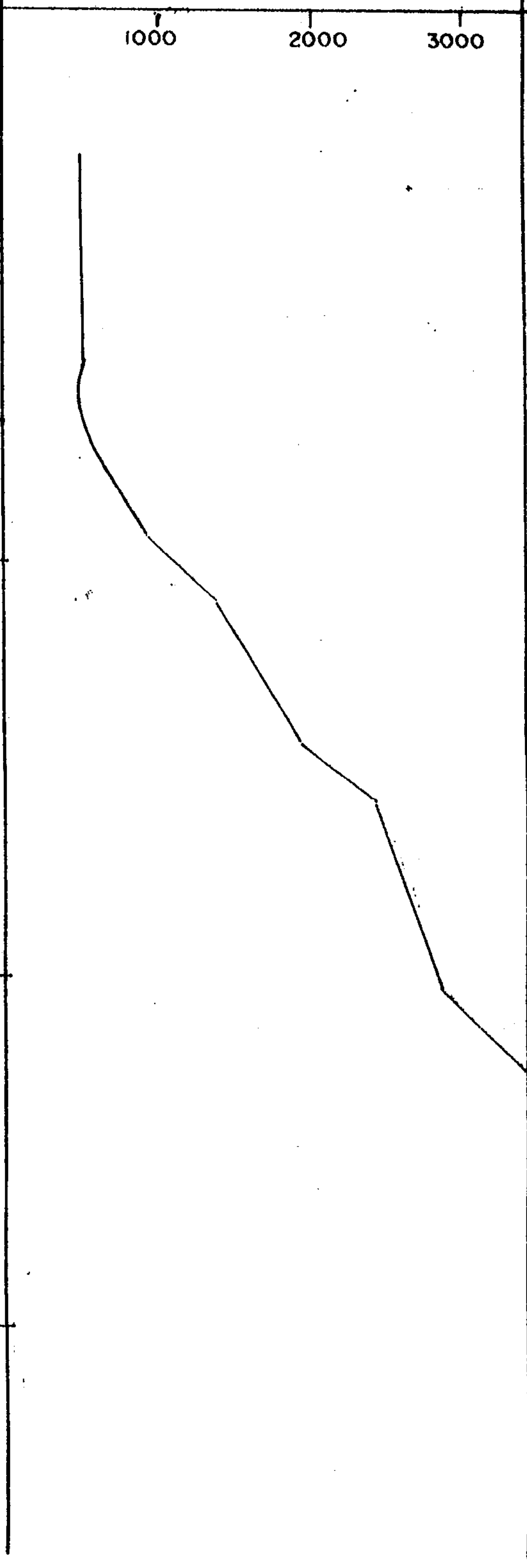
DRILLING METHOD - MUD ROTARY

ESTIMATED YIELD - 60 l.pm

WATER LEVEL - 2.78 m

DEPTH (m)	CASING DIA	LITHO LOG	DESCRIPTION
0 – 4.0	8"		Fine to medium grain sand with shell fragments
4.0 – 6.0			Medium grain Qtz / feldpathic sand absence of shell
6.0 – 8.0			Medium to coarse (less) grain sand Qtz content high.
8.0 – 14.0			Coarse grain sand Qtz. feldspar garnet (low) and fragments.
14.0 – 19.0			Highly weathered rock consisting of coarse grains Qtz feldspar garnet Biotite rock fragments.

ELECTRICAL CONDUCTIVITY



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decided groundwater in that range could be used for exploitation purposes. Finally seven number of bore holes were converted to the production wells (fig 5).

Since 1992 pumping has been started on three production wells (x -122 , x -135 , x -137) and the number of pumping wells have been increased up to six at the beginning of the year 1993 (x - 150 , x - 135 , x - 137 , x - 138 , x - 139, x - 140). The present extraction rate is 120000 g/d.

The groundwater contour map indicates a groundwater mound occur at the western part of the project area. The groundwater flow seems to be directed to the Koggala Lake and to the sea.

Environmental aspects

The Koggala project falls on the coastal belt and it composed of sand and sandy clay formations. Because of the high transmissivity values of formations there is a possibility of pollutants to get enter into the groundwater system very easily.

Two incidents were reported.

1. At the end of the year 1992 the salinity level and the cadmium level of groundwater in the production well x -122 was suddenly increased. Investigations were commenced and finally it was found that it was happened due to dumping of salt solutions, chemicals and dyes in unprotected manner. The salts and dyes were gradually entered into the groundwater system through sand and sandy clay formations and caused groundwater pollution. Finally the well had to be abandoned.

2. In late 1995 a softener plant was put-up at the project area in order to reduce the hardness of groundwater. Generally Nacl was used for cleaning the softener plant and after cleaning it, the effluents were dumped into the open ground. As a result of that the salinity levels of water in the well x - 135 was suddenly increased (fig 6) . Therefore this well had to be abandoned.

The project area covers sand, sand clay, clay laterite and charnockite rocks. The main recharge zone of the area is looking like to be the sand and sandy clay formation spreading over the area of 1.4 km^2. The sand formation covers 0.6 km^2 along the coastal belt. Those formations may provide the passage for groundwater recharge. As the groundwater flow directed outwards from the project area a considerable amount of groundwater which is originated within the project area is flowing into the sea or to the Koggala lake. But according to the information available this area has been disturbed by the present infrastructure and the recharge area is reduced by at least 30%, compare to the recharge area available at the initial stage of the project.

As the project area is located in the coastal zone the pumping rates should be managed carefully, otherwise the over pumping may cause salinization problems and also the regional groundwater depletion.

BOREHOLE LOCATIONS - KOGGALA EPZ PROJECT

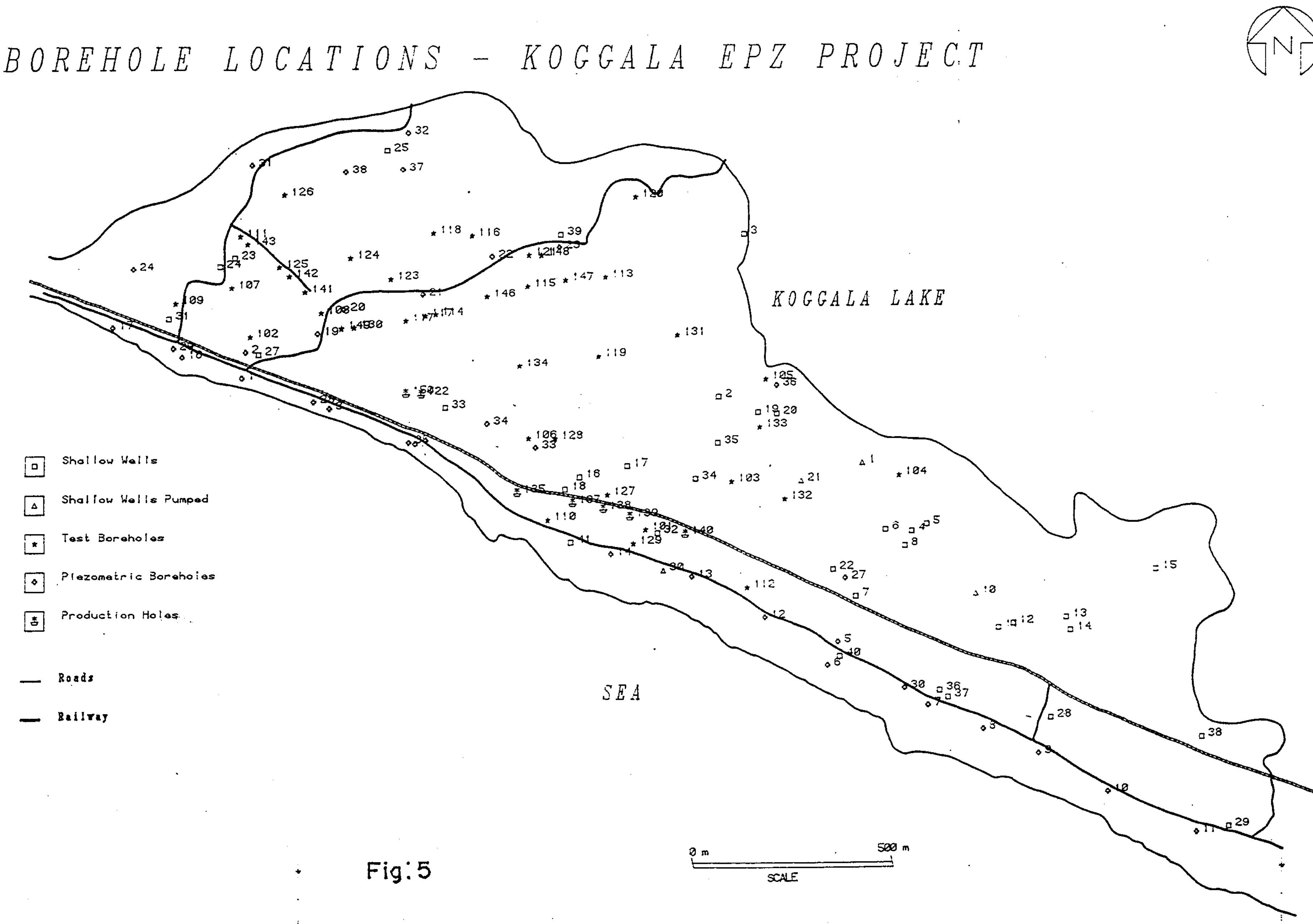
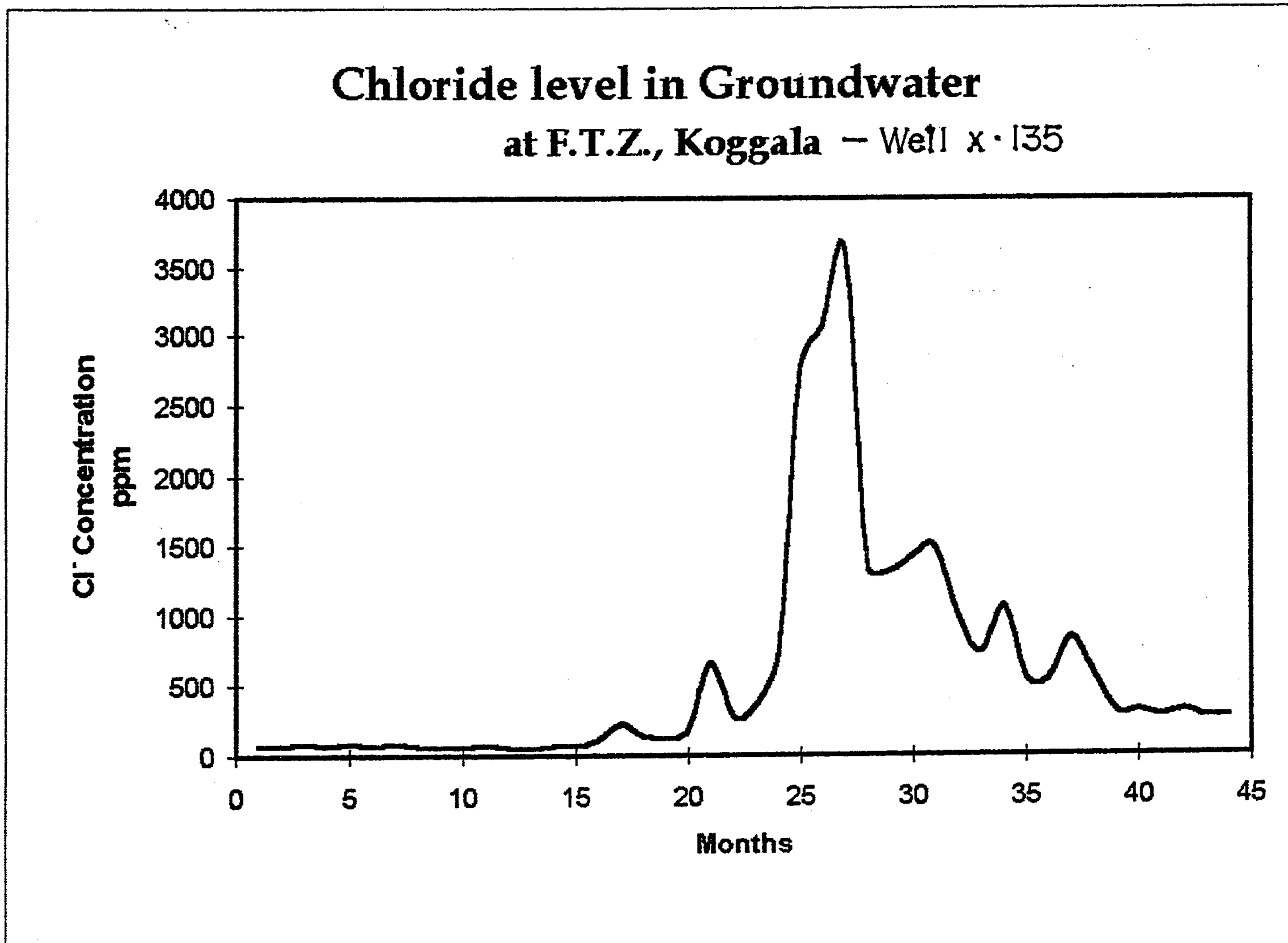


Fig: 5

Fig. 6


Chloride level in Groundwater
at F.T.Z., Koggala – Well x · 135
Cl⁻ Concentration
ppm
4000
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
40
45
Months

Conclusion

Water supply system of the Koggala free trade zone area is completely depend on the groundwater sources. Based on the results of the study it was attempted to identify the major activities that might cause environmental hazards in the Koggala free trade zone.

1. The study area is located in the coastal zone. Therefore the overextraction of groundwater may cause salinization problem.

2. As the area is composed of sand, sandy clay the tendency for polluting groundwater is relatively high. Therefore the application of various chemicals, dyes, salts and disposal of factory effluents may cause groundwater pollution chemically.

3. Unprotected sewerage system may cause bacteriological pollution.

4. Reduction of the recharge zone will cause regional groundwater depletion.

Extraction of groundwater according to the recommended limits, application of proper system for dumping the factory effluents, introduction of a proper sewerage system and protection of the recharge zone will helpful to overcome the above environmental hazards.

A Rational Approach to the Use of Limited Shallow Groundwater Supplies Within the Small Tank Cascade Systems of the North Central Province of Sri Lanka

C. R. Panabokke
Research Fellow IWMI

1. Introduction

One of the more significant developments that has taken place at a very rapid pace during the last decade has been the construction of agrowells under the numerous small tanks that are located within well defined small tank cascades. Each agrowell irrigates between 0.25 to 0.50 ha by lift irrigation during the dry yala season. The small tank cascades (STCs) range in size between 1,000 and 4,500 ha, and within each such cascade one finds between 6 to 8 small tanks of varying size. A total of 457 small tank cascades (STCs) have been identified and demarcated across nine major river basins that made up the North Central Province (NCP).

It is reported that at present there are approximately 12,500 agrowells located within the Anuradhapura District alone. The main issue at stake, however, is how many agrowells could be permitted in this region, bearing in mind that there is an upper limit to the safe exploitation of this shallow ground water resource that occurs within these cascades.

2. General Background

Groundwater occurrence in the study area can be divided into two main categories.

i. Shallow groundwater in the soil overburden and weathered rock.
ii. Deeper groundwater in the deeper fracture zones of the basement hard rock.

The nature of occurrence and the behaviour of the **shallow groundwater** in the soil overburden and saprock has been described by Panabokke (1959). As could be observed in Figure 1, this shallow groundwater level rises almost to the surface during the wet (maha) season, and this water table goes down gradually through the dry season to a very low level along the floor of the valley in this undulating landscape.

The agrowells which are usually located in the lower aspects of the landscape exploit this shallow groundwater table. In general, an agrowell has a depth of between 5 to 10 m and a diameter of around 5m. Most agrowells are dug in the soil overburden and the saprock or weathered rock, and only a very few penetrate into the fracture zones of the hard basement rock.

The deeper groundwater which is restricted to deeper joints, fractures and fissures in the underlying basement rocks, occurs at depths beyond 50m and this can be exploited only

by deeper boreholes. These are locally referred to as "tube wells", and are used mainly for domestic requirements and drinking supply wherever the quality is satisfactory.

3. Hydrology of the Tank Cascade Environment

The nature of small tank cascade systems, their general setting and their main hydrological characteristics have been adequately described by Sakthivadivel et al (1996). Some aspects of the groundwater in the cascade and the amounts of recharge that take place have also been discussed in the same publication.

It is observed that the shallow groundwater is mainly confined to a narrow belt along the main valley of each cascade, and to a smaller extent along the side valley of the cascade. This is shown schematically in Figure 2. Because this shallow groundwater is confined to a specific landscape position within a cascade of small tanks, the seepage from small tanks help to recharge and augment the shallow groundwater aquifer. In the study area it was observed that almost all agrowells are distributed around the small tanks situated within the cascade.

All agrowells that were studied in this survey could be grouped into three categories as follows:

- i. Agrowells in the upper cascade catchment area.
- ii. Agrowells in the intermediate mid-cascade catchment area.
- iii. Agrowells in the lower reaches of the cascade area.

In general, it is observed that around 20 percent of agrowells are located in the upper catchment area, 40 percent in the intermediate mid-cascade area, and 20 percent in the lower reaches of the cascade area.

During pumping, agrowells showed a varied drawdown and recovery rates. Those in category 1, showed a drawdown of 1m/h and a recovery time of 2 days; and those in category 2 showed a drawdown of 0.8m/h and a recovery time of 1 day; and those in category 3 showed a drawdown of 0.7m/h and a recovery time of 1 day. Agrowells located close to irrigation channels and below small tanks show a quicker recovery time.

What time of the Yr.? (wet or Dry)

Although the siting of most of the already functioning agrowells have not been made by using scientific methods, several of the groundwater potential areas had been identified by the indigenous knowledge of villagers. These are based largely on geomorphological relationships that could be easily observed in the field.

4. Methodology

The following five step procedure was adopted in the field studies.

i. Plotting available data on 1:50,000 scale cascade maps.
ii. Demarcating potential areas for shallow groundwater extraction in each cascade based on geomorphological characteristics.
iii. Field checking of well data plotted on 1:50,000 scale maps.
iv. Field checking of potential areas and existing agrowells and their performance.
v. Confirmation of groundwater potential in predicted areas (where agrowells are not present) by means of electrical resistivity and light drilling surveys.

The fracture zones and lithological strike lines were drawn on the cascade maps in order to demarcate the potential areas for agrowells. It was also observed that the underlying rock at the soil-rock interface is very highly weathered, and that the lower level of this weathered zone is highly fractured. The transsmissivity in this fractured weathered rock is very high and it forms a very effective pathway for groundwater flow to take place.

In the field studies, geophysical surveys were employed to verify the results of the geomorphological and topographic interpretation, especially in those instances where the presence of water is not indicated on the ground, but where farmers had requested the siting of agrowells based on their own understandings (Senaratne 1996).

Geophysical surveys were conducted at locations where there were no previously constructed agrowells. The resistivity data obtained from the soundings were analyzed using RESLXS, a special software developed by the ITC of Netherlands (Senaratne 1996).

A total of 50 cascades spread across 12 Divisional Secretariat Divisions (DSS) distributed across the Anuradhapura district of the North Central Province were studied by the foregoing method, and the potential area for location of agrowells were demarcated in each of these 50 cascades on maps of scale 1:50,000.

5. Determination of Number of Agrowells within a Cascade

In order to determine the number of agrowells that could be constructed within a cascade the following assumptions have been made.

i. A cascade is a closed system.
ii. Water contribution to a cascade is only through rainfall.
iii. Water loss from a cascade is only through evapotranspiration, tank evaporation and surface and underground outflow.

Using the following relationship

Rainfall - Evapotranspiration = Tank Retention + Groundwater Flow + Surface Flow + Soil Saturation,

the groundwater availability in a cascade is calculated.

The potential recharge per agrowell is estimated assuming a depth to water table of 4m; maximum depth of agrowell as 7m; and a 50 percent volume of underground storage is extractable in order to satisfy environmental requirements (Senaratne 1996).

6. Results and Discussion

Based on the foregoing methodology the number of agrowells recommended in respect of the 50 cascades which are spread across 15 DS Divisions are shown in Table 1.

It could be observed that in three cascades more than 150 agrowells are recommended per cascade; and that in 18 cascades less than 150 but more than 100 agrowells are recommended per cascade; and that in 13 cascades less than 100 but more than 50 agrowells are recommended; and that in 7 cascades less than 50 agrowells are recommended. For the remaining 9 cascades no agrowells are recommended.

Of these nine cascades, there are five in which the number of agrowells has already exceeded the upper critical limit. Since this can give rise to serious environmental hazards, timely action should be taken from now on to limit any further expansion of agrowell construction in this region. In sum, the upper limit of the total number of agrowells that could be safely accommodated within the 50 cascades is approximately 3,600. Although it is estimated that at present there are a total of approximately 12,500 agrowells distributed across 457 cascades in the NCP, it does not necessarily follow that each of these cascades could support an average of 72 agrowells per each cascade. There are some cascades in the drier regions that could support only a few or no agrowells, while those in the better hydrologically endowed areas could support more agrowells. Thus a variable density based on the degree of hydrological endowment is recommended as a rational approach.

References

Panabokke, C. R. 1959. A study of some soils in the dry zone of Ceylon. Soil Sci. 87: 67-74.

Sakthivadivel, R.; Panabokke, C. R. and N. Fernando. 1996. Nature of small tank cascade systems. IIMI Country Paper No. 13.

Senaratne, Athula. 1996. Use of groundwater in the NCP. Consultancy Report to IIMI.

A Rational Approach to the Use of Limited Shallow Groundwater Supplies Within the Small Tank Cascade Systems of the North Central Province of Sri Lanka

C. R. Panabokke
Research Fellow IWMI

SUMMARY

The shallow groundwater in this region occurs mainly within a narrow belt along the main valleys of a cascade, and to a lesser extent along its side valleys. Agrowells within this study area could be grouped into three broad categories according to their position in the upper, mid- and lower aspects respectively of a cascade valley. A procedure for determining the maximum number of agrowells that could be permitted within a cascade has been briefly outlined. It is estimated that within the selected 50 cascades studied, the maximum total number of agrowells that could be permitted is 3,600; and that within five of these fifty cascades studied, the permitted upper limit has already been exceeded.

Table 1

Number of Agrowells Recommended for each Cascade

DS Division	Cascade Name and Number	Cascade Area ha (A)	Recommended Number of Agrowells
PADAWIYA	1 NAWAGASWEWA	299	32
KEBITHIGOLLEWA	2 KUNCHUTTUWA	1671	116
	3 KOLIBENDAWEWA	2565	65
	4 THAMMANNEWA	1451	140
	5 USGOLLEWA	701	165
MEDAWACHCHIYA	6 MAKICHCHAWA	2816	10
	7 MURUTHAMADU	4226	-
	8 PARANAHALMILLEWA	3750	-
	9 KONGOLLEWA	1643	117
NUWARAGAMPALATHA CENTRAL	10 TAMMANNEWA	1835	90
	11 GALPOTTEGAMA	1778	106
	12 GALKADAWALA	1044	122
	13 BELLANKADAWALA	1451	99
MAHAWILACHCHIYA	14 DUNUMADALAWA	782	108
	15 SANDAMAELIYA	1938	-
RAJANGANA	16 IHALA THAMMENNAWA	299	107
NUWARAGAMPALATHA EAST	17 KUDAKALETHTHEWA	1308	82
MIHINTALE	18 UKKULANKULAMA	2020	102
	19 MAHAKIRINDEGAMA	1483	91
	20 KATUPOTHA	1064	165
	21 MANKULAM	1225	70
	22 MAHA RAMBAWA	749	115
RAMBEWA	23 KAPIRIGAMA	2321	102
	24 PIHIMBIYAGOLLEWA	3425	-
	25 KENDAWA	1204	104
KAHATAGASDIGILIYA	26 HAMMILLEWA	2869	18
	27 RANPATHWILA	3137	-
	28 GANGUREWA	3141	-
	29 MAHAKIRIMETIYAWA	2393	39
	30 PANDARELLEWA	2654	38
	31 NELLUGOLLEKADA	2762	72
HOROWPATHANA	32 DUTUWEWA	2328	117
	33 PULIYANKADAWALA	2430	71
	34 DEMATAWEWA	2678	38
	35 DIYATITITHTHA WEWA	3241	91
GALENBINDUNUWEWA	36 CHCHANKULAMA	1022	145
	37 HIMBUTUGOLLEWA	2421	1
	38 SIVALAKULAMA	2204	60
	39 KARUWALAGASWEWA	545	151
	40 TAMMANNEWA	135	126
	41 DIWULWEWA	2375	87
THIRIPPANE	42 MAHAKANAMULLA	4494	-
	42 ULAGALLA	4918	-
	44 PAHALA AMABATALE WEWA	1601	96
	45 WANNAKKULAMA	998	113
PALUGASWEWA	46 MAHADIWULWEWA	2054	72
	47 PALUGASWEWA	1860	113
	48 WERAGALA	898	112
PALAGALA	49 HALMILLEWA	933	109
	50 MEEGASWEWA	4421	-

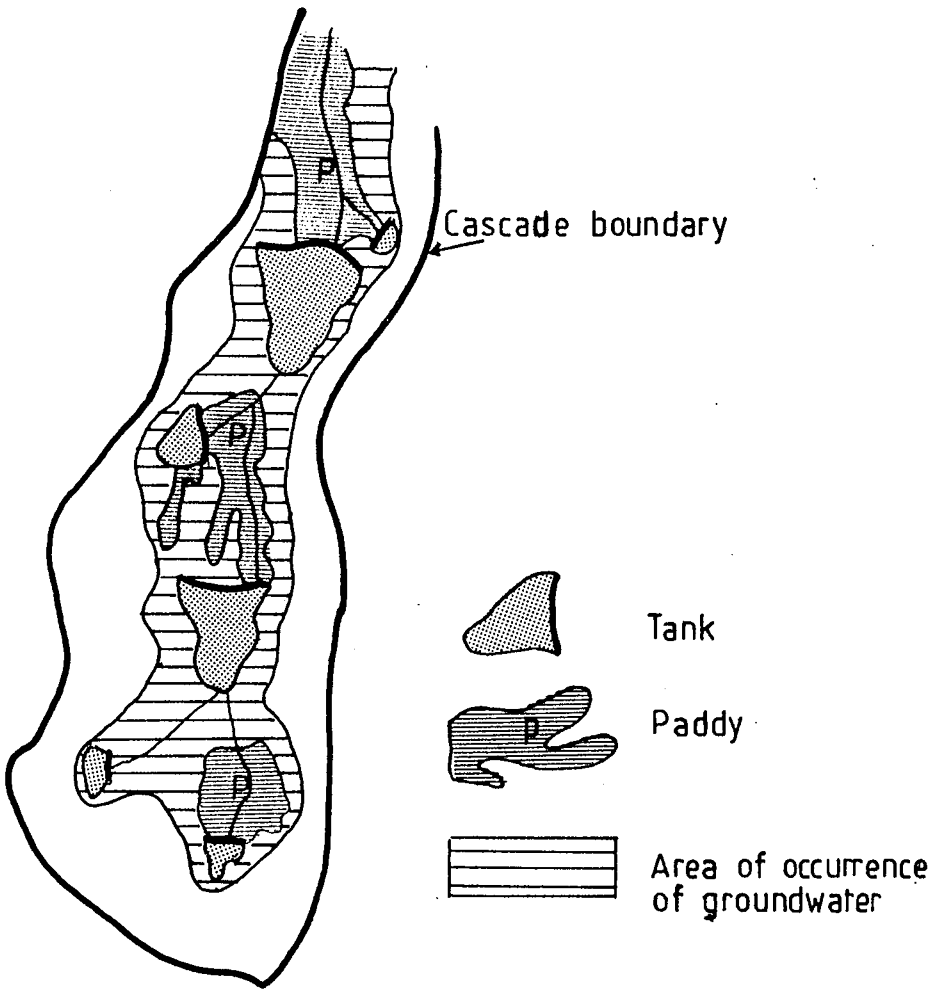


Figure.2. Schematic Representation of Groundwater area within a Cascade

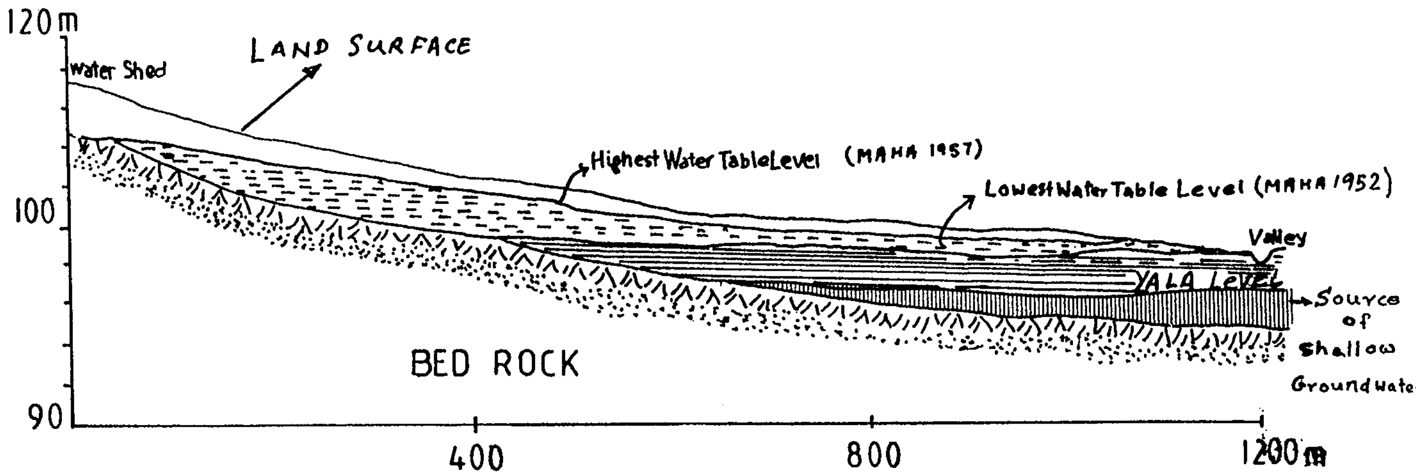


Fig.1 Ground-water table behavior Maha-illuppallama (1950-1960)

NATIONAL WATER CONFERENCE
Nov. 4-6, 1998
BMICH, Colombo Sri Lanka

RESEARCH PAPERS PRESENTED

Session No.23 6 November 1998 *11:00 a.m.*

Water Management Research Needs

Paper No.76
de Alwis, Dharmasiri
Need For Water Research During Planning Of Rural Integrated Development Projects - Based On Lessons Learned In Mahaweli Ganga Development Scheme

Paper No.77
Kurukulasuriya, Mahinda
Some Promising Research Fields For Sustainable Water Resources Development

Paper No.98
Gunawardena, E.R.N.
Assessing The Impact Of Land Use Conversions On Water Demand: A Pre-Requisite For The Formulation Of Policy For Water Allocation

NEED FOR WATER RESEARCH DURING PLANNING OF RURAL INTEGRATED DEVELOPMENT PROJECTS- BASED ON LESSONS LEARNED IN MAHAWELI GANGA DEVELOPMENT SCHEME

Eng. DHARMASIRI DE ALWIS

MECA
MAHAWELI AUTHORITY OF SRI LANKA
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ABSTRACT

The purpose of this paper is to demonstrate that research for both irrigation and potable water should necessarily be an integral part of initial planning, particularly in the case of rural integrated development projects. Mahaweli Ganga Development Scheme (MGDS) has been the centerpiece of the public investment programme since 1970. The development areas under MGDS are called systems, and they are scattered over the dry zone. The thirteen systems are identified as A,B,C, ... K,L, M. The independent project areas, which have been developed so far to receive the water resources of Mahaweli ad its adjacent basins are System-H, System-C, System-G, System- B and System-L.

All functions related to resource management within a system, are made to take place in the following environments.
(a) Terrestrial Environment (b) Aquatic Environment (c) Human Environment

The basic facility that is most essential in a Mahaweli System is irrigation infrastructure. Therefore, quality of irrigation water is of paramount importance. Several water samples taken from a number of sources such as, rivers, streams, reservoirs, ground wells, etc. located over the Systems implemented so far had been tested before the development activities got underway. The findings of such testing, it is reported, had been favourable for both agriculture and human consumption. However, the quality of water available in the areas in question, during operation of the system for agricultural production, has been found, to be contaminated with bacteria, toxic metals, salt and iron at least at some locations . A notable feature characterised in the minor reservoirs particularly as a post implementation result is eutrophication due to high nutrient loadings in the water.

The settlement planning of the villages and their homesteads is such, each settler would have a ground well in their homesteads, in addition to a few community wells in each village, as a public amenity. These community wells are either ground wells or tube wells.

As a policy in the Mahaweli Systems, a township is provided with a full fledged drinking water supply scheme. An Area Centre, which is also an Urban Centre, but much below the level of a township, in respect of civic amenities, is also provided with a water supply scheme, catering to the facilities in the Centre only. In designing a water supply scheme, the water source is tested for physical, chemical and biological characteristics. Very often, the water is tested, long before the actual activities of irrigated agriculture get underway.

The changes that would take place in a System, when the land within is augmented with regulated or diverted water are too numerous. One such change is the increase in water spread area or the creation of water bodies. In other words, the land use changes would cause various effects on surface water in the watershed.

The impacts and implications of integrated rural development, therefore centered around humans, water and land. The consequences included both benefits and detrimental effects to the natural environment and the man himself. Since the impacts caused by the water and the land uses are of serious concern, intensive research during planning is of vital importance, to derive the desired benefits of the project.

(1.0) MAHAWELI GANGA DEVELOPMENT SCHEME

Mahaweli Ganga Development Scheme (MGDS) has been the largest multipurpose water resources development project ever undertaken in this country. The MGDS was implemented in the year 1970 attaching very high priority by the government of Sri Lanka.

The river Mahaweli which originates from the hill country is the largest river in Sri Lanka and it drains more than 16% of the land surface of the island. It also carries approximately one seventh of the total annual run-off of all the rivers in Sri Lanka.

The development areas under the MGDS are called systems and they are scattered in the dry zone. There are thirteen systems, which are identified as, A,B,C,D.......K,L and M.

(1.1) MAHAWELI SYSTEMS AND INTEGRATED DEVELOPMENT

The cardinal concept adopted in transferring the Systems, H,G,C,B and L into irrigated agriculture based on human settlement is the "Integrated Rural Development Approach". In the planning process, this concept has been enshrined in the development strategy of each system with the integration of the following environments.

(i) Terrestrial Environment
(ii) Aquatic Environment
(iii) Human Environment

SEE DIAGRAM: SYSTEMS APPROACH TO INTEGRATED DEVELOPMENT

The physical infrastructure that have been determined in compliance with the approved policies of the MGDS can be divided into Irrigation Infrastructure and Social Infrastructure basically.

IRRIGATION INFRASTRUCTURE
Reservoirs
Canals
Drainages
Ditches
Streams
Farm lots etc.

SEE DIAGRAM: PHYSICAL COMPONENTS OF IRRIGATION SYSTEM

SOCIAL INFRASTRUCTURE
Roads
Electricity
Telecommunication
Drinking water supply
Sewerage

Homesteads
Recreational facilities etc.

In the provision of both irrigation and social infrastructure, the fundamental resource, that should necessarily be available is surface water. In planning the irrigation infrastructure, which takes precedence over the other, a necessary condition that must be satisfied is the quality of irrigation water, which would be available in the Reservoirs, Canals and the Drainages eventually and during operation it should be suitable for irrigated agriculture.

(2.0) AUGMENTATION OF BASINS WITH MAHAWELI WATERS

The water flow in the Mahaweli river is diverted at several places in augmenting several other basins.

(a) System - H was the maiden area which was transformed into irrigated agriculture, with the augmentation of the Kala Oya basin with Mahaweli waters. This system has been in operation since 1976.
(b) Elahera-Minneriya Yoda Ela (EMYE) is the feeder canal which releases water to System-G. The EMYE takes off from Amban ganga which is the main tributary of Mahaweli Ganga. System-G comprises the old area and the new area. The latter received irrigation in 1987 or so.
(c) System-C was in the Accelerated Mahaweli Development Programme and the farm allotments have been receiving irrigation water from early 1980's. The full irrigable area was in operation by 1992 or so. System-C is in the Mahaweli basin and the area is augmented by a transbasin canal taking off from the river-Mahaweli at Minipe.
(d) Maduru Oya was the first adjacent basin, to be augmented by Mahaweli waters by means of the Minipe Transbasin canal which carries water to Maduru Oya Reservoir from Mahaweli. System-B is the command area of Maduru Oya Reservoir. The left bank of Maduru Oya within System-B has been under irrigated agriculture since 1985.
(e) Compared to the Systems H,G,C and B, System-L has still not received Mahaweli waters. However, it is an independent basin, part of it is commanded by the Padaviya Reservoir. A relatively small area on the left bank of Ma-Oya is under irrigated agriculture since 1985, with the help of several minor reservoirs in cascade. Therefore, use of return flows is the cardinal principle adopted in the area referred to.

The table shown below explains the incorporation of water bodies into the irrigation network in each System, while highlighting the area occupied by water on a unit area basis.

SEE TABLE: WATER BODIES AND IRRIGATION SYSTEM IN OPERATION

(3.0) CIVIC AMENITIES, UTILITIES AND SERVICES

The "Human Environment" in these systems is made up of the settlement areas, Hamlets, Village Centres and Urban areas. The hierarchy of the settlement areas and the urban areas are shown in the figure produced below.

SEE DIAGRAM: DISTRIBUTION OF SETTLEMENT AREAS, VILLAGES AND URBAN CENTRES IN A SYSTEM

In each of these "Settlement Centres" the most important natural resource is potable water. As a policy, for domestic uses and drinking water, facilities planned or assistance given to settlers in establishing both community and domestic water sources is as described below.

(a) Hamlet Centre	-	Community Well
Homesteads	-	Ground Well in each homestead
(b) Village Centre	-	Community Well
Homesteads	-	Ground Well in each homestead
(c) Area Centre	-	Water Supply Scheme treated / untreated.
Homesteads	-	Pipe-borne water, Individual Ground wells or community wells
(d) Town Centre	-	Water Supply Scheme with treated water.
Homesteads	-	Treated pipe-borne water.

SEE TABLE: PRESENT STATUS OF DRINKING WATER FACILITIES

It is quite clear, according to the data related to the drinking water facilities available in these systems, that even after one or two decades of operation, one of the most essential services is not in place to facilitate growth of urban centres. Following are some requirements which have not been considered during initial planning.

(a) Availability of a reliable water source in close proximity to urban centre
(b) Suitability of water, when available under irrigated agriculture
(c) Uninterrupted augmentation of source reservoir
(d) Issue of water for both irrigation and drinking water from the reservoir
(e) Social background and cultural practices of consumers (settlers)
(f) Inappropriate design
(g) Poor operation and maintenance

The inference therefore would be, that the availability of adequate supply of drinking water has to be ensured during planning, of infrastructure.

(4.0) DEVELOPMENT OF HOMESTEADS

The extent of a homestead in a Hamlet is 0.20 Ha. and the number of homesteads in a hamlet is generally in the range 200 - 300 except in System - H, in which the range is 100 - 150.

There are three fundamental facilities that should be installed by the settlers in their homesteads. They are, a House, a Latrine and a ground (dug) well. The table produced below shows the status of these three physical facilities in four systems.

SEE TABLE : SETTLERS AND WATER RELATED FACILITIES

According to the data, the situation in System - G is very poor. Despite a two decade operation of System - H, availability of Latrines and ground wells is very unsatisfactory. Drinking water sources are concerned, all four systems have not come upto the expectations.

However, there are very significant deficiencies in the land, attributing to unhygenic factors in respect of drinking water. A few notable factors are,

(a) Presence of Flouride in excess of permissible limits
(b) Excessive hardness
(c) Underlying hard layer of earth below top soil
(d) Low water table
(e) Easy access to canal water

(5.0) <u>APPLICATION OF AGRO-CHEMICALS (FERTILIZERS, WEEDICIDES, INSECTICIDES)</u>

(5.1) <u>ENVIRONMENTAL CONCERNS</u>

In general, the problems that could commonly occur with irrigation supplies are,

(i) association of high levels of salinity, and
(ii) high proportion of Sodium.

Due to salinity (accumulation of salt in the root zone) reduction in yields can result. The upward movement of water and salts from the groundwater also can cause salinity problems, if the water table is shallow.

Similarly, a high level of Sodium in comparison with other ions such as Calcium, Magnesium and Bicarbonate can result in the formation of alkaline soils with very low permeability.

According to the findings in the Environmental Assessment (Vol.III), Tams, 1980 the quality of waters of the Mahaweli Ganga, Kotmale Oya, Amban Ganga which are tributaries of the largest river, and the Maduru Oya in an adjacent basin were highly suitable for irrigation purposes. The quality of water in the Reservoirs and the Villus was also suitable for most irrigation purposes. Furthermore it confirms both ground water and surface water as suitable for drinking water for livestock. The suitability of surface water as suitable for drinking water for livestock. The suitability of surface water was however limited for swimming, bathing, washing and other related domestic uses. The suitability of well waters for human consumption had not been confirmed, as verification needed in respect of californ bacteria, metal toxicity etc.
TDS < 500 mg/l (Equivalent to a conductivity of about 700 mocromhos/cm)
The suitability of well water in System-C had been doubted according to these results.
The surface waters in the System under consideration had exhibited quality above standards, as far as fish faunas are concerned. For the protection of aquatic organisms the Iron level is 1.0 mg/litre.

For pest control, chlorinated pesticides including DDT, BHC, Heptachlor, Endrin, Aladin and Dieldrin had been used in Sri Lanka until mid 70's. According to TAMS (1979) the concentration of pesticides had been very high, especially DDT, exceeding mortality levels threshold for some aquatic organisms.

Most of the reservoirs, particularly the smaller were characterized as eutrophic systems with high nutrient (phospate) loadings. These water bodies had extensive algae and aquatic weed growths. It should be emphasized that eutrophic waters are highly productive and they are desirable for the development of inland fisheries.

An Environmental Evaluation of the Accelerated Mahaweli Program (AMDP) was carried out by the USAID in 1992/1993 based on the impacts envisaged in the TAMS Report, (1980). Listed below are some excerpts from the Evaluation Report of the consultants.

(5.2) ADVERSE EFFECTS

(a) Chemical inputs to agricultural systems in the upper and lower catchment areas are degrading surface and ground water quality.
Studies conducted within specific systems do indicate a very high use of agrochemicals. Fertilizer use has probably contributed to the very evident algae blooms in drainage canals, as well as extensive Salvinia growth on the water surface of reservoirs. This eutroprication is partly responsible for some loss of habitat for fish.
It is estimated that less than one percent of farmers even resort to use of gramaxone. The usual response by farmers to insect problems is repeated applications of a variety of chemicals throughout the growth period.

(b) Poor water management practices in irrigated areas, have increased the threat of soil salinization and soil losses.
Salinity levels in System-H appears to be more common in localized patches. These levels are likely to be aggravated during dry spells and reduced during rainy seasons.

(c) AMDP has been cited as a leading cause of the increase in the occurrence of Malaria in general. Data clearly show that the spread of Malaria re-activated during the commencement of AMDP. This is mainly due to,

Standing water in newly developed reservoirs, irrigation canals, and on-farm fields provides an excellent habitat for breeding mosquito vectors.

SEE TABLE: FERTILIZER USAGE IN METRIC TONS

(6.0) AGRICULTURAL PRODUCTION

Development of agriculture is one of the principal aims of the MGDS/AMDP. The other is community development, which includes, education, health, recreation etc. of settlers. The Table and the Diagram produced below confirms that in terms of crop yields, investment on Mahaweli Systems is justified. Also, it is a fact that the potential is available for increase of crop yields further.

SEE DIAGRAM: AGRICULTURAL PRODUCTION

However, it has to be emphasised that the increase in agricultural production should not be at the expense of community development. Particularly the environmental issues, which have a direct bearing on the welfare and the wellbeing of the settlers and their physical environment should be addressed appropriately and their adverse impacts mitigated adequately.

(7.0) CONCERNS AND SUGGESTIONS

(7.1) Establishment of a National Water Research Centre

(7.2) Minimising, managing toxin measurement by means of nutrient management strategies, flow management and destratfication

(7.3) Algal toxins – Safe levels in water for various uses

(7.4) Health assessment – Identify appropriate pollutant loads from urban and rural sources

(7.5) Implications of hydrological changes

(7.6) Salinity – Ecological damage

(7.7) Pesticides - Ecological impacts of chemicals and food chains. Need to develop restoration strategies for contaminated waterways.

(7.8) Riparian Area Management – Nutrient and energy to acquatic ecosystem.

(7.9) Restoration and Rehabilitation of Aquatic Systems

(7.10) Multidisciplinary Collaboration on issues and research

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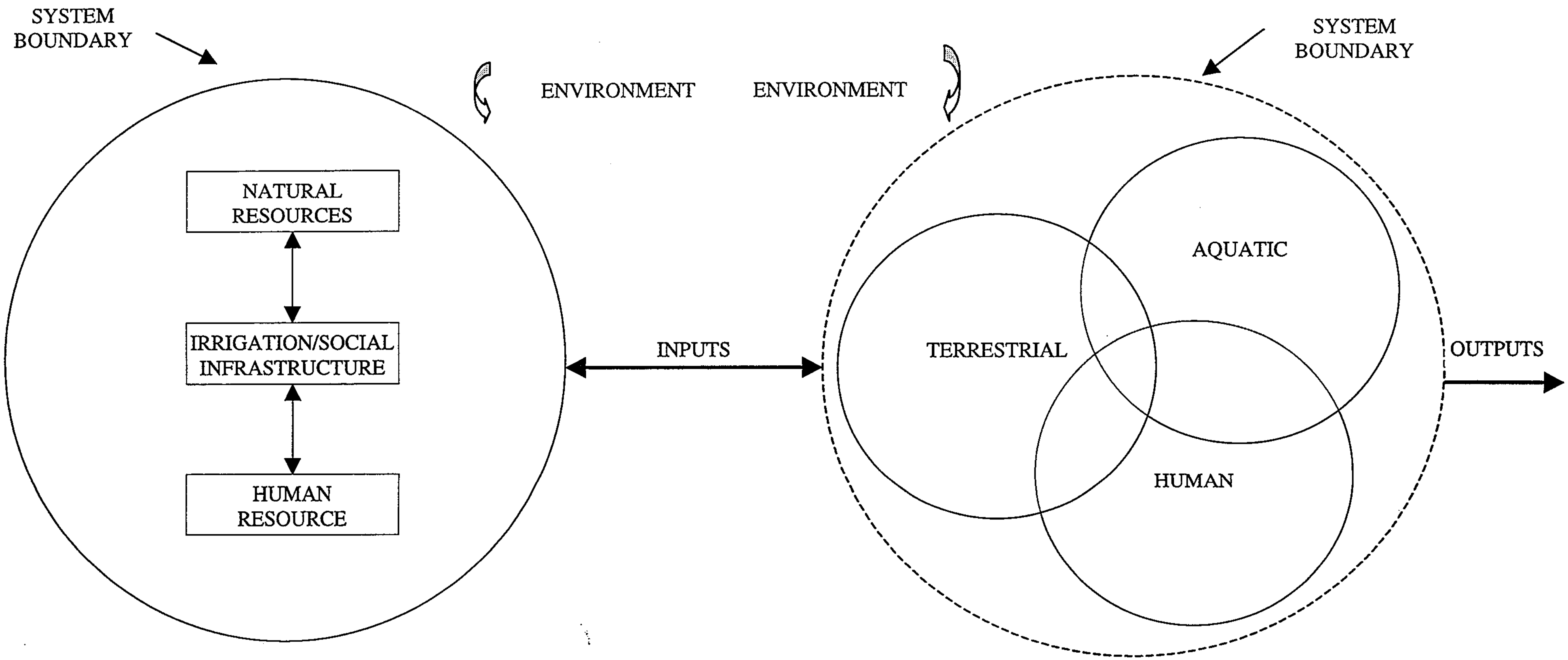
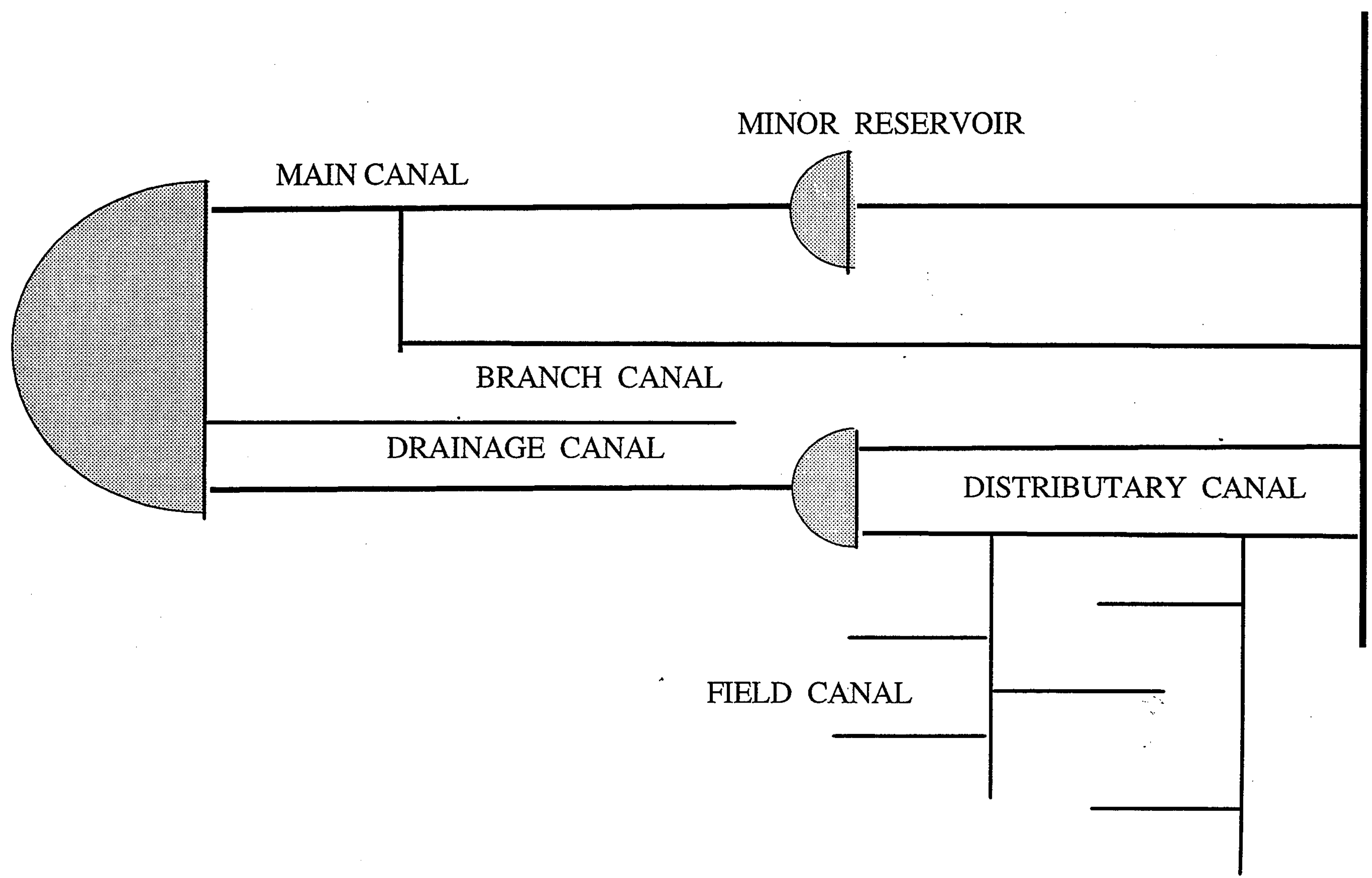
SYSTEMS APPROACH TO INTEGRATED DEVELOPMENT



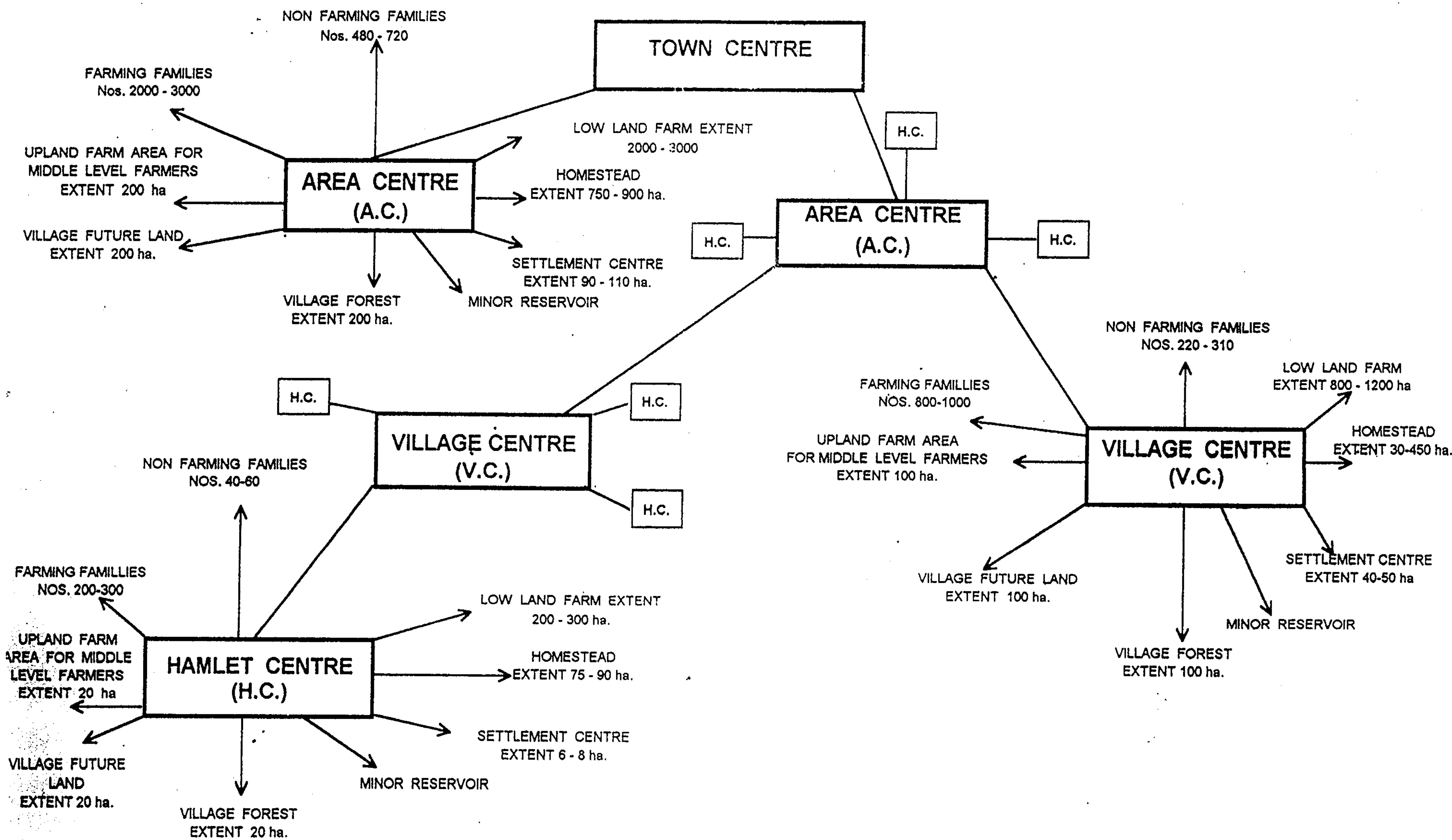
PHYSICAL COMPONENTS OF IRRIGATION SYSTEM



WATER BODIES AND IRRIGATION SYSTEM IN OPERATION

System	Gross Area (Ha)	Farm Area (Ha)	Settler Families (No)	Canals (km)					Total Canal Length/ Gross Area m/Ha	Medium/Minor Reservoirs
				Main	Branch	Distributary	Field	Drainage		
System-H	75,000	31,759	31,000	152	100	660	1,505	2,250	62.2	76
System-G	10,524	5,400	4,585	32	5	89	281	420	78.6	-
System-C	67,950	27,843	21,039	92	98	552	1,275	1,920	57.9	56
System-B	75,640	26,681	18,795	53	72	602	1,536	2,300	60.3	85
System-L	163,000	39,029	1,700	-	-	12	10	36	-	17
Total	*392,114*	*130,712*	*77,119*	*329*	*275*	*1,915*	*4,607*	*6,926*	*64.8*	*234*

DISTRIBUTION OF SETTLEMENT AREAS, VILLAGES AND URBAN CENTRES IN A SYSTEM



PRESENT STATUS OF DRINKING WATER FACILITIES

SYSTEM-H

URBAN CENTRE	SOURCE	WATER SUPPLY SCHEME			
		Function	Supply	Treatment	Management
Thambuttegama T/C	M.R.	Operational	Inadequate	Purified	NWSDB
Galnewa T/C	Well	Operational	Adequate	Purified	L.Authority
Nochchiyagam T/C	M.R	Operational	Adequate	Purified	L.Authority
Eppawal T/C	M.R	Operational	Adequate	Purified	L.Authority
Meegalewa T/C	-	-	-	-	-
Madatugama	-	-	-	-	-
Galkiriyagama T/C	Well	Non Operational	-	-	-
Talawa T/C	-	-	-	-	-
Aukana T/C	-	-	-	-	-
Kekirawa T/C	M.R	Operational	Adequate	Purified	NWSDB
Dambulla T/C	River	Operational	Adequate	Purified	NWSDB
Bulnewa T/C	Well	Operational	Adequate	Purified	L.Authority

SYSTEM-G

URBAN CENTRE	SOURCE	WATER SUPPLY SCHEME			
		Function	Supply	Treatment	Management
Bakamuna T/C	EMYE	Operational	Adequate	Purified	MASL
Attanakadawala V/C	-	-	-	-	-

SYSTEM-C

URBAN CENTRE	SOURCE	WATER SUPPLY SCHEME			
		Function	Supply	Treatment	Management
Dehiattakandiya T/C	River	Operational	Adequate	Purified	MASL
Girandurukotte T/C	MR	Operational	Adequate	Purified	MASL
Batalaya A/C	MR	Operational	Adequate	Purified	MASL
Medagama A/C	MR	Operational	Adequate	Purified	MASL
Sandunpura A/C	MR	Operational	Adequate	Purified	MASL
Lihiniyagama A/C	MR	Operational	Adequate	Purified	MASL
Siripura A/C	MR	Operational	Adequate	Purified	MASL
Mahawanawela A/C	MR	Operational	Adequate	Purified	MASL
Veheragala A/C	MR	Operational	Adequate	Purified	MASL
Nuwaragala A/C	MR	Operational	Adequate	Purified	MASL

SYSTEM-B

URBAN CENTRE	SOURCE	WATER SUPPLY SCHEME			
		Function	Supply	Treatment	Management
Welikanda T/C	MR	under Construction	-	-	-
Aralaganwila T/C	MR	Operational	Inadequate	Purified	MASL
Manampitiya T/C	MR	under Construction	-	-	-
Siddhapura T/C	-	-	-	-	-
Damminna A/C	MR	Operational	Adequate	Purified	MASL
Wijayabapura A/C	-	-	-	-	
Ellewewa A/C	MR	Operational	Adequate	Purified	MASL
Dimbulagala A/C	MR	Operational	Adequate	Purified	MASL

SETTLERS AND WATER RELATED FACILITIES

YSTEM-H — Settler Families - 31,000

EAR	Houses	Latrines		Dug Wells		Tube Wells
		Nos	% of Families	Nos	% of Families	
992	23,922	20,118	64.9	9,468	30.5	171
993	24,258	20,697	66.8	9,673	31.2	185
994	24,862	21,273	68.6	10,060	32.5	200
995	24,934	21,438	69.2	10,084	32.5	200
996	25,209	21,692	70.0	10,846	35.0	200

SYSTEM-G — Settler Families - 4,585

YEAR	Houses	Latrines		Dug Wells		Tube Wells
		Nos	% of Families	Nos	% of Families	
1992	2,590	2,318	50.6	109	2.4	163
1993	2,590	2,318	50.6	109	2.4	163
1994	2,590	2,318	50.6	163	3.6	163
1995	2,590	2,318	50.6	163	3.6	163
1996	2,590	2,318	50.6	163	3.6	163

YSTEM-C — Settler Families - 21,039

EAR	Houses	Latrines		Dug Wells		Tube Wells
		Nos	% of Families	Nos	% of Families	
992	20,028	15,578	74.0	8,522	40.5	23
993	20,913	16,617	79.0	8,831	42.0	23
994	20,995	16,965	80.6	9,482	45.1	23
995	21,160	17,507	83.2	9,569	45.5	23
996	22,453	17,507	83.2	11,176	53.1	23

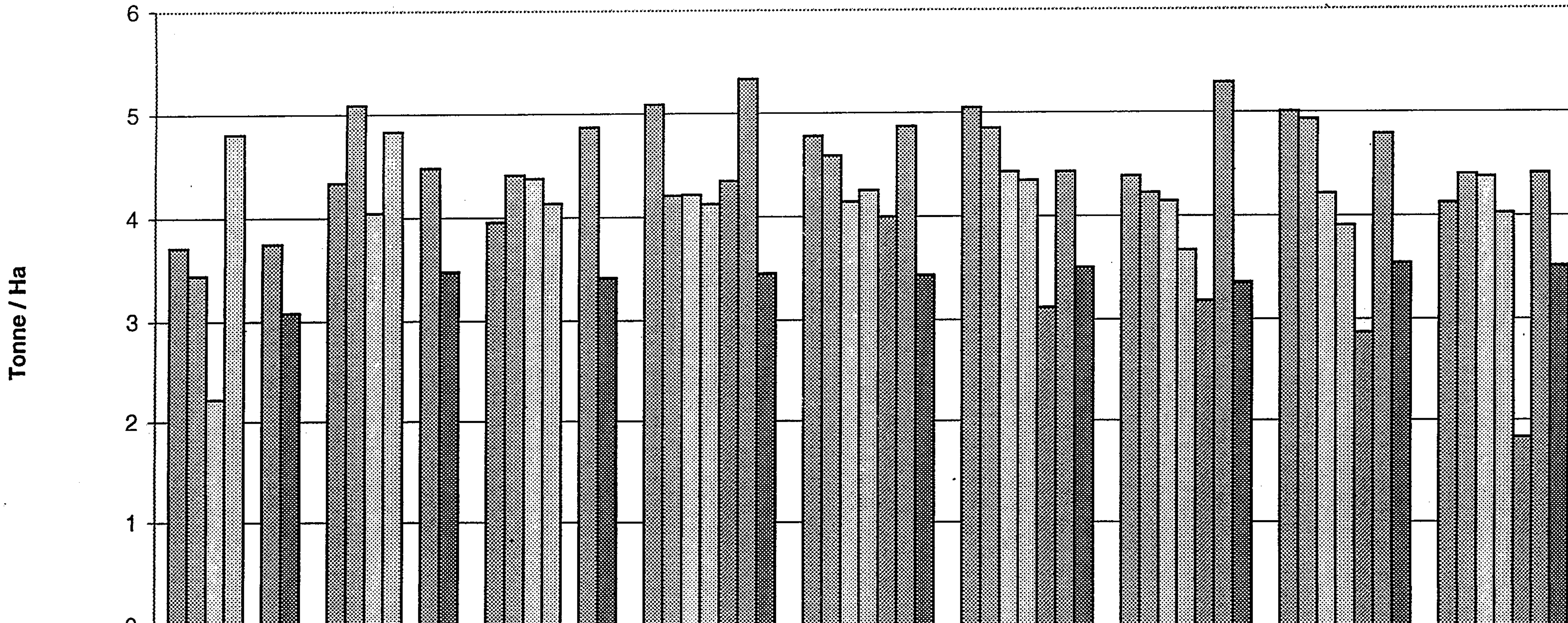
SYSTEM-B — Settler Families - 18,795

YEAR	Houses	Latrines		Dug Wells		Tube Wells
		Nos	% of Families	Nos	% of Families	
1992	14,489	9,665	51.4	5,847	31.1	347
1993	16,330	10,780	57.4	5,963	31.7	414
1994	17,869	11,855	63.1	6,409	34.1	421
1995	18,221	12,478	66.4	7,400	39.4	432
1996	18,372	13,691	72.8	7,401	39.4	432

FERTILIZER USAGE IN METRIC TONNES

SYSTEM	FERTILIZER	1991/1992 MAHA	1992 YALA	1992/1993 MAHA	1993 YALA	1993/1994 MAHA	1994 YALA
C	VMIX	872.00	436.00	823.00	795.00	1091.00	802.00
	UREA	980.00	680.00	2002.00	969.00	1389.00	1259.00
	TDM	760.00	652.00	2183.00	730.00	1223.00	1063.00
	TSP	20.00		16.00		0.90	3.10
	MOP	11.00		9.00		0.70	1.10
B	VMIX		415.00	785.00	688.00	1272.00	1150.00
	UREA		510.00	692.00	634.00	1178.00	1124.00
	TDM		482.00	327.00	289.00	401.00	829.00
	TSP		0.25			2.50	
	MOP		0.25				
H	VMIX	2434.00	81.00	3472.00	186.00	2650.00	935.00
	UREA	3167.00	115.00	3496.00	117.00	2593.00	628.00
	TDM	3060.00	36.00	2081.00	133.00	2243.00	197.00
	TSP						
	MOP						
L	VMIX	4.00		4.00		7.80	
	UREA	36.00		14.00	1.00	41.00	1.10
	TDM	18.00		0.60	0.45	10.00	0.40
	TSP			0.10			
	MOP			1.70			
TOTAL	VMIX	3310.00	932.00	5084.00	1669.00	5020.80	2887.00
	UREA	4183.00	1305.00	6204.00	1721.00	5201.00	3012.10
	TDM	3838.00	1170.00	4591.60	1152.45	3877.00	2089.40
	TSP	20.00	0.25	16.10	0.00	3.40	3.10
	MOP	11.00	0.25	10.70	0.00	0.70	1.10

AGRICULTURAL PRODUCTION



	1984	1986	1988	1990	1992	1993	1994	1995	1996
H	3.71	4.34	3.96	5.09	4.78	5.05	4.39	5.01	4.13
G	3.44	5.09	4.41	4.21	4.59	4.85	4.23	4.93	4.4
C	2.22	4.05	4.38	4.22	4.15	4.43	4.15	4.22	4.38
B	4.81	4.83	4.14	4.13	4.26	4.35	3.67	3.91	4.03
L	0	0	0	4.35	4	3.12	3.18	2.87	1.83
Walawe	3.75	4.48	4.87	5.33	4.87	4.43	5.29	4.79	4.41
National	3.08	3.47	3.41	3.45	3.43	3.5	3.36	3.54	3.51

Year

H G C B L Walawe National

SOME PROMISING RESEARCH FIELDS FOR SUSTAINABLE WATER RESOURCES DEVELOPMENT IN SRI LANKA.

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1. Introduction

Freshwater is a basic requirement for life, yet water resources are facing increasing demands from, and competition among, users. Shrinking supply of freshwater in reality has not been due to the reduction of potential supply, but the pollution to which it is being subjected, the demands which are placed on this supply, have indeed increased, complicated by irregular rainfall patterns.

Water pollution is responsible for deaths and diseases transmitted by or through water. It has been estimated that 45% of Sri Lanka's rural population lacks safe drinking water and 55% lacks access to adequate sanitation.

The water use increased by a factor more than the rate of population growth. The population of Sri Lanka is approximately projected to increase from the current 18 to 25 millions in 2025. The result is already evident in the competition for water for agriculture (around 75%), domestic, and industrial purposes.

At the turn of the century, some estimates suggest that, the amount of water available to each person in Sri Lanka would be about half the 1950 figure. This situation is aggravated by the longer term threat of global warming with high impact on regional water resources significantly, having floods in some areas and droughts in others.

The current use of freshwater resources in our country is not sustainable. According to UN predictions, water withdrawal as a percentage of water availability by 2025 would be more than 40% for Sri Lanka.

2. Objectives

Ensure sustainable development through integrated rational use of water and other natural resources of Sri Lanka.

2.1. Specific Objectives

Research work specifically directed to improve the sustainability of water resources development.

* rational use of treated water in piped water schemes by minimising losses due to poor maintenance, avoid pilferage in distribution systems by community participation and introduce a separate system for washing purposes and flushing of toilets, in order to limit usage of treated water only for drinking.

* embark on rainwater harvesting.

* popularize alternatives to cut drastically use of firewood and /or replace firewood cooking in households to reduce deterioration of the environment.

* introduce purification of water through biological processes, solar distillation and other methods to ensure potable water to all.

* adapt new farming techniques to reduce irrigation requirements of water, minimise use of harmful fertilizer by introducing innovative farming (mixed farming, intercropping etc) to prevent pollution of water resources.

* control and govern watershed management, removal of sand from river-beds, release of water with high bed-loads to irrigation fields, salinity of irrigated fields including salt water seepage from the sea to inland and reclaim land uncultivated due to bad drainage.

* embark on ways and means of harnessing energy of the Indian Ocean for sustainable development (small scale electricity generation from sea water in a cell, wave, tidal and OTEC etc.).

* rehabilitation and study of aspects of ancient soil and water ecosystems and their integration and applications to modern water resources projects.

3. Problems Encountered

* increase in population demands more agricultural production, depletes the forest cover, consumption rises and ultimately reduces available water resources.

* destruction of forest cover to prepare more agriculture fields, intensive application of chemical/fertilizers to increase yields, practically 65% of the population uses firewood and other biomass for preparation of food, uncontrolled and intensive slash and burn cultivation, haphazard development activities etc. do result in pollution of water resources.

* irrational and uncontrolled use, wastage, non integrated utilisation of resources etc., would result in fresh water shortages in the near future.

4. New Approaches to Ensure Sustainable Development of Water Resources.

Considering various scenarios of population growth in Sri Lanka matched against the existing pattern of consumptions, destructions and pollution of natural resources, there have been several research work concluded indicating that there would be a shortage of fresh water in the island in the near future.

As a first step, the country should take account of natural resources such as water, land, forest etc. in each district /region / province and keep records of consumption /development/ destruction etc. and make the population aware of the trends of water use and consequences of unplanned development.

Water resources and natural resources development should be executed with the community collaboration at all levels, commencing from the grass root beneficiaries. This step guarantees prevention of catastrophic destruction of the environment, thus ensuring rational use of water and other natural resources.

4.1 Minimise Wastage and utilisation of Treated Water for Sanitation.

The community and the consumers should realise the cost of one cubic meter of treated water produced in a system and the benefits of the prevention of wastage and rational use brought to the society. Practical measures necessary, awareness, social mobilisation etc. could be initiated throughout the country to achieve goals.

4.1.1 Operation, Maintenance and Management

It should be properly established that the production costs in a system should be borne by the consumer. Research could identify the consumptions (drinking, washing, gardening etc) for dwellings and for encouragement of rational use, price structure could be established for enhanced payment for quantities beyond set-limits. Private enterprises should be formed in selected areas as pilot schemes, incorporating these measures.

Water released, distributed and consumed should be well accounted and maintenance personnel should be held responsible for their control. A system should be created to prevent illegal tappings and their detection, finally to punish and disgrace them in public. Success could be attained only through community participation. Public and private enterprises could set-up units for water supply and sanitation in rural and municipal areas.

4.1.2 Restrict Treated Water Exclusively for Drinking

In existing piped water schemes the treated water has been extensively applied not only for drinking and cooking purposes, but for gardening, washing, flushing of toilets etc. This aspect of use needs careful research and observations to make sure that the treated water to be used only for drinking. Alternatives for water supply for other purposes has to be thoroughly studied, researched to enable the available treated water to be extended to people in need. More than 50% of treated water is being utilized for other purposes and more than 35% of treated water goes as unbilled. A professional team of researchers should address the problems to look for a satisfactory solution within a limited period of several months. The investment on research could be justified within a year and the benefits accrued could be highlighted as follows : extension of available water to more people (50%); establish proper management; recover unbilled water costs for extension to others; and awareness of the community for conservation of water etc.

4.1.3 Rainwater Harvesting

In a very broad manner it could be mentioned that practically 50% of the population has no access to a source of safe drinking water and proper sanitation facilities. In order to provide all people of the country access to safe water and sanitation, viable alternatives have to be found. Pollution is causing widespread public health problems, adding to the water shortages, and causing serious harm to ecosystems, especially in rivers, lakes, man-made reservoirs and costal areas. Fresh water resources are unevenly distributed due to the precipitation pattern, but throughout the country there is rainfall, which could be harnessed to attain goals.

Contribution of rainwater harvesting to solve the national problems should be a high priority in the agenda for research. The following are highlighted for research attention : determine the per capital potential for drinking and agriculture purpose (especially in the dry zone); possibility to create stable eco-systems; improvements to present technology and future research for domestic systems (integrate rainwater system with air-conditioning, water supply and sanitation, energy generation etc).

4.1.4 Ancient Soil and Water Ecosystems

Ancient soil and water ecosystems that existed for more than 2000 years distributing water for irrigation in dry zone could be highlighted as unique in the world over. How these systems were planned, executed and managed should be studied and researched. Equal importance should be paid to the suffering of neglect, decline, deterioration and destruction of man-made water and soil ecosystems of Sri Lanka, to make sure that the existing / functioning systems could serve our country by promoting measures and applying some unknown management techniques of the past, which could be directly adapted for modern development schemes.

In ancient Rajarata and Ruhunurate water and soil conservation systems consisted large networks of distribution canals. The gradient, linining etc. of these networks of channels play a great role for efficient water use. Taking into consideration the losses in irrigation distribution networks in this country, a serious effort should be launched to embark on research to minimise losses. Any investment should bring positive results within a limited period enabling the saved water to be utilised to increase agriculture produce.

4.1.5 Alternative Energies

Majority of the population uses firewood and biomass for cooking of food. Malnutrition of children under five years has been identified as a problem needing priority redressing. Affordable alternative energy for cooking of food, revolution in preparation and consumption of food etc. are important fields attracting research. Contribution of research would have immense impact to reduce malnutrition, minimise biomass use for food preparation and finally ascertain conservation of water resources.

Rural communities and communities living close to the sea shore do not have access to electricity for basic purposes such as drinking water, sanitation, refrigeration of vaccines/medicaments, house lighting etc. Instead of expecting the extension of the expensive national grid to those communities, innovative use of small scale renewable sources of energy would immensely contribute to sustainable use of water resources and conservation of the environment.

Community cooking during agreed periods using electrical energy produced from renewable energy sources, illumination of dwellings etc. are some of the basic needs of the population for raising of living standards. In order to achieve these, the following should be exposed to research, finally meant for conservation of natural resources:

* biogas production for cooking and lighting;

* harnessing of energies of water spouts (for example at Kudawella near Tangalla), tidal and waves of the ocean (prevents sea erosion); and

* integrated harnessing of energies of small rivers, solar, wind, OTEC etc. for rural development (encourage reduce slash and burn cultivation).

5. Conclusions

* Concerted research and their application should be a necessity for rational use of water resources
* Integrated utilisation of water resources should be established by responsible authorities having a central master plan.
* Private and public enterprises should be held responsible for management of water resources with complete cost recovery.
* Social mobilisation, community participation, public awareness etc. are major contributing factors for sustainable water resources development in Sri Lanka.

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Assessing the impact of land use conversions on water demand: A pre-requisite for the formulation of policy for water allocation

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Introduction

Vegetation is the major user of water on the earth. Water is lost from the vegetation back into the atmosphere through the evapo-transpiration process. Manipulation of this loss through land use management could either increase or decrease the available water for alternative uses. Information on the impact of such changes is, therefore, a pre-requisite in formulating a national policy on water resources management.

Evapo-transpiration demand is influenced by the climatic and vegetation factors whilst the ability to satisfy such requirement depends on the available water and the supply mechanism, which in turn is determined by the water storage capacity of soil, characteristics of the vegetation and the transpiration dynamics (*Calder, 1992*). The degree to which the evapo-transpiration demand is satisfied may also be determined by the application of water through irrigation.

There have been very few studies conducted in Sri Lanka until 1993 with regard to the water use of different vegetation in major climatic zones. Therefore, a series of studies have been initiated with the objective of assessing the impact of land use conversions on water yield in major climatic zones from the funds provided from donors, such as the Department For International Development (DFID) of the UK and the USAID.

This paper briefly describe the studies conducted in different climatic zones and the major findings originated from them. A water use model developed and verified from the above studies is used to simulate the water use of selected land use types in three different climatic zones. The simulated results are then discussed to indicate the relevance and the usefulness of assessing the water demand in different conditions for watershed management planning and water allocation for alternative uses.

Water use studies in different agro-climatic zones

Field monitoring of water use studies were conducted during the period from 1993 to 1997 in three different climatic zones. The instrumentation, land use monitored, and the types of data collected are given in Table 1. The details of these studies and the results have been published elsewhere (*Gunawardena, 1998a: Gunawardena 1998b; Rosier et al, 1994*). However, the major findings are described in the following section.

Table 1. Details of study sites

Study Area	Horton Plains	Dodangolla	Puwakpitiya
Location	N 6^0-48', E 80^0-48'	N 7^0-17', E 80^0-41'	N 8^0-04', E 80^0-45'
Agro-Climatic Zone	WU3	IM3	DL1
Elevation	2100 m	370 m	160 m
Mean Annual Rainfall	2150 mm	1400 mm	1468 mm
Land Use Monitored	1. Montane Forest 2. Grassland	1. Kandyan Forest Gardens 2. Grassland 3. Acacia	1. Forest 2. Shrub 3. Fallow
Instrumentation	1. Automatic Weather Station 2. Fog Collector 3. Neutron Probe	1. Automatic Weather Station 2. Neutron Probe	1. Raingauge 2. Evaporation pan 3. Neutron Probe
Data recorded	1. All the meteorological parameters 2. Fog interception 3. Interception 4. Soil Moisture	1. All the meteorological parameters 2. Interception loss 3. Soil Moisture	1. Daily rainfall 2. Daily Evaporation 3. Soil Moisture
Duration	May 93-Dec 96	Oct 93 - Dec 96	May 97-Oct 97

Highlights of field research

High elevation site

At the higher altitude site at Horton Plains, there is a substantial moisture contribution to the land from fog interception or cloud deposition (*Gunawardena et al, 1988*). This additional contribution is about 1/4th of the rainfall at that altitude. However, most of this additional moisture is evaporated back into the atmosphere as evaporation from the canopy. During the period from 02/11/1993 to 09/12/1996, the net rainfall was 2% higher than the rainfall. This indicated that the additional moisture from fog contributed 2% of additional moisture to the ground after the interception loss. However, this does not necessarily mean that cloud forests increase stream flow. Though, there was an addition moisture contribution after offsetting the interception loss, trees still transpire more water compared to grasslands. For example, montane forest transpire 3.0 mm of water per day during a dry spell followed by a rainy period compared to 1.6 mm from the grassland (*Kannangara et al, 1994*).

Mid elevation site

At the mid elevation site, net interception loss from plant canopies are very much higher compared to the high elevation site. There are two hydrological processes, namely interception and transpiration, which together determine the water use of a plant. During the period from 27/04/1993 to 12/12/1996, the total interception loss from Kandyan Forest Gardens (KFG) amounts to 33% of the rainfall. This higher interception loss is due mainly to the dense canopy of the KFG. Interception loss from acacia is slightly less than the KFG. Reduction of the canopy area will undoubtedly reduce the interception loss which helps to increase the amount of water reaching the soil. When compared to KFG and acacia, there is hardly any interception loss from grass since it was grazed to the ground. However, this may not always be the case. In some instances Gini grass, which can grow up to about 1.7 m, has a very high leaf area index which is comparable with pinus (*Nadhisudhasharma, 1996*). However, for the same leaf area index, interception loss from trees could still be higher due to their lower aerodynamic resistance. Though there was a problem with regard to the estimation of transpiration loss, it is still possible to conclude that trees use considerably higher amount of water compared to grasslands purely on high interception loss making a very conservation assumption that the transpiration rate of trees is equal to grass.

Low elevation site

The results from the site at Puwakpitiya in the dry zone showed that water use was higher in forest followed by scrub and fallow (*Gunawardena, 1998a*). The forests removed most of the water from the deeper layers during the dry period due to the absorption from deep roots. The published work in the dry zone indicate that there is hardly any runoff generated under the forest and scrub during dry season though there is rainfall (*Munasinghe and Somasiri, 1992; Dharmasena, 1994*). Much of the rain fall in to these two land use types either get intercepted and evaporated back into the atmosphere or has infiltered to refill the moisture depleted soil. This additional water is again returned back to the atmosphere through evapotranspiration. In contrast, rain reaches the soil in chena lands with hardly any interception. Low infiltration opportunity time and the rate due to less surface roughness together with less soil moisture depletion tends to generate runoff in the chena lands. The simulation studies indicated that if the fallow land is cultivated with agricultural crops under irrigation, the water use increased considerably. Water use of most irrigated crops are higher than shrubs, fallow and forest.

Development and verification of the water use model

The water use of a given land use will depend on may factors, such as climate (including rainfall amount and distribution), elevation, tree species, planting density, age, soil characteristics, slope of land etc. These factors will influence the water use in varying degrees so that a combined effect is difficult to anticipate without understanding the different processes which are operating in a given situation. A water use model was developed and verified during these studies to assess the impact of land use changes on water use and associated hydrological processes. Improvements to

the model are being made with the ongoing research work to make it more applicable to the very complex climatic and physiographic conditions in Sri Lanka.

Simulations of water demand for different land use types

The simulation was carried out for a period of two hydrological years from October 1994 to September 1996 at the same locations where filed studies have been conducted For the first simulation run, the information and the model parameters from the field studies were used. The long term pan evaporation values for Sita Eliya, Kundasale and Kalawewa are used for Upcountry, Mid Country and Low Country sites since there the methodology adopted to measure the evaporation from the field sites are very different and not comparable. The conditions under which the simulations are carried out are given in Table 2.

Table 2. Climatic and land use information for the first simulation

Climatic Zone	Up Country- Wet Zone	Mid Country- Intermediate Zone	Low Country- Dry Zone
Annual Rainfall (Average of Oct. 1994 to Sep. 1996)	1625 mm	1583 mm	1415 mm
Average Annual Pan Evaporation	1312 mm	1338 mm	1908 mm
Land Use	1. Montane Forest 2. Grasslands 3. OFCs (Maha Irrigation only with 100% application efficiency)	1. Kandyan Forest Gardens 2. Grasslands 3. OFCs (Maha Irrigation only with 100% application efficiency)	1. Forest 2. Fallow 3. OFCs (Maha Irrigation only with 100% application efficiency)

The results given in Figure 1 shows that the water use of forests as a percentage of rainfall is lowest in the higher altitude, mainly due to fog capture and low evaporative demand. Almost all the rainfall is used by the dryzone forests. It is to be noted that the forests, referred to in this simulations are tall trees with dense canopies which normally occupies valleys with deep soils. They do not represent the typical thorny shrub jungles in the dry zone, which are very common in slopes with shallow soils. Nearly 2/3rd of the rainfall is used by the grass as well as irrigated crop in the dry zone, whilst about ½ of rainfall is used by the respective vegetation in the upcountry. The water use of KFG, grass and irrigated crops in the mid country intermediate zone lies in between the two ranges, ie up country-wet zone and low country dry zone.

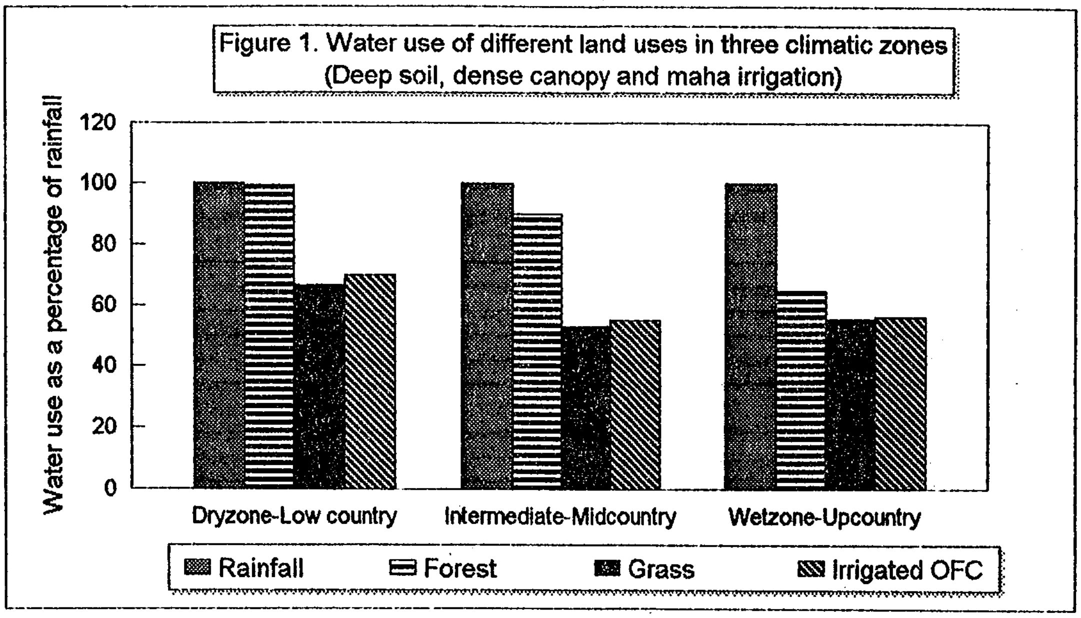
Figure 1. Water use of different land uses in three climatic zones
(Deep soil, dense canopy and maha irrigation)
Water use as a percentage of rainfall
120
100
80
60
40
20
0
Dryzone-Low country
Intermediate-Midcountry
Wetzone-Upcountry
Rainfall
Forest
Grass
Irrigated OFC

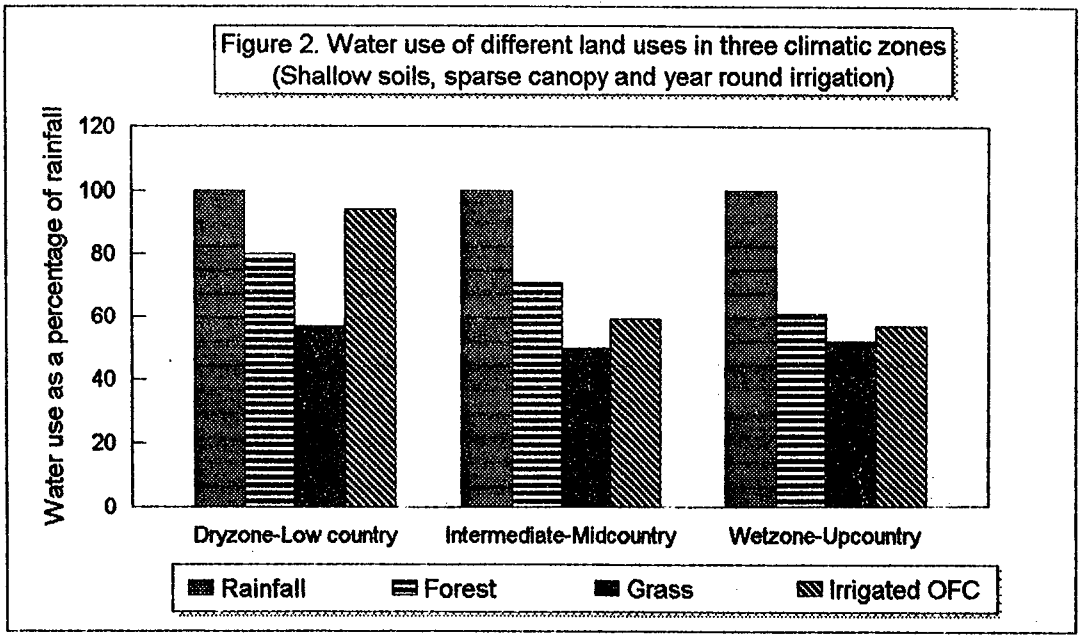
Figure 2. Water use of different land uses in three climatic zones
(Shallow soils, sparse canopy and year round irrigation)
Water use as a percentage of rainfall
120
100
80
60
40
20
0
Dryzone-Low country
Intermediate-Midcountry
Wetzone-Upcountry
Rainfall
Forest
Grass
Irrigated OFC

The water use of vegetation depends on many factors. Figure 2 shows the simulation results of all the land uses mentioned in Table 1 with some modifications. For the second simulation run, soil depth was reduced by 50%, forests were assumed to have sparse canopies and the OFCs were irrigated year round with 100% application efficiency.

The results shows that the water use of forests has reduced considerably especially in the dry zone and intermediate zones. This is due to the lower interception loss and the reduced transpiration since the soil moisture storage is limited compared to the previous case. The effect on water use is very little in the upcountry mainly because, the soil moisture reservoir gets filled up more frequently with well distributed rainfall. Another notable feature is the very high water use of irrigated OFCs in the dry zone. The water use Is higher compared to all the land uses. In other two climatic zones, irrigated agriculture still uses less water compared to forest.

Conclusions

It was shown that demand for water varies according to the climatic zone, land use and practices that are adopted in a given land use. Analysis of the simulation results indicated that water use of trees and grasses in higher altitudes in the cloud base, above 1500 m, have little difference when compared to mid country intermediate zone and the low country dryzone. This is because, the additional moisture contribution due to cloud deposition by trees compensate its high interception and transpiration losses compared to grass. In mid elevation, water use of KFG and acacia are substantially higher compared to grasslands, mainly because of high interception loss. The magnitude of this difference depends on the management of the grasslands, since interception loss from the grasslands depends on its leaf area index. In the dry zone too, forest has a higher water use compared to grasslands. However, these findings, some times, can not be generalized due to local climatic, physiographic, vegetation and soil variations. Therefore, a simulation model which takes all these parameters in to consideration is required to assess the impacts of land use variations on water use.

In the low country dry zone irrigated agriculture is the highest water user. Forests use more water, followed by shrub and fallow lands. Therefore, manipulation of land use in a watershed could either increase or decrease the water available from the watershed for other uses. Promotion of irrigated agriculture in the upper watersheds inevitably reduces the water available to the tanks located in the down stream areas. Rehabilitation of minor tanks in the upper watersheds, expansion of its command areas and the augmentation of well irrigation, therefore, will have a serious negative impact in terms of water availability to the down stream tanks.

A water use model, developed and verified, for different climatic zones have been used to determine the impacts of different land use conversions. Simulation studies have shown, in general, that the irrigated agriculture is the main water user compared to all other land uses with natural vegetation. The magnitude of this difference is mainly influenced by the climatic factors and cropping intensity, under the existing irrigation practices adopted by the farmers. Intensive development of irrigated agriculture would, therefore, reduces the water available for other

alternative uses. This indicate that, land use, agriculture and water resources planning and development should be carried out, at least on watershed basis so that the policies for water allocation could be formulated to optimize the multiple objectives.

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NATIONAL WATER CONFERENCE
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RESEARCH PAPERS PRESENTED

Session No.24 6 November 1998 *11:00 a.m.*

Water Allocation

Paper No.10a
Nandalal, K.D.W.
Ratnayake, U.R.
Optimum Water Allocation In A Diversion Type Irrigation Scheme: Gampolawela Rajaela Diversion Scheme

Paper No.20
Samaraweera, P.
Mahaweli water management to maximise the benefits

Paper No.120
Abeywickrema, W.D.S.
Benefits of Integrated Water Management
(in Sinhalese)

ශ්‍රී ලංකාව තුල ඒකාබද්ධ ජල පරිහරණයෙ
ලැබිය හැකි ආර්ථිකමය වාසි

Optimum Water Allocation in a Diversion Type Irrigation Scheme: Gampolawela Rajaela Diversion Scheme

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ABSTRACT: The use of optimization techniques for supplying irrigation water can significantly improve the water use efficiency. The paper presents a methodology developed to optimize water allocations in a diversion type irrigation scheme. The methodology, which is in two stages develops potential release policies during its first stage. The second stage, which is based on Dynamic Programming technique, selects the optimum release pattern from the above potential policies. The application of the model to the Gampolawela Rajaela Diversion Scheme revealed the effectiveness of the decisions made by the model over the actual release pattern.

INTRODUCTION

Central region of Sri Lanka has a large number of diversion type irrigation schemes. The availability of a considerable amount of rain in this area, for the provision of crop water requirement reduces the irrigation demand and makes such schemes viable. The limitation of the irrigable lands due to the terrain that consist of many streams located close to each other is another factor that favours diversion schemes. Further, the topography may not favour construction of reservoirs in this area most of the time.

The main problem that a diversion scheme faces is the insufficiency of water during dry periods due to increase in crop water requirement and the decrease in main stream flow. This makes the distribution and management of irrigation water in diversion schemes a difficult task during such periods. Design and operation of diversion schemes could be handled efficiently if the available water and the rainfalls are incorporated into the decision making process. Incorporating these aspects to estimate an optimal irrigation requirement can be achieved through operations research techniques.

Application of operations research techniques for allocation of irrigation water is limited. Complicated models due to the large number of variables such as irrigation requirements, releases, canal discharges together with number of plots and time periods necessary to describe irrigation systems may be the reason. To overcome such difficulties, this model separates the modeling process in to two stages. First stage derives number of alternatives for supplying the irrigation demand within a given time period and the other stage applies operations research techniques to find their best combination for optimal operation.

Linear programming (LP) was used by Holzapfel *et al* (1986) for optimization of a furrow and border irrigation design. The objective function and the constraints were non-linear and they

were linearized to use LP technique. Such simplifications may not represent the real system. Boman and Hill (1989) developed a model for making daily operating decisions required for operation of an irrigation water delivery system. The model determines optimum releases for each gate in the system based on time interval between gate changes, the demands for the downstream use and the demand for water withdrawals within each reach. The LP optimization model minimizes the differences between the demands and the gate releases.

The objective functions of irrigation system operations are mostly non-linear and Dynamic Programming (DP) technique (Bellmann, 1957) can solve them without any simplification. This paper presents a model developed based on DP technique for the optimal allocation of irrigation water in a diversion type scheme.

MODEL DESCRIPTION

Dynamic Programming was selected as the optimization technique mainly due to its ability to incorporate non-linear objective functions and constraints without simplifications. The model optimally allocates irrigation water to different plots along a main canal. This spatial distribution is limited to a single time step and the optimum results are sequentially integrated in time to form the final policy. The present model assumes that the irrigation requirement in a period is independent of the amount of irrigation water supplied previously. Physical canal properties of the system such as reach length, maximum canal capacities, area of plots, evapotranpiration and rainfall are the initial inputs required for the model. Weekly total irrigation requirements of each plot were estimated and various different patterns of daily releases during the week were derived to supply these requirements. These patterns were the alternatives used in the model. Output of the model was the set of alternatives, which provide a flow with a least amount of deviations within a period.

Objective function

The objective of the model is to keep the diversion into the main irrigation canal at a constant value. This is achieved in the objective function by minimizing the squared sum of the hourly deviation between the diverted flow and the available flow over a week in each canal reach. The release patterns during a week is pre-determined and given to the model as a set of different alternatives. The final result will select the best alternative from this set.

$$z = \min_{j} \sum_{p=1,np} (Q_i - r_{ijp})^2 h_{ijp}$$

where,

Q_i - Discharge available at the diversion in week i,

h_{ijp} - Duration of release 'r_{ijp}' in hours,

r_{ijp} - Rate of release of alternative j of irrigation plot p during week i,

np - Total number of irrigation plots,

i - Index of weeks,

j - Index of release alternative, and

p - Index of irrigation plots.

Constraint on canal capacity

The releases made to any irrigation plot at any given time should not exceed the maximum carrying capacity of the canal.

$$r_{ijp} \leq C_p$$

where,

C_p - Capacity of the canal of plot p.

Constraint on duration of the release

The releases to an irrigation plot should be determined so that the supply can be made within a week (168 hrs). The duration of each release is upwardly round off to the nearest hour.

$$h_{ijp} \leq 168$$

Constraint on irrigation water supply

The irrigation water supply should cater to the demand to meet the crop water requirement and associated losses from irrigation fields and canals.

$$r_{ijp} h_{ijp} \geq D_{ip}$$

where,

D_{jp} - Irrigation duty for plot p for the week i.

Evaluation of irrigation demand

The irrigation demand in a week is calculated in the daily basis and sum up for the week. Daily evapotranspiration of the reference crop is calculated using the Penmann Method. Standard crop coefficients are used in the calculations. The field losses are considered in two different components. The losses at the application level is considered as an application efficiency and the continuing loss from the fields due to deep percolation are considered as a percentage loss from irrigation water. The losses from irrigation canals are considered as a constant loss per unit length of the canal, which depends only on the wetted area.

$$D_{jp} = \sum_{d=1,7} \left[\frac{(K_c ET_0 - I)_d}{E_a (1 - L_{prc})} + L_{cnv} l_p \right]$$

where

K_c - Crop coefficient,

E_a - Application efficiency,

ET_0 - Reference crop evapotranspiration,

I - Rainfall during the day,

L_{prc} - Deep percolation loss as a percentage of irrigation water,

L_{cnv} - Conveyance loss as the loss from canal per unit length per day,

l_p - Length of canal up to plot p, and

d - Index of a day in a week.

Recursive Equation

Above model is solved using the deterministic dynamic programming and the following recursive equation is used in evaluating the objective function.

$$f_{ip}(r_{ip}) = \min_{j}\left[(Q - r_{ijp})^2 h_{ijp} + f_{i(p-1)}(r_{i(p-1)})\right]$$

Decision variable and release alternatives

Decision of the model is the release pattern during a week. A set of patterns, called here the release alternatives, are derived separately and input to the optimization model. The constraints on minimum release, duration of release and the constraint on canal capacity are considered during the formulation of the release alternatives.

PROJECT AREA

The Gampolawela Rajaela Diversion Scheme is a medium scale irrigation scheme located in the Kandy district of the Central Province of Sri Lanka. The scheme irrigates its command area by diverting water from Ulapone Oya, a tributary of the Mahaweli river. The main canal, which starts from the diversion weir across Ulapane Oya is about 17.4 km long. The total irrigated area of 162 ha is divided into several sub-areas as shown in Figure 1.

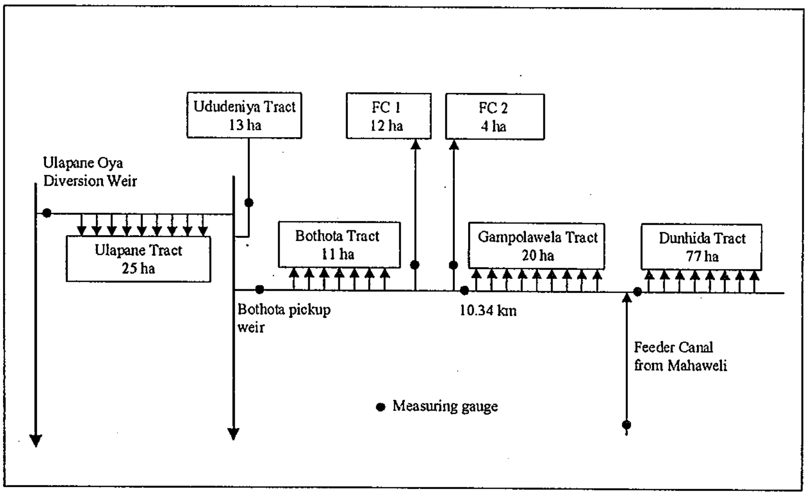

Figure 1 Schematic diagram of the Gampolawela Rajaela Scheme

From the Ulapone headworks, water is distributed to its first tract at Ulapone having 25 ha and the main canal beyond this point takes its course in natural stream. Water is picked up by Ududeniya anicut from this natural stream for a tract extending to 13 ha. The natural stream is intercepted by Bothota pickup weir, and the main canal, which originates from Bothota anicut, supplies water to Bothota tract extending to 11 ha. The next area is fed from FC1 and FC2, which take off from the main canal. The main canal continues and supplies water to Gampola tract of 20 ha before encountering the feeder canal from Dunhinda in Mahaweli river, which brings in diversion water from the Mahaweli river to feed the last tract of the Gampolawela Rajaela scheme in Dunhinda of 77 ha.

APPLICATION

The Gampolawela Rajaela Scheme served as the source of test data for the model. Release data and climatological data were collected for the Yala season 1997. The irrigation demands of the area were estimated based on the evapotranspirations calculated from the Penmann Equation for the same period. The equation according to Doorenbos and Pruitt (1984) is,

$$ET_0 = c[W.Rn + (1-W).f(u).(ea-ed)]$$

Where,

W	- Weighting factor,
Rn	- Net radiation,
f(u)	- Wind function,
ea	- Saturated vapour pressure,
ed	- actual vapour pressure, and
c	- adjustment factor.

The parameters were estimated using climatological data and the relevant tables given in Doorenbos and Pruitt (1984). The required climatological data were gathered from a station near Peradeniya. The historical rainfalls were considered at this stage to calculate the net crop water requirements. The application efficiency and deep percolation were taken as 60% and 20% respectively (Doneen and Westcot, 1988). The conveyance losses were estimated based on the infiltration rate per unit area of the wetted surface of the canal and its value is 5 mm/hr.

In the first stage, the model develops alternative release patterns for each plot based on above irrigation requirement for each week. This weekly requirement is supplied in seven days in equal amounts in the fist alternative. The same is supplied in five days in the second alternative. Third alternate supplied the requirement at the canal capacity, but the time of supply was round off to nearest day and the rate of supply was reduced accordingly. Fourth and fifth alternatives consider a supply a day and two days longer than the third alternative respectively. Table 1 presents the alternatives derived for a plot for a week as an example.

TABLE 1 – Alternative releases for plot-1 in week-2 in m^3/s

Day		1	2	3	4	5	6	7
Discharge	Alt. I	0.0169	0.0169	0.0169	0.0169	0.0169	0.0169	0.0169
	Alt. II	0.0237	0.0237	0.0237	0.0237	0.0237	0	0
	Alt. III	0.1185	0	0	0	0	0	0
	Alt. IV	0.0592	0.0592	0	0	0	0	0
	Alt. V	0.0395	0.0395	0.0395	0	0	0	0

In its second stage, the model selects the optimum release pattern for a week for each plot from the candidate release policies. Thus the optimum releases are derived for the whole irrigation season by sequencing the weekly policies. Table 2 presents the optimum release pattern for the system in a week.

TABLE 2 – Optimum releases during week–2 in m^3/s

Plot	Day 1	day 2	day 3	day 4	day 5	day 6	day 7
1	0.0237	0.0237	0.0237	0.0237	0.0237	0	0
2	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088
3	0.0174	0.0174	0.0174	0	0	0	0
4	0.0114	0.0114	0.0114	0.0114	0.0114	0	0
5	0.0038	0.0038	0.0038	0.0038	0.0038	0	0
6	0.0190	0.0190	0.0190	0.0190	0.0190	0	0
7	0.0521	0.0521	0.0521	0.0521	0.0521	0.0521	0.0521
Tot. rel.	0.1362	0.1362	0.1362	0.1188	0.1188	0.0609	0.0609

As seen in Table 2 the total releases have daily deviations, which is not the most desirable operational pattern. This deviation is due to the limitation of the number of alternatives considered in this application.

The actual releases during the Yala season 1997 were collected from the Department of Irrigation. The optimal releases and the actual releases in the canal, at Ulapane and at the head end of Gampola tract, are compared in Figure 2 and Figure 3, respectively.

The optimal releases required at Ulapane in Figure 2, increase during early mid season and decrease towards the end. This change is mainly due to rainfall compensating part of crop water requirement, which reduces the irrigation demand. The actual releases do not reflect this trend as the controls at the head end of the canal are not functioning presently due to vandalism. This lack of control may be one of the reasons for optimal releases to be always less than the actual releases at Ulapane. Also, the flow measurements were found to be doubtful in certain cases as the measuring fumes near gauges were found to be silted, giving increased water depths. Besides, the results from the model may be on the lower side. One reason for this may be the values assumed for losses, viz, application efficiency, conveyance losses and deep percolation are less than the actual values. It is necessary to check these values for their validity for the field conditions. The model calculates the irrigation demands using a perfect foresight for the rainfall.

In contrast to the above, the comparison of releases in the canal at 10.34 km in Figure 3 shows lesser deviations. The control of the canal originating from Bothota pickup weir is functioning properly. Optimal release pattern at this point has less fluctuation than the observed releases.

CONCLUSIONS

Conventionally the irrigation systems operations are scheduled to handle a given release pattern to irrigation plots. A rotational system with fixed releases and duration are commonly used as these release patterns. The model presented in the paper can consider several such release patterns to a plot and, it determines the optimum one. The optimum releases minimize fluctuations in the canal discharge. Such a policy will be simple enough to allow easy implementation in diversion irrigation schemes with minimum gate operations. Reductions in fluctuation in canal discharge allow supply from a constant flow as available in a diversion type irrigation scheme.

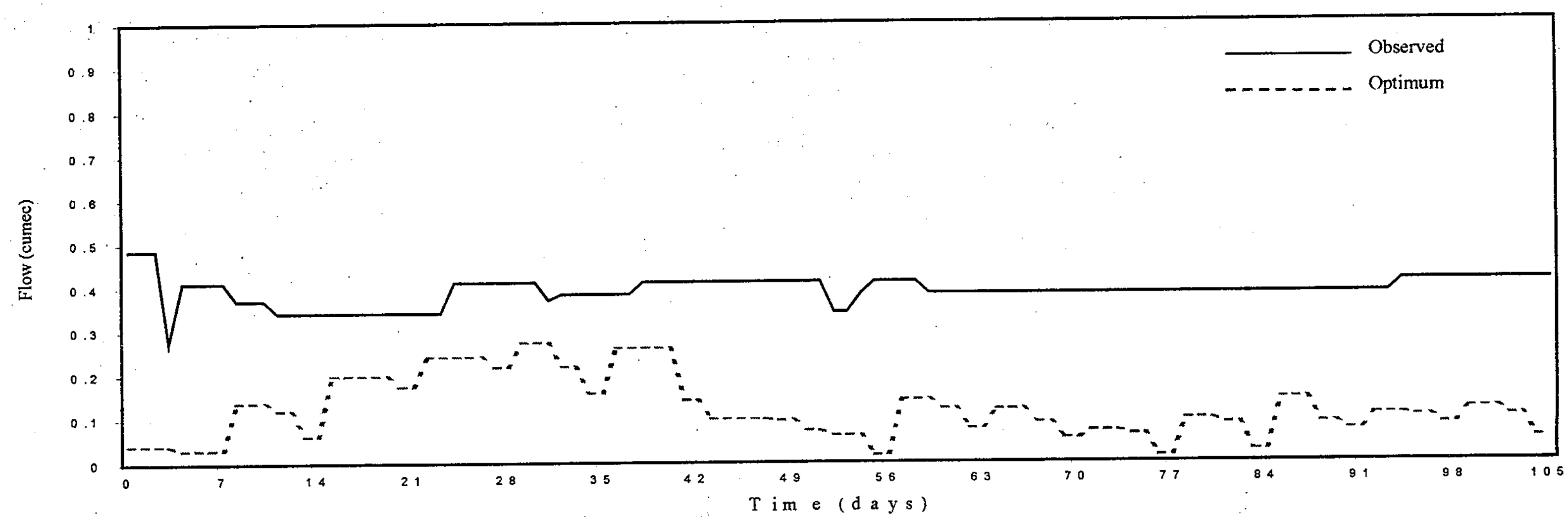

Figure 2. Comparison of observed and computed releases in the canal at Ulapane – Yala 1997

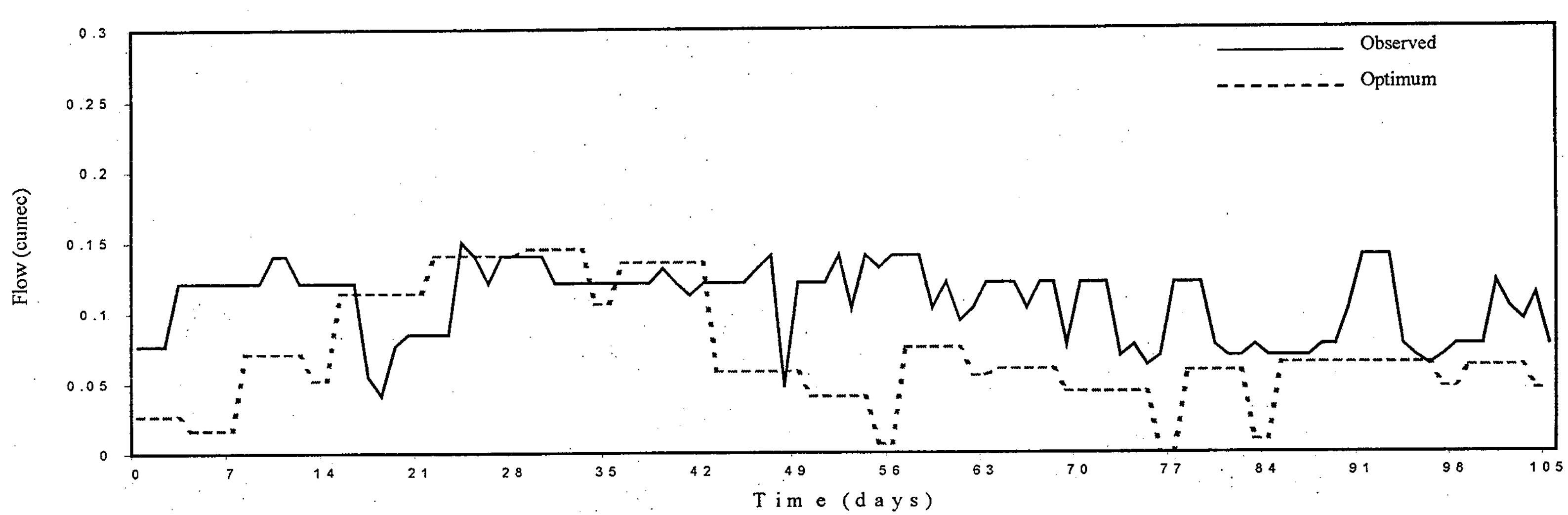

Figure 3 Comparison of observed and computed releases in the canal at 10.34 km. – Yala 1997

ACKNOWLEDGEMENTS

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MAHAWELI WATER MANAGEMENT TO MAXIMISE BENEFITS

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Executive Summary

The Mahaweli scheme is a comprehensive multipurpose water resources development project intended to harness the hydroelectric and irrigation potential of the Mahaweli Ganga and its tributaries.

The system consists of hydro-power plants, irrigation systems regulating reservoirs, diversion anicuts and conveyance canals and tunnels.

The rainfall pattern of the country is dominated by two monsoons, the South-West monsoon (May – July) and North-East monsoon (Nov-Jan). The geography of the central hills brings rainfall to the South-Western and Central hill regions during both monsoons while the rest of the country get its rainfall mostly from the North-East monsoon.

Anticipating the growth of competing water demands and the need for cooperative water management, the Mahaweli Authority of Sri Lanka (MASL), with the assistance of the other agencies and ministries involved, has established the Water Management Panel (WMP) and a Water Management Secretariat (WMS). The principal function of the WMP and WMS is to govern the management of the water resources of Mahaweli, Kelani and Walawe rivers to achieve optimum benefits. The WMS uses a computer model called Acres Reservoir Simulation Program (ARSP) in seasonal planning. Regular weekly meeting are held with the Irrigation Department, Ceylon Electricity Board, Mahaweli Economic Agency and Mahaweli Head Works unit to make bulk allocation of water in these 3 rivers for irrigation and power generation.

Water quality and sedimentation studies are done regularly to monitor the situation. This paper attempts to identify some options to optimise the benefits from the water resources from Mahaweli, Kelani and Walawe rivers and to show how these benefits were optimised during the construction period as well.

INTRODUCTION

The Mahaweli Ganga is the most important river in Sri Lanka with a basin area equivalent to fifteen percent of the country's land area and receives rain from both South-West and North-East monsoons. It carries the largest volume of discharge amounting to one seventh of the island's total runoff. The Mahaweli Basin covers an area of 10320 KM. A cascade of dams and power houses has been constructed for irrigation and hydro-power generation. The system consists of hydro-power plants, irrigation projects, regulating reservoirs, diversion anicuts and conveyance canals and tunnels. The Kelani Ganga, which is an independent river located to the West of the Mahawei Ganga basin, supports a complementary hydroelectric generating capability in Sri Lanka. The Walawe Ganga which is located South of Mahaweli Ganga basin has hydro-power and irrigation capabilities.

Water is indispensable for life on earth and also an essential natural resource for food production and many productive activities. Therefore continued availability of adequate fresh water of acceptable quality is needed for sustainable development of a country. Due to increasing demand and degradation of quality of water by pollution and saline intrusion, the availability of safe and adequate water is fast becoming one of the most important factors limiting social economic development and thus, creating local, regional, national and international conflicts. This situation calls for a comprehensive water resource management plan and compel us to treat water as an economic good and manage it to get the maximum benefits out of this limited scarce natural resource.

Fig 1 Illustrates the 3 hydrologic zones in Sri Lanka.

Fig. 2 Illustrates the stream flow volumes in the Mahaweli and Kelani Ganga systems.

The Mahaweli System

The Mahaweli Ganga development consists of multipurpose projects constructed in the Mahaweli Ganga and the Amban Ganga together with irrigation projects served by diversions from the principal rivers.

Fig. 3 shows the general layout of projects in two rivers, which together comprise the Mahaweli System.

Kotmale project consists of a concrete face rock fill dam and a hydropower station.
Polgolla diversion is a multipurpose project comprising a low, gated barrage across the Mahaweli Ganga and a power tunnel which diverts water from the Mahaweli Ganga to the Amban Ganga through the Ukuwela power station.

Victoria multipurpose projects comprising a concrete double curvature arch dam and hydropower station in the Mahaweli Ganga.

Randenigala multipurpose project comprising a rock fill dam and hydropower station in the Mahaweli Ganga.

Rantambe multipurpose project comprising a low concrete dam and a hydro power station in the Mahaweli Ganga, Minipe diversion weir permits diversion of Mahaweli Ganga flows to serve agricultural needs in irrigation system B and C on the right bank, and irrigation system E on the left bank.

Bowatenna multipurpose project consists of concrete dam and a hydropower station in the Amban Ganga. This project permits the diversion of flows to irrigation system H,IH and MH to the north, and regulates flow to Elahera and Angamadilla irrigation diversion located downstream.

Elahera diversion is a low weir and intake structure which allows diversion of Amban Ganga flow to serve agricultural needs in irrigation system D1 on the left bank.

Angamadilla diversion consists of a low weir and intake structure which allows diversion of Amban Ganga flows to serve agricultural needs in irrigation system D2 in the left bank.

The water available in the Mahaweli Ganga is more than what is required for the development of the land in its own basin. Therefore the Master Plan recommended diversion of the surplus water into the adjacent basins of Kala Oya, Malwatu Oya, Yan Oya and Maduru Oya where a large part of the irrigable lands is located. The Mahaweli water is diverted at Polgolla and Minipe for irrigation .

Table 1 shows the irrigation area and the extent under cultivation.

Table 2 shows the Polgolla diversion to Amban ganga during last few years.

The schematic diagram of Mahaweli System is as shown in Fig 3.

The network of multipurpose reservoirs, diversion and irrigation facilities that are being developed under the Mahaweli Project become more complex with the completion of each new project. It is essential to establish appropriate operating policies to govern the releases and subsequent distribution of Mahaweli water. This will ensure that the maximum possible benefits are achieved from the Mahaweli scheme as it grows, and will provide a sound base on which to plan further development.

The operation of the Mahaweli system has three principal objectives.

1. To provide a reliable irrigation water supply to the crops for food production.
2. To get the maximum possible hydro electric benefits from the irrigation releases.
3. To provide an additional benefits to the electrical system through the release of water that is not required for irrigation purposes.

The task of meeting these objectives is complicated by the need to phase electrical outputs to complement the operation of other components of the electrical system. These systems are Kehelgamuwa-Maskeli oya complex (K-M complex) of reservoirs and power stations, the Samanalawewa reservoir and power stations and all the other thermal stations.

The studies to examine alternative operating policies are complex in nature. The physical description of the principal elements of the Mahaweli system and the important components of the natural electrical system has already given.

Operating Policy Alternatives

Scarcity of water and the variability of the water supply have governed the Mahaweli Development water management policy in the past. The addition of major multipurpose reservoirs under the accelerated Mahaweli Programme has provided a measure of improved flexibility and water supply reliability in certain systems. However, the reservoirs cannot provide complete regulation of the Mahaweli system. Therefore, water security and water supply variability will continue to dominate operational policies in future.

Before examining operating policies for the future it is useful to review present operating policy scenarios, as some elements of their policies will be incorporated into the future policies. Other factors that will influence future polices include.

- Commitments made to farmers in various irrigation projects.
- Practical limitations imposed by hydrology and by the characteristics of the reservoirs diversion facilities and land in the command areas.
- Reliability requirements for the national electrical system.
- The returns to investment.

Implications of new Developments

As irrigation and hydropower development proceed in the lower Mahaweli Ganga basin it has became less attractive economically to divert water at Polgolla from Mahaweli Ganga into the Amban Ganga. With the Victoria, Randenigala and Rantambe dam are completed, it will be more attractive economically generate energy at there 3 power houses than to generate energy at Ukuwela and they use the water for irrigation in system H. While this can be shown to be true in principle realistic alternatives diversion policies must be examined using simulation analysis.

It is necessary to consider the effect of wet, dry and average hydrological conditions and to develop realistic alternative operating polices that could potentially be used to govern diversion operations. An overall assessment of diversion policy, option can be then made, considering socio-economic and regional development factors, as well as broader economic criteria.

In addition to the effects of new system developments in diversion policies, it is necessary to consider the construction of new multi-purpose reservoirs since those reservoirs can provide an additional reliability to the irrigation water and power supply.

Planning for System Operation

Anticipating the growth of competing water demands and the need for cooperative water management, the Mahaweli Authority of Sri Lanka (MASL), with the assistance of the other agencies and ministries involved, has established the Water Management Panal (WMP) as a decision making body. The Water Management Secretariat (WMS) was formed under MASL to provide technical advice to WMP, and to co-ordinate operation throughout the Mahaweli system. One of the major responsibilities of WMS is managing, regulating and forecasting of the storage and distribution of water for multiple usage for and within all present and future components of the Mahaweli System.

The WMS does long term planning, annual planning , seasonal planning and weekly planning to maximise the benefits from water resource of Mahaweli, Kelani and Walawe river systems.

With the completion of Polgolla and Bowatenna projects in mid seventies the diversion policy at Polgolla was to divert maximum for generating at Ukuwela power house and to irrigate lands in system H and D. Since H area was not fully developed for irrigation at initial period maximum power release was made at Bowatenna power house and large portion of water was allowed to spill at Elahera anicut due to capacity limitation in Elahera, Minneriya and Yoda Ela. With the development of system H more water was diverted at Bowatenna to System H through the irrigation tunnel and the water duties in system H was very high due to cultivation of paddy even during Yala.

In 1979 NEDECO submitted a revised proposal to increase the Victoria reservoir capacity to 721 MCM and the long term average annual diversion at Polgolla to 875 MCM . These values were used by the consultants for the design of Victoria, Randenigala and Rantambe projects. The values of 875 MCM was the result of a series of studies carried out on the water balance in order to obtain maximum power benefits while satisfying the irrigation requirements in systems 'H', D and 'G'.

The rated heads for power generation under the Mahaweli cascade down stream of Polgolla are as follows.

Victoria	190 m
Randenigala	78 m
Rantambe	31.5 m

The rated heads of the power generation after Polgolla diversion are given below.

Ukuwela	78 m
Bowatenna	52 m

Only part of the flow diverted at Polgolla will pass through Bowatenna Power station.

All the irrigation systems have to be rehabilitated to increase the efficiency of the system to that suitable arrangements for the operation and maintenance of D-canal and field canal can be put in place.

Agro based industries as well as other industries have come up in these rural areas due to availability of water and electricity. Hundreds of hectares of land are cultivated with banana particularly in Walawe special area, where banana has been a traditional crop for many centuries.

The cost of the Mahaweli Project was recovered with hydro-power and agricultural benefits alone within 10 years.

At present the total paddy land acreage coming under WMP is 170,000 ha which is ¼ of the total paddy land in Sri Lanka. At present the plant installed capacity in Mahaweli System is 660 MW. Kelani and Samanalawewa total is 455 MW with 446 MW thermal capacity the total hydro and thermal availability is 1560 MW. It is recommended to increase the area under irrigation and hydropower generation to meet the future needs of the people.

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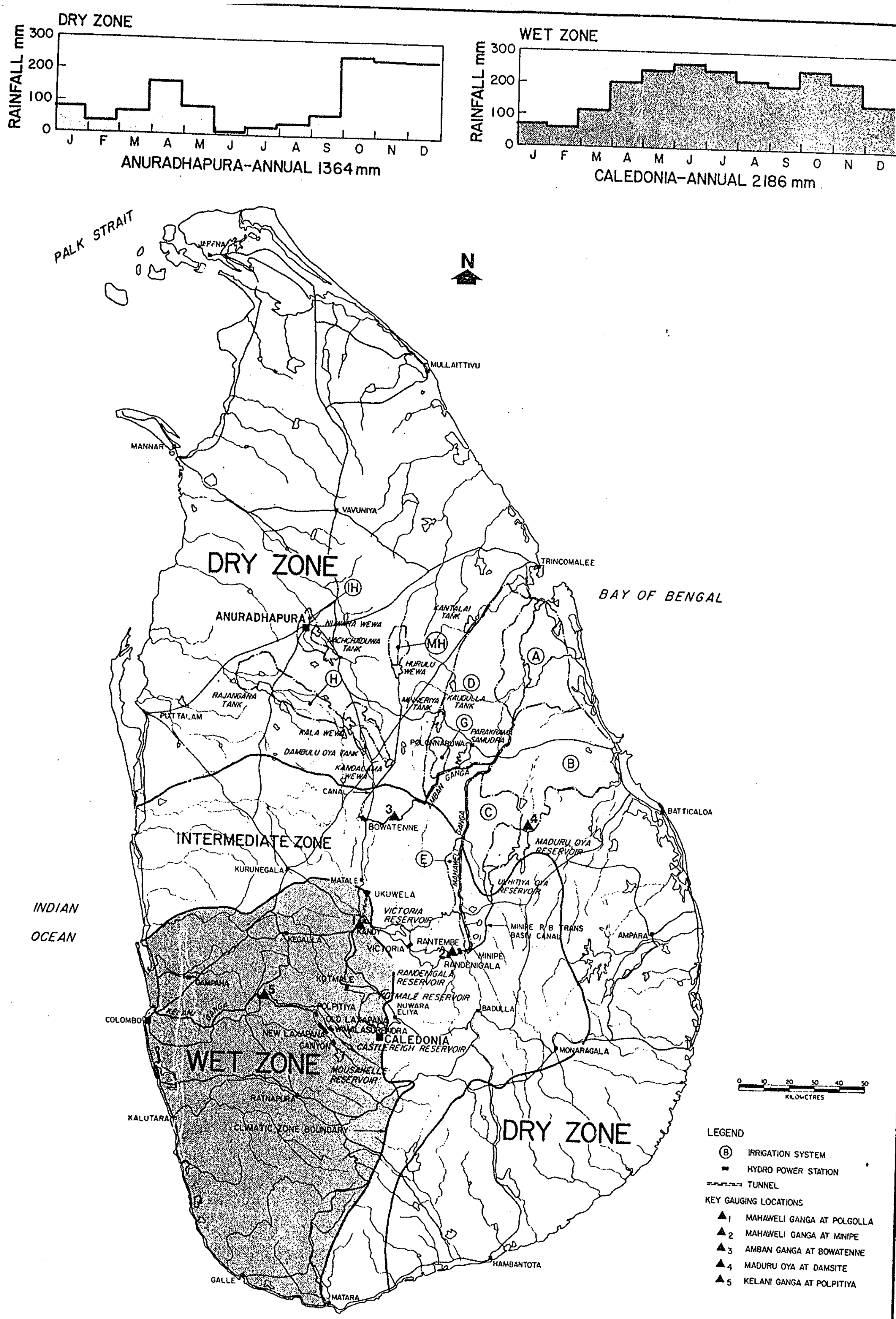

Figure 1 HYDROLOGICAL REGIONS OF SRI LANKA

The 875 MCM diversion policy started with Victoria project in 1984, but average annual Polgolla diversion has been maintained around 1000 mcm to increase the total benefits from irrigation and hydro power generation. This was due to power demands at that time was less than the availability till end of eighties and the system B,C,A was not fully developed as planned earlier.

At present the Polgolla diversion is maintained to give full extent of paddy cultivation in System H, D, G in Maha season and the extent in yala season is planned between 40% - 80% of the total available extents depending on the water availability and to maintain the limit 875 mcm diversion.

Conclusions and Recommendations

Due to Bowatenna irrigation tunnel capacity constraints it is not possible to increase the extent cultivated is system H to more than 60% even in a very wet year. The income of farmers in system H is maximised by cultivation of mostly other field crop in Yala season and action has been taken to improve a marketing of these products.

Annually more than 500 mcm spills at upper Mahaweli and Kelani reservoirs. To increase the benefits it is suggested to reduce the tariff on power during November and December, so that the spill water can be used for power generation due to increase of power demand. If we have good storage like Moragahakanda in the Ambanganga system part of the water that spills now can be diverted at Polgalla and stored in Moragahakanda reservoir.

If the Moragahakanda reservoir is constructed the cropping extents in System H,D,G can be increased to two since a proposed new NCP (North Central Province) canal starting from Moragahakanda reservoir can take water to Anuradhapura city tank as well as to Huruluwewa tank.

By constructing a new canal just up stream of Minipe LB canal water can be taken to Minneriya and other tanks in System D1. Still only 1/3 of the extent has been developed down stream of Minipe for irrigation and water is lost.

In future Maduruoya RB, System A Kaudulla has to be developed for agriculture and few more reservoirs like Upper Kotmale, Moragahakanda, Kaluganga, Uma Oya projects to be constructed to meet the future power and irrigation demands of the country.

Due to availability of Mahaweli water in dry zone, districts like Anuradhapura, Polonnaruwa and Trincomalee have been benefited a lot. If not for the Mahaweli Project these people would have migrated to the wet zone areas and created a lot of problems in these areas and this therefore is of some benefit to the country overall.

Due to regulation of water, flood damage in downstream areas has been reduced and the reliability of water supply has been granted not only for irrigation but for the domestic needs of urban and rural population living in these areas.

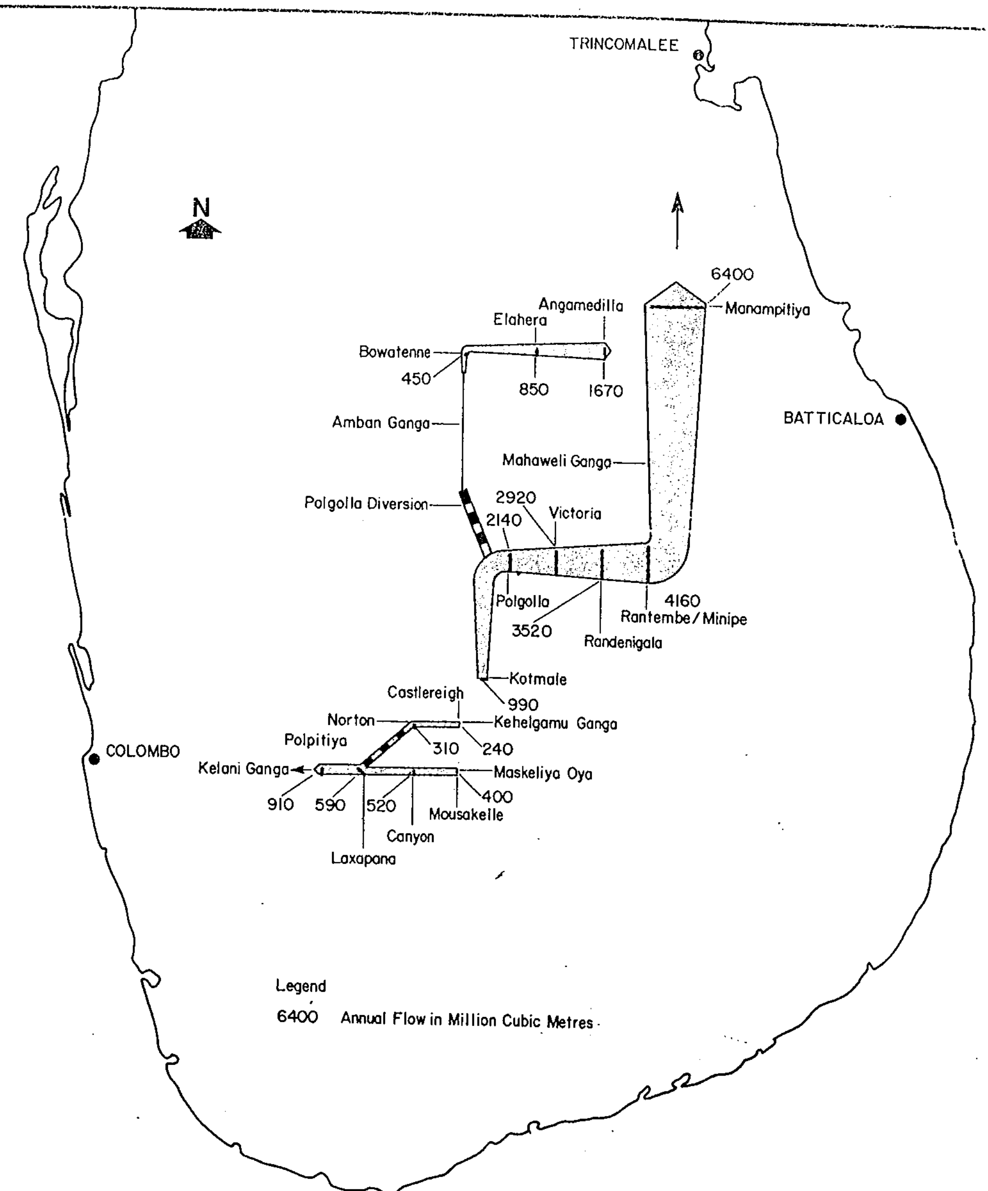

Figure 2
STREAMFLOW VOLUMES IN THE MAHAWELI AND KELANI GANGA SYSTEMS

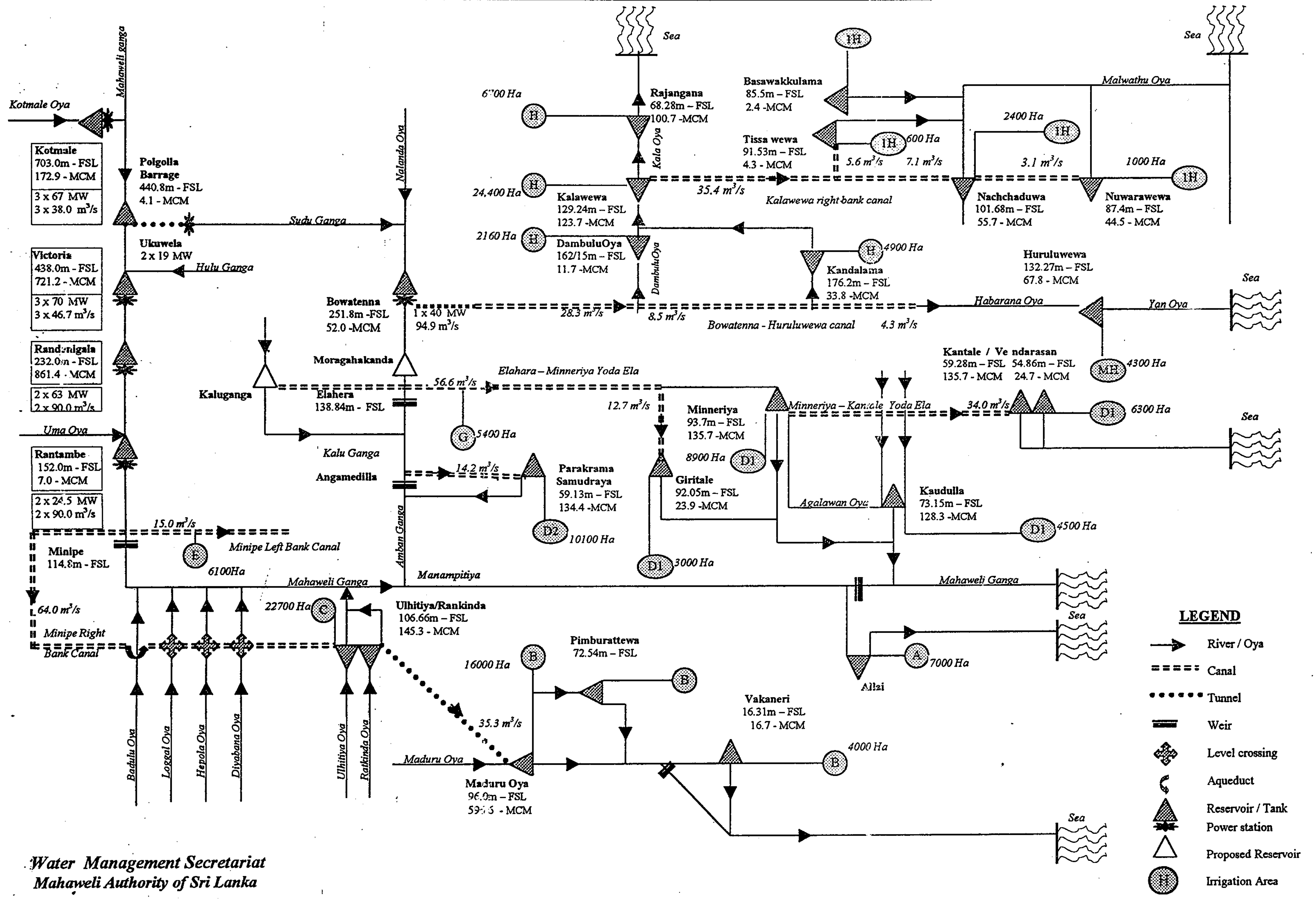
Kotmale Oya
Mahaweli ganga
Kotmale
703.0m - FSL
172.9 - MCM
3 x 67 MW
3 x 38.0 m3/s
Polgolla
Barrage
440.8m - FSL
4.1 - MCM
Ukuwela
2 x 19 MW
Sudu Ganga
Hulu Ganga
Victoria
438.0m - FSL
721.2 - MCM
3 x 70 MW
3 x 46.7 m3/s
Randenigala
232.0m - FSL
861.4 - MCM
2 x 63 MW
2 x 90.0 m3/s
Uma Oya
Rantambe
152.0m - FSL
7.0 - MCM
2 x 24.5 MW
2 x 90.0 m3/s
15.0 m3/s
Minipe Left Bank Canal
Minipe
114.8m - FSL
6100Ha
64.0 m3/s
Minipe Right
Bank Canal
Badulu Oya
Loggal Oya
Hepola Oya
Diyabana Oya
Nalanda Oya
Bowatenna
251.8m -FSL
52.0 -MCM
1 x 40 MW
94.9 m3/s
Moragahakanda
Kaluganga
Elahera
138.84m - FSL
Kalu Ganga
Angamedilla
Amban Ganga
Manampitiya
Mahaweli Ganga
22700 Ha
Ulhitiya/Rankinda
106.66m – FSL
145.3 - MCM
Ulhitiya Oya
Ratkinda Oya
Maduru Oya
Maduru Oya
96.0m – FSL
- MCM
35.3 m3/s
16000 Ha
Pimburattewa
72.54m – FSL
Vakaneri
16.31m – FSL
16.7 - MCM
4000 Ha
Allai
7000 Ha
Sea
5400 Ha
56.6 m3/s
Elahara – Minneriya Yoda Ela
14.2 m3/s
Parakrama
Samudraya
59.13m – FSL
134.4 -MCM
10100 Ha
12.7 m3/s
Minneriya
93.7m – FSL
135.7 -MCM
8900 Ha
Giritale
92.05m – FSL
23.9 -MCM
3000 Ha
Minneriya – Kantale Yoda Ela
Agalawan Oya
Kaudulla
73.15m – FSL
128.3 -MCM
4500 Ha
34.0 m3/s
Kantale / Vendarasan
59.28m – FSL 54.86m – FSL
135.7 - MCM 24.7 - MCM
6300 Ha
4300 Ha
Yan Oya
Habarana Oya
Huruluwewa
132.27m – FSL
67.8 - MCM
Bowatenna - Huruluwewa canal
28.3 m3/s
8.5 m3/s
4.3 m3/s
Kandalama
176.2m – FSL
33.8 -MCM
4900 Ha
DambuluOya
162/15m – FSL
11.7 -MCM
2160 Ha
Kalawewa
129.24m – FSL
123.7 -MCM
24,400 Ha
Kala Oya
Rajangana
68.28m – FSL
100.7 -MCM
6700 Ha
35.4 m3/s
Kalawewa right bank canal
Tissa wewa
91.53m – FSL
4.3 - MCM
600 Ha
5.6 m3/s
7.1 m3/s
Basawakkulama
85.5m – FSL
2.4 -MCM
Malwathu Oya
2400 Ha
3.1 m3/s
1000 Ha
Nachchaduwa
101.68m – FSL
55.7 - MCM
Nuwarawewa
87.4m – FSL
44.5 - MCM
LEGEND
River / Oya
Canal
Tunnel
Weir
Level crossing
Aqueduct
Reservoir / Tank
Power station
Proposed Reservoir
Irrigation Area
Water Management Secretariat
Mahaweli Authority of Sri Lanka

Table 1 : **SUMMARY OF CROPPING DATA**

System	Scheme	Avail Area (ha)	Proposed Crop %	Type	Area (ha)	Water Issue 1st Date	Last Date
H,IH,MH	Dambulu Oya	2160	95	Paddy	2060	Oct 15	Mar 15
			5	Upland	100	Oct 15	Mar 15
	Kandalama	4900	95	Paddy	4650	Oct 15	Mar 15
			5	Upland	250	Oct 15	Mar 15
	Huruluwewa	4300	100	Paddy	4300	Oct 15	Mar 15
	Feeder Canal`	1500	100	Upland	1500	Jan 01	Apr 30
	Kalawewa RB	13565	95	Paddy	12890	Oct 01	Feb 28
			5	Upland	675	Oct 01	Feb 28
	Kalawewa YE	4700	95	Paddy	4450	Oct 15	Mar 15
			5	Upland	230	Oct 15	Mar 15
	Kalawewa LB	6100	95	Paddy	5800	Oct 15	Mar 15
			5	Upland	300	Oct 15	Mar 15
	Nachchaduwa	2500	100	Paddy	2500	Oct 10	Feb 28
	Nuwarawewa	972	100	Paddy	972	Oct 10	Feb 28
	Tissawewa	600	100	Paddy	600	Oct 10	Feb 28
D1 & G	Elahera	5400	96	Paddy	5100	Oct 15	Mar 15
			4	Upland	300	Oct 15	Mar 15
	Giritale	3036	100	Paddy	3036	Oct 15	Feb 28
	Minneriya	8900	100	Paddy	8900	Oct 15	Feb 28
	Kaudulla	4500	100	Paddy	4500	Oct 15	Feb 28
	Kantale	6143	100	Paddy	6143	Oct 15	Feb 28
D2	Parakrama Sam	10100	100	Paddy	10100	Oct 10	Feb 28
E	Minipe LB	6100	100	Paddy	6100	Oct 10	Feb 28
	Ulhitiya	22700	96	Paddy	21800	Oct 01	Feb 28
	Maduruoya	16000	95	Paddy	15300	Oct 01	Feb 28
	Vakeneri	4000	100	Paddy	4000	Oct 15	Feb 28
A	Allai	7000	100	Paddy	7000	Oct 15	Feb 28
Z	Udawalawe RB	11900	66	Paddy	7902	Sep 21	Feb 28
			34	Upland	4050	Sep 21	Feb 28
	Udawalawe LB	5820	62	Paddy	3630	Sep 25	Feb 28
			38	Upland	1947	Sep 25	Feb 28
	Liyangastota LB	2554	100	Paddy	2554	Sep 20	Jan 30
	Liyangastota RB	2455	100	Paddy	2455	Oct 20	Feb 28
	Kaltota	915	100	Paddy	915	Oct 01	Mar 30

Table 2 - Polgolla Power and Spill Releases

Spill Release (mcm) POLGOLLA BARRAGE Historic data

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1984	63.6	49.5	40.6	109.6	18.4	149.2	471.1	78.9	118.0	171.3	49.3	27.1	1346.6
1985	40.5	8.0	8.9	21.0	94.2	720.9	419.2	137.4	22.5	179.9	285.9	64.5	2002.9
1986	301.7	93.0	111.9	172.5	102.2	50.2	33.5	151.6	204.4	356.7	212.6	2.8	1793.1
1987	1.6	4.3	1.8	1.9	26.3	54.3	52.3	62.2	228.2	326.9	207.6	43.9	1011.3
1988	3.4	4.8	21.1	76.6	47.1	67.2	228.6	294.1	366.7	179.4	193.5	24.3	1506.8
1989	20.8	0.4	3.6	5.9	57.1	319.0	573.6	277.4	217.4	181.0	359.6	91.4	2107.2
1990	148.9	12.3	17.0	0.1	66.5	95.0	101.2	90.4	35.8	60.0	98.8	21.2	747.0
1991	42.3	1.8	0.4	5.0	0.0	82.7	27.3	23.0	25.8	87.0	53.0	70.1	418.4
1992	39.7	4.9	0.0	16.8	32.5	83.1	171.0	217.4	120.8	156.0	135.3	92.4	1069.9
1993	4.8	0.2	0.0	0.0	84.2	296.7	238.9	79.0	6.0	136.4	213.8	217.1	1277.1
1994	131.3	89.9	9.6	5.6	19.4	17.4	12.7	81.6	59.5	214.2	305.7	155.2	1102.0
1995	21.7	30.7	10.0	68.6	274.8	207.8	57.0	75.3	135.6	229.0	215.0	28.6	1354.1
1996	2.9	3.8	4.0	60.5	4.5	71.0	81.3	95.2	202.8	251.6	64.9	46.2	888.6
1997	4.2	0.2	3.5	35.4	99.0	12.8	55.9	39.5	187.4	168.6	260.4	165.1	1032.0
1998	45.2	3.9	13.0	0.0	11.7	35.7	89.6						
AVG	59.1	21.7	16.6	41.4	66.2	159.1	180.2	121.6	137.9	192.7	189.7	75.0	1261.2
STD	80.9	31.4	28.5	49.3	67.0	181.0	177.0	81.7	99.4	77.9	94.1	61.2	456.4
MAX	301.7	93.0	111.9	172.5	274.8	720.9	573.6	294.1	366.7	356.7	359.6	217.1	2107.2
MIN	1.6	0.2	0.0	0.0	0.0	12.8	12.7	23.0	6.0	60.0	49.3	2.8	418.4

Power Release/Polgolla Div. (mcm) POLGOLLA BARRAGE Historic data

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1984	142.1	123.4	126.0	132.4	115.7	144.8	145.9	90.7	75.2	139.7	131.3	74.7	1441.9
1985	74.9	24.0	15.1	50.2	79.5	115.3	139.5	130.8	120.0	124.0	117.8	107.5	1098.6
1986	64.7	53.2	39.9	35.6	87.5	118.6	124.3	105.7	72.9	62.6	63.6	91.3	919.9
1987	60.2	53.9	23.6	46.7	52.3	83.8	51.3	58.0	0.0	0.0	80.2	124.9	634.9
1988	98.1	74.1	54.1	32.3	100.2	120.5	81.2	49.6	0.0	14.0	65.6	121.2	810.9
1989	99.0	78.1	56.5	38.0	57.9	63.5	85.1	110.3	114.2	112.6	80.4	82.1	977.7
1990	38.5	104.0	101.9	61.3	91.7	134.2	129.4	129.7	113.4	64.1	103.9	84.9	1156.8
1991	52.5	92.1	60.8	42.5	42.9	116.9	122.6	129.3	104.0	92.0	124.8	68.1	1048.5
1992	47.4	69.4	32.1	8.5	12.8	87.1	110.0	115.6	111.3	144.8	123.8	60.6	923.4
1993	72.8	60.3	17.4	24.3	59.9	105.2	148.1	138.0	140.0	114.2	75.9	13.4	969.3
1994	12.8	19.0	54.0	59.2	109.7	119.6	89.4	121.7	94.8	84.7	18.3	7.2	790.2
1995	60.8	34.2	59.6	44.3	32.6	82.5	133.0	117.8	97.9	124.2	69.3	99.2	955.4
1996	83.8	57.0	19.4	37.2	25.2	20.8	66.6	82.2	92.2	123.8	133.4	103.1	844.7
1997	75.3	57.5	12.8	38.4	53.0	65.5	103.5	91.1	43.3	116.0	73.2	28.2	757.7
1998	31.2	54.7	63.9	25.9	66.1	101.7	120.0						
AVG	70.2	64.3	48.1	46.5	65.8	98.5	109.3	105.0	84.2	94.0	90.1	76.2	952.1
STD	29.7	28.1	32.1	27.1	31.0	32.0	29.4	26.4	41.1	42.9	32.1	36.1	191.1
MAX	142.1	123.4	126.0	132.4	115.7	144.8	148.1	138.0	140.0	144.8	133.4	124.9	1441.9
MIN	12.8	19.0	12.8	8.5	12.8	20.8	51.3	49.6	0.0	0.0	18.3	7.2	634.9

ශ්‍රී ලංකාව තුල ඒකාබද්ධ ජල පරිහරණයෙන් ලැබිය හැකි ආර්ථිකමය වාසි

ඩබ්ලියු ඩී එස් අබේවික්‍රම

වාරි කළමණාකරන ඒකකය, දකුණු කලාප නියෝජ්‍ය වාරිමාර්ග අධ්‍යක්ෂ කාර්යාලයේ, දෙබරවැව, තිස්සමහරාම, ශ්‍රී ලංකා

සංක්ෂිප්තය (*ABSTRACT*)

ජලය ඉතා අගනා ස්වාභාවික සම්පතකි. ලෝක ජනගහනය වර්ධනය වීමත් සමග ගෘහස්ථ, කෘෂිකාර්මික සහ කාර්මික ජල භාවිතයත් ඉහල යයි. මෙය නිශ්චිත ස්වාභාවික සම්පත් ප්‍රමාණයක් මත ඉහල යන ස්වාභාවික සම්පත් ඉල්ලුම සපුරා ගැනීම දැඩි ගැටලුවකි. මෙම ගැටලුවට මුහුණ දීමට ජල සම්පත නියමිත ලෙස සැලසුම් කිරීම,සංවර්ධනය කිරීම, කළමණාකරනය සිදු කිරීම සහ අවම ජල පරිමාවකින් උපරිම ඵලදායීතාවයක් ලබා ගැනීමට අවශ්‍ය විවිධ අත්දමේ පර්යේෂණ සහ එහි ප්‍රථිඵල මත වඩාත් වාසි දායක ව්‍යාපෘති හඳුන්වාදීම කල යුතු වේ.

මෙම පත්‍රිකාවෙන් සාකච්ඡාවට භාජනය කරන්නේ අවම ජල පරිමාවකින් උපරිම ඵලදායීතාවයක් ලබාගැනීම මෙන්ම නූතන සමාජයේ වඩා ඉහල ආර්ථිකමය ප්‍රථිලාභ මෙන්ම සමාජ අවශ්‍යතාවයන් සඳහා එකම ජල පරිමාවක් යොදාගෙන එය කිසිදු වියදමක් දැරීමකින් පිරිසිදු කිරීමක් සිදු නොකර විසිතුරු මසුන් වගාවකට යොදාගෙන ඉන් පසුව එය ආහාරය සඳහා ගන්නා මිරිදිය මසුන් වගාවකට යොදා ගෙන අවසානයේ Drip Irrigation මගින් කෘෂිකර්මාන්තයට යොදාගන්නා පරීක්ෂණයක් සහ එහි ප්‍රථිඵල ආශ්‍රිතවයි.

ඉදිරිපත් කිරීම (*INTRODUCTION*)

විසිතුරු මසුන් වගා කිරීම:

මෙහිදී මුල්ම අවස්ථාවේදී $P^H=6.5$, Hardness = 40 mg l^{-1} ජලය යොදාගෙන අපනයන තත්වයේ සුරතල් මසුන් ඇති කලහ. සුරතල් මසුන් ඇති කිරීම ආර්ථිකමය වාසි දායක කර්මාන්තයකි. මෙමගින් රටට විශාල විදේශ විනිමය ලබාගත හැකි අතර විරැකියාවද යම් ප්‍රමාණයකින් අඩු කල හැක. මෙම කාර්මාන්තයේ ඇති විශේෂත්වයක් වන්නේ ආර්ථිකමය වාසි ලැබීමට අමතරව මෙම කර්මාන්තය පරිසර පද්ධතියට සහ ස්වාභාවික සම්පත්වලට

අහිතකර බලපෑම් අවම මට්ටමක පැවතීමය. ලොව සුරතල් මසුන් අපනයනයෙන් 90% පමණ ආසියානු රටවල් වන පිලිපීනය, චීනය, තායිවානය, ඉන්දුනීසියාව, ඉන්දියාව, සිංගප්පූරුව සහ ශ්‍රී ලංකාව මගින් සිදු කෙරේ. ශ්‍රී ලංකාවට මෙම කර්මාන්තයේ ඉදිරියට යාම සඳහා අවශ්‍ය සියලුම සම්පත් ඇත.

සුරතල් මසුන් ලෙස ගප්පි (*Poecilia reticulata*) යොදා ගත්හ. මොවුන් පැටව් බිහිවූ අවස්ථාවේ සිට අපනයනයට සුදුසු තත්වයට වර්ධනය වීමට දින 70 - 80 අතර කාලයක් ගත වේ. මෙහිදී වර්ධනය සඳහා පැටව් 3m x 3m ටැංකිවල පිරිමි පැටව් 925 ක් දැමූහ. එම ටැංකියේ ජලය 0.3m උසට තබයි. මෙහිදී මසුන් සූක්ෂම අන්දමෙන් වගාකරන නිසා අපනයනයට සුදුසු අන්දමේ තත්වයෙන් තබා ගැනීමට දිනකට තෙවරක් ආහාර සැපයිය යුතුය. බැක්ටීරියා සහ දිලීර මගින් වැළඳෙන රෝග වලින් ආරක්ෂා කිරීමටත් ශරීරයේ පැහැය සහ වර්ධනය හොඳතත්වයෙන් පවත්වා ගැනීමටත් නිරතුරුව දූෂිත ජලය ඉවත්කර අලුතෙන් ජලය සැපයිය යුතුය. මෙලෙස මසුන් සූක්ෂම අන්දමෙන් වගාකිරීමට ඇති ප්‍රධාන බාධකය නම් ජලයේ නයිට්‍රයිට් සහ ඇමෝනියා ප්‍රමාණය ඉහල යාමයි. මෙය මසුන්ට විෂ වේ. මෙය මසුන්ට දරා ගත හැකි මට්ටම $1\ mg\ l^{-}$ වඩා අඩු මට්ටමක විය යුතුයි. (Liao and Mayo, 1972; Otte and Rosenthal, 1979; Poxton and Allhouse, 1982) මෙලෙස ජලයේ විෂ තත්වයන් ඇතිවීමට ප්‍රධාන හේතුව නම් මසුන්ගේ මලද්‍රව්‍ය සහ මසුන් ආහාරයට නොගෙන ඉතිරි වන ආහාර ද්‍රව්‍ය නරක් වීමෙන්ය. මෙම තත්වය වලක්වා ගනිමින් මසුන් ප්‍රශස්ත තත්වය යටතේ වගාකිරීමට නම් දිනපතා ටැංකියක ජලය 0.1m ඉවත් කර නැවත පිරවීම කළහ. දවස් 10 ට වරක් සම්පූර්ණයෙන්ම ජලය ඉවත්කර නැවතපිරවීම කළහ.

මිරිදිය මසුන් ඇතිකිරීම:

මෙහිදී ඉවත් කරන ජලය පහල පිහිටි මඩ පොකුණකට රැස්කරන ලදහ. මේ මඩ පොකුණ පතුලේ දිය සීරාව සහිත විය. මේ නිසා මෙමගින් කාන්දුවන ජල ප්‍රමාණය පිළිබඳව පැහැදිලිව නිගමනය කිරීමට නොහැකි විය. මෙම මඩ පොකුණේ ප්‍රමාණය 10mx 10m විය. මෙහි ජලවාංග මත යැපෙන මත්ස්‍ය විශේෂයක් වන "තිලාපියා නයිලොටිකා" මසුන් පැටව් 2500 ක් දැමූහ. මෙම ජලය නයිට්‍රයිට සහ ඇමෝනියා වලින් සරු නිසා එම ජලයේ ජලවාංග හොඳින් වැඩේ.අස්වැන්න නෙලන විට ඉතිරි වී සිටියේ මසුන් 1890ක් පමණි. නමුත් අලුතෙන් මසුන් පැටව් ඇතිවී තිබුනි. ඔවුන් මෙම ගණනය කිරීම සඳහා භාවිතා නොකළහ. මඩ පොකුණේ මසුන් බහා සති 3 ක් පමණ කාලයක් ගත වූ පසු පොකුණ විශාල ලෙස කොළ පැහැති විය. එය "Algae bloom" ලෙස හඳුනාගත් අතර එය ප්‍රධාන වශයෙන් *Nostoc* නැමති නීලහරිත ඇල්ගාව නිසා ඇති වන බව පරීක්ෂණ වලින් වැටහිනි. ඉන් පසු එය අතින්

ඉවත් කල අතර ඉන් පසු මාලු ටැංකි වල සිට එවන ජලය මයික්‍රෝන1000 දැලකින් පෙරා එවීමට පටන්ගත් අතර මින් පසු එවැනි තත්වයක් නිරීක්ෂණය කිරීමට නොහැකිවිය. මෙම මසුන් මාස 6න් පසු අස්වැන්න නෙලූ අතර එහිදී 01 වන වගුවේ දැක්වෙන ලෙස බර නිරීක්ෂණය විය.

අප රටේ ජනතාවට ප්‍රෝටීන් අවශ්‍යතාවය මූලික ලෙස දෙන්නේ මත්ස්‍ය පරිභෝජනයෙනි. වෙරළබඩින් ලබාගන්නා මත්ස්‍ය අස්වැන්න ප්‍රශස්ත සීමාවකට ලගාවී ඇති නිසාත්, කරදිය මත්ස්‍ය මිල අධිකවීම නිසාත් දුප්පත් ජනතාවට අවශ්‍ය ප්‍රෝටීන් ප්‍රමාණය නිසි ලෙස නොලැබීම නිසා ශාරීරික සහ මානසික වර්ධනය අඩු වේ. මෙම තත්වයට ඇති එකම විකල්පය නම් ලාභයට ලබාගත හැකි මිරිදිය මත්ස්‍ය වගාව වැඩි දියුණු කිරීමයි. මෙය ඉතා විශාල සමාජ මෙහෙවරකි.

කෘෂිකර්මාන්තයට:

ඉහත භාවිතා කල ජලය යොදාගෙන Drip Irrigation මගින් කෙසෙල් වගාවක් සඳහා ජලය සපයයි. මෙහිදී කෙසෙල් පැලය සිටවූ අවස්ථාවේ සිට මාස **3** ක් යන තෙක් දිනකට ලීටර් 4 බැගින් ලබා දුනි. ඉන් පසුව සිට මේ දක්වා (දැනට මාස 8 ක් පමණ වේ) දිනකට ලීටර් 8 බැගින් ලබා දෙයි. ඒ සමගම පැලකල මේ වර්ගයේම කෙසෙල් පැල සඳහා මතු පිටින් ජලය යොදයි. එයට ආසන්න වශයෙන් දිනකට ලීටර් 40ක් පමණ ගසකට අවශ්‍ය වේ. මෙලෙස ජලය සැපයීම නිසා හටගන්නා කෙසෙල් ගස් බාහිර පෙනුමෙන් හොඳින් වර්ධනය වන අතර ජල හිඟ බවක් ගසෙන් පෙන්නුම් නොකරයි. නමුත් මෙහි ඵලදාව හටගෙන නොමැති බැවින් මෙලෙස ජලය සැපයීම නිසා කෙසෙල් කැනේ ප්‍රමාණය පිලිබඳව අදහස් පලකල නොහැක.

02 වැනි වගුවෙන් මෙම ප්‍රදේශයේ 95, 96, 97 යන වර්ෂවල වර්ෂාපතන සහ වාෂ්පීකරන අගයන් දැක්වේ.

Drip Irrigation මගින් මුළු ක්ෂේත්‍රයටම ජලය යෙදීම සිදුනොකරන අතර, අවශ්‍ය ශාකයට පමණක් ජලය ලබා දේ. මෙහිදී සිදුවන ජල හානිය ඉතා අල්පය. දැනට ගොවි ප්‍රජාව තුල පහත් ආදායම් මට්ටමක් පවතින්නේ කෘෂිකර්මාන්තයේ ඵලදායීතාවය ඉතා අඩු වීම නිසාය. මෙම ඵලදායිතාවය වැඩි කිරීමට නම් ඔවුන් නවීන විද්‍යාත්මක කෘෂිකර්ම ක්‍රම ඒ සඳහා යොදාගත යුතුය. ඒ සඳහා ආකල්ප වෙනස් කිරීමට මින් ලද හැකි දායකත්වය විශාලයි. තවද ඔවුන් යම් භෝගයකට අවශ්‍ය ජල ප්‍රමාණයට වඩා ඉතා වැඩියෙන් ජලය භාවිතා කිරීම නිසාද ඵලදායීතාවය අඩුවේ. ඉහත ක්‍රමය නිසා ඔවුනට අවශ්‍ය ජල ප්‍රමාණය ගැන නියම අදහසක් ඇතිවේ.

මසුන්ගේ බර (ග්‍රෑම්)	මසුන් මුළු සංඛ්‍යාව ප්‍රතිශතයක් ලෙස	සම්පූර්ණ මසුන් ගේ බර :කි ග්‍රෑ
175 අඩු	20%	62
175 200 අතර	27%	96
-200˚ 225 අතර	40%	162
225 වැඩි	13%	57
එකතුව		377

1 වගුව˚ අස්වැන්න නෙලීමෙන් පසු මසුන්ගේ බර පංතිය සහ එම පංතියේ සිටින මසුන් ප්‍රතිශතය සහ මසුන්ගේ සම්පූර්ණ බර

මාසය	වර්ෂාපතනය			වාෂ්පිකරනය		
	94/95	95/96	96/97	94/95	95/96	96/97
ජනවාරි	45.4	241.5	12.3	82.2	93	96.4
පෙබරවාරි	20.1	135.4	19.5	86	103	54.9
මාර්තු	34.8	9.9	61.3	143.9	157.9	128.1
අප්‍රේල්	359.9	306.1	122.7	109.7	100.2	122.2
මැයි	353.5	121.3	406.1	82.1	126.8	109
ජූනි	525.4	220.5	260.9	113.5	83.6	75.8
ජූලි	141.5	323.3	246.6	89.2	64.2	81.6
අගෝස්තු	176.2	240.6	160.9	142.4	107.9	113.4
සැප්තැම්බර්	207.9	463.6	542	104.46	134.6	57.2
ඔක්තෝම්බර්	293	385.96	247.3	67.5	104.5	85.4
නොවැම්බර්	447	713.7	371.1	86.96	121	92.7
දෙසැම්බර්	163.1	62.4	189.8	78.7	60.9	85.2

2 වගුව˚ මෙම පර්යේෂණය සිදුවූ බෝඹුවල ප්‍රදේශයේ 95 96 97 යන වර්ෂවල වර්ෂාපතන සහ වාෂ්පිකරන අගයන් (ප්‍රභවය වාරිමාර්ග දෙපාර්තමේන්තුව)

මෙම පර්යේෂණ පත්‍රිකාවේ මූලික අදහස වන්නේ ජල පර්යේෂණයන් හා ජල භාවිතයෙන් විවිධ ආර්ථිකමය නුතන කරුණු බැවින්ද මෙම පත්‍රිකාව දීර්ඝවීම වැලැක්වීම සඳහාද මෙම පත්‍රිකාවේ ප්‍රතිපත්තිමය අනුමිතියන්ට හානියක් නොවන අයුරින් පහත සඳහන් උපකල්පනයට එළඹී ඇත.

මෙහිදී සිදුකරන වගාවන් තුළදී ජලයට අමතරව ඒ සඳහා අවශ්‍ය අනෙකුත් අමු ද්‍රව්‍යවල මිල අතර ඉතා විශාල පරතරයක් නොමැත.

උදා:- එක් මත්ස්‍ය පැටවකු අපනයන තත්වයට වර්ධනය කිරීම තෙක් බෙහෙත් සහ ආහාර වලට වැයවන්නේ ශත 60 ක පමණ මුදලකි. drip Irrigation මගින් සිදු කරන වගාවේදී එම ගසට අවශ්‍ය පොහොර එම ජලයේ දියකර එවන බැවින් සාමාන්‍ය අවස්ථාවට වඩා අඩු මුදලක් පොහොර සඳහා වැය වේ.

මේ අනුව එම වියදම් මෙම පත්‍රිකාවේ ගනනය කිරීම් වලට එකතු නොකිරීමට උපකල්පනය කර එම එක් එක් වගාවේදී ජලයට ලැබෙන ආර්ථිකමය වටිනාකම පමණක් ගනනය කර ඇත.

විසිතුරු මසුන් ඇති කිරීමට අවශ්‍ය ජල ප්‍රමාණය (1 ටැංකියකට)

ටැංකියේ ජල පරිමාව $= 3 \times 3 \times .3 = 2.7m^3$

මෙහිදී මුල් දින 20 අතර ජලය ඉවත් කිරීමක් සිදු නොකරන අතර දින 20-30 දක්වා එක වරක් ජලය සම්පූර්ණයෙන් ඉවත් කරයි. ඉන් පසු දින 80 වන තෙක්ම ජලය ඉවත් කිරීම සිදුකරයි.

දිනකට ඉවත් කරන ජල ප්‍රමාණය $= 3 \times 3 \times .1 = .9m^3$

මේ අනුව දින 10 ට ඉවත්කරන ජල ප්‍රමාණය $= .9 \times 9 + 2.7 = 10.8m^3$

දින 50 කට අවශ්‍ය ජල ප්‍රමාණය $= 10.8 \times .5 = 54m^3$

සම්පූර්ණ මසුන් වර්ධනය කාලයතුල

අවශ්‍ය ජල ප්‍රමාණය $= 5.4 + 54 = 58.4m^3$

පිරිමි ගප්පියකුගේ අපනයන වටිනාකම දළ වශයෙන් රු.10/- ක් පමණ වේ.

මෙම ටැංකියේ අපනයන තත්වයේ මසුන් 810 සිටින ලදී.

මේ නිසා මෙම මසුන්ගේ ආර්ථිකමය වටිනාකම =810x10= රු.8100/-

ජලය $58.4m^3$ නිසා ලැබුනු ආර්ථිකමය වටිනාකම = රු. 8100/-

ජලය $1m^3$,, ,, ,, ,, $= \frac{8100}{58.4}$

රු.138.6

කෙසෙල් ගසක් ක්‍ෂෙත්‍රයෙන් සිටවූ කාලයේ සිට අස්වැන්න ලැබෙන තෙක් (අවුරුද්දක පමණ කාලයක්) එක ගසකට දෙන

ජලය ප්‍රමාණය = 8L x 360 = 2880
= $2.88m^3$

කෙසෙල් ගසකින් ලැබෙන ආදායම = රු. 300/- පමණ

ජල $1m^3$ ලැබෙන ආර්ථිකමය වටිනාකම = $\frac{300}{2.88}$
= රු.104.16

වී වගාවේදී ජලයට ලැබෙන ආර්ථිකමය වටිනාකම ගනනය කලවිට

$4047m^2$ (අක්කරයකින්) ඇති කුඹුරක වී වගාව සඳහා අවශ්‍ය

සම්පූර්ණ ජල ප්‍රමාණය = $4047m^2$ x 1.52m
= $6151.4m^3$

මින් ලැබෙන වී අස්වැන්න = 115 x 23 Kg
= 2645 Kg

වී 1Kg ක මිල රු.10 යැයි සැලකූ විට

මින් ලැබෙන ආදායම = රු.26450/-

මෙම වගාවේදී ජලය $1m^3$,ලැබෙන

ආර්ථිකමය වටිනාකම = $\frac{26450}{6151.4}$
=රු.4.30/-

මෙලෙස ඒකාබද්ධ වගාව මගින් සිදුවන ආර්ථික ප්‍රතිලාභ විගොවිතැනට සාපේක්ෂව ගත් විට විසිතුරු මසුන් ඇති කිරීමෙන් වී ගොවිතැනට වඩා **30** ගුණයක් පමණද, Drip Irrigation මගින් වී ගොවිතැනට වඩා **23** ගුණයක් පමණද ආර්ථිකමය වටිනාකමක් ජලයට ලැබේ.

නිගමනය (*Conclusions*)

1. ලංකාව තුල ජලය ඵලදායීලෙස භාවිතාකිරීමේ ප්‍රවනතාවය සාපේක්ෂව පහල මට්ටමක පවතී.මෙම තත්වයෙන් මිදීමට ගතහැකි එකම විකල්පය නම් ජල පර්යේෂණයන් තව තවත්සිදු කරමින් ජලයේ ඵලදායීතාවය ඉහල නැංවීමයි. තවද ශ්‍රී ලංකාවේ කෘෂිකර්මාන්තය ඇත්තේ සහනාධාර මත යැපෙන තත්වයකය. මෙම තත්වයෙන් මිදී වාතිජමය තත්වයකට පත්කල යුතුය. නැතහොත් 2001 දී බිහිවන "SAFTA" ගිවිසුම යටතේ බිහිවන නිදහස් වෙළඳ කලාපය යටතේ ඵලදායීතාවය ඉහල රටවලින් පාලනය කිරීමකින් තොරව කෘෂි ද්‍රව්‍ය අපනයනය කිරීමෙන් අප රටේ කෘෂිකර්මාන්තය තව තවත් ප්‍රපාතයට ඇද වැටේ.

2. තරුණ ශ්‍රමිකයින් කෘෂිකර්මාන්තයට එක් වීම ඉතා පහළ මට්ටමක පවතී. මෙයට ප්‍රධානතම හේතුව වන්නේ අප රටේ තවම පවතින්නේ පාරම්පරික කෘෂිකර්මාන්තය බැවින් එහි අඩු ඵලදායීතාවය නිසා ලැබෙන ලාභය අඩු වීම නිසාය. මේ නිසා මෙවැනි පර්යේෂණ වලින් ඵලදායීතාවය වැඩිය. ඒ නිසා ලැබෙන ලාභය වැඩි ව්‍යාපෘති හඳුන්වාදීම මගින් විරැකියාවෙන් පෙළෙන තරුණයන්ට ස්වයං රැකියා ලෙස මෙවැනි ව්‍යාපෘති ආරම්භ කිරීමට යොමු කල හැක. විශේෂයෙන්ම විරැකියාවෙන් පෙළෙන උපාධිධාරීන් හා කෘෂිකර්ම ඩිප්ලෝමාධාරීන් සඳහා.

3. ලෝක කාර්මීකරණයත් සමඟ පරිසර දූෂණය විශාල ප්‍රශ්ණයක් වී ඇත. එහෙත් මෙම ව්‍යාපෘතිය මගින් එවැනි පරිසර දූෂණයක් සිදු නොවේ. මෙම කර්මාන්තයේ තවත් අරමුණක් වන්නේ අප රටේ වැඩි වැඩියෙන් මෙවැනි පරිසරයට අයහපතක් සිදු නොවන කර්මාන්ත ආරම්භ කරවීමට ප්‍රජාව උනන්දු කරවීමයි.

4. මෙම ව්‍යාපෘතිය වැනි එකම ජල පරිමාව කිහිපවරක් යොදා ගනිමින් සිදු කරන ඵලදායිතාවයෙන් ඉහල ඒකාබද්ධ කර්මාන්ත පිහිටුවීම දිරිමත් කිරීම සඳහා රජය විසින් මෙවැනි ස්වාභාවික සම්පත් ඉතා උපරිම ඵලදායීතාවයකින් භාවිතා කරන කර්මාන්තවලට අය වැය යටතේ විශේෂ සහන ප්‍රධානය කල යුතුය. එමගින් මෙවැනි කර්මාන්ත පිහිටුවීම වර්ධනය වීම මගින් අප රට දිගු කල් පවතින සංවර්ධන මාවතක් සඳහා යොමු කල හැක.

5. මෙම පර්යේෂණයේදී ජලයේ රසායනික හා භෞතික ලක්‍ෂණ කෙරෙහි දැඩි සැලකිල්ලට භාජනය කරමින් පර්යේෂණ සැකිල්ල සාදා ඇත. 1 සහ 2 වන අවස්ථාවෙන් පසුව 3 වන අවස්ථාව වන කෘෂිකර්මාන්තයට ජලය යොදා ගැනීමට පෙර කර්මාන්තශාලාවක යන්ත්‍ර සිසිල් කිරීම වැනි කාර්යයක් සඳහා ද ජලය යොදා ගැනීමෙන් එහි ඵලදායීතාවය තවත් ඉහල නැංවිය හැක. මෙමගින් මා ජල පර්යේෂකයන් මෙවැනි තවත් විවිධ ඒකාබද්ධ කර්මාන්ත සඳහා අවශ්‍ය පර්යේෂණයන්ට යොමු කිරීම එක් බලාපොරොත්තුවකි.

<u>ආශ්‍රිත ග්‍රන්ථ (*Reference*)</u>

1. ශ්‍රී ලංකාවේ ස්වාභාවික සම්පත් - ශ්‍රී ලංකාවේ ස්වාභාවික සම්පත් බලශක්ති සහ විද්‍යා අධිකාරිය උදෙසා පිළියෙල කල වාර්ථාව 1991 (මිහිකත ආයතනය විසින් ප්‍රකාශයට පත් කෙරිනි.)

2. මත්ස්‍ය නිෂ්පාදනය නැංවීමට ජල ජීවිවගාව — ඒ.එම්.ජයසේකර, අධ්‍යක්ෂක ජල ජීවි වගා සංවර්ධන අංශය

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