WORKING PAPER 44

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Contents

Terms and Abbreviations

AS	Agrarian Service
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
DTCM	Detailed Tank Cascade Model
EC	Electric Conductivity
ET	Evapotranspiration
ET_0	Reference Evapotranspiration
FAO	Food and Agricultural Organization of the United Nations
FSL	Field Supply Level
HIRDP	Hambantota Integrated Rural Development Program
HUC	Hambantota Urban Council
IR	Infra-Red band (for satellite images)
IWMI	International Water Management Institute
JBIC	Japanese Bank for International Cooperation
LBMC	Left Bank Main Channel of Uda Walawe Irrigation Scheme
MAP	Mean Annual Precipitation
MASL	Mahaweli Authority of Sri Lanka
MCM	Million Cubic Meters
NBRO	National Building Research Organization
NGO	Non Governmental Organization
OFC	Other Food Crops/Other Field Crops
Ramsar	Convention on Wetlands signed in Ramsar, Iran in 1971 (www.ramsar.org)
RBMC	Right Bank Main Channel of the Uda Walawe Irrigation Scheme
SAPI	Special Assistance for Project Implementation
SCM	Simplified Catchment model
TCS	Tank Cascade System
WCP	Wetland Conservation Project
WNPS	Wildlife and Nature Protection Society
WSA	Water Spread Area
Lewaya	Lagoon
Tank	Reservoir
Terminal tank	Most downstream tank of a TCS
Maha season	Main cultivation season, October to January
Yala season	Minor cultivation season, April and May
Chena	Shifting cultivation
Ara	Small stream
Oya	Small river
Ganga	Big river

Summary

The extension of the Uda Walawe irrigation scheme in southern Sri Lanka may have a significant ecological impact on the development area and its downstream wetlands. The evaluation of this impact is the subject for a long-term study that is presently being carried out by the International Water Management Institute (IWMI). In this study, the pre-development environmental conditions in the area are being investigated and the changes caused by the new irrigation system will be monitored in the future. Part of this study is a hydrological assessment of the coastal lagoon (Karagan Lewaya) and its small catchment to the south of the development area. The lagoon is likely to receive high quantities of drainage flows from the future scheme. This could deteriorate its water quality and hence affect the suitability of the lagoon as a habitat for migratory birds and might lead to flooding of adjacent settlements.

Models of the lagoon and its catchment were developed to predict the hydrological impacts of irrigation development. The first catchment model included a detailed description of all separate components of the Karagan system (tanks, catchments and paddy fields) and all individual physical and artificial processes which operate in these components (rainfall, evaporation, runoff, water issues, etc.). Lack of required input data was found to be the major constraint for model development, calibration and application in this area. Consequently, a “more lumped” model was developed to be compatible with existing information. The simplified model splits the entire catchment upstream of the Karagan Lagoon into a limited number of components, with similar descriptions of the primary processes. The third model is the model of the lagoon itself. All three models are water balance models—they are set up as spreadsheet applications and operate with a weekly time step.

A monitoring network was set up in order to collect more data for improvement of models and to monitor future changes. A variety of additional data sources, including available hydrological and rainfall observations, tank characteristics, topographical maps and remote sensing images, have been used to provide model input information. Most of the calculations have been carried out using the combination of a simplified catchment model and the lagoon model. Several realistic scenarios pertaining to irrigation development and lagoon management were defined and simulated. They included different levels of inflows from the future scheme into the lagoon, envisaged upstream catchment changes associated with the future scheme and some aspects associated with lagoon management (e.g. flow diversion to the sea). Although the results remain preliminary due to uncertainties associated with data limitations, it was possible to investigate the effects of different scenarios on the hydrology of the lagoon. The results of scenario simulation are expressed in terms of changing lagoon water levels.

Introduction

Part of IWMI's research focuses on assessing the impact of large-scale irrigation systems on the biodiversity of natural ecosystems. One such study monitors the impact of the extension of the Uda Walawe irrigation scheme in southern Sri Lanka. Phase two of the Uda Walawe left bank extension project will extend the main canal by 19 km, divert large quantities of water into the area, irrigate an additional 5150 ha, lead to a major change in land use and facilitate the settlement of almost four thousand families. With completion targeted for 2004, this irrigation project provides a unique opportunity to assess the pre-development status as well as to monitor ongoing changes. A comprehensive assessment includes:

- Hydrology surveys
- Water quality surveys
- Socio-economic surveys
- A biodiversity assessment, i.e., sampling of fauna and flora

The assessment of the pre-development hydrology of the area and possible future impacts caused by the new irrigation system is the subject of this report. A hydrological assessment is of paramount importance for understanding the impact of irrigation on biodiversity. This is especially true for the Uda Walawe left bank extension area that features three brackish water lagoons in its southernmost part: Koholankala Lewaya, Maha Lewaya and Karagan Lewaya, lying within a small catchment, known as Karagan Oya. These wetlands are brackish water ecosystems and are habitats for many animals and plants characteristic of this region. Maha Lewaya and Koholankala Lewaya are part of the Bundala national park, which is recognized as a Ramsar site (www.ramsar.org). Karagan Lewaya is not part of this park, although it was included in the *Directory of Asian Wetlands* as a wetland of international importance (Scott 1989; WCP 1994).

At present there is no connection between Karagan Oya and the large scale Uda Walawe irrigation scheme. After the implementation of the extension project, a significant amount of drainage water from the irrigated areas is expected to flow into these lagoons. This inflow could also contain high amounts of fertilizers and pesticides. However, the main adverse effect is believed to be a change in water levels and a reduction in salinity of the lagoons, which could have significant impacts on the habitat quality. For example, certain bird species characteristic of the region (e.g., the greater flamingo–*Phoenicopterus ruber*), visit mainly brackish wetlands with very low water levels. Many of the brackish water lagoons in southern Sri Lanka are in a degraded condition, with some directly affected by irrigation water flows. As a result, these bird species are compelled to exploit less suitable habitats.

It is possible that other species might appear when the environment changes. In fact, it is believed that in terms of biodiversity, lagoons that turn from brackish to fresh water might even benefit, because the variety of species in brackish water lagoons is usually lower than in fresh water lakes. This has already happened in lagoons in adjacent basins, such as the Embilikala and the Malala lagoon in the Kirindi Oya basin. However, it has also been shown that the total number of birds decreases with higher water levels in these lagoons (Matsuno and van der Hoek 2000; Amerasinghe et al. 2002).

Changes in hydrology of the lagoons, however, do not affect wildlife only, but also have an impact on people living in the surrounding area, particularly those settling close to the banks of lagoons. This is especially the case for Karagan Lewaya with the town of Hambantota on its eastern shores, which will also receive the biggest portion of drainage flows from the future irrigation scheme. Maha Lewaya and Koholankala Lewaya are basically used as salterns, and for that reason were excluded from the current study.

The objectives of this study were:

- To improve the knowledge about the hydrology of the Karagan Lewaya and its catchment area.
- To assess the impacts of the implementation of the Uda Walawe left bank extension project on the hydrology of Karagan Lewaya, particularly on its water levels and salinity.
- To explore means for ongoing monitoring and for a comprehensive assessment of irrigation impacts on the biodiversity of the area.

The methods used were:

- Gathering and comparing existing data about both the lagoon and its catchment in its present state and during the extension project.
- Developing a computer model to simulate the present hydrological behavior of Karagan Lewaya and to predict future changes.
- Setting up a monitoring network to improve the data availability, for calibrating the model and for the on-going monitoring during the extension project implementation.

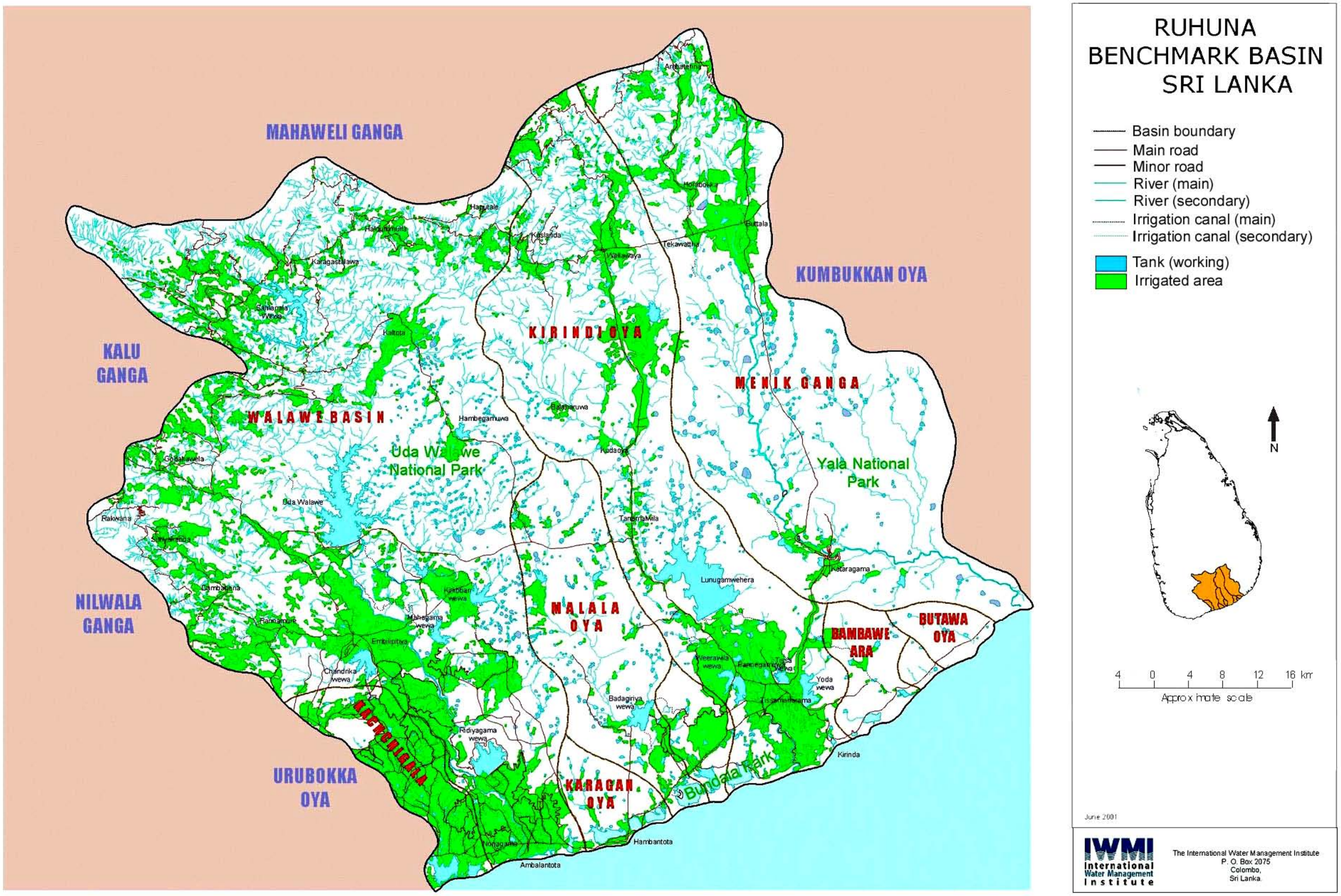
The introductory section describes the background of the study, defines the problem, and summarizes the study objectives and the methodology applied. The study area is described in the next section. An overview of the various sources of information used in this project follows this. The next section describes the monitoring network and its development during the course of the study. The structure and formulae of the developed simulation models are explained next. Model calibration and scenario simulation is described next. A separate section deals with preliminary salt balance modeling. The conclusion and prospects for future work are outlined in the final section.

Description of the Study Area

Uda Walawe Basin and Irrigation Schemes

The Uda Walawe basin is located in the south of Sri Lanka. It is one of several neighboring river catchments often referred to in IWMI publications as the Ruhuna benchmark basin (figure 1). IWMI currently conducts research in several benchmark basins in different countries. Long-term research activities and data sets are developed and maintained in benchmark basins, and identified

Figure 1. A map of the Ruhuna benchmark basin in southern Sri Lanka.



problems related to environment and agricultural development are being resolved together with local partners and stakeholders (Hemakumara et al. 2001).

Irrigation engineering has a long tradition in the Uda Walawe basin, and can be traced back to around 900 A.D. (Brohier 1934). In the twentieth century, several irrigation works were undertaken in the basin. The most important were the constructions of the Liyangastota anicut and the Ridiyagama tank in the 1930s, the Chandrikawewa reservoir in the early 1960s and the Uda Walawe reservoir in the late 1960s, and their associated irrigation schemes. In 1992 the Samanalawewa reservoir in the upper Walawe catchment area was finished, generating hydropower and a steadier inflow into the downstream Uda Walawe reservoir.

The Uda Walawe reservoir, which is also partially used for hydropower generation, has a capacity of 268 million cubic meters (MCM) and feeds both the Uda Walawe right bank main channel (RBMC), with a design discharge of 25 m^3/sec and the Uda Walawe Left Bank Main Channel (LBMC), with a design discharge of 28 m^3/sec. The Walawe development project in the 1970's and the subsequent Walawe irrigation improvement project focused on the development of the right bank area, where presently 9,700 ha of a command area of 12,000 ha are under irrigation. On the left bank of the Walawe Ganga, only 6700 ha in the north were developed, of which 2400 ha are a sugar cane plantation (SAPI 2000). In the rest of the irrigated areas, right bank as well as left bank, rice is the main crop, followed by bananas.

A first feasibility study for the left bank extension project was conducted in 1993, and the construction began in 1995. Of the total area of 15,700 ha of the extension area, roughly 5150 ha will be irrigated. The LBMC will be extended some 19 km to the south, with a design discharge of approximately 9.1 m^3/sec. 3900 families are planned to be settled in the area. At the inflow point into the study area, Karagan Oya, which is located in the south of the extension area, the LBMC has a design discharge of 4.6 m^3/sec (SAPI 2000; Nippon Koei 1999).

Karagan Oya

Located in the southern portion of the left bank extension area, the small Karagan Oya basin combines the areas draining into three coastal lagoons: Karagan Lewaya, Maha Lewaya and Koholankala Lewaya (figure 2). In this study only Karagan Lewaya and its catchment area are considered, because they will receive most of the drainage flows from the extended Uda Walawe irrigation scheme, and because the other two lagoons are used and managed as salterns.

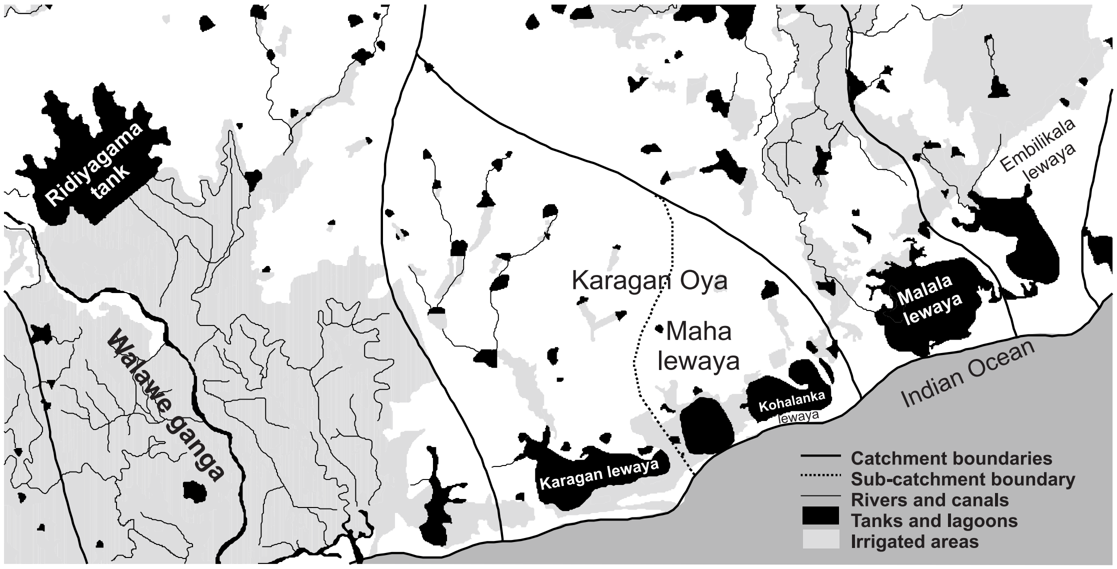
Location and Topography

The Karagan catchment area falls approximately between latitudes 6°07' and 6°13' and longitudes 81°03' and 81°08'. It has a size of roughly 54 km^2 and extends about 8 km from east to west and 12 km from north to south. The topography is undulating in the north, with a gentle seaward slope to the flat southern parts. The elevations range from 60 m in the northeast to 1.5 m below sea level at the bottom of the Karagan lagoon, with an average slope of 1:200.

Climate

Karagan Oya is located in one of the driest regions of Sri Lanka, with mean annual precipitation (MAP) during the last 40 years of 1035 mm. The monthly pattern of rainfall has two distinct peaks (figure 3). The main wet season in the months of October, November and December is called

Figure 2. A location map of the Karagan Oya catchment and Karagan lagoon.



maha, the minor rain period in the months of April and May is referred to as *yala*. A high variability in annual and seasonal rainfall (figures 4 and 5) has a direct impact on local farming. During the wet periods, most of the rainfall is received in a few very intensive storms, which are only partially stored in local tanks.

Temperatures, in contrast, vary only little, with a mean monthly temperature ranging from 26°C in December to 28°C in May and mean monthly minimum and maximum temperatures being about 3°C lower or higher, respectively.

Winds in the area generally have high speeds of 4 to 6 m/sec, and are stronger on the coast than in the interior. The prevailing directions are southwestern from May to September and northeastern from November to March (WCP 1994).\

Evaporation is high and almost constant throughout the year. Mean annual reference evapotranspiration (ET_0) is estimated at 1393 mm (also see Model Input, p.35). With the exception of the maha wet season, mean monthly ET_o exceeds mean monthly precipitation.

Hydrology and Hydrogeology

Very little has been reported about the hydrology of Karagan Oya, and its investigation is one of the focal points of this study. Most of the catchment area drains through two tank cascade systems (TCS), shown in figure 6.

Each TCS is a series of small reservoirs, in which rainfall and runoff water is stored for irrigation. Drainage water from irrigated areas flows into the next downstream tank, where this water can be reused for further irrigation. This is a traditional technique, practiced for centuries in the dry zone of Sri Lanka. The capacities of the tanks in the Karagan basin are small (mostly less than 100,000 m^3) and they can usually provide sufficient irrigation water only during the main maha rainy season. The tanks are also used for domestic purposes, for bathing cattle and for fishing. Runoff in the drainage lines connecting the tanks of the TCS and the downstream lagoon occurs only after intensive rainfall.

Figure 3. Average monthly rainfall in the Karagan Oya catchment.

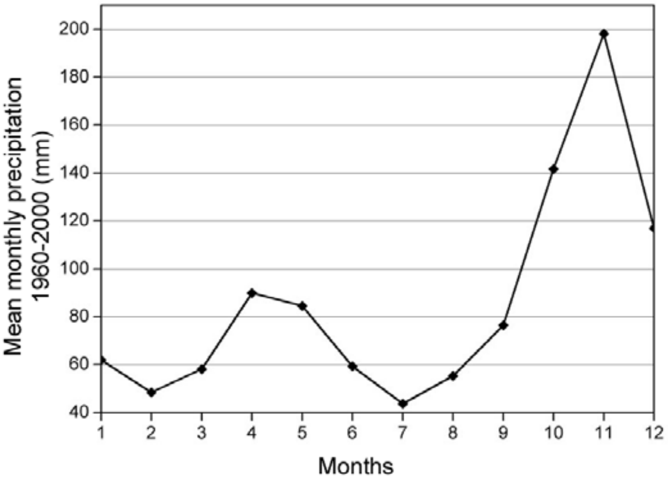


Figure 4. A historical time series of annual rainfall in the Karagan Oya catchment.

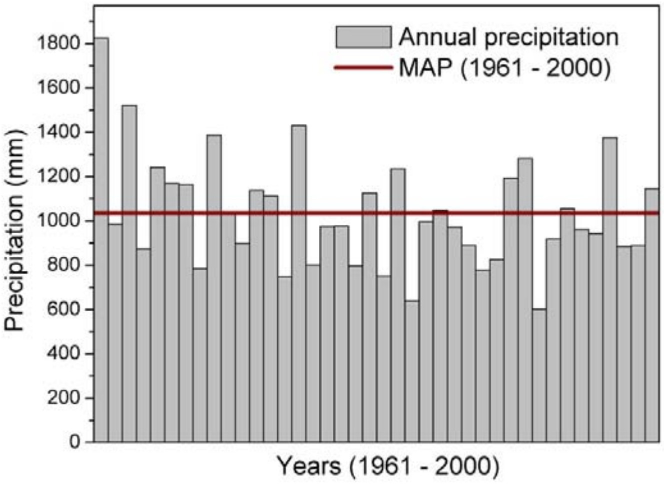


Figure 5. Historical time series of seasonal rainfall in the Karagan Oya catchment.

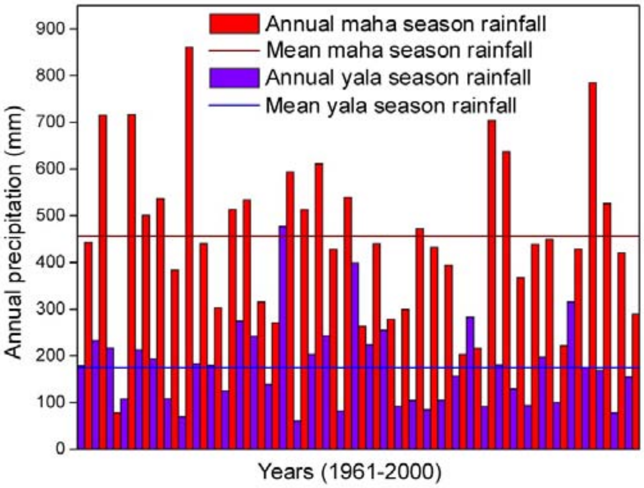
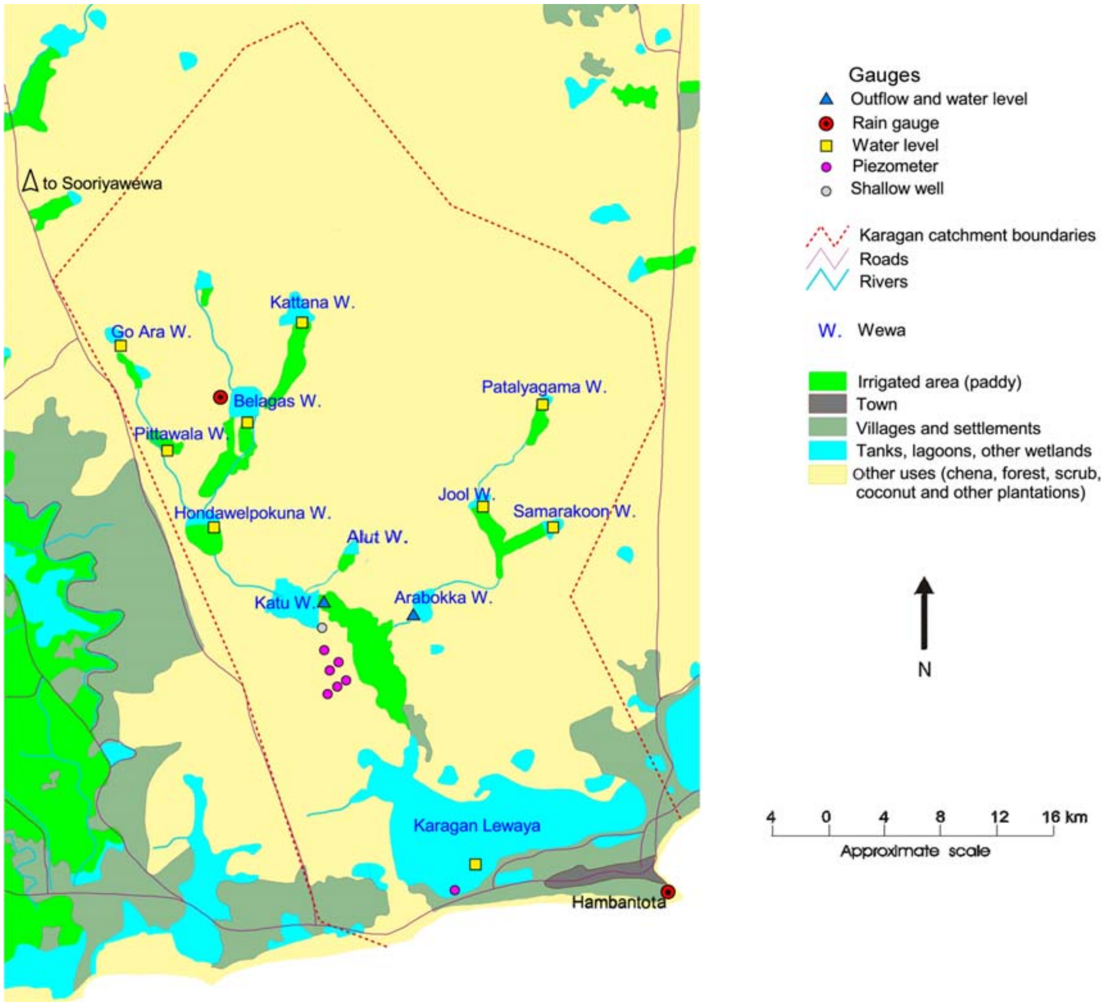


Figure 6. A map of the Karagan Oya catchment showing the tank cascade systems, land-use and location of data collection points.



Knowledge about groundwater is poor. There are almost no wells in the area, groundwater is not used for irrigation and only seldom for domestic purposes. Drinking water for the areas not connected to the Hambantota municipal water supply is usually provided by tank lorries. In the southern part of the area, groundwater was found to have a high salinity.

Vegetation and Agricultural Activities

Due to shifting cultivation, fuel wood extraction, cattle grazing and other human influences, degraded secondary forests, shrub jungle and scrub thornland have spread over the study area at present. The canopy height ranges from 2 to 5 m, with scattered trees throughout the area. Despite its degraded condition, the almost uninhabited northern part of the extension area serves as a reasonably good wildlife habitat, with a considerable number of wild elephants (Amasekara 1992).

Irrigated paddy is cultivated downstream of the small tanks. Rainfed shifting cultivation (or *chena* cultivation, as it is known in the dry zone of Sri Lanka) is practiced in scattered non-irrigated areas. Dominant chena crops are cereals, grain legumes and vegetables. Both forms of cultivation are usually only possible in the wet maha season. The whole Karagan basin is used as pastureland for cattle and large herds can generally be found surroundings the tanks.

Karagan Lewaya

Karagan Lewaya is a naturally formed, seasonally hyper-saline lagoon in the southwestern part of Karagan Oya, northwest of Hambantota. Similar lagoons are found all along the southeastern coast of Sri Lanka. Karagan Lewaya is separated from the sea by the main road to Hambantota and a sand dune of approximately 15 m height and 100 to 200 m width in its western part, and by the town of Hambantota in its eastern areas.

The maximum water-spread area (WSA) in the lagoon (at a maximum depth of 1.5 m) is about 3.2 km^2. Water area and depth, however, are subject to high seasonal and annual variations. In very wet maha seasons, flooding occurs, with water levels exceeding the level of the main road (1990, 1998), whereas in the dry season the lagoon can dry up completely (2001). Since 1970, the lagoon has had no connection to the sea, with an exception of temporarily built channels through the sandbar for the drainage of excess water during the above mentioned floods. A mounted outlet channel through Hambantota constructed after the floods in 1998 was never used to date.

Karagan Lewaya was included in the *Directory of Asian Wetlands* (Scott 1989), together with the adjacent Maha Lewaya, because it:

- Is “a particularly good example of a wetland characteristic of the region”
- “Supports an appreciable assemblage of rare, vulnerable or endangered species or subspecies of plant or animal, or an appreciable number of individuals of any or more of these species”, and
- “Regularly supports 20,000 waterfowl”

These criteria to identify wetlands of international importance are the same as applied by the Ramsar Convention (www.ramsar.org). Karagan Lewaya, however, unlike Maha Lewaya, was not included in the Bundala national park, which is recognized as a Ramsar site.

No fish are found in the lagoon at present. Shell mining for the production of gypsum and non-managed salt extraction occur on a limited scale in times of low water levels. Therefore, Karagan Lewaya´s major value is in serving as a refuge for migratory waterfowl. However, even the large number of birds listed by Scott (Scott 1989) is reported to have decreased in the last decade, probably because of more intensive settlement on the shores of the lagoon (WCP 1994).

Overview of Data Sources

Catchment Area and Tank Cascade Systems

The major part of the Karagan lagoon catchment area is drained through the two TCSs (figure 6). It was anticipated originally that detailed modeling of the catchment and irrigation system would be carried out. Therefore, the available data on TCSs were collected. Because a lot of these data were inconsistent and often contradictory between different sources, it was believed that a thorough inventory of all the tanks was imperative before the simulation of catchment hydrology. Therefore, data from the different sources were compared and thoroughly evaluated. The data sources included:

- Farmers
- Irrigation Department
- Agrarian Service
- Topographical maps from the Mahaweli Authority of Sri Lanka (MASL), the authority in charge of the operation of the Uda Walawe irrigation scheme
- Satellite images
- Observations and measurements

Farmers

There was no cultivation in 2001 under most tanks. Most farmers do not live near the tanks, but in nearby towns. At least one farmer per tank was interviewed. The main points of interests in these interviews were command areas, cropping patterns and spill histories.

Irrigation Department

The Irrigation Department supplied data on one of the terminal tanks, Katu Wewa. For this tank the Irrigation Department had conducted rehabilitation work in 1996, and a copy of the report of the pre-rehabilitation investigation was obtained.

Agrarian Service

The Agrarian Service is in charge of most of the tanks in the project area and has a database for several relevant parameters of the tanks. These include:

- Tank command area
- Maximum dam height
- Maximum water height

- Number of farmers served
- Water spread area (WSA)
- Gross catchment area (including upstream irrigation area)
- Net catchment area (excluding upstream irrigation area)

However, the quality of these data is low. Figures given in Agrarian Service books had to be checked and tables from different branch offices (Hambantota, Ambalantota and Bandagirya) had to be compared.

Mahaweli Authority of Sri Lanka (MASL) Maps

A3 size (29.7 × 42.0 cm) copies of MASL contour line maps were used to derive:

- Bund top level (elevation of the upper rim of the tank)
- Full supply level (FSL – elevation of spillway crest)
- Level of the deepest point inside the tank (deepest point and FSL set the range for the tank capacity calculation)
- WSA at different water levels for depth-volume and depth-area relations

Satellite Images

An ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) satellite image taken on 10 July 2000 was used to verify the plausibility of tank areas and command areas. This image has a resolution of 15×15 m. It was geo-referenced with the help of ground control points, which were identified in the satellite image as well as in the MASL maps. At the time the image was taken, there was no paddy cultivation in the project area. Therefore, it could only be used to identify the maximum possible irrigated area under each tank. Actual water surface area as seen in the ASTER image is very likely to be smaller than at FSL, because water levels in the tanks are usually quite low at this time of the year. For most of the tanks, however, a line could be identified. This appears to be a watermark and was assumed to correspond with FSL. The main characteristics of individual tanks of the TCSs are listed in table 1.

Lagoon

Hambantota Integrated Rural Development Program (HIRDP) Map

A one-foot-contour line map of the lagoon bottom was used for the derivation of the depth-volume and depth-area relations. This map is the result of a topographic survey done in 1991 or 1992 by the Survey Department for the HIRDP. It has a scale of 80.48 m to 2.54 cm (4 chains to 1 inch) and consists of three sheets. The water-spread areas for different water levels were determined

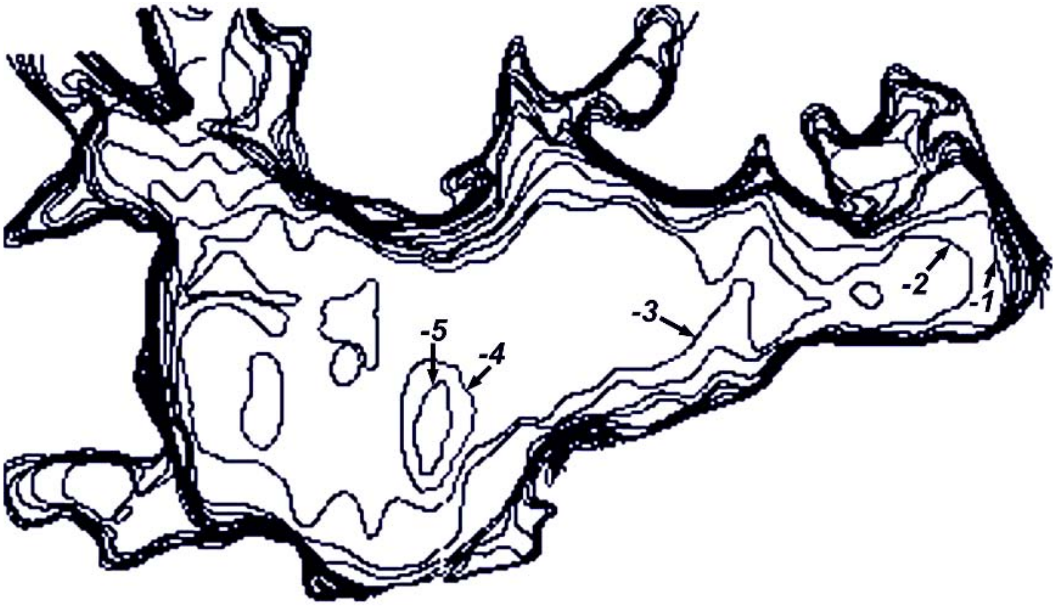
Table 1. Tanks in the Karagan Oya catchment.

Tank Local name	Katu Ara	Hondawelpokuna	Belagas	Pitawala	Go Ara	Kattana	LT 6	Alut	LT 11	LT 10	Arabokka	Jool	Samarakoon	Patalyagama
New name	LT 12	LT 9	LT 7	LT 20	LT 21	LT 8	LT 6	-	LT 11	LT 10	LT 15	LT 13	LT 14	LT 16
Gross catchment area (ha)	2,541	1,640	1,122	270	75	571	131	561	378	206	1,121	550	164	159
Maximum depth at present (m)	3.5	1.3	1.8	1.6	1.2	1.8	0	2.2	0	0	2.3	1.8	1.7	2.3
Maximum depth in the future (m)	3.5	1.3	3.1	1.6	4	2.3	3.5	0	2.6	3.5	2.3	1.8	1.7	2.3
Paddy area at present (ha)	76	20	12	5	8	32	0	7	0	0	20	6	12	9
Paddy area at present (ha)	76	40	35	18	19	43	37	0	75	29	101	31	39	31
New upstream paddy fields														
Paddy area (ha)	0	0	53	53	0	93	10	0	0	27	0	103	23	24
Inflow from Irrigation canals (m^3/s)	0.259	0.122	0.259	0.142	0.037	0.439	0.127	0	0	0.136	0.103	0.461	0.064	0.135
Inflow from feeder canals (m^3/s)	0	0	0	0	0.178	0.115	0.154	0	0.342	0.075	0	0.073	0.345	0.074

from a copy of the original map. This paper copy was digitized and areas were derived both manually (up to the zero contour line) and with the ArcView software.

Distortions due to the copying and digitizing processes are supposed to have only little influence on areas derived from the map because of its large scale. The area calculated manually for the zero contour line, 879 acres (3.557 km^2), corresponds well with the area calculated by ArcView (3.562 km^2), and the area given in the HIRDP files of 892 acres (3.610 km^2) (Provincial Irrigation Department 1991). For further analysis the areas calculated from the digitized map were used, a down-scaled version of the digitized map is shown in figure 7.

Figure 7. The bathymetry of the Karagan Lewaya.



Observations during Filling-up

The slow filling-up of the lagoon was observed during the end of 2001. Inspections of the dry lagoon bottom, observations of the chronology of the spreading of the water surface and attempted crossing at low water levels indicated that the HIRDP map might not reproduce the lowest parts of the lagoon bottom correctly.

As the survey for the map was done some ten years ago, changes in the shape of the lagoon bottom could be expected. One cause could be sedimentation processes, although these are believed to be of minor influence because of the high capability of sediment retention of tanks in TCS and the practice of bund-farming (Dharmasena 1994; Palanisami 2000). Other more influential causes are human activities in the dried-up lagoon. Considerable volumes of soil are moved when pits are dug for shell mining and ramparts are built for salt extraction.

Because of the field observations it was decided to assume the deepest spot in the lagoon to have an elevation of –5 feet or –1.52 m from mean sea level. The contour lines of –4 and –5 feet and the indicated deepest spot of –6 feet of the HIRDP map were omitted and the lowest contour line considered in the calculation of the lagoon volume was –3 feet. The difference in volumes amounts to only 2 percent of this volume (2.956 km^3 with areas and depths as in the map, 3.018 km^3 with a deepest spot of –5 feet and disregarding the –4 and –5 feet contour lines).

Hambantota Urban Council (HUC) Information and Map

Elevations on the few roads in the contour-line-map were verified at HUC using a more detailed map of Hambantota. Also available were photos of the flood in 1997/98 and a design plan of the artificial flood control channel that, when opened, connects the lagoon with the sea.

During the flood of 1997/98 the flood level rose up to more than 2.3 m above sea level, flooding the main road to Hambantota. Immediately after the flooding of the main road a channel through the dune to the sea was dug. The elevation of this temporary canal is not known, but was estimated from photos as 1 to 1.5 m above sea level.

After this flood a gabion-mounted outlet channel through Hambantota was constructed. This channel has a length of 360 m, a width of 12 m and a depth of 2 m. The elevations of the inflow point from the lagoon and the outflow point to the sea are 0.6 m and 0.15 m above sea level, respectively.

Satellite Images

Satellite images of the lagoon were used in order to obtain information about water levels in the past. An overview of the used images and the determined WSA are given in table 2.

Table 2. Characteristics of satellite images of Karagan Lagoon.

Date	Sensor	Bands	Surface water area (m^2)
23-Jan-00	LANDSAT	Visual + near IR + IR	3,200,000
10-Jul-00	ASTER	Visual + near IR	2,900,000
19-Nov-00	ASTER	Visual + near IR	3,050,000
14-Mar-01	LANDSAT	Visual + near IR + IR	3,200,000

Wetland Site Report

The wetland site report by the Wetland Conservation Project, a project of the Central Environmental Authority of Sri Lanka (WCP 1994) is an attempt to give an extensive overview of the existing knowledge of the lagoon and provides some additional information. Concerning Karagan Oya, however, it states that no hydrological data were found. The information given on the hydrologic processes of the lagoon itself— based on two reports by an NGO called Wildlife and Nature Protection Society (WNPS) (De Silva and Rhaman 1987; WNPS 1988)—turned out to be incomplete.

Irrigation Development

The sources that were used to assess the hydrological changes of the implementation of the Uda Walawe left bank extension project included:

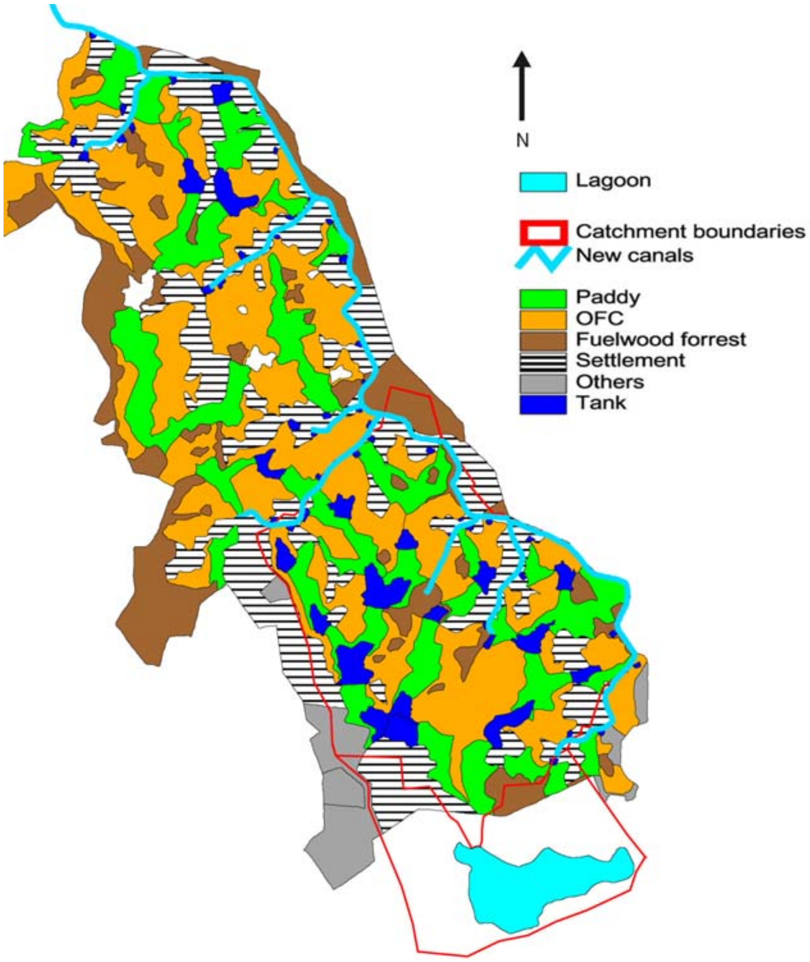
- The design report of the construction company in charge, the Japanese Nippon Koei Co., Ltd. (Nippon Koei 1999)

- The “issue tree” of the MASL, i.e., a diagram describing the planned irrigation issues to the various tanks and command areas
- A study by the Japanese Bank of International Cooperation (SAPI 2000), which includes a thorough water balance study of the whole Uda Walawe basin
- Interviews with the MASL Walawe extension project manager
- An M.Sc. thesis about the impact of canal lining in the Uda Walawe left bank extension area (Meijer 2000)

Parts of the information obtained from these various sources were contradictory. The irrigation issue planned by the MASL and the special assistance for project implementation (SAPI) information on irrigation demand and possible irrigation issue showed big discrepancies.

Because of the contradictory information, several scenarios of future irrigation management were defined. These are described in latter sections of this paper, where more details on the above mentioned data sources are also given. The proposed land use pattern for the irrigation extension area with the superimposed catchment boundaries is shown in figure 8.

Figure 8. Future land use associated with Uda Walawe Irrigation Extension Project.



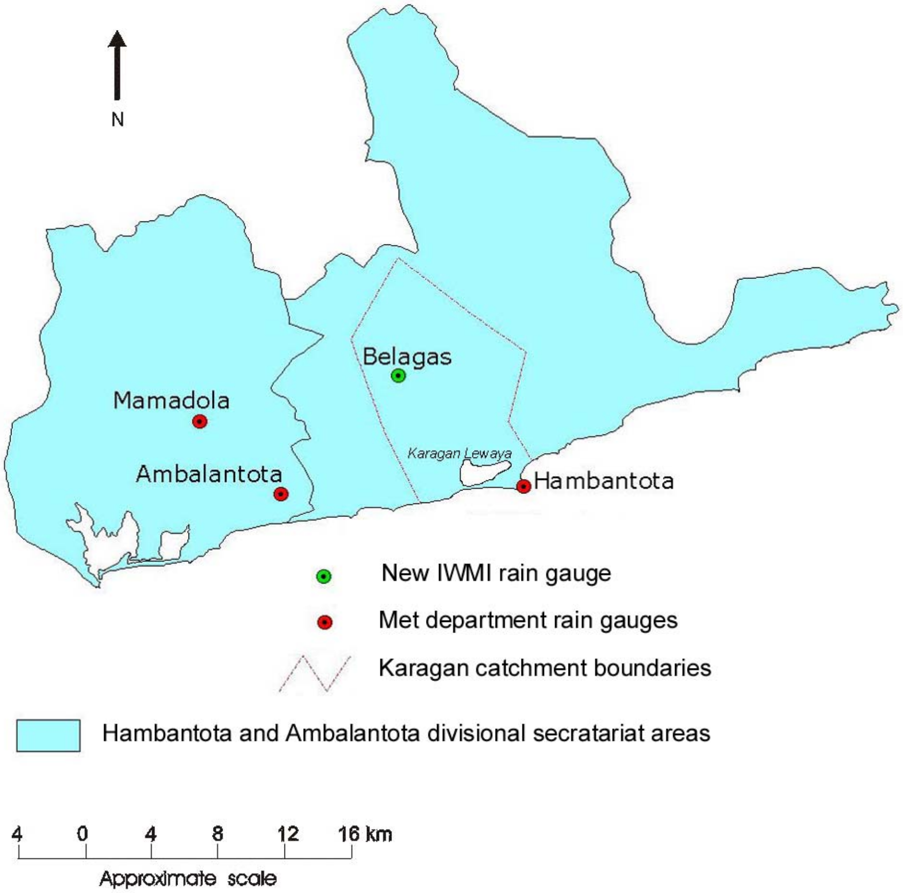
Climatic data

Climatic data used in the simulation models are daily rainfall and daily maximum and minimum temperatures from the Hambantota meteorological station.

Rainfall

Several rainfall measurement stations exist close to the Karagan Oya catchment (figure 9). The Hambantota meteorological station is located next to Karagan Lewaya. Its records may be used to calculate the direct rainfall on the lagoon water surface and the immediate adjacent areas of the catchment. Due to the spatially changing rainfall pattern, it might not, however, be entirely suitable for calculating the runoff from the upstream catchment areas in Karagan Oya. However, no rain gauges exist in these upstream areas.

Figure 9. A schematic map showing the locations of rainfall stations, nearby and within the study area.



In order to evaluate spatial variability of rainfall in southern Sri Lanka (moving inland from the coast), daily rainfall data for two other rainfall gauges in the region, Ambalantota and Mamadola, were analyzed. Similar to Hambantota, the Ambalantota station is located very close to the coast. Mamadola is located about 5 km further inland. The rainfall pattern at Ambalantota and Hambantota may therefore be expected to be similar. The differences between rainfall timing and amount at Ambalantota and Mamadola on one hand, and Hambantota and the upper catchment areas of Karagan Oya, on the other, may also be assumed to be similar.

The MAP values for Ambalantota and Mamadola during the period 1991 to 2001 were 940 and 1082 mm, respectively. The comparison of daily rainfall values at Ambalantota and Mamadola revealed a low correlation of 0.38, which can be explained by shifts in time (for a day or two) of the corresponding rainfall events on both rain gauges. The monthly rainfall totals at Ambalantota and Mamadola correlate much better (0.82). This clearly illustrates the increasing spatial homogeneity of rainfall with increasing temporal resolution of the data. The relationship between standard deviation of daily rainfall values within a month and this month's total rainfall showed a high correlation of 0.93 for both gauges. This is an indication of the similarity between increasing variability of daily rainfall values at both gauges with increasing wetness of the month. These results suggest that the longer period record at Ambalantota may be used instead of the shorter record at Mamadola in future simulations, particularly, if the time step of simulations is larger than 1 day. It also suggests that, generally, a record at a coastal rainfall gauge could be used instead of a record a few kilometers further inland, given the same restriction on the time step. For daily simulations, if coastal rainfall records are used for the entire catchment, the simulated runoff will be statistically similar to runoff, which could have been simulated with representative "inland" rainfall gauge data.

The implication for simulating runoff into Karagan Lewaya is that the use of Hambantota rainfall data is suitable. At present, the main input to the lagoon is rainfall on its surface, while drainage water from irrigation is likely to be the primary contributor in the future. However, the spatial rainfall variations must be taken into consideration if simulated water levels in the tanks and in the lagoon are to be compared with corresponding measured water levels.

To increase understanding of spatial rainfall variability, a new rain gauge was installed in the upstream part of Karagan catchment. This new gauge is located close to a tank called Belagas and therefore is referred to in this paper as the Belagas rain gauge (figures 6 and 9).

Temperature

Minimum and maximum temperature values are required to calculate evapotranspiration (ET), which is of utmost importance in the assessment of the lagoon and catchment hydrology. As no evaporation pans exist in the catchment or its vicinity, the temperature data at the Hambantota meteorological station were used for ET calculations.

Measurement Network Development

Tanks

Water levels in the Upstream Tanks

In all of the tanks upstream of the two terminal tanks, Katu Wewa and Arabokka Wewa, water-level gauges have been installed (figure 6). Staff gauges were considered to be too fragile for these measurements as cattle, buffalo and elephants often come to the tanks. Therefore, it was decided to paint gauges on either the outlet structures or the spill structures. Although such gauges are not ideal in terms of accuracy and readability, they were preferred to more complicated approaches, because of their quick and simple installation. The field staff is reading these gauges once a week.

Water Levels and Outflow at the Terminal Tanks

At the terminal tanks of the TCS, Katu Wewa and Arabokka Wewa, water levels and outflows during the rainy season are measured (figure 6). These outflows represent a big part of the lagoon surface inflow, although losses through evaporation in the paddy fields have to be also taken into account.

Surface inflow into Karagan Lewaya comes from two sources. Water released from the two most downstream reservoirs of the Karagan TCS, irrigates the downstream paddy fields and flows through one major drainage channel to the lagoon, comprising the biggest portion of surface inflow. Direct runoff from adjacent sub-catchments, which have about 33 percent of the total catchment area, also drain into this channel and partially into a large number of small ditches that eventually meet the lagoon. Measurements in the major drainage channel are not possible due to the very shallow water depth of only a few centimeters, the large width of several 100 m and the channel's highly variable profile. It was therefore decided to determine the outflows from the two terminal tanks instead. The outflows include water issued for irrigation and excess water that flows over the spillways during wet season events.

For the measurement of irrigation issue an orifice formula is used. The geometric features of the outlet pipes and sluice gates were determined at low tank water levels. Water level gauges were painted on the concrete outlet structures. Readings at these gauges indicate the head above the sluice gate sill (for calculating irrigation issue) and the tank water level below spillway crest level (the reference level used in all the tanks) or above spillway crest level (for estimating the spillway discharge).

The spillway discharge is estimated by regarding the spillway structures as broad-crested weirs. On the sidewalls of the spillway structures of both terminal tanks signs were painted to indicate where to measure the water level with a measuring tape, as proper water level gauges would not be visible. Left and right of these signs (yellow stripes), two lines of white lime were applied. As the lime absorbs water and then changes its color it is possible to observe the highest level during the night on the following morning. Without flow, no proper measurements can be done downstream of the structures, which makes it impossible to determine discharge coefficients through calibration. The lime measurements will give rough estimates of the spillway discharge. During the cultivation period, the readings will be done daily by local farmers and these data will be collected by the field staff once a week. During the rest of the year, only weekly water level measurements will be done by field staff members.

Due to the drought in summer and the very scarce rains in the 2001 maha season, water levels remained below the zero levels of the gauges during the period of the study in most of the tanks. In three tanks, water levels rose above the gauge zero datum towards the end of November. Only in the two terminal tanks, Katu Wewa and Arabokka Wewa, could water levels continuously be recorded. However, no water was issued for irrigation, and the above-described outflow gauges could not be rated.

For the period from the beginning of July to the end of October, when almost no rainfall was observed in the area, seepage and percolation losses were estimated for these two tanks.

Qualitative Data on Spillage, Cropping and Irrigation Water Issue

In addition to the water level readings, the field staff notes whether the tanks are spilling, the stage of paddy cropping under the tanks (first, second or third ploughing, sowing, cultivation and harvest), the exact day of the starting of cultivation and whether water is issued from the tanks or not. This is expected to provide data for a calibration of the models described further in this paper, and for checking the assumptions of irrigation practices used in these models.

Lagoon Water Level Gauge

The measurement of water levels in the lagoon is of paramount importance, both for the validation and calibration of the models and for the monitoring of future changes. At the beginning of the study no recorder or gauge existed. Therefore, a simple wooden staff gauge was installed when the lagoon was dried up completely. The point chosen for the installation was in the central southern part of the lagoon, where a rain water pool seemed to indicate the deepest spot of the lagoon (figure 6). The gauge is situated at a distance of about 100 m from the edge of the lagoon and close to the mouth of an artificial canal. From the mouth of this canal, the gauge readings can be made with binoculars.

Observations made during the filling-up of Karagan Lewaya at the end of 2001 showed, that the point chosen for the installation of the water level gauge was not the deepest spot of the lagoon bottom. The zero datum of the gauge could not be determined accurately. From a comparison of observations and information from maps, the zero datum was defined as related to a depth of 0.36 m and an elevation of 1.16 m above sea level. A better estimation of the elevation of the gauge's zero level can be done when the water level rises to the spillway level of the outlet channel through Hambantota, of which the elevation is known. The weekly water level measurements are carried out by IWMI field staff.

Piezometers

As the current knowledge about groundwater is very limited, piezometers were installed to get a better understanding of subsurface-surface water interactions. Nine piezometers were set up between the last terminal tank, Katu Wewa, and the lagoon. They were arranged in three lines with three piezometers each. In addition to these nine piezometers, a hand-dug shallow well immediately downstream of Katu Wewa was included in the monitoring program. Between the sea and the lagoon, three piezometers were installed to improve the knowledge about sea water seepage into the lagoon (figure 6). Groundwater levels and electrical conductivity (EC) are measured weekly by IWMI field staff.

Of the twelve piezometers installed in August 2001, only six remained intact by December 2001. The others had fallen dry or been damaged. Of the four locations only one reported no damages—on a chena farmer's land. For future piezometer installation, this fact should be taken into consideration, and only supervised locations should be selected.

Rain Gauge

In order to obtain data about the rainfall variations within the Karagan catchment area, for future computations and for model calibration, a rain gauge was installed in the northwestern part of the Karagan catchment, close to Belagas Wewa (figures 6 and 9). The daily rainfall records are taken by the farmer on whose land the gauge is located. The data are collected by IWMI field staff once a week.

Monthly rainfall for November and December recorded at the new Belagas rain gauge was 229 and 52 mm, respectively. These values are close to those recorded in Hambantota: 211 and 29 mm, respectively. This suggests that the readings were taken carefully and that the data from the new rain gauge can contribute to a better understanding of spatial variability of rainfall in the Karagan catchment.

Daily values for November and December 2001 in Hambantota and Belagas exhibit negligible correlation. The two most intense events were recorded in November. However, similar values were recorded at both stations, and both occurred one day later at Belagas than at Hambantota. A delay of one or two days of some corresponding rainfall events in Belagas was also observed in December. For a more thorough analysis of the reliability of data recorded at Belagas and the spatial rainfall variability, a longer data series is needed. This could be established if observations at Belagas can continue without interruption.

Simulation Models–Structure

The objectives of the development of a simulation model for Karagan Lewaya and its catchment were:

- To contribute to a better understanding of the hydrology in the Karagan catchment
- To be able to investigate impacts of future scenarios of irrigation management

Calculating catchment runoff to Karagan Lewaya was attempted as a first step. A water balance model was developed. This model included a detailed description of the existing TCS structure. This model is referred to below as the detailed tank cascade model (DTCM). However, this model appeared to be too complex for a sound parameter estimation with the limited amount of data available at the stage of model development. This is a typical problem in data poor regions, and the use in such conditions is often made of more parsimonious simulation methods. A simpler runoff model has therefore been developed, hereafter referred to as simplified catchment model (SCM). Both models were developed in a spreadsheet format.

The second step included the development of a water balance model for the lagoon itself (again using a spreadsheet approach) and its conjunctive use with the simplified runoff model. In principle, as more data become available, the DTCM may replace the SCM. The structures of the three developed models are described below.

Detailed Tank Cascade Model (DTCM)

This spreadsheet model was developed as a first step to understanding the dynamics of the Karagan basin. As almost 70 percent of the catchment area drains through the TCS, it was assumed that understanding its hydrology and cultivation practices would be useful for predicting the hydrologic behavior of the whole basin. The catchment of the lagoon may be characterized by a combination of four different units:

- Catchments
- Tanks
- Paddy fields (and other field crops)
- Additional inflow (only relevant in the context of future irrigation development)

The links between these units in Karagan Oya are illustrated in figure 10. Very small tanks and one tank outside of the TCSs are not included in this layout. Tanks are located downstream of catchments, and paddy fields are located downstream of tanks and usually upstream of the next catchment. The water from the two most downstream paddy fields flows together in one catchment and from there to the lagoon. Additionally, a catchment area separated from the tank cascade is introduced in order to consider direct runoff to the lagoon.

An overview of the processes which operate in different units and the linkages between units are presented in figure 11. It can be seen that water from upstream units or rainfall is either being depleted by evapotranspiration or transferred to downstream units. No water is assumed to bypass downstream units by percolating to deep groundwater. Similarly, capillary rise from deep groundwater is neglected. The reason for these assumptions is that the soils in the project area appear to have very high clay contents and therefore very low permeability. The vertical movement of water is therefore assumed to be minimal. The monitoring network serves to verify these assumptions.

Subsurface water flow is not completely excluded from the processes framework. It is simply not explicitly specified whether the flow is surface or subsurface for flow between a paddy field and a catchment, as well as between a catchment and a tank. The mathematical formulae which describe processes in each model unit are explained below. In the equations, index “c” refers to catchment, “T” to tank unit and “P” to paddy unit.

Figure 10. The layout of the DTCM of the Karagan Oya.

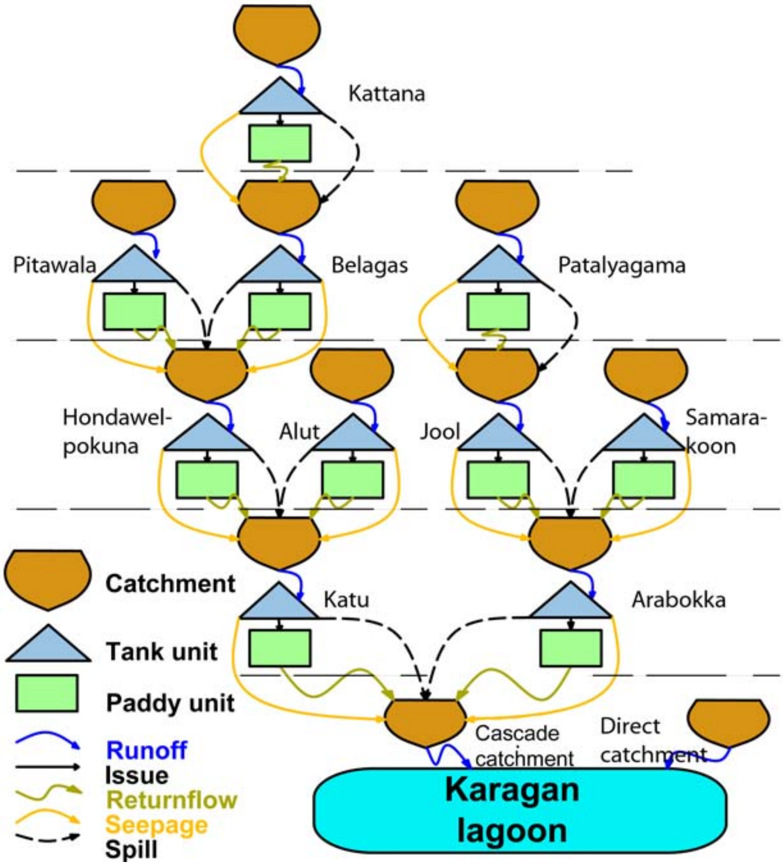
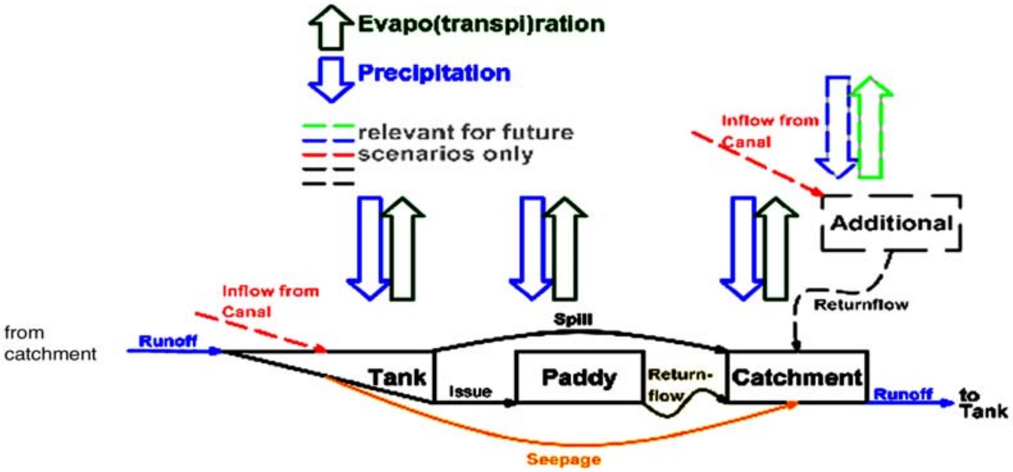


Figure 11. Hydrological processes operating in different units of the DTCM of the Karagan Oya.



Catchments

The basic concept of this unit is a simple reservoir model, which aggregates different kinds of water storage such as changes in soil moisture and changes in the shallow groundwater table. The storage volume at time interval “t” (e.g. week “t”) is calculated as:

$$V_{C,t} = V_{C,t-1} + P_{C,t} + I_{C,t} - ET_{C,t} - R_{C,t} \tag{1}$$

where:

V_c	Water stored (m^3)
P_c	Precipitation (m^3)
I_c	Inflow (m^3)
ET_c	Evapotranspiration (m^3)
R_c	Runoff (m^3)

Evapotranspiration is calculated as:

$$ET_{C,t} = \frac{ET_{0,t} * kc_C * A_C}{1000} \tag{2}$$

where:

ET_0	Reference evapotranspiration (mm)
A_C	Catchment area (m^2)
$kc,_c$	Catchment crop factor (non-dimensional)

Reference evapotranspiration (ET_0) indicates the evapotranspiration of a reference crop under ideal water supply conditions. Actual ET_c is determined by crop coefficients. The values for kc are based on Allen et al. (1998). Since the natural vegetation in the study area consists of dry scrub, which can be expected to have a low kc, and trees, which have higher kc, a factor of 1 is used.

Inflows from upstream units are estimated using:

$$I_{C,t} = \sum_{U=1}^{Umax} (R_{P,u,t} + R_{A,u,t} + X_{T,u,t} + S_{T,u,t}) \tag{3}$$

where:

S_T	Seepage from upstream tank (m^3)
X_T	Water spillage from upstream tank (m^3)
R_A	Return flow from additional upstream paddy area (m^3)
R_P	Return flow from upstream paddy field (m^3)

Index u refers to units (catchments and paddy fields) immediately upstream of the catchment (figure 10).

Runoff from paddy fields is explained in the section on the SCM (see p.28) and runoff from catchments is calculated as

for $V_{C,t-1} > V_{Cmin}$:

$$R_{C,t} = X_{C,t} + f_C * Vr_{C,t-1} * V_{C,t-1} \tag{4}$$

$$X_{C,t} = V_{C,t-1} + P_{C,t} + I_{C,t} - ET_{C,t} - V_{Cmax} \tag{5}$$

$(X_{C,t} \geq 0)$

$$Vr_{C,t} = \frac{V_{C,t}}{V_{Cmax}} \tag{6}$$

for $V_{C,t-1} \leq V_{Cmin}$

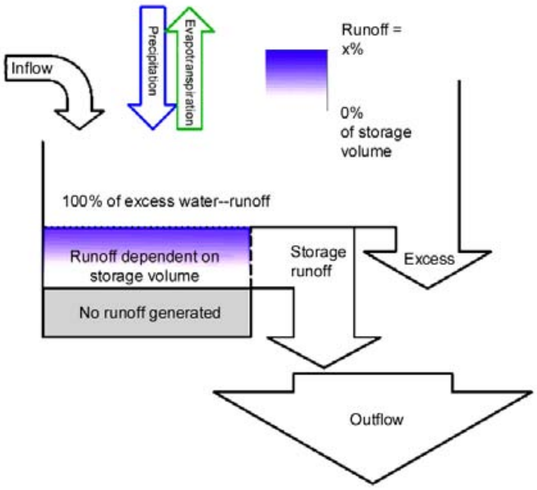
$R_{C,t} = 0$

where:

X_C	Excess runoff from catchment (m^3)
Vr_C	Relative water storage in catchment (non-dimensional)
f_C	Runoff factor – catchment (non-dimensional) (calibration parameter)
V_{Cmax}	Maximum water storage in catchment (m^3) (calibration parameter)
V_{Cmin}	Minimum water storage in catchment (m^3) (calibration parameter)

Maximum and minimum storage values, as well as f_C are to be determined by calibration. An illustration of runoff calculation is shown in figure 12. For catchments, the term outflow refers to surface runoff.

Figure 12. A schematic description of runoff generation process in a "catchment" unit of the DTCM.



Tanks

A tank is represented by a simple reservoir model, with inflow components being precipitation and inflow from the catchment. Outflow components on the other hand are evaporation, seepage, issued water and spill. The tank volume at time t is calculated as:

$$V_{T,t} = V_{T,t-1} + R_{C,t} + N_{T,t} + P_{T,t} - S_{T,t} - E_{T,t} - Irr_{T,t} + X_{T,t} \tag{7}$$

$$V_{T,t} > 0$$

where:

V_T	Tank volume (m³)
R_C	Runoff from catchment of the tank (m³)
N_T	Additional inflow from new irrigation scheme (m³)
P_T	Precipitation on maximum tank WSA (m³)
S_T	Seepage from a tank (m³)
E_T	Open water evaporation from a tank WSA (m³)
Irr_T	Water issued from a tank for irrigation (m³)
X_T	Water spilled from a tank (m³)

To simulate precipitation and evaporation of tanks, the following assumptions have been made with regard to WSA. Calculating precipitation using maximum WSA means that all of the precipitation that falls onto maximum WSA ends up in the tank, regardless of WSA variations. Evaporation on the other hand is calculated based on actual WSA, because a calculation based on maximum WSA would result in overestimation of evaporation losses at low water levels. The values for maximum water depth and for maximum WSA are considered to be time invariant. In reality, in some cases farmers might block the spill to increase tank capacity, or on the contrary, may dig a bypass to lower the water level and reduce the risk of breaking the bund.

Actual WSA and water depth are calculated as follows:

$$A_{T,t} = b^{*} H_{T,t}^{2} \tag{8}$$

$$H_{T,t} = \sqrt[3]{\frac{V_{T,t}}{a}} \tag{9}$$

where:

A_T	WSA (m²)
H_T	Water depth (m)
a and b	Non-dimensional parameters determined using the MASL maps.

Seepage calculation includes the following:

$$S_{T,t} = SF_{T,t} * 7 * V_{T,t-1} \tag{10}$$

$$SF_{T,t} = \frac{1}{100}\left(-4.3625 * \ln(Hr_{T,t} - 1) + 0.4292\right) \tag{11}$$

$$Hr_{T,t} = \frac{H_{T,t}}{H_{Tmax}} \tag{12}$$

where:

SF_T	Daily seepage fraction (non-dimensional)
Hr_T	Relative water depth (non-dimensional)
H_{Tmax}	Maximum water depth (m)

The formula for daily seepage was derived for the Thirappane TCS in Anuradhapura, located in the dry zone of Sri Lanka (Jayatilaka et al. 2001). For the four tanks in this study, the authors derived logarithmic relationships between tank water height and daily seepage losses as percentages of the tank volume. After converting absolute water depth into relative (actual tank water depth divided by tank water depth at full supply level), a standardized relationship for the whole TCS was calculated. In this paper we follow the authors' suggestion to use this seepage function for other TCSs in the dry zone of Sri Lanka, as no information for determining the seepage function is available. H_{Tmax} was derived from the MASL maps.

Issued water is calculated as follows. As long as the resulting tank volume is higher than dead storage volume (V_{Tmin}):

$$Irr_{T,t} = GD_{P,t}$$

$$I_{T,t} = GD_{P,t}$$

If tank volume would fall below dead storage:

$$Irr_{T,t} = V_{T,t-1} + R_{C,t} + P_{T,t} - S_{T,t} - E_{T,t} - V_{Tmin} \tag{13}$$

$$I_{T,t} > 0$$

where:

GD_P	Gross irrigation demand of paddy fields (m^3)—as described in the paddy unit section below
V_{Tmin}	Dead storage (m^3)

As no information about dead storage was available, a fraction of the tank capacity (10%) has been arbitrarily set as dead storage, assuming that local people would not release all water from the tanks, because the tanks are used for other purposes than irrigation as well, such as bathing, cattle-bathing and washing clothes.

Spillway discharge equals the volume exceeding maximum tank capacity and is directly routed to the successive catchment.

Paddy Fields

Similar to catchments, a paddy field is represented by a simple reservoir model. The volume of water in this reservoir in week t is computed as follows:

$$V_{P,t} = V_{P,t-1} + P_{P,t} + Irr_{T,t} - ET_{P,t} - R_{P,t-1} \qquad (14)$$

$$V_{P,t} > 0$$

where:

V_P	Water stored in a paddy field (m³)
P_P	Precipitation on a paddy field (m³)
ET_P	Evapotranspiration from a paddy field (m³)
R_P	Return flow from a paddy field (m³)

Evapotranspiration:

$$ET_{P,t} = (kc_{P,p} + kc_{P,p}) * \frac{ET_{O,t} * A_P}{1000} \qquad (15)$$

where:

A_P	Paddy area (m²)
ET_0	Reference Evapotranspiration (mm)
kc_P	Crop factor, zero during off-season (non-dimensional)
kn_P	Non crop factor, zero during cultivation season (non-dimensional) (including evapotranspiration from bare soil and weeds or open water evaporation during land preparation period)
Index p	week in paddy cultivation sequence, starting with the first week of land preparation (as soon as a tank water level threshold is reached) for harvest

Values for kc and kn were chosen according to Allen et al. (1998)

Return flow calculation:

for $V_{P,t-1} > V_{Pmin}$

$$R_{P,t} = X_{P,t} + f_P * Vr_{P,t-1} * V_{P,t-1} \qquad (16)$$

$$X_{P,t} = V_{P,t-1} + P_{P,t} + Irr_{T,t} - ET_{P,t} - V_{Pmax} \tag{17}$$

$(X_{P,t} \geq 0)$

$$Vr_{P,t} = \frac{V_{P,t}}{V_{Pmax}} \tag{18}$$

for $V_{P,t-1} > V_{Pmin}$

$R_{C,t} = 0$

where:

X_P	Excess runoff from paddy field (m³)
f_P	Runoff factor – paddy field (non-dimensional calibration parameter)
Vr_P	Relative water storage in paddy field (non-dimensional)
V_{Pmax}	Maximum water storage in paddy field (m³), calibration parameter
V_{Pmin}	Minimum water storage in paddy field (m³), calibration parameter

This calculation corresponds with the runoff calculation in the catchment units (equations 4 to 6 and figure 12).

Irrigation water demand is calculated differently for two seasons:

For cultivation season

$$GD_{P,t} = ef_P * \left(ETC_{P,t} + LP_{P,t} + V_{Pmax} - P_{P,t} - V_{P,t-1}\right) \tag{19}$$

$(GD_{P,t} \geq 0)$

for off-season

$GD_{P,t} = 0$

where:

ef_P	Calibration factor (non-dimensional) can be used for changing gross irrigation demand
L_P	Water demand for land preparation (m³)

$$L_{P,t} = \frac{LL_{P,p} * A_P}{1000} \tag{20}$$

where:

LL_P	Required water level for land preparation (mm) (Ponrajah 1984)

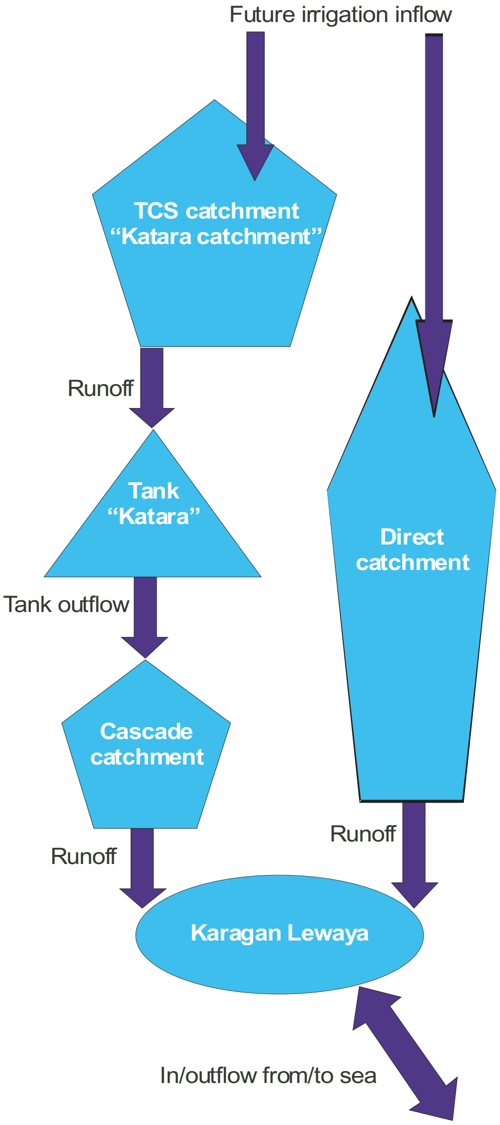
Additional Upstream Paddy Fields

After the implementation of the extension project, crops irrigated directly from new irrigation canals will be situated upstream of some of the tanks. The calculation procedures for these model units are analogous to those of the paddy units (equations 14 to 20); yet irrigation issue is provided from the canals instead of the tanks.

Simplified Catchment Model (SCM)

A SCM was developed as an alternative to the DTCM in order to reduce the number of model parameters and to make the modeling approach commensurate with the existing level of input information. In general, the modeling approach was not changed, yet the number of units represented was decreased. The SCM only consists of four units, represented by Excel worksheets. A schematic illustration of the layout of the SCM is shown in figure 13.

Figure 13. The layout of the simplified catchment model of the Karagan Oya.



In the SCM, the entire catchment of the two TCSs of 36 km^2 is simulated as one reservoir, representing surface and sub-surface storage and runoff. Percolation to deep groundwater, which was previously neglected, is now introduced. The main reason for this is that by the time the SCM was developed, the first results of groundwater monitoring were available. Percolation is calculated only as a loss from the surface/subsurface reservoir and no groundwater simulation is used, because it is assumed on the basis of soil characteristics that groundwater flow does not contribute to the inflow into Karagan Lewaya. The upstream tanks of the TCSs are described as one lumped catchment, and are not represented individually. The same applies to paddy fields, which are represented as separate units in the DTCM, but are treated as parts of the catchment areas in the SCM. Runoff from the TCS catchment area ("Katara catchment", combining the names of the Katu and Arabokka TCs) is routed into one lumped virtual reservoir, called "Katara tank". This lumped reservoir pools the capacities of the two terminal tanks. Outflow from the reservoir is routed into a smaller catchment, "cascade catchment", which includes the cultivated and non-cultivated areas draining into the shallow channel that leads to Karagan Lewaya. The areas draining into Karagan Lewaya through minor streams and ditches, both east and west of the "cascade catchment" area, are combined in one catchment, denominated "direct catchment". "Cascade" and "direct" catchments are each simulated as one reservoir that represents surface and sub-surface storage, runoff and percolation. Runoff from these catchments is routed into the Karagan Lewaya model lagoon.

The simulation of the processes within each unit is generally the same as in the DTCM. Minor changes made were associated with changed model layout and the first results of the monitoring.

Catchments

With the introduction of percolation to deep groundwater, the calculation of the storage volume in time step t is changed to the following form:

$$V_{C,t} = V_{C,t-1} + P_{C,t} + I_{C,t} - ET_{C,t} - R_{C,t} - D_{C,t} \qquad (21)$$

where:

V_C	Water stored in catchment (m^3)
P_C	Precipitation on catchment (m^3)
I_C	Inflow into catchment (m^3)
ET_C	Evapotranspiration from catchment (m^3) (see equation 5.1.2)
R_C	Runoff from catchment (m^3) (see equations 5.1.4 to 5.1.6)
D_C	Deep percolation (m^3)

The inflow computation is basically the same as for the DTCM model, but the equation's components are different because of the omission of the paddy field units:

$$I_{C,t} = S_{T,t} + X_{T,t} + Irr_{T,t} + N_{C,t} \qquad (22)$$

where:

S_T	Seepage from upstream tank (m^3)
X_T	Water spilled from upstream tank (m^3)
Irr_T	Water issued from upstream tank for irrigation (m^3)
N_C	Additional inflow from new irrigation scheme (m^3)

Deep percolation:

for $V_{C,t-1} > Vd_C$

$$D_C = dp_C * Vr_{C,t-1} * V_{C,t-1} \qquad (23)$$

for $V_{C,t-1} \leq Vd_C$

$$D_C = 0$$

where:

where:

dp_C	Deep percolation factor – catchment (non-dimensional calibration parameter)
Vr_C	Relative water storage in catchment (non-dimensional)
Vd_C	Deep percolation threshold volume (m^3), calibration parameter

The deep percolation threshold volume represents the fact that initially rainfall on dry soil leads to an increase in soil moisture, until the soil is saturated and water percolates to lower layers. The percolating water is assumed not to contribute to the inflow into Karagan Lewaya, but is rather used in the basin by capillary rise, uptake by roots, pumped by tube-wells, etc.

Tank Unit

The two terminal tanks, Katu Wewa and Arabokka Wewa, are now represented by one single dummy tank. Respective volumes and WSAs for respective water levels of both tanks were added together and thus volume-depth and volume-area-relations for the model tank were derived.

The processes are again calculated in the same way as in the DTCM Model (see equations 7 to 9)—only the calculations of seepage and irrigation issue have been changed.

$Q = A*k*\frac{dH}{dL}$ and can be described as:

$$S_{T,t} = fs_T * S_T * H_{T,t-1} * A_{T,t-1} \qquad (24)$$

Seepage and percolation to deep groundwater from the tank is calculated with a formula based on Darcy’s law:
where:

S_T	Seepage and deep percolation (m³), corresponding with Q in Darcy’s law
fs_T	Fraction of seepage and percolation losses routed into next catchment (non-dimensional), calibration parameter
S_T	Seepage and deep percolation factor (non-dimensional), combining hydraulic conductivity and distance of percolation (k/dL)
H_T	Water depth (m), corresponding to dH
A_T	Water surface (m²), corresponding with cross-sectional area A

The seepage and deep percolation factor S_T, which combines hydraulic conductivity and the distance of seepage and percolation, is derived from a calculation of seepage losses. These were estimated with a water balance approach based on water level data of the terminal tanks during a period of no inflow. Although this period spanned only 13 weeks and only comparatively low water levels were observed, the results were believed to be more reliable than the calculation with the previously used formula by Jayatilaka et al. (2001)—see equations 10 to 12.

In the SCM, a defined fraction fs of the calculated seepage and percolation losses is assumed to be seepage through the bund of the tank and routed into the next catchment area, the rest is lost to groundwater. This factor is arbitrarily chosen and can be changed when more data is available. The construction works on the tanks might also lead to changed seepage losses.

$$Irr_{T,t}= i_T{}^{*}V_{T,t-1}{}^{*}\,Hr_{T,t-1} \tag{25}$$

Irrigation issue is calculated as:
where :

Irr_T	Irrigation issue (m³)
i_T	Irrigation factor (non-dimensional)
V_T	Tank Volume (m³)
Hr_T	Relative tank water depth (non-dimensional)

In the model, irrigation starts as soon as a water level threshold is exceeded. Irrigation will then continue for a maximum of 18 weeks, which is the usual paddy irrigation period in the area or until the dead storage depth is reached. Neither land preparation requirements, crop requirements or rainfall are taken into consideration in this form of simulation, because it is not possible without explicit representation of paddy fields. The value for the irrigation factor is chosen to roughly meet the requirements of paddy cultivation in the actually cultivated areas, as calculated in the DTCM model. Decreasing tank water levels during the cultivation period result in a decrease in irrigation issues over time. This decrease does not match with actual farmer practices, if sufficient water is available, but may represent the adaptation of cultivated area (and therefore irrigation issue) in times of water scarcity.

Karagan Lagoon Model

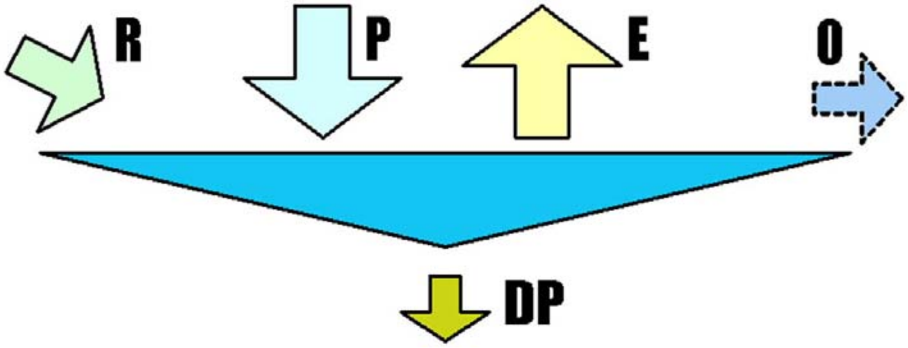
The weekly water balance for Karagan Lewaya is calculated in a single Excel spreadsheet. The processes considered are shown in figure 14. The water balance for time interval t can be described by the following equation:

$$V_{L,t} = V_{L,t-1} + \sum R_{C,t} + P_{L,t} - E_{L,t} - D_{L,t} - O_{L,t} \tag{26}$$

where:

V_L	Water volume in the lagoon (m³)
R_C	Runoff from catchment areas (m³)
P_L	Precipitation on maximum surface (m³)
E_L	Open water evaporation from actual water surface (m³)
D_L	Deep percolation (m³)
O_L	Outflow (m³)

Figure 14. A schematic representation of the processes operating in Karagan Lewaya.



The runoff into the lagoon is calculated as part of the SCM, as described above. In calculations of evaporation, the influence of salinity is ignored, even though it is known to have some effect on evaporation from hyper-saline water bodies (Oroud 2001). Depth-volume and area-volume relations are of utmost importance for the computation of lagoon water levels. The basis for their determination was the 1-ft contour line map of HIRDP (see p12). The calculated volume in relation to measured depth and area is shown in table 3. In the model, calculated volumes are converted to depths and WSAs by linear interpolation.

Table 3. Volume-depth and volume-area relations of Karagan Lagoon.

Elevation (ft above sea level)	Elevation (m above sea level)	Depth (m)	Area (m^2)	Volume (m^3)
-5	-1.524	0	0	0
-3	-0.914	0.610	1,891,062	384,264
-2	-0.610	0.914	2,712,260	1,082,059
-1	-0.305	1.219	3,218,723	1,984,840
0	0	1.524	3,562,183	3,017,808
1	0.305	1.829	3,839,627	4,145,580
2	0.610	2.134	4,066,299	5,350,278
3	0.914	2.438	4,303,109	6,625,605
4	1.219	2.743	4,529,749	7,971,585
5	1.524	3.048	4,899,383	9,408,216
6	1.829	3.353	5,224,150	10,950,778
7	2.134	3.658	5,443,604	12,576,429

When the lagoon is not completely full, which is almost always the case, rainwater will be partially stored in the surrounding bare soil. Similarly, water will evaporate from the soil. These processes are particularly important in times of low water levels and for the drying up of the lagoon. To represent these processes in a simple way in the computation of water levels in the lagoon model, an additional storage volume, "below" the 0 water level, and an additional water surface area have been introduced. This means that up to this additional soil storage volume the water level will remain zero despite water input, yet there will be some evaporation. The resulting depth-volume and area-volume relations are shown in figures 15 and 16.

Deep percolation is calculated in the lagoon model as seepage and in the tank unit as deep percolation (equation 24), but with a different percolation factor. As the knowledge on the lagoon subsoil is limited, the deep percolation factor estimate is rather arbitrary. It only takes into account a likely low hydraulic conductivity in the range of loamy sand.

If the volume of the lagoon exceeds its volume at the defined maximum depth, the difference between the two is considered to be outflow. The defined maximum depth depends on whether the channel connecting the lagoon with the sea is considered to be open or closed.

Seawater inflow is not considered in the Karagan Lagoon model. At present, this assumption can be assumed as a correct one. In the future, however, if the outlet channel is opened, seawater inflow can occur. Information on tides may be incorporated in future model modifications.

Figure 15. Depth-Volume relationship for the Karagan Lagoon.

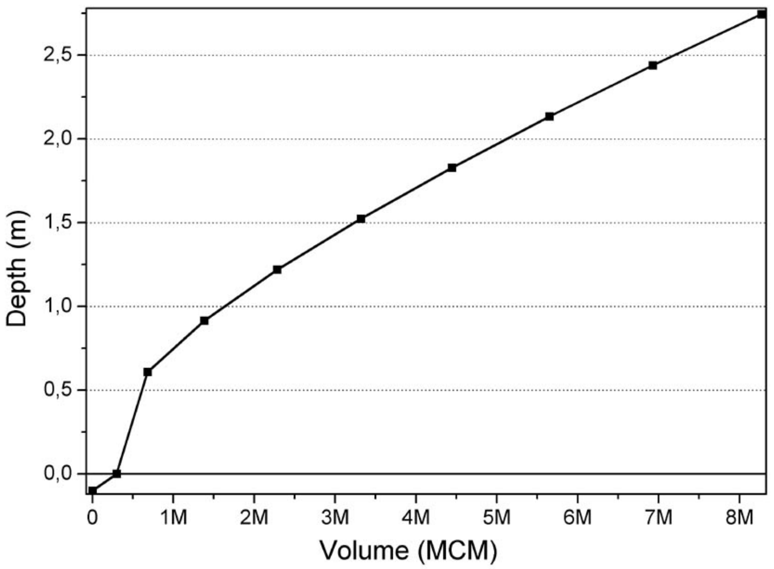
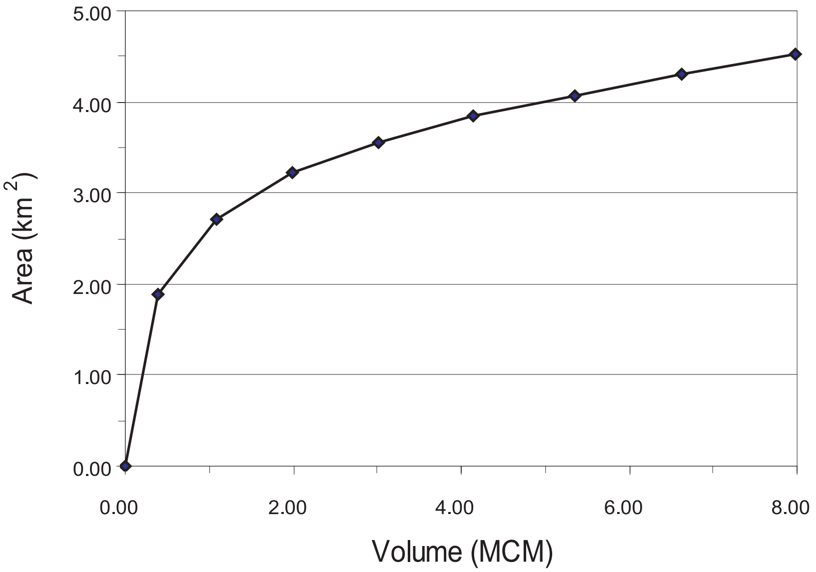


Figure 16. Area-volume relationship for the Karagan Lagoon.



Sea water intrusion and urban drainage are two other components of the lagoon water balance. Small pools of water that obviously seeped through the sandbar can be observed in the southernmost area of the lagoon, close to the main road, at low water levels. The volume of water that seeps into the lagoon is, however, minimal, and certainly lower than urban drainage water, which also partially flows into the lagoon. These components are very small in all practical terms and their more detailed assessment may not be justified. Urban drainage, however, should be monitored to determine whether flows increase with further expansion of the Hambantota town.

Model Applications

Model input

The time step used in simulations with all three models is 1 week. The input data therefore include weekly values of rainfall, ET_0 and evaporation from an open water surface. Weekly time steps are assumed to be long enough to avoid detailed description of hydrodynamic processes and use a water balance approach. On the other hand, weekly time steps allow a more accurate simulation of the processes than monthly time steps. As the model reservoirs are comparatively small and some flow components are based on the previous time step, monthly time steps would lead to a "jumping" behavior of the model outputs (e.g., one month the lagoon would be completely empty, next month completely full).

The input rainfall data are derived from recorded precipitation data at the Hambantota meteorological station for the period 1991 to 2001. ET_0 is calculated with maximum and minimum temperatures of the same period and station using the Hargreaves equation (as recommended by FAO for areas where reliable climatic data are insufficient).

$$ET_0 = 0.0023 * 0.408 * RA\left(T_{avg} + 17.8\right)\left(T_{max} - T_{min}\right)^{0.5} \tag{27}$$

where:

ET_0	Reference evapotranspiration (mm day^{-1})
RA	Extraterrestrial radiation (MJ m^{-2} day^{-1})
T_{max}	Maximum daily air temperature (°C)
T_{min}	Minimum daily air temperature (°C)
T_{avg}	Mean of daily minimum and maximum temperature (°C)

This equation is derived from the Penman-Monteith equation by using only temperature and radiation data and fitting measured ET_0 values in order to obtain the parameters 0.0023 and 17.8. The constant 0.408 is used to convert the radiation to evaporation equivalents in millimeters (Droogers and Allen 2002).

Evaporation from open water surface is calculated with ET_0 and a K_C factor. Doorenbos and Pruitt (1977) suggest values of K_C of 1.1 to 1.2 and Allen et al. (1998) a value of 1.05. The latter value, however, is likely to be higher for semi-arid conditions and wind speed higher than "calm to moderate wind speed averaging 2 m/sec", by 0.01 to 0.1. WCP (1994) reports wind speeds between 4 and 6 m/sec. The Heargreaves equation has a tendency to underestimate ET_0 under such conditions (Droogers and Allen 2002). Therefore, an increase of 0.05 was assumed, resulting in a K_C of 1.15.

For the simulation of the effects of the future irrigation scheme, inflows from the irrigation canals into the Karagan catchment are specified directly.

Sensitivity Analyses

Karagan Lagoon Model

A simple sensitivity analysis has been carried out by plotting the relative change in mean lagoon water level (over 11 years of simulations) and its standard deviation against the relative change of one parameter, while other parameters are kept constant (figures 17a and 17b). The parameter which has the most impact on model output was found to be the k_c-factor, determining open water surface evaporation. Changes in catchment runoff, simulated by simply routing a part of the calculated weekly runoff into the lagoon, are the second-most influential factor, but of a remarkably smaller degree. Changes in the additional surface area introduced to take into account the evaporation from wet soil (referred to as "soil storage A" in figure 17) have only a minor influence. These factors affect the mean water level and its standard deviation similarly. The deep percolation factor also shows minor influence on mean water levels, but has almost no effect on standard deviation. Changes in the additional volume introduced to represent soil storage were found to have almost no influence on calculated water levels, which is why this parameter is not shown.

Simplified Catchment Model (SCM)

A simple sensitivity analysis has been carried out by plotting the relative change in mean weekly runoff and its standard deviation against the relative change of one parameter (while other parameters were kept constant) shown in figures 18a and 18b. This is only done for the "Katara catchment", to show the general sensitivity of the runoff simulation to the main model parameters. Similar to the lagoon model parameters, the parameter which has the most impact on model simulations, the evapotranspiration factor k_c, followed by the upper storage limit. The lower storage limit still has considerable influence on the mean weekly runoff, whereas the runoff and deep percolation factors were shown to be of little influence. The standard deviation, indicating the extent of runoff peaks, is sensitive only to changes in the upper storage limit and the k_c-factor.

Model Calibration and Parameter Estimation

Proper calibration of model parameter values through comparison of model simulations with corresponding observed variables is impossible at this stage. As the data becomes available, more complex modeling techniques could be employed. At this stage, most of the simulation experiments have been carried out using the SCM, as this simpler model needs less observed data for calibration. However, a few initial tests were conducted with the DTCM as well. In all three component models (two catchment models and one lagoon model) a number of suppositions had to be made about model parameter values. The techniques used to provisionally "calibrate" the models are described below.

Figure 17a. The results of lagoon model sensitivity analysis: Mean water depth.

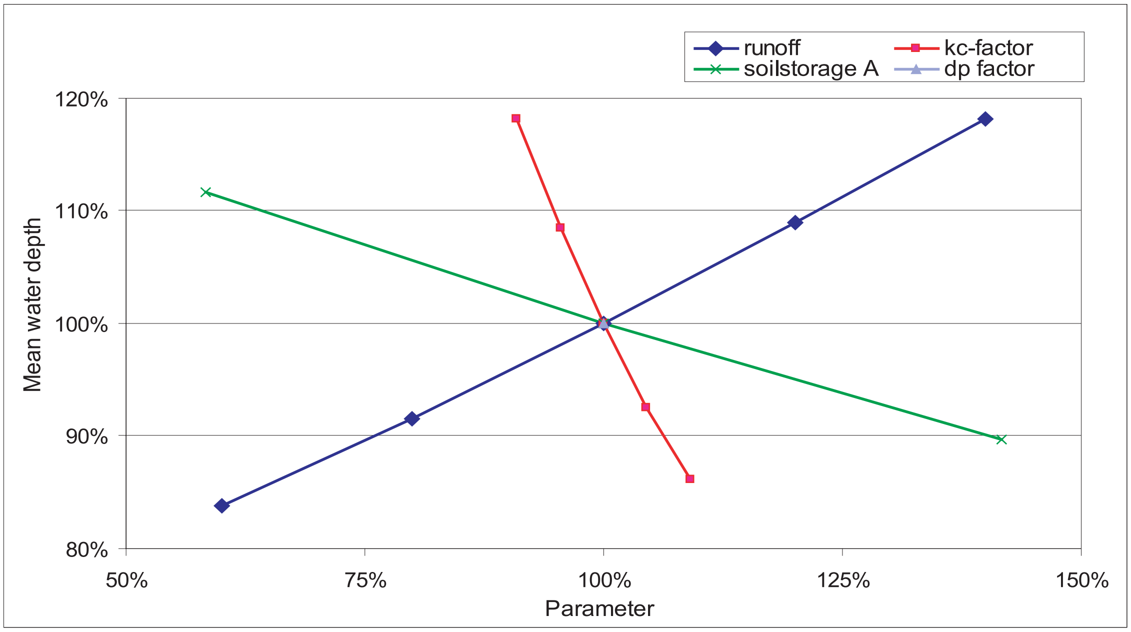


Figure 17b. The results of lagoon model sensitivity analysis: Lagoon water level.

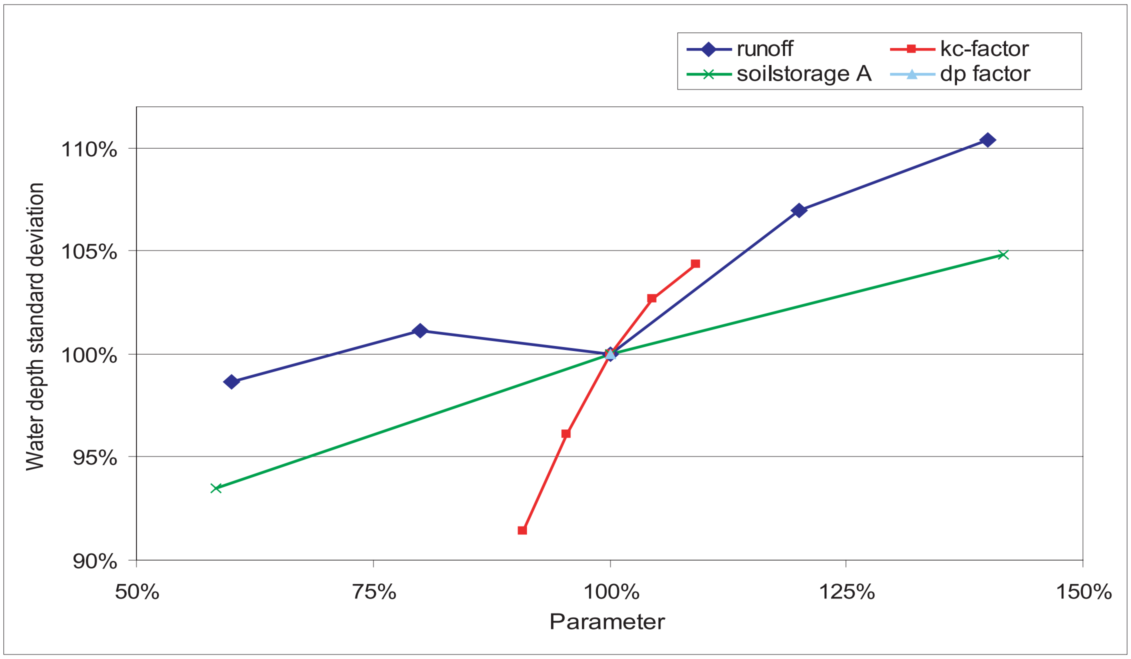


Figure 18a. The results of the simplified catchment model sensitivity analysis: Mean weekly runoff.

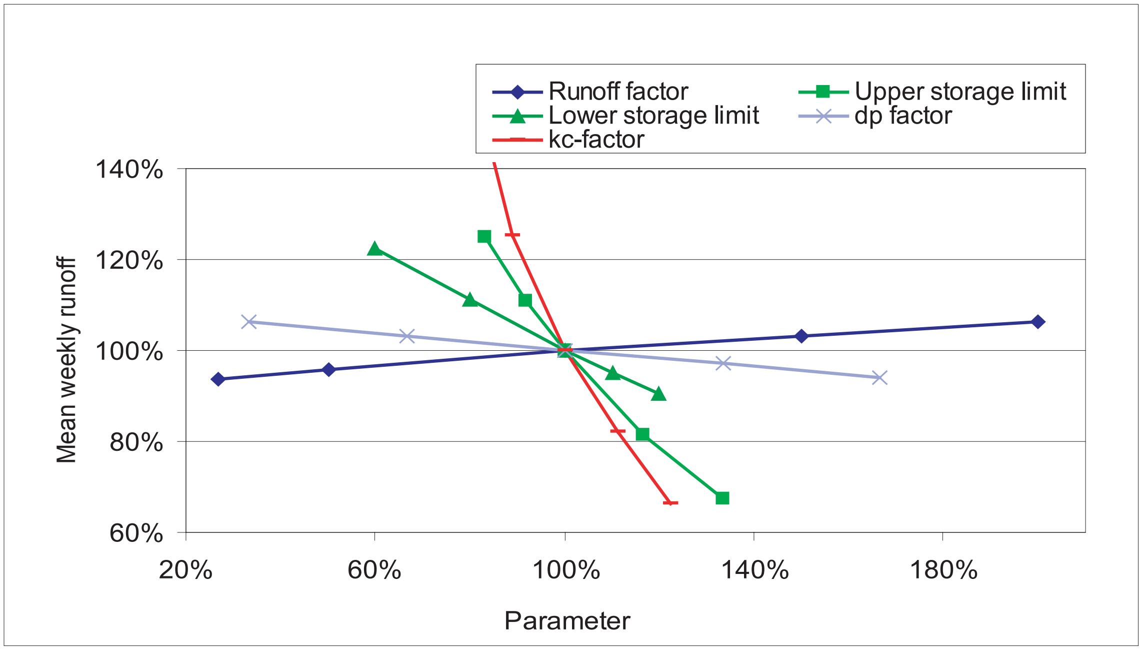
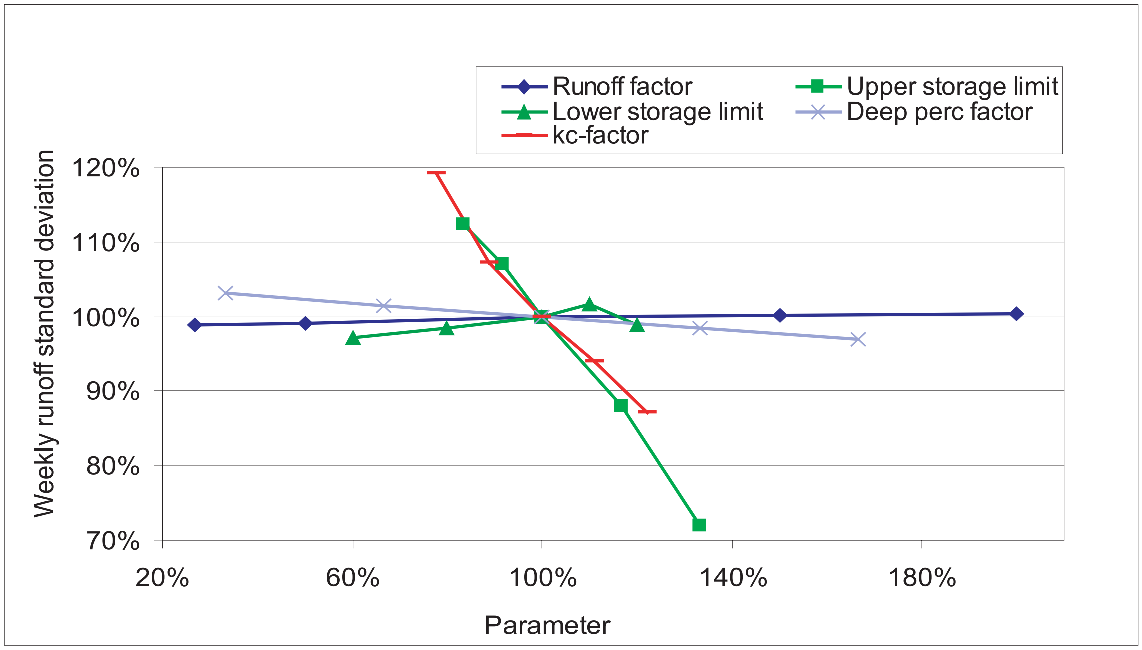


Figure 18b. The results of the simplified catchment model sensitivity analysis: Mean weekly runoff standard deviation.



Detailed Catchment Model (DTCM)

As no “hard” data were available for calibration, information gathered in informal discussions with local farmers, fishermen and cattle owners was used to calibrate model parameters. Some model parameters may also be derived from available literature sources. All this is referred to here as “soft calibration” and consists of two “calibration levels”: calibration at the paddy field level and calibration of the sub-catchment runoff.

Ponrajah (1984) suggests an overall irrigation efficiency for paddy cropping in Sri Lanka of approximately 40 percent, which means that the ratio of evapotranspirated to non-evapotranspirated water is about 4 to 6. If the paddy units in the simulation model are assumed to behave similarly, the accumulated values of evapotranspiration and return flow for an average cropping season should have the same ratio. This ratio has been approximated in the model by changing the paddy field units’ parameters.

Another type of information used to “calibrate” catchment parameters is the number of weeks, in which the tanks in the system spill. Most of the tanks were reported to spill for a total period of 2 to 3 weeks in a usual maha season. As this does not happen consecutively (tanks spill for about 2 - 3 days every time they start spilling), an attempt was made to keep the number of weeks in a range of 4-8 weeks. The amount of catchment runoff determines the frequency of irrigation. Therefore, the information that paddy was cultivated regularly, but not every year during the simulation period, was used to determine the catchment parameters. Also, the fact that the comparatively low yields in the area indicate frequent water shortages was considered in the parameter estimation.

The DTCM was run using three catchment conditions: one baseline—which describes the current status of the catchment, and two hypothetical, which vary in level of agricultural development. One such state, “tanks, but no paddy”, includes tanks, but no paddy fields and was used to test the impact of the representation of the paddy cultivation practices on runoff. This condition is anticipated to result in reduced inflow to the lagoon, with water stored in the tanks, without being released for irrigation. The second scenario is the “no tanks, no paddy” state, in which both these units were excluded from the simulation process. In this condition without agricultural water storage, the assumption was that less storage and less evaporation in the catchment area lead to higher simulated water levels.

Figure 19 shows the simulated water levels in the Karagan Lewaya with runoff calculated at the three different conditions. The small difference between the water levels resulting from three simulations, suggests that the influence of paddy cultivation on runoff as represented in the DTCM is relatively small. This effectively stands as another justification for the use of the SCM, if the purpose of the simulation exercise is to simulate the lagoon water levels only.

Figure 20 compares the water spread areas observed in the lagoon in the recent period of study, with water spread area time series simulated by DTCM and SCM. An overestimation of runoff into the lagoon by the DTCM with the current parameters is evident. As long as no detailed data about tanks and paddy fields are available for proper calibration of the DTCM, the SCM remains the preferred option and is used for further model applications.

Simplified Catchment Model (SCM)

Two considerations have been used in parameter estimation of the SCM. First, the runoff volumes into the lagoon were constrained to ensure the observed lagoon water levels. Second, similar to

Figure 19. Karagan Lewaya water levels simulated by the DTCM at three different upstream catchment conditions.

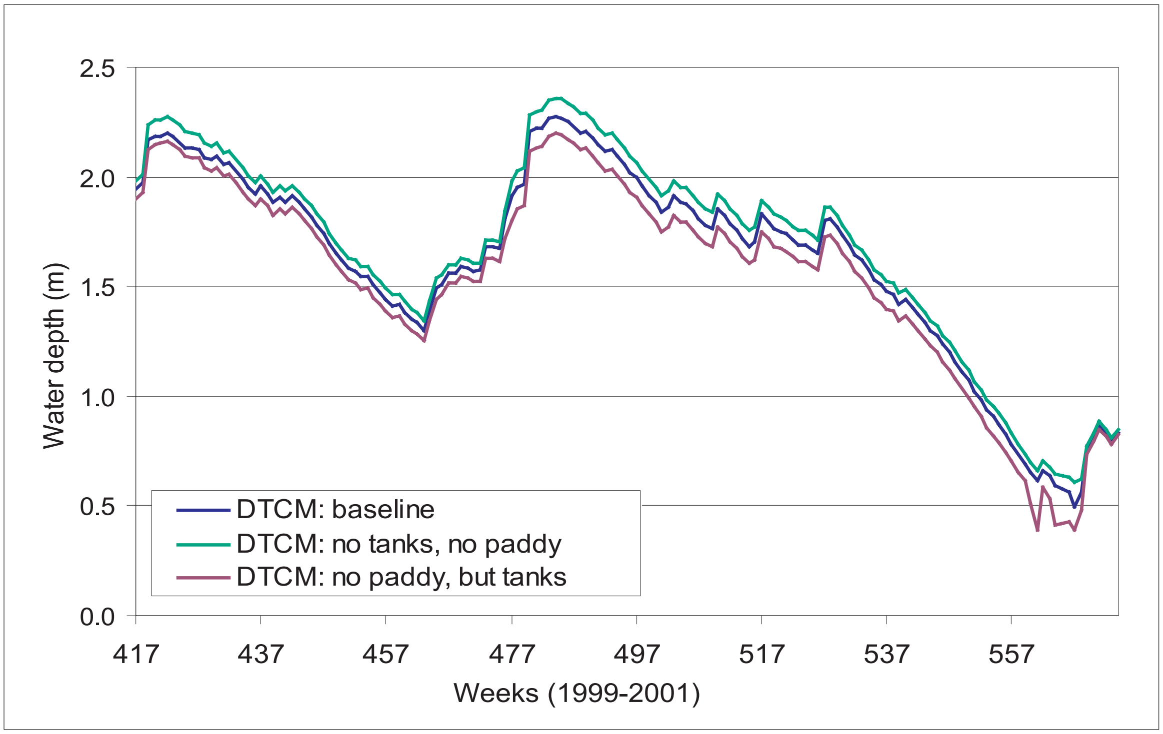


Figure 20. Karagan Lewaya water spread areas observed and simulated by two models at the current state of upstream catchment development.

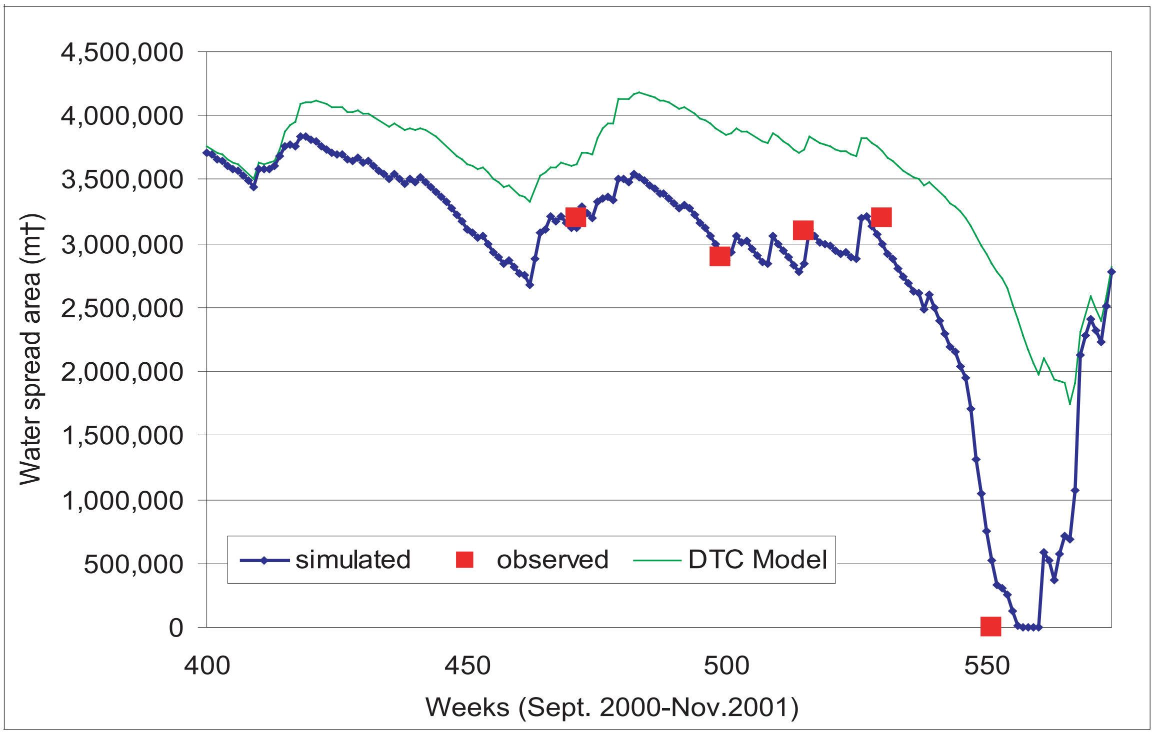
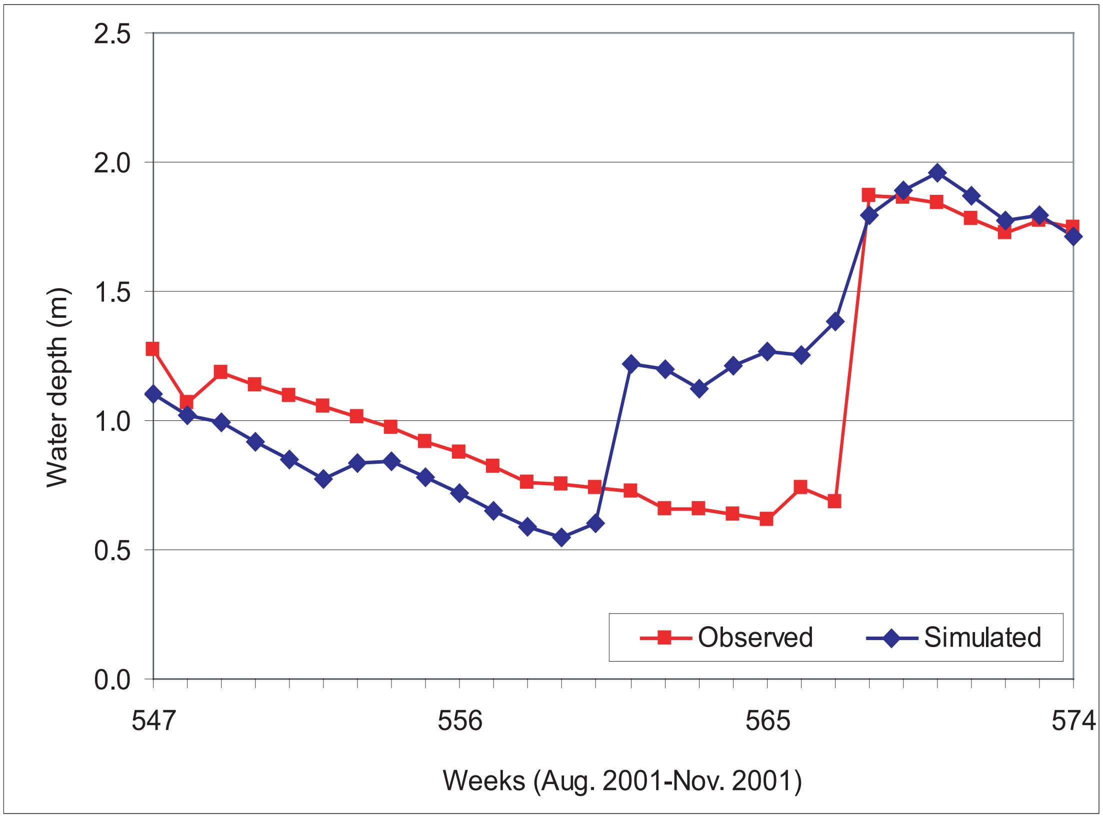


Figure 21. Water level curves of the model tank and the combined real tank.



the "soft calibration" of the DTCM above, an attempt was made to determine irrigation issues and spilling in at least some of the 11 years of simulation (as reported by local farmers).

The first data obtained from the new monitoring network were used. Although the run of the water level curves of the model tank and the combined real tank is not exactly the same, the general water depth fluctuation patterns match well, despite the short series of available data. The rise to a water level of 2 m and the following gentle drop were simulated correctly (figure 21). Differences in the two time series may result from the use of Hambantota rainfall data for the whole of the catchment area, despite spatial rainfall variations discussed in the section on Climatic Data (p.15). Validation and calibration must be repeated when more data are collected.

Karagan Lagoon Model

The parameter estimation for the lagoon model is based on various observations: reported information on its "normal behavior" and flood levels, WSAs measured from satellite images and the observation of a completely dried-up lagoon from August to September 2001. Because of the meagerness of available data, the commonly used criteria of model performance have been replaced by a simple comparison of the run of the water level curve with the few known or estimated data.

Figure 22 shows the simulated lagoon water level fluctuations during the 11-year long simulation period. The pattern of very low water levels in some summers and higher water levels in wet maha seasons (WCP 1994) is reproduced in the simulated time series. However, a complete drying up of the lagoon, which is common according to WCP (1994), has been reproduced in 2001 only. This could be an illustration of the overestimation of water levels. As no specific information about earlier drying up is available, it could as well correctly reflect an almost completely dry lagoon in earlier years. At water levels of 12 to 19 cm, as calculated for the summers of 1994, 1996 and 1997, the corresponding WSA is only 8 to 13 percent of the maximum WSA. Such a situation could easily be interpreted by observers as being "a dry lagoon."

The gradual fall of water levels from the assumed flood water level of 1998 to zero in autumn 2001 was reproduced in the model simulations. The WSAs derived out of the satellite images of 2000 and 2001 matched fairly well with simulated results (figure 20). The first 12 water level measurements recorded after the installation of the gauge in Karagan Lewaya have also been used (figure 23). The timing of the simulated filling up was again similar to the observed, although the simulated water levels increased more rapidly than the observed levels. It remains to be clarified with further measurements whether this is a problem of simulation or due to the not yet accurately determined zero datum of the water level gauge. Also, measured values below approximately 0.50 m have to be treated with caution, because up to this level the lagoon consists of several little pools instead of a single water body.

Developing Scenarios of Future Irrigation Development for Model Simulations

The main source of information for application of the model in the context of quantifying future changes has been provided by the MASL. The SAPI study by the Japanese Bank for International Cooperation (JBIC), however raises doubts about these data. The water balance carried out in the scope of this study for the entire Uda Walawe irrigation scheme predicts water shortages if the extension project is implemented as planned, without water saving management techniques throughout the whole area. It also shows some discrepancies between the MASL planning and the water requirements in the extension area.

If additional inflow is calculated with MASL's design values, the amount of water is unreasonably high. The design discharge for the LBMC at the head end of the second phase extension area is 9.12 m³/sec. If the canal is assumed to operate as planned by the MASL (full flow for nine months of cultivation period and 50 percent to full every tenth day during the rest of the year [Meijer 2000]), the amount of delivered water would be 216 MCM. The SAPI study, using more conservative assumptions on irrigation efficiencies than previous studies, calculates the water demand for the left bank extension area as 166 MCM (for a cropping intensity of 200%). Furthermore, the amount of water that could be issued to the extension area without causing water shortages in the whole Uda Walawe scheme is calculated to be about 120 MCM. However, the MASL is implementing the project as designed, in expectation of various programs in the basin to raise overall efficiency.

If the 166 MCM from the SAPI study is compared to the 216 MCM calculated from the "issue tree", 75 percent of the design discharge will be sufficient to fulfill crop water requirements in the extension area. For the second amount of 120 MCM, only 55 percent of the design discharge is required. It can be concluded, that the new canals may turn out to be over-dimensioned and are most unlikely to be totally filled for longer periods of time.

Based on these assumptions, three different scenarios with different inflow volumes of 100, 75 and 50 percent of the design inflow have been investigated (table 4).

Figure 22. Karagan Lagoon water depths simulated by the simplified catchment model.

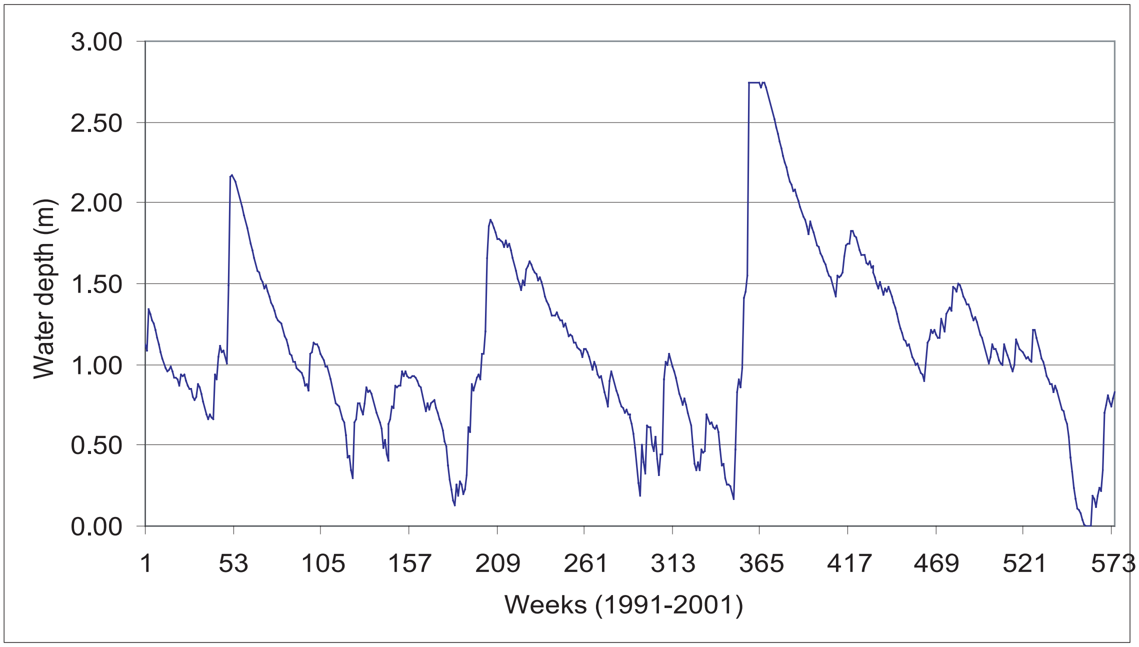


Figure 23. Observed and simulated water levels in Karagan lagoon during the most recent study period.

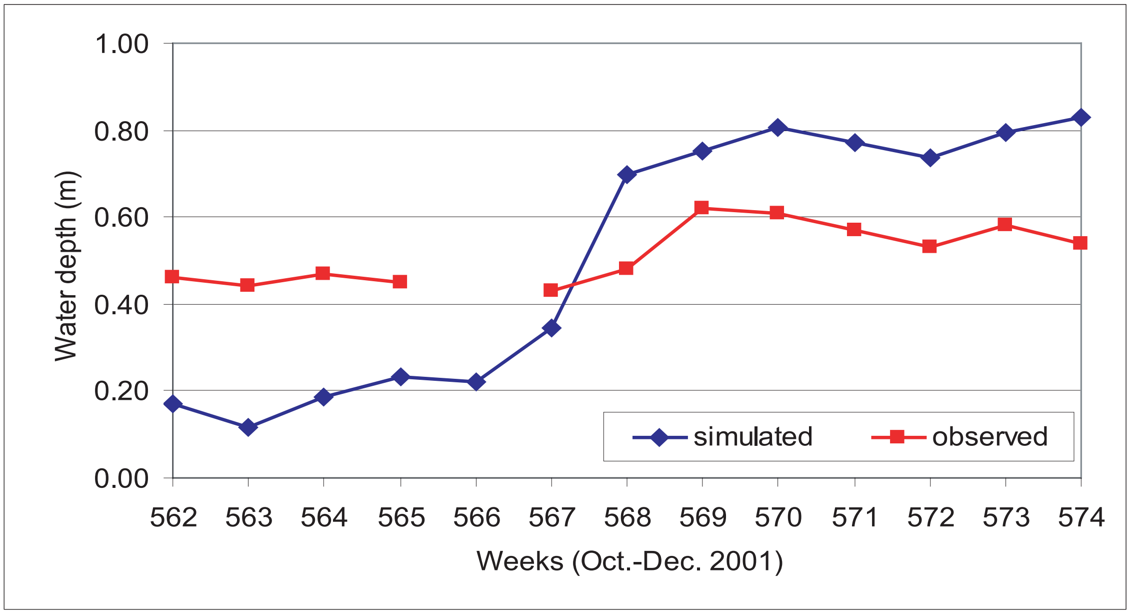


Table 4. Future scenarios of irrigation inflows to the study area.

Scenarios: Inflow	Sub-scenarios: Parameters	Sub-scenarios: lagoon management	
100% of maximum canal capacity	Baseline parameters		
	Changed parameters		
75% of maximum canal capacity	Baseline parameters		
	Changed parameters	diversion to sea	25%
			0%
		outlet closed	
50% of maximum canal capacity	Baseline parameters		
	Changed parameters		

The increase in catchment storage volume by the construction of new tanks and the augmentation of the capacity of some existing tanks has been included in all future scenarios.

The increase in paddy cultivation area is envisaged to lead to a higher storage capacity in the basin. Also in fields used for other crops, more water can be stored than in non-managed natural areas. In additional sub-scenarios such higher storage capacity was taken into account by further increasing the catchment storage parameters. In these scenarios, referred to as "changed parameters" in table 4, the evapotranspiration factor k_C was increased as well, representing the anticipated higher evapotranspiration capacity of the extended cultivated areas.

The extent of these probable parameter changes cannot be determined accurately. It is possible to calculate several different scenarios with varying parameters, but the effect of these parameter changes is likely to be small compared to the influence of additional irrigation water inflow. Such variations have therefore been ignored at this stage of the study.

A possible option for reducing the impact of increased flows from the extension area on Karagan Lewaya is a drainage channel diverting drainage flows directly to the sea before they reach the lagoon. The effect of such a diversion channel is investigated in two sub-scenarios ("diversion to sea" in table 4). In these scenarios, only 25 percent or 0 percent of the total runoff from the "cascade catchment" was routed into the lagoon. Both sub-scenarios are based on the runoff calculated in the most probable scenario, with 75 percent inflow and changed parameters ("75 percent changed parameters").

Lagoon water levels can also be managed by opening or closing the outlet channel to the sea. As it is not very probable that this channel will remain closed when Hambantota faces the drainage inflows into Karagan Lewaya, it is generally assumed to be open in the future scenarios. To illustrate the effects of not opening the channel, the "75 percent changed parameter" scenario was also simulated with a closed channel ("outlet closed" scenario in table 4).

Additional scenarios can be easily simulated in the model to investigate other assumptions or include new information.

Results of Scenario Simulations

The irrigation inflow from the extended Uda Walawe scheme has a profound impact on the hydrology of Karagan Lewaya. In all scenarios with full drainage flow into the lagoon, the spillway level of the outlet channel is reached frequently and high water quantities flow into the sea.

The amount of irrigation inflow is the most significant factor in future scenarios, while changes in runoff model parameters have a much smaller effect. The simulated water levels of the three "baseline parameters" scenarios and the three "changed parameter" scenarios are illustrated in figure 24. For illustrative purposes, only the period from 1997 to 2001 is shown (which includes the wettest maha season 1997 and the very dry year of 2001).

In the two 100 percent scenarios, the results of which show almost no difference, water levels in the lagoon never drop below 1.60 m and outflow to the sea occurs during long periods. The periods of outflow are slightly shorter in the two 75 percent scenarios, which, except for the second half of 2001, also do not differ very much from each other. The lagoon water level drops to 1.40 m in dry periods. The 50 percent scenarios result in significantly lower water levels in the lagoon: less than 1 m in dry periods. They also exhibit a noticeable difference between results produced with unchanged and changed runoff model parameters.

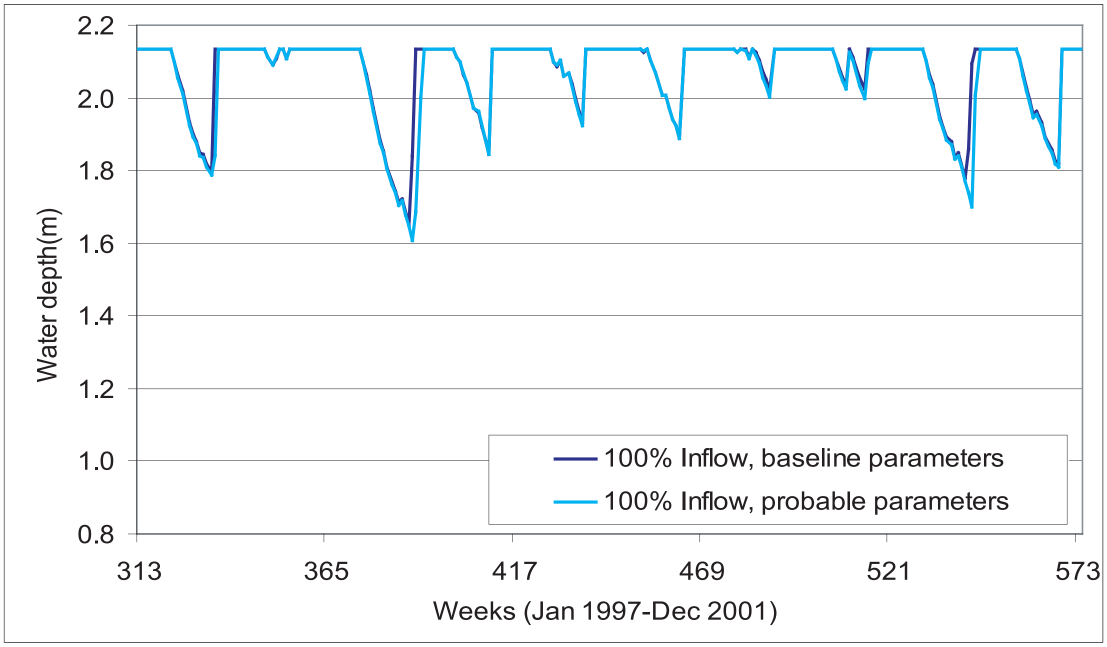
A constant inflow of only 50 percent of the design capacity might seem to be an unrealistic scenario. In very dry years, however, when the supply from the Uda Walawe reservoir can not meet the demands, the inflow could be even lower than this simulation, and resulting lagoon water levels could be as low as in this scenario or even less.

The scenario "outlet closed" shows that this is a practically impossible option. The simulated water levels are almost constantly above a level at which the houses closest to the lagoon would be flooded. As the water levels would frequently rise to the level of the emergency outlet channel through the sandbank, built in 1998, it is expected that this channel would be opened to the sea for most of the year (figure 25).

Figure 26 illustrates the lagoon water levels simulated in the scenario "diversion to sea." The baseline scenario water levels are presented for comparison. The partial diversion of 75 percent leads to no significant fall of simulated water levels, showing that higher portions would have to be diverted for that purpose. A complete diversion of the water draining into the lagoon through the main drainage channel leads to simulated water levels, which are considerably lower than the levels of the baseline condition.

Apart from the time series of water levels in Karagan Lagoon, a useful measure for summarizing and presenting the simulation results is a duration curve of water levels. A duration curve is a cumulative distribution of values in a time series. It shows the percent of time that a certain value (lagoon water level in this case) is equaled or exceeded. In other words, it provides a measure of assurance and risk of exceeding certain water levels and can give the indication of how frequently a certain water level occurs in a simulated (or observed) time series. The duration curves of water levels simulated by all different scenarios are presented in figure 27. They illustrate, for example, that if 75 percent capacity inflow to the lagoon is expected, its water levels will remain above 2 m for about 75 percent of the time on average throughout the year. If 50 percent capacity inflow will occur, the level of 2 m will be exceeded only for 50 percent of the time. The duration of different water levels together with their actual values, may point to various thresholds, which may need to be avoided (or maintained). The percentage of the time that different water levels are equaled or exceeded effectively introduces the concept of assurance in this study.

Figure 24. Simulated water depths in the Karagan lagoon under different scenarios of future irrigation development.



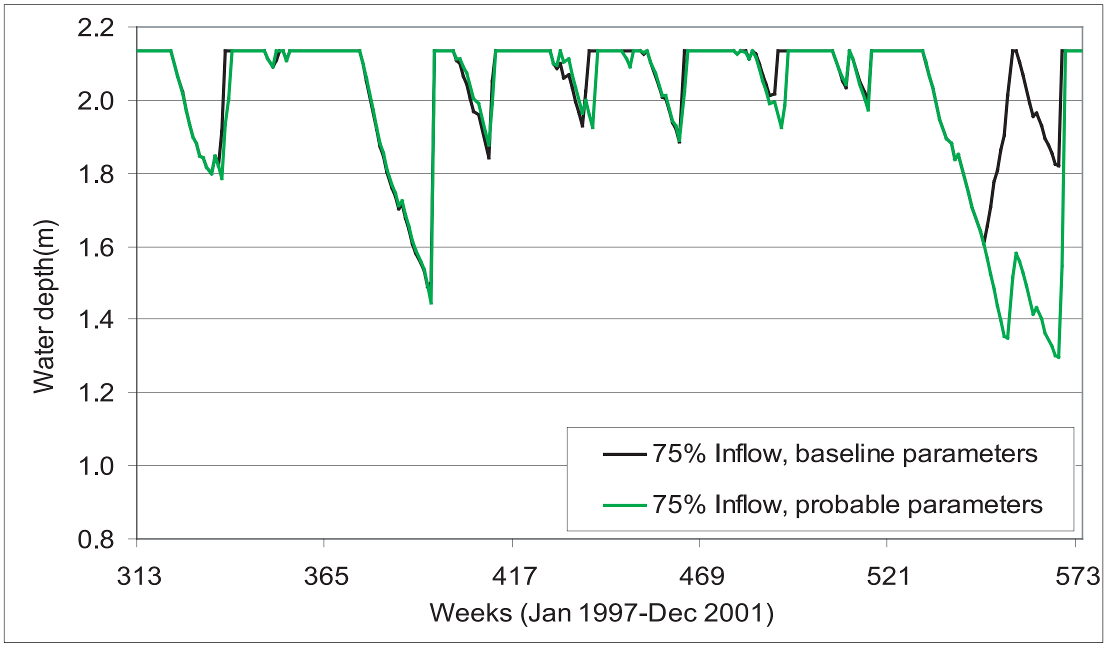
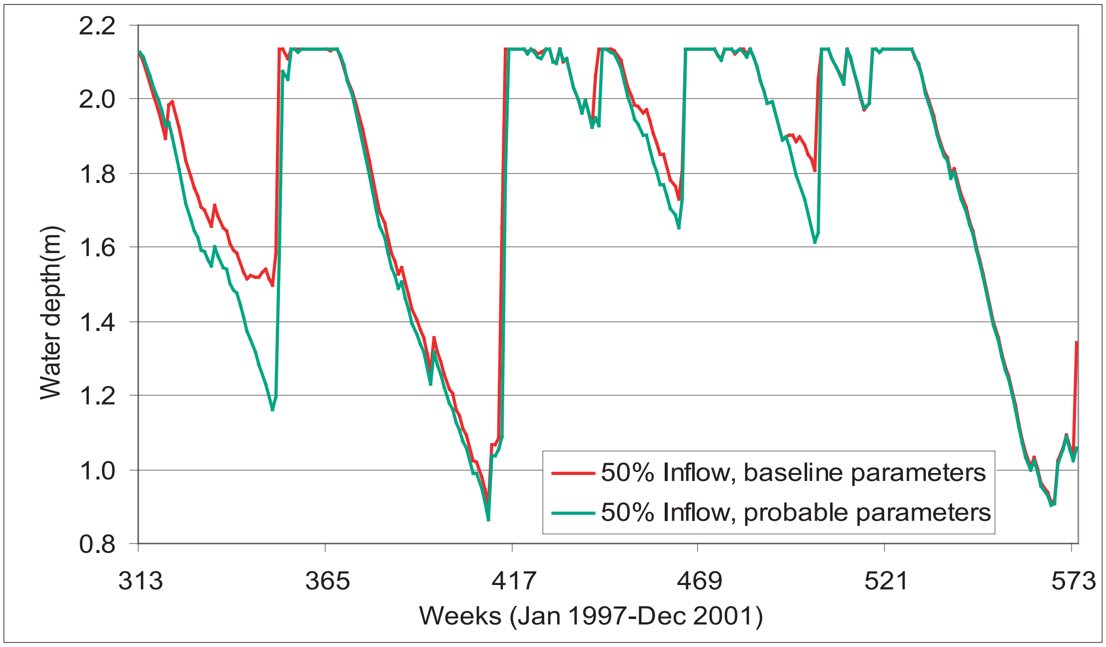


Figure 24. Simulated water depths in the Karagan lagoon under different scenarios of future irrigation development (continued).



Simulating Karagan Lewaya Salt Balance

The Model

It is not only the anticipated rise in water levels but also decline in salinity levels that are of concern for the habitat quality of Karagan Lewaya. Therefore the simulation of changes in salinity was also initiated. Weekly time steps are unlikely to be suitable for adequate representation of the salt balance, particularly when outflow is simulated in times of flooding. A proper daily simulation, however, is not possible because of the weekly time steps of the water balance models (DTCM, SCM and the lagoon model). Therefore weekly values for precipitation, evaporation, percolation and runoff as calculated by these models have been split into seven equal daily values. The results at the end of each seven-day period are considered to represent a weekly value. This approach does not lead to a correct simulation of daily salt variability, but the results are envisaged to yield an estimate of the expected changes in salinity.

Figure 25. Lagoon water levels simulated in "outlet closed" scenario.

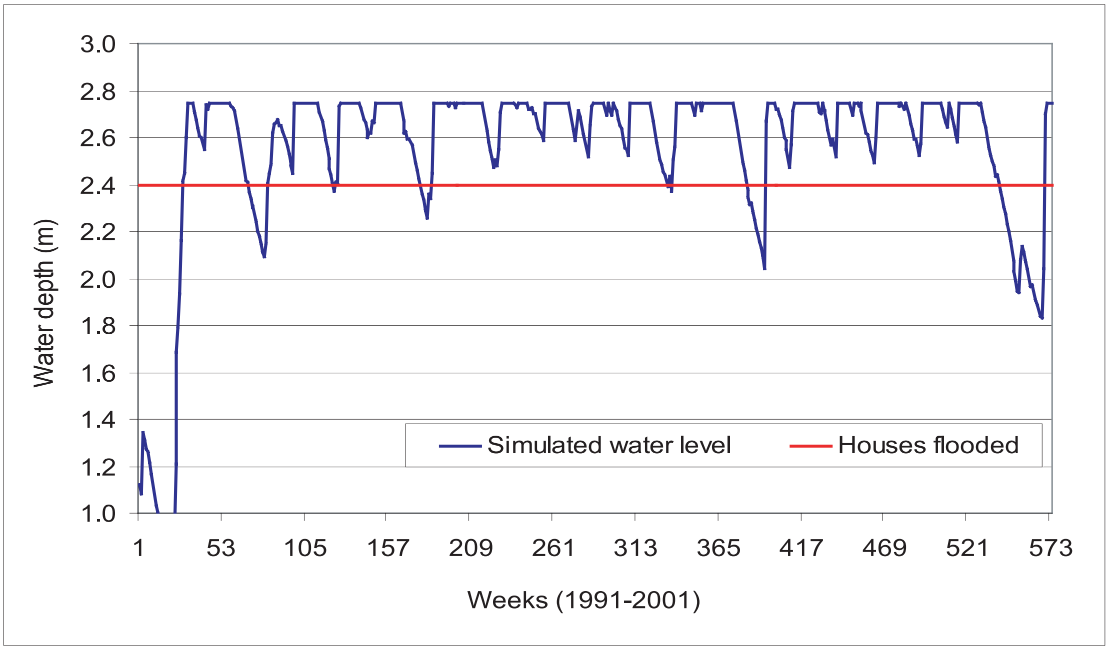


Figure 26. Lagoon water levels simulated in the "diversion to sea" scenario.

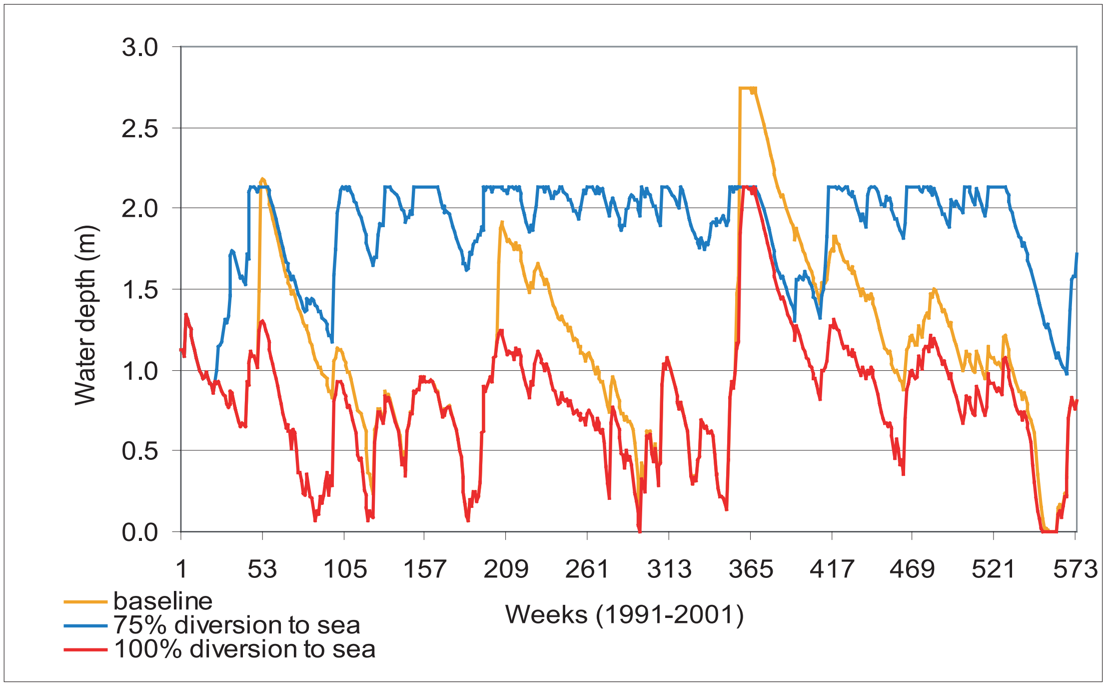
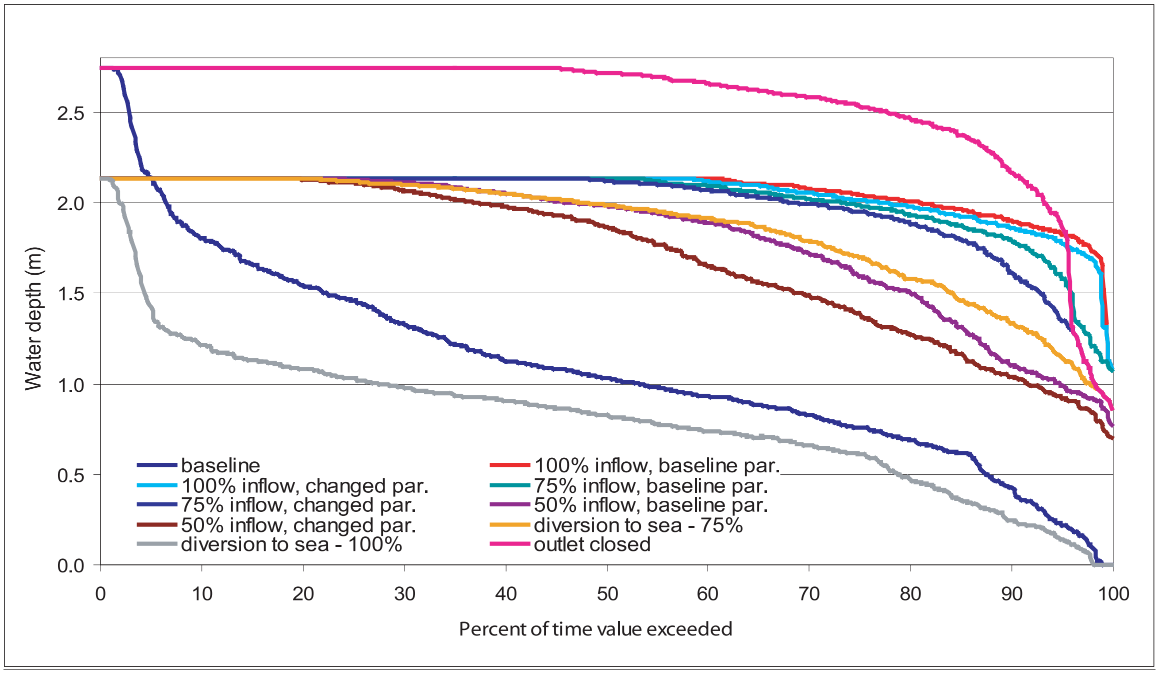


Figure 27. Duration curves illustrating the variability of simulated Karagan Lagoon water levels under different scenarios of future irrigation development.



The concentration of salts in the lagoon at the end of day “i” is calculated as:

$$C_i = \frac{L_i}{V_i} \tag{28}$$

where:

C Concentration of salts in the lagoon (dS/m)

L Load of salts in the lagoon (the concentration is given in dS/m, which equates to approximately 0.5 kg/m³—therefore, the value for the load gives about two times the load in kg)

V Volume of water in the lagoon (m³)

The load of salts in the lagoon at the end of day “i” is calculated with the following equation:

$$L_{i+1} = L_i + RO_{irr,i} *C_{irr} + RO_{dir,i} *C_{dir} - O_i *C_i \tag{29}$$

where:

L_{i+1}	Load of salts in the lagoon (dS/m)
L_i	Load of salts in the lagoon (dS/m)
$RO_{irr,i}$	Runoff from irrigated areas (m³)
C_{irr}	Concentration of salts in runoff from irrigated areas (dS/m)
$RO_{dir,i}$	Runoff from non-irrigated areas (m³)
C_{dir}	Concentration of salts in runoff from non-irrigated areas (dS/m)’

The volume of the lagoon at the end of each day is calculated as in the water balance (see equation 26). Runoff, precipitation, evaporation, percolation and outflow as calculated by the SCM and the lagoon model, are used, but the weekly values are split into daily values by dividing them by seven. Runoff from the uncultivated catchment and runoff from the tank catchments are differentiated, because they have different concentrations of salts during the cultivation period.

Contributions from seawater seepage and urban drainage are difficult to quantify, but are likely to have minor influence on salt balance. The removal of solidified salt by local residents when the lagoon is dried up may be established by interviews, but it has not been done at this stage of the study. Salt removal quantities may be larger than contributions from seawater, but still insignificant in a salt balance. These components were therefore ignored in the model calculations. Seawater inflow could have an impact on salt balance but has not been considered at this stage of model development and may need to be incorporated in the future. Monitoring the outflows and inflows from and to the lagoon once the channel through Hambantota is operational, is strongly recommended. With these data a better representation of the processes could be made.

Parameter Estimation and Discussion

The concentration of salts in runoff from the catchment immediately adjacent to the lagoon (not "regulated" by tanks) is assumed to be constant. The constant value chosen is based on electrical conductivity measurements in some tanks of Karagan Oya in December 2001. After the implementation of the extension project, there will be small areas of cultivation (about 7 ha) in the direct catchment and some irrigation inflow and hence some return flow with higher concentrations because of upstream use of fertilizer and pesticides. But because of the relatively small amount of irrigation inflow this is neglected in the model calculation and the value is the same for baseline and future scenarios. The concentration of salts in the runoff water from the cascade catchment is set to the same value for periods with no cultivation, and to a higher value for periods of cultivation. The latter value was estimated from measurements in return flows of the (large-scale) Kirindi Oya irrigation scheme.

Water quality will be monitored throughout the implementation and operation of the extension project. According to results of these investigations, the above-described values can be changed.

For the estimation of the initial concentration of salts, which is of paramount importance for the simulation results, three measurements of salinity in the lagoon were considered. For February 1992, WCP reports 21 dS/m (WCP 1994). In June and December 2001 180 dS/m and 56 dS/m, respectively, were measured. These data give an idea of the range of salinity levels in the lagoon, because the 1992 measurement was taken at a very high water level and the June 2001 measurement at very low water levels, shortly before the drying up of the lagoon.

Fluctuations in this range were simulated only for the period of 1991 to 1997. After the flood of 1997/98, simulated salinity levels are much lower than the expected values and the values measured in 2001. Apparently, the assumption of complete mixing is adequate as long as no outflow occurs, but the flushing of solids during the flood is strongly overestimated (figure 28).

For the future scenarios however, in which outflow will be more constant over longer periods, the assumption of complete mixing is expected to apply better. Figure 29 shows the results of all the future scenarios with open outlet channel and without diversion of drainage water to the sea. It demonstrates a strong trend towards lower salinity levels after irrigation development.

Figure 28. Simulated salt concentrations in Karagan lagoon under current conditions.

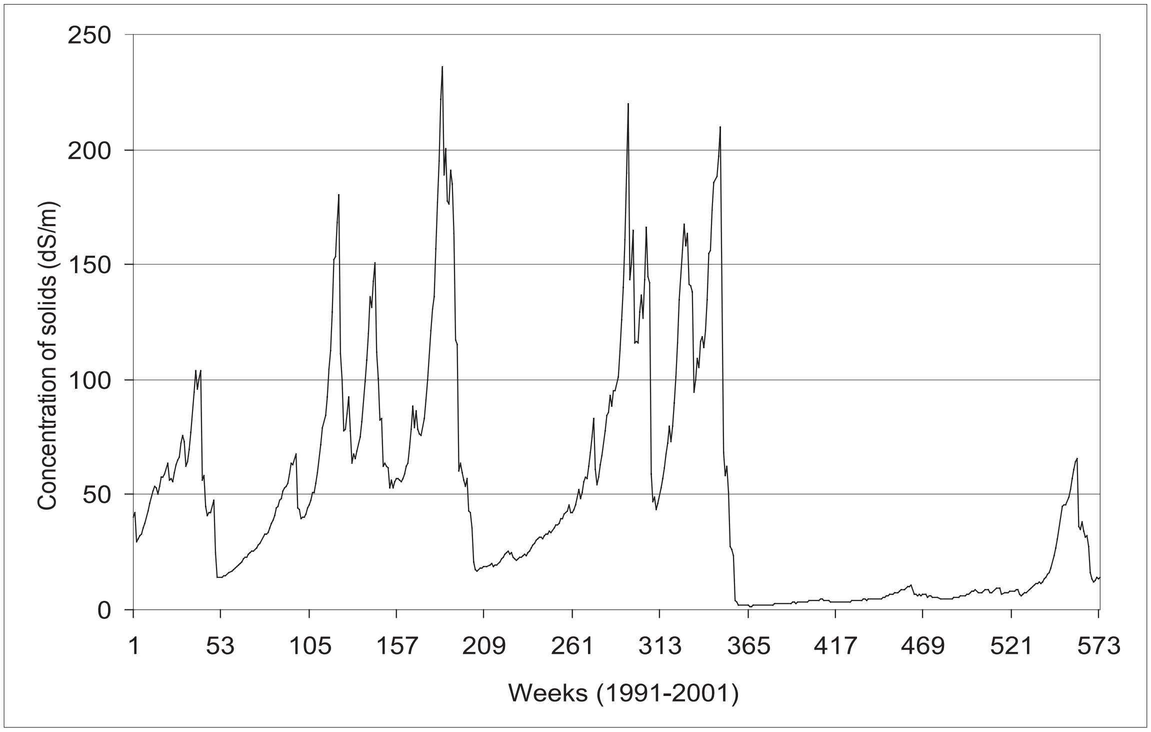
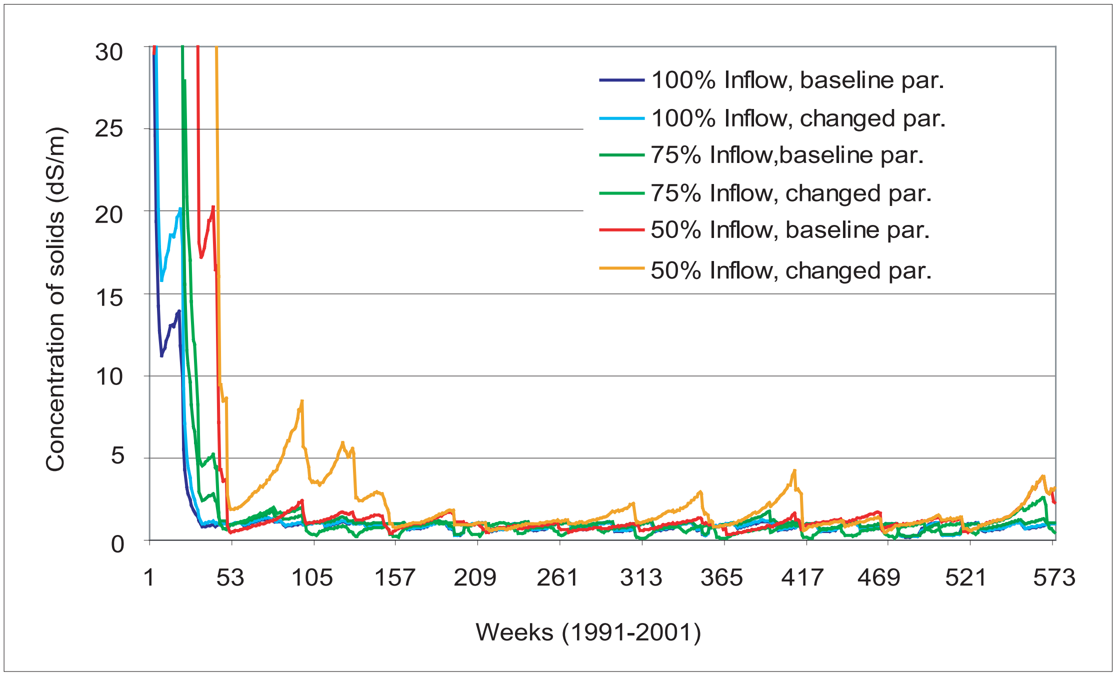


Figure 29. Simulated salt concentrations in Karagan lagoon under different scenarios of future irrigation development.



Conclusions

The study has focused on simulation of changes in hydrology of the Karagan lagoon, which are expected to occur after expansion of the irrigation scheme in the Uda Walawe basin. The developed mathematical models of the Karagan catchment and Karagan lagoon represent valuable quantative tools, which are easy to set up and run and allow different scenarios of future management of the irrigation scheme be simulated and their effects on the hydrology of the lagoon to be examined.

The information environment in which this study was carried out was extremely poor. The study has therefore illustrated the difficulties associated with the quantification of impacts of water resources development projects in data poor regions. No hydrographic data of Karagan Lewaya and its catchment (apart from rainfall data) existed at the beginning of this study. During the present investigation, considerable rainfall leading to runoff and the subsequent filling-up of irrigation tanks and Karagan lagoon was recorded in November and December 2001. Useful data about the runoff characteristics and the behavior of the lagoon were collected only during this period. With such little data, no proper calibration of the presented models could be done, and therefore, all conclusions drawn from it will remain preliminary until more data are available.

The scenarios examined in this study illustrate that drainage flows from the extended Uda Walawe scheme would lead to a significant rise in water level at the Karagan Lagoon throughout the year. To prevent flooding of settlements close to the lagoon, the outlet channel through Hambantota will have to be opened for long periods and large volumes would flow to the sea. The lagoon would not dry up in summer anymore—it would change its characteristics from a seasonally hyper-saline to a freshwater wetland.

With low inflows of only 50 percent of the design capacity, water levels will drop significantly in dry years. In such years of low irrigation water supply, lagoon water levels of less than one meter can still be expected after the implementation of the extension project. However, salinity levels will most likely remain low.

The diversion of most of the drainage water to the sea before it reaches Karagan lagoon can achieve the conservation of the lagoon's high salinity. As direct rainfall was found to be the major input into the lagoon, even the diversion of the complete runoff from the major drainage channel would not lead to frequent drying up.

The quality of Karagan lagoon as a habitat for birds would possibly deteriorate with higher water levels and lower salinity levels. High water levels might adversely affect the wading birds, making feeding sites unavailable to them. Low salinity will affect fewer species, as many are capable of utilizing freshwater habitats as well. However, it is precisely the brackish water specialized species that need conservation of habitats such as the Karagan lagoon for their survival, especially in the context of fast depleting coastal habitats in Sri Lanka.

On the other hand, the presence of a constant large body of freshwater could be of benefit for the local population. It could develop into a fishing ground (if fish recruitment occurs through the lagoon mouth) and also provide water for domestic purposes and cattle rearing.

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