Linda Maring
Hanneke Schuurmans

Wetland versus irrigation

Scenario analysis of water quantity and water quality aspects of the Kirindi Oya Irrigation and Settlement Project and Bundala National Park using simulation modeling

WAGENINGEN UNIVERSITY

IWMI

Wetland versus irrigation

Scenario analysis of water quantity and water quality aspects of the Kirindi Oya Irrigation and Settlement Project and Bundala National Park using simulation modeling

Linda Maring
Registration number: 77-05-23-543-010
Hanneke Schuurmans
Registration number: 77-03-05-755-050

Supervisor: Dr. P. Droogers

July, 2000

WAGENINGEN UNIVERSITY

IWMI

Preface and acknowledgements

We carried this study out as the obligatory MSc training period of 24 weeks of the study 'Soil water and atmosphere' of Wageningen University, the Netherlands.
First of all we want to thank Peter Droogers for his excellent help and advice during our work. We also like to express our thanks to the researchers of Applied Information and Modeling Systems and the Health and Environment departments who offered us help and information.

We are very grateful to the people that collected data in the field and which applied us with data. Ranasinghe and Dayananda did a lot of field work for and with us, P.K. Ranjith took measurements and let us work on his paddy field and especially our fellow student Piyankarage supplied us with a lot of the data he collected for his thesis.

The next persons are acknowledged for the valuable information they gave us:
Mr Mullegamoda, deputy director of the irrigation department in Tissamaharama
Mr Jayaweera of the water resources department
Mrs. Sandhana Dias of the national building and research organization
Mr. Mallawatantri, director of US-Asia Environment Partnership

These people and all others who helped and supported us made this study possible and are as well responsible for the result.

Summary

This study is carried out to evaluate some scenarios to see how different management practices in the irrigated area of the Kirindi Oya Irrigation and Settlement Project (KOISP) affects both crop productions on field level and the valuable wetland Bundala National Park. The problems in the KOISP and Bundala National Park study area are related to the different interests of competitive water users: the agriculture upstream and the Bundala National Park downstream. The agriculture upstream exists mainly of paddy fields. Pesticides and fertilizers used by farmers, flow trough the drainage canals into the Bundala National Park.

After the implementation of the KOISP, the Bundala National Park received more fresh water, which declined the salinity levels in the lagoons. Also the above mentioned nutrient and pesticide load affected the Bundala National Park. Although drainage water is considered to be one of the major causes of the changes in the lagoon's ecology, there is still a lack of knowledge about the impact of drainage water on the ecosystem of the park. The aim of this study is therefore to analyze some different upstream water management scenarios and to estimate how these affect crop production and the Bundala National Park.

Some canals as well as two paddy fields in one of the irrigated areas (Bandagiriya) were selected to collect data. These data are used to setup two models, one for the large-scale study and one for the small-scale study. For the large-scale study it was first the idea to use Mike Basin. Because there appeared to be some shortcomings in this model, a model was made in the form of a spreadsheet. For the small-scale study the model SWAP was used. With the large-scale model the whole irrigation scheme from the Right Bank system was modeled to predict how much water flows through the canals and what the quality of the water is. To predict how much irrigation water is used for agriculture and what the changes in water quality are, the small scale model was used. By integrating those two models, it can be predicted how much water of what quality flows into the Bundala National Park.

In the baseline study, the current situation was modeled to derive an output that will match reality. In this baseline study, a calibration was performed for the large-scale model. For the small-scale study this was not possible, because only one set of data is available. However, the SWAP model is a well-tested physical model, so no problems concerning the reliability were expected.

The first step of the integration between models was to compare their information and making it compatible. After that, SWAP simulate a representative field in the Kirindi Oya irrigation and settlement project, derived from the measured data of the large-scale project and the paddy field measurements. This output could be used again as input for the large-scale model.

After a model is set up and working, scenario analyses could be performed. The scenarios should define possible interventions and the models evaluate the impact of these

interventions. In the case of the interaction between the KOISP and the Bundala National Park it is interesting to look at the management changes and the consequences for the park.

The following scenarios were considered:

- increasing fertilizer application
- decreasing fertilizer application
- more irrigation
- less irrigation
- less inflow of drainage water into Bundala

The results show on field level that the baseline scenario never causes water or salt stress. However, there can be concluded that too much water was issued in the baseline. The doubled or halved fertilizer applications cause a proportional increase or decrease in the nutrient outflows. This can also be seen in the large-scale output; change in fertilizer applications has the biggest influence on the amount of total nitrogen and total phosphorus in the lagoons. This suggests that modeling of N and P in SWAP as well as in the large-scale model should be studied more in detail, because some processes are not taken into account because they were not implemented in the models or no measurements were available. The scenario with the drainage canal from Bandagiriya to the sea causes 10-20 per cent less nutrient loads and an increased salinity in the lagoons. The salinity of the lagoons appeared not to change too much with the different scenarios.

Concluded was that the large-scale model Mike Basin was not suitable to use in this study, therefore it was replaced by spreadsheets. Also in the small-scale model SWAP were some shortcomings apparent. It was not adapted to model paddy fields and the water quality module is somewhat limited. This could be solved sufficiently.

For data collection was concluded that rainfall should be measured twice a day instead of once and that care should be taken by measuring ground water levels, to not measure an apparent ground water table. The canals in the study area need more measurements to calibrate them, calibrations should be repeated in time, because erosion causes changing environmental situations and therefore changed Q-h relationships.

Table of contents

PREFACE AND ACKNOWLEDGEMENTS

SUMMARY

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ANNEXES

1 INTRODUCTION 1

2 STUDY AREA 3

2.1 LOCATION 3
2.2 LAND USE 3
2.3 SOILS AND GEOMORPHOLOGY 4
3.4 HYDROLOGY 4
2.5 CLIMATE 6

3 METHODOLOGY 7

3.1 LARGE- SCALE STUDY 7
3.1.1 Return flow Tracts and Bandagiriya *9*
3.1.2 Water quality *11*
3.1.3 Water management lagoon *12*
3.1.4 Water quality in lagoons *15*
3.2 SMALL-SCALE STUDY 16
3.2.1 The simulation model *16*
3.2.2 The Data *18*
3.2.2.1 Soil 18
3.2.2.2 Water quantity 20
3.2.2.3 Water quality 23
3.2.2.4 Meteorology 24
3.2.2.5 Plant data 24
3.3 INTEGRATION OF THE MODELS 25
3.4 SCENARIOS 26

4 RESULTS AND DISCUSSION 29

4.1 LARGE- SCALE 29
4.2 SMALL-SCALE STUDY 33
4.3 SCENARIOS 38
4.3.1 Effects on small scale *38*
4.3.2 Effects on large scale *41*

5 CONCLUSION AND RECOMMENDATIONS 45

5.1 BANDAGIRIYA AND KOISP 45
5.2 MODELS 45
5.2.1 Mike Basin *45*
5.2.2 SWAP *46*
5.3 DATA COLLECTION 46

LITERATURE CITED

ANNEXES

List of figures

Figure 2.1:	Location of Kirindi Oya Irrigation and Settlement Project and the Bundala National Park.
Figure 2.2:	Distribution of R.B.E. on the landscape (Joshua, 1985)
Figure 2.3:	Irrigation scheme of KOISP (Kirindi Oya Irrigation and Settlement Project)
Figure 3.1:	Schematization of study area in Mike Basin 2000
Figure 3.2:	Water transport processes in the paddy field.
Figure 3.3:	The concentration of total-P and total-N at two places in the Right Bank Main Canal.
Figure 3.4:	Relationship between sum of NO3-N and NH3-N and total-N
Figure 3.5:	Water transport processes in Embilikala and Malala lagoon
Figure 3.6:	SWAP dynamics (Kroes et al., 1998)
Figure 3.7:	Map of paddy field 1, Bandagiriya
Figure 3.8:	Map of paddy field 2, Bandagiriya
Figure 3.9:	Calibration curves of inlet field 1 and field 2
Figure 3.10:	Q-h diagram with combined data of outlets of field 1 and 2
Figure 3.11	Total nitrogen and total phosphate in the soil
Figure 3.12:	Yield response as function of development stage (Doorenbos et al., 1979)
Figure 3.13:	Growing periods of the Kirindi Oya Irrigation and Settlement Project and a paddy field in Bandagiriya and the correction for differences
Figure 4.1:	Discharges of the drainage canals from Tract 5, Tract 6/7 and Bandagiriya as they are measured and simulated.
Figure 4.2:	Water levels of Embilikala and Malala lagoon as they were measured and simulated
Figure 4.3:	Concentrations of total nitrogen total phosphorus and salt as the are simulated and measured in Embilikala and Malala lagoon.
Figure 4.4	Changes of water and nutrients during ten-year period of the baseline situation
Figure 4.5:	Graphs showing the distribution of in- and outflow of water in the baseline situation
Figure 4.6:	Soil - water profile for the baseline scenario
Figure 4.7:	Salt, Phosphor and Nitrogen, as function of time and depth in the baseline scenario
Figure 4.8:	N outflows with half, regular and double application
Figure 4.9:	P outflows with half, regular and double application
Figure 4.10:	Effects on water quantity caused by varying irrigation gifts. With baseline scenario of 1000 mm and Bandagiriya scenario of 560 mm.
Figure 4.11:	Relative yield, influenced by water stress at varying irrigation gifts
Figure 4.12:	Relative yield, influenced by salt and water stress and the crop's sensitivity at varying irrigation gifts
Figure 4.13:	Salt in runoff and percolation at varying irrigation gifts

Figure 4.14: Nutrients N and P in root uptake, runoff and percolation at varying irrigation gifts
Figure 4.15: results of the different scenarios on the total nitrogen, total phosphorus and salt concentration in Embilikala and Malala lagoon
Figure 4.16: Water level in Malala lagoon as simulated in the baseline and in the scenario drainage Bandagiriya to sea

List of tables

Table 3.1: Results soil sampling pit 1
Table 3.2: Results soil sampling pit 2
Table 3.3: Fertilizer applications in paddy field, Bandagiriya
Table 3.4: Fertilizer gifts in fertilizer scenario per growing period and total application per year
Table 3.5: Irrigation gifts in varying irrigation gift scenario

Table 4.1: Values of optimized parameters for calculation of the return flow
Table 4.2: Values of optimized parameters for calculation of the lagoon levels
Table 4.3: Annual water and nutrient balance of the baseline scenario
Table 4.4: Nutrient balances of double and half fertilizer applications with regard to the baseline scenario
Table 4.5: Calculated nutrient balance in Embilikala lagoon for the different scenarios
Table 4.6: Calculated nutrient balance in Malala lagoon for the different scenarios

List of annexes

Annex I:	Half and double N application
Annex II:	Half and double P application
Annex III:	PF values with more or less irrigation
Annex IV:	Salt content with more or less irrigation
Annex V:	N content with more or less irrigation
Annex VI:	P content with more or less irrigation

1 Introduction

Wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal life. They occur where the water table is at or near the land surface, or where the land is covered by shallow water (Voogt, De, 2000). In 1990 the Bundala National Park was added to the Ramsar list, which is a list of wetlands of international importance. Wetlands are fragile ecosystems. Drainage water from upstream irrigation areas can threaten the wetlands because of the load of nutrients and pesticides that flow into these wetlands.

Kirindi Oya Irrigation and Settlement Project (KOISP) in southern Sri Lanka is a project, which is studied intensively by IWMI. In 1986 a big tank, Lunugamwehera tank, was constructed, which is one of the largest in the region (Stanbury, 1989). With the construction of this tank also new irrigated areas were constructed. Part of the drainage water from this new area flows into the Bundala National Park. The park contains five lagoons, which were originally brackish. However with the construction of the Lunugamwehera tank and the new irrigated area, the lagoons receive a considerable amount of fresh water.

A few years ago the question arose what the influence of this drainage water is on the Bundala National Park. Therefore IWMI started a monitoring program in the Right Bank system. Some canals were selected as well as two paddy fields in one of the irrigated areas (Bandagiriya) to collect data. This study focuses on two scales: the small-scale and the large-scale. Small-scale means that the processes on the irrigated areas are studied on field level. What are management practices, what happens with water quantity, salts and applied nutrients? At large-scale level these data are used and estimations were made on how much drainage water of what quality flows into the Bundala National Park. For the large-scale study it was planned to use the water quantity and quality model Mike Basin from the Danish Hydraulic Institute (DHI). Because there appeared to be some shortcomings in this model, a model was made in the form of a spreadsheet based on the Mike Basin concepts. For the small-scale study the model SWAP from Wageningen University (WU) and Wageningen Research Centre was used. Both models are described in more detail in chapter four. After model calibration and validation, scenarios can be defined to examine what happens if upstream water management will be changed. That was one of the main reasons to use simulation models. First of all models help to give a better understanding of the processes that take place. Second, with models it is possible to do scenario analyses, to predict what happens in the future.

In summary, the main objective is to analyze different upstream water management scenarios and to estimate what the effects are on field scale and the Bundala National Park.

2 Study area

2.1 Location

The KOISP and the Bundala National Park are located in the south of Sri Lanka, in the Hambantota district (figure 2.1). The KOISP exists of a large tank, the Lunugamwehera tank, which has a maximum capacity of about $2 \cdot 10^8$ cubic meters. This tank supplies water to two irrigation canals, the Left and the Right Bank Main Canal. The Right Bank Main Canal is about 32 km and the Left Bank Main Canal is about 22 km. In total there are 6 smaller irrigation tanks (Panagumuwa, Wirawila, Debara, Tissa, Yoda and Bandagiriya), which are much older then, the Lunugamwehera tank. The total irrigated are exists about 10,900 ha, of which 5,600 ha old irrigated area (green area in figure 2.1) and about 5,300 ha new area (yellow area in figure 2.1).

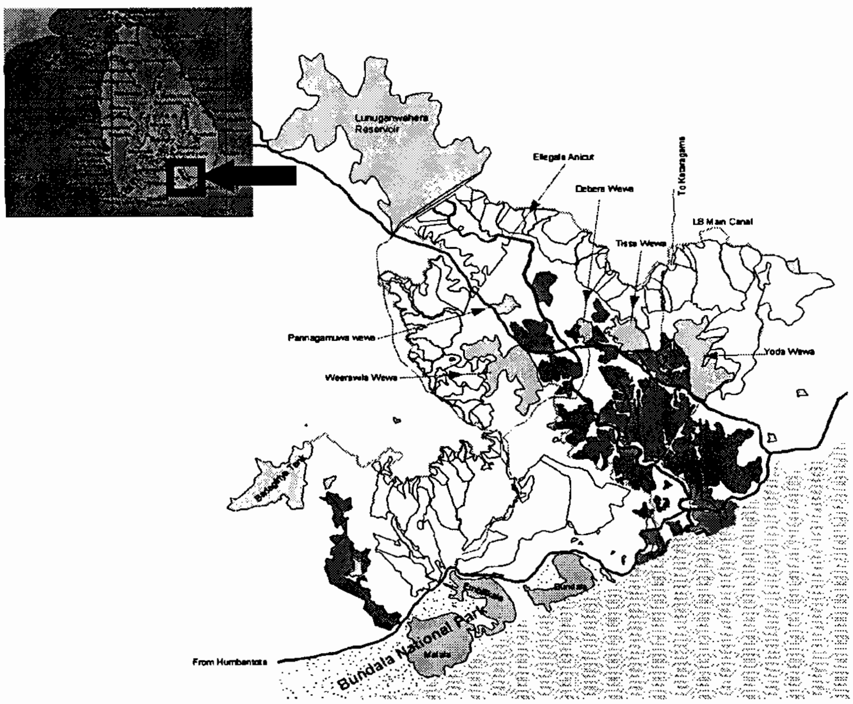


Figure 2.1: Location of Kirindi Oya Irrigation and Settlement Project and the Bundala National Park.

The total area of Bundala National Park is approximately 6,216 hectares. There are 5 lagoons situated in the park with a total area of 2,250 hectares. The lagoons considered are Bundala (520 ha), Malala (650 ha) and Embilikala (430 ha).

The paddy fields selected for the small-scale study are situated in the Bandagiriya area, at the southwestern part of the KOISP. The first field has an area of 2.56 ha and the second field, close to the first, has an area of 0.87 ha.

2.2 Land use

In 1969 the Bundala Park was declared a sanctuary, in 1922 it became a National Park and in 1990 it was added to the Ramsar list. It is an important habitat for bird communities and other wildlife. Also some agriculture and mining takes place in the

park. The irrigated area upstream the Bundala Park is mainly used for irrigated agriculture, especially paddy rice (Central environment authority Sri Lanka, 1993). Besides this there are also some banana plantations and some livestock. Paddy is the land use at the field in the study area in Bandagiriya.

2.3 Soils and geomorphology

The soils of this area belong to the reddish brown earth and low humic gley soils (see figure 2.2). Also regosols on recent beach and dune sands can be found in the south of the Park. The area has as parent material biotites and biotite-hornblende and gneisses. One can find a succession of well-banded gneisses, granulites and quartzites. The Bundala sand dunes consist of garnet-rich sands.

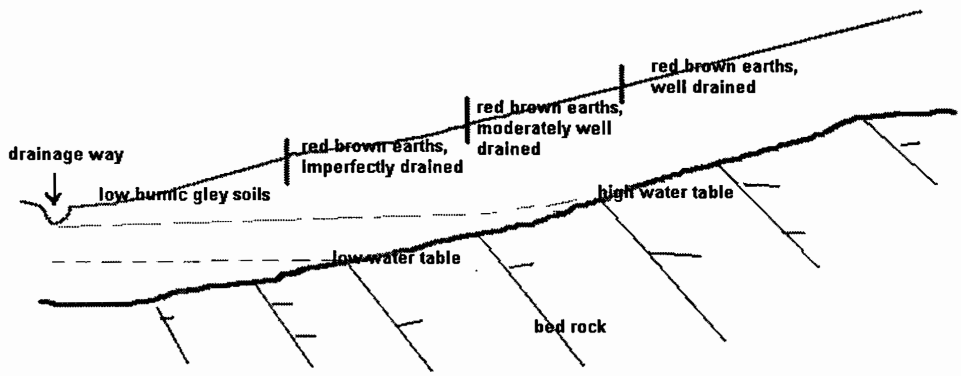


Figure 2.2: Distribution of R.B.E. on the landscape (Joshua, 1985)

There are three main types of geomorphology from the south to the north in the park: 1- beaches and sand dunes, 2- outer coastal plains with lagoons, 3- innercoastal plains. The floor of the lagoons consist of crystalline rock floor, situated nine meters below main sea level, on which a calcareous clay layer can be found (Central environment authority Sri Lanka, 1993).

At the field of the small-scale study, a more thorough soil investigation was carried out. For this augerings and soil pits were made and some soil physical tests were carried out. (For more data, see annex). The field was at the highest part quite sandy, while the lower parts became more clayey. No much soil formation could be seen. This suggests that the fields are the result of a young river deposit.

3.4 Hydrology

In figure 2.3 the schematic irrigation scheme of KOISP is given with the location of the measuring points. The measurement points can be divided into water quantity and water quality measurement points. Water quantity is already measured for more than one year, while the water quality measurements started around July 1999. In the flow chart it can be seen that irrigation water flows from the Lunugamwehera tank into the Right Bank Main Canal (RBMC) and the Left Bank Main Canal (LBMC). From the Left Bank Main Canal, some water flows to Kirindi Oya, from where a part flows into the older, smaller tanks downstream. Besides water directly from the Lunugamwehera tank, some small

tanks also receive drainage water from the new irrigated area. In case of water shortage, the old irrigation area always gets priority. Then, most of the water will flow from the LBMC into Kirindi Oya and into the old tanks and only few water (drinking water) flows trough the RBMC and LBMC. This means that in those dry periods, the new area is not irrigated. Therefore most farmers in the old area harvest two times a year and most farmers in the new area only once a year (Hemakumara, personal communication).

The two lagoons Embilikala and Malala in the Bundala National Park receive drainage water from the upstream-irrigated area. Embilikala lagoon receives all the drainage water from Tract 5 and part of the drainage water from Tract 6/7. Malala lagoon receives also a part of the drainage water from Tract 6/7 and all the drainage water from Bandagiriya area. Because Malala and Embilikala receive drainage water, these lagoons have a dropping salt level (Matsuno et al., 1998). All the lagoons in the park are fed by surface run off from streams and rivers. There are six catchments influencing the hydrology of the park. The most important one for Malala lagoon is the catchment area of Malala oya, with a total area of 404 km^2, and the most important one for Embilikala lagoon is the catchment area of Embilikala oya, with a total area of 60 km^2 (Central environment authority Sri Lanka, 1993). A natural canal connects the lagoons Embilikala and Malala to each other. This means that Malala also receives water from Embilikala lagoon. From Malala lagoon there is an artificial canal to the sea. The Bundala lagoon is still brackish, because it doesn't receive other fresh water than rainwater and only a little run-off of the area upstream (Central environment authority Sri Lanka, 1993).

Because the aim of this study is to look at the effects on Bundala National Park with different scenarios, only the part that influences the park is taken into account. This means that only a part of the Right Bank Main Canal is considered.

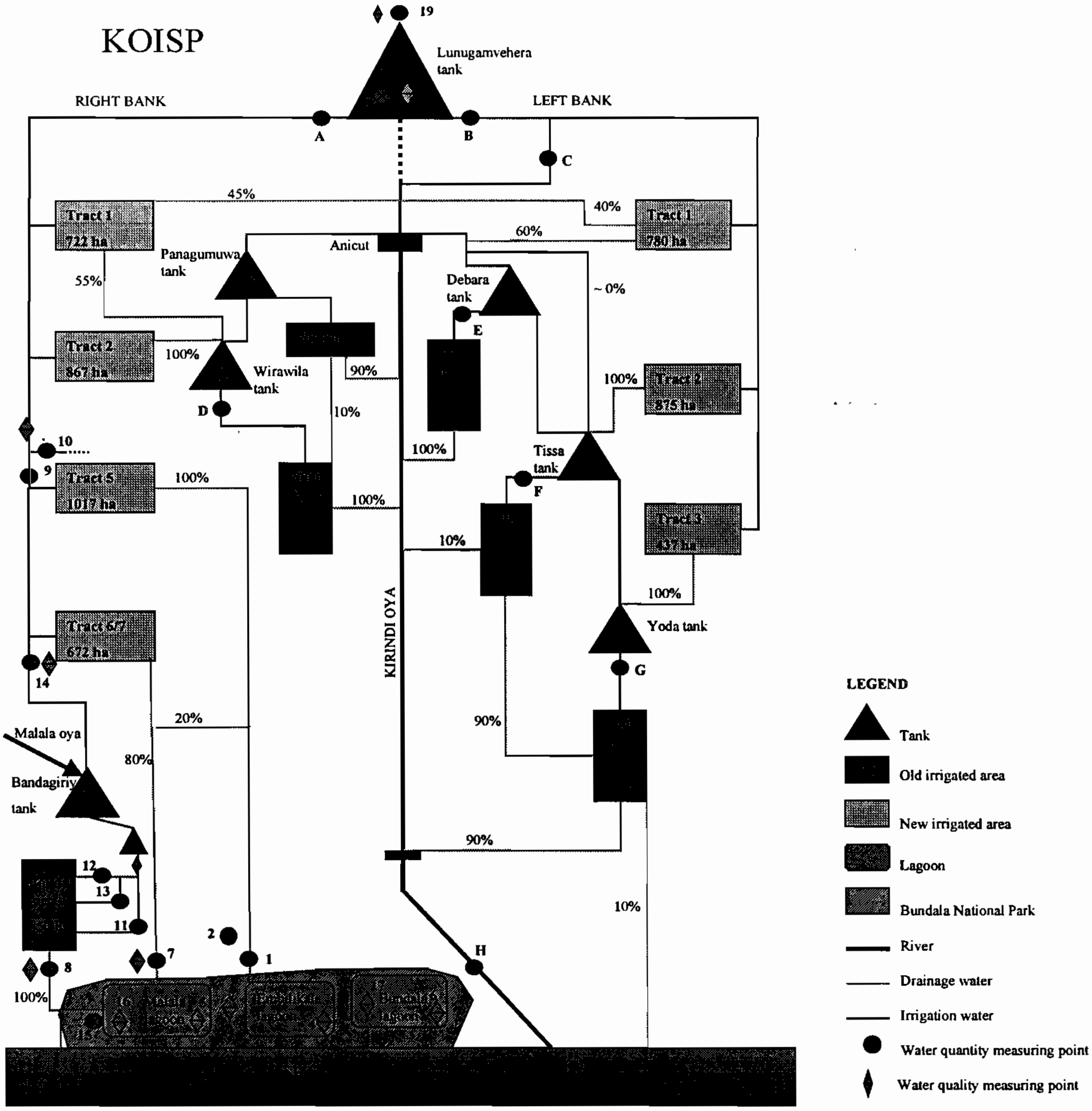


Figure 2.3: Irrigation scheme of KOISP (Kirindi Oya Irrigation and Settlement Project)

2.5 Climate

The climate in the study area is hot and dry. The average temperature is 27.1 degrees Celsius and the average yearly rainfall is 1074 mm (Matsuno et al., 1998). Seventy-five percent of it falls during the rainy season from October to March and is known as maha season. The dry period from April to August is known as yala (Stanbury, 1989). For this study the climate data from the weather station near to the Bandagiriya area was used.

3 Methodology

In this chapter a separation is made between the baseline study and the simulation of scenarios. In the baseline study, the current situation is modeled to derive an output that matches reality. In the baseline study of the large-scale study a calibration is made. For the small-scale study this is not possible, because only one set of data is available. However, the SWAP model is a well-tested physical model, so no problems concerning the reliability were expected, in spite of the lacking calibration and validation.

3.1 Large- scale study

The aim of the large-scale study is to model both the water quantity and the water quality of the Right Bank Main Canal, which influences Bundala National Park. As can be seen in figure 1, Bundala Park receives drainage water from Tract 5, Tract 6/7 and Bandagiriya. At the start of the study it was the original idea to use a try out version of Mike Basin, in which the water quality is included. This program was chosen because it is a simple water quantity model, which also includes a water quality module. The simplicity of the program was needed because there were not enough data available to build a reliable model with a hydrodynamic program. In Mike Basin a schematization of the study area was made (figure 3.1).

If figure 3.1 is compared with figure 3.3, it can be seen what the different nodes in the schematization represent. The first discharge node in the schematization represents the Lunugamwehera tank. From this point water flows down streams through the Right Bank Main Canal. The first offtake node represents the offtake point to Tract 1. The withdrawal node that is connected to this offtake node represents Tract 1 itself. Further down the canal the other three withdrawal nodes represent respectively Tract 2, Tract 5 and Tract 6/7. As can be seen in figure 3.3, the Right Bank Main Canal ends in the Bandagiriya tank. From that tank water flows into Bandagiriya. In the schematization, a discharge node represents the Bandagiriya tank.

For all the discharge and withdrawal nodes in Mike Basin, the model requires a time series data file for the quantity of water that is given, respectively withdrawn. If the water quality module is used, Mike Basin requires also a time series data file for the solutes that are taken into account in the model. With this information the model calculates how much water flows through the nodes, with which quality. It is very strange that Mike Basin requires water quality data for the withdrawal nodes. Because the model does not use these data this is superfluous.

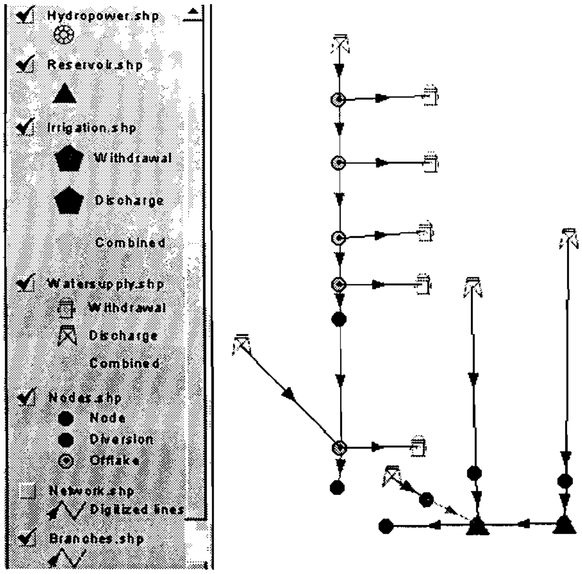


Figure 3.1: Schematization of study area in Mike Basin 2000

A big shortcoming in Mike Basin is that it can not handle correctly with return flows from irrigation areas. If an irrigation node is used to represent an irrigation area, the model requires a percentage that calculates a return flow out of the given quantity of water. In reality however, the return flow is not a percentage of the amount of water that is given. There is certain storage in the irrigation areas. This storage is filled by irrigation water and rainfall and reduced by evapotranspiration, runoff and percolation. When the storage capacity is exceeded, there will be runoff. The runoff, a part of the percolation water and a percentage of the water that flows through the canals for domestic use form the return flow. To overcome this shortcoming a spreadsheet was made to represent an irrigation node. This spreadsheet will be explained later on in this chapter.

Return flows of the different irrigation areas are again represented as discharge nodes in the schematization (figure 3.1). From there, water flows into two lagoons in Bundala Park, Embilikala and Malala. Reservoir nodes represent these lagoons. Although Mike Basin calculates the water quantity correctly, there appeared to be a very big shortcoming in the calculation of the water quality. Mixing of reservoir water and canal inflow is ignored and it is simply assumed that the concentration in a reservoir is always the same as the concentration in the canal that flows into that reservoir.

The two shortcomings mentioned above in Mike Basin made the model unsuitable for this study. Instead of Mike Basin a model in the form of a spreadsheet was made. The principles of some calculations, especially for the water quantity in the reservoirs, come however from Mike Basin. In the following paragraphs, the baseline model will be explained.

3.1.1 Return flow Tracts and Bandagiriya

The first step is to derive the total extraction of irrigation water by the Tracts and Bandagiriya. For the Tracts the total extraction per day was calculated by the daily discharge at point A minus the daily discharge at ID number 14 (see figure 2.3). It is assumed that the total extraction is divided proportionally over the different areas of the Tracts. The total extraction of Bandagiriya was calculated by adding all the daily discharges of the ID numbers 11, 12 and 13 (see figure 2.3).

The total extractions can be divided into irrigation water and urban water. The division factor is determined by the total amount of irrigation water divided by the total amount of extracted water. The total amount of irrigation water comes from the SWAP model. For the baseline model, the total extraction in the Tracts was 3002 mm and in Bandagiriya 2972 mm. Of this 2365 mm was used for irrigation.

What happens with the irrigation water per Tract is given schematically in figure 3.2. On the basis of this figure the calculations that are made will be explained.

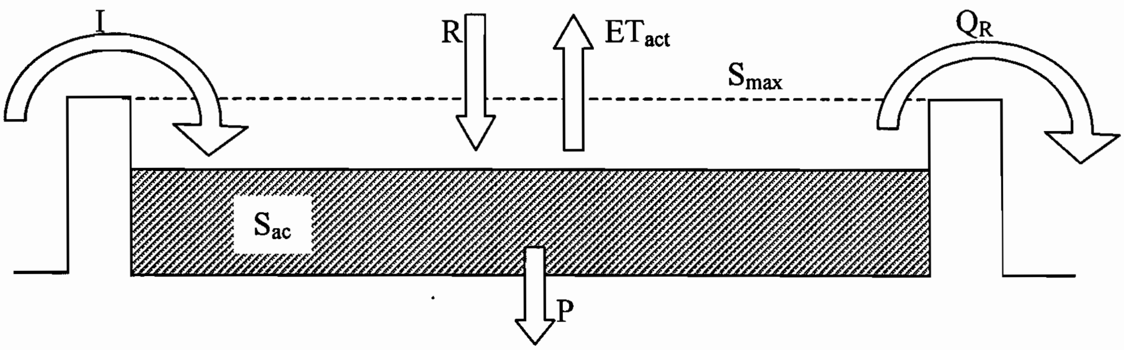


Figure 3.2: water transport processes in the paddy field.

In which:

I:	Amount of irrigation water each day [mm]
R:	Rainfall per day [mm]
ET_{act}:	Actual evapotranspiration [mm]
P:	Percolation per day [mm]
Q_R:	Amount of runoff water each day [mm]
S_{act}:	Actual storage [mm]
S_{max}:	Soil water storage capacity [mm]

- Irrigation (I):
  The amount of irrigation water per Tract per day is calculated as explained above.

- Rainfall (R):
  The daily rainfall in the study area is measured at ID number 2 (see figure 3.3). These data are used as input data

- Evapotranspiration (ET):
  The daily values of ET_{ref} (reference evapotranspiration) come from SWAP and are used here as input data. With these data the daily ET_{act} (actual evapotranspiration) is calculated as follows;
  If $S_{act,\,t-1} \geq ET_{ref,\,t}$, then $ET_{act,\,t} = ET_{ref,t}$ Formula 3.1a
  If $S_{act,\,t-1} < ET_{ref,\,t}$, then $ET_{act,\,t} = S_{act,\,t-1}$ Formula 3.1b

- Percolation (P):
  $P_t = S_{act,\,t-1} \cdot a$ Formula 3.2
  a = percolation fraction [-]

- Storage (S_{act}):
  $S_{act,\,t} = S_{act,\,t-1} + I_{,\,t} + R_t - ET_{act,\,t} - P_t - Q_{R,\,t}$ Formula 3.3

- Runoff (Q_R):
  If $S_{act,\,t-1} > S_{max}$, then $Q_{R,\,t} = S_{act,\,t-1} - S_{max}$ Formula 3.4a
  If $S_{act,\,t-1} \leq S_{max}$, then $Q_{R,\,t} = 0$ Formula 3.4b
  S_{max} = soil water storage capacity [mm]

The percolation factor (a) and the soil water storage capacity (S_{max}) are unknown and have to be optimized.

These calculations apply only to water extracted for irrigation. The total return flow in the drains however includes also return flows from the urban extraction. The total return flow is calculated as follows;

$\text{Return flow}_{,\,t} = Q_{R,\,t} + b \cdot P_t + c \cdot \text{Urban}_{,\,t}$ Formula 3.5
b = percentage of the percolation water that flows into drainage canal
c = percentage of the urban water that flows into drainage canal
b and c are set as parameters that had to be optimized. Because an unknown part of the drainage from Tract 6/7 flows into the drainage canal of Tract 5, this factor was also set as an parameter that had to be optimized.

3.1.2 Water quality

The water quality is focused on the total phosphorus, total nitrogen and salt because SWAP only takes these solids into account. Salt is known as a conservative solid, there are no degradation processes. To get an idea of the possible degradation processes of nitrogen and phosphorus in the canal the measurements that were taken in the Right Bank Main Canal are analyzed. The first water quality measuring point is in the Lunugamwehera tank, the second is near the ID numbers 9 and 10 (see figure 3.3). In figure 3.3 it can be seen that is not possible to derive a relationship in the concentration of these two solids. It would have been better to have a look at the loads of the two solids. However, during the measurement period at Lunugamwehera there was no water flowing through the beginning of the Right Bank Main Canal.
This means it was not possible to calculate a load in point A (see figure 3.3). The water that flowed at the ID numbers 9 and 10 during that period exists out of rainwater. Because it was not possible to derive a relationship for the concentration of total-P and total-N, these solids are set as conservative solids. For many cases this is valid (Help file Mike Basin 2000).

Most part of the integration between the large- and small-scale model takes place in calculating the water quality of the return flow. As is mentioned in the previous paragraph, the total return flow consists of percolation and runoff from the irrigation and urban flow. The water quality of the agricultural water comes from the SWAP model. It was assumed for urban water that extraction and drainage water quality were similar, as no data were available.

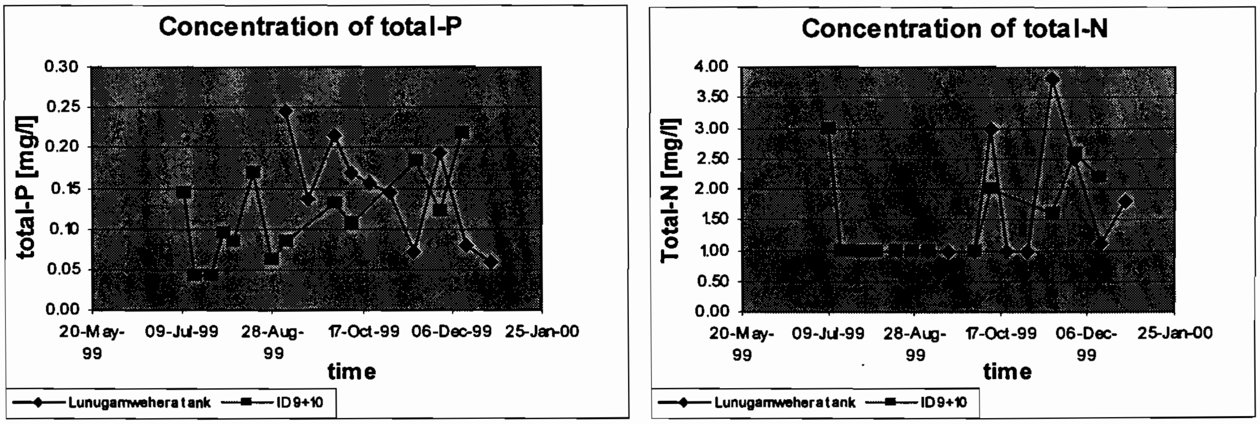


Figure 3.3: The concentration of total-P and total-N at two places in the Right Bank Main Canal.

The water quality data of the water that is extracted comes from two sources. The water quality measurements that are taken in 1999 started around July up to September. Before that monthly measurements of 1998 are used as input. In 1998 the total nitrogen was not measured, only ammonia (NO_3-N) and nitrate (NH_3-N). To get a rough estimate of the value of total nitrogen, it was assumed that there is a relationship between the sum of NH_3-N and NO_3-N and the amount of total-N. Therefore all the measuring points were set out and a regression line was drawn through these points, showing the relationship

(figure 3.4). It can be seen that the relationship is very weak. As no other data were available, this relationship was used to calculate the total-N from NH_3-N and NO_3-N.

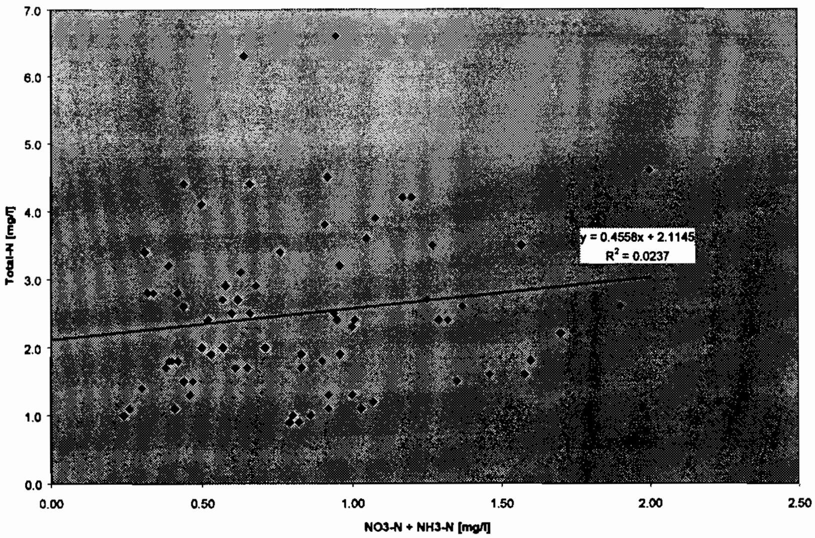


Figure 3.4: relationship between sum of NO3-N and NH3-N and total-N

Water quality results from SWAP simulations were used as input for the large-scale model. In terms of water quantity return flows, a deviation between SWAP and the large-scale model was observed on a daily base. Therefore, water quality from SWAP was not used as concentrations, but as total loads. These loads were calculated for four periods: two growing periods and two intermediate periods. These loads were converted to concentrations using the water quantity from the large-scale model.

3.1.3 Water management lagoon

Embilikala and Malala lagoon receive drainage water from the upstream-irrigated area (figure 3.3). Embilikala lagoon receives drainage water from Tract 5 and a part of the drainage water of Tract 6/7. Because of a connecting canal between Embilikala and Malala lagoon, Malala lagoon receives water from Embilikala. Malala receives also drainage water from Tract 6/7 and Bandagiriya. Through a canal that connects Malala lagoon with the sea, water flows to the sea. This is the normal procedure. However, sometimes the fishermen cut down the sandbank that separates the Malala lagoon from the sea. If they do that, the water level in both Malala and Embilikala drops considerably. A lot of fresh water flows out and seawater with a high salinity enters the lagoons. As a result, the salt concentration in the lagoons increases. After approximately one or two weeks, the sandbank is recovered naturally and the water level rises again. In 1999 the sandbank was cut at the end of November.

The processes of the water transport in the lagoon, including cutting of the sandbank, are modeled in a spreadsheet. This spreadsheet will be explained on the basis of figure 3.5. The principle of this transport process is based on the water transport process of reservoir nodes in Mike Basin 2000.

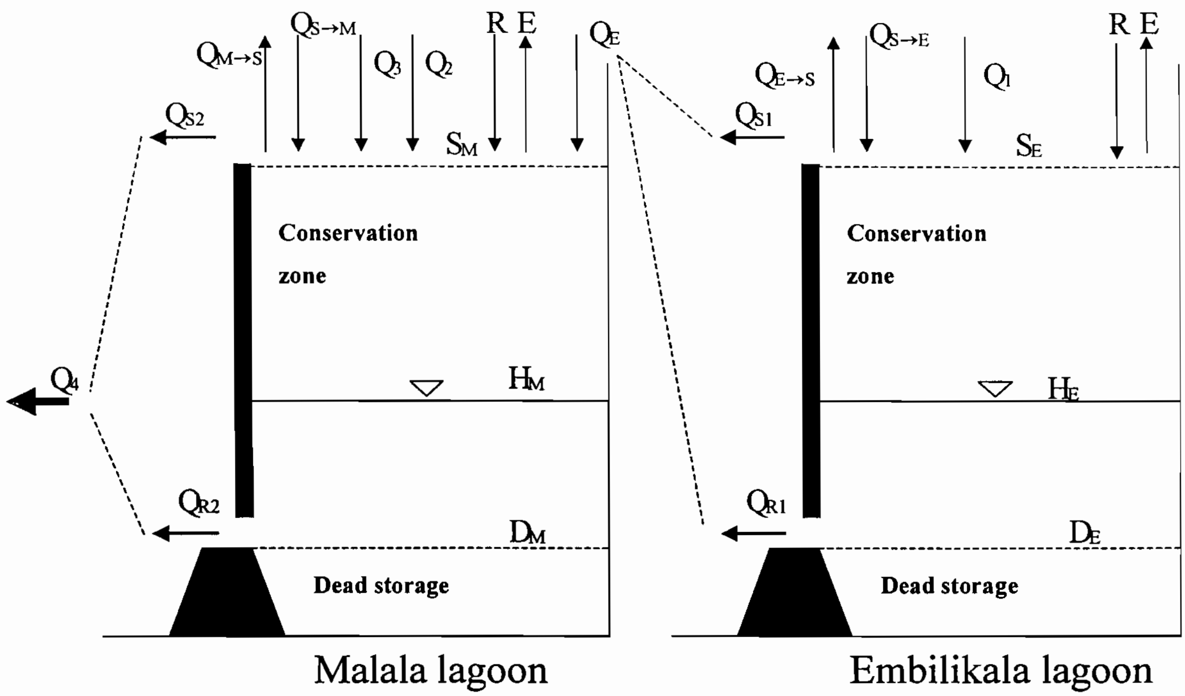


Figure 3.5: Water transport processes in Embilikala and Malala lagoon

In which;

S_E, S_M:	Spill level of respectively Embilikala and Malala lagoon [m]
H_E, H_M:	Actual water level of respectively Embilikala and Malala lagoon [m]
D_E, D_M:	Dead storage level of respectively Embilikala and Malala lagoon [m]
R:	Rainfall [m]
E:	Open water evaporation [m]
Q_1:	Drainage water from Tract 5 and part of drainage water Tract 6/7 [m^3]
Q_2:	Drainage water from Tract 6/7 [m^3]
Q_3:	Drainage water from Bandagiriya [m^3]
Q_4:	Amount of water from Malala lagoon to sea [m^3]
Q_E:	Amount of water from Embilikala lagoon to Malala lagoon [m^3]
$Q_{S\rightarrow E}$:	Inflow of seawater into Embilikala lagoon [m^3]
$Q_{E\rightarrow S}$:	Outflow of water from Embilikala into the sea [m^3]
$Q_{S\rightarrow M}$:	Inflow of seawater into Malala lagoon [m^3]
$Q_{M\rightarrow S}$:	Outflow of water from Malala into the sea [m^3]
Q_{S1}, Q_{S2}:	Spill flow of respectively Embilikala and Malala lagoon [m^3]
Q_{R1}, Q_{R2}:	Minimum release of respectively Embilikala and Malala lagoon [m^3]

First it will be explained how the water level in both lagoons is calculated. After that the different parameters that are used will be handled.

- Water level Embilikala lagoon (H_E):

$$H_{E,t} = H_{E,t-1} + \frac{Q_{1,t} + (R_t - E_t) \cdot A_E + Q_{S\rightarrow E,t} - Q_{E\rightarrow S,t} - Q_{E,t}}{A_E}$$ Formula 3.6

In which;
A_E: Area of Embilikala lagoon (set as constant value) [m^2]

- Water level Malala lagoon (H_M):

$$H_{M,t} = H_{M,t-1} + \frac{Q_{E,t} + Q_{2,t} + Q_{3,t} + (R_t - E_t) \cdot A_M + Q_{S \to M} - Q_{M \to S} - Q_4}{A_M} \quad \text{Formula 3.7}$$

In which;
A_M: Area of Malala lagoon (set as constant value) [m^2]

- Rainfall (R)
The daily rainfall in the study area is measured at ID number 2 (see figure 3.3). These data are used as input data

- Evaporation (E)
The open water evaporation is set as a constant value throughout the year. The value of 5 mm/day is used as default value.

- Inflow from drainage canals (Q_1, Q_2, Q_3)
The amounts of drainage water from the upstream irrigation areas is calculated in the spreadsheet that is explained in chapter 3.1.1.

- Inflow from sea water in Embilikala and outflow of lagoon water ($Q_{S \to E}$, $Q_{E \to S}$)
As mentioned before the sandbank between Malala lagoon and the sea was cut at the end of November 1999. Because of the connection canal between Embilikala and Malala, the water quantity and quality of Embilikala is also influenced. In the spreadsheet however, water can only flow one direction. To be able to model the effect, it was assumed that also the sandbank between Embilikala and the sea was cut.

  The water level in the Embilikala lagoon is measured daily. These measurements showed that the water level in Embilikala drops to 16 cm. The water level before the sandbank cutting is simulated. With these two water levels it can be calculated how much water flowed from the lagoon into the sea.

  Because the salinity is measured in the lagoon, it is known what the concentration of salt was before and after the sandbank was cut. The salt concentration of the sea is also known. With this information it can be calculated how much seawater flowed into the lagoon.

  For Embilikala lagoon it was calculated that 662,200 m^3 flowed from the lagoon into the sea and 67,399 m^3 flowed from the sea into the lagoon. In the spreadsheet the water that flows out of the lagoon to the sea flows out in one day. The water from the sea that enters the lagoon is divided over nine days. These nine days are based on the measurements of the water level in the lagoon.

- Inflow from sea water in Malala and outflow of lagoon water ($Q_{S\rightarrow M}$, $Q_{M\rightarrow S}$)
The same procedure as explained for the Embilikala lagoon was applied for Malala lagoon. It was calculated that 8,385,000 m³ flowed from the lagoon into the sea and 375,173 m³ seawater flowed into the lagoon. In the spreadsheet the water that flows out of the lagoons flows out in one day. The water from the sea that enters the lagoon is divided over 7 days.
- Amount of water from Embilikala lagoon tot Malala lagoon (Q_E) Formula 3.8
$Q_{E,t}$ = maximum ($Q_{R1,t}$; $Q_{S1,t}$)

If $H_{E,t} < D_E$, then $Q_{R1,t} = 0$
If $D_E < H_{E,t} < S_E$, then $Q_{R1,t}$ = minimum (($H_{E,t} - D_E$)·A_E; $Q_{min\ E}$)
If $H_{E,t} > S_E$, then $Q_{S1,t}$ = maximum (($H_{E,t} - S_E$)·A_E; $Q_{min\ E}$)

In which;
$Q_{min\ E}$ = minimum release per day from Embilikala lagoon [m³]

- Amount of water from Malala lagoon to sea (Q_4) Formula 3.9
$Q_{4,t}$ = maximum ($Q_{R2,t}$; $Q_{S2,t}$)

If $H_{M,t} < D_M$, then $Q_{R2,t} = 0$
If $D_M < H_{M,t} < S_M$, then $Q_{R2,t}$ = minimum (($H_{M,t} - D_M$)·A_M; $Q_{min\ M}$)
If $H_{M,t} > S_M$, then $Q_{R2,t}$ = maximum (($H_{M,t} - S_M$)·A_M; $Q_{min\ M}$)

In which;
$Q_{min\ M}$ = minimum release per day from Malala lagoon [m³]

In the equations above the following parameters are set as values that needed to be optimized;
- Initial water level of Embilikala and Malala lagoon ($H_{E,t-1}$ respectively $H_{M,t-1}$ at t = 1)
- Dead storage level of Embilikala and Malala lagoon (D_E respectively D_M)
- Spill level of Embilikala and Malala lagoon (S_E respectively S_M)
- Minimum release of Embilikala and Malala lagoon ($Q_{min\ E}$ respectively $Q_{min\ M}$)

3.1.4 Water quality in lagoons

To calculate the water quality in the lagoon all the spreadsheets have to be integrated.

- Concentrations of solids Embilikala lagoon

$$C_{E,t} = \frac{L_{E,t}}{H_{E,t} \cdot A_E}$$ Formula 3.10

With;

$$L_{E,t} = L_{E,t-1} + C_{return\ flow} \cdot Q_1 - C_{E,t-1} \cdot Q_E + C_{sea} \cdot Q_{S\rightarrow E} - C_{E,t-1} \cdot Q_{E\rightarrow S}$$

In which;
L_E: Load of solid in Embilikala lagoon [g]

H_E: Water level Embilikala [m]
A_E: Area of Embilikala [m^2]
$C_{return\ flow}$: Concentration of solid in return flow [g/m^3]
C_E: Concentration of solid in Embilikala [g/m^3]
C_{sea}: Concentration of solid in the sea [g/m^3]
Q_1: Drainage water from Tract 5 and part of drainage water Tract 6/7 [m^3]
Q_E: Amount of water from Embilikala lagoon to Malala lagoon [m^3]
$Q_{S\rightarrow E}$: Inflow of seawater into Embilikala lagoon [m^3]
$Q_{E\rightarrow S}$: Outflow of water from Embilikala into the sea [m^3]

- Concentrations of solids in Malala lagoon

$$C_{M,t} = \frac{L_{M,t}}{H_{M,t} \cdot A_M}$$ Formula 3.11

with;

$$L_{M,t} = L_{M,t-1} + C_{return\ flow} \cdot (Q_2 + Q_3) + C_{E,t-1} \cdot Q_E + C_{sea} \cdot Q_{S\rightarrow M} - C_{M,t-1} \cdot Q_{M\rightarrow S}$$

In which;
L_M: Load of solid in Malala lagoon [g]
H_M: Water level Embilikala [m]
A_M: Area of Embilikala [m^2]
$C_{return\ flow}$: Concentration of solid in return flow [g/m^3]
C_E: Concentration of solid in Embilikala [g/m^3]
C_M: Concentration of solid in Malala [g/m^3]
C_{sea}: Concentration of solid in the sea [g/m^3]
Q_2: Drainage water from Tract 6/7 [m^3]
Q_3: Drainage water from Bandagiriya [m^3]
Q_E: Amount of water from Embilikala lagoon to Malala lagoon [m^3]
$Q_{S\rightarrow M}$: Inflow of seawater into Malala lagoon [m^3]
$Q_{M\rightarrow S}$: Outflow of water from Malala into the sea [m^3]

The initial load of the solids ($L_{E,t-1}$ and $L_{M,t-1}$ at t = 1) is derived by using an average concentration that comes from the measurements that were taken in the lagoons and the initial water levels in the lagoons.

The concentration of salt in seawater is set as 35.5 g/m^3. The concentration of total nitrogen and total phosphorus is set as zero (NVON, 1977).

3.2 Small-scale study

3.2.1 The simulation model

At the initiation of this study, the idea was to use the program UNSATCHEM (Šimunek et al., 1996) for modeling the water quantity and quality at paddy field level. The benefit of this program is that it has a very clear interface and easy usage. Unfortunately it turned out that this model didn't have an option for modeling nitrogen and phosphor, which was

necessary for this study. After that, the program SWAP (Soil-Water-Atmosphere-Plant) was selected because it met all requirements (see figure 3.6).

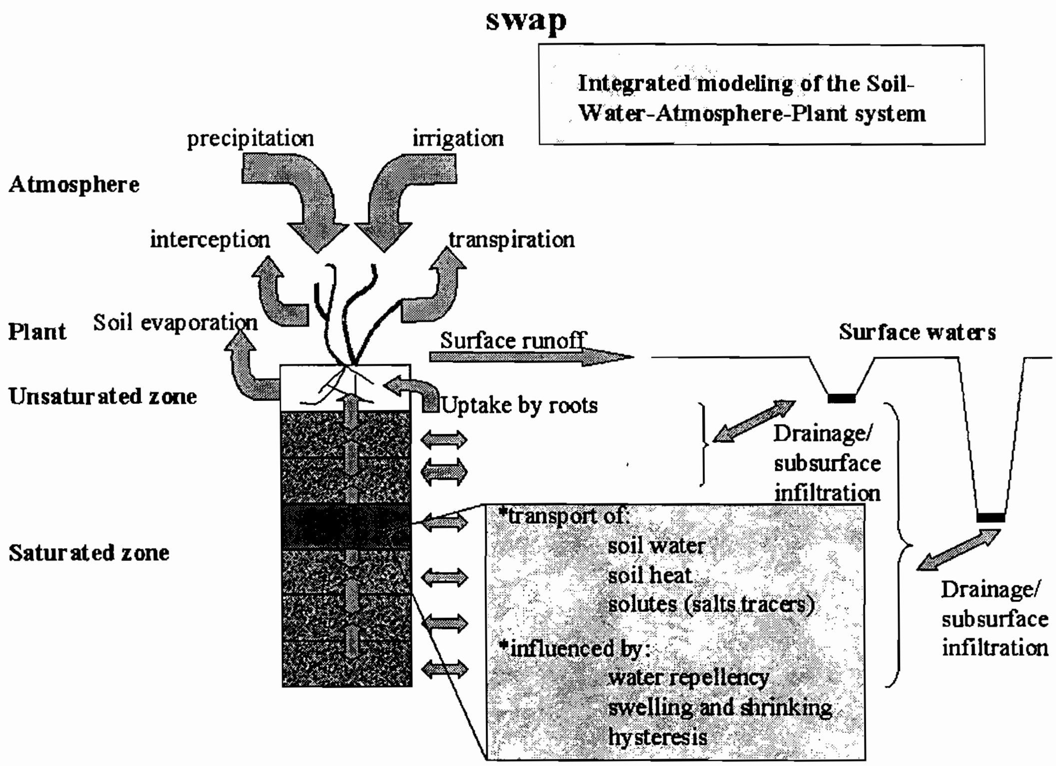


Figure 3.6: SWAP dynamics (Kroes et al.; 1998)

In Kroes et al, 1998, a system definition of SWAP is given:
'SWAP is a computer model that simulates transport of water, solutes and heat in variably saturated topsoils. The program is designed for integrated modeling of the soil-water-atmosphere-plant system. Transport processes at field scale level and during whole growing seasons are considered. System boundaries at the top are defined by the soil surface with or without a crop and the atmospheric conditions. The lateral boundary simulates the interaction with surface water systems. The bottom boundary is located in the unsaturated zone or in the upper part of the groundwater and describes the interaction with regional groundwater.'
Because in this study only one set of measured data was available, the model could not be calibrated. SWAP is physical based however and has proofed to be reliable in small-scale modeling. A calibration is therefore not indispensable.
To run SWAP, some input modules have to be created. These are necessary to characterize the features of the situation. These modules consist general information, meteorological and irrigation data, crop rotation, crop growth, the soil and water profile, soil hydraulic functions, drainage, bottom boundary conditions, heat flow and solute transport. In this study, no subsoil drainage takes place and heat flow is not taken in account. For crop growth and meteorological data, the simple modules are selected instead of detailed options, because of lacking data. SWAP was also somewhat modified,

because it was not possible to adjust the ponding layer during the year and there was no module that contained superficial drainage, as is practiced in rice agriculture.
For more details about SWAP, see Theory of SWAP version 2.0 (Dam, Van et al., 1997) and User's guide of SWAP version 2.0 (Kroes et al., 1998)

3.2.2 The Data

3.2.2.1 Soil

For soil data, an augering transect was made through both study fields. This was done perpendicular to the contour lines, as soil characteristics are expected to be related to elevation levels. These transects can be seen on the maps of field 1 and 2, figures 3.7 and 3.8.

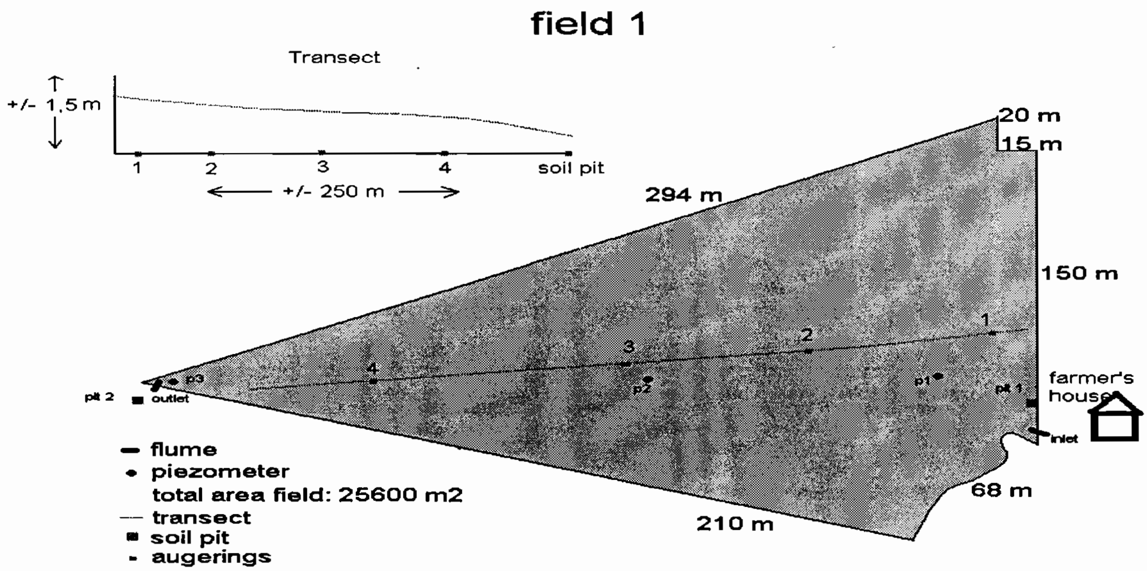


Figure 3.7: Map of paddy field 1, Bandagiriya

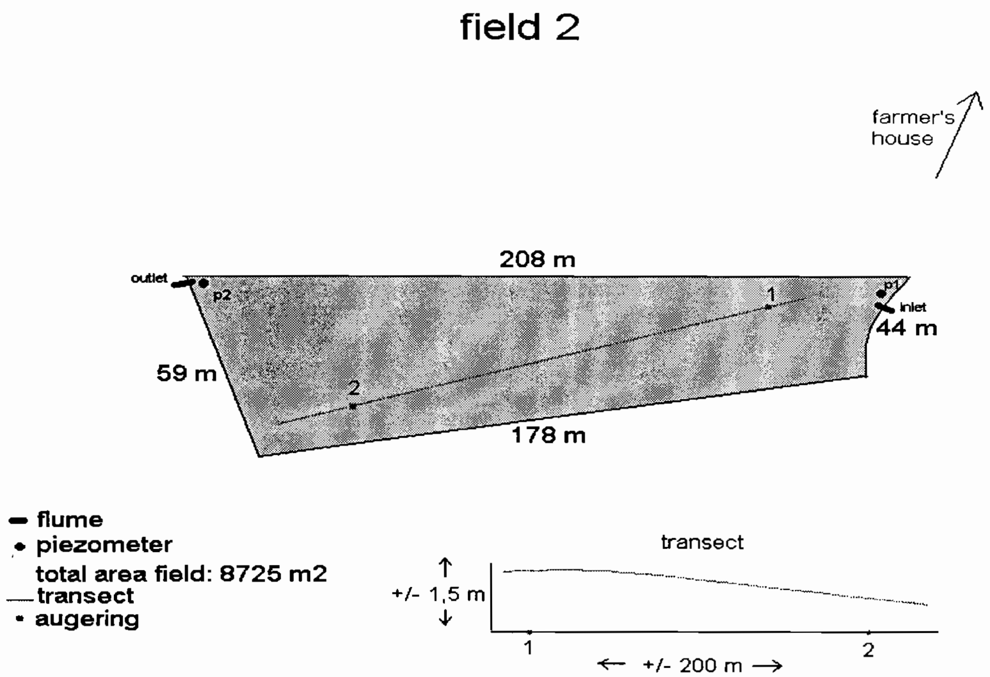


Figure 3.8: Map of paddy field 2, Bandagiriya

As described in chapter 3.3, Soils and geomorphology, the soil material consists of young river deposits. To obtain hydraulic parameters out of more easily measurable data, like density and particle size distribution, two soil pits of at least 1 meter deep were sampled.

One pit (pit 1, see figure 3.7) at the higher part of the field and one (pit 2) at the lower part of the field where the soil was more clayey. No samples could be taken in the center part of the field, because the owner was afraid for stability problems. It was assumed that field 1 and 2 had the same soils because of nearby locations. The results of the augerings confirmed the similarity in soils, so only field 1 was sampled. Soil samples were taken in the pits with a sampling ring of known volume to obtain dry density and disturbed soil samples for determining particle size distribution. A soil laboratory performed the analyses, determining dry weight for the samples with fixed volume and a hydrometer analyses to find the percentages sand (>50 μ), clay (<2 μ) and silt (<50μ and >2μ). The results of these tests can be seen in tables 3.1 and 3.2. Samples were taken in duplicate at three heights in the profile. In pit one, a distinction could be made between the first compacted layer and the soil underneath.
0-20 cm, fine sandy soil, compacted, blackish of organic matter, many roots.
20-100, cm fine sandy soil, compacted, brownish with many oxidation, reduction and some manganese spots, till +/- 50 cm many roots, till 80 cm some roots.
Remarks: the pit is situated at the edge of the field, 10 meters from the inlet of field 1.
At pit two there was no very obvious layering. The description is:
0- 23 cm, clay soil, somewhat compacted, disturbed topsoil, blackish of organic matter, many roots.
23- 50 cm, clay soil, compacted, organic matter vertically spooled down, many roots.

50-120 cm, clay soil, some coarser particles, compacted, some roots (weeds), some oxidation spots, reduced grayish material, shiny slickfaces.
Remarks: the pit is situated a little bit outside the paddy field, weeds cover the area.

Table 3.1: Results soil sampling pit 1

Sample #	Depth (cm)	Bulk density (g/ml)	Clay %	Silt %	Sand %	Textural name (USDA)
1	10	1.59	35	28	37	clay loam
2	15	1.63	52	15	33	clay
3	35	1.67	47	14	39	clay
4	35	1.66	52	22	26	clay
5	60	1.70	38	22	40	clay loam
6	70	1.70	39	25	36	clay loam

Table 3.2: Results soil sampling pit 2

Sample #	Depth (cm)	Bulk density (g/ml)	Clay %	Silt %	Sand %	Textural name (USDA)
1	25	1.42	49	17	34	clay
2	25	1.50	44	17	39	clay
3	50	1.49	45	19	36	clay
4	50	1.56	45	17	38	clay
5	75	1.52	52	17	31	clay
6	75	1.48	40	25	35	clay / clay loam

The soil hydraulic functions were obtained by using a program, produced by Peter Droogers, which is based on the theory of Wösten et al.: 'Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and land use planning' (Wösten et al., 1998). In this program, the data input are clay and sand fraction, organic matter percentage, which is taken the default value for tropical soils of 1 per cent, bulk density and whether the relative soil layer is top- or subsoil. The outputs are the parameters of the Van Genuchten (1980) functions that describe the soil hydraulic function: retention and conductivity curve. The alpha for the main wetting curve is not calculated but this value is not important because it is assumed that there is no hysteresis. Topsoil was assumed to be very low (0.2 cmd^{-1}) to represent the compact layer as observed in the field. The puddle layer was not modeled because it was not possible to sample this layer at all. Moreover, the SWAP model was not able to simulate such a mud layer on top of a dense layer. After some simulations, it appeared that SWAP's output for soil 1 or 2 was more or less similar.
No hysteresis, immobile water, flow through soil cracks and partition drainage flux were taken into account, mainly because the soil never dries out completely.

3.2.2.2 Water quantity

For water quantity, measurements were done at the in- and outlets of the fields (for location, see figures 3.7 and 3.8). The water heights and corresponding time were measured at opening flumes, during the irrigation or superficial drainage and at the

closing time. In this way, the irrigation gifts as well as the amounts of drained water could be monitored.

To use water height data, the flumes had to be calibrated. This has been done at the inlets by partly closing the water supply and measuring with a bucket the amounts of water going through the flume at different water heights. At the outlet, a small cup flow meter was used because it was not possible to arrange the amounts of water upstream, without changing the situation. Q-H relations were derived using:

$Q = a \cdot (h\text{-}h0)^b$ Formula 3.12

With:

Q:	Discharge [l/sec]
a and b	Parameters which have to be optimized [-]
h	Water height [cm]
h0	Water height when discharge is zero [cm]

From these Q-h diagrams and the water heights, water quantity could be derived (see figures 3.9 and 3.10).

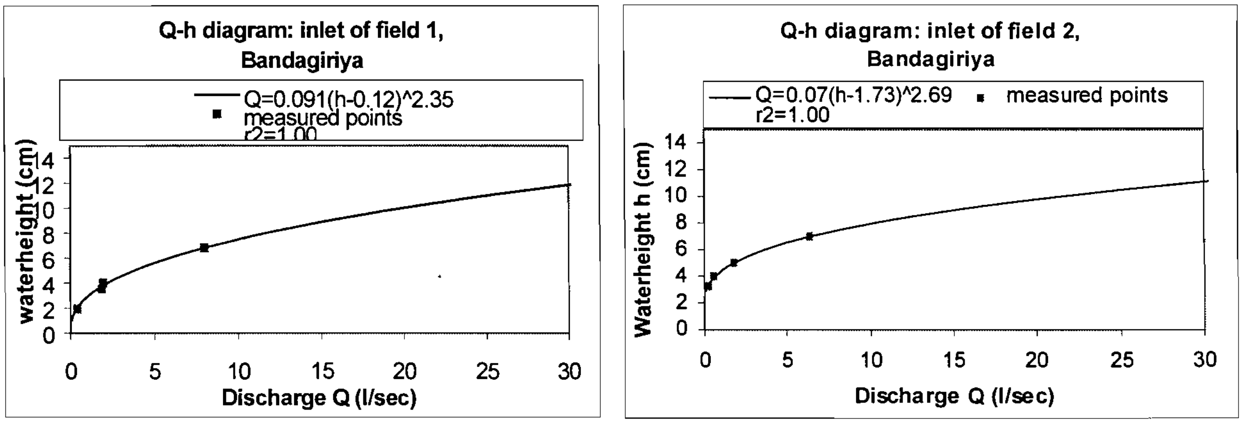


Figure 3.9: Calibration curves of inlet field 1 and field 2

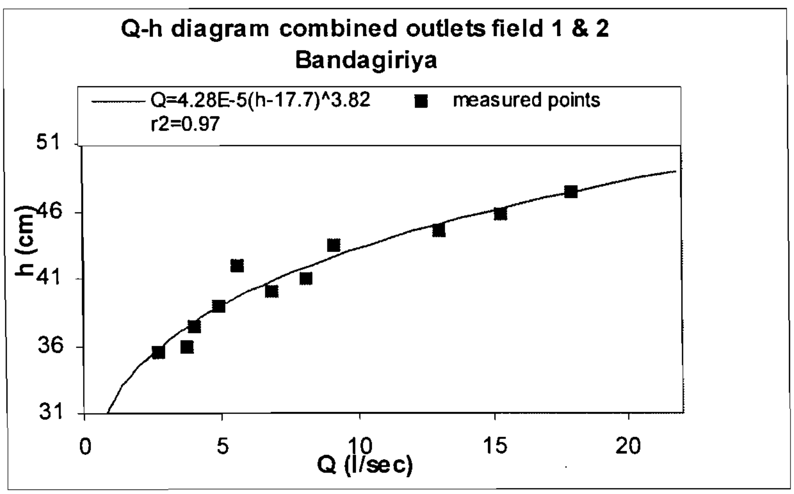


Figure 3.10: Q-h diagram with combined data of outlets of field 1 and 2

The gauges of the inlets started with the value of 0 cm, the outlet gauges started with value 31 cm, these values are used in the charts on the y-axis. The correlation factor r^2 between the observed data and the calculated curve are given, but because there is only little data, these r^2 values seem to be very close to one, while they actually don't give a good indication of the accuracy.

Piezometers were installed to observe water table depths and groundwater quality (see figures 3.7 and 3.8). The measurements taken in the field during the growing season were showing high and very fluctuating water levels, suggesting that water flew along the piezometer so the groundwater level appeared to be too high. Proceeding with taking measurements after the harvest solved this, because all water was drained out of the field.

3.2.2.3 Water quality

At the piezometers were also temperature, conductance, TDS, pH, DO, total nitrogen (N) and total phosphate (PO_4) measured. From these measurements only conductance, total nitrogen and total phosphate were used. In the charts (figure 3.11) of the total N and total P one can see some of the peaks after fertilizer application, but because the values are in mg/cm3, variations of water are also influencing the course of the chart.

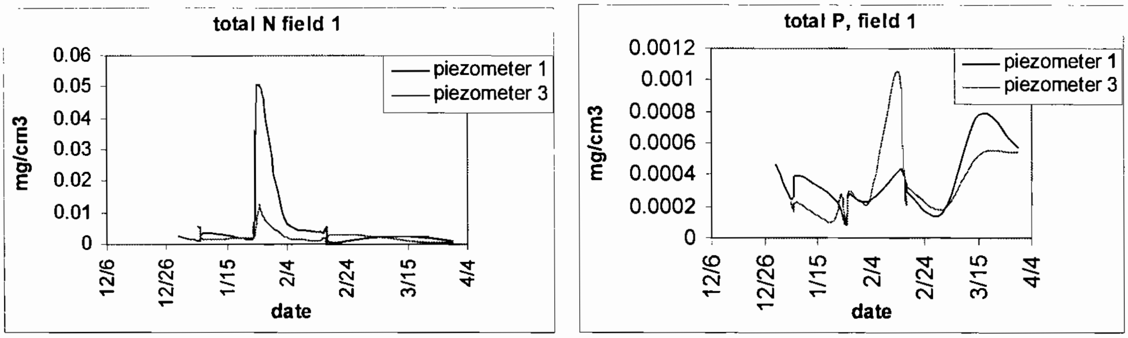


Figure 3.11: Total nitrogen and total phosphate in the soil

The application scheme can be seen in table 3.3. The following fertilizers were used: Urea (NH_2-CO-NH_2), with 46 percent of N, Mada pohora, with 5 percent of N, 15 percent of both P and K and TDM, a mixture of fertilizers with 20 percent of P, K and N.

Table 3.3: Fertilizer applications in paddy field, Bandagiriya

field	date	fertilizer	Amount (kg)	N (kg)	P (kg)	K (kg)
1	18/12/99	Mada pohora	175	9	26	26
1	04/01/00	Urea	200	92	---	---
1	22/01/00	Urea	200	92	---	---
1	14&15/02/00	Urea	150	69	---	---
1	14&15/02/00	TDM	100	20	20	20
1	**Total application (kg/ha)**			**110.06**	**18.07**	**18.07**
2	14/12/99	Mada pohora	75	3	11	11
2	02/01/00	Urea	75	35	---	---
2	12/01/00	Urea	100	46	---	---
2	11/02/00	Urea	50	23	---	---
2	11/02/00	TDM	50	10	10	10
2	**Total application (kg/ha)**			**133.81**	**24.36**	**24.36**

It also appeared that the values of salt at piezometer 2 in field 1 were unrealistic high. Therefore, no more measurements were taken there.

The water quality data that were used for the irrigation consisted of measurements of the CEC, total nitrogen (N) and total phosphor (P). Normally the data of the inlet was used, if not available that was data of the field canal. In the case of a fertilizer application (N and P), it was assumed that the total amount of fertilizer was applied within an irrigation gift. For the quality of the ground water, the first measurements of the piezometers in the growing season were taken.

Some interactions between nutrients and plant and soil like diffusion, dispersion, solute uptake by roots, adsorption and decomposition had to be specified in SWAP.
For salt, it was assumed that only dispersion of these interactions takes place. In the case of nitrogen and phosphor, dispersion and root uptake is specified. The other interactions also take place, but no measurements or data were available, so they were not taken into account.
Transfer between mobile and immobile water volumes was also ignored.

3.2.2.4 Meteorology
Daily meteorological data were available from a small meteorological station near to Bandagiriya. Only rainfall and pan evaporation were measured. Because the measurements were taken in the morning only, all data had to be put one day back, because no evaporation takes place in the night. An improvement would be that measurements would be taken in the morning as well as in the evening, to make this data set more accurate. By multiplying the pan evaporation with a factor of 0.7 for, a very global value for the reference evaporation was obtained.

3.2.2.5 Plant data
Data was collected in the field by taking measurements during the growing period. In this way, the root and shoot development and soil cover fraction were monitored as a function of the development stage. Further, extensive research is done about rice and for the program necessary data could be found in literature. The values for yield response as function of development stage was taken from a FAO paper, 'yield response to water' (Doorenbos et al., 1979) (see figure 3.12)

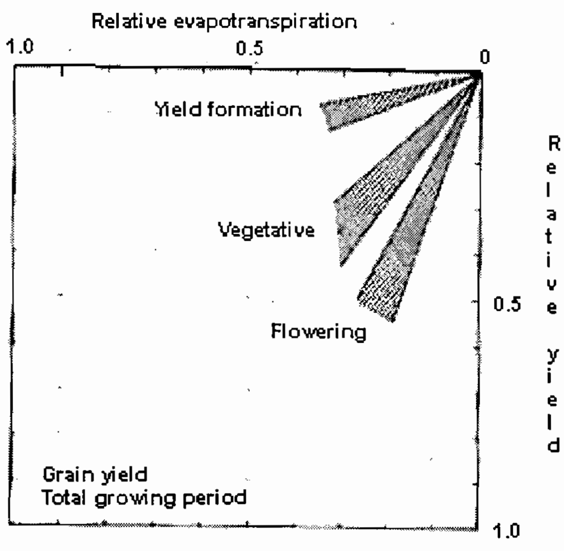


Figure 3.12: Yield response as function of development stage (Doorenbos et al., 1979)
The following formula was used:

K = relative yield/relative evapotranspiration Formula 3.13

With:

K:	Yield response factor
Relative yield:	$(1\text{-}Y_{actual}/Y_{maximum})$
Relative evapotranspiration	$(1\text{-}Et_{actual}/Et_{maximum})$.

The average values for every stage were used.

Because rice doesn't suffer oxygen stress, the pressure head below which roots start to extract water from the soil is positive. The relative root density was determined, using the knowledge that within 20 cm 90 percent of the roots are situated (Wopereis et al., 1996) and, in this case, the remaining 90 percent from 20 till 80 cm below the surface.
For SWAP, the crop rotation scheme had to be determined. The time of emergence, the end of the crop and the start of the scheme are here necessary.

3.3 Integration of the models

The first step of the integration between the models was to compare their information and making it compatible. After that, SWAP could run the situation how it is supposed to be in the Kirindi Oya irrigation and settlement project, derived from the measured data of the large-scale project and the paddy field measurements. This output could be used again as input for the large-scale model.

The different amounts of water extracted from the irrigation channels between the paddy field and the KOISP were striking. The more in detail measured irrigation gifts of the farmer were half of the irrigation gifts of what was given in a similar period and area in KOISP, as appeared from the large scale measurements. After investigating what is common, the amounts derived from measurements from KOISP were more representative than those in the paddy field. The SWAP scenario was changed, using double irrigation gifts. Because the soils in the paddy field seemed to have a lower saturated hydraulic conductivity than more upstream soils, the soil hydraulic properties were also slightly corrected using texture data for reddish brown earths of W.D. Joshua (1985).

After comparing further measurements on large-scale and small-scale, it appeared that the growing periods were slightly different as well. The rice crops are not initiated at exactly the same time in KOISP, so the irrigated period was longer than the109 day's growing period that was observed in the paddy field. To represent the entire KOISP in SWAP, the total irrigation period season was considered in the simulations. This period is longer than the requirements for one single crop (109 days) so a factor (crop season over irrigation season) was introduced to correct for this.
After that, the percolation, irrigation and evapotranspiration, which would be used in the large-scale model, were divided by the same factor during the growing periods to fit a normal 109 days period. (see figure 3.13)

With:

K:	Yield response factor
Relative yield:	$(1\text{-}Y_{actual}/Y_{maximum})$
Relative evapotranspiration	$(1\text{-}Et_{actual}/Et_{maximum})$.

The average values for every stage were used.

Because rice doesn't suffer oxygen stress, the pressure head below which roots start to extract water from the soil is positive. The relative root density was determined, using the knowledge that within 20 cm 90 percent of the roots are situated (Wopereis et al., 1996) and, in this case, the remaining 90 percent from 20 till 80 cm below the surface.
For SWAP, the crop rotation scheme had to be determined. The time of emergence, the end of the crop and the start of the scheme are here necessary.

3.3 Integration of the models

The first step of the integration between the models was to compare their information and making it compatible. After that, SWAP could run the situation how it is supposed to be in the Kirindi Oya irrigation and settlement project, derived from the measured data of the large-scale project and the paddy field measurements. This output could be used again as input for the large-scale model.

The different amounts of water extracted from the irrigation channels between the paddy field and the KOISP were striking. The more in detail measured irrigation gifts of the farmer were half of the irrigation gifts of what was given in a similar period and area in KOISP, as appeared from the large scale measurements. After investigating what is common, the amounts derived from measurements from KOISP were more representative than those in the paddy field. The SWAP scenario was changed, using double irrigation gifts. Because the soils in the paddy field seemed to have a lower saturated hydraulic conductivity than more upstream soils, the soil hydraulic properties were also slightly corrected using texture data for reddish brown earths of W.D. Joshua (1985).

After comparing further measurements on large-scale and small-scale, it appeared that the growing periods were slightly different as well. The rice crops are not initiated at exactly the same time in KOISP, so the irrigated period was longer than the109 day's growing period that was observed in the paddy field. To represent the entire KOISP in SWAP, the total irrigation period season was considered in the simulations. This period is longer than the requirements for one single crop (109 days) so a factor (crop season over irrigation season) was introduced to correct for this.
After that, the percolation, irrigation and evapotranspiration, which would be used in the large-scale model, were divided by the same factor during the growing periods to fit a normal 109 days period. (see figure 3.13)

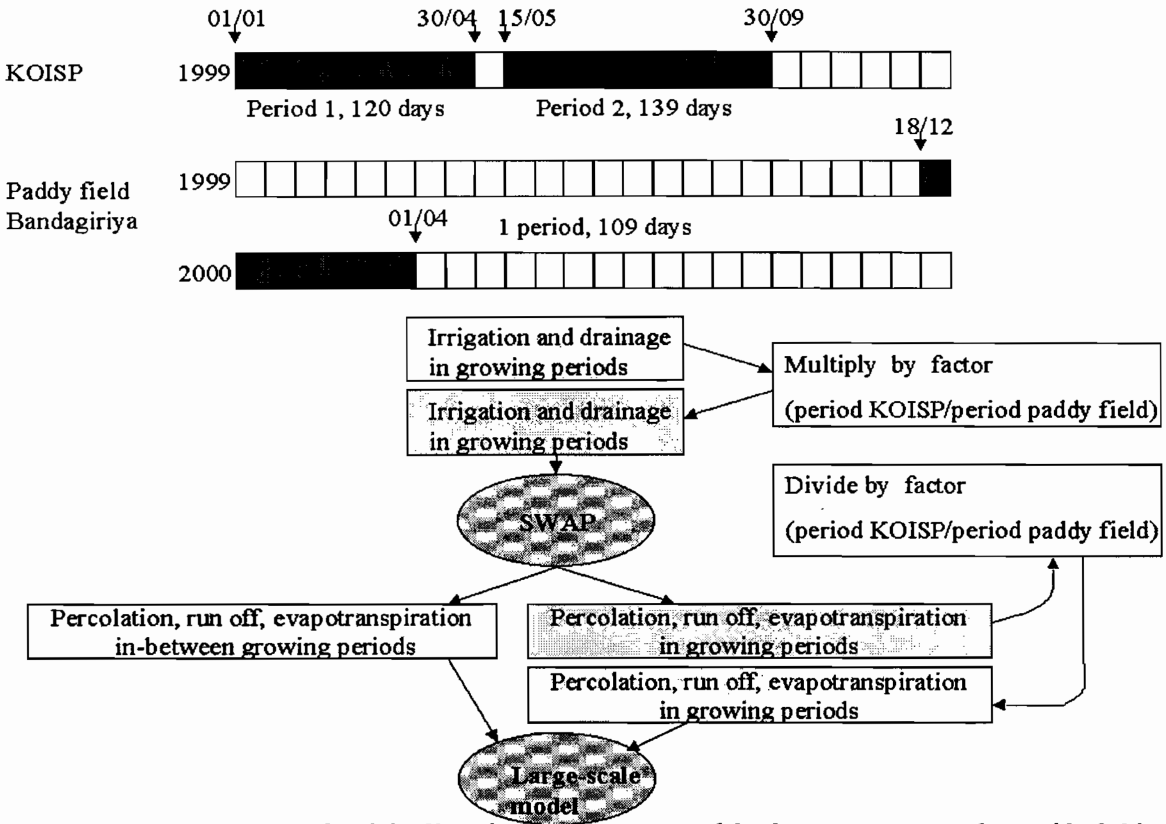


Figure 3.13: Growing periods of the Kirindi Oya Irrigation and Settlement Project and a paddy field in Bandagiriya and the correction for differences

The input for the new baseline of SWAP were assumed values for soil, the growing periods and irrigation from KOISP measurements and remaining data came from corrected paddy field measurements and literature. SWAP was run for ten years and the output of the tenth year was used in further analyses. This was done because initial conditions were not exactly known. After those ten years the situation was stabilized, as it is in the field, so no extreme events would show up in the model's output. For the whole ten-year run, meteorological data of 1999 were used.

3.4 Scenarios

After a model is set up and working, the possibility of deriving scenarios exists. The scenarios should be saying something about factors that can be changed and which results and impact this gives. In the case of the interaction between the KOISP and the Bundala National Park it is interesting to look at the management changes and the consequences for the park.

The first scenario was to look at impact of in increasing or decreasing fertilizer application. Next to the baseline situation, another run with SWAP was carried out with doubled gifts of nitrogen and phosphor and another with the half amounts of fertilizer (see table 3.4).

The outputs of the small-scale model were again used in the large-scale model as described in paragraph 3.1.2, to see the influence on the Bundala Park

Table 3.4: Fertilizer gifts in fertilizer scenario per growing period and total application per year

date	fertilizer	P (kg/ha) half	P (kg/ha) baseline	P (kg/ha) double	N(kg/ha) half	N (kg/ha) baseline	N (kg/ha) double
01/01, 15/05	Mada pohora	5	10	20	2	3	6
16/01, 30/05	Urea				18	36	72
05/02, 19/06	Urea				18	36	72
25/02, 09/07	Urea & TDM	4	8	16	17	35	70
Total per year (kg/ha/yr)		18	36	64	110	220	440

The results of this scenario will show how effective the fertilizer will be used by the plant, what percentage will be lost by percolation and run-off and how much of this will reach the lagoons in the Bundala Park.

Another scenario was to vary the irrigation gifts. Here again, the measurements on the paddy field could be used after changing the soil in the same as the new baseline. The following gifts per growth period of 109 days were applied (see table 3.5):

Table 3.5: Irrigation gifts in varying irrigation gift scenario

		Paddy field		Baseline	
Irrigation per 109 days (mm)	350	560	800	1000	1300
Irrigation first period (mm)	376	613	880	1090	1426
Irrigation second period (mm)	450	710	1025	1275	1650
Total for 1 year (mm)	826	1323	1905	2365	3076

This scenario can show below which amount of irrigation the crop will suffer drought stress. The scenarios of 800 and 1300 mm irrigation are translated to the large-scale study. This will show what happens with nutrients if more or less water is applied and again, how this influences Bundala Park. In the large scale model the division factor for the ratio of irrigation water and urban water, as explained in paragraph 3.1.1, changes. Besides that the outputs of the small-scale model about the loads of nutrients are used again in the large-scale model as described in paragraph 3.1.2.

The last scenario was to reduce the inflow of drainage water into Bundala Park. Therefor the inflow from Bandagiriya was set as zero throughout the year. This means that Bandagiriya drains off directly into the sea. This scenario can show how the water quality of the lagoons in Bundala change if there is less inflow from the above stream irrigation area.

4 Results and discussion

4.1 Large- scale

As mentioned in paragraph 3.1.1. the percolation factor (a) and the soil water storage capacity (S_{max}) have to be optimized. These parameters apply to water extracted for irrigation. The total return flow in the drains however includes also return flows from the urban extraction. The total return flow is calculated as follows;

$$\text{Return flow}_{,t} = Q_{R,t} + b \cdot P_t + c \cdot \text{Urban}_{,t}$$

Formula 4.5

b = percentage of the percolation water that flows into drainage canal
c = percentage of the urban water that flows into drainage canal

In this equation the parameters b and c had to be optimized. Because an unknown part of the drainage from Tract 6/7 flows into the drainage canal of Tract 5, this factor also had to be optimized.

These parameters are optimized by comparing the measured and calculated return flows, using the excel solver. The values of the solved parameters for Bandagiriya and the Tracts are given in table 4.1.

Table 4.1: Values of optimized parameters for calculation of the return flow

	Tracts	Bandagiriya
Percolation fraction (a) [-]	0.26	0.22
Soil water capacity (S_{max}) [mm]	119	151
Percolation rate to drain (b) [-]	0.64	0.66
Urban rate to drain (c) [-]	0.1	0.1
Fraction drainage water from Tract 6/7 to drainage Tract 5 [-]	0.03	-

In figure 4.1 the graphs of the measured and simulated return flow of Tract 5, Tract 6/7 and Bandagiriya are given. As can be seen in this figure, the model calculates the return flows of the irrigation areas quite well. For all the irrigation areas the total amount of drainage water is the same in the model as measured.

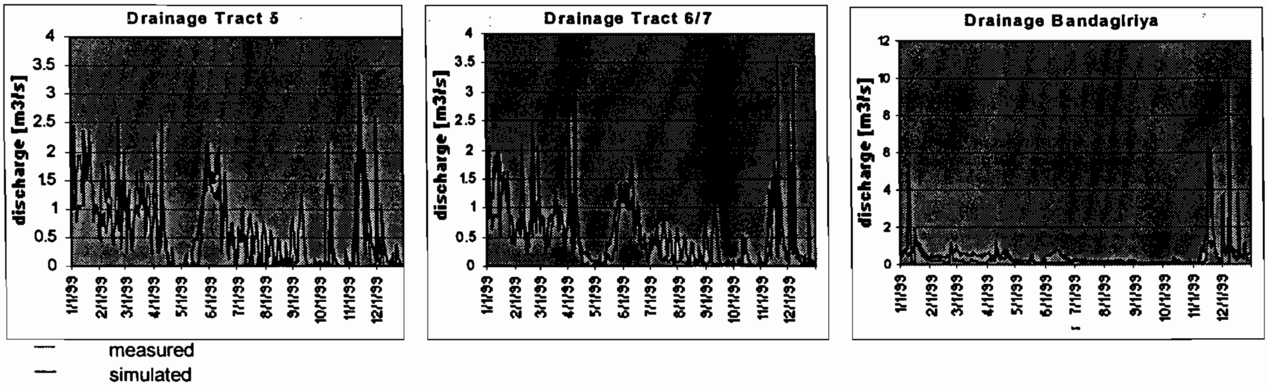


Figure 4.1: Discharges of the drainage canals from Tract 5, Tract 6/7 and Bandagiriya as they are measured and simulated.

To simulate the water management in the lagoon, the following parameters are optimized (paragraph 3.1.3);
- Initial water level of Embilikala and Malala lagoon ($H_{E,t-1}$ respectively $H_{M,t-1}$ at $t = 1$)
- Dead storage level of Embilikala and Malala lagoon (D_E respectively D_M)
- Spill level of Embilikala and Malala lagoon (S_E respectively S_M)
- Minimum release of Embilikala and Malala lagoon ($Q_{min\,E}$ respectively $Q_{min\,M}$)

These parameters are optimized by comparing the measured water level and the calculated water level from the Embilikala and Malala lagoon, using the excel solver. For the calibration the measured amounts of drainage water were used, not the amounts that are calculated by the return flow spreadsheet. The values of the solved parameters are given in table 4.2. Figure 4.2 shows the measured and simulated water level after optimizing the parameters.

Table 4.2: Values of optimized parameters for calculation of the lagoon levels.

	Embilikala lagoon	**Malala lagoon**
Initial water level [m]	1.44	1.67
Dead storage level [m]	1.43	1.06
Spill level [m]	2	1.52
Minimum release [m^3/day]	113,654	35,351

In figure 4.2 it can be seen that the simulated water level in Embilikala remains low after the sandbank was cut. The reason for that is there was almost no incoming drainage water measured (ID number 1; see figure 3.3) during end of 1999. During that period there was however a lot of rainfall. Apparently Embilikala received rainwater from the watershed that is not taken into account in the model. Another explanation could be that the discharge in the drainage canal is not measured correctly.

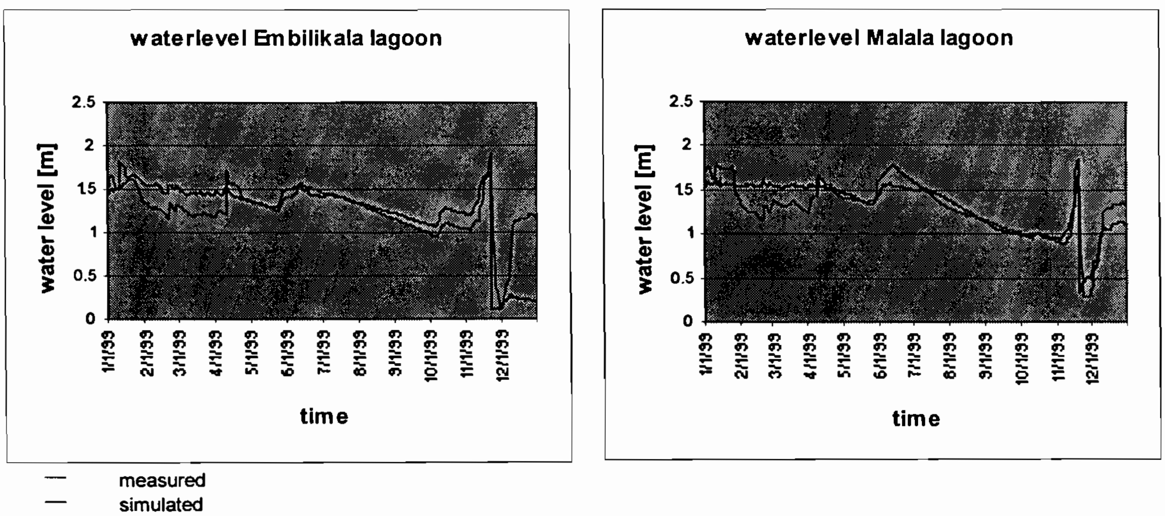


Figure 4.2: Water levels of Embilikala and Malala lagoon as they were measured and simulated

As explained in paragraph 3.1.4 the water quality in the lagoons is calculated by integrating all the spreadsheets. The simulated concentrations of total nitrogen, total phosphorus and salt in Embilikala and Malala lagoon are shown in figure 4.3. The values of the measurements are also given. As can be seen, the simulated total nitrogen is too high. The measurements of total nitrogen in Embilikala and Malala lagoon show the same trend, which cannot be seen back in the simulated concentration. The simulated concentration of total phosphorus is also too high. Two explanations can be given for this. The first is that SWAP models too much outflow of both total nitrogen and total phosphorus. The second reason is that the spreadsheet does not deal with degradation processes in the lagoons and canals.

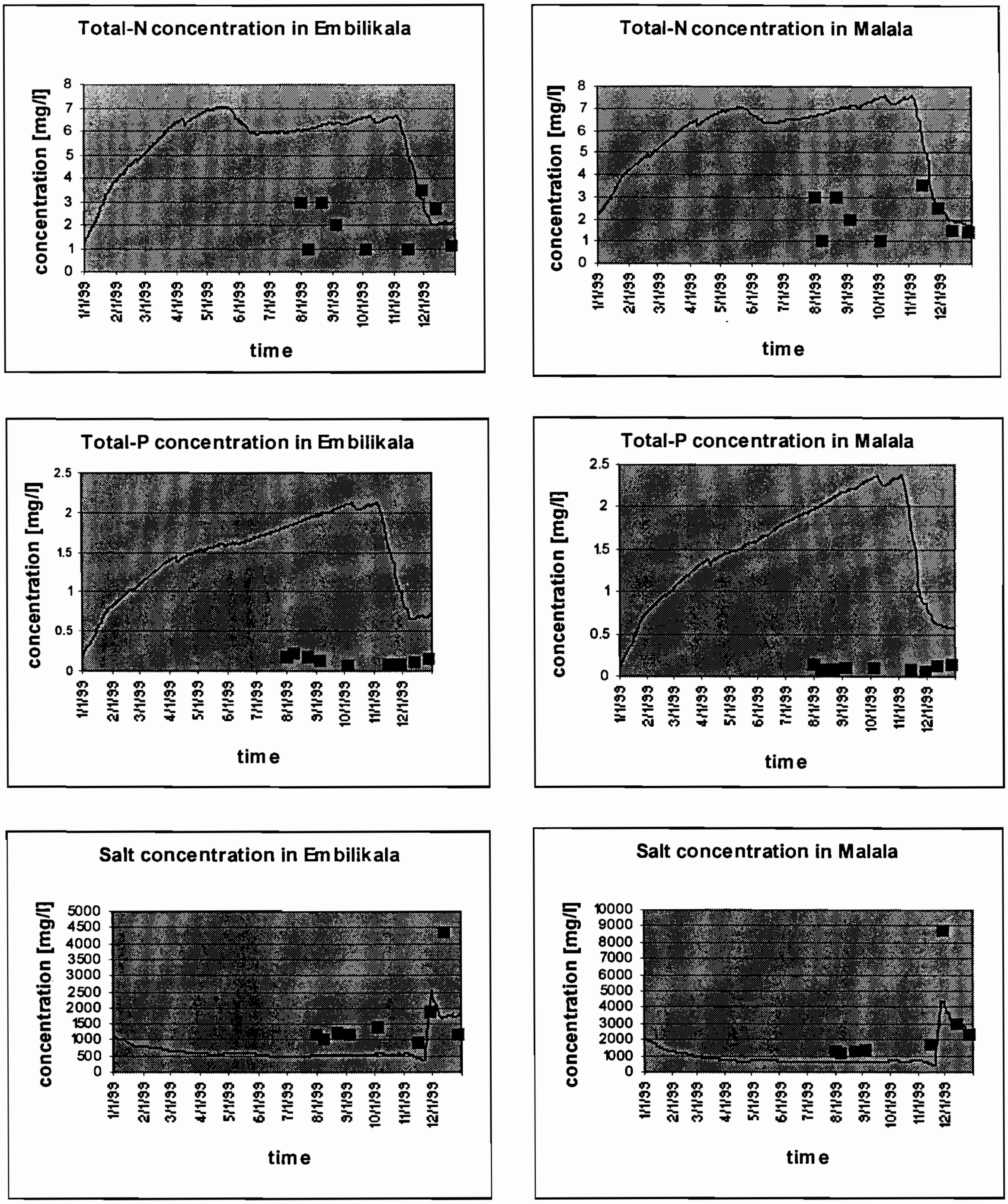


Figure 5.3: Concentrations of total nitrogen total phosphorus and salt as the are simulated and measured in Embilikala and Malala lagoon.

4.2 Small-scale study

As explained in chapter 3.3, the baseline study for the small-scale study was based on the measured values of the paddy field in Bandagiriya, but with an increased irrigation gift and a more permeable soil. The model was applied for 10 years, while keeping the input data constant and the output for the tenth' year was used. In this way the situation in the field had reached an equilibrium situation.
Using these adaptations, with data of the large-scale and small-scale measurements and some assumptions from literature or personal communication, a simulation of a common paddy field the Kirindi Oya Irrigation and Settlement Project was produced. As said before, the model couldn't be calibrated because only one data set was available, but assumed was that because of the physical nature of the model, the output was meeting the field situation quite well (see chapter 3.2.1). In the charts in figure 4.4 the reaching of an equilibrium situation after several years for the water and nutrient balances of the paddy field is showed.

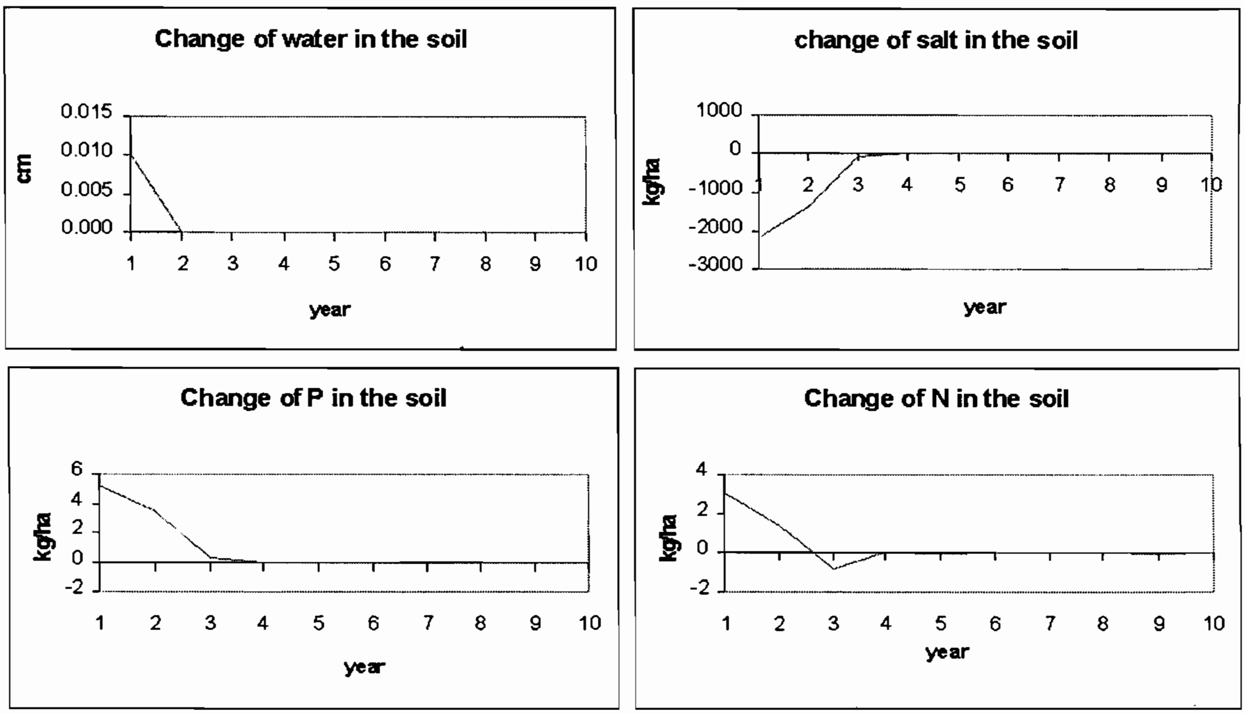


figure 4.4 Changes of water and nutrients during ten-year period of the baseline situation.

Table 4.3 gives the water and nutrient balance of the baseline situation in equilibrium. Surface runoff and drainage are taken together, because the superficial drainage practices that take place in paddy field agriculture is included in this term. Furthermore, irrigation and fertilizer are showed together because fertilizers are applied in SWAP within the irrigation gift. The common concentration of the irrigation water was increased during a fertilizer application.

Table 4.3: Annual water and nutrient balance of the baseline scenario

	Potential mm	Inflow mm	Outflow mm	Salt, kg/ha in	Salt, kg/ha out	P, kg/ha in	P, kg/ha out	N, kg/ha in	N, kg/ha out
Transpiration	709		709						
Evaporation	474		368						
Interception			13						
Precipitation		1083							
Irrigation & fertilizer		2365		5037		47		258	
Bottom flux			839		3122		10		24
Surface runoff & drainage			1519		1918		19		75
Root uptake							18		159
Mass balance error				3					
Total	1183	3448	3448	5040	5040	47	47	258	258

The water and nutrient amounts do not change as simulations were performed till equilibrium was reached (10 years) on annual base. Obviously their application and removal are not constant within one year. The daily distribution over the year can be seen in figure 4.5.

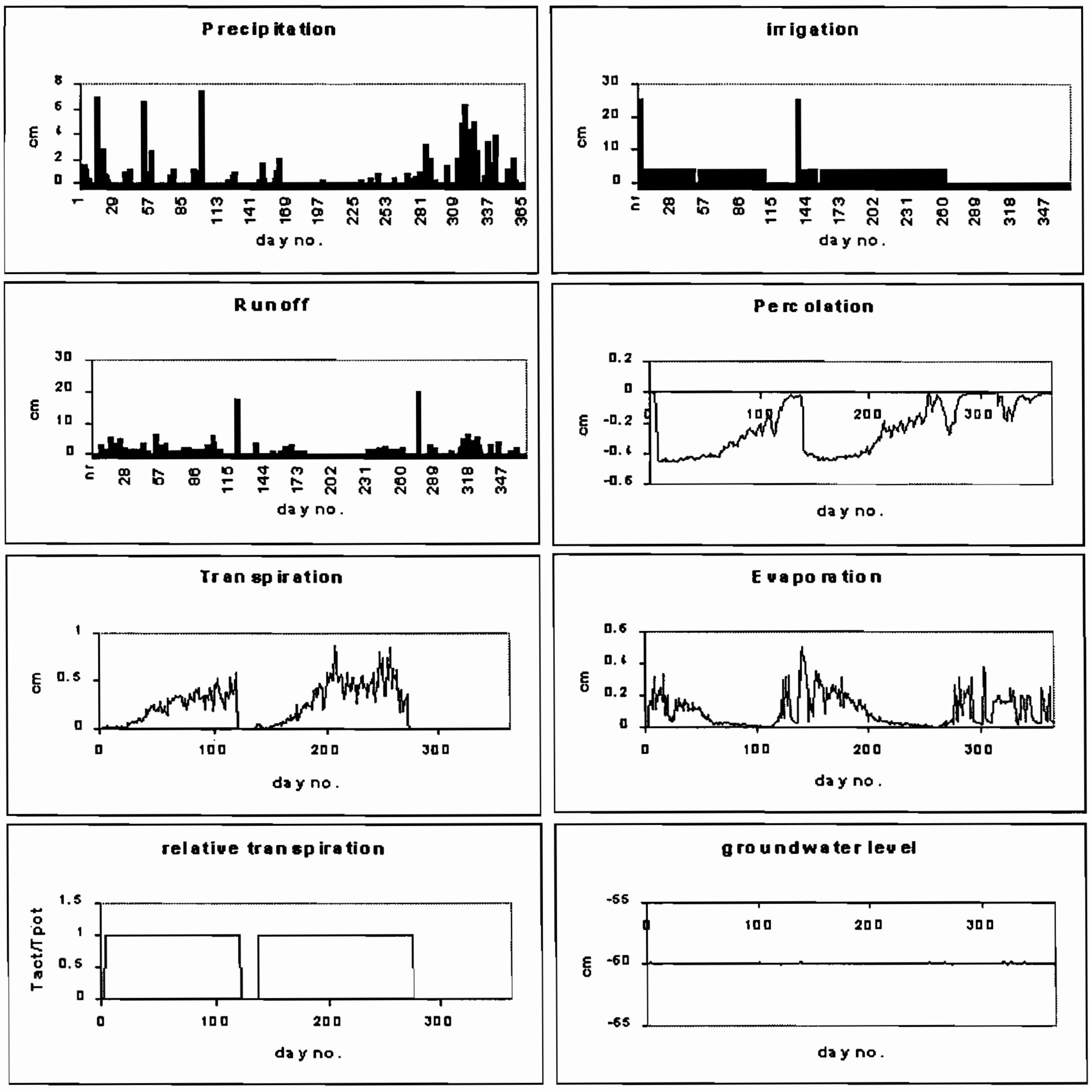


figure 4.5: Graphs showing the distribution of in- and outflow of water in the baseline situation

The precipitation data is of 1999. The first growing season (day 1-120) benefits of the rainfall, but for the second season (day 135-273), the rainfall comes late.
The first irrigation gift is for flooding the paddy field. This is 25 cm, as high as the ponding layer can be. After that, every five days an application of 4 cm in the first period and 4.1cm in the second period is given till about 2 weeks before the harvest. The runoff shows peaks at the end of the growing season, this because at that time all the water will be let out of the field, as preparation for the harvest. The first growing period has more runoff than the second does. This is because more water is available due to rainfall. Negative values in percolation indicate a downward flux, while positive values indicate upward flux by capillary rise. The percolation reflects the irrigated periods and the rainfall. The transpiration and soil evaporation show the growing period, with the transpiration increasing during the growth of the rice crop and the evaporation decreasing because of a higher soil coverage.
The relative transpiration (actual transpiration/ potential transpiration) is always 1, except of the first day of the growing season and in between growing periods, then it is 0. This means there is never water stress, only at the first day the actual transpiration is 0 because the plant does not transpire because it has just germinated. (Note that in this case no small plants from a nursery are planted, but germinated rice kernels are seeded.) The groundwater level is stabile because it was set on 60 cm, the measured water level after the field was drained completely.

In figure 4.6, the pF values in the soil can be seen as a function of time (x-axis) and depth (y-axis). As can be seen, the upper dense layer of 20 cm, with a low saturated hydraulic conductivity is always saturated during the growing season. In between seasons, the soil dries but never gets above the wilting point, pF 4.2.
The ground water table remains at 60 cm. After the second season, again some intrusion of water from precipitation can be seen.

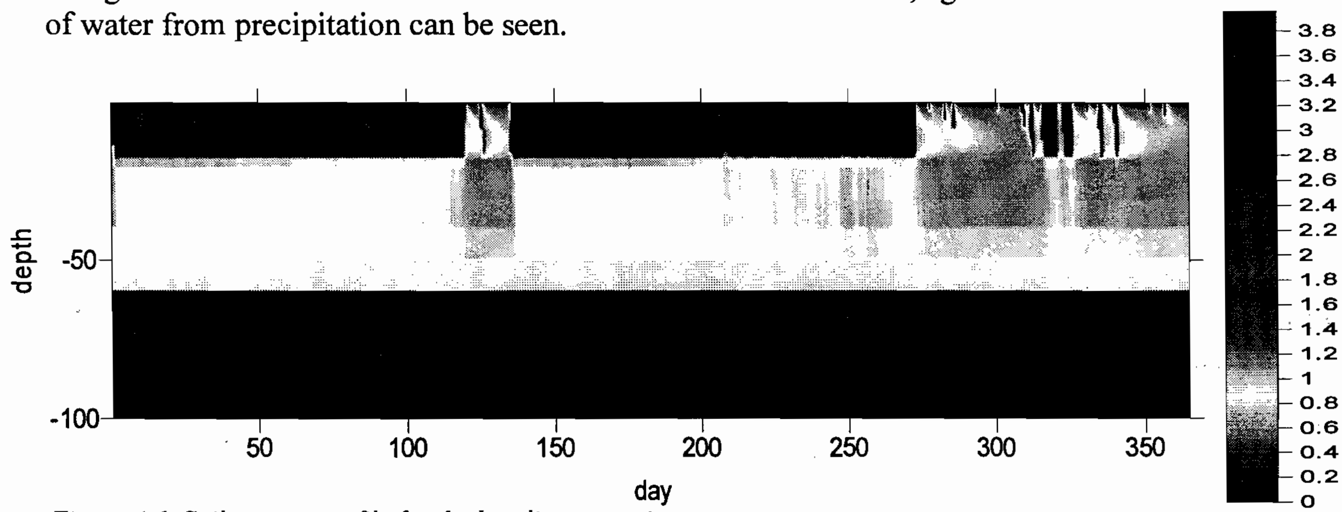


Figure 4.6: Soil - water profile for the baseline scenario

The profiles of salt, phosphor and nitrogen are highly connected to what happens with the water (see figure 4.7). If more irrigation or rainfall, more leaching to lower soil layers occurs. After fertilizer applications (see table 3.4), the topsoil has a higher amount of nutrients. In between the growing periods, the topsoil has quite high amounts of salt, P and N, because no leaching, runoff or plant uptake takes place and in the upper part of the

profile, some upwards movement takes place, caused by soil evaporation. This high content in the topsoil will decrease again after the first irrigation event of the next growing season or precipitation.

Also can be seen in figure 4.7 that the salt levels are higher in the second than the first growing period, this because less water is available. The irrigation water supplies salt but doesn't leach it sufficiently. The plants will take up the nutrients P and N, so their level is not increasing.
After the second period, the rain causes again leaching to deeper soil layers. The load within the soil doesn't change after a year with two growing seasons, this because an equilibrium had reached. The amounts of salt, N and P flowing in and out can be seen in table 4.3.

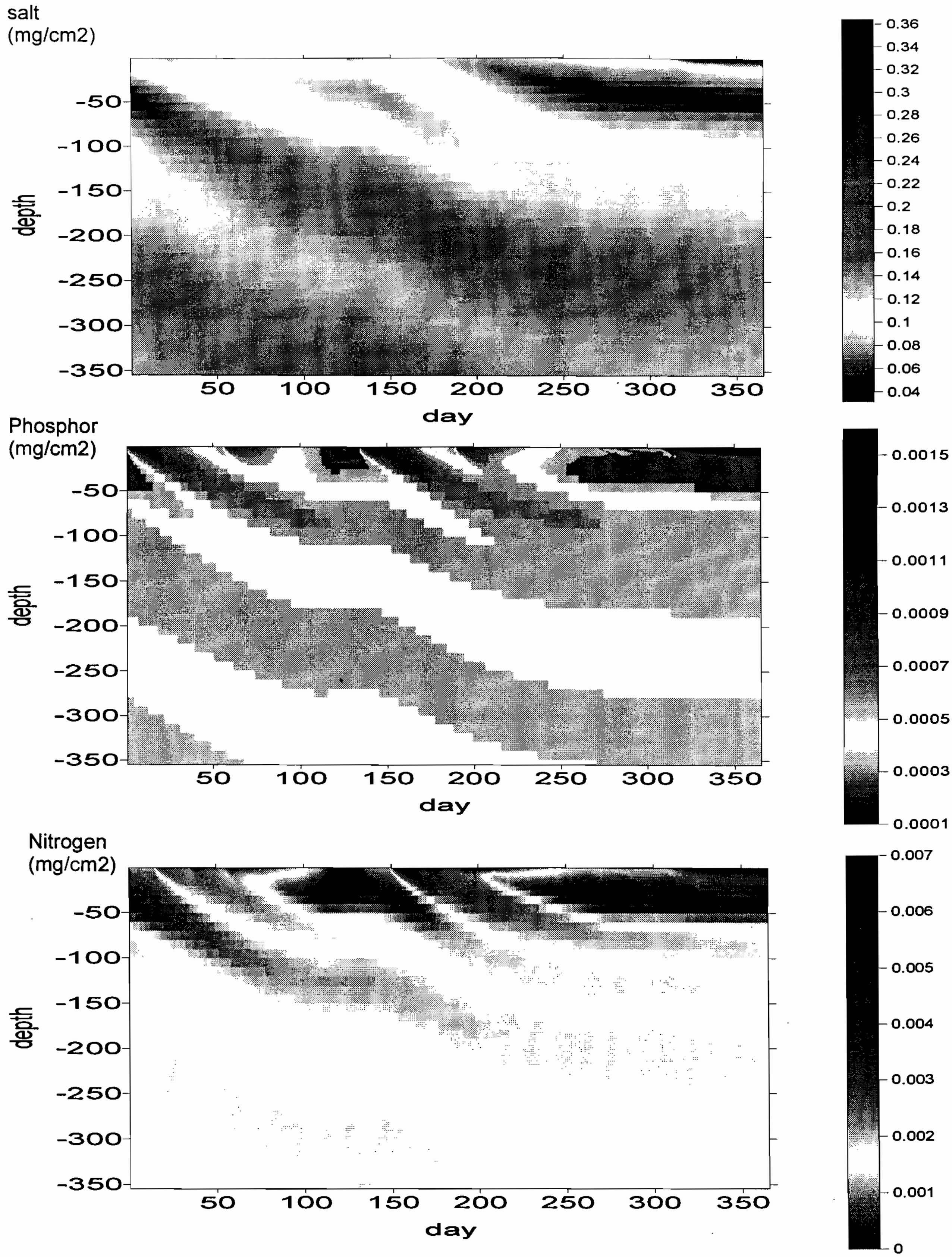


Figure 4.7: Salt, Phosphor and Nitrogen, as function of time and depth in the baseline scenario

4.3 Scenarios

4.3.1 Effects on small scale

The first scenario was to apply half or double amount of fertilizer. This was done for the nutrients N and P. Amounts of these nutrients already present in irrigation water were not changed. In table 4.4 it becomes clear that by changing the application to half or double amounts, gives almost the same change in the output values.

Table 4.4: Nutrient balances of double and half fertilizer applications with regard to the baseline scenario

	Nutrients (fertilizer & irrigation water quality) kg/ha/yr	**Irrigation** % of baseline	**Root uptake** % of baseline	**Percolation** % of baseline	**Runoff** % of baseline
Half N	141	55%	54%	54%	56%
Baseline N	258	100%	100%	100%	100%
Double N	491	191%	192%	193%	187%
Half P	27	58%	60%	57%	58%
Baseline P	47	100%	100%	100%	100%
Double P	86	183%	180%	186%	184%

In figures 4.8 and 4.9, the same trend is visible. The outflows are distributed evenly with regard to the total given input. The different uptake factors of the crop and the varying timing of application cause the difference in distribution between N and P. See annex I and II for the course of nutrient contents in the soil profile as a function of time at different fertilizer applications.

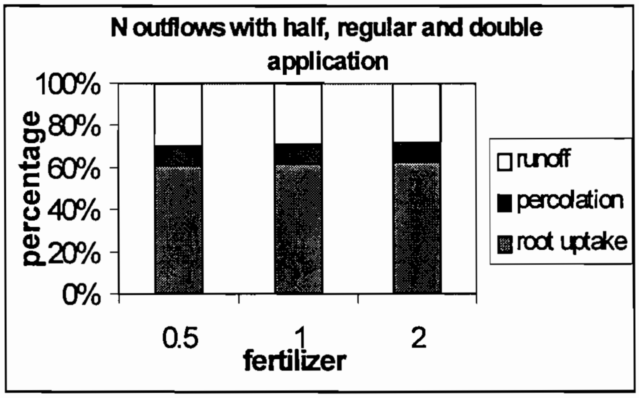


Figure 4.8: N outflows with half, regular and double application

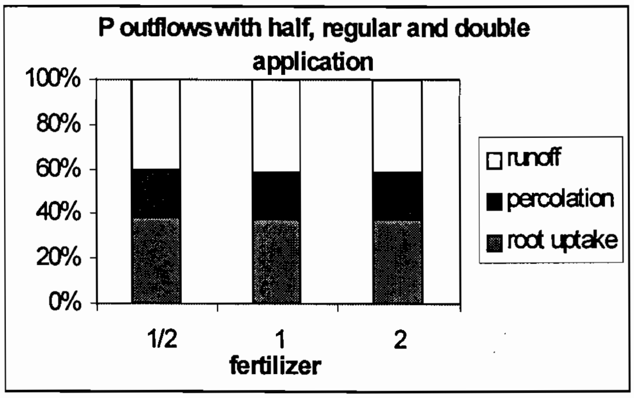


Figure 4.9: P outflows with half, regular and double application

Another scenario was to increase or decrease the irrigation gift. Applications per growing periods of 350 mm, 560 mm, 800 mm, 1000 mm and 1300 mm were taken into account, with 560 mm the Bandagiriya and 1000 mm the baseline scenario. In the group of charts in figure 4.10, the effects on the water quantity can be seen. Note that the irrigation gifts mentioned above are the gifts for one 109-day growing period. The applications given during the two growing periods are corrected for the longer duration. The runoff shows large peaks at the ends of the growing seasons, (1^{st} period: day 1-120, 2^{nd} period: day 135-273) the days that the fields are drained completely. Within the growing seasons, the

runoff increases with the irrigation gift. At the end of the year, there can be seen again some runoff caused by the precipitation during that time.
The relative transpiration is an indicator for water stress to the crop. In the first growing period, there is enough rainfall with the irrigation to never cause stress. At the second period however, the 350-mm case is showing after 1.5 months already water stress and this lasts till the end of the period. In the Bandagiriya case (560 mm), some water stress can be observed after 2.5 months. This last only for two weeks, then some precipitation solves the problem. At 800-mm and higher irrigation gifts, no water stress occurs. In between growing periods, no transpiration takes place, so the relative transpiration is zero. Negative percolation values indicate downward flux, positive values indicate upward flux by capillary rise. The percolation is with the baseline 1000-mm irrigation gifts and higher always downwards. At the end of the second growing season, some capillary rise occurs after the irrigation has stopped, but this is only a little and lasts for two weeks. The Bandagiriya scenario (560 mm) has more capillary rise. This starts in the second period at day 216 and lasts till the end of the growing season, when also some rain falls. The 350-mm case has already between the first and second period some capillary rise, a week before the first period ended and till a few days after the second starts. This happens again after the first 2.5 months of the second period, when water stress occurs and it lasts till after this period, when the rain starts to fall. See annexes III, IV, V and VI for the course of pF, salt, N and P contents as a function of time at different irrigation gifts.

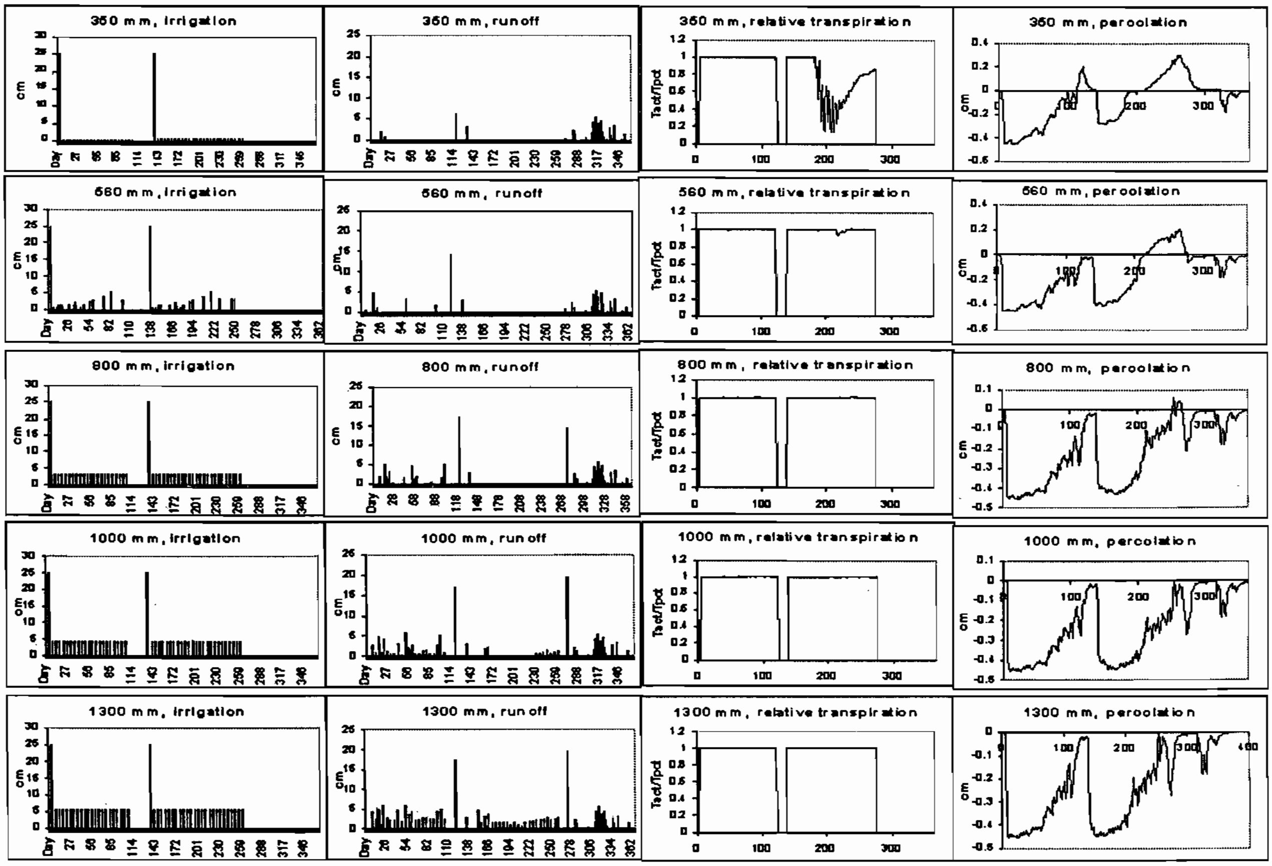


Figure 4.10: Effects on water quantity caused by varying irrigation gifts. With baseline scenario of 1000 mm and Bandagiriya scenario of 560 mm.

The relative yield is strongly related with the relative transpiration. However, the sensitivity of the crop during the growth should be taken into account as well. Without using this sensitivity of the crop, the following chart is the result (figure 4.11). It can be seen that in the first period a relative yield of 100% can be obtained by all irrigation gifts. In the second period water stress causes decreased yields only at application rates lower than 560 mm.
The output of SWAP gives also values for the salt and water stress on the relative yield. These effects do take into account the crop sensitivity during the growth (see figure 4.12). The charts are a lot alike, only the 350-mm case gives no yield if the crop sensibility for drought and the salt stress are included and for the 560-mm Bandagiriya case it makes a few percentages difference.
This is mainly due to on the sensitivity of the crop at a certain time that stress occurs. The critical EC, as the yield starts to be effected is 3.0 dS/m for rice and the value that no growth is possible is 12 dS/m (Theory of SWAP version 2.0, 1997). This value for the 350-mm case is at 23 days reached between day 203 and 273, the last day of the second period, with a maximum value of 3.8 dS/m. In the case of the 800-mm irrigation; this critical EC is never reached.

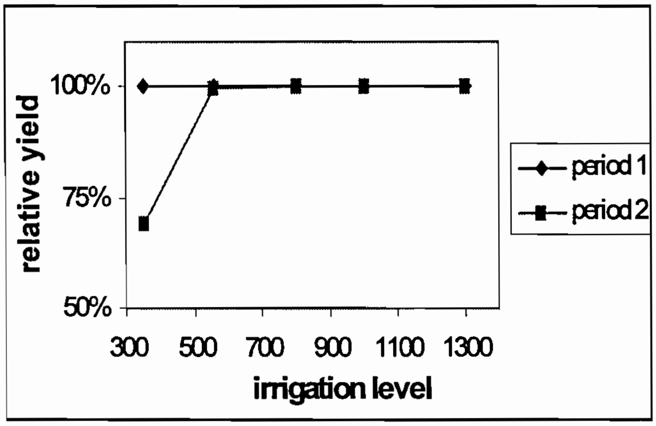


Figure 4.11: Relative yield, influenced by water stress at varying irrigation gifts

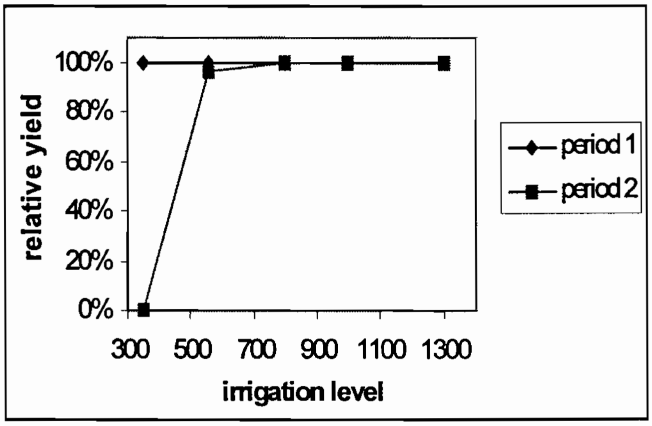


Figure 4.12: Relative yield, influenced by salt and water stress and the crop's sensitivity at varying irrigation gifts

In figures 4.13 and 4.14, the effect of the irrigation gift on salt, N and P is showed. Because the soil is in equilibrium, everything that goes in goes out again. The increase of the output is due to the increase of the irrigation water that delivers more salt and nutrients with it. In the salt case, where no root uptake takes place, it can be seen that after 800-mm irrigation the salt loss by leaching stabilizes while the runoff increases more for leveling this stabilization of the percolation out. With N and P the leveling of the leached nutrients also takes place at 800-mm irrigation. Striking however is that the root uptake of nutrients decreases with a higher irrigation gift. This is caused by the runoff that increases with an increased irrigation gift and the lower concentration of soil water taken up by roots. The less irrigation, the fewer nutrients will be lost by runoff and leaching. Of course the problem of water stress has to be taken into account by probable management recommendations.

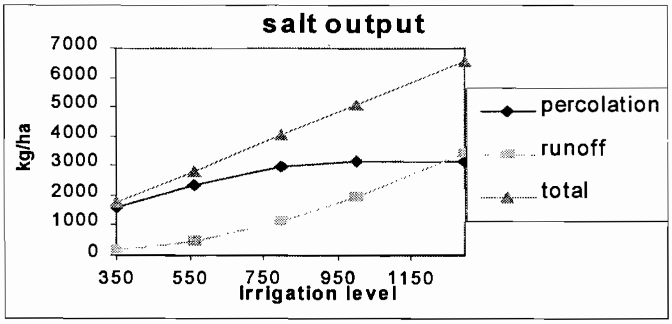


Figure 4.13: Salt in runoff and percolation at varying irrigation gifts

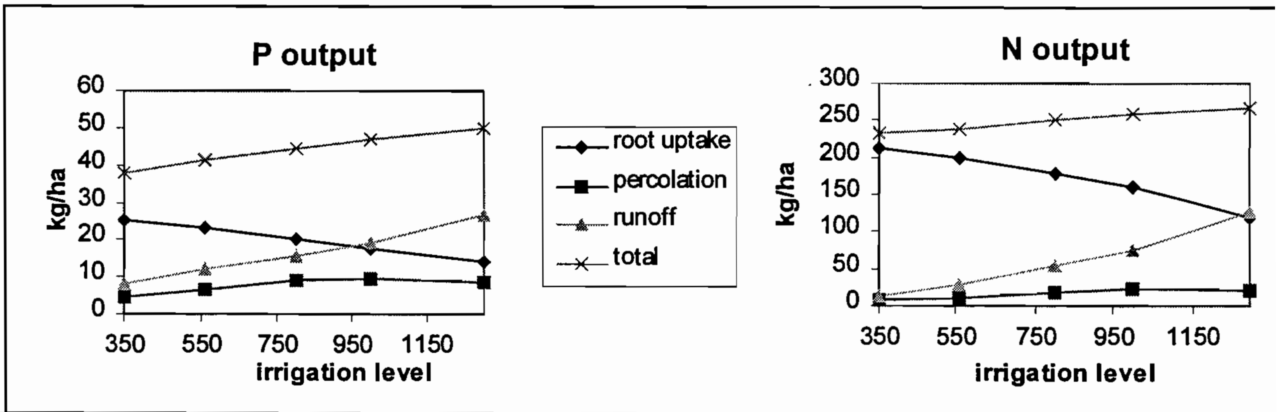


Figure 4.14: Nutrients N and P in root uptake, runoff and percolation at varying irrigation gifts

4.3.2 Effects on large scale

For the large scale, the following scenarios are derived;

- Double amount of fertilizer application on the field (double N + P)
- Half amount of fertilizer application on the field (half N + P)
- Increased irrigation; 1300 mm (more irrigation)
- Decreased irrigation; 800 mm (less irrigation)
- Less inflow from upstream irrigation area (drainage Bandagiriya to sea)

In table 4.5 the calculated nutrient balance in Embilikala is given for the different scenarios. In table 4.6 the same is done for Malala lagoon. Figure 4.15 shows the simulated results on total nitrogen, total phosphorus and salt.

Table 4.5: Calculated nutrient balance in Embilikala lagoon for the different scenarios

Scenario	Total nitrogen		Total phosphorus		Salt	
	[g]	% of baseline	[g]	% of baseline	[g]	% of baseline
Baseline	1.15E+10	100	3.10E+09	100	1.30E+12	100
Double N+P	2.09E+10	182	5.63E+09	182	1.30E+12	100
Half N+P	6.80E+09	59	1.83E+09	59	1.30E+12	100
More irrigation	1.34E+10	116	3.14E+09	101	1.20E+12	92
Less irrigation	1.02E+10	89	2.99E+09	97	1.40E+12	107
Drainage Bandagiriya to sea	1.15E+10	100	3.10E+09	100	1.30E+12	100

Table 4.6: Calculated nutrient balance in Malala lagoon for the different scenarios

Scenario	**Total nitrogen**		**Total phosphorus**		**Salt**	
	[g]	% of baseline	[g]	% of baseline	[g]	% of baseline
Baseline	1.88E+10	100	4.85E+09	100	3.04E+12	100
Double N+P	3.36E+10	179	8.84E+09	182	3.04E+12	100
Half N+P	1.13E+10	60	2.86E+09	59	3.04E+12	100
More irrigation	2.23E+10	119	5.11E+09	105	2.77E+12	91
Less irrigation	1.62E+10	86	4.47E+09	92	3.25E+12	107
Drainage Bandagiriya to sea	1.67E+10	89	4.01E+09	83	3.53E+12	116

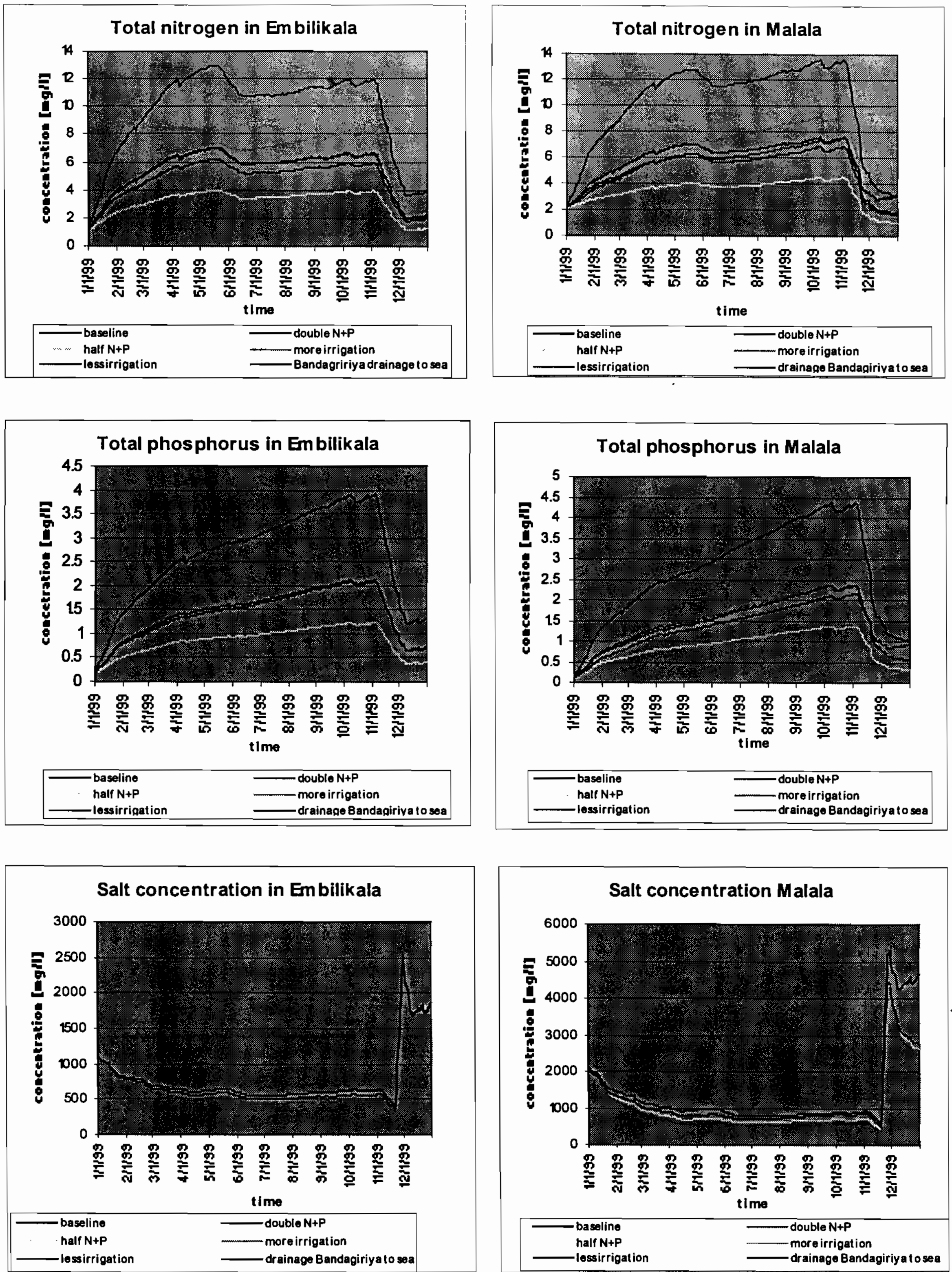


Figure 4.15: results of the different scenarios on the total nitrogen, total phosphorus and salt concentration in Embilikala and Malala lagoon

The simulated concentration of the total nitrogen in Embilikala is the same for the baseline as for the scenario that Bandagiriya drains into the sea. This is because Bandagiriya drains into Malala, so in the model it only influences the solid concentration in that lagoon. In Malala lagoon, a change in the total nitrogen can be seen at the scenario of drainage of Bandagiriya to sea. The concentration reduces a bit, but less then with the scenario of less irrigation. After the sandbank is cut the total nitrogen raises with the scenario of Bandagiriya drainage into sea in contrast with the rest of the scenarios. The raising of the concentration is due to the less amount of water in Malala lagoon (see figure 4.16). The cause of this is that Malala does not receive water from Bandagiriya anymore. As can be seen in table 4.5 and figure 4.15, double and half fertilizer application has the most impact on the concentration of total nitrogen in the lagoons. This scenario is however not very reliable. As explained at the small-scale study, SWAP models probably too much outflow of nitrogen for these scenarios. Besides that, degradation processes are not taken into account.

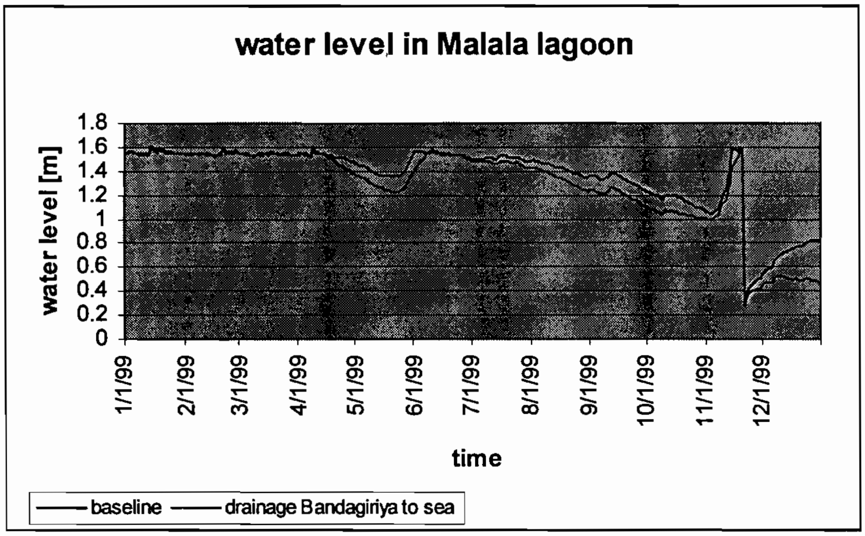


Figure 4.16: Water level in Malala lagoon as simulated in the baseline and in the scenario drainage Bandagiriya to sea

As for total nitrogen different amount of fertilizer application has the most influence on the total phosphorus concentration in the lagoons. The scenarios of more and less irrigation are not much different from the baseline. This is due to the fact that there is not much change in the load phosphorus in the return flow As explained before in Embilikala lagoon there is no difference between the baseline and the scenario of drainage water from Bandagiriya to sea. In Malala lagoon this scenario causes a small declination in the phosphorus concentration. Only after cutting the sandbank, the concentration is higher because there is less water in the Malala lagoon (see figure 4.16).

The salt concentration in the lagoons does not change appreciably with the different scenarios. For Embilikala lagoon it only varies a bit with the scenarios of more and less irrigation. In Malala for the scenario of drainage water from Bandagiriya to sea, a difference can be seen after the cutting of the sandbank. In this scenario the salt concentration stays higher after cutting the sandbank because Malala lagoon receives less fresh water.

5 Conclusion and recommendations

5.1 Bandagiriya and KOISP

At field level, it can be said that the new baseline scenario is functioning well for the rice crop. The water and nutrient supplies are sufficient. No water stress or nutrient stress will take place.
With doubled or halved nutrient supply, it seemed that the proportions between nutrient outflows kept the same values. In that case, the current nutrient supply was sufficient. However, it is recommended to survey the interactions of the nutrient with soil and plant more carefully to make statements in this case.

The double and halved nutrient supply has the most influence on the total nitrogen and total phosphorus concentration in the lagoons. Therefore, to reduce eutrofication it is recommended to reduce fertilizer application on the field.

Too much water was issued in KOISP in 1999. Water stress only will start in this case at 560 mm per growing period and less. In years with another precipitation distribution, also this 560-mm might be sufficient for the rice crop. Now the precipitation falls after instead of during the second growing period. Also salt stress plays a role in this matter. At 560 mm, stress will take place, but also with another precipitation distribution the problems are much smaller. At lower issues of water, more serious problems can be expected.

The drainage canal from Bandagiriya to the sea reduces nutrient loads with 10-20 per cent and increases the salinity in the lagoons.

The salinity in the lagoons does not change very much with the different scenarios. To increase the salinity it is recommended to use less irrigation water and to cut the sandbank between Malala lagoon and the sea more often.

5.2 Models

Simulation models are necessary to do scenario analyses. With models it is possible to do predictions in the future. In this study the integration between the large-scale and the small-scale model is indispensable to understand processes on both small and large scale.

5.2.1 Mike Basin

Mike Basin appeared to have two big shortcomings. First of all Mike Basin can not simulate the return flow from the irrigated areas properly. It does not take into account the storage on the field. Therefore another model was made in the form of a spreadsheet. Another very big shortcoming in Mike Basin is that is does not calculate new concentrations of solutes in the reservoirs. This is a very big mistake, which should be changed.

5.2.2 SWAP

During this study, some shortcomings with SWAP appeared. For modeling paddy fields, it would be recommendable that a muddy layer on top followed by a dense layer and than the subsoil could be programmed. This gave problems in this study, so the muddy top layer was ignored.
Also, superficial drainage as practiced in paddy fields could not be modeled. This was also the case with the varying height of the ponding layer. These shortcomings were corrected in the soil and water profile module during the study in this SWAP executable. The runoff was also not showed in the nutrient balance in the output of SWAP. Also this was changed. Another difficulty was the fertilizer application; the nutrients had to be given within the irrigation water. It would be more convenient to have a separate fertilizer module were fertilizer can be issued in kg/ha. Another useful extra variable could be 'maximum uptake' within the simple crop module. A value that reflects the maximum amount of a specific nutrient that a crop can take up during a growing season.

5.3 Data collection

The meteorological data is now measured once a day, as rainfall takes place day and night and evaporation only at daytime, it is recommended that both in the morning and in the evening measurement should be taken. For measurements in the paddy field, care should be taken with the ground water level measurements. As noted before, the danger exists that an apparently high groundwater level is measured, caused by flow along the piezometer when there is a ponding layer. The calibrations done for the in- and outlets were only valid for this set of measurements. If another set of measurements will be performed, these calibrations have to be done again, because of a changing environment up- and downstream the flumes.

Everyday the water height of the gauges in the selected canals is measured. To know which discharge corresponds to this height it is necessary to derive the Q-h relationship in these canals. At the moment there are not enough measurements taken to derive a reliable Q-h relationship for every canal. Because the environment changes every time caused to erosion it is recommended to calibrate the canals more often.

Literature cited

Central environmental authority Sri Lanka, 1993.Wetland conservation Project. Wetland site report and conservation management plan: Bundala National Park. Central environmental authority Sri Lanka, Euroconsult The Netherlands. Colombo, Sri Lanka: 103 p.

Dam, van, J. C., Huygen, J., Wesseling, J. G., Feddes, R. A., Kabat, P., Walsum, van, P. E. V., Groenendijk, P., Van Diepen, C. A., 1997. Theory of SWAP version 2.0. Simulation of water flow, solute transport and plant growth in the soil-water-atmosphere-plant environment. Report 71, Department of water resources, Wageningen Agricultural University. Technical document 45, DLO Winand Staring Centre, Wageningen, The Netherlands: 167 p.

Doorenbos, J., Kassam, A. H., 1979. Yield response to water. FAO irrigation and drainage paper no. 33. FAO, Rome, Italy: 125-130.

Genuchten, Van, M. Th., 1980. A closed form equation for prediction the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44: 892-898.

Joshua, W. D. 1985, Physical properties of reddish brown earths and their relationship to agriculture. Soil science society of Sri Lanka, Colombo, Sri Lanka: 1-12

Matsuno, Y., Hoek, van der W., Ranawake, M., 1998. Irrigation water management and the Bundala National Park. Proceedings of the workshop on water quality of the Bundala lagoons. IWMI, Colombo, Sri Lanka: 48 p.

Kroes, J. G., Dam, van, J. C., Huygen, J., Vervoort, R. W., 1998. User's guide of SWAP version 2.0. Simulation of water flow, solute transport and plant growth in the soil-water-atmosphere-plant environment. Technical document 48, DLO-Staring centre. Report 81, Department water resources, Wageningen Agricultural University. Wageningen, The Netherlands: 119 p.

NVON commission, 1977. BINAS. Information book vwo-havo for education in physics (in Dutch). Wolter-Noordhoff Groningen, The Netherlands: 156.

Šimunek, J., Suarez, D. L., Šejna M., 1996. The UNSATCHEM Software Package for Simulating the One-Dimensional Variably Saturated Water Flow, Heat Transport, Carbon Dioxide Production and Transport, and Multicomponent Solute Transport with Major Ion Equilibrium and Kinetic Chemistry, Version 2.0. U.S. Salinity Laboratory Agricultural Research Service U.S. Department of Agriculture, Riverside, California, USA: 186 p.

Stanbury, P. 1989. Land Settlement Planning for Improved Irrigation Management: A Case Study of the Kirindi Oya Irrigation and Settlement Project. Colombo, Sri Lanka. International Irrigation Management Institute (IIMI). IIMI Country Paper.

Voogt, K. de. 2000. Modeling water allocation between a wetland an irrigated agriculture in the Gediz Basin, Turkey. Wageningen, The Netherlands. Agricultural University. Master of science thesis.

Wopereis, M. C. S., Bouman, B. A. M., Tuong, T. P., Berge, H. F. M., Kropff, M. J., 1996. Oryza_W: Rice growth model for irrigated and rainfed environments. DLO-Research Institute for Agrobiology and Soil Fertility, WAU department of Theoretical Production Ecology, IRRI. Wageningen, the Netherlands, Los Baños, Philippines: 7-75.

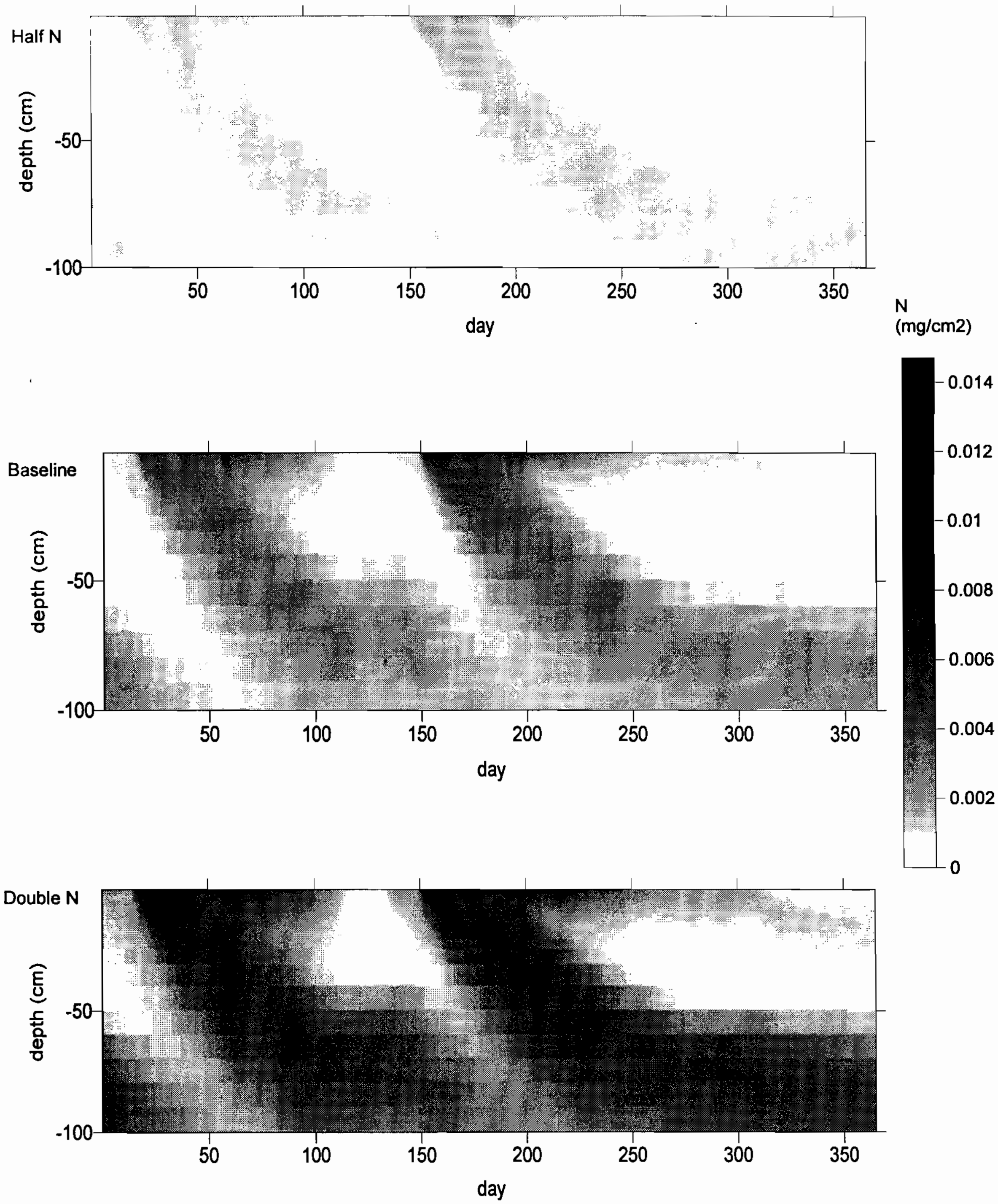
Wösten, J. H. M., Lilly, A., Nemes, A., Le Bas, C., 1998. Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning. Final report on the European Union Funded project. Report 156. DLO-Staring Centre. Wageningen, the Netherlands: 109 p.

Voogt, K. de. 2000. Modeling water allocation between a wetland an irrigated agriculture in the Gediz Basin, Turkey. Wageningen, The Netherlands. Agricultural University. Master of science thesis.

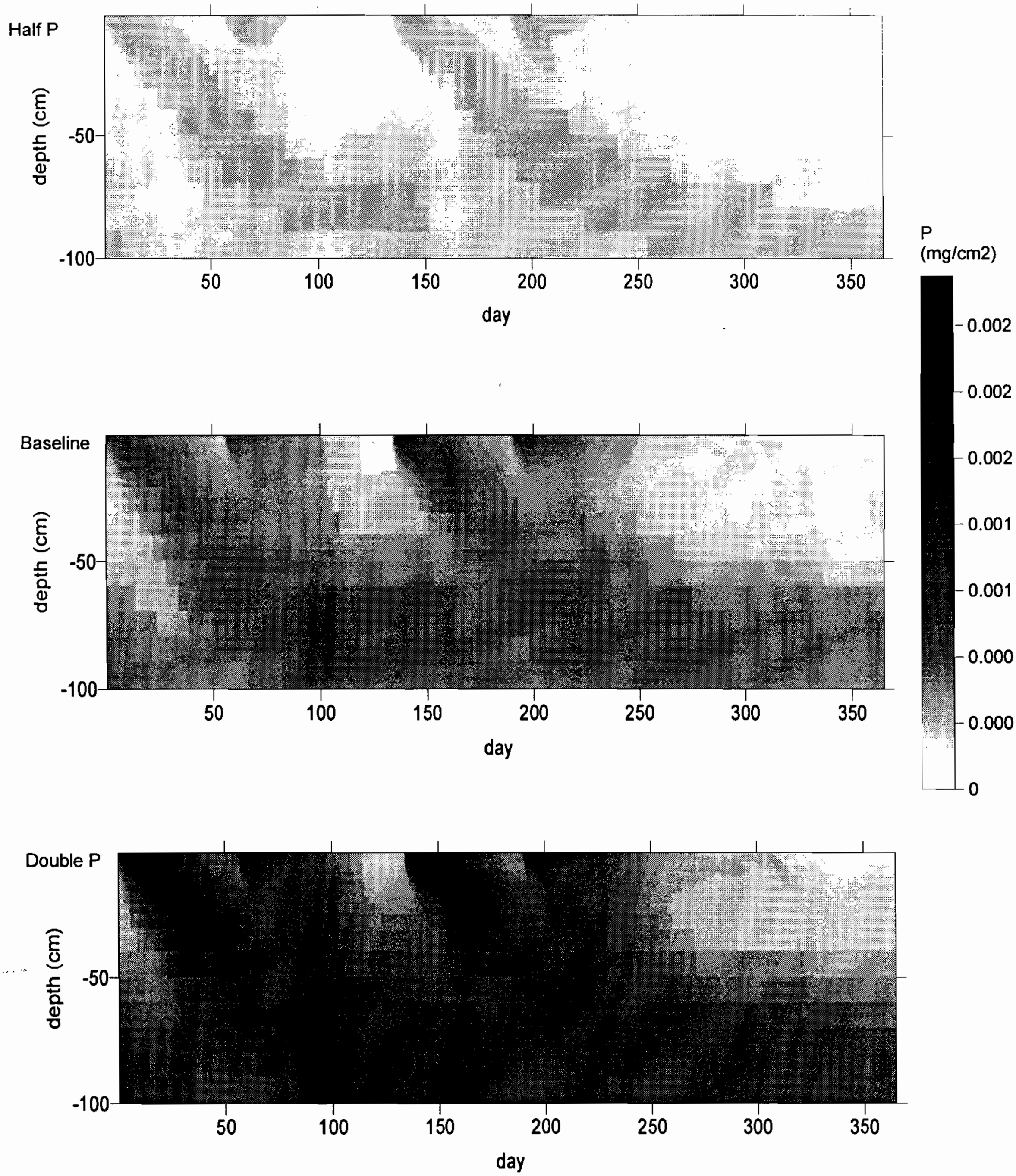
Wopereis, M. C. S., Bouman, B. A. M., Tuong, T. P., Berge, H. F. M., Kropff, M. J., 1996. Oryza_W: Rice growth model for irrigated and rainfed environments. DLO-Research Institute for Agrobiology and Soil Fertility, WAU department of Theoretical Production Ecology, IRRI. Wageningen, the Netherlands, Los Baños, Philippines: 7-75.

Wösten, J. H. M., Lilly, A., Nemes, A., Le Bas, C., 1998. Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning. Final report on the European Union Funded project. Report 156. DLO-Staring Centre. Wageningen, the Netherlands: 109 p.

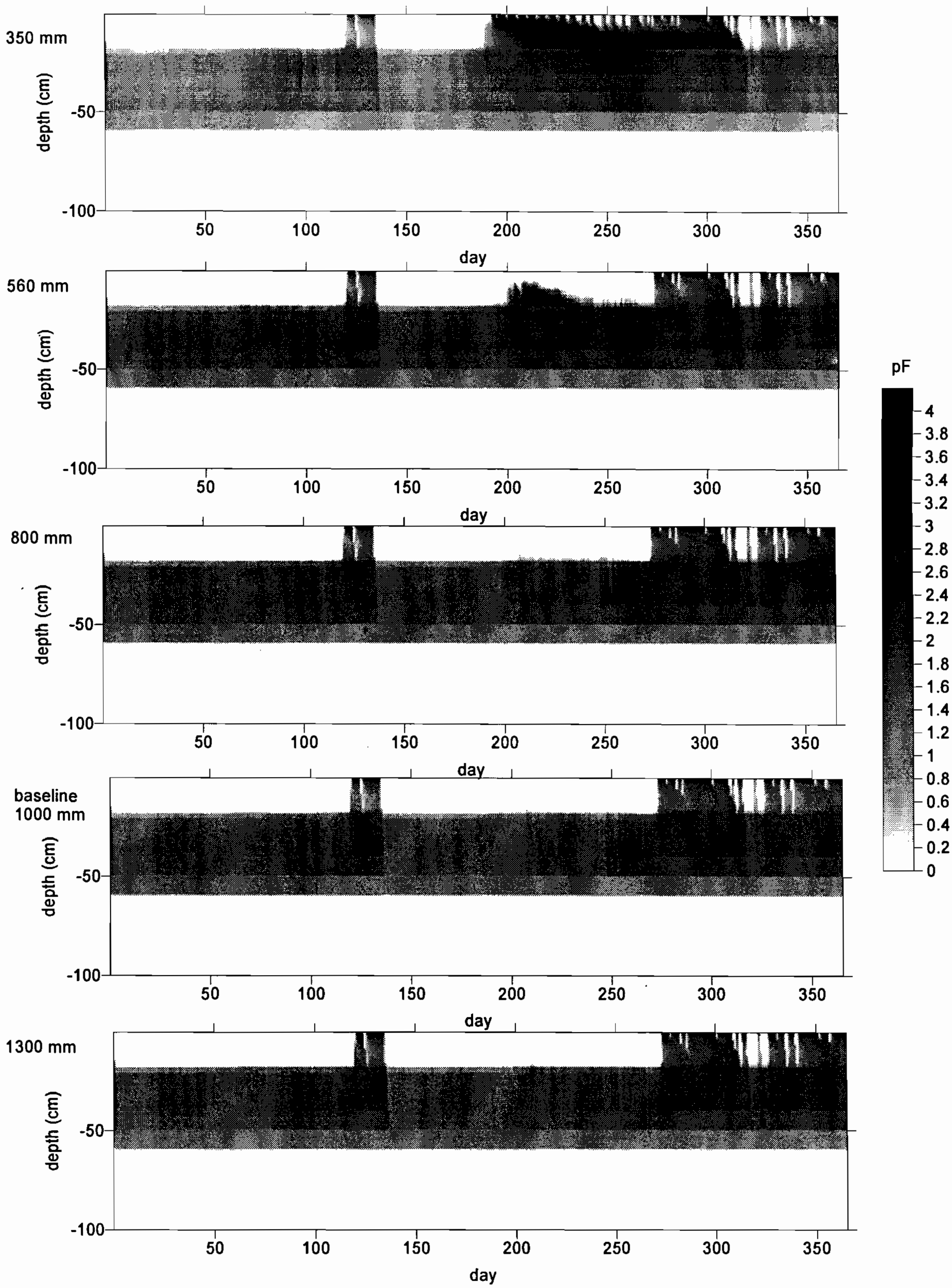
Annex I: Half and double N application



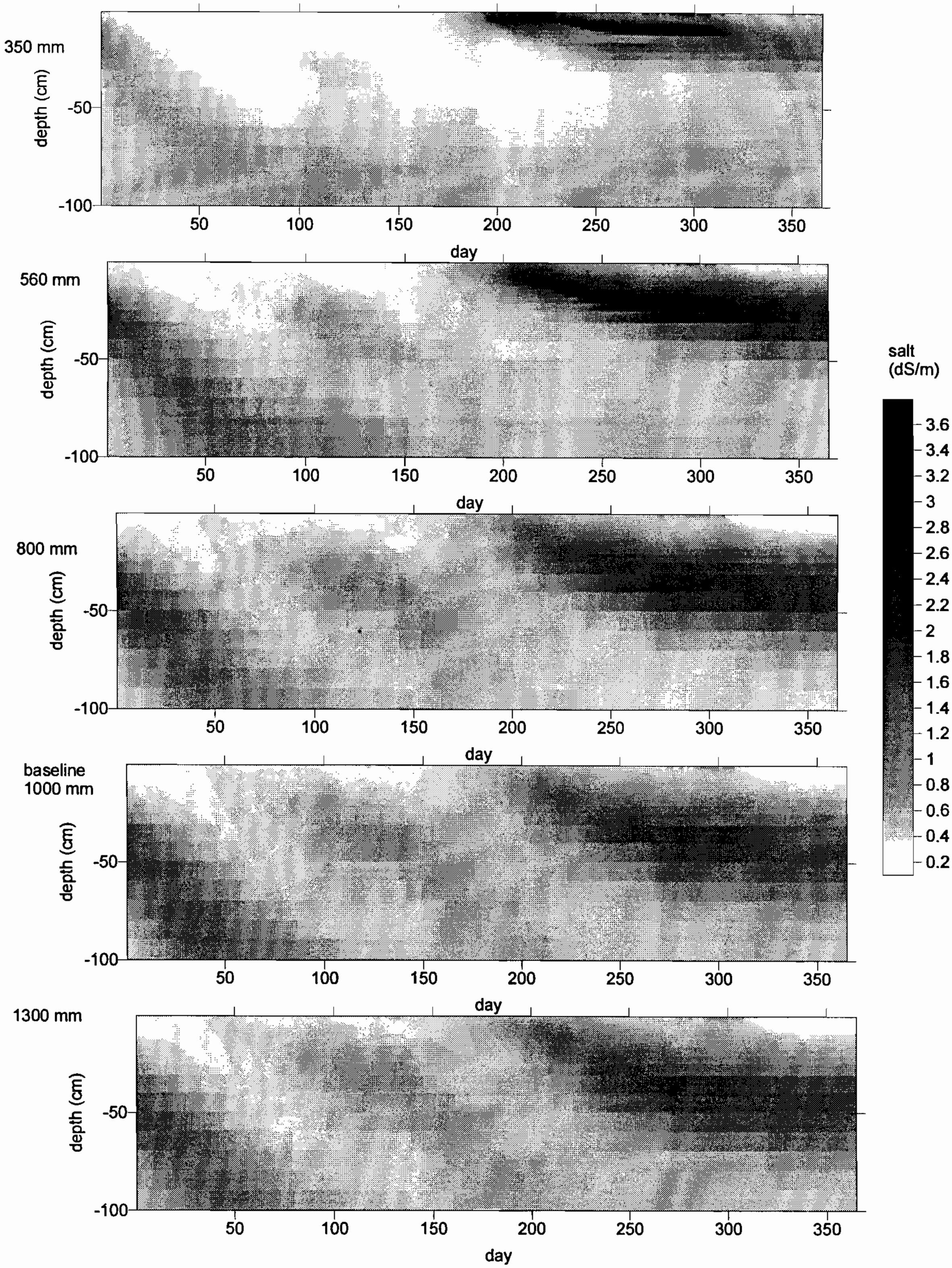
Annex II: Half and double P application



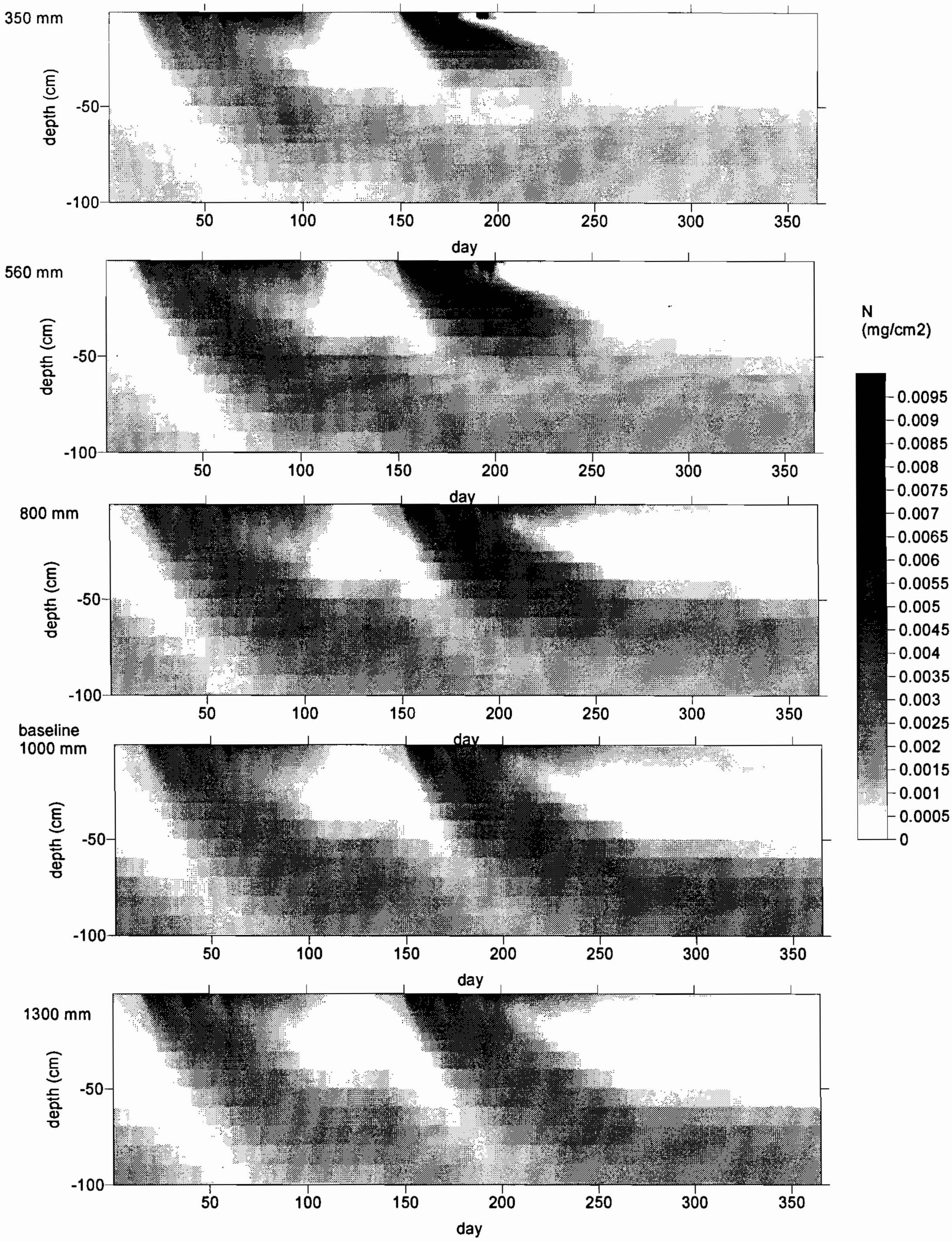
Annex III: pF values with more or less irrigation



Annex IV: Salt content with more or less irrigation



Annex V: N content with more or less irrigation



Annex VI: P content with more or less irrigation