Modeling
the water movement and water quality
of a mangrove-shrimp system
in Vietnam

REPORT

By: E.T.M. Klaassen
December 1999

TU Delft
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Preface

This is the final report of my graduation at Delft University of Technology, the Netherlands. This research is part of the MHO-8 project (a project between Wageningen Agricultural University, the Netherlands and Can Tho University, Vietnam) and contains the modeling of a shrimp farm in Thanh Phu, Ben Tre province, Vietnam. Delft University of Technology was asked to help making a computer model that describes and combines the water movement and water quality of the shrimp farm.

I like to take this opportunity to thank the people who helped me during my stay in Vietnam. Mr. Hùng staff member of Can Tho University who was my supervisor in Vietnam. Mr. Phân, staff member of Can Tho University who joined and helped during the first fieldtrip. Mr. Tuan, member of Can Tho University who helped me during all three fieldtrips and the drivers of the university who drove us to and from the research area. I want to thank the staff members, farmers and helpers, of the Statefarm in Thanh Phu who allowed me and helped me working at their farm.

I also want to thank Miss. Nga who was always available when I had questions about the water quality. Marc Zitzen whom I worked with during my stay in Vietnam, and who was responsible for the water quality measurements and the analysis of it and Mr. Tri who supervised the whole project and who was always available when there was a problem.

Also thanks go to Mr. Schiereck from Delft University of Technology who helped me during the second fieldtrip and with the start of the computer model in Vietnam and Mr. de Klein from Wageningen Agricultural University who helped me with modeling the water quality part.

Special thanks goes to Mr. Tam and Mr. Trung, staff members of Can Tho University, who helped me a lot preparing for the three fieldtrips, and to the people of campus one, my neighbors, who made the living in Can Tho very pleasant.

Thanks go to the members of the graduation board who helped me during my graduation

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E.T.M. Klaassen

Summary

Shrimp farming is an important source of income in Vietnam. In the Mekong Delta several shrimp farms are established, and is a good place for shrimp farming due to its stable weather and environmental conditions making it possible to farm throughout the whole year.
The farm where this research was done is an extensive culture system. In these systems, the water is exchanged using the tidal range. During low water, water is let out and with the incoming tide water is let in. No feeding or other improvements to increase the shrimp harvest are done. These systems are often combined with another agricultural production system like for instance rice or mangroves.
The extensive culture system used for this research is a so-called mangrove-shrimp system. Channels are used to farm shrimp and the land between the channels is used to grow mangroves.

A good harvest is important for the farmers to earn money, manage the pond, and stay independent. It is said that during the last decade the harvest of shrimp has decreased. A large number of factors can cause this decrease of the harvest:

- Decrease of the population in the sea.
- Decrease of the tidal volume exchanged by the system.
- Death during residence in the system. Whether this plays a role is not known. Possible causes of mortality are: asphyxiation, poisoning, e.g. by ammonia, hydrogen sulfide, plant toxins from the mangroves, pesticides, industrial and urban pollution upstream the river, consumption of shrimp by fish and other animals (large crabs and aquatic snakes were observed) in the system, viral infections and other diseases.

During previous research done by Agricultural University Wageningen in co-operation with Can Tho University low dissolved oxygen concentrations were found. It was assumed that these low concentrations could be the cause of the decreasing harvest, so this research concentrates on the water quality in the pond.

A computer model is made describing the water movement in combination with the water quality to understand the system and to find alternatives to improve the dissolved oxygen concentration. Measurements were done in Vietnam concerning the water movement (water levels, velocity and geometry) and water quality (suspended solids, sediment oxygen demand, biochemical oxygen demand, ammonium, hydrogen sulfide, temperature, pH, salinity, and the dissolved oxygen concentration). After analyzing these measurements the computer model was designed. During analyzing it was seen that the sediment consumed a lot of dissolved oxygen due to the decomposition of the high amount of organic material from the leaf litter from the mangroves. The providers of oxygen to the system were the process reaeration and the water coming from the sea containing a higher dissolved oxygen concentration of.

The model showed, due to the higher amount of leaf litter in the forest, that the dissolved oxygen concentration in the forest was lower compared to the channels. During inlet water from the forest, containing very low dissolved oxygen concentrations flowed into channels and decreased the dissolved oxygen concentrations in it. During inlet the dissolved oxygen concentrations increased rapidly. The sections situated further from the sluices were not good influenced, by the time the water reached these parts the dissolved oxygen concentration already decreased due to the high consumption of dissolved oxygen by the sediment.

Several different options were looked at to improve the dissolved oxygen concentrations. These options concerned increasing the influence oxygen providers (the reaeration process and the water coming from sea), and decreasing the influence of the oxygen consumers (the sediment).

From the different options is was seen that:

- Exchanging more water in combination with more side connections to have a better circulation, the dissolved oxygen concentration in the system improved. However, low dissolved oxygen concentrations were still found.
- The best option improving the dissolved oxygen concentration was separating the forest from the channels. This caused the leaf litter to decrease so the consumption of dissolved oxygen by the sediment decreased too causing the dissolved oxygen concentrations to be higher.
- Letting the water levels inside the pond to follow the tide like it does in a natural system longer periods of higher dissolved oxygen concentrations were seen. Due to exchanging more water the pond will clean itself causing the leaf litter to be less, increasing the dissolved oxygen concentrations.

The most important conclusions found after this research were that

- If the water level inside the pond follow the tide, the water level changed constantly causing a permanent flow in the system. Together with exchanging more water, more leaf litter will be transported out of the pond. Less leaf litter present decreases dissolved oxygen consumption resulting in higher dissolved oxygen concentrations.
- If the pond is managed using sluices, the combination of mangroves and shrimp decreases the amount of water daily exchanged and so decreases the self-cleaning of the system. The combination of the mangroves and shrimp in a system managed with sluices is not a good one.
- More research must be done concerning the functioning of the pond (nursery or shrimp trap), population dynamics and other factors for the decreasing harvest that like predators and diseases.

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De appendixes of this report are collected in a separate report.

List of symbols

Symbol	Description	Dimension
ρ	density of the water	kg/m^3
μ	discharge coefficient	-
$\mu_{cal.}$	calibrated discharge coefficient	-
Δh	height difference between the in- and outside water levels	m
μ_{input}	initial value of the discharge coefficient in Duflow	-
Φ_k	phase of k^{th} component	°
η_{ott}	number of revolutions per second	rev./s
$\rho_{water, correction}$	correction factor because of density differences	-
ω	circular frequency	s^{-1}
$A_{sl.}$	cross-section sluice	m^2
BOD^5_{20}	biochemical oxygen demand after 5 days and at 20°C	g/m^3
DO	dissolved oxygen concentration	g/m^3
$DO_{average}$	average dissolved oxygen concentration	g/m^3
DO_{bottom}	dissolved oxygen concentration at the bottom	g/m^3
$DO_{reaeration}$	dissolved oxygen provided by reaeration	g/m^3
DO_{sat}	dissolved oxygen saturation concentration	g/m^3
DO_{SOD}	dissolved oxygen consumed by sediment	g/m^3
$DO_{surface}$	dissolved oxygen concentration at the surface	g/m^3
f	character of the tide	-
f_{SOD}	Monod-factor for SOD	-
g	acceleration of gravity	m/s^2
g-K1	phase of the K1 component of the tide	°
g-M2	phase of the M2 component of the tide	°
g-O1	phase of the O1 component of the tide	°
g-S2	phase of the S2 component of the tide	°
H-K1	amplitude of the K1 component of the tide	m
H-M2	amplitude of the M2 component of the tide	m
H-O1	amplitude of the O1 component of the tide	m
H-S2	amplitude of the S2 component of the tide	m
k	component number	-
Kl_{20}	reaeration coefficient at 20°C	m/day
Kl_{min}	minimum reaeration coefficient at 20°C	m/day
K_{re}	reaeration coefficient	1/day
K_{SOD}	constant value of DO-concentration when $f_{SOD} = 0.5$	g/m^3
N	number of components	-
P_{air}	air-pressure	mbar
P_{Diver}	total pressure measured by the Diver	cm water column
$P_{Diver,corrr}$	total pressure by Diver after correction	cm water column
pH	acidic or alkaline character of water	-
PL_{15}/m^2	density of post larvae, 15 days old	$number/m^2$
PL_{45}/m^2	density of post larvae, 45 days old	$number/m^2$
$P_{total.1}$	total pressure (air and water)	m water column
$P_{total.2}$	total pressure (water and air)	$kg/(m \cdot s^2)$
$P_{water.1}$	water pressure	mbar

$P_{water.2}$	water depth	cm water column
Q	discharge	m^3/s
Q_{weir}	discharge of the weir	m^3/s
S	salinity	‰
Sal.	salinity	‰
SOD	influence sediment oxygen demand	$g/m^3 \cdot day$
$SOD_{T.P.}$	sediment oxygen demand measured in Thanh Phu	$g/m^2 \cdot day$
SS	suspended solids	g/m^3
T	temperature	°C
t	time	s
temp.	temperature	°C
T_{re}	temperature coefficient reaeration	-
T_{SOD}	temperature coefficient SOD	-
u	velocity	m/s
v_{Duflow}	velocity in Duflow	m/s
$v_{meas.}$	measured velocity with the Ott-meter	m/s
v_{weir}	velocity over the weir	m/s
y_0	mean value water level	m
y_k	amplitude k^{th} component	m
y_t	water level at time t	m
z	water depth	m
Z_0	average level with regard to the nautical chart datum	m

1. Introduction

This project took place in Vietnam. First a short impression of Vietnam and the Mekong delta, where the research was done, will be given here. Followed by an introduction about different shrimp cultures in Vietnam.

1.1 Vietnam

The Socialist Republic of Vietnam was founded in 1975 after the reunion between the north and the south. The capital of Vietnam is Hanoi situated in the north of the country. Vietnam has a land area of approximately 329.566 square kilometers, somewhat larger than Italy and a bit smaller than Japan. It has a coastline of 3.451 km and landborders of 1.550 km with Laos, 1.281 km with China and 982 km with Cambodia. Figure 1 shows a map of Vietnam.

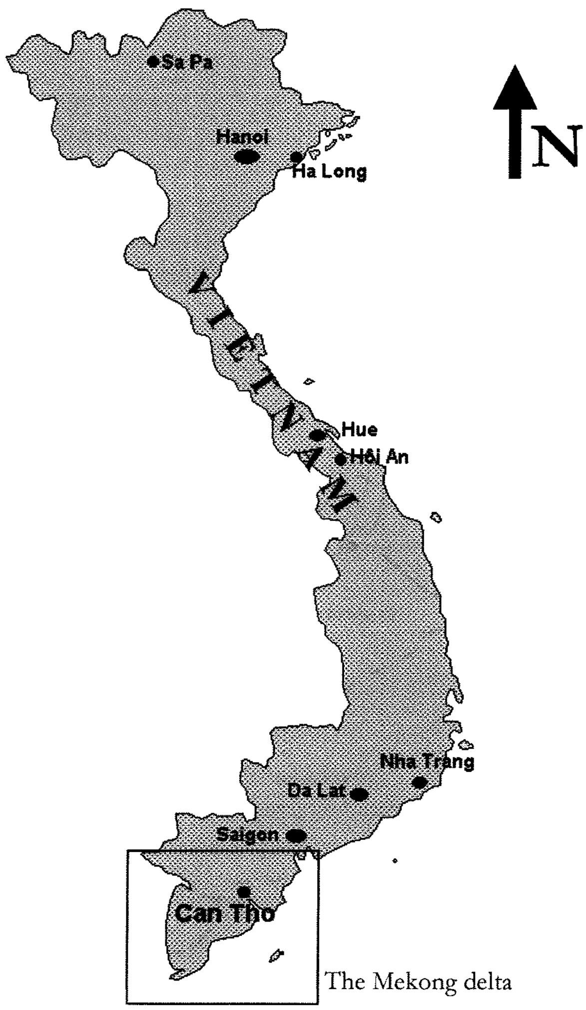

Figure 1: Vietnam

Vietnam has a remarkably diverse climate. The south has a tropical monsoon climate with two seasons, wet and dry. The dry season lasts from November to May with an average annual temperature in Ho Chi Minh city (formerly known as Saigon) of 27 °C. The north of Vietnam is characterized by two seasons, the winter (from November to April) and summer. During the hot summer months the north of Vietnam is occasional subject to devastating typhoons.

In 1996 the population in Vietnam reached 75 million, of which 84% is ethnic-Vietnamese, 2% ethnic-Chinese, and the rest Kmer, Chams and members of some 60 ethno-linguistic groups. Vietnam has an overall population density of 225 persons per sq. km, one of the worlds highest for an agricultural country. About 21% of the area are used for agricultural purposes and 70% of the population is farmer. Most of the agriculture land is located in the two major deltas: the Red River delta in the north and the Mekong delta in the south.

1.2 The Mekong delta

The Mekong delta, figure 2 is the south-most region of Vietnam (see figure 1). This part of the country is flat and green. The delta is known as the "breadbasket" of Vietnam, but a better name for it should be rice-basket. The rice-plants contribute enough rice to feed the whole country with a sizable surplus left over. Vietnam became the world's third largest rice exporter. Besides rice, shrimp farming is an important source of income.
The delta was formed by sediment deposited by the Mekong River and is still continuing today. The total area of the delta is 5.5 million ha; of which 1.6 million ha are situated in Cambodia and 3.9 million ha in Vietnam.
The Mekong River is one of the largest rivers in Asia; ranking twelfth on the list of the longest rivers of the world, and six in terms of mean annual discharge. The Mekong River originates high in the Tibetan plateau flowing after 4.500 km into the South China Sea. In Cambodia at Phnom Penh the river splits into two branches: the Hau Giang (the lower river, also named the Bassac River) and the Tien Giang (the upper river). The upper river splits in several branches at Vinh Long. The numerous branches explain the Vietnamese name for the Mekong, Song Cuu Long, river of nine dragons. The discharge of the Mekong River ranges from 1.900 m^3/s to 38.000 m^3/s. The water level starts to rise around the end of May and reaches its highest level around September.

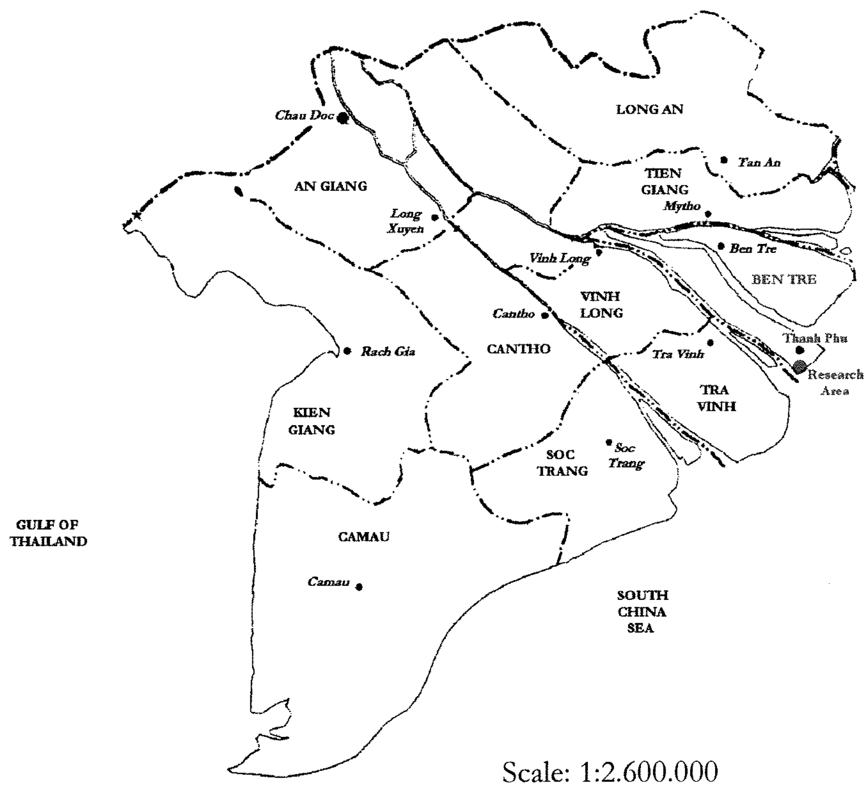

Figure 2: The Mekong delta

1.3 Shrimp farming in Vietnam

Shrimp farming is one of the traditional farming systems in Vietnam. The country can be divided into three zones. The north where originally shrimp farming was concentrated, the middle of the country and the Mekong delta. The Mekong delta, because of the most stable weather and environmental conditions, like temperature and salinity, is the best place for shrimp farming. These stable weather and environmental conditions make farming possible throughout the entire year. The other two zones, the north and the middle, have more varying conditions making these areas to be less suitable for shrimp farming.
A short description of various methods of shrimp farming that exist in Vietnam will be given here.

1.3.1 Intensive culture system

These systems are stocked with post larvae (PL) with a density of 20 - 60 PL_{45}/m^2 (PL_{45} are the number of 45 days old post larvae). The post larvae are bought from a hatchery in Nha Trang. The potential productivity of these intensive systems is about 3000 kg/ha/crop cycle. One crop cycle is four months (*Bui Thi Nga, 1998*). The shrimp are fed with high quality food and before stocking, the water is fertilized and lime is added to improve the algae bloom. Because of feeding and fertilizing the pond must be cleaned after every harvest to avoid the presence of toxic substances. The outlet and inlet of water will be completely regulated with pumps. The extra costs of these pumps are negligible compared to the yield. To have a controllable system it can not be too large, but for economic reasons these ponds should not be smaller than 0,1 ha. Most ponds are about 2 ha.

1.3.2 Semi-intensive culture system

The systems are stocked with post larvae (PL) with a density of 7 - 10 PL_{15}/m^2 (PL_{15} are the number of 15 days old post larvae) or 5 - 7 PL_{45}/m^2 (PL_{45} are the number of 45 days old post larvae). The post larvae are bought from a hatchery in Nha Trang. Water intake is done with incoming tide and water outlet is done with pumps. The shrimp are fed twice a day and before stocking the water is fertilized, and lime is added to improve the algae bloom. Due to the feeding and fertilizing these ponds must be cleaned after every harvest. This to avoid the presence of toxic substances in the system. The potential production of this system is 500 kg/ha/crop cycle. Like the intensive culture system this system also has to be controlled so the pond can not be too large. Most of these ponds have an area of 2 ha.

1.3.3 Extensive culture system

The shrimp enter the system with incoming tide and are harvested from the outgoing stream. This kind of systems can only be operated along the coast and in the tidal region of rivers. No pumps are used, only sluices to control the exchange of water. The shrimp are not fed, water is not fertilized, and no lime and larvae are added. Because no extra products are added, cleaning is less important than in the more intensive systems. The potential production of such systems is 70 - 250 kg/ha/crop cycle. Because less control is needed, only opening and closing of the sluices, the ponds can be made larger than (semi-) intensive culture ponds. These systems can be larger than 6 ha. When shrimp enter the pond with the incoming tide and leave the pond during the next outlet, the pond is not working as a nursery but as a shrimp trap.
These systems can be improved, some farmers are already doing it, by feeding and adding larvae to the system to improve the harvest. This method is called the improved extensive culture system.

2. The Thanh Phu shrimp farm

This chapter contains a description of the research area in Vietnam, and describes the variables that influence the shrimp and their interactions.

2.1 Thanh Phu, plot 3.1

Thanh Phu is situated in the Ben Tre province on the East Coast of Vietnam. The position of the Ben Tre province, Thanh Phu and the research area are shown in red in figure 2. From Thanh Phu the pond is reached using a boat. The pond, plot 3.1, is situated far away from any industry and other possible sources of pollution, and is managed by a few farmers who live near the pond. This place was chosen because Wageningen Agricultural University in co-operation with Can Tho University already did research here (MHO-8 project). Results of these preceding studies can be used in this project. It must be kept in mind that the system has changed since these earlier studies. Dams (see picture 1, appendix A.1) now divide the plot into two sub-plots and more sluices, to exchange water, are used.

Plot 3.1 is a so-called mangrove-shrimp system. Channels are used for farming shrimp and the land between these channels is used for wood-production (mangroves).

The method of farming this pond is like the extensive culture system (paragraph 1.3.3). The water in the channels is brackish or salt, depending on the amount of rainfall and the exchange of water with the sea. Dams divide plot 3.1 into two sub-plots, 3.1.A and 3.1.B. In each sub-plot two sluices are used to exchange water. In sub-plot 3.1.B, the channels outside the pond at the two sluices are connected with the sea. In the other sub-plot the outside channels at the sluices are connected with a river that flows into the sea. The pond is shown in figure 3.

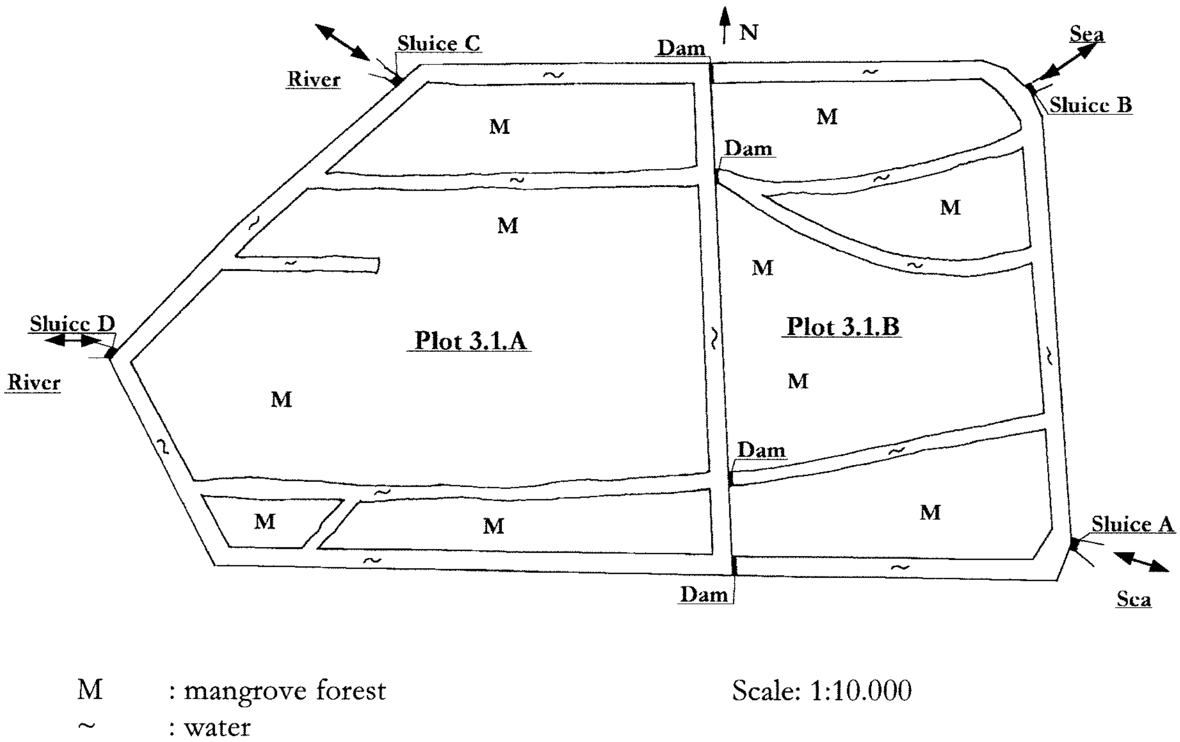

Figure 3: The Thanh Phu shrimp farm, plot 3.1

The outside channels were, directly or indirectly, connected with the sea so the water levels in these channels follow the tide at sea. The tidal range in these channels was used to exchange water.

Tidal information was gathered from the British Admiralty, who publishes lists of tidal constants along the coasts all over the world. Along the coast of the Mekong delta, the tidal constants of only two places were available. These places were Mui Vung Tau, at the mouth of the Saigon River, and near Con Dao Island, about 90 kilometers of the coast of Vietnam. The harmonic constants are shown in table 1.

Table 1: Harmonic constants of the tide

Location	**Z_0 [m]**	**g-M2 [°]**	**H-M2 [m]**	**g-S2 [°]**	**H-S2 [m]**	**g-K1 [°]**	**H-K1 [m]**	**g-O1 [°]**	**H-O1 [m]**
Mui Vung Tau	2.41	036	0.79	081	0.31	312	0.60	263	0.45
Con Dao	2.28	052	0.80	112	0.28	318	0.64	274	0.45

Z_0 is the average level with regard to the nautical chart datum. H and g stands for the respectively the amplitude [m] and phase [°]. With the amplitudes of the tidal constants shown in table 1, the character of the tide can be determined. This was done using formula 2.1.

$$f = \frac{H\text{-}K1 + H - O1}{H\text{-}M2 + H - S2} \qquad \text{(Formula 2.1)}$$

When:
$f < 0.25$: the tide is semi-diurnal (twice high and low water)
$f > 3$: the tide is diurnal (once a day high and low water)
$0.25 < f < 1.5$: the tide is a mixed tide mainly semi-diurnal
$1.5 < f < 3$: the tide is a mixed tide mainly diurnal

The calculated f-values of Mui Vung Tau and Con Dao were respectively 0.95 and 1.01. Both indicate a mixed tide mainly semi-diurnal. Thanh Phu is situated between these to measuring stations so the assumption was made that the tide in Thanh Phu would be the same; a mixed tide, mainly semi-diurnal. Two high and two low waters were observed every day.
Low tide was used to let water out of the pond, and to harvest the shrimp by putting nets in the sluices. The shrimp that want to spawn in the sea are caught in these nets. The incoming tide is used for the inlet of water. Together with the inlet of water shrimp enter the pond, the more water is let in the more shrimp will enter the pond.

The periods of water exchange depend of the day in the lunar month. A lunar month is a month of the lunar calendar and contains 29 or 30 days. The first day of the lunar month coincides with New Moon, which is the phase of the moon-cycle when the moon is positioned between the earth and the sun. Looking from earth the moon is not visible, the sun only lightens the back of the moon.
Two periods of each lunar month are used to exchange water, from 13 lunar month until 20 lunar month (during Full Moon) and 27 lunar month until the third of the next lunar month (during New Moon). During these periods, the farmers open the sluices by hand at different times. Their decisions to open the sluices are based on their experience, mostly when the difference in height between the in- and outside water levels reaches its maximum. The gates are closed when the velocity of the water through the sluices is low meaning that the water levels in- and outside are almost the same.

A dredge is used to clean the pond. This is done every five years and was last done in August 1998.

Figure 4 shows schematically the most important variables that enter the channels of the pond.

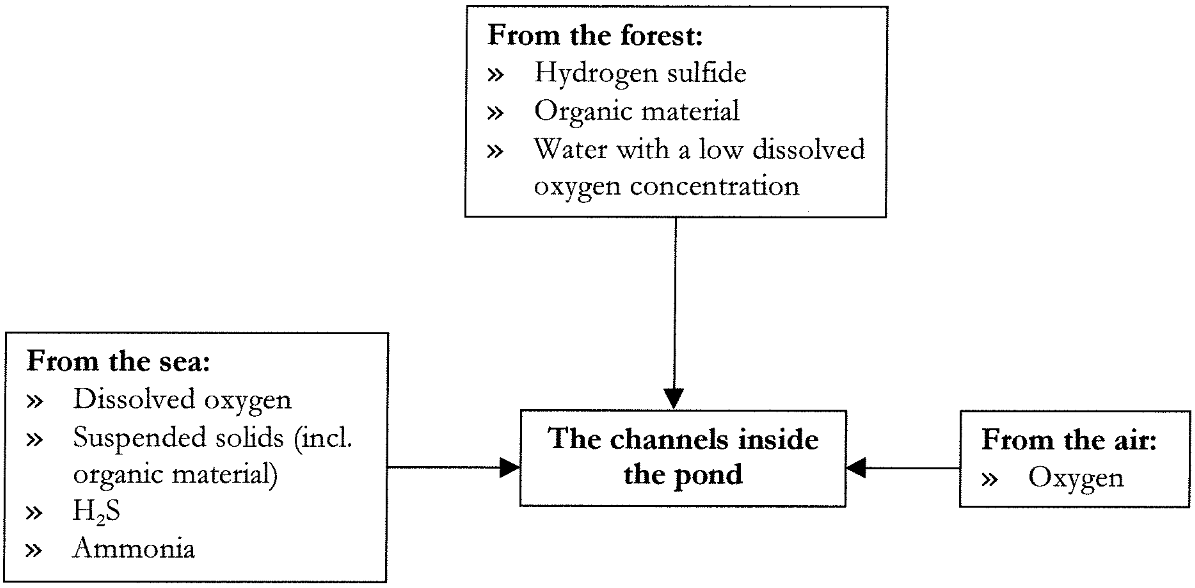

Figure 4: Variables entering the inside channels

The variable temperature, pH and salinity were not shown in figure 4 but were present in the whole system.
A more detailed description of the several variables named here and their influence on shrimp will be discussed in following paragraph.

2.2 General factors influencing the shrimp

Shrimp are influenced by several variables (variables change in time). To have a proper understanding about the system, it is important to know what variables influence the shrimp. This paragraph will discuss these variables and their interactions. First the variables and the interactions are shown schematically, figure 5. The variables that influence the shrimp often also influence each other. Showing all these interactions between the variables will lead to an unclear schema. To avoid this only the most important variables and their interactions are shown, see figure 5.

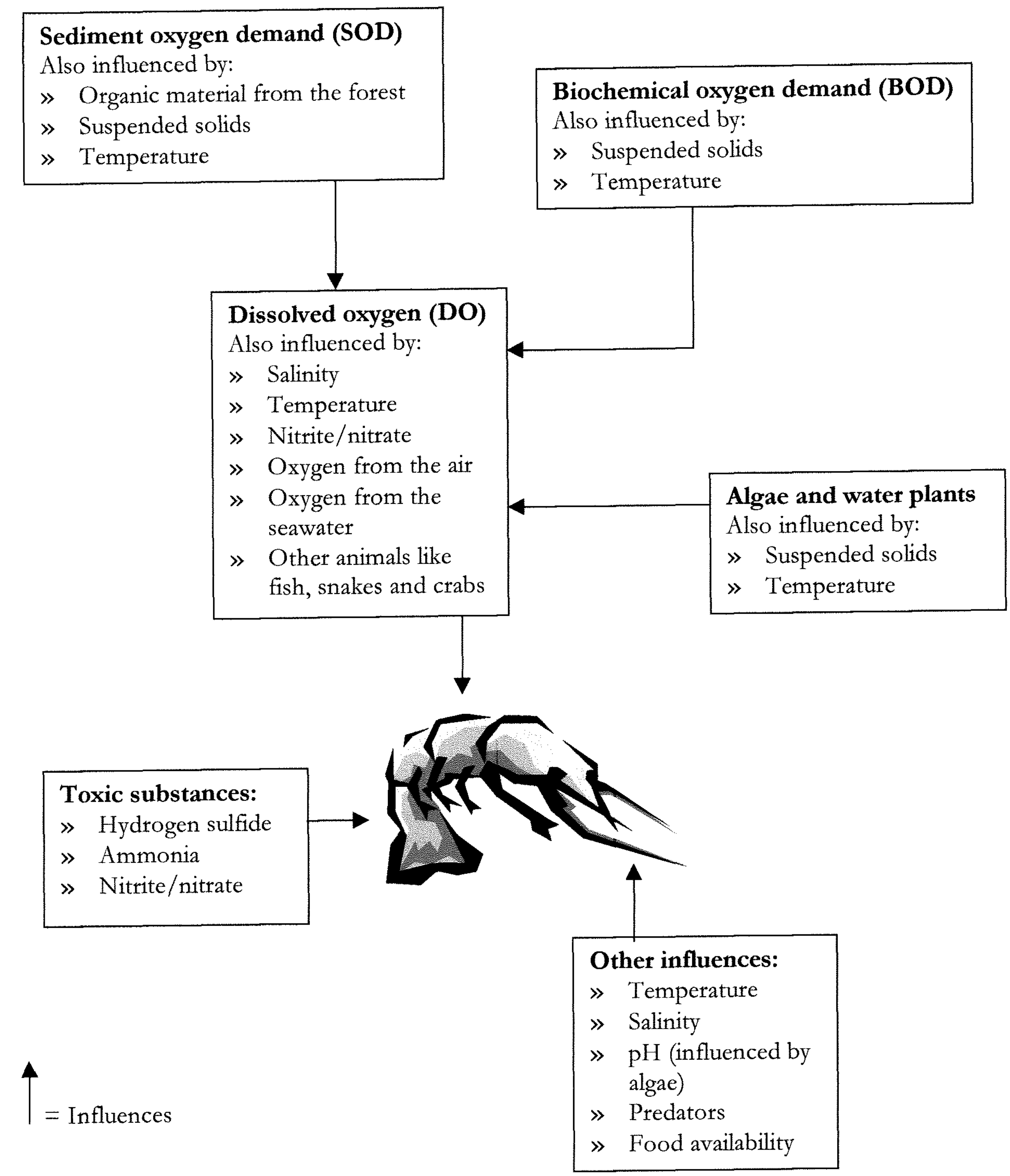

Figure 5: Variables that influence shrimp

A description of the variables shown in figure 5 is given here.

- **Temperature**

The rate of oxygen consumption by shrimp increases with the temperature of the water, during warm periods more dissolved oxygen (DO) is required compared to colder periods. However, the DO-solubility decreases with increasing temperature.
Besides influencing the oxygen requirements, the temperature effects also several water quality processes that take place in the water.

Sudden changes of temperature (as little as 5°C) can cause stress to the shrimp and will eventually lead to death.

- **Dissolved oxygen (DO)**

Together with temperature, DO is the most important factor in the system. DO is probably the first limiting factor in a pond aqua-culture. The temperature (see temperature) influences the DO-concentration, but DO is also influenced by other variables (see figure 5). These variables are discussed here.

- *Air*: The air is one of the providers of oxygen. Oxygen from the air enters the water through absorption at the surface. This process is called reaeration and is influenced by the flow velocity of the water. With higher flow velocities and more turbulence, more oxygen is absorbed.
- *Algae and water plants*: Photosynthesis, done by water plants and algae provide the system of oxygen. Photosynthesis together with reaeration must produce as much as oxygen as consumed by shrimp, other life forms, and reactions in the system. Photosynthesis depends on the intensity of the light, the more light the more oxygen is produced. The DO-concentration is the lowest before sunrise when the photosynthesis is not active (absence of light) and has its highest level in the late afternoon.
  The algae growth is influenced by *light* and *temperature*. The higher the temperature and a better light intrusion, the more growth of algae there is. The higher density of algae (more photosynthesis) the more DO is produced. The *SS* that are present in the water decrease the light intrusion and so negatively influence the DO production.
- *BOD*: BOD, an oxygen consuming process, is a measurement of the oxygen required by microbes to reduce waste into simple compounds. The *SS*-particles in the water contain also an amount of organic material and will increase the BOD value.
- *SOD*: SOD, an oxygen consuming process, represents the amount of oxygen that is used for the breakdown of the organic compounds present in the sediment that is lying on the pond bottom. The SOD is influenced by the amount of organic material on the pond bottom caused by *organic material coming from the forest* (leaf litter) and from the *SS*-particles that settle on the pond bottom. Oxygen is used to decompose the organic material. The more organic material available the higher the SOD-value is.
- *Salinity*: Salinity, together with the temperature, influences the DO-saturation in water. A higher salinity causes lower DO-saturation.
- *Nitrite/nitrate*: this process is called nitrification and is oxygen consuming. This process will be discussed below; nitrogenous compounds.

- **Nitrogenous compounds**

These compounds are often the second limiting factor in a pond. Different nitrogenous compounds are present in a system, but not every compound is dangerous. Because the chemistry of nitrogen is very complex, only a few factors are discussed here.

Ammonia: Two types of ammonia exist namely ionized ammonia (NH_4^+) and unionized ammonia (NH_3). Ammonia is formed by an aerobic decomposition of organic material. The equilibrium-state of ammonia is (equation 2.1):

$$NH_3 + H_2O \Leftrightarrow NH_4^+ + OH^- \qquad \text{(Equation 2.1)}$$

NH_4^+ is not toxic. When the *pH* increases the equilibrium shifts to the left and more NH_3 will be in the system. NH_3 is a very toxic compound even in small quantities. Beside pH, temperature and salinity also influence ammonia.

Nitrite/nitrate: unionized ammonia will change into nitrite according the following equilibrium (equation 2.2). This process is called nitrification (an oxygen consuming process):

$$2NH_3 + 3O_2 \Leftrightarrow 2NO_2^- + 2H^+ + 2H_2O \qquad \text{(Equation 2.2)}$$

When enough dissolved oxygen present in the system NO_2^- will be transformed into nitrate like:

$$2NO_2^- + O_2 \Leftrightarrow 2NO_3^- \qquad \text{(Equation 2.3)}$$

NO_3^- is not very toxic. Shrimp can withstand high concentrations of NO_3^-. On the other hand, NO_2^- is very toxic. When not enough dissolved oxygen available in the system equation 2.3 will not take place and NO_2^- will stay in the system, causing death of the shrimp.

- **Toxic substances**

Seawater that enters the pond can be polluted with toxic substances. Here only natural toxic substances are discussed. Two of the most problematic toxic substances are ammonia (NH_3) and hydrogen sulfide (H_2S). The toxic ammonia was already discussed in the part about nitrogenous compounds.

Hydrogen sulfide: H_2S formed in anaerobic zones is released from bacterial processes in the sediment. In Thanh Phu, this zone can be the forest. Because of the decomposing process of leaf litter, the DO-concentration decreases, making the area anaerobic (this mainly happens when there is no refreshing of the water), leading to the production of H_2S by bacteria. A high pH ionizes the H_2S in a less toxic form.

- **Other influences**

These other influences effect the different processes, as discussed earlier in this paragraph but also influences the shrimp directly.

pH: The pH of the water expresses the intensity of its acidic or alkaline character. The optimum level of pH is between 7.5 and 8.5. Rapid changes of the pH can be lethal to shrimp. pH strongly influences the toxicity of ammonia (see nitrogenous compounds) and hydrogen sulfide (see toxic substances). pH can change due to for instance acid rain, pollution, and metabolic activity of algae and other organisms.

Salinity: All living species have an optimal salinity range. The salinity for the shrimp is optimal between 10 ‰ and 30 ‰. As the salinity deviates too far from these values, the shrimp will die. Quick changes in the salinity cause stress and eventually lead to death of the shrimp. Fresh water, for instance rain decreases the salinity.
Salinity changes also influence the dissolved oxygen saturation. A higher salinity concentration decreases the dissolved oxygen saturation.

Predators: Predators like fish, snakes and crabs can eat the shrimp and so cause a decrease of the harvest.

Food availability: When not enough food is available in the system, the shrimp will die.

Besides the above mentioned biological and chemical influences, other factors can also be limiting, like site-selection, pond design, and pond management. Because the pond already exists, site-selection and pond design will not be discussed.

Pond management of an extensive shrimp culture concerns mainly managing the sluices. The exchange of water can strongly influences the shrimp, changing more than 20% of the inside water volume on one occasion can result in too rapid changes in the system. Rapid changes of the water quality variables lead to stress, mortality and increase of susceptibility to diseases.

3. Problem analysis

Before a study can be done, the problem must first be analyzed. In this chapter a description of the problem is given. Knowing the problem the objective of this project can be formed.

3.1 Problem description

In the south of Vietnam, the Mekong delta several shrimp farms are established. These farms originally owned by the state are becoming increasingly private property of the farmers. Therefore, a good harvest is important for the farmers to earn money, to manage the farm and to stay independent. However, during the last few years the harvest of the shrimp is decreasing.

3.2 Objective

The harvest is or can be affected by a large number of factors like:
- Decrease of the population in the sea so fewer shrimp enter the system.
- Decrease of the tidal volume exchanged by the system (the more water is let in the more shrimp will enter).
- Death during residence in the system. Whether this plays a role is not known. Possible causes of mortality are: asphyxiation, poisoning, e.g. by ammonia, hydrogen sulfide, plant toxins from the mangrove trees, pesticides, industrial and urban pollution upstream the outside channels, shrimp eaten by fish and other animals (large crabs and aquatic snakes were observed) in the system, viral infections and other diseases.

During previous research, (*Roozen and Rosenboom, 1997*) low dissolved oxygen concentrations were measured. From Wageningen Agricultural University, it was assumed that these low dissolved oxygen concentrations could be the cause of the problems, so the assignment to do this research about the water quality in the pond was made. The objective can be divided into two parts a primary objective and a secondary one.

Primary objective:
To obtain a good understanding how the system works, what parameters are important and how do they interact. Understanding how the system works and how the dissolved oxygen concentration is influenced. With that knowledge about how the system works, other systems that have the same problems can be improved too.

Secondary objective:
With the knowledge how the system works several alternatives to improve the dissolved oxygen concentrations can be found.

4. Problem approach

This chapter will give a description of the steps to be taken to obtain the objective.

Understanding the interactions the water quality processes have and how they can be influenced, a computer model was made describing the water movement in the real system and the most important water quality processes in the water. Using this computer model different alternatives for pond management are designed to improve the quality of the water.

Before having a complete model, several steps, after the problem analysis, were taken.
First, the different variables that influence the shrimp are analyzed. What variables will be of influence? These were discussed in paragraph 2.2. Knowing the most important variables the data needed for the model was collected.
The data was collected during three fieldtrips at the shrimp farm in Thanh Phu, Vietnam. The first fieldtrip was used to collect data concerning the geometry of the farm. The data, concerning the water movement and water quality found during the second and third fieldtrip was used to calibrate the computer model. A description of the fieldtrips and the used equipment is given in chapter 5 and appendix A.2 and A.3.
After analyzing the collected data (chapter 6), a start was made modeling the pond. The computer program Duflow was used to model the shrimp farm. A description of Duflow is given in appendix B.
First, the water movement will be modeled (chapter 7). After calibrating the water movement, the water quality is modeled. Modeling and calibration of the water quality part is done simultaneously. Finishing a part of the water quality program, calibrating it and when necessary extending the water quality program with different variables. The steps to be taken to obtain the water quality model are discussed in chapter 8.

After the complete model is calibrated, a start is made understanding the system. What are the influences of the different variables and their interactions? How can these variables be positively influenced? Looking at different options, by changing the model the influence of the changes on the water quality can be seen. The different options to improve and their results are shown in chapter 9. Knowing the effect of the alternatives, a recommendation for improving the water quality of the pond can be given (chapter 10).

The method of working is schematically shown in figure 6 (*Wiggers et al, 1998*, in adapted form). This figure shows that it is a cycle process and not a linear one.

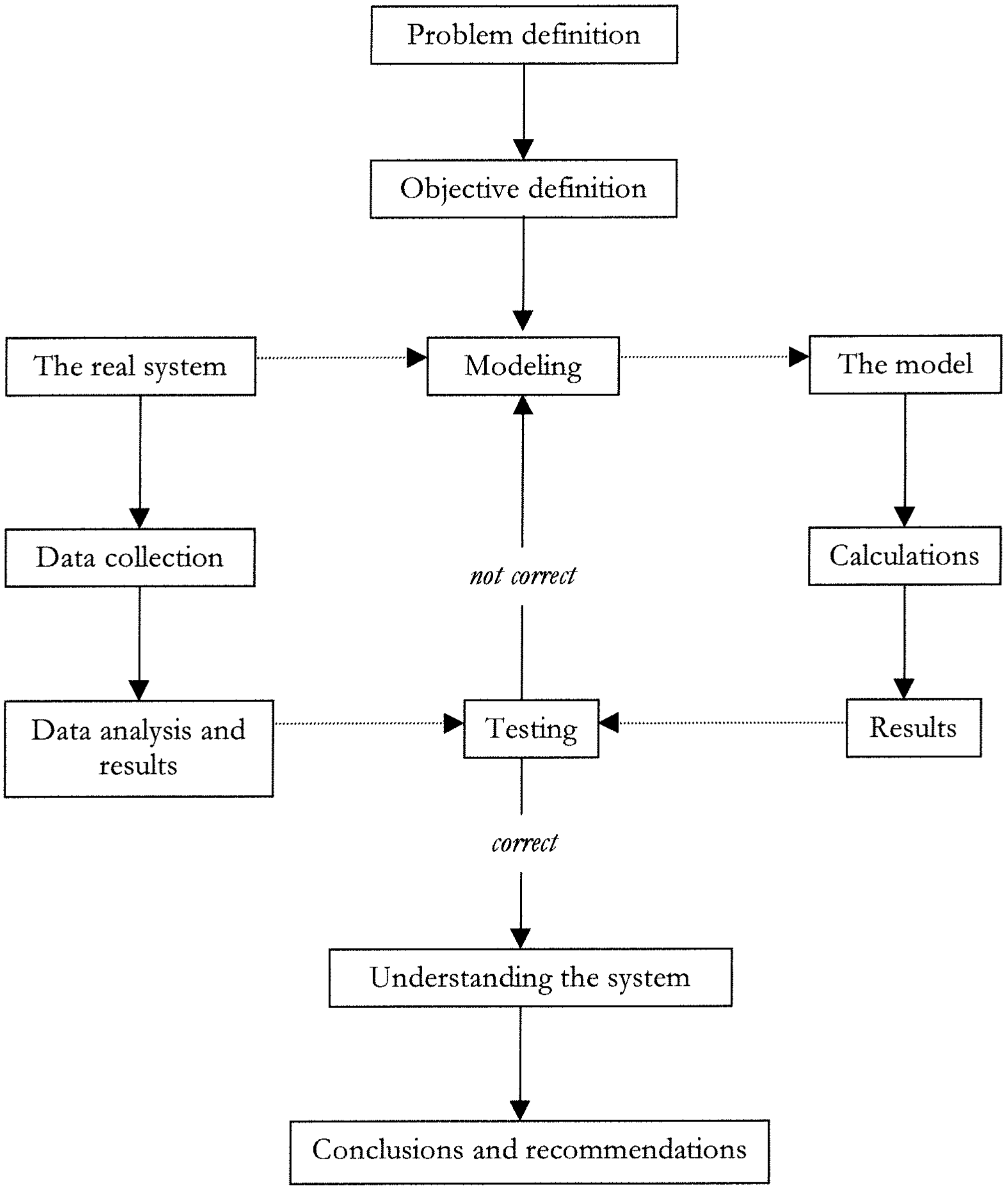

Figure 6: Problem approach (*Wiggers et al. 1998*, in adapted form)

The dotted arrows represent the connections between the real system and the model.

- The real system will be described using a model. This model describes the most important characteristics of the real system.
- The results of the model are compared with the results of the measured and analyzed data.

The other arrows show the following of actions in order to obtain the objective.

5. The fieldwork

This chapter gives a description of the fieldwork and the collected data. First, some remarks are made about the amount of collected data followed by discussing the water movement and the water quality measurements.

5.1 Difficulties in collecting data

Difficulties in logistics were the reason for the limited amount of the collected data. From the base-camp (6-7 hours driving from Can Tho University) it was about 20 minutes by motorboat, followed by a walk of about 2 kilometers before reaching the pond. Everything had to be carried, so a limited amount of equipment could be brought to the pond. Besides the limited amount of equipment to be taken to the pond, the limited amount of sample bottles that were available was also a problem. The laboratory did not have enough sample bottles available to take samples for all the measurements. Therefor some measurements could not done during every fieldtrip.
The storage of the samples was also a problem. Due to the high temperatures, keeping the samples cold was difficult; no refrigerator (there was no electricity) was available. The samples were cooled as good as possible using blocks of ice.
Some samples had to be analyzed within 5 days causing a time-limiting factor. No equipment for analyzing the samples was available at the research area.
The large research area with the spread sample points, together with the hot weather caused long travelling times from one measuring point to another making it impossible to collect a lot of data during a limited amount of time. The only way of transportation was walking or rowing a boat.
Measuring the storage area of the channels, the forest was a serious problem. Due to the high density of mangroves (see picture 4, appendix A.1) it was impossible to enter the forest to measure the water depth in it.
Thievery was also a problem. Three of the four baskets for measuring the leaf fall were stolen. Besides these baskets, one Diver that registered the tide was stolen during fieldtrip 3. A Diver is a measuring instrument that automatically registers (a data-logger) the total pressure that can be used to define the water depths.
For the water quality measurements no data-loggers were available. Everything had to be measured by hand what took time.

The idea was to model the entire pond. However, during the second fieldtrip the decision was made, in consultation with Ir. G.J. Schiereck of Delft University of Technology that concentrating on only one part of the pond was better. The difficult circumstances mentioned above, were the reason of the little amount of data that was collected during one fieldtrip. Doing two fieldtrips both concentrated on one part of the pond gave more information about that part resulting in a better description of it. It is worthy having a better description of one part than an inaccurate one of the complete pond. When this decision was made, measurements were already done in sub-plot 3.1.B meaning that this sub-plot was also investigated during fieldtrip 3.

5.2 The geometry and water movement measurements

A more detailed description about the fieldtrips and the used equipment is given in appendix A.2. This paragraph describes the measurements done during each fieldtrip. Appendix C.1 till C.5 show the collected data.

5.2.1 Fieldtrip 1

This fieldtrip was used for measuring the geometry of the pond. During this phase of the project, the whole pond was still examined.

The following measurements were done:

- leveling of the land;
- leveling and installing the gauges;
- measuring the length of the channels;
- measuring the sluice dimensions;
- measuring the cross-sections of the channels.

A description of the geometry of the pond was needed to make the computer model.
In a computer model, all the defined levels must be referring to one reference level (the zero-level). Because of the absence of landmarks, a reference level had to be chosen. A point on a steel pump with a concrete foundation was chosen as reference level, the zero-level (see picture 5, appendix A.1). The concrete foundation of the pump made sure that it would not change place during the stay in Vietnam.
At each sluice one mark was made with paint on the concrete parts of the sluices and leveled during the circle leveling. Knowing the levels of these marks, the gauges were installed rapidly near the sluices at a different time during the fieldtrip also referring to the reference level. Still the leveling machine was needed but the whole circle leveling did not have to be done over. In each channel outside the pond, near the sluices, a gauge (a total of four) was installed. Because the pond was divided into two parts, two gauges were installed inside, each part one gauge. All the gauges refer also to the reference level. During this trip the sluice dimensions, the length of the channels and 32 cross-sections (see picture 6, appendix A.1) were measured. The collected data is shown in appendix C.1 and C.2.

5.2.2 Fieldtrip 2 and 3

Only one part of the pond, plot 3.1.B, was examined during these two fieldtrips. Both fieldtrips contained the same calibration measurements and will be discussed here together. These measurements were:

- measuring the water levels in- and outside the pond;
- measuring the air-pressure;
- measuring the velocity in the sluices during water exchange;
- measuring more cross-sections in the outer channels;
- taking readings of the gauges.

These measurements were used for calibrating the model and describing the initial and boundary conditions. The measurements of the water levels in- and outside the pond was done using two Divers. A Diver is a measuring instrument that automatically registers the total pressure (water and air). The Diver stores the data in its memory and can be read into a computer using an optical reading device and the appropriate software. The calculation of the water depths from the Diver-data will be discussed in chapter 6: data analysis. Because the Divers registered the total pressure (water and air), air-pressure measurements were needed to calculate the water depth. To refer the Diver-data to the chosen reference level, readings of the gauges were done. These gauges were leveled so a link between the Diver-data and the reference level could be made.
During fieldtrip 2, a 24-hour measurement was done, to see the changes during the night. It was Full Moon during that fieldtrip giving enough light to work in. A 24-hours measurement was not done during the third fieldtrip due to New Moon, causing no moonlight, making the place very dark and not suitable to work.
After fieldtrip 2, a start was made modeling the pond. It was seen that the geometry of the outer channels, especially near sluice B, strongly influenced the water levels. Because of this reason, more cross-sections in the outer channels were measured during the last fieldtrip.

During the exchange of water, velocity measurements were done in the sluices. One entrance contained four measuring points. The measuring points are schematically shown in figure 7, looking from inside the pond to the outside.

Sluice A			Sluice B			
3	4	Surface	7	8	3	4
2	1	Bottom	6	5	2	1

Figure 7: Measuring points velocity in sluices

All the measuring points in a sluice together (for sluices A four [one entrance] and sluice B eight points [two entrances]) form one complete measurement from where the velocity was calculated. These measurements were used to estimate the discharge coefficients of the sluices. The velocity measurements were done using an Ott-meter; an instrument that has a propeller what will rotate owing to the flow of the water. The number of revolutions measured during a known period was used to calculate the flow velocity.

Figure 8 shows the positions where the measurements were done during fieldtrip 2 and 3. Besides the positions of the measurements concerning the water movement, it also includes the positions where the water quality samples were taken. These water quality measurements are discussed in paragraph 5.3. Figure 8 only shows plot 3.1.B, from this moment all the measurements were done in this part of the pond.

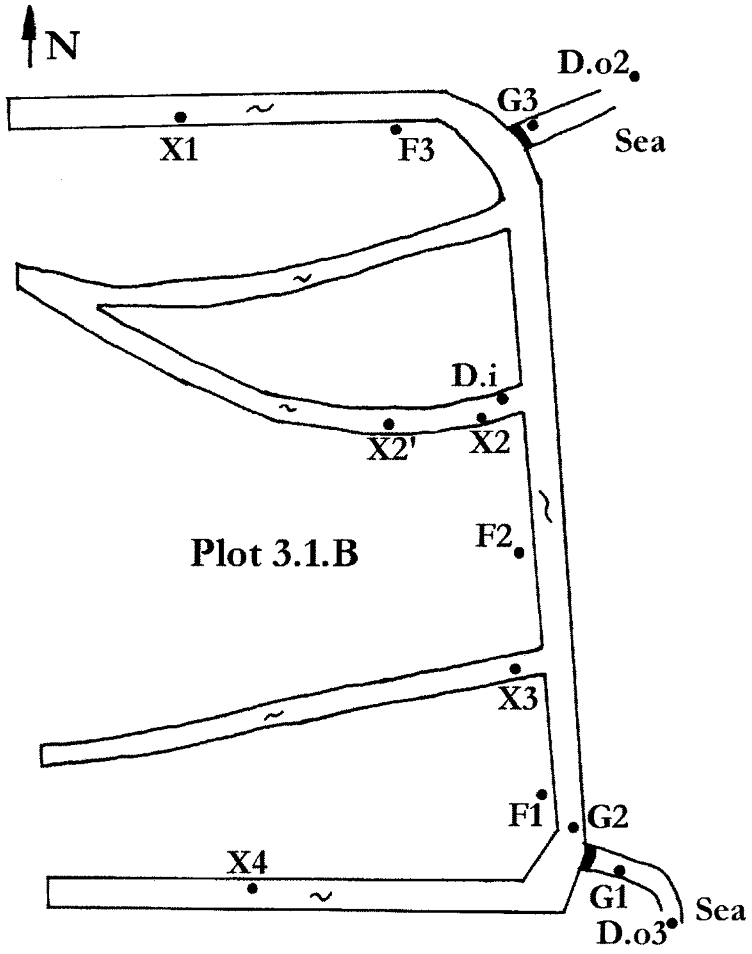

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Figure 8: Positions of measuring and sample taking

X1, X2, X2', X3 and X4 are the points where the samples were taken. G1, G2 and G3 are the gauges with the numbers 1, 2 and 3. D.i is the position of the inside Diver during both fieldtrips. D.o2 and D.o3 are the positions of the Diver outside the pond during respectively the second and third fieldtrip. They were installed as close as possible to the sea, sheltered from the waves. F1, F2 and F3 are sample points in the shallow water of the mangrove forest.

5.2.3 Other observations

Besides the planned measurements described above other observations were done. These observations were:

- *Wind:*

During the first and second fieldtrip, a stronger wind than normal was blowing over the pond. An estimation of the wind-force was about force 4 (5.3 – 7.4 m/s).

- *Storage area:*

Measuring the storage area was a problem (see paragraph 5.1). The storage area, the forest was covered with a high density of mangroves, making it impossible to enter the forest to measure the water depth. No use could be made of the sunlight glistering in the water, because not enough light fell on the bottom caused by the high density of mangrove trees. Estimations of the water depths were made near the borders of the forest. Some parts remained dry and some parts had a water level of approximately one meter. Most of the storage area had a water level near the border of the forest of 5 till 10 cm.

- *The sluices:*

When the sluices were open, the following observations were done.

- Sluice A

Sluice A has one entrance (see picture 3, appendix A.1). The channel outside at sluice A is a wide channel and during low tide, no water was present in this channel. Two parallel dams, outside the pond in front of sluice A, guided the water towards the sluice. During high tide, these dams were completely sub-merged.
During the inlet, water was headed up against the beams of the sluice.
When the water level in the outside channel was low, it was observed that dirty looking water from the surrounding mangrove forests (outside the pond) flowed through the dikes into the outer channel. It was not expected that this dirty looking water be of influence on the water quality of the inside water because the next opening of the sluice would be used to let the water out. The dirty water would than flow towards the sea, were it will be diluted.
Schematically the situation around sluice A with the flow patterns is shown respectively in figure 9, the inlet and figure 10, the outlet of water. During inlet, the water was well guided towards the sluice and flowed at high speed to the other side of the inside channel where it deviated to the left and right.

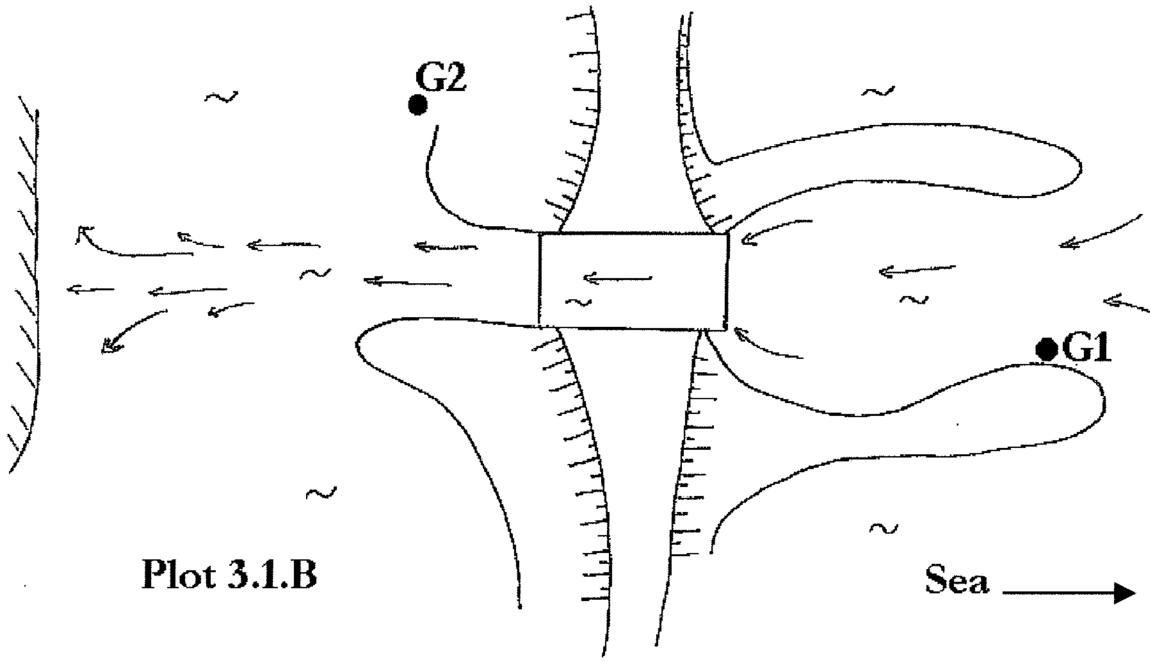


Figure 9: Flow patterns at sluice A, inlet

During outlet, figure 10 the water was, because of the shape of the land, well-guided towards the sluice.

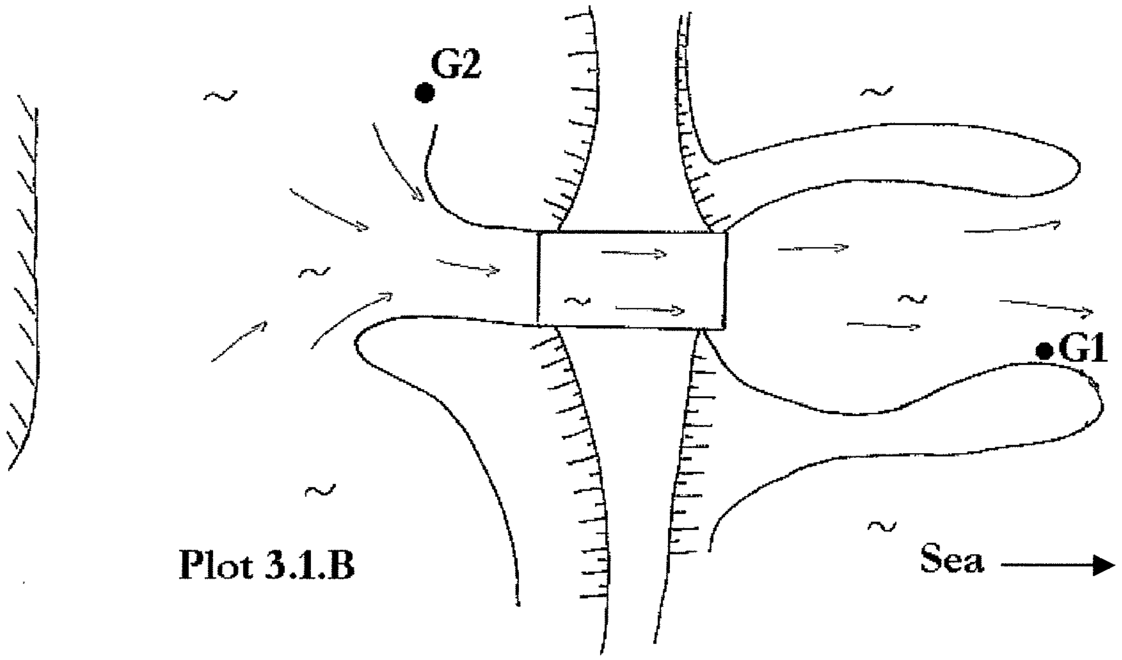


Figure 10: Flow patterns at sluice A, outlet

- Sluice B

Sluice B (see picture 2, appendix A.1) had two entrances. When the water level in the outside channel was low, the sluice was opened and the water was let out. During the outlet of water on March 1 at about 18:15 it was seen that because of the large height differences between the in- and outside water levels, water with a high velocity flowed into the outer channel. Before that outlet the water level of the tide in the channel just outside sluice B was about –2.0 m. The first part of this channel starting at sluice B was very narrow causing heading up of water and leading to a rapid rise of the water level during outlet. The gauge reading outside near sluice B showed

during the outlet of water a level of –1.36 m meaning that a heading up of approximately 0.64 m was seen in the narrow part of the channel.
During outlet, vortexes were seen in front of the sluice caused by the fact that the land inside the pond that did not guide the water well towards the sluice resulting in a separation of flow causing these vortexes. After closing the sluice gate a translatory wave was observed for a few minutes in the channel outside the pond, causing the water level to change rapidly until the wave was completely damped.
Sometimes no water was present in the outside channels caused by the high tidal range.
During inlet, the water was headed up against the beams of the sluice.
It was observed that dirty looking water was flowing from the mangrove forests outside the pond into the outer channel during low water.
The situations at sluice B and the flow patterns as observed during the periods of in- and outlet are shown respectively in figure 11 and figure 12. The inlet of water showed the same flow patterns as seen at sluice A.

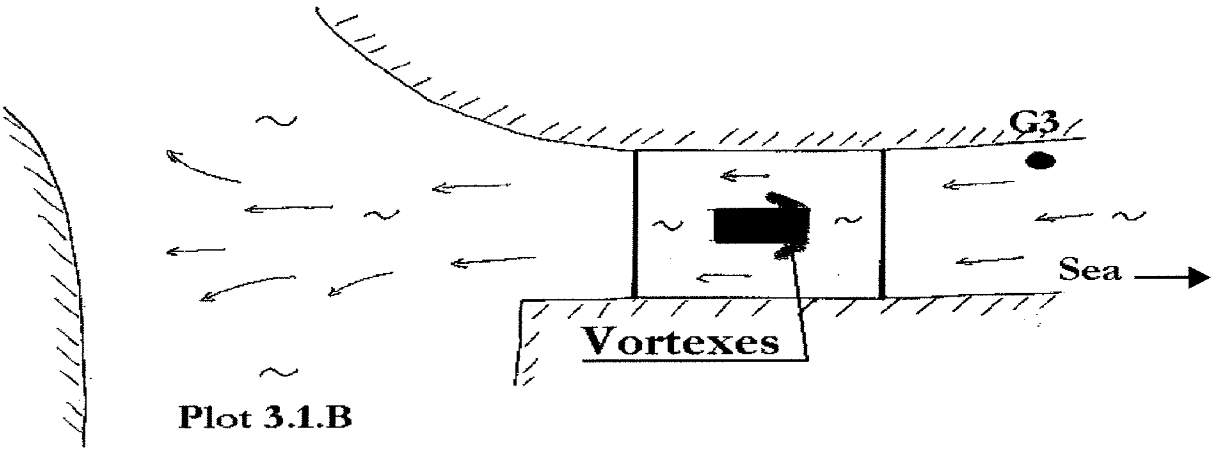


Figure 11: Flow patterns at sluice B, inlet

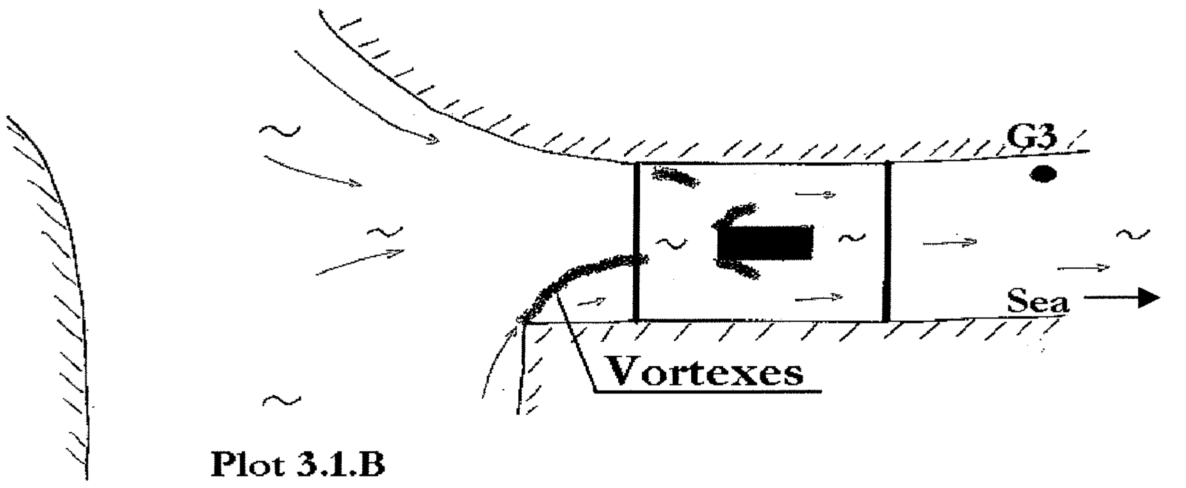


Figure 12: Flow patterns at sluice B, outlet

5.3 The water quality measurements

During the second and third fieldtrip, water quality measurements were done that would be used to calibrate the water quality part of the model. The water quality measurements and the analysis of it were done by Marc Zitzen from the Agricultural University of Wageningen and will be discussed here and in appendix A.3 and C.6. For a more detailed description of the water quality analysis reference is made to the report: *Water quality changes in a sluice gate controlled extensive mangrove-cum-shrimp system at Thanh Phu, Ben Tre province, Viet Nam (M. Zitzen, May 1999).*
The following measurements were done

- Direct measurements

These measurements immediately gave results without doing further analysis. Electrodes were used to measure the temperature of the water, the pH and the DO-concentrations. The DO-concentrations were measured near the bottom and surface to see if there were differences in the vertical water column. Due to the high velocities during the exchange of water no bottom measurements were done in the sluices. The assumption was made that these high velocities lead to good mixing of the water so the DO-concentrations at the bottom and surface were identical. The temperature and the pH were measured only at the surface.
Salinity was measured directly using a hand-refractometer. Light passes through a thin layer of water and is refracted. The salinity can be read on a scale in the eyepiece of the refractometer by the observer.
Because the importance of $SOD_{T.P.}$ (the sediment oxygen demand measured in Thanh Phu) for the system, the measurement will also be discussed here in spite of the fact that these measurements were done during earlier fieldtrip (28/01/1999 – 29/01/1999). Because no instrument to measure the $SOD_{T.P.}$ was available one was self-made using an oxygen electrode and a bucket with a propeller in it to stir up the water.

- Sample measurements

During the fieldtrips several samples were taken and were analyzed in the laboratory of Can Tho University in Can Tho. These measurements were:

- Suspended solids (SS)
  During each SS-measurement one sample was taken that was analyzed in the laboratory to be able to define the SS-concentration.
- Biochemical oxygen demand (BOD)
  Two samples were taken during each measurement. One of the samples was stored in the dark. Both samples were analyzed and the BOD-value was calculated.
- Chlorophyll-A
  With these measurements, the density of the algae was estimated. Samples were taken and analyzed in the lab. Problems occurred during the analysis, which will be discussed later (paragraph 6.2).
- Organic material
  When the water level dropped because of the outlet of water, water from the forest containing organic material as leaf litter flowed into the channels. The amount of organic material was measured and calculated doing following experiments.
  First leaf fall, leafs were catched in baskets, 50 cm above the ground and analyzed in the lab to estimate the amount of organic material.
  Second the top layer of sediment. With a ground-drill, ground samples were taken. At each sample point (x1 – x4) at three different places; in the forest, at the border of the forest, and in the channel. The samples were analyzed in the lab, where the amount of organic material was calculated.

Third the sedimentation. Installing at every inside sample point (x1 – x4) three buckets with the upper level 5 till 10 cm above the bottom, the sedimentation was estimated. After 48 days, 4 periods of water exchange, the buckets were removed and the sediment was measured and analyzed in the lab.

- Hydrogen sulfide (H_2S)
  Hydrogen sulfide measurements in the forest were done during an earlier fieldtrip (28/01/1999 – 29/01/1999). During fieldtrip 3 measurements were done near the sluices during the exchange of water.
  During the last fieldtrip, samples were taken in the outside channels near the sluices.
- Ammonium
  Ammonium measurements in the forest were done during an earlier fieldtrip (28/01/1999 – 29/01/1999). During fieldtrip 3 measurements were done near the sluices during water exchange. Samples were taken near the sluices in the outside channels during the exchange of water.

6. Data analysis

This chapter describes the analysis of the data (geometry, water movement and water quality) that was collected during the fieldtrips. The results of the analysis will also be shown in appendix C.

6.1 Geometry and water movement data

- *Leveling*

During the first fieldtrip a circle leveling was done, followed by a calculation to check the accuracy of the leveling. Starting and ending at the same point, the pump, the level must start and end at the same level. A difference of 12 mm was found what was acceptable according to *A.M. Sluis, 1979.* For the 12 mm difference a correction was made on the readings.
The results of the leveling are shown in appendix C.1.

Knowing that the circle leveling was done correctly, the levels of the marks made on the sluices were determined. With these levels, the levels of the sluice bottoms and gauges were calculated. The results are shown in respectively table 2 and 3.

Table 2: zero-level gauges

Gauge	Zero-level [m]	Position
Gauge 1 (G1)	-1.70	Outside near sluice A
Gauge 2 (G2)	-1.70	Inside near sluice A
Gauge 3 (G3)	-1.66	Outside near sluice B

Table 3: Level of the sluice bottoms

Sluice	Level [m]
Sluice A	-2.39
Sluice B	-2.26

Making use of some readings of the leveled gauges, a link between the in- and outside water levels, measured by the Divers and the chosen reference level was made.
Knowing the water levels during the measurements of the cross-sections, the bottoms of the channels were referred to the reference level.
The results are shown in appendix C.1.

- *The Divers*

As written before the Diver is a measuring instrument that automatically registers the pressure and stores this in its memory expressing it in cm water column. This memory can be read using a computer in combination with an optical reading device and the appropriate software.
When the Diver is in the water it registers the total pressure, water and air, expressed in cm water column. When the Diver was fabricated, it was calibrated for the use in fresh water. However, this research was done in salt water so a correction was made on the Diver-data because of difference in density. The designer of the Diver also assumed that the Diver would never measure below the 950 cm water column and named this level the zero-level of the data. In order to get the correct pressure, 950 cm water column had be added to the measured data.

The following calculation was done to obtain the water depth in the channels from the Diver-data and was further used to define the water levels with reference to the reference level. First the measured data, P_{Diver} [cm water column] was corrected with the correction factor,

$\rho_{water, correction}$, because of the difference in density. Adding 950 cm water column (the defined zero-level of the Diver) to the corrected measured data the total pressure in cm water column is found. To express the total pressure in [m water column], the total pressure is divided by 100 (1 cm = 0.01 m). Equation 6.1 shows these calculations.

$$\frac{(P_{Diver} \cdot \rho_{water,correction}) + 950}{100} = P_{total.1} \text{ [m water column]} \qquad \text{(Equation 6.1)}$$

Where:

$\rho_{water, correction}$: 1.018 [-]

To obtain the pressure in [kg/m·s²] the $P_{total.1}$ was multiplied with the density of the water (ρ) and the acceleration of gravity (g). Equation 6.2 shows this calculation.

$$P_{total.1} \cdot \rho \cdot g = P_{total.2} \left[\frac{kg}{m \cdot s^2}\right] \qquad \text{(Equation 6.2)}$$

Where:

ρ : 1000 [kg/m³] (density of fresh water)
g : 9.81 [m/s²]

Wanting to know the water pressure, the air pressure is subtracted from $P_{total.2}$. Because the measured air-pressure is expressed in mbar, $P_{total.2}$ has to be transferred into mbar, using the following relation between mbar and kg/(m·s²):

$$1 \text{ bar} = 1000 \text{ mbar} = 10^5 \text{ Pa} = 10^5 \text{ kg/(m·s}^2)$$
$$1 \text{ mbar} = 100 \text{ kg/(m·s}^2)$$

Transferring $P_{total.2}$ into mbar and subtracting the air-pressure, P_{air} [mbar] the water pressure is obtained. This is shown in equation 6.3.

$$\frac{P_{total.2}}{100} - P_{air} = P_{water.1} \text{ [mbar]} \qquad \text{(Equation 6.3)}$$

Knowing the water pressure [mbar], the water depth can be calculated doing the opposite calculations as discussed above. Equation 6.4 describes this calculation to obtain the water depth.

$$\frac{P_{water.1} \cdot 100}{\rho \cdot g} \cdot 100 = P_{water.2} \text{ [cm water column]} \qquad \text{(Equation 6.4)}$$

With some water levels readings of the gauges, in- and outside the pond a link is made between the Diver-data and the chosen reference level.

Some problems occurred during the analysis of the data. The barometer used to measure the air-pressure seemed to be unreliable. Readings from the barometer were registered before leaving the Statefarm, when the pond was reached and just before the Diver was installed. Before installing the Diver in the water, the Diver only measures the air-pressure so it is working as a barometer. Comparing the barometer readings with the registrations of the Diver before installation, similar readings were seen before leaving the Statefarm. However, comparing the readings just before the Diver was installed greater differences occurred. Table 4 shows some readings from fieldtrip 2. The differences also occurred during the last fieldtrip.

Table 4: A not reliable barometer

Time	Air-pressure barometer [mbar]	Air-pressure Diver [mbar]	Remarks
07:29	1011.0	1010.8	At the Statefarm
12:19	1003.0	1009.4	At the pond
15:05	1004.5	1008.4	Just before the Diver entered the water

The Diver was checked in Holland and gave reliable data but to see if the Diver was still giving reliable data another check was made. At the position where the inside Diver was installed a water depth of approximately 69 cm was measured. A distance of approximately 26 cm was measured between the position of the sensors of the Diver, where the pressure was measured, and the bottom. That means that the Diver must register a water depth around 43 cm. The depth calculated at that time the Diver was installed, using the air-pressure measured by the Diver just before it entered the water, gave a water depth of 41.5 cm. This was close to the measured depth, and it was concluded that the Diver gave reliable output. With the knowledge of the Diver giving reliable output it was concluded that the barometer was not reliable and assumptions had to be made concerning the air-pressure when calculating the water levels. The transport from the Statefarm to the pond disordered the barometer, causing these differences in readings. During a later stage of the fieldtrip, the barometer readings, due to not moving the barometer, were getting more reliable.
Figure 13 shows a part of a Diver registration before it entered the water showing that the air-pressure changes in time. Due to this changing, the assumptions made concerning the air-pressure can be slightly different from the real air-pressure leading to different results. Differences of 2 or 3 cm can occur (1 mbar ≈ 1 cm).

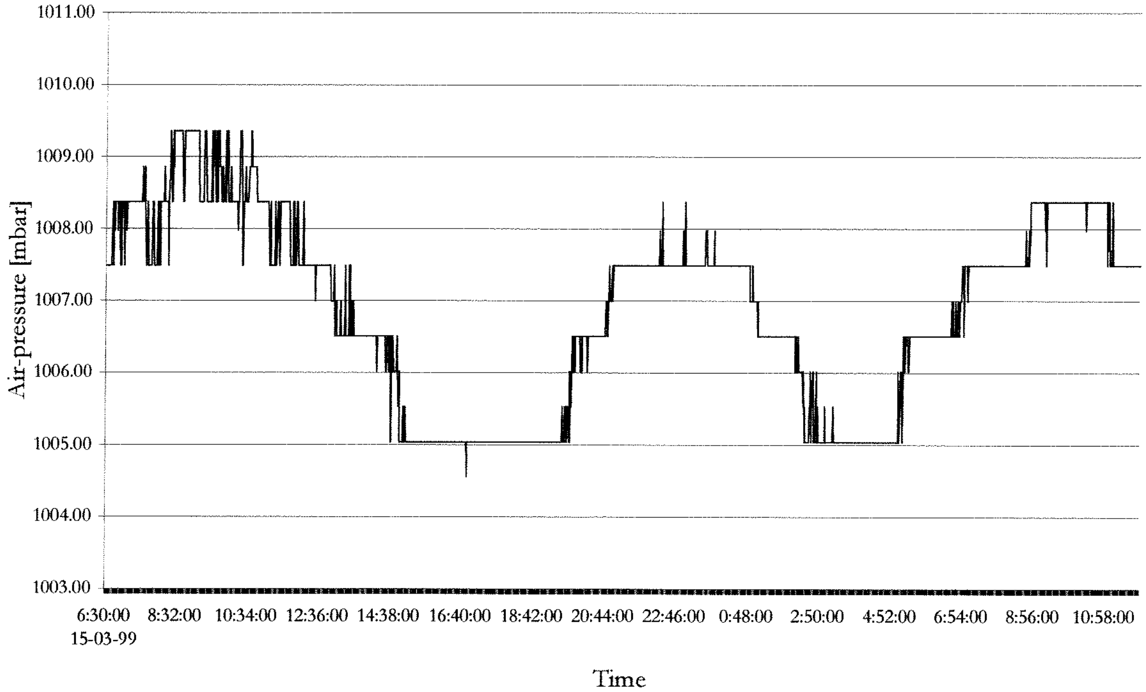


Figure 13: Air-pressure data from a Diver

From previous studies of plot 3.1 in Thanh Phu, also using Duflow, it was seen that there was not a slope (the found differences were negligible) in the water level inside the pond (*Schiereck*, *1998*). This means that the water level was the same for every point and that the water level rose and dropped as a horizontal plate. This will be proven when the computer model is finished (see chapter 7). With the water level rising and dropping as a horizontal plate, only one measuring point was needed to measure the inside water levels. The Diver installed inside the pond measured this the water level representing the whole inside pond. The inside water levels were defined first. Different values were found comparing the water level measurements outside the pond, the tide with the gauge readings near sluice B. This was caused by the heading up of water near sluice B where the gauge was installed during outlet (see paragraph 5.2.3).

The value registered by the Diver just before installation in the water was the first value of the air-pressure used to calculate the water level. For the first part the air-pressure (from the Diver-data) and the water level (gauge) was known so the first Diver registrations were referred to the reference level. Then the intervals with the sluices closed, the horizontal water levels, were defined. With the help of the readings of the gauges during those periods, assumptions were made concerning the air-pressure. Knowing the water levels during the periods of not exchanging water, the water levels during water exchange were defined by making assumptions of the air-pressure.
Knowing the inside water levels during the whole fieldtrip, the assumed air-pressure during the whole fieldtrip was also known. These air-pressure values were used to define the water levels from the Diver that was installed outside the pond, the tide.
A maximum difference of 3 cm was found when comparing the calculated water levels from the Diver installed outside the pond with the readings of the outside gauge near sluice A. This difference can be caused by the assumptions made concerning the air-pressure. Due to the heading up of water during outlet near sluice B, it was difficult to compare the water levels of the Diver with the readings of the gauge that was positioned near sluice B.
The results of the water levels inside and outside are shown in respectively figure 14 and 15.

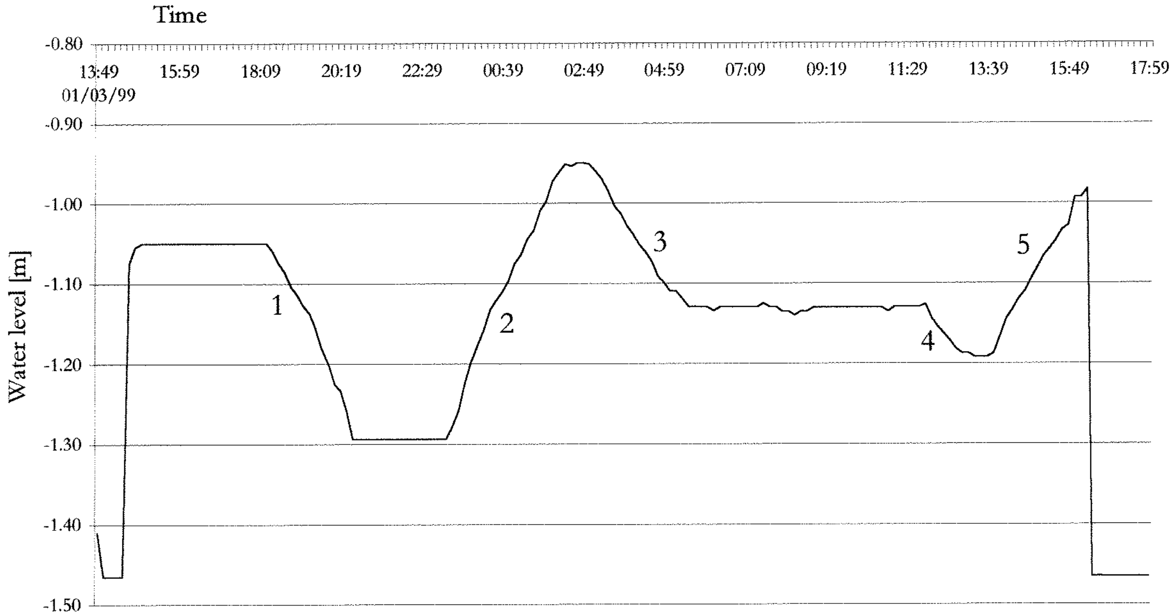


Figure 14: Water levels inside, fieldtrip 2

Five periods of exchanging water were seen (number 1 till 5, figure 14) during this trip, three times outlet (number 1, 3 and 4) and twice inlet (number 2 and 5) of water.

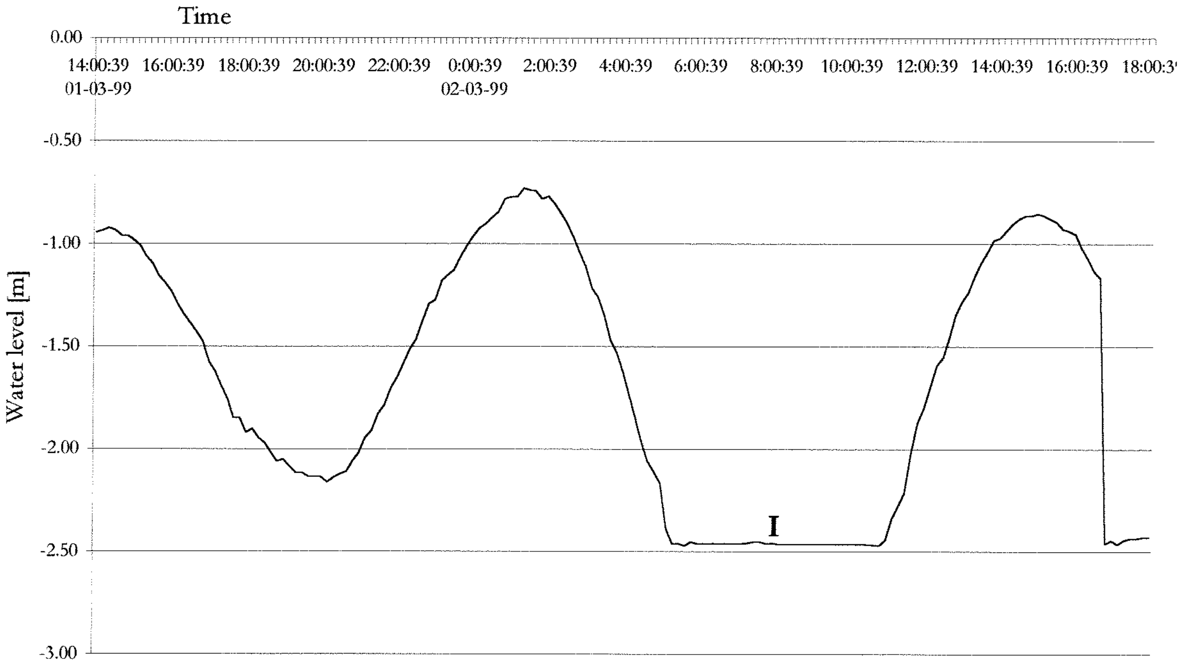


Figure 15: Water levels outside, fieldtrip 2

The horizontal period of the registration outside water levels (I in figure 15) means that the Diver was hanging above the water level. The high tidal range caused the channel to dry up during some period of the day. During this period, the Diver only registered the air-pressure and with the assumptions made the air-pressure was almost constant during that period resulting in a horizontal line.
This analysis was also done with the Diver-data of the third fieldtrip but during that fieldtrip, as written before, the Diver installed outside the pond was stolen so no data concerning the outside water levels was available. The calculated inside levels are shown in figure 16.

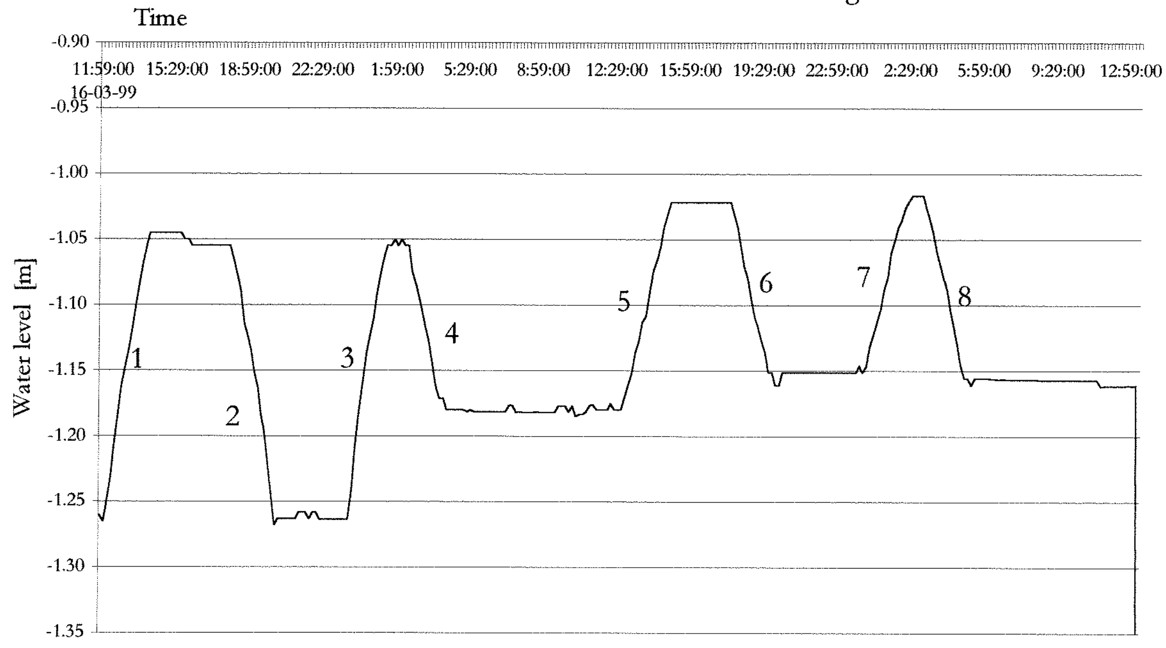


Figure 16: Water levels inside, fieldtrip 3

Figure 16 shows that water was exchanged eight times (numbers 1 till 8, figure 16). The numbers 1, 3, 5 and 7 show the inlet of water and the numbers 2, 4, 6 and 8 the outlet.

The results of the analysis of the water levels in- and outside for both fieldtrips are shown in appendix C.4.

- *Flow velocity*

Velocity measurements were done using an Ott-meter, an instrument with a propeller that will rotate owing to the flow of the water. The revolutions measured during a known period are used to determine the flow velocity.
The Dutch Rijkswaterstaat, who donated this Ott-meter, calibrated this instrument to determine a formula that must be used to calculate the flow velocity. This formula (formula 6.2) is instrument dependent and can only be used when measurements were done with the Ott-meter that was used.

$$v_{meas.} = 0.257 \cdot \eta_{ott} + 0.007 \qquad \text{(Formula 6.2)}$$

η_{ott} is the number of revolutions per second. One complete measurement contained for every sluice entrance four sub-measurements, two near the bottom and two near the surface (see paragraph 5.2.2). For measuring the velocity in sluice A four sub-measurements (1 entrance) were done and in sluice B eight (2 entrances). Calculating the velocity of each sub-measurement formula 6.2 was used. The average velocity in a sluice during the exchange of water was calculated by taking the average of the sub-measurements of one complete measurement. The average measured velocities are shown in table 5. Due to the definition of the network, Duflow gives the outgoing velocities as negative. Therefor the outgoing velocities are also shown in table 5 as negative. The number of the measurements coincides with the data shown in appendix C.3.

Table 5: Average measured velocities in the sluices

Sluice A		
Measurement	**$v_{meas.}$ [m/s]**	**Direction**
Fieldtrip 2		
1A	-1.78	outgoing
2A	1.67	incoming
3A	1.56	incoming
4A	1.70	incoming
Fieldtrip 3		
5A	-1.67	outgoing
6A	1.66	incoming

Sluice B		
Measurement	**$v_{meas.}$ [m/s]**	**Direction**
Fieldtrip 2		
1B	-0.72	outgoing
2B	-1.09	outgoing
3B	1.17	incoming
4B	-0.81	outgoing
5B	1.31	incoming
Fieldtrip 3		
6B	-1.04	outgoing
7B	1.16	incoming

The velocity measurements, shown in table 5 and appendix C.3, were done in order to estimate the discharge coefficients of the sluices. The discharge formula (formula 6.3) was used to estimate the discharge coefficients. The discharge formula is:

$$Q = A_{sl.} \cdot \mu \cdot \sqrt{2 \cdot g \cdot \Delta h} \qquad \text{(Formula 6.3)}$$

Formula 6.3 was rewritten in formula 6.4.

$$\mu = \frac{Q}{A_{sl.} \cdot \sqrt{2 \cdot g \cdot \Delta h}} \qquad \text{(Formula 6.4)}$$

Where:
μ : the discharge coefficient [-]
g : 9.81 m/s^2
Δh : the height difference in water level between the in- and outside of the pond [m]
$A_{sl.}$: the cross-section of the sluice [m^2]
Q : $v_{meas.} \cdot A_{sl.}$ [m^3/s]

Where:
$v_{meas.}$: the average measured velocity through the sluice [m/s]

μ is a dustbin-factor that includes factors, like friction that cause the differences between the ideal velocity and the velocity in the system.
When calculating the height differences between the in- and outside water levels, Δh near sluice A during the measurements the readings of the two gauges, both situated in- and outside the pond near sluice A were used. Near sluice B only one gauge was installed, outside the pond, so to calculate the height differences between the in- and outside during the measurements, the readings of the inside Diver were used.
Table 6 shows the average values of the calculated discharge coefficients.

Table 6: Calculated average discharge coefficients

Sluice	**Incoming**	**Outgoing**
Sluice A	0.73	0.46
Sluice B	0.93	0.53

The value of 0.93 of sluice B was very high, caused by the little height difference between the in- and outside water levels during the measurements. Larger height differences between the in- and outside and heading up of water against the beams of the sluice were observed, so a lower μ was expected. Comparing the flow patterns during inlet around sluice A with sluice B it was seen that in both situations the water was well guided in the direction of the sluices. At sluice A due to the parallel dams and at sluice B because of the narrow channel. Therefor it was expected that due to these similar flow patterns, the discharge coefficients for both sluices would be the same.
When comparing the discharge coefficients for the outgoing flow, the opposite as shown in table 6 was expected. Looking at the flow patterns during outlet (see paragraph 5.2.3) more turbulence was observed at sluice B caused by the separation of flow, the flow was not able to follow the geometry of the land. It was expected that the discharge coefficient near sluice B, due to the more observed turbulence would be lower compared to the discharge coefficient of sluice A.
The reason for these differences could be caused by the problems during the measurements. Because of the high velocities, it was difficult to hold the Ott-meter in the direction of the flow of the water.

6.2 Water quality data

This chapter describes a summary of the analysis done by M. Zitzen and the results found concerning the water quality measurements. For a more detailed description of the water quality analysis reference is made to the report: *Water quality changes in a sluice gate controlled extensive mangrove-cum-shrimp system at Thanh Phu, Ben Tre province, Viet Nam (M. Zitzen, 1999).*
The collected data and the results of the analysis are also shown in appendix C.6.

- Chlorophyll-A

The chlorophyll-A measurements were done to calculate the concentration of the algae that were present in the system. After the chlorophyll-A analysis, negative concentrations were found. This is not possible and probably caused by a mistake made during the analysis, or very low algae concentrations were in the system. Because of the negative concentrations of algae, the measurements will not be discussed further.

- DO-concentration

Slightly lower DO-concentrations were measured near the bottom compared to the DO-concentrations near the surface. The reason for only small differences could be the mixing of water during exchange leading to fewer differences in the vertical water column. Larger differences of the DO-concentrations between the bottom and surface were expected during the first water exchange after a long period of not exchanging. Due to practical reasons, this first water exchange was not measured. The first water exchange measured was not the first water exchange that period but one or two days later.
Occasionally a change of the DO-concentration as much as 1 g/m^3 during a short period occurred. These rapid changes may cause stress to the shrimp. Before the first exchange of water, the DO-concentrations probably were lower leading to changes that are more rapid, due to the larger differences between the in- and outside DO-concentrations. Besides at the four sample points inside the pond, measurements were done near the sluices during the exchange of water. Especially the measurements during inlet were important because they represent the quality of the water that entered the pond. In table 7 and 8 the average, minimum and maximum DO-concentrations, for every measuring point are shown. Only near the sluices, due to the high velocities, no bottom measurements were done. Due to the high velocities during the exchange of water and turbulence, it was assumed that the water was well mixed so no differences between bottom and surface occurred.

Table 7: DO-concentrations, fieldtrip 2

Position	Average DO [g/m^3]	Minimum DO [g/m^3]	Maximum DO [g/m^3]	Number of measurements
x1-surface	5.7	5.0	6.3	4
x1-bottom	5.6	4.8	6.3	4
x2'-surface	4.5	4.0	5.6	4
x2'-bottom	4.3	3.9	5.1	4
x3-surface	5.1	4.3	6.2	4
x3-bottom	4.6	3.8	5.4	4
x4-surface	5.2	4.7	6.0	4
x4-bottom	5.2	4.6	5.7	4
sluice A-outgoing	5.5	-	-	1
sluice A-incoming	6.6	-	-	1
sluice B-outgoing	5.4	-	-	1
sluice B-incoming	6.6	6.5	6.7	2

Table 8: DO-concentrations, fieldtrip 3

Position	Average DO [g/m^3]	Minimum DO [g/m^3]	Maximum DO [g/m^3]	Number of measurements
x1-surface	6.0	5.5	6.5	2
x1-bottom	5.7	5.0	6.3	2
x2'-surface	5.6	4.6	6.5	2
x2'-bottom	5.5	4.6	6.3	2
x3-surface	5.7	4.8	6.7	2
x3-bottom	4.8	3.6	5.9	2
x4-surface	5.9	5.1	6.7	2
x4-bottom	5.9	5.1	6.6	2

Position	Average DO [g/m³]	Minimum DO [g/m³]	Maximum DO [g/m³]	Number of measurements
sluice A-outgoing	6.2	-	-	1
sluice A-incoming	6.7	6.4	7.1	3
sluice B-outgoing	6.5	-	-	1
sluice B-incoming	6.6	6.5	6.6	2

The differences in the DO-concentration between the incoming and outgoing water were the result of oxygen consuming processes inside the pond.

- Suspended solids (SS)

After the analysis in the laboratory the results, as shown in table 9 were found..

Table 9: SS-concentrations, fieldtrip 2

Position	Average SS [g/m³]	Minimum SS [g/m³]	Maximum SS [g/m³]	Number of measurements
x1	97.2	52.3	142.0	2
x2'	132.3	61.7	203.0	2
x3	88.5	74.7	102.3	2
x4	68.5	62.3	74.7	2
sluice A-outgoing	153.7	-	-	1
sluice A-incoming	400.7	-	-	1
sluice B-outgoing	73.0	-	-	1
sluice B-incoming	327.7	-	-	1

Table 10 shows the results of the analysis of the SS measurements done during fieldtrip 3.

Table 10: SS-concentrations, fieldtrip 3

Position	Average SS [g/m³]	Minimum SS [g/m³]	Maximum SS [g/m³]	Number of measurements
x1	102.3	40.0	164.7	2
x2'	53.0	33.3	72.7	2
x3	75.8	57.3	94.3	2
x4	63.7	54.0	73.3	2
sluice A-outgoing	146.3	-	-	1
sluice A-incoming	153.0	80.0	146.3	3
sluice B-outgoing	80.0	-	-	1
sluice B-incoming	253.0	204.0	302.0	2

Large differences occurred between the minimum and maximum SS-concentrations. Outside the pond, the incoming water, high SS-concentrations were measured. Due to the lower velocities inside the pond causing the SS-particles to settle, the SS-concentrations decreased.

- Biochemical oxygen demand (BOD)

Measuring the biochemical oxygen demand was done at all six measuring points during fieldtrip 2 and only near the sluices during fieldtrip 3. After analysis in the laboratory, the following results, shown in table 11, were found. BOD^5_{20} is the biochemical oxygen demand after 5 days with a temperature of 20°C. The biochemical oxygen demand is expressed in g/m^3, representing the amount of DO used by microbes that are in the vertical water column.

Table 11: BOD^5_{20}, fieldtrip 2

Position	Average BOD^5_{20} [g/m³]	Minimum BOD^5_{20} [g/m³]	Maximum BOD^5_{20} [g/m³]	Number of measurements
x1	1.8	1.4	2.3	2
x2'	2.7	0.9	4.5	2
x3	2.2	2.1	2.4	2
x4	4.0	2.0	6.0	2
sluice A-outgoing	5.3	-	-	1
sluice A-incoming	3.6	-	-	1
sluice B-outgoing	7.7	-	-	1
sluice B-incoming	2.4	-	-	1

During fieldtrip 3 only measurements near the sluices were done. Table 12 shows the results.

Table 12: BOD^5_{20}, fieldtrip 3

Position	Average BOD^5_{20} [g/m³]	Minimum BOD^5_{20} [g/m³]	Maximum BOD^5_{20} [g/m³]	Number of measurements
sluice A-outgoing	-	-	-	0
sluice A-incoming	5.7	5.2	6.1	3
sluice B-outgoing	-	-	-	0
sluice B-incoming	3.9	2.4	5.0	3

The outside values were higher than the inside concentrations, caused by the higher SS-concentrations outside the pond. The SS-particles contained a certain amount of organic material that used oxygen. The more the amount of organic material, the more oxygen was used, the higher the BOD^5_{20} will be.

- Salinity

All measurements were done during the dry season. It did not rain during the measurements, so the inside water was not diluted and the inside salinity concentrations resemble the salinity concentrations on sea. During the analysis, no great differences were found in time and between the sample points. The absence of great differences in salinity is good for the shrimp, because quick changes during a little period may lead to stress to the shrimp and eventually into death. The results are shown in table 13.

Table 13: Salinity, fieldtrip 2

Position	Average Sal. [‰]	Minimum Sal. [‰]	Maximum Sal. [‰]	Number of measurements
x1	30.3	29.0	32.0	4
x2'	29.6	26.0	32.0	4
x3	29.6	26.5	32.0	4
x4	29.8	28.0	32.0	4
sluice A-outgoing	27.0	-	-	1
sluice A-incoming	28.5	30.0	27.0	2
sluice B-outgoing	30.0	-	-	1
sluice B-incoming	28.8	27.0	30.0	3

The same salinity measurements were done during fieldtrip 3 and the results are shown in table 14.

Table 14: Salinity, fieldtrip 3

Position	Average Sal. [‰]	Minimum Sal. [‰]	Maximum Sal. [‰]	Number of measurements
x1	24.0	22.0	26.0	2
x2'	25.0	24.0	26.0	2
x3	25.5	24.5	26.5	2
x4	25.8	25.5	26.0	2
sluice A-outgoing	26.5	-	-	1
sluice A-incoming	25.0	25.0	25.0	2
sluice B-outgoing	26.5	-	-	1
sluice B-incoming	23.0	21.0	25.0	2

- pH

Algae strongly influence the pH of the water. Due to the high concentrations of SS, the light intensity in the water decreased causing a limited growth of algae. Because of the small algae-concentrations, no great changes in the pH occurred.
Another process that influences of the pH is the acidification of the soil. When the soil of the pond dries in the sun, acid producing processes (cat's clay) occur influencing the pH. The channels inside the pond never dried up so acidification problems are of no concern in the channels. The land in the forest could dry up for a short period but this is too short and due to the high density of mangrove, the ground never dried directly in the sun. Acidification of the pond soil does not occur.
The pH values are shown in table 15.

Table 15: pH, fieldtrip 2

Position	Average pH [-]	Minimum pH [-]	Maximum pH [-]	Number of measurements
x1	7.95	7.73	8.13	4
x2'	7.64	7.55	7.79	4
x3	7.80	7.65	8.06	4
x4	7.79	7.63	7.94	4
sluice A-outgoing	7.97	-	-	1
sluice A-incoming	8.11	-	-	1
sluice B-outgoing	7.84	-	-	1
sluice B-incoming	8.08	-	-	1

Table 16 shows the measured pH values from fieldtrip 3.

Table 16: pH, fieldtrip 3

Position	Average pH [-]	Minimum pH [-]	Maximum pH [-]	Number of measurements
x1	7.97	7.79	8.15	2
x2'	7.72	7.41	8.02	2
x3	8.14	8.12	8.15	2
x4	7.87	7.62	8.12	2
sluice A-outgoing	8.10	-	-	1
sluice A-incoming	8.07	7.98	8.16	3
sluice B-outgoing	8.11	-	-	1
sluice B-incoming	8.12	8.12	8.12	2

Small differences in pH were found. As said in paragraph 2.2 the optimum value of the pH is between 7.5 and 8.5. The pH satisfied these values meaning that the pH did not give stress or other negative effects on the shrimp.

- Temperature

The temperature of the water was suitable for shrimp to life in. The changes of the temperature that can vary due to the exchange of water, solar radiation, and rain were small. Table 17 and 18 show the values of the temperature during respectively fieldtrip 2 and 3.

Table 17: Temperature, fieldtrip 2

Position	Average temp. [°C]	Minimum temp. [°C]	Maximum temp. [°C]	Number of measurements
x1	27.3	26.2	28.3	4
x2'	27.5	25.8	29.5	4
x3	27.3	25.9	28.9	4
x4	27.3	26.2	28.9	4
sluice A-outgoing	26.0	-	-	1
sluice A-incoming	28.0	-	-	1
sluice B-outgoing	28.2	-	-	1
sluice B-incoming	28.5	-	-	1

Table 18: Temperature, fieldtrip 3

Position	Average temp. [°C]	Minimum temp. [°C]	Maximum temp. [°C]	Number of measurements
x1	29.9	29.0	30.8	2
x2'	30.4	29.4	31.3	2
x3	30.9	30.8	31.0	2
x4	30.2	29.6	30.8	2
sluice A-outgoing	29.7	-	-	1
sluice A-incoming	30.1	30.1	30.1	3
sluice B-outgoing	29.9	-	-	1
sluice B-incoming	30.3	30.0	30.5	2

- Sediment oxygen demand

The sediment oxygen demand is the demand of dissolved oxygen the sediment lying on the bottom has. The sediment oxygen demand is expressed in g consumed DO per m^2 bottom area per day, [$g/m^2 \cdot day$]. In normal natural systems, the sediment oxygen demand ranges between 1 – 3 $g/m^2 \cdot day$. In heavily polluted systems, values of 10 $g/m^2 \cdot day$ can be found. Two places in the forest where SOD measurements were done gave extreme high results, 63.1 and 52.6 $g/m^2 \cdot day$. At these positions, the sediment was colored black, indicating rotting processes of organic materials, like leaf litter, with the release of H_2S.
Also many SS entered the forest and settled due to the low velocities.
At the other positions the values of the sediment oxygen demand was also high. An average value of 10.0 $g/m^2 \cdot day$ was measured, only looking at the channels an average of 6.6 $g/m^2 \cdot day$ was measured. The high values of the sediment oxygen demand in the forest were the result of organic material from the leaf litter that used DO during the decomposition of the organic material. During the first drop of the water level, a lot of water from the forest containing a high amount of organic material flowed into the channels causing the sediment oxygen demand in the channels also to become very high. Because of the high values, the sediment oxygen demand strongly influences the DO-concentration in the system.

- Organic material (C)

Estimating the input of organic material from the forest these three experiments were done.

Leaf fall: The analysis was done with leafs from the remaining baskets. The average amount of organic material found falling from the forest onto the bottom was 2.03 g-C/m^2·day. The forest in the pond has an area of approximately of 220.000 m^2 (see appendix D.1), making the amount of organic material in the forest that falls on the bottom 445.5 kg-C/day.
Layer of sediment: Most of the organic materials were found in the top-layer of the sediment (0 – 5 cm), and can be explained by the high amount of leaf litter lying on the bottom. The high amount of leaf litter in the forest caused the differences between the concentrations of organic material in the channels and the forest. From the water quality analysis (*M. Zitzen, 1999*) it was concluded that 85% of the organic material came from the leaf litter from the forest and the rest, 15% from the SS.
The ratio between channel and forest is 46% : 54%, meaning that 84 – 54 = 31% flows from the forest into the channels. That is 138.1 kg-C/day.
Sedimentation: This was a second method to estimate the input from the forest. Table 19 shows the average values of sedimentation. The sediment in some buckets was neglected because crabs were found in those buckets and ate the sediment.

Table 19: Sedimentation of organic material

Position	Organic material [g-C/m^2·day]
x1	4.0
x2	8.4
x3	3.3
x4	4.9

During the analysis, it was found that more than 10% of the sediment was organic material. This was very high but it explains the high DO consumption found during the SOD-analysis.
Installing the buckets near the forest sedimentation from two sources, from the SS and the forest was measured.
C_{total} = 445.5 kg-C/day
$C_{channel}$ = 231.3 kg-C/day (average sedimentation · surface area channels)
The settled sediment from the SS is 100.3 kg-C/day. This leads to input from the forest into the channels of 131 kg-C/day

Two methods were used to estimate the input of organic material from the forest. Both methods gave values close together namely 138.1 kg-C/day and 131 kg-C/day.

- Hydrogen sulfide (H_2S)

Because of the high amount of leaf litter in the forest, a lot of organic material was decomposed using DO making the area anaerobic. Under these circumstances, anaerobic area bacteria produce H_2S a toxic substance that can be lethal to shrimp.
During the last fieldtrip, measurements were done in the channels outside the pond near the sluices. The first measurement, having a value of 0.615 g/m^3 was 6 - 20 times higher than the other results. This very high concentration of H_2S is lethal to shrimp, a mistake was probably made during the measurement and will therefor be further neglected.
The average input of H_2S from the sea is very low, 0.071 mg/l.
During an earlier fieldtrip (28/01/99 - 29/01/99) more measurements concerning H_2S were done. To show the influence of H_2S these results will be discussed here. From table 20 the influence of the forest concerning the H_2S can be seen. The concentrations of H_2S were

measured at several places before and after the first opening. The first opening was used to let water out so water from the forest flowed into the channels.

Table 20: Changing of H_2S after the first opening

Position	Before opening [g/m^3]	After opening [g/m^3]
In the forest	0.8	0.7
At the border of the forest	0.3	0.4
In the channel	0.0	0.7

The concentrations of H_2S increased when the water was let out due to the water containing higher concentrations of H_2S that flowed from the forest into the channels.
The H_2S concentrations in the forest were rather stable. Due to the lack of data it is impossible to see how many openings were needed before the concentrations inside the channels stabilized.

- Ammonium

During fieldtrip 3, measurements were done in the channels near the sluices, outside the pond. A very low average concentration of 0.008 g/m^3 was found. Changes in the pond must be caused by other sources.
From measurements during an earlier fieldtrip (28/01/1999 – 29/01/1999) the results shown in table 21 were found.

Table 21: Average ammonium concentrations

Position	Before opening [g/m^3]	After opening [g/m^3]
In the forest	0.04	0.04
At the border of the forest	0.05	0.05
In the channel	0.03	0.08
Average	0.04	0.07

After the exchange of water the ammonium concentrations increased. This increase could not be the result of the flow of water coming from the forest into the channels during outlet because the concentrations were lower in the forest. It was assumed that the ammonium produced in the pond bottom was released when the bottom was disturbed due to of the exchange of water.
In the beginning the influence of the forest was small but after some exchanges of water, the water in the forest will be fresher containing more DO, resulting in a increase of ammonium and a decrease of sulfide production. After several exchanges of water the influence from the forest, concerning ammonium was expected to be higher.
After the first and second opening, the N-flux was respectively 0.04 g/m^3 and 0.03 g/m^3.
The ammonium concentrations were low, not having a negative effect on the shrimp.

The lengths of the channels in the system were long compared to the depth a width of them. In addition, the velocities were low meaning that when the channels bend no strong secondary flow was induced meaning that the decisive flow was in the length direction of the channels. The channels can be modeled as one-dimensional.
A program for making one-dimensional models is used to model the pond. Because the water quality has to be modeled also it was chosen to use the program Duflow. Duflow has besides modeling the water movement also the possibility to program and model the water quality processes. A description of Duflow is given in appendix B.

7 The water movement

This chapter describes the modeling of the water movement and is divided into two parts. Paragraph 7.1 and 7.2 describe for respectively fieldtrip 2 and 3 the modeling and calibration. The problem during the last fieldtrip was that one Diver, measuring the outside water levels, was stolen. Because of the limited amount of data it was important also to use the water quality data collected during fieldtrip 3 in order to give a better description of the processes inside the pond. To be able to use these water quality data it was necessary to make assumptions for the outside water levels, the tide, during fieldtrip 3.

7.1 Modeling and calibration fieldtrip 2

The results of the analysis (chapter 6 and appendix C) were used to model the pond. Three different models were used to obtain the final model that was used be combined with the model describing the water quality processes.
Model 1 describes the definition of the geometry without separating the forest from the channels; defining the forest as the storage area of the channels. This model and the calibration of it are discussed in paragraph 7.1.1.
Considerable differences between the water quality processes in the forest and the channels were seen discussing the water quality data. To model these differences, the forest, in Model 1 defined as storage area of the channels, was separated from the channels. Model 2 describes the pond when the forest and channels were separated, both defined as sections parallel to each other and connected with weirs (paragraph 7.1.2).
Problems concerning the water quality output occurred in Duflow when the water depths were close to 0 m or negative. Duflow itself defines a very narrow and deep cross-section that does not effect the water movement below the defined bottom level. When the water level is below the defined bottom level, Duflow calculates a negative water depth. To avoid these problems in the water quality model, the bottom levels in the sections describing the forest were lowered making sure that the water level was permanent above the defined bottom levels. Model 3, paragraph 7.1.3 describe the pond with the bottom levels in the forest lowered.

The many uncertainties like the storage width were the reason for dividing the modeling into three different models. Due to assumptions made concerning these uncertainties when defining each model, a correct description of the water movement was eventually found and was used to model the water quality. The last defined model; Model 3 will be combined with the model describing the water quality processes. The other two models, Model 1 and 2 were only used to obtain this last model, Model 3 and will not be used further to model the water quality processes. Every paragraph starts with describing the purpose of each defined model.

7.1.1 Model 1: forest modeled as storage area of the channels

The purpose of Model 1 is:

Defining the geometry and calibrating the model to define:

- *The level the storage area starts.*
- *The storage width.*
- *The discharge coefficients of the sluices.*

Modeling and calibrating Model 1 is divided into three parts. The first part, paragraph 7.1.1.1 describes the geometry of the model with the forest defined as the storage area of the channels. The second part, paragraph 7.1.1.2 discusses the parameters used to calibrate Model 1, and the last part, paragraph 7.1.1.3 discusses the output of the model after calibration.

7.1.1.1 Defining the geometry of Model 1

The definition of Model 1 discussed in this paragraph is before calibration.

- The network

The pond was schematized having four parallel channels, meaning that two channels were combined with each other into one. These two channels were close together and had similar dimensions. The purpose of the final model was describing the water quality processes, so the geometry did not need to be identical as the real system. Duflow is used for modeling one-dimensional systems so the channel bends (secondary flow) are of no importance and were neglected.

The now four parallel channels inside could be defined each as one long section but it was chosen to divide each channel into three smaller sections. The reason for dividing each section into three smaller ones had to do with the water quality part of the model. In Model 2 (paragraph 7.1.2), the forest and channels are separated. More connections between the forest and the channels causes the water quality variables to be better spread out over the forest and channel sections, giving better results.

The outside channels from sluice A and B were connected with the sea. Both channels enter the sea at a different place. However, at both places the boundary condition, the tide was the same so the choice was made that in the model the two outside channels meet at one point where the boundary condition was defined (node 1 see figure 17).

The length and cross-sections of the channels were calculated from the measurements done during fieldtrip 1(see appendix C.1). Assumptions were made for the length of the two inside channels through the forest and the outside channels.

Defining the storage width per section, a calculation for each section was made (appendix D.1). This calculation was only an assumption and could be adjusted during the calibration.

The Chézy-factor was set on 50 $m^{1/2}/s$. From earlier studies it was seen that the Chézy-factor did not strongly influence the water movement, due to the low flow velocities in the pond.

The used network is shown in figure 17.

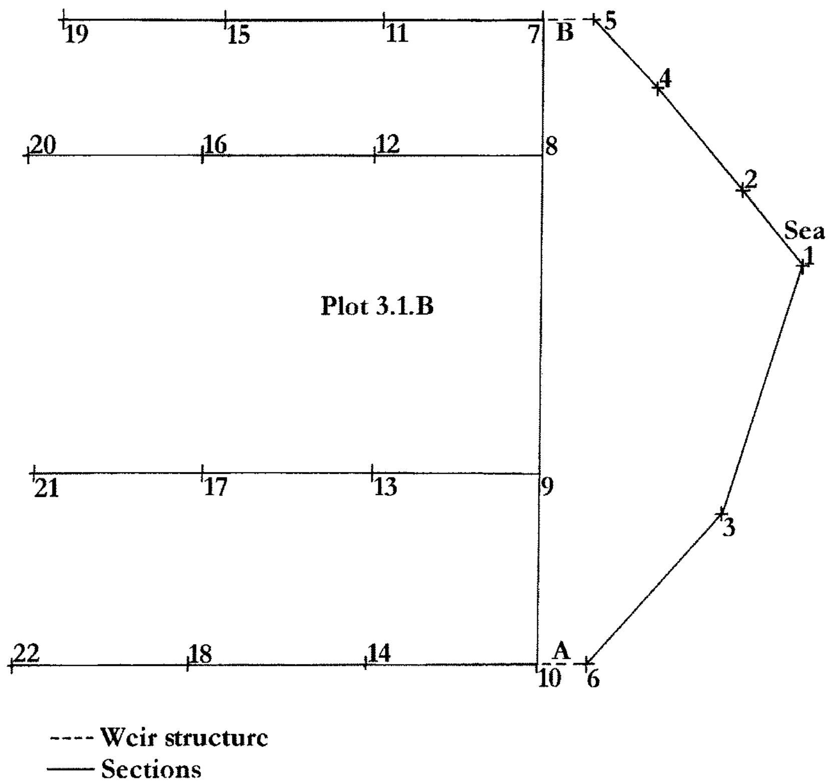


Figure 17: Network Model 1

A and B shows the positions of respectively sluice A and B that were used to exchange water.

- The sluices

The two sluices used in this model were respectively defined between node 6 and 10 (sluice A) and between 5 and 7 (sluice B), see figure 17. Both sluices are of the same type and were defined in Duflow as: weir with underflow. This structure has a sluice gate and when opened the water will flow into the other channel. The entrance width, sill- and gate-level had to be defined. The dimensions of the sluices are shown in table 22.

Table 22: The sluice dimensions

Parameter	Sluice A	Sluice B
Entrance width [m]	1.20	2.10
Sill level [m]	-2.39	-2.26
Gate level [m]	2.00	2.00

During the exchange of water, the sluice gates were for both sluices completely above the water level. Therefor the gate level for both sluices was set on 2.00 m. The water level never reached this level so the gates are out of the water during exchange.

From the Diver-data and observations the times of water exchange were found. These times were defined in the model. Table 23 shows the times the sluices were opened and closed during fieldtrip 2.

Table 23: The times of water exchange, fieldtrip 2

Sluice A			
Date	Time open	Time closed	Direction
01-03-99	18:30	20:50	Out
01-03-99	23:20	02:10	In
02-03-99	03:10	05:30	Out
02-03-99	13:50	15:50	In

Sluice B			
Date	Time open	Time closed	Direction
01-03-99	18:30	20:40	Out
01-03-99	23:20	02:10	In
02-03-99	03:10	05:30	Out
02-03-99	12:10	13:10	Out
02-03-99	13:50	15:50	In

Defining the discharge coefficients of the sluices, see table 24 the calculated discharge coefficients during the data analysis were used. Only the value 0.93 of sluice B representing the incoming was assumed to be too high (see paragraph 6.1) and was changed into 0.73. The same as the value of the coefficient of sluice A.

Table 24: First definition of the discharge coefficients

Direction	μ_{input} [-]
Sluice A inlet	0.73
Sluice B inlet	0.73
Sluice A outlet	0.46
Sluice B outlet	0.53

- The boundary conditions

The tide, measured by the Diver, installed outside the pond, was the boundary condition in this model. In Duflow this tide was described using Fourier series (formula 7.1):

$$y_t = y_0 + \sum_{k=1}^{N} y_k \cos(k\omega t - \Phi_k) \quad \text{with } \omega = \frac{360}{P_1} \qquad \text{(Formula 7.1)}$$

Use was made of two cos. functions and with trial and error a curve was fitted. Figure 18 compares the Diver-data with the fitted curve that represent the tide in Duflow.

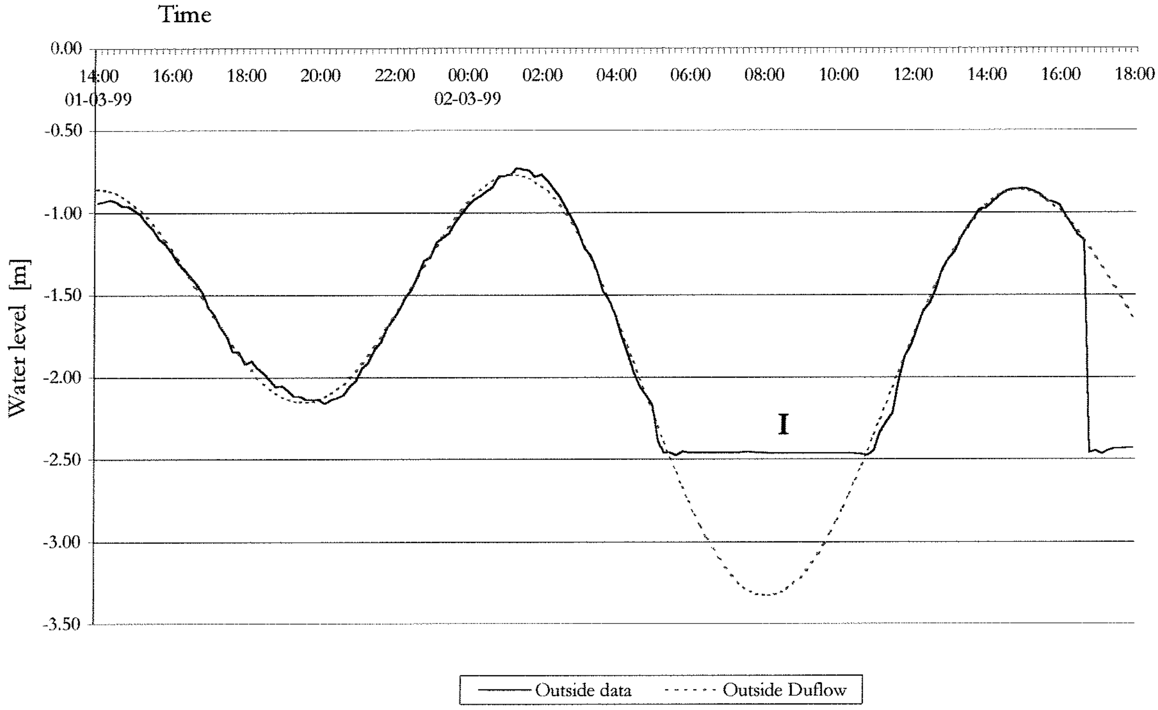


Figure 18: Comparing the measured outside water levels with Duflow

The fitted curve was close to the measured data. Figure 18 showed that during a period of time the water level was constant (number I in figure 18). During that period, due to the high tidal range, the Diver was above the water level, only measuring the air-pressure that was assumed constant during that period. If the fitted curve followed the tide during that period is not known, but the water level during that period was on no importance because the sluices were not opened then.

The used parameters to describe the boundary condition in Duflow are shown in table 25.

Table 25: Parameters Fourier series, fieldtrip 2

Component	Amplitude [m]	Phase [°]	Cycle component [hhmm]
0	-1.80	-	-
1	0.59	101	2450
2	0.94	13	1225

- The initial conditions

The calculation starts 01-03-1999 at 13:00 hours. At that time, the sluices were closed resulting in a horizontal water level. From the data the water levels at those times were found. Due to the closed sluices, the discharge was 0 m^3/s. Table 26 shows the initial conditions.

Table 26: Initial conditions, fieldtrip 2

	Water level [m]	Discharge [m^3/s]
Inside	-1.05	0
Outside	-0.99	0
Sluices	-	0

7.1.1.2 Parameters used for calibration

After defining the model, it was calibrated. This paragraph describes the two parameters, the storage area and the discharge coefficients that were used to calibrate Model 1 to get the wanted results. The reasons why it was allowed to use both parameters in order to calibrate Model 1 is discussed here.

- The storage area

Due to the high density of mangroves (see paragraph 5.1) no measurements could be done in the forest to define the dimensions of the storage area, causing this to be the most uncertain parameter in the model.
A first estimation of the storage width was made calculating the whole storage area and dividing this over all sections. For this calculation, shown in appendix D.1, the length measurements done during fieldtrip 1 were used.
The level the storage area starts was also unknown and assumptions were made concerning this level it started and the width of it. Calibrating Model 1 was done by first changing the level the starting level, followed by changing the width of the storage area of the sections.
Most of the calibration was done changing the parameters of the storage area. When changing the storage area parameters did not improve the model anymore the other parameter, the discharge coefficients were used to calibrate the model further.

- The discharge coefficients

The discharge coefficients were calculated using the velocity measurements in the sluices. Due to the high velocities of the water through the sluices during water exchange, high forces worked on the Ott-meter making it difficult to hold the instrument in the flow direction causing the measurements to be not very accurate.
It was seen calculating the discharge coefficients that values were found that were not expected. The value of 0.93 during inlet at sluice B, caused by the small height difference during the measurements was too high. According to observations done, the assumption was made that the discharge coefficients of sluice A and B during inlet would be the same.
In spite of the more vortexes observed near sluice B during outlet, the discharge coefficient of sluice A was lower compared to the discharge coefficient of sluice B. A higher discharge coefficient for sluice A was expected.
Comparing two sub-measurements of one complete measurement near the bottom during the inlet of water (the water flowed in a straight line towards sluice A), large differences occurred. At the left side of sluice A, near the bottom, 284 revolutions were measured and at the right side near the bottom 356. These differences are the result of the difficulties during measuring like holding the Ott-meter in the flow direction.
The assumption was made that the differences discussed above were the result of the inaccurate measurements meaning that the calculated discharge coefficients should only be used as indications instead of exact values. It was concluded that changing the discharge coefficients to calibrate Model 1 to diminish the small differences between Duflow and reality was allowed.

7.1.1.3 Results of the calibration

To show the reliability of the model the results are discussed here. The output will be compared with the measured data. As seen in paragraph 7.1.1.1, the boundary condition used was fitted to the measured data and will not be discussed further.
The found values of the discharge coefficients of the sluices will be discussed first. The calibrated values are shown in table 27.

Table 27: Calibrated discharge coefficients

Direction	$\mu_{cal.}$ [-]	μ_{input} [-]
Sluice A inlet	0.70	0.73
Sluice B inlet	0.70	0.73
Sluice A outlet	0.55	0.46
Sluice B outlet	0.53	0.53

The coefficients that represent the inlet had, as expected for both sluices the same value, and were close to the first estimation. The coefficient for the outlet of sluice B remained the same. On the contrary, the discharge coefficient of sluice A changed a lot compared with the values before calibration and became higher than the discharge coefficient during outlet of sluice B. The value was higher than the discharge coefficient of sluice B. From the observations done (see paragraph 5.2.3) a higher value of sluice A during outlet was expected.
Also one value of the Chézy-factor was changed. The Chézy-factor of section 4 was changed from 50 into 30 $m^{1/2}/s$. This change made the model stable.

Figure 19 compares the inside water levels that were measured with the output of Duflow after calibration.

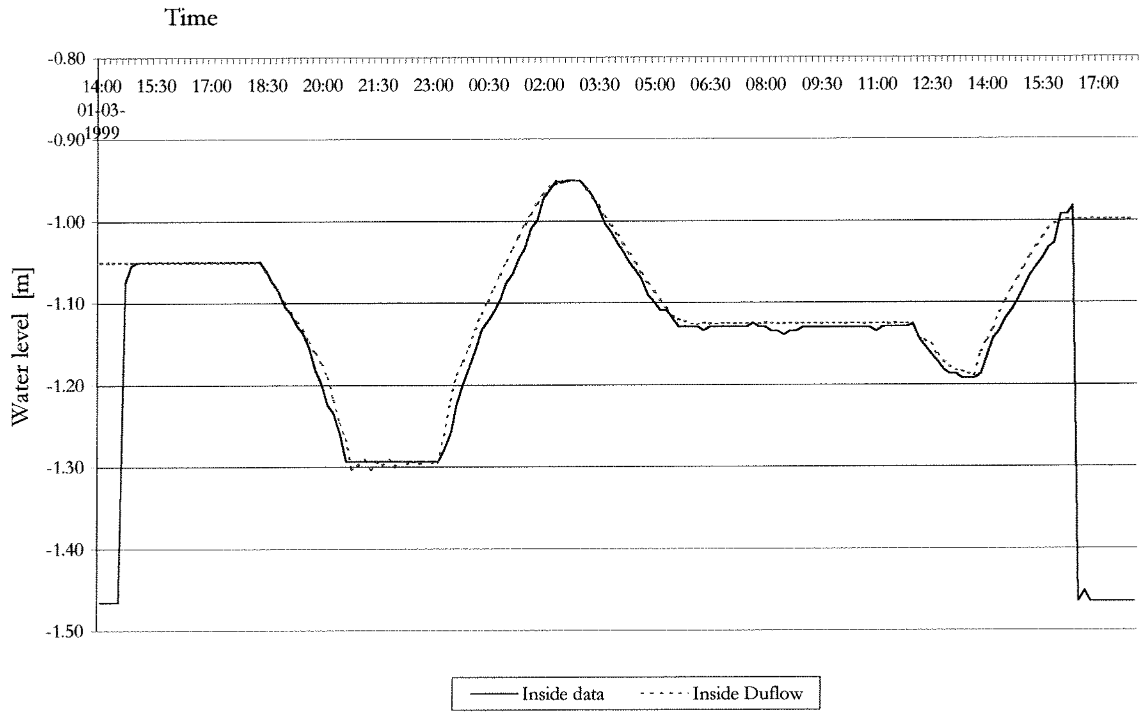


Figure 19: Comparing the measured inside water levels with Duflow

Figure 19 shows that the Duflow output was not exactly the same as the measured water level. Because of the assumptions made, it was difficult to obtain the same results compared to the measured data. An accuracy of 3 – 4 cm was allowed describing the water movement. Comparing the Diver-data with the Duflow output it was concluded that the water levels describe the reality close enough.
Figure 20 shows the in- and outside water levels of both the measured data and Duflow.

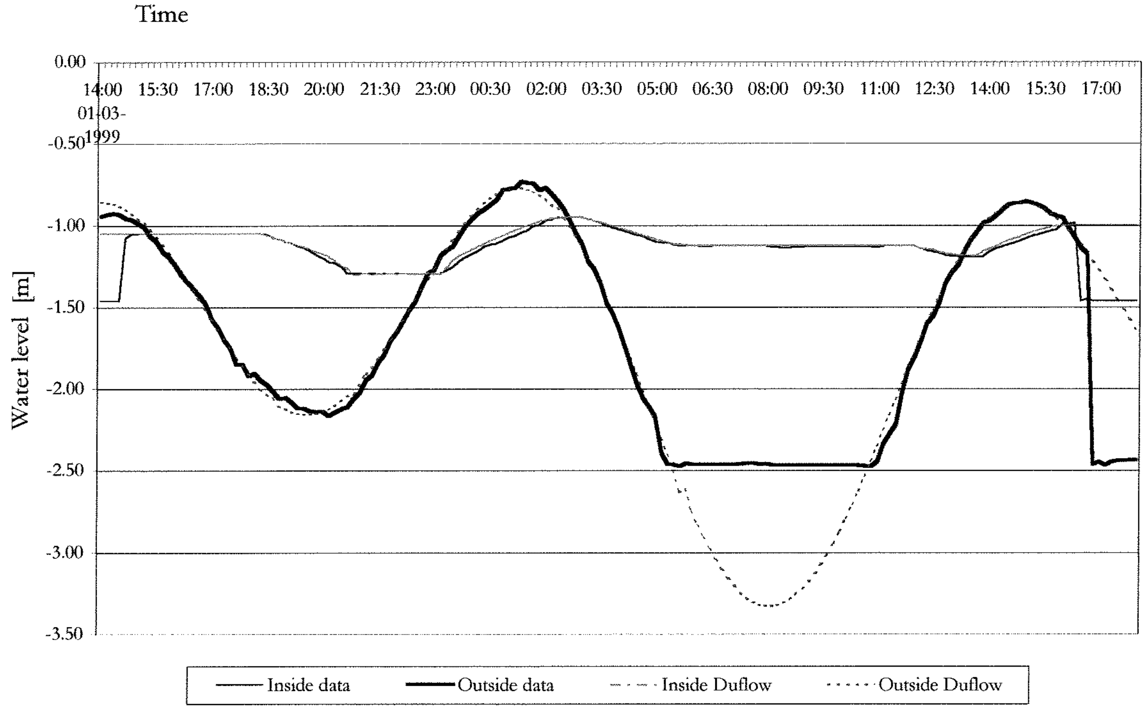


Figure 20: Comparing the measured in- and outside water levels with Duflow

After having a good description of the water levels in- and outside the pond other observations like heading up and translatory waves were checked. During the outlet of water, due to the narrowness of the first part of the channel, near sluice B heading up occurred and was observed; a quick rise of the water level. Figure 21 shows the output of Duflow describing the heading up (number I, II and III, figure 21) of water just outside the pond at sluice B. Besides the water level near sluice B, the tide and the inside water level are shown.

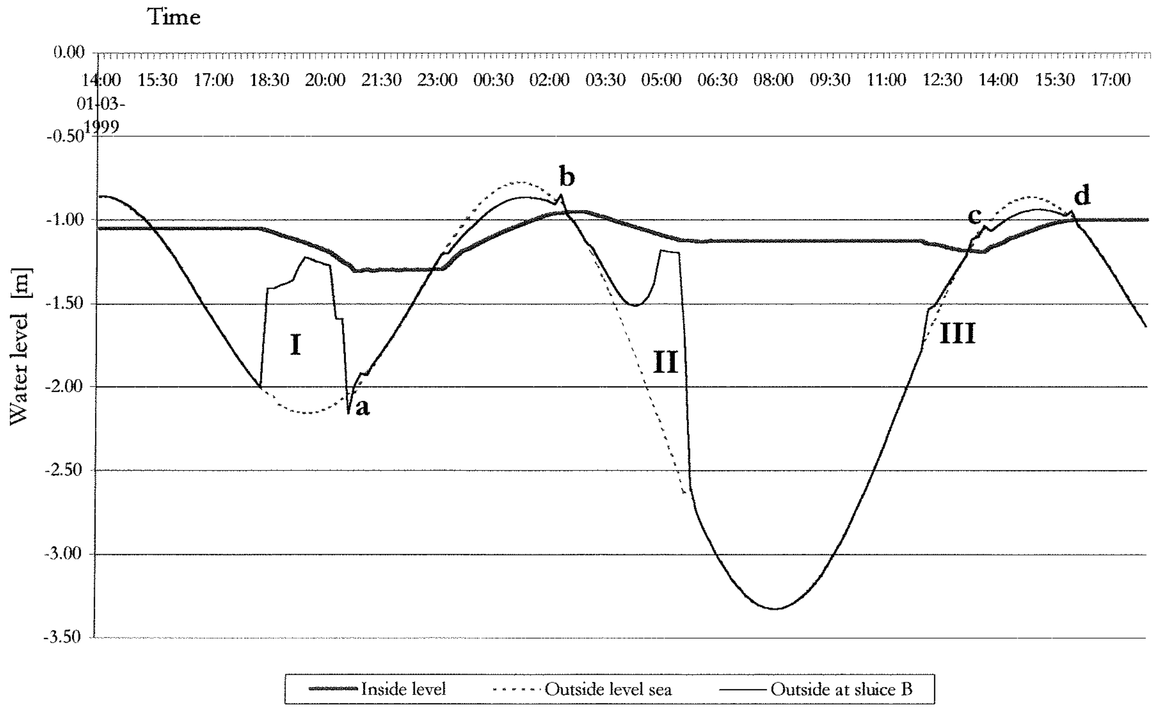


Figure 21: Water levels Duflow, fieldtrip 2

Figure 21 shows the water level in the channel just outside of sluice B. It can be seen that this level was sometimes below the defined bottom level (≈ -2.26 m). Below the defined bottom level,

Duflow itself defines a very narrow and deep cross-section that does not influence the water movement. Due to the very deep cross-section, the water level followed the tide below the defined bottom level.
Figure 21 shows three (number I, II and III) times heading up of water. All three registrations were different from each other caused by different outside water levels when the water was exchanged was started. All three the heading ups are discussed here.

I: The water level outside the pond just before opening was low, -2.00 m and still dropping. Opening the sluice, the water was let out causing the water level due to the narrowness of the first part of the channel just outside sluice B to rise quickly. Water that entered this part of the channel could not flow with the same velocity into the wider channel that led to the sea causing the heading up of water. The water level in Duflow rose until a level of –1.24 m (measurements showed a level of –1.36). Due to the rise of the water level just outside sluice B the height difference between the in- and outside water levels decreased causing the flow velocity through sluice B and so also the discharge to decrease too. At a certain moment the discharge through sluice B had the same value as the volume of water that was discharged from the narrow channel into the wider channel causing the water level near sluice B to stop rising. This discharge was the maximum discharge of the narrow channel towards the wider one. With a dropping inside water level and maintaining the constant maximum discharge into the wider channel, the water level outside near sluice B also dropped. After closing the sluice the water level in the channel outside near sluice B dropped further until it reached the water level at sea. From that moment it followed the tide again until the next outlet of water.

II: Due to a higher water level, ≈ -1.15 m just before water outlet compared to situation I, not a lot of heading up of water was seen. The water level outside, the tide dropped even further until the narrow channel could not handle the water that entered from the pond (water level tide was ≈ -1,75 m) anymore. At this moment the water was headed up, a rapid rise of the water levels. When the sluices were closed the water level dropped quickly and followed the tide again.

III: Because the tide was high (≈ -1.75 m) and still rising, the heading up of water was not clearly visible as seen during the other two periods.

Besides the heading up of water, also a translatory wave was observed in the channel just outside sluice B after closing the sluice. The water level rose and dropped for a few minutes until the wave was damped out. A total of 4 of these waves were visible in figure 21: a, b, c and d. Not a change of water level describing a wave was seen but only a peak. The reason for not seeing the wave is because during the fieldtrip this wave was only observed for a few minutes before it was damped out and the time-step used here is 10 minutes.

The velocities in the sluices were checked comparing them with the measurements done. Because, as said before, the measurements were not very accurate the measured values must be used as an indication of the velocity. The velocities are shown in figure 22.

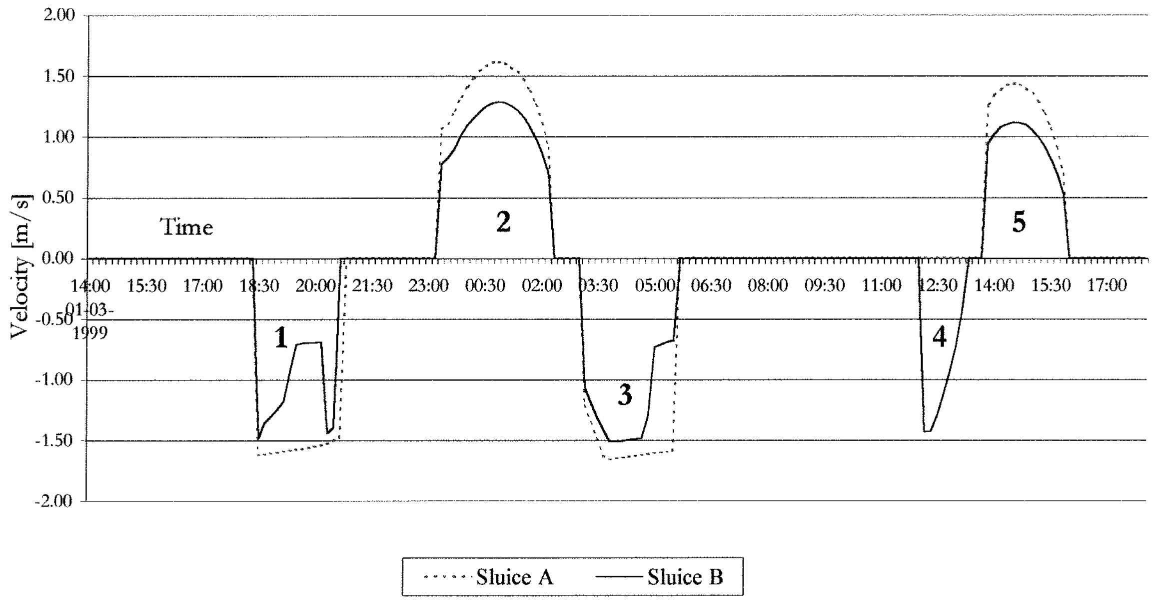


Figure 22: Velocities in the sluices in Model 1, fieldtrip 2

Due to the heading up of water outside sluice B the height difference between the in- and outside water levels reduced causing the flow velocity through sluice B to decrease. Because of this it was expected that the velocities through sluice B should be lower compared with sluice A. The reduction of the velocities, because of heading up, through sluice B during outlet 1 and 3 were clearly visible in the figure 22. No change in the velocities was seen during outlet 4 due to the little heading up (see figure 21).
Table 28 compares the velocities measured with the velocities calculated by Duflow. The numbers of opening refer to the numbers shown in figure 22.

Table 28: Comparing the velocities, fieldtrip 2

Sluice A		
Opening	$v_{meas.}$ [-]	v_{Duflow} [-]
1	-1.78	-1.63
2	1.67	1.59
5	1.56	1.33
5	1.70	1.44

Sluice B		
Opening	$v_{meas.}$ [-]	v_{Duflow} [-]
1	-1.08	-0.99
2	1.17	1.09
4	-0.87	-0.80
5	1.31	1.10

As result of the inaccurate measurements and the assumptions made during modeling the velocities were not completely the same but were of the same order.

In paragraph 6.1 it was written that the inside water levels would rise and drop as a horizontal plate. Figure 23 shows several nodes throughout the whole pond that confirm the rising and dropping of the water level as a horizontal plate. The differences in the water levels can be neglected.

Figure 23: Water levels inside the pond

From the results of calibration it can be seen that the inside water levels, the tide and the velocities were close to the measured data. With the assumptions made it was concluded that this model was reliable when it comes to describing the water movement.

7.1.2 Model 2: separated definition of the forest and channels

The purpose of Model 2 is:

Defining and calibrating the model with the forest and channels separated to define:

- *The new sections that describe the forest.*
- *The sill levels of the weirs that connect the forest sections with the channel sections.*

In paragraph 7.1.1.3 Model 1 was calibrated. With this calibration the discharge coefficients and the storage area parameters were defined.
From the data analysis, it was seen that considerable differences occurred between the SOD values in the forest and in the channels, differences as 63.1 and 1.7 $g/m^2 \cdot day$. To model these differences the forest was separated from the channels.
The calibrated model, Model 1 is improved, but no changes will be made concerning the discharge coefficients and the storage area parameters.
Parallel to every channel section inside the pond another section representing the forest was defined, having bottom levels that were the same as the levels the storage area started in Model 1. The dimensions of the new sections were the same as the storage area of the channels from the calibrated model, Model 1. An example of defining the new sections is shown in figure 24.

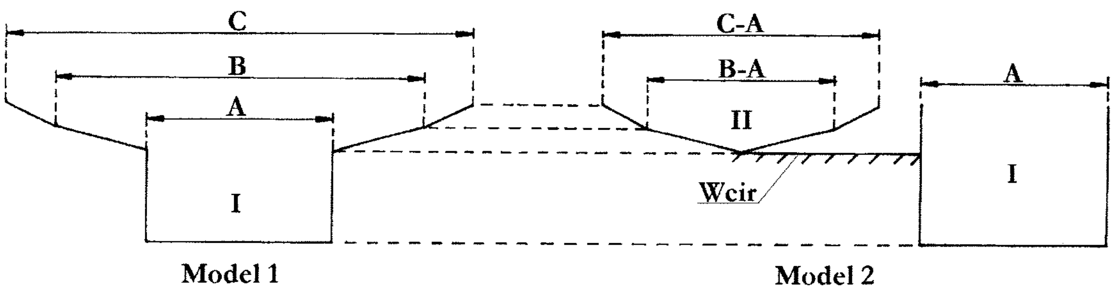
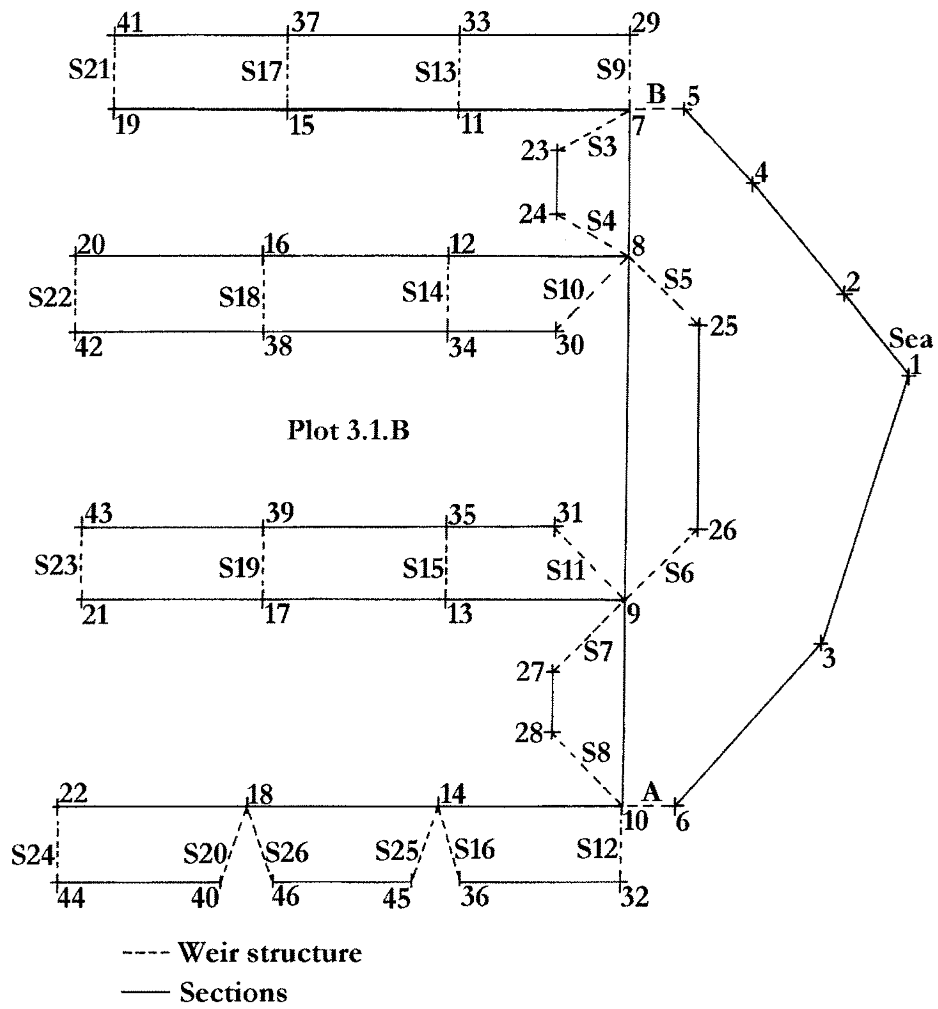


Figure 24: Defining the new cross-section

In Model 2 see figure 24, channel I represent the channels in the pond and channel II the forest. The dimensions used in Model 2, see figure 24 were the same as used in Model 1. The sections representing the channels and forest in Model 2 were connected using weirs. The new network is shown in figure 25. The length of the forest sections was the same as the length of the channel sections.

The dotted lines between the sections represent the weirs (see figure 25). "S" stands for structure, for instance S22 is weir number 22. The coordinates and length of the sections together with the characteristics of the structures are shown in appendix D.2.



---- **Weir structure**

—— **Sections**

Figure 25: Network Model 2 and 3

The sections representing the forest and the channels were connected using weirs with free overflow. With the water level below the defined sill level of the weir, no water will be exchanged between the channels and the forest. There would only be an exchange of water when the water level was above the defined sill level. Besides the sill level the width of each weir had to be defined. One section contained two weirs. The width of the weirs was the same as the length of the section equally divided between the two weirs. For instance: the width of weir S18 (see figure 25) was half the length of the section between node 12 and 16 with half the length of the section between node 16 and 20 added to it. The total length of all the channels is equal to the total width of the weirs. Defining the sill levels of the weirs only constant values could be used. Because the level the storage area starts at the beginning of each section was different compared with the end of it, an average value was used to define the sill level.
During calibration the levels of the sills were adjusted to get the same results compared to the results of the calibrated model, Model 1 in paragraph 7.1.1.3.
As seen in figure 25 the lowest of the four parallel sections was slightly different modeled. Connecting the new sections with the channels using only four weirs it was not possible to obtain the same results as calibrated in Model 1. Correct output was found when two more weirs were defined that separated the three sections.
The reason for these wrong results could be the combination of the constant sill level with the slope in that channel. The difference in bottom level between the beginning and end of the channel, 0.43 m was larger compared to the other channels.
Model 2 gives the same results as the calibrated model, Model 1 of paragraph 7.1.1.3 so it was concluded that Model 2 was reliable when it comes to describing the water movement.

7.1.3 Model 3: Permanent water in the forest

The purpose of Model 3 is:

> *To lower the bottom level of the sections that describe the forest to have a permanent level of water in it to avoid problems during the modeling of the water quality.*

The water quality processes are described using mathematical equations (see chapter 8). To get the average value of the water quality variables over the vertical water column the processes were divided by the water depth. When the water depth in the sections was very small, close to 0 m, or a water level below the defined bottom level (negative depth) problems occurred in water quality output, giving extreme concentrations were calculated.
To avoid these problems a permanent water level must be present in each section, above the defined bottom level. The way the sections describing the forest were defined in Model 2 they would dry up after water outlet causing these problems in the water quality output. Therefor it was chosen that the highest part of each section describing the forest at least contained a water level of five centimeters. The choice of this five-centimeter height was arbitrary.

Due to the changing of the storage area the Duflow output was not the same anymore as measured so adjustments to the storage area were done to obtain the same results as before. The only parameters to be changed here were the storage width and the level each width was defined during the calibration of Model 1. The other parameters like discharge coefficients and sill levels of the weirs were not changed.

After calibrating the model by changing the storage area, the following results were found. Figure 26 shows the inside levels are the same as calibrated in paragraph 7.1.1.3.

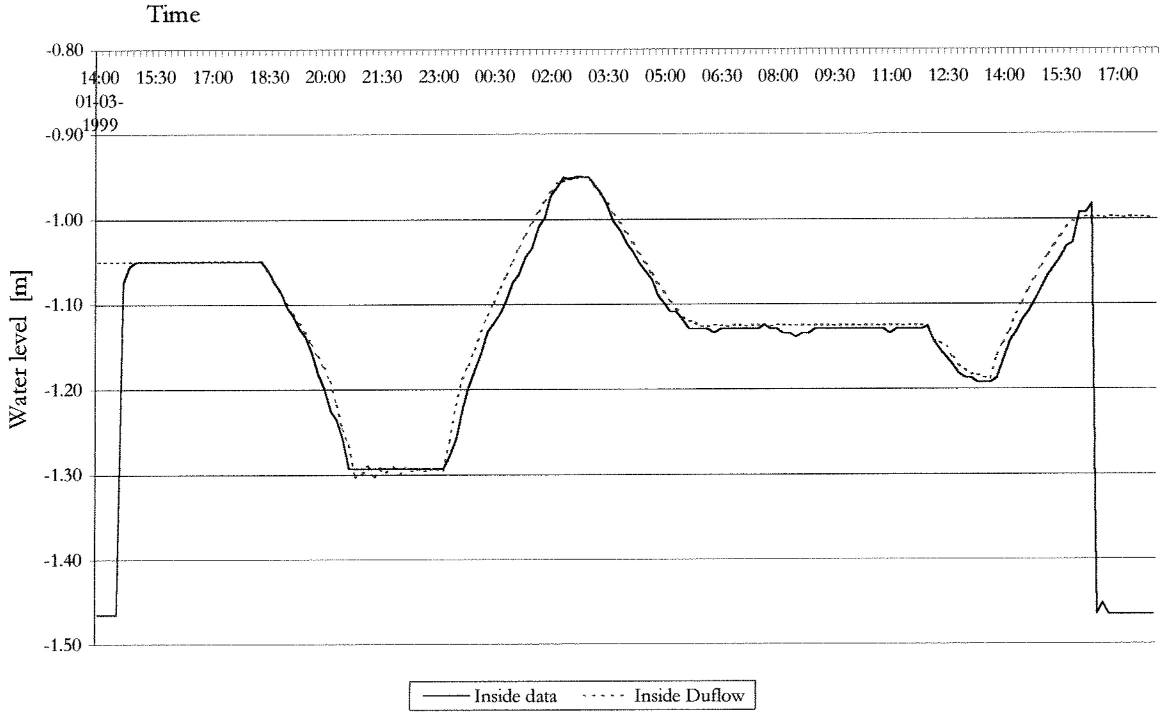


Figure 26: Comparing the measured inside water levels with Model 3, fieldtrip 2

Figure 27 shows the inside water levels combined with the outside water levels at sea and near sluice B. Near sluice B again the heading up of water (number I, II and III in figure 27) and the induced translatory wave (a, b, c and d in figure 27) are visible.

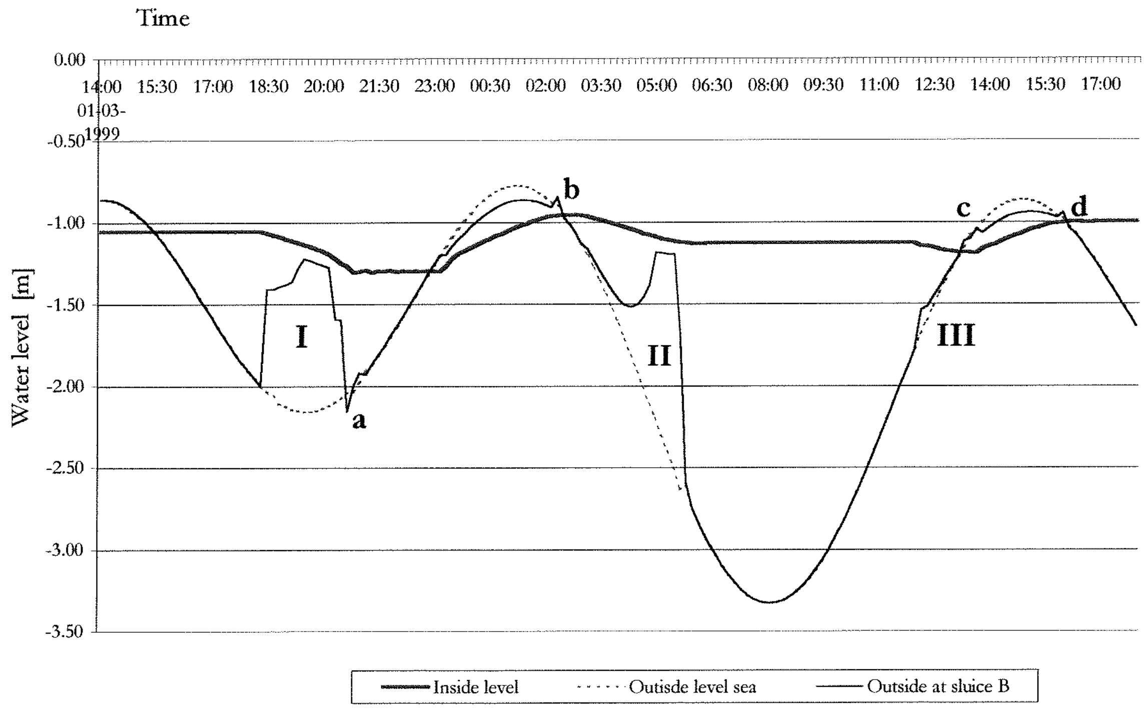


Figure 27: Water levels Model 3, fieldtrip 2

The found velocities, see figure 28 were identical to those who were found during the calibration of Model 1 in paragraph 7.1.1.3.

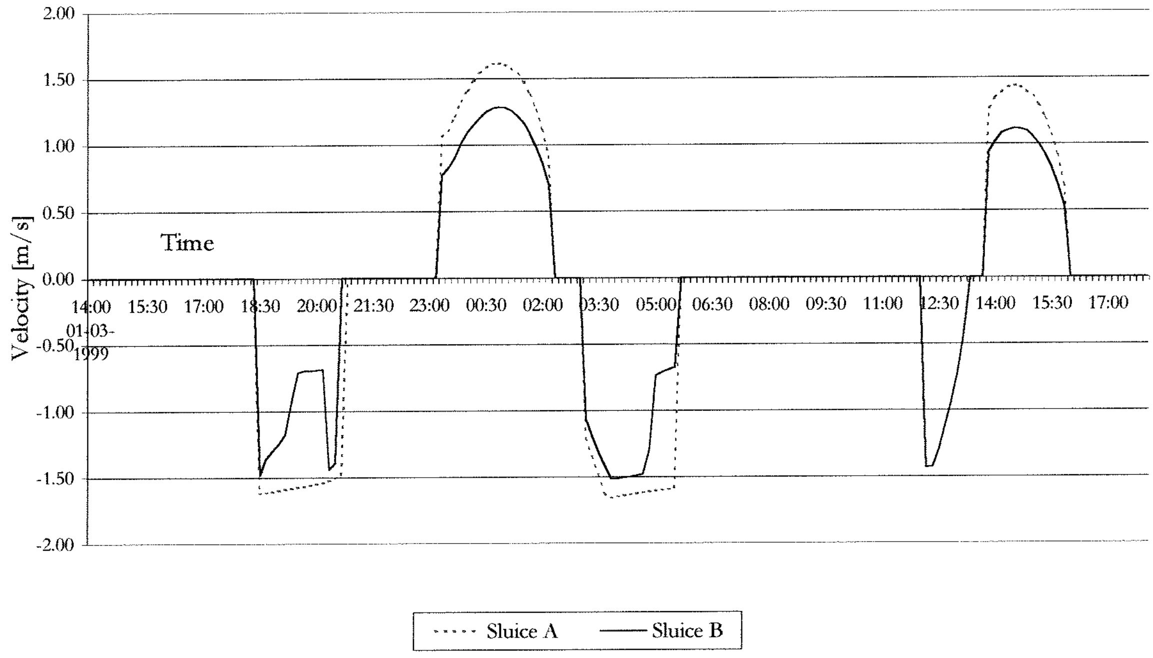


Figure 28: Velocities in the sluices in Model 3, fieldtrip 2

The velocities were identical to those of the calibration of Model 1 and 2, so no further comparison was made here between the measured velocities and the Duflow output. This was already done in paragraph 7.1.1.3.

Looking at the results of this model it can be seen that they were close to the measured data. With the assumptions made it was concluded that the model here was reliable when it comes to describing the water movement of fieldtrip 2.
Model 3 will be used to model the water quality. The other two models, Model 1 and 2 will not be used further.

7.2 Modeling and calibrating fieldtrip 3

Due to the lack of water quality data it was important also to use the water quality data collected during fieldtrip 3 to give a better description of water quality processes in the pond.
During this fieldtrip the Diver that registered the outside water levels, was stolen so no data for defining the boundary condition was available. To be able to use the water quality data of this fieldtrip a boundary condition was assumed.
Normally the measurements of fieldtrip 3 would be used to verify the assumptions made defining the geometry of Model 3 in paragraph 7.1.3. Replacing the initial and boundary conditions from that fieldtrip in those of fieldtrip 3 the output should be the same as measured during fieldtrip 3. Due to the stolen Diver no data was available to describe the boundary condition of fieldtrip 3 so the model defined in paragraph 7.1.3 could not be verified. Instead of verifying Model 3, Model 3 was used to define a boundary condition for fieldtrip 3. Calibrating a model to get the boundary condition is unusual but is necessary to complete the model so the water quality data measured during fieldtrip 3 could be used.
The found dimensions of the geometry of the pond and the discharge coefficients were assumed to be correct. During the modeling of fieldtrip 3 no defined parameters of Model 3 describing fieldtrip 2 were changed.
This paragraph is divided into two parts; the model definition discussed in paragraph 7.2.1, followed by calibrating this model to get a boundary condition, paragraph 7.2.2.

7.2.1 Defining the model

The parameters describing the geometry (cross-sections and storage area) and the sluice dimensions as defined in Model 3 were the same for both fieldtrips and assumed to be correctly modeled. The parameters that were different from fieldtrip 2 were besides the boundary condition, the times of water exchange, and the initial conditions. These parameters are discussed here.

- Times of water exchange

The only thing that was different compared to fieldtrip 2 were the times of water exchange of both sluices. Table 29 shows the times of water exchange during fieldtrip 3.

Table 29: Times of water exchange, fieldtrip 3

Sluice A			
Date	**Time open**	**Time closed**	**Direction**
16-03-99	18:15	20:15	Out
16-03-99	23:50	01:30	In
17-03-99	02:45	04:20	Out
17-03-99	12:55	14:55	In
17-03-99	18:05	19:55	Out
18-03-99	00:15	02:25	In
18-03-99	03:15	05:05	Out

Sluice B			
Date	**Time open**	**Time closed**	**Direction**
16-03-99	18:15	20:15	Out
16-03-99	23:50	01:30	In
17-03-99	02:45	04:20	Out
17-03-99	12:55	14:55	In
17-03-99	18:05	19:55	Out
18-03-99	00:15	02:25	In
18-03-99	03:15	05:05	Out

- The initial conditions

Because this model starts at a different time the initial conditions were different. The calculation starts at 16-03-1999 at 13:00 hours. The initial conditions used are shown in table 30.

Table 30: Initial conditions, fieldtrip 3

	Water level [m]	Discharge [m^3/s]
Inside	-1.05	0
Outside	-0.87	0
Sluices	-	0

- The boundary condition

A tide-prediction program (*Simplified harmonic method of tidal prediction, NP159a, Version 2.00*) gave similar output describing the tide during both fieldtrips. Comparing the results of the prediction program with the measured data of fieldtrip 2 it was seen that they were not similar making the program not useful to make an assumption for the tide during fieldtrip 3. Because the prediction program gave for both fieldtrips a similar development of the water levels in time, the assumption was made that the tide during fieldtrip 3 should also be similar to the tide measured during fieldtrip 2. Therefor the boundary condition used to model fieldtrip 2 was used here as an initial value. The parameters to describe the boundary condition are shown in table 31.

Table 31: Initial parameters boundary condition, fieldtrip 3

Component	Amplitude [m]	Phase [°]	Cycle component [hhmm]
0	-1.80	-	-
1	0.59	101	2450
2	0.94	13	1225

7.2.2 Calibrating the model

The correctness of the defined boundary condition was checked comparing the inside water levels measured with the Duflow output. Using the initial parameters of the boundary condition (table 31) of fieldtrip 2 the flow-calculation became unstable. This problem was solved adjusting the parameters describing the boundary condition.
During the calibration only changes were made concerning the phases and amplitudes of component 1 and 2. With trial and error the model was calibrated and a boundary condition was defined. The parameters found after calibration to describe the boundary condition are shown in table 32.

Table 32: Calibrated boundary condition, fieldtrip 3

Component	Amplitude [m]	Phase [°]	Cycle component [hhmm]
0	-1.80	-	-
1	0.645	89	2450
2	0.930	11	1225

To show that these found parameters can be used for modeling fieldtrip 3 the inside levels of the data were compared with the output of Duflow. Figure 29 shows this comparison.

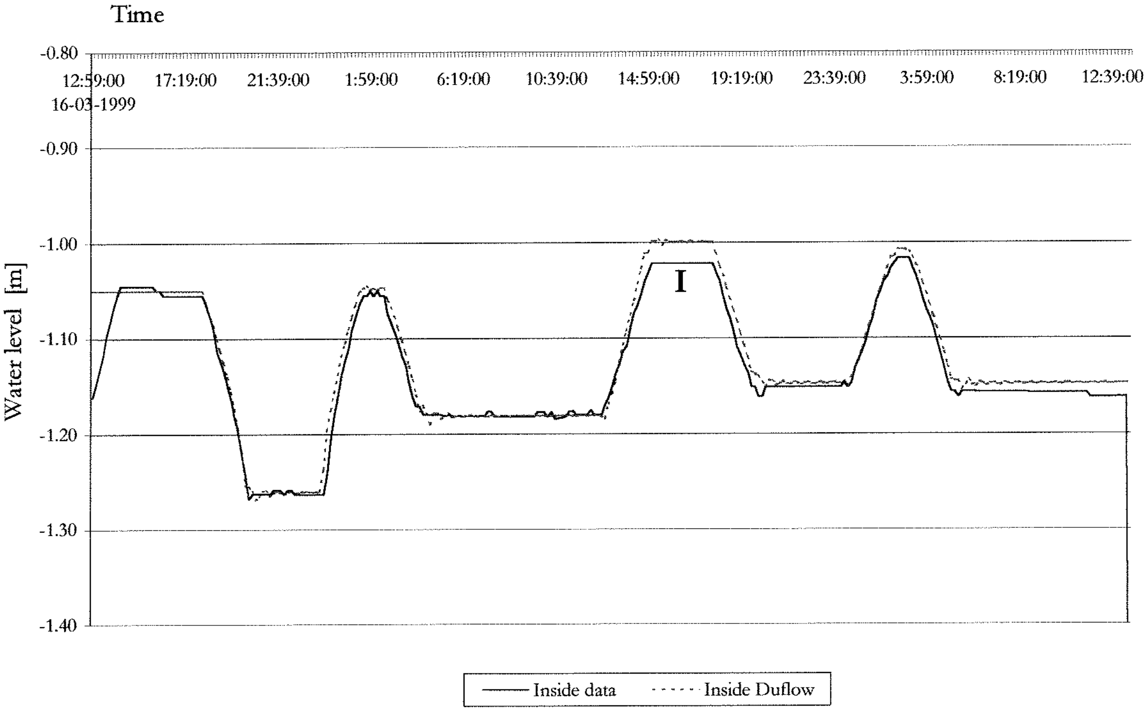


Figure 29: Comparing the measured inside water levels with Duflow, fieldtrip 3

From figure 29 shows that the measured inside water levels and Duflow were close together. At point I (see figure 29) a difference of 2 cm was seen. As written before an accuracy of 3 – 4 cm was wanted. During that period, no gauge readings were done so the water levels were not known and with the assumptions made concerning the air-pressure, a difference could easily occur. The difference of 2 cm was allowed.
This model also described the heading up of water, as observed, in the channel outside sluice B. The heading up of water (number I, II, III and IV of figure 30) in this channel together with the in- and outside water levels will be shown in figure 30. The outside water level, the tide, was the calibrated boundary condition.

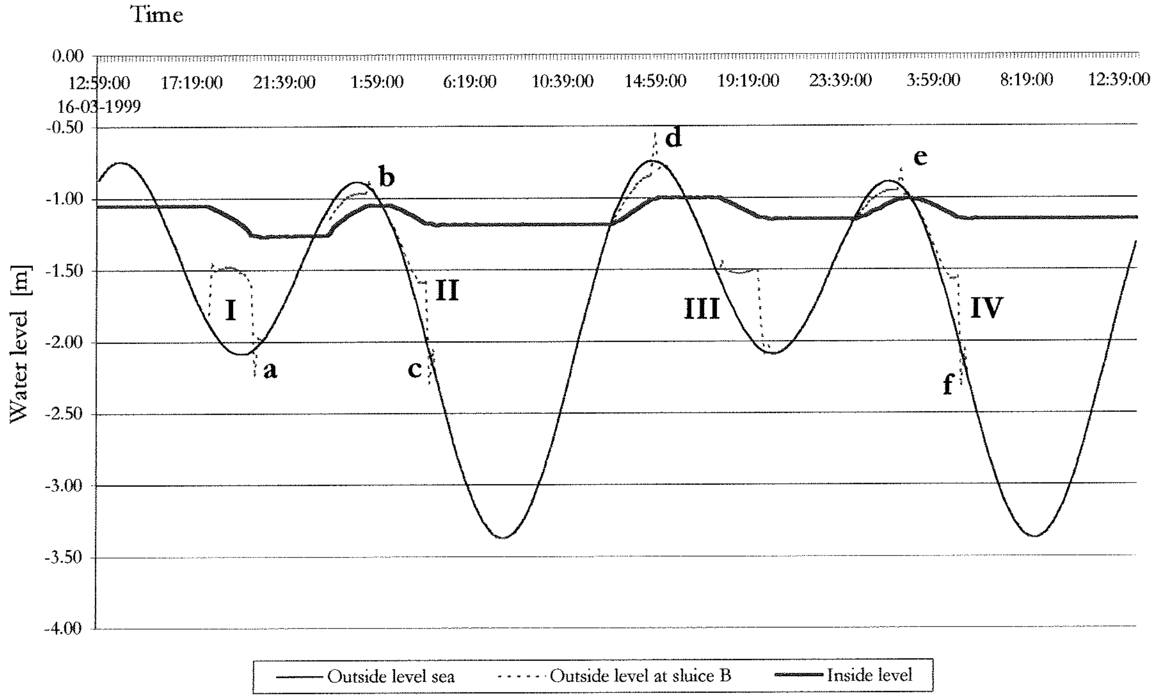


Figure 30: Water levels Duflow, fieldtrip 3

Points I till IV of figure 30 refer to the heading up during the outlet of water. a till f in figure 30 shows the places of the translatory waves.
Figure 31 shows the velocities of the water through the sluices.

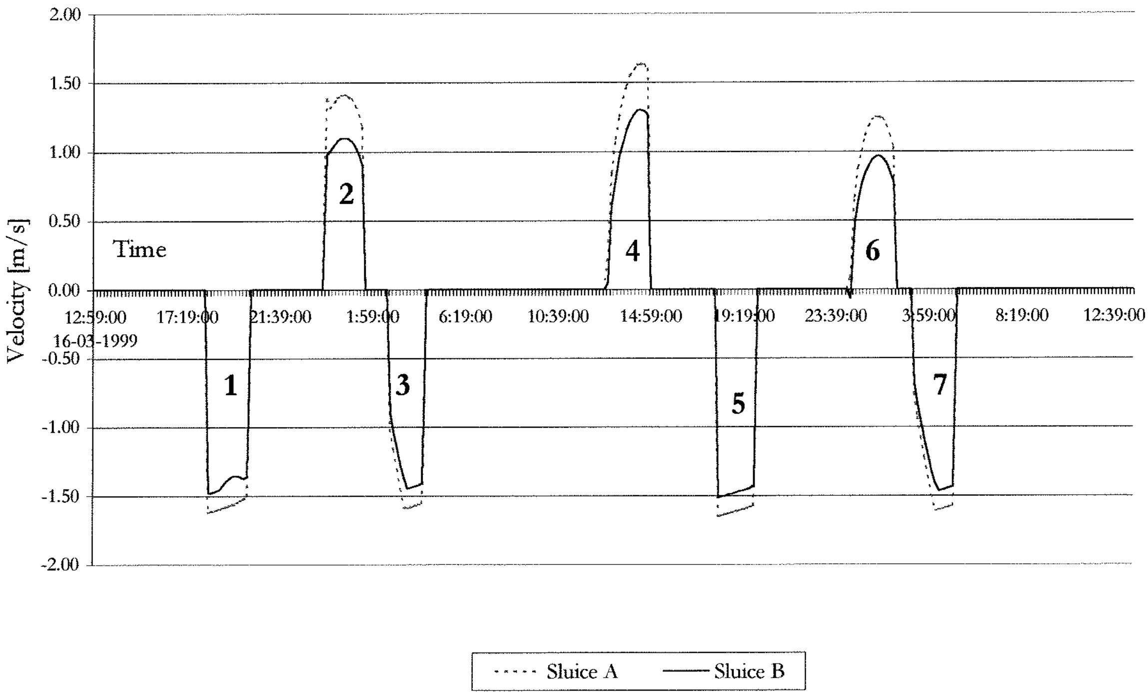


Figure 31: Velocities in the sluices Duflow, fieldtrip 3

During opening 1 and 4 (see numbers figure 31) velocity measurements were done. A check was made comparing the velocities from the measurements with Duflow. This is shown in table 33.

Table 33: Comparing the velocities in the sluices, fieldtrip 3

Sluice A		
Opening	$v_{meas.}$ [m/s]	v_{Duflow} [m/s]
1	-1.67	-1.60
4	1.66	1.60

Sluice B		
Opening	$v_{meas.}$ [m/s]	v_{Duflow} [m/s]
1	-1.04	-1.48
4	1.16	0.97

Comparing the measured velocities with the output of Duflow at sluice A, the similar values were seen. Larger differences occurred at sluice B during the outlet, caused by the heading up of water in that outside channel. The heading up is difficult to model but it strongly influences the height difference between the in- and outside water levels, so also influencing the amount of water that is exchanged.

With the assumptions made for the boundary conditions it was seen that the results of Duflow were close too the measurements. Therefore it was concluded that this model was reliable when it comes to describing the water movement and could be used to model the water quality processes of fieldtrip 3.

8. The water quality

After modeling the water movement the water quality was modeled and will be discussed in this chapter. Only the most important processes were modeled using the variables that had the most influence. First the processes together with the reasons for modeling or neglecting certain variables will be discussed (paragraph 8.1). Every process will be described using mathematical equations. These equations together with the used parameters are discussed in paragraph 8.2. After defining the processes in Duflow and defining the external variables, parameters, initial and boundary conditions (paragraph 8.3), the output of the model will be discussed (paragraph 8.4). This chapter ends with a summary of the most important phenomena seen during the discussion of the output of the model (paragraph 8.5). The decisions made in this chapter were made together with Ir. J.J.M. de Klein from Wageningen Agricultural University, Department of Environmental Sciences, Aquatic Ecology and Water Quality Management group.

8.1 Selection processes and variables to model

Defining the water quality model, it was chosen only to model those processes that were very important. Modeling the processes only the most important variables will be used or those that could easily be influenced in order to improve the system. The reasons for modeling or neglecting variables will be discussed in this paragraph.
The most important process in the pond was the changing of the DO-concentration in time, which was also the main reason to do this research. Figure 32 schematically shows the water quality variables that influence the DO-concentrations as discussed in paragraph 2.2.

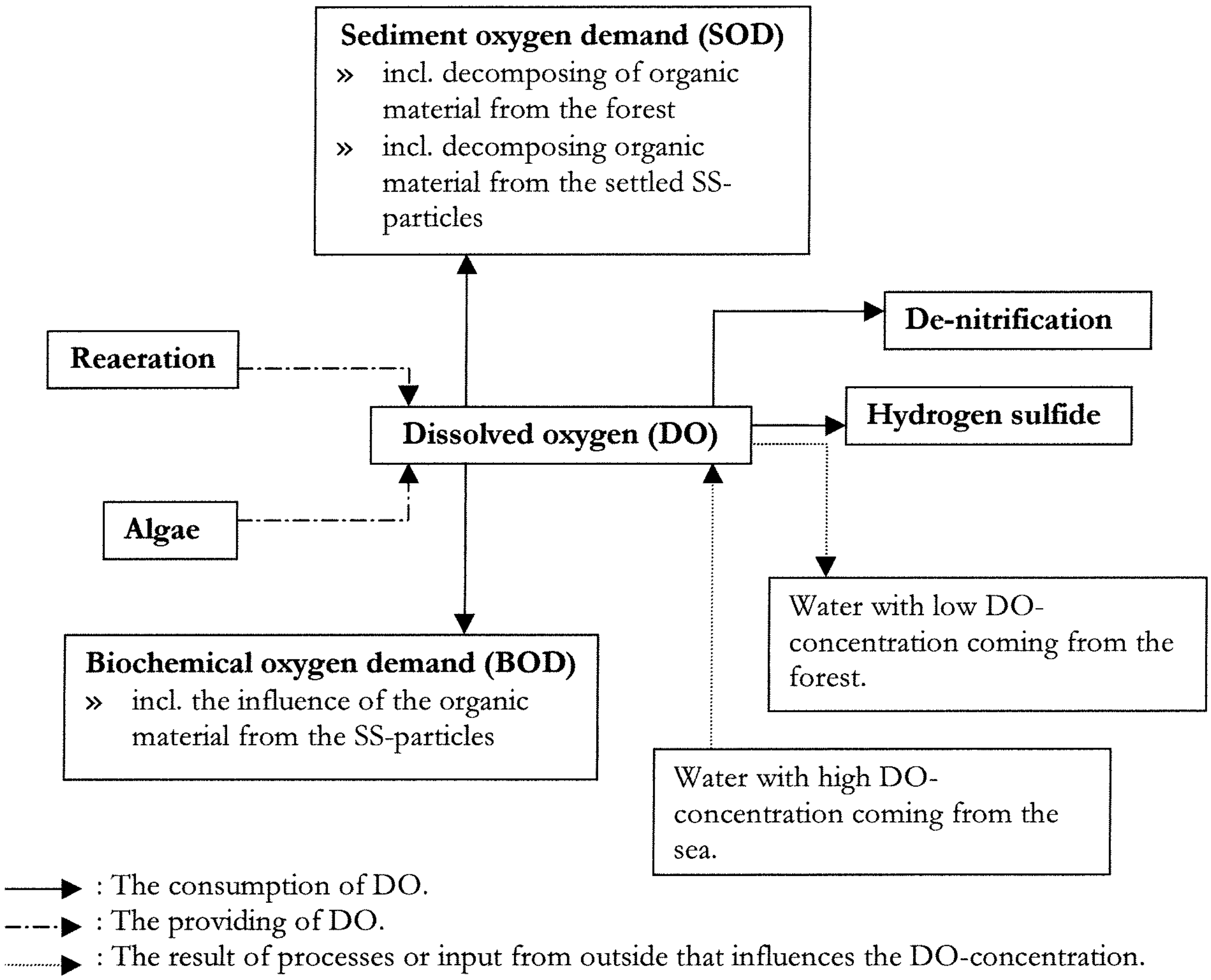


Figure 32: The DO-balance

Discussing the variables of figure 32, modeling or neglecting them is divided into three parts: DO providers, DO consumers and other variables.

- DO providers

DO is provided to the system by: algae, reaeration and water containing a higher DO-concentration coming from sea.

- Algae

As discussed in paragraph 2.2 algae produce oxygen by doing photosynthesis. The more algae present in the system the more oxygen will be produced. From the chlorophyll-A analysis, indicators for algae negative results were found. Negatives concentrations of algae are not possible and indicate that or wrong actions were made during this analysis, or that the concentration of the algae was very low. A decision had to be taken in order to model or neglect the influence of algae.
During previous research done in Thanh Phu, plot 3.1 (*Roozen and Rosenboom, 1997*) very low concentrations of algae (but also negative ones) doing the chlorophyll-A analysis were found. The measurements in 1997 were done during a different period of the year, from May till the end of July. It must be said that during that research the pond was slightly different. The dams that now divide the pond into two parts were not there and the number of sluices used to exchange water has now been increased.
During the research in 1997 the temperature was 3 to 4 °C higher than measured now. A higher temperature increases the growth of the algae, increasing the photosynthesis.
Because more sluices were now used to exchange water, more suspended solids (SS) will enter the pond. It was seen during the analysis (paragraph 6.2) that the outside concentrations of SS were very high. More SS in the system will lead to a decrease of light intrusion. Light is needed for algae to grow and to do photosynthesis. Due to the increase of the SS the light intrusion is less causing the growth of the algae and the photosynthesis to be less too.
Looking at the differences between the two periods of research it can be seen that because of a lower temperature and less light intrusion (increase of SS) the growth of the algae was less. This means that the concentration of the algae should be lower compared with the research done in 1997.
Also looking at the pH measurements it was seen that the pH did not change a lot in time during this research period (paragraph 6.2). Algae, because of their use of CO_2 during the photosynthesis, strongly influence the pH. Due to the photosynthesis the pH should rise during the day and drop during the night. The rather stable pH that was measured indicated that the concentration of the algae was very low. From the above mentioned arguments the assumption was made that the concentration of algae would be lower this period compared to the research done in 1997. From the measurements in 1997 an average primary production, the production of DO by algae in the shallow channels was found from 2 $g/m^3/day$ near the surface till –3 $g/m^3/day$. This shows that the produced DO at the surface was consumed near the bottom. Having lower concentrations of algae now the assumption was made that the values would be more negative during this period. Therefor, it was concluded that the influence of the algae can be neglected compared to the input of the water coming from sea with a DO-concentration 6.6 g/m^3. The influence of the algae will be neglected here and are be modeled.

- Reaeration

Reaeration describes the absorption of oxygen from the air, at the surface of the water and is influenced by the velocity of the water. The higher the velocity of the water and the more turbulence, the more oxygen will be absorbed. The velocities inside the pond were low causing the reaeration also to be low. Still this process was modeled because it always takes place and can be influenced easily.

- Water coming from the sea

The water coming from the sea has a DO-concentration that will not change quickly in time, caused by the high volume of water (the South-China Sea). This water containing the higher DO-concentration is an important source of DO and was defined in the model.

- DO consumers

Comparing the different water quality variables that consume DO (BOD, SOD, Hydrogen sulfide and ammonium) from paragraph 6.2 it was seen that the DO-concentrations is mostly influenced by SOD. Therefor, the choice was made only to model the SOD and neglecting the other DO consuming water quality variables. SOD represents the consumption of DO by the sediment that lies on the bottom.

The water flowing from the forest during outlet into the channels was not consuming DO but due to its low DO-concentration, it only diluted the water in the channels causing the DO-concentration to decrease. The transport-equation in Duflow automatically models the effect of dilution. Besides the water with a low DO-concentration coming from the forest also, leaf litter flowed into the channels causing this considerable influence of the SOD in the channels.

- Other variables

Besides the mentioned variables above also other variables were measured.

- SS

The SS has two influences. First, due to the decrease of the light intrusion the SS have a negative effect on the growth of algae. Second, due to the organic material present on the SS-particles in suspension using DO cause the BOD to increase. When the particles settled on the bottom, the organic material was decomposed increasing the SOD-value. From the water quality analysis (*M. Zitzen, 1999*) the conclusion was made that 15% of the organic material present in the sediment came from the SS. The SS did not strongly influence the SOD compared to the influence of the organic material coming from the forest (85%) has.
Not modeling the algae and BOD, and the minor influence the SS had on the SOD it was chosen not to model the SS.

- Temperature

Temperature is not a process but it influences the rate of the processes that took place. Besides influencing the rate of the process, it also influenced the DO-saturation concentration. The changing of the temperature was defined in the model.

- Salinity

Like temperature salinity is not a process. Salinity influences the shrimp and the DO-saturation concentration. The measured values of salinity did not cause any harm to the shrimp. The influence of the salinity on the DO-saturation was defined in the model.

- pH

It was seen during the analysis that the pH did not differ a lot. The pH gave results that did not effect the shrimp. The pH was not defined in the model.

Looking at the above descriptions the following processes and variables were modeled:
The process: - Changing of the DO-concentration in time
The variables: - SOD
- Reaeration
- Temperature

- Salinity
- Water coming from the forest and sea

It must be said that the measurements concerning the SOD were done during a different fieldtrip (28/01/1999 - 29/01/1999). This fieldtrip was made one month before the first scheduled fieldtrip that would be used to gather the data for making the model. Due to the considerable influence this variable has on the DO-concentration, these measurements still were used in this model.

8.2 Process definitions

This paragraph describes the different mathematical equations used to describe the processes to be modeled and programmed in Duflow. The parameters in these equations were assumed due to the lack of data.
Figure 33 shows schematically the how the DO-concentration in the water is influenced by the different processes.

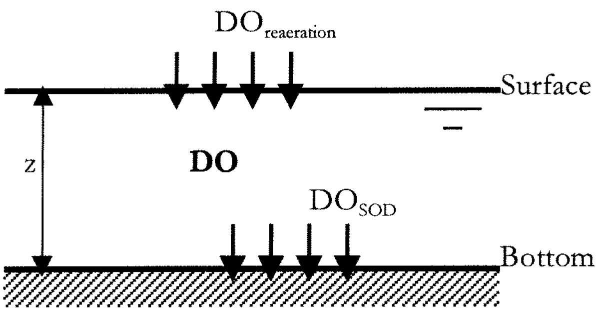


Figure 33: The processes that influence the DO

The changing of the DO-concentration in time is the most important process in the system and was positively influenced by reaeration ($DO_{reaeration}$) and negatively by the SOD (DO_{SOD}). Reaeration takes place at the surface of the water and depends on the flow velocity of the water and SOD is the consumption of dissolved oxygen by the sediment that is lying on the bottom. Formula 8.1 show the changing of the DO-concentration. In this formula, due to considering the whole water column the water depth multiplies the changing of the DO-concentration in time.

$$z \cdot \frac{dDO}{dt} = \text{reaeration} - \text{SOD} \qquad \text{(Formula 8.1)}$$

In Duflow the influence of the water depth is processed by dividing the SOD and reaeration processes by z.

Besides these processes, the water coming from the sea containing a higher DO-concentration also influences the DO-concentration.
The equations describing the influence of reaeration and SOD on the DO-concentration are discussed here.

- Reaeration

Reaeration is a process that provides the system of DO. Formula 8.2 shows the mathematical equation that describes the influence of reaeration on the DO-concentration.

$$\frac{dDO_{reaeration}}{dt} = K_{re} \cdot (DO_{sat} - DO) \qquad \text{(Formula 8.2)}$$

Where

- DO_{sat} [g/m^3] is the saturation concentration of DO in seawater. This concentration depends on the combination of temperature [T in °C] and salinity [S in ‰] and was described with formula 8.3 (*Chemical oceanography, volume 2*).

$$DO_{sat} = e^{(A+B)} \qquad \text{(Formula 8.3)}$$

Where:

» A : -173.4292 + 249.6339·(100/T) + 143.3483·ln(T/100) – 21.8492·(T/100)

» B : S‰ [-0.033096 + 0.014259·(T/100) – 0.0017000·(T/100)^2]

» T [°C] is the temperature.

» S [‰] is the salinity.

- DO [g/m^3] is the DO-concentration.
- K_{re} [m/day] is the reaeration coefficient calculated with formula 8.4. Dividing formula 8.4 by z, the influence of the water depth concerning the reaeration process (see formula 8.1) is modeled in Duflow (not shown here).

$$K_{re} = Kl_{20} \cdot T_{re}^{(T-20)} \qquad \text{(Formula 8.4)}$$

Where:

» T_{re} [-] is the temperature coefficient of reaeration. With this parameter the influence of the temperature on the reaeration process was modeled.

» T [°C] is the temperature.

» Kl_{20} [m/day] is the reaeration coefficient at 20°C. This coefficient was calculated with formula 8.5.

$$Kl_{20} = 2.33 \cdot u^{0,67} \cdot z^{-0,85} \qquad \text{(Formula 8.5)}$$

Where:

» u [m/s] is the velocity calculated by dividing the discharge [m^3/s] with the flow area [m^2].

» z [m] is the water depth.

Reaeration always takes places when water is present, so a minimum value of Kl_{20} was defined. This parameter was named Kl_{min} [m/day].

- SOD

The process describing the change of the DO-concentration in time under the influence of SOD was described using formula 8.6. Modeling the influence of the water depth in Duflow, formula 8.6 was divided by z (not shown here).

$$\frac{dDO_{SOD}}{dt} = f_{SOD} \cdot T_{SOD}^{(T-20)} \cdot SOD_{T.P.} \qquad \text{(Formula 8.6)}$$

Where:

- f_{SOD} [-] is the so-called Monod-factor. The Monod-factor models the decrease of the rate the SOD process due to the decrease of the DO in the system. The less DO available in the system the slower the process takes place. A Monod-factor of 1 means that enough DO is present in the system causing the process not be slowed down. On the contrary, a Monod-factor of 0 indicates that no DO is present in the system causing the process not to take place. Figure 34 shows the changing of the Monod-factor as function of the DO-concentration. The changing of the Monod-factor is different for each process and is also different under other circumstances. The real changing of the Monod-factor of SOD in this situation is unknown so figure 34 should only be used as an explanation of the Monod-factor and its parameter, K_{SOD}.

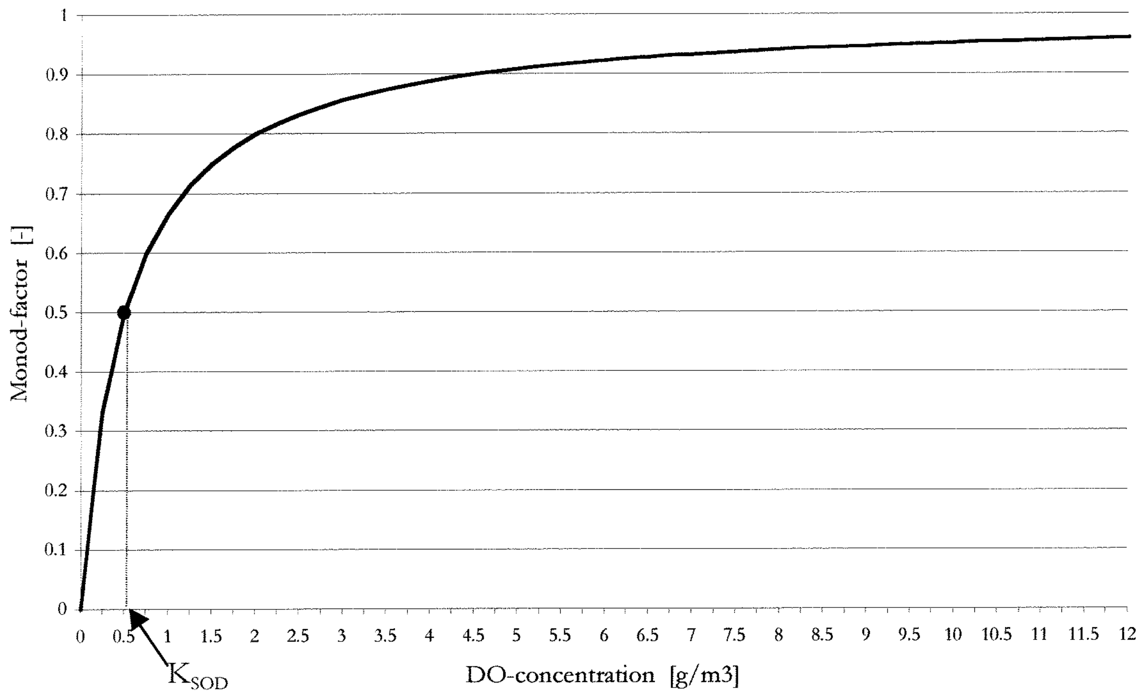


Figure 34: The changing of the Monod-factor

The Monod-factor was calculated using formula 8.7.

$$f_{SOD} = \frac{DO}{DO + K_{SOD}} \qquad \text{(Formula 8.7)}$$

Where:

» DO [g/m^3] is the DO-concentration.

» K_{SOD} [g/m^3] is the value of the DO-concentration when the f_{SOD} is 0.5 (figure 34).

- T_{SOD} [-] is the temperature coefficient of SOD. This parameter was used to define the influence of the temperature.
- T [°C] is the temperature.
- $SOD_{T.P.}$ [g/m^2·day] is a value that must be defined in Duflow describing consumption of DO by the sediment that is lying on the pond bottom expressed g consumed DO per m^2 bottom area per day. These values were found from analyzing the measurements done in Thanh Phu.

8.3 The quality model

Describing the modeling of the water quality part is divided into two parts. First, the problems that were found during modeling are discussed together with the assumptions made to solve them (paragraph 8.3.1). Second, the model itself is discussed (paragraph 8.3.2).

8.3.1 Problems found during modeling the water quality

Problems occurred in Duflow when the water depths in the outside channels became close to 0 m or negative. These negative water depths occurred in Duflow when the water level was below the defined bottom level. Duflow itself defines a very narrow and deep cross-section below the defined bottom level, without effecting the water movement. Due to the high tidal range, the channels dried up during some periods of the day causing these problems in Duflow. The main interest was what happened inside the pond, so it was not important to have the outside channels modeled perfectly. Problems occurred in the outside channels just before water was let out meaning that the extreme concentrations did not influence the DO-concentrations inside the pond. Only one time an extreme DO-concentration was calculated in the outside channels just before water inlet and influenced the inside DO-concentrations when the water was let in. This extreme concentration occurred in section 3 and 5 and was solved lowering the bottom levels making sure a permanent positive water level was present in those sections.
The exchange of water was influenced by the height difference of between the in the in- and outside water levels. In section 3 and 5 no heading up was observed, meaning that the geometry of the channel, so also the bottom level did not have any influence on the water level unlike what happened in section 4. Not influencing the water movement, the bottoms in section 3 and 5 were lowered to solve the problems of the extreme concentrations. The changes of the bottom levels are shown in table 34.

Table 34: Lowering the bottom levels

Section	Node	Old bottom level [m]	New bottom level [m]
3	1	-3.01	-3.43
3	3	-3.16	-3.58
5	3	-3.16	-3.58
5	6	-3.07	-3.43

The problem of the extreme values was solved using these new bottom levels. A check was made to see if the lowering of the bottom levels had any influence on the water movement. It was seen that the water movement did not change compared to the calibrated model, Model 3 described in paragraph 7.1.3. Due to not influencing the water movement, and improving the water quality output the lowering of the bottom levels were allowed.

Besides the problems with Duflow, problems with the used data concerning the water quality data were seen. After comparing the DO consuming water quality variables with each other, it was seen that the sediment oxygen demand influenced the DO-concentration the most and is the most important variable. The $SOD_{T.P.}$ was measured during an earlier fieldtrip than those fieldtrips that would be used to measure the water quality data for making the model.
The $SOD_{T.P.}$ does not change rapidly and will be constant for a period of time. The measurements of the $SOD_{T.P.}$ were done one month before fieldtrip 2 and it was expected that the values would have changed a little during this period. In spite of these changes the measurements were used to model the influence of the SOD.
When modeling the water quality, it was seen that the DO-concentrations in certain sections would rapidly decrease to zero, meaning that no DO would be available in those sections. That the DO-concentration would decrease to zero was possible but the rate of decrease was very high. In consultation with Dr. R.M.M. Roijackers of Wageningen Agricultural University it was assumed that the quality of the SOD measurements were dubious. No instrument to do these measurements was available so one was self-made with the limited available equipment. This self-made instrument was maybe not very accurate but it gave an indication that the influence of sediment oxygen demand on the DO-concentrations was very high. The observation of the black

colored sediment in the forest indicating rotting processes confirmed this expectation of the strong influence of the SOD. Instead of working with the measured data, sometimes 63.1 $g/m^2 \cdot day$ in the forest and 12.5 $g/m^2 \cdot day$ in the channels, the choice was made to use the following values $SOD_{T.P.}$:

$SOD_{T.P.}$ in the forest	: 10 $g/m^2 \cdot day$
$SOD_{T.P.}$ in the channels	: 3 $g/m^2 \cdot day$

This choice was made in consultation with Dr. R.M.M. Roijackers. The chosen values are extreme values for normal systems. The value, $SOD_{T.P.}$ used for the forest represents a highly polluted area. The bottom of the forest contained a high amount of organic material caused by leaf-litter from the trees. These organic materials had to be decomposed, using DO leading to high values of $SOD_{T.P.}$. Due to the less amount of leaf litter in the channels, compared to the forest the $SOD_{T.P.}$ in the channels must be. The value of 3 $g/m^2 \cdot day$ used to define the $SOD_{T.P.}$ in the channels is a high value in normal systems.
With the assumptions made for the $SOD_{T.P.}$ calibrating the model to obtain the same DO-concentrations as measured during fieldtrip 2 was not useful. Not correctly describing the DO-concentrations in time, this model can be used only to show how the DO-concentrations can be influenced.

8.3.2 The water quality model

The model describing the water movement as defined in paragraph 7.1.3, Model 3, is combined with the part of the model describing the water quality processes. Model 3 describes the water movement during the second fieldtrip. The model that described the third fieldtrip was not used in spite of the longer period of measuring. The reason for not using the model describing fieldtrip 3 was because of two reasons. The first one concerned the measurements of $SOD_{T.P.}$. $SOD_{T.P.}$ was already measured before the second fieldtrip and changes in time. Fieldtrip 2 was the fieldtrip closest to the measurements. The second reason concerned the boundary condition. The boundary condition during the second fieldtrip was known.
Duflow contains a module that gives the opportunity to define these processes and was done first. Use was made of the following statements: a formula-statement, an IF-statement and (see appendix B.2). After defining the processes the other parts of the model were defined and are discussed here. The definitions of the water quality model are also shown in appendix D.4.

- The initial conditions

The initial conditions of the water quality model were the DO-concentrations at the beginning of the calculation. For the initial conditions the first measurements of the DO-concentration of fieldtrip 2 were used. The initial conditions differ inside the pond. The initial conditions are shown in table 35.

Table 35: The water quality initial conditions

Node	DO-concentration [g/m^3]	Node	DO-concentration [g/m^3]
1, 2, 3, 4, 5, 6	6.600	10, 14, 18, 22, 28, 32, 36, 40, 44, 45, 46	5.910
7,11, 15, 19, 23, 29, 33, 37, 41	5.880	12, 16, 20, 34, 38, 42	5.360
8, 24, 25, 30	5.890	13, 17, 21, 35, 39, 43	5.490
9, 26, 27, 31	5.900		

- The boundary condition

One boundary condition was used in this model to define the input of the DO coming from the sea. The boundary condition, defined at node 1 is shown in table 36.

Table 36: The water quality boundary condition

Description	Definition
Type	Concentration
Variable	DO [g/m^3]
Type of function	Constant
Constant value	6.600

- External variables

External variables are variables declared in the process description file and are space and/or time dependent. Three external variables were defined: salinity, temperature and SOD.

» Salinity

The salinity influences the DO-saturation in seawater. Because the salinity of the sea did not change quickly it was almost constant in time. From tables (*Chemical oceanography, volume 2*) it was seen that the influence of the salinity on the DO saturation was small. Therefor the salinity was defined as a constant value of 29.2 ‰, the average of the in- and outside measurements. Defining the salinity as a constant value, it could also have been defined as a parameter.

» Temperature

Besides strongly influencing the DO-saturation, temperature also influences the different water quality processes. Therefor it was chosen to describe the changing of temperature in time more accurately. Due to the lack of data, it was difficult to define an equation describing the changing of temperature in time. To define the changing of the temperature in time average values were used. These were defined in Duflow and shown in table 37.

Table 37: The external variable temperature

Date [yymmdd]	Time [hhmm]	Temperature [°C]
990301	1300	29.25
990301	1500	29.25
990302	0415	25.90
990302	1500	28.60
990302	1800	27.75

» SOD

As written in paragraph 8.3.1 the values of $SOD_{T.P.}$ were assumed. The $SOD_{T.P.}$ does not change quickly in time and was defined as a constant value. Distinction was made between the forest, the channels inside the pond and the channels outside the pond. Table 38 shows the used values.

Table 38: The external variable $SOD_{T.P.}$

Position	$SOD_{T.P.}$ [g/m^2·day]
The forest	10
Channels inside the pond	3
Channels outside the pond	0

The DO-concentrations describing the boundary condition were measured near the sluices, including also the influence the sediment oxygen demand in the outside channels during the time the water flowed from the sea in the direction of the sluices. The boundary condition was defined at sea several meters away from the sluices. Because the influence of the SOD was already included in the measurements of the DO-concentrations the $SOD_{T.P.}$ in the outside channels was defined at 0 $g/m^2 \cdot day$.

- The parameters

Parameters are constant during the whole calculation and were used describing the different water quality processes. The values of these parameters were not known so assumptions concerning these values were made. The meanings of the different parameters were discussed in paragraph 8.2; here only the used values will be shown. The used parameters with their values are shown in table 39.

Table 39: Values of the used parameters

Parameter	Description	Value	Unit
kmin	Minimum oxygen mass constant	0.100	1/day
ksod	Monod factor SOD	2.000	$g/m^2 \cdot day$
tre	Temperature coefficient reaeration	1.024	-
tsod	Temperature coefficient SOD	1.060	-

The values of the parameters could be adjusted when calibrating the water quality model. However, due to the assumptions made it was not useful to calibrate the model to obtain the same results as measured.

8.4 The output of the model

The output of the model is described in this paragraph. Comparing the measured DO-concentrations with the output of Duflow (appendix E.1) differences were seen caused by the assumptions made. In Duflow lower DO-concentrations were calculated compared to the measured DO-concentrations during fieldtrip 2 and 3. Lowering the values of $SOD_{T.P.}$ result in higher DO-concentrations in the model but was not done because during previous fieldtrips also low DO-concentrations were measured in both the channels and forest (*M.Zitzen, 1999; Roozen and Rosenboom, 1997*). Low DO-concentrations could also have been present in the system during the two fieldtrips but because of the limited time causing the lack of data, these low concentrations were not measured. Due to the assumptions made, this model can only be used to see how the DO-concentrations can be. Discussing the output of the model use is made of three double sections that describe all the most important phenomena in the system. One double section contains a section describing a part of a channel together with its parallel section describing a part of the forest. The following sections are discussed: section 7 with 22; section 9 with 24 and section 19 with 34. The positions of these sections will be shown in figure 34. These three double sections describe all the phenomena that occurred, and they also show the influences of the sluices. Sections 9 with 24 were situated near sluice B, sections 7 with 22 were in the middle of the pond influenced by both sluices. Sections 19 with 35 were situated far from the sluices and show the influence the sluices have on sections further situated.

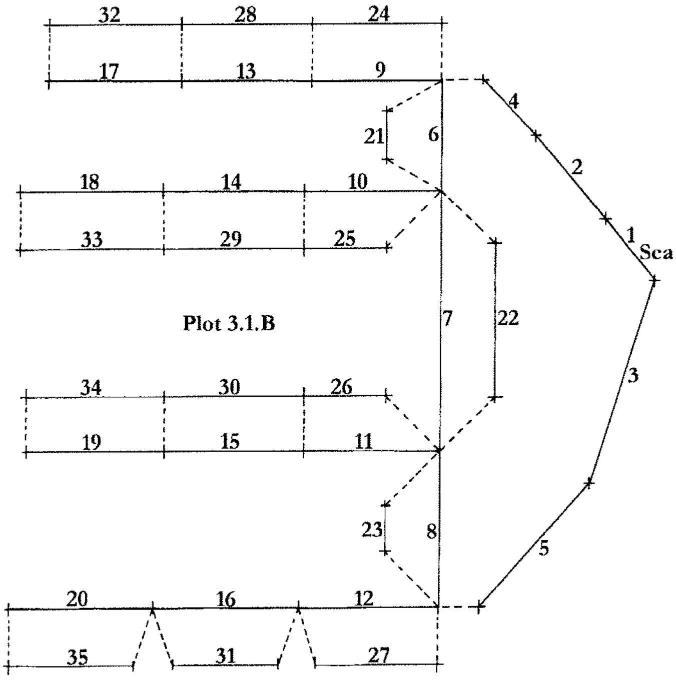


Figure 35: Section numbers

Discussing the output of the sections, each section will be described using two figures. One figure describes the changing of the DO-concentration and the other figure describes the influence of the SOD and reaeration. The reaeration and SOD shown in the figures discussing the output is calculated with respectively formula 8.4 and formula 8.6, both divided by the water depth, z. All the used symbols were explained in paragraph 8.2. Formula 8.8 and 8.9 shows respectively both formulae of reaeration and SOD used in the figures describing the output.

$$\text{Reaeration} = \frac{Kl_{20} \cdot T_{re}^{(T-20)}}{z} \quad [1/\text{day}] \qquad \text{(Formula 8.8)}$$

$$\text{SOD} = \frac{f_{SOD} \cdot T_{SOD}^{(T-20)} \cdot SOD_{T.P.}}{z} \quad [\text{g/m}^3\cdot\text{day}] \qquad \text{(Formula 8.9)}$$

In both figures, the shown water level is divided into 10 periods. Discussing the output of a section reference is made to these periods for instance to DO-4, refer to the figure describing the DO-concentration of the discussed section during period 4. SOD-7 and Rea-7 refer respectively to figures describing the SOD and reaeration of that section during period 7.

8.4.1 Describing section 7 with 22

First forest section 22 will be discussed followed by channel section 7.

- Section 22

Section 22 represents a part of the forest. Figure 36, describes the DO-concentration in combination with the water level in section 22. Figure 37, describes the influence of the SOD and reaeration on the DO-concentration.

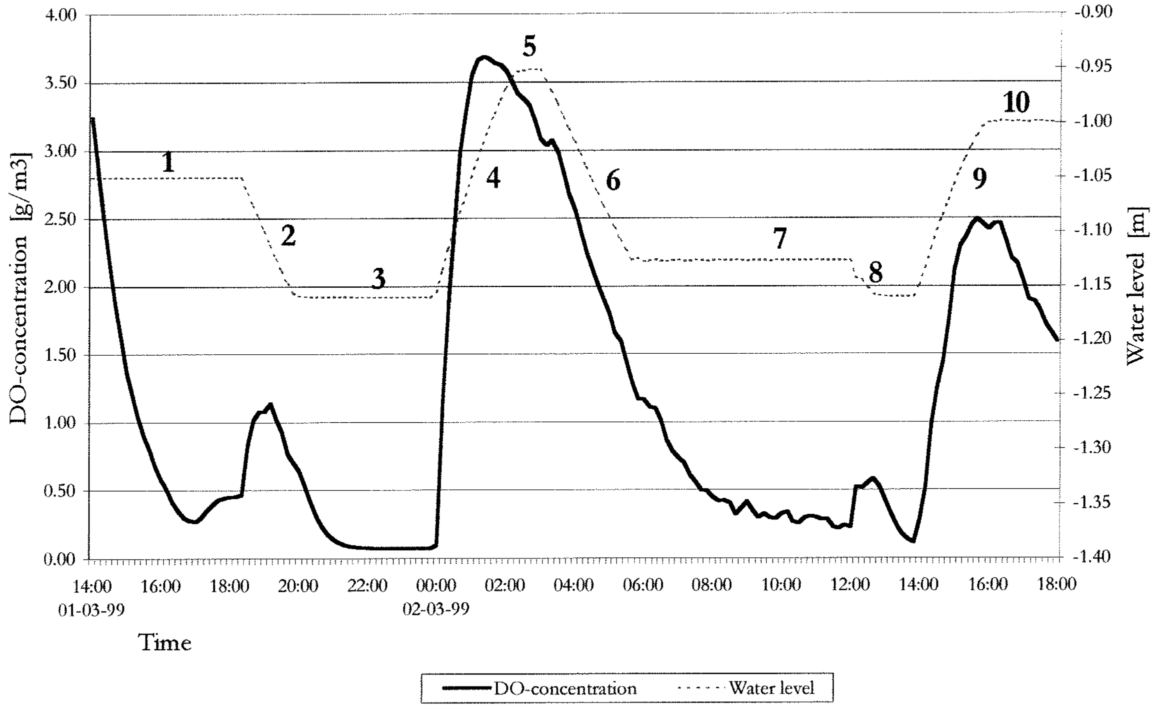


Figure 36: The DO-concentration and water level in section 22

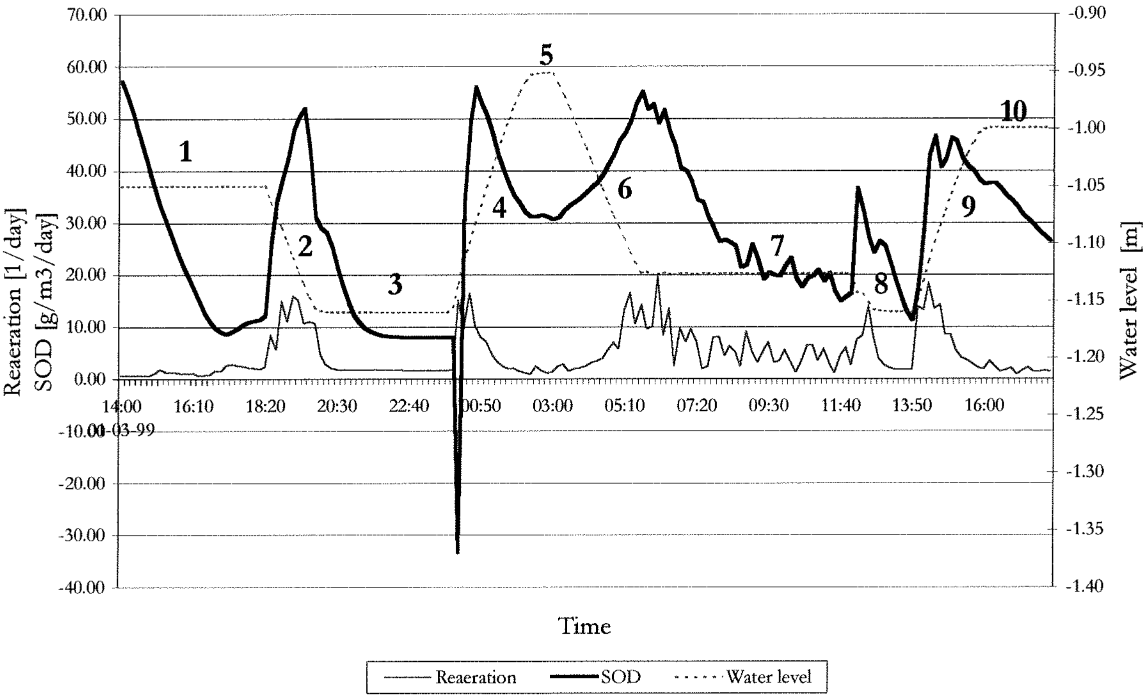


Figure 37: Reaeration, SOD and water level in section 22

In both figures the numbers 2, 4, 6, 8 and 9 show that there were 5 exchanges of water. The reference made in the following discussion of the output, refer to figures 36 and 37. The number between the brackets, for instance (1), refers to the defined periods (1 – 10). Before discussing the different periods, it can be seen that the reaeration show the same course as SOD.

When the reaeration increased, more DO entered the pond, meaning that the SOD could consume more DO so also increased.

» Before the first measured exchange of water the water level was constant (1 and 10). It can be seen that during that period the DO-concentration decreased quickly (DO-1, DO-10) caused by the high value of SOD (SOD-1, SOD-10). When the DO-concentrations were low the rate of decrease diminished caused by the Monod-factor (paragraph 8.2). Due to the decrease of the DO-concentration, the SOD (SOD-1, SOD-10) decreased. Lower DO-concentrations, caused by the consumption of DO by SOD, less DO was available so the Monod-factor decreased causing a decrease of SOD. Not exchanging water the reaeration that depends on the flow velocity, was very low (Rea-1, Rea-10) and almost constant.

» Water was let out resulting in a drop of the water level (2 and 8). During this period the DO-concentration first increased and later decreased (DO-2, DO-8). The flow velocity inside the pond increased due to the outlet of water. This increase of the velocity increased the reaeration (Rea-2, Rea-8), causing the DO-concentration to increase too. At the same time, due to the more DO becoming available, the Monod-factor became higher causing the SOD to increase (SOD-2, SOD-8). At first during the exchange of water, the reaeration was dominant and the DO-concentration increased, but later the SOD became dominant compared to the reaeration and resulted in a rapid decrease of the DO-concentration.

» During this period (3), no water was exchanged causing the water level to stay constant. The DO-concentration decreased quickly, became very low and stayed constant during this period (DO-3). Not exchanging water, the flow velocity inside the pond was very low causing a low value of reaeration (Rea-3). Also the SOD decreased and became constant (SOD-3). Due to the lower DO-concentrations in the system, the Monod-factor became lower reducing the rate of the SOD process. The DO that entered the system due to reaeration was probably the same as the amount of DO the SOD process consumed resulting in constant values of the SOD and the DO-concentration.

» Due to the inlet of water, the water level rose (4 and 9). Water that was let in contained a higher DO-concentration. The inlet of water caused the flow velocity inside the pond to increase making the reaeration values to become higher too (Rea-4, Rea-9). The high DO-concentration coming from the sea together with the DO provided by reaeration caused the DO-concentration in this section to increase rapidly (DO-4, DO-9). The increase of the DO-concentration caused the SOD also to increase (SOD-4, SOD-9); more DO became available in the system (higher Monod-factor). The negative value of SOD is not normal and can be a numerical problem in the model, caused by the sudden rapid changes of the DO-concentration.

» This is the same situation as discussed during period 1. Not exchanging water (5), the flow velocity decreased causing a decrease of reaeration (Rea-5). The DO-concentration decreased (DO-5) due to the consumption of DO by SOD. The lower DO-concentration caused the Monod- factor to become lower causing the decrease of SOD (SOD-5).

» Water was let out causing the water level to drop (6). Reaeration increased because of the water movement causing an increase of the flow velocity (Rea-6). In spite of the increase of reaeration, the DO-concentration still decreased (DO-6). The high DO-concentrations made sure the Monod-factor and so also the SOD value (SOD-6) to be high causing the SOD to be dominant over the providing of DO by reaeration. Due to this influence of the SOD, the DO-concentration still decreased.

» No water was exchanged causing the water level to stay constant (7). The changing of reaeration in time (Rea-7) indicated that there was water movement. This can be water movement between sections. Due to the consumption of DO by SOD the DO-concentration decreased (DO-7) causing the SOD to decrease (lower Monod-factor) again because less DO was available in the system.

- Section 7

Section 7 represents the channel that was connected with section 22, the forest. Figure 38 shows the DO-concentration in combination with the water level. Figure 39 shows the processes of reaeration and SOD together with the water level.
Only the most important phenomena shown in figure 38 and 39 are discussed here. Some phenomena seen in these figures are similar to those seen discussing section 22.
These phenomena were:

- The SOD increased when the DO-concentration increased. Because more DO became available in the system causing the Monod-factor to become higher. A higher Monod-factor causes the SOD to consume more DO so the SOD increased.
- The higher SOD also caused a decrease of the DO-concentration because of the consumption of DO causing the DO-concentration to decrease again. Because less DO became available the Monod-factor decreased too causing the SOD to decrease. This shows that the DO-concentration and SOD influence each other.
- Due to the increase of the flow velocity when exchanging water, the values of the reaeration became higher. The higher values of reaeration provided the pond of more DO causing the DO-concentration to increase. The providing of DO caused by the increase of reaeration was not always seen by an increase of the DO-concentration. The high SOD caused this during those periods. SOD was dominant compared to the influence of reaeration and immediately consumed the extra DO.
- During the inlet of water the DO-concentration increased rapidly because of the incoming seawater containing a high DO-concentration and the increase of reaeration.

No reference is made discussing section 7 to the different phenomena mentioned above.

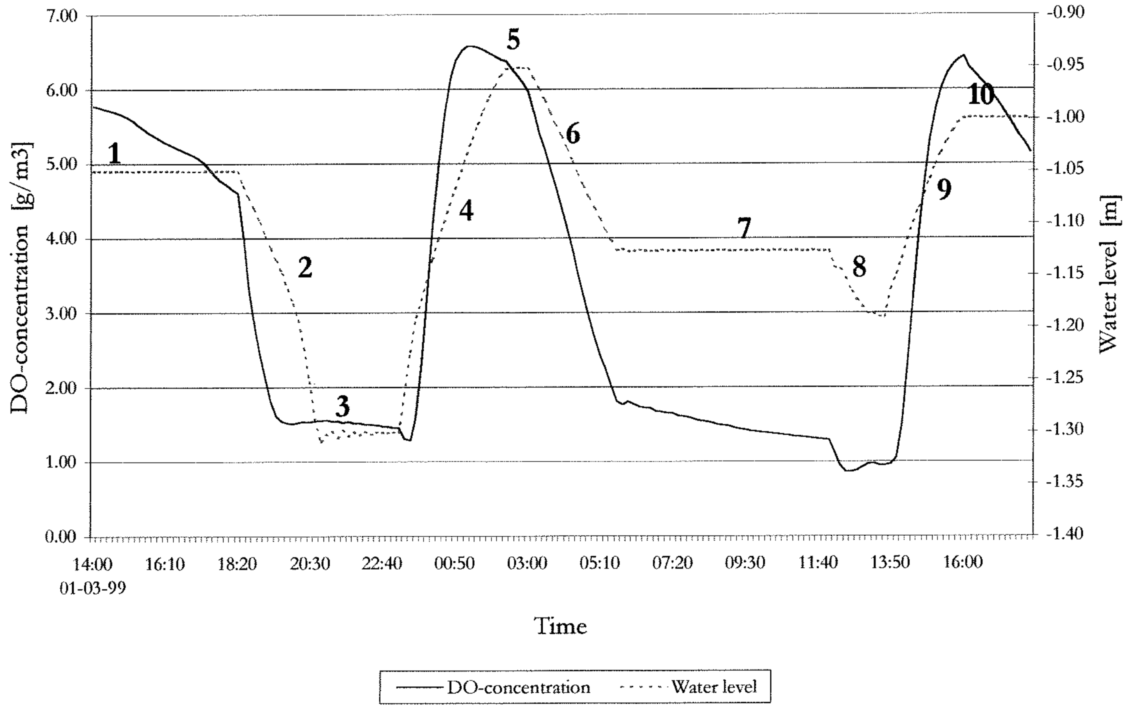


Figure 38: The DO-concentration and water level in section 7

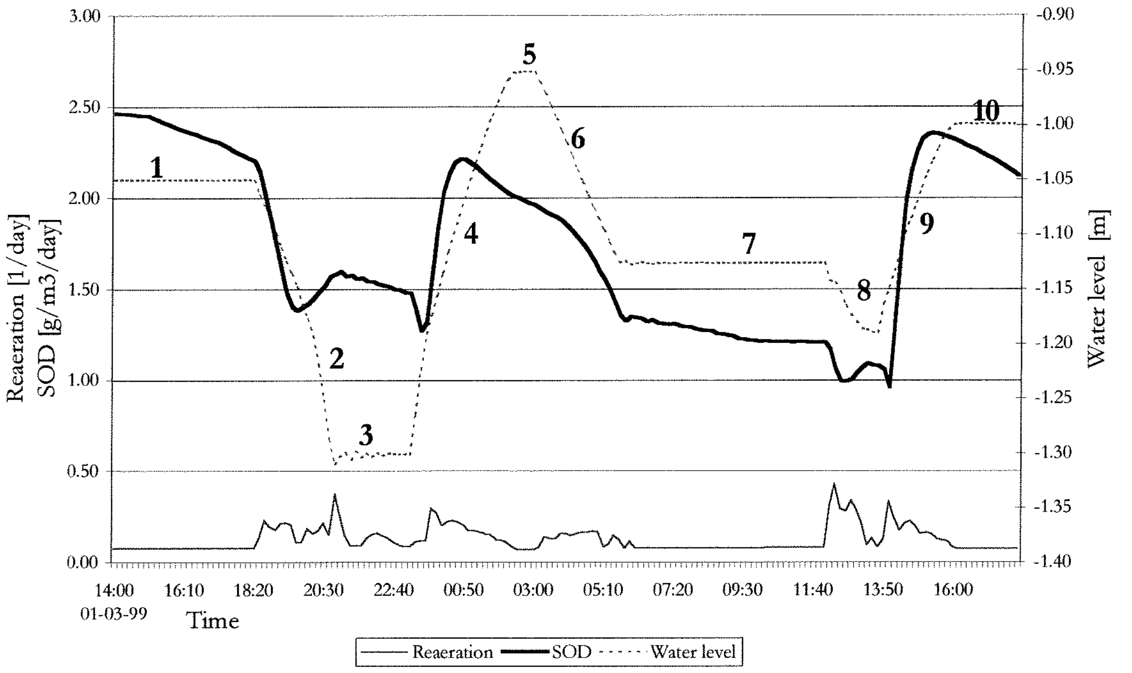


Figure 39: Reaeration, SOD and water level in section 7

The reference made in the following discussion refers to figures 38 and 39.

- The water level was constant because no water was exchanged (1). The DO-concentration decreased (DO-1) but less rapidly compared to the decrease of the DO-concentration seen in section 22 during the same period (DO-1 of figure 36). This was caused by the lower defined value of $SOD_{T.P.}$ in the channels compared to the forest. Therefor, lower values of the SOD (SOD-1) were found compared to the values of the SOD in section 22 (see figure 37).

- Due to the outlet of water, the water level dropped (2). A quick decrease of the DO-concentration was visible (DO-2) caused by the water coming from the forest containing a very low DO-concentration (see figure 36 at the end of period DO-1). This water containing a low DO-concentration diluted with the water in the channels what resulted in the quick decrease of the DO-concentration.

- The inlet of water (4 and 9) resulted in an increase of the DO-concentration (DO-4 and DO-9). The increase of reaeration (Rea-4 and Rea-9) in combination with the water coming from sea containing a higher DO-concentration caused this increase of the DO-concentration.

- Due to the outlet of water, the water level dropped (6 and 8) causing water with a low DO-concentration to flow from the forest into the channels that resulted in a quick decrease of the DO-concentrations (DO-6 and DO-8). Due to the outlet of water, the flow velocity and the reaeration increased (Rea-6 and Rea-8). In spite of the increase of reaeration providing more DO, the SOD still decreased (SOD-6 and SOD-8). The water coming from the forest strongly influenced the DO-concentrations in the channels causing the DO provided by the increase of reaeration to become of a minor importance. The DO-concentration still decreased. Less DO became available in the system causing the Monod-factor to become lower decreasing the SOD.

8.4.2 Describing section 9 with 24

First section 24 will be discussed followed by section 9. Only the most important phenomena and the differences between these sections and section 7 and 22 will be discussed.

- Section 24

The DO-concentration and the changing of reaeration with SOD in time are both in combination with the water level respectively shown in figure 40 and 41.

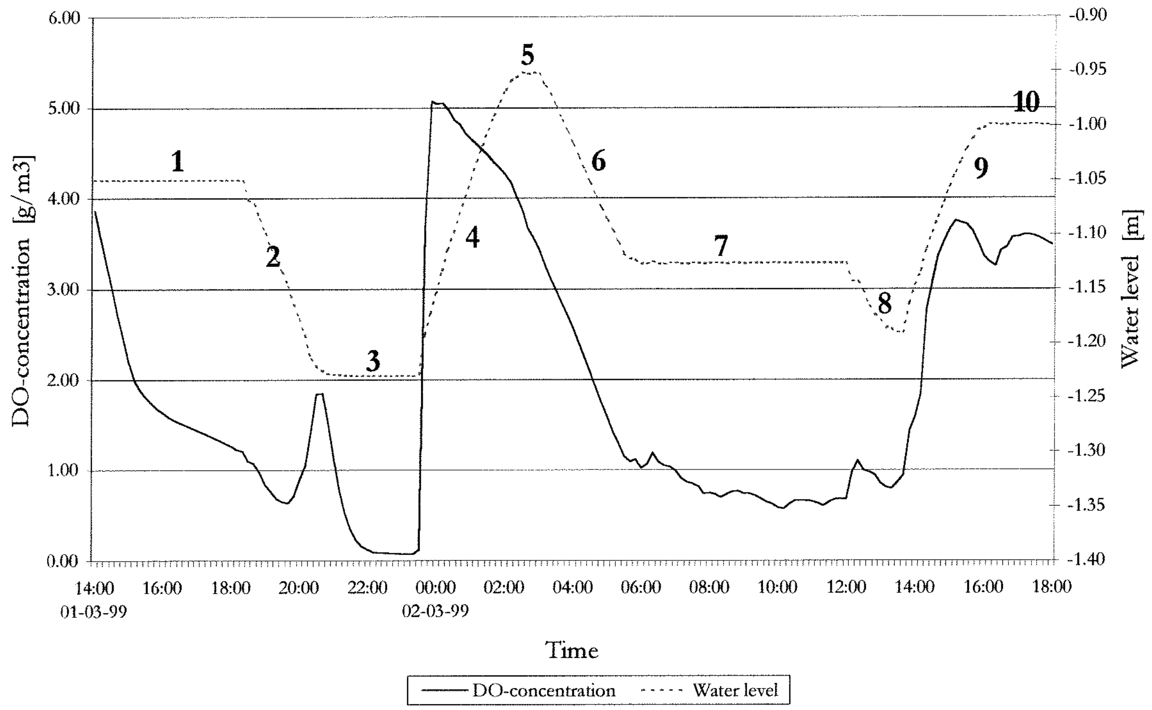


Figure 40: The DO-concentration and water level in section 24

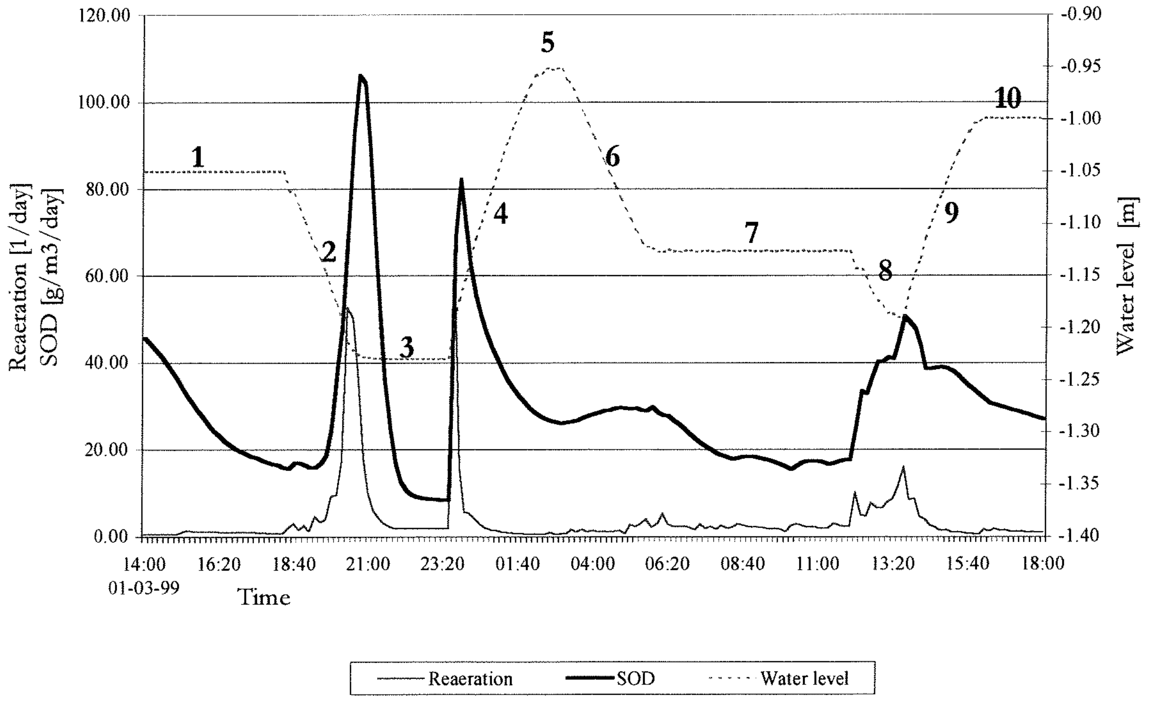


Figure 41: Reaeration, SOD and water level in section 24

The references made in this discussion of the output of section 24 refer to figure 40 and 41, unless mentioned otherwise.

» During the period (1) before the first measured exchange of water the DO-concentration decreased (DO-1). First the DO-concentration decreased rapidly but then the process slowed down causing the DO-concentration to decrease slower. The SOD (SOD-1) decreased normally and was slowed down due to the Monod-factor when the DO-concentrations became very low but a change in the curve as seen in the curve of the DO-concentration did not occur here. The little change in reaeration (Rea-1) can be the cause of the flowing of water, but still it was to small to provide as much as DO to cause the change in the DO-concentration. With SOD and reaeration not being the cause of the change in the development of the DO-concentration, an exchange between other section can be the cause. By diffusion but than it should have occurred from the start and not suddenly after a few hours. A sudden flow of water transporting DO form parts with higher DO-concentrations to parts with lower concentrations can be the cause of the sudden changing of the development of Do in section 24. Due to the slower decrease of the DO-concentration in section 24, it was assumed that DO enters section 24. The SOD still consumed a lot of DO but due to the fact that more DO entered the section the decrease of the DO-concentration was less, causing this change in the DO-concentration curve. To check this the discharge of structure S9 that connects section 24 with section 9, will be shown in figure 42.

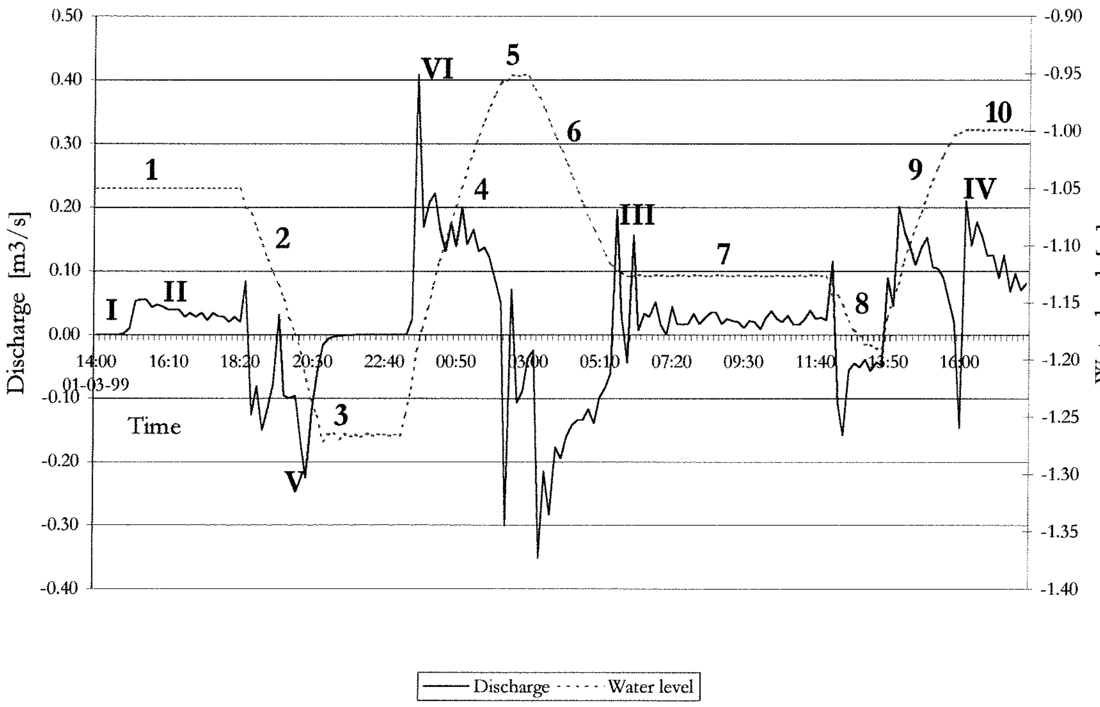


Figure 42: The discharge and water level of structure S9

In the beginning, the discharge was zero (I) and the DO-concentrations changed normally, a strong decrease of the DO-concentration (DO-1) due to the high consumption of DO by SOD. In spite of the closed sluices, a sudden discharge was seen over the weir (II) caused by the rounding of the calculated water levels in Duflow. To show this a calculation was made:

The water level over the weir is: –1.05 m; the sill level of the weir is: -1.23 m and it has a width of 70 m. The maximum discharge, Q_{weir} over the weir was approximately 0.05 m^3/s (see figure 42).

The velocity over the sluice is:

$$v_{weir} = \frac{Q_{weir}}{cross-section} = \frac{Q_{weir}}{width \cdot water\ depth} = \frac{0.05}{70 \cdot 0.18} = 4.0 \cdot 10^{-3}\ m/s.$$

The height difference over the weir to cause this flow velocity was:

$$v_{weir} = \sqrt{2 \cdot g \cdot \Delta h} \rightarrow \Delta h = \frac{(v_{weir})^2}{2 \cdot g} = \frac{4.0 \cdot 10^{-3}}{2 \cdot 9.81} = 8.2 \cdot 10^{-7}\ m.$$

This calculation shows that only a very little height difference was needed to create this flow. The rounding of the calculated water levels in Duflow caused this height difference. Unless the very small difference in the water level it had a considerable influence on the DO-concentration.
The discharge was positive meaning that water was flowing from the channel (section 9), containing a higher DO-concentration into the forest (section 24) causing this change in the development of the DO-concentration.
Figure 42 also show that there was a lot of exchange of water during most of the other periods when the sluices were closed (5, 7 and 10). Only during period 3, the discharge was 0 m^3/s, what is remarkable according to the discussion above where it was concluded that the rounding of the water levels caused the discharge.

» After the third exchange of water when the sluices were closed (7) the SOD increased a little (SOD-7). This increase was caused by the increase of reaeration (Rea-7) caused by the flowing of the water (III, figure 42). This flow can be the result of closing the sluices suddenly causing a numerical wave that changed the water levels a little bit before the water level remained horizontal again. Alternatively, the flow can be the result of the rounding of the calculated water levels in Duflow. More DO entered section 24 so more DO could be consumed causing an increase of SOD. An increase of the DO-concentration was not seen because the SOD was high immediately consumed the extra DO. The same happened after the last exchange of water (DO-9 and IV).

» Two very high values of reaeration and SOD during the first (SOD-2 and Rea-2) and second (SOD-4 and Rea-4) exchange of water were found, probably caused by the discharges, V and VI, between the sections as seen in figure 42. The discharge caused higher flow velocities increasing the reaeration providing more DO to the system increasing the DO-concentration causing the Monod-factor to become higher and the SOD to increase too.

- Section 9

Figure 43 and 44 shows respectively the DO-concentration and the functions reaeration and SOD that influence the DO-concentration in section 9. In both figures also the water levels in section are shown.

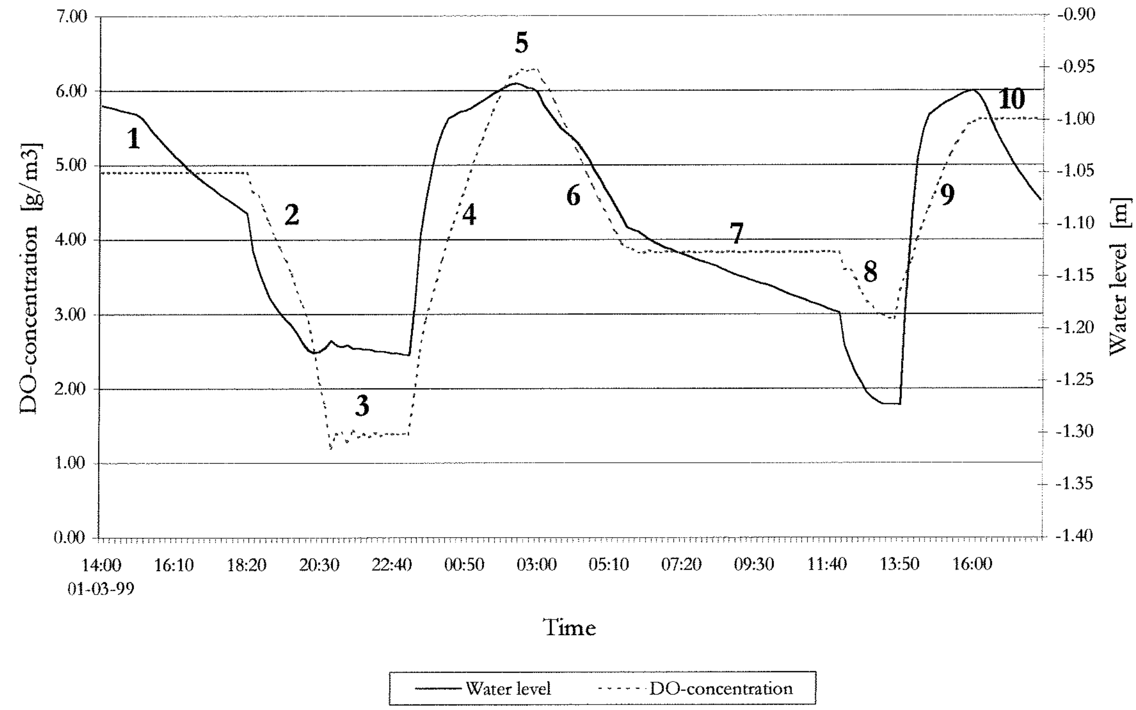


Figure 43: The DO-concentration and water level in section 9

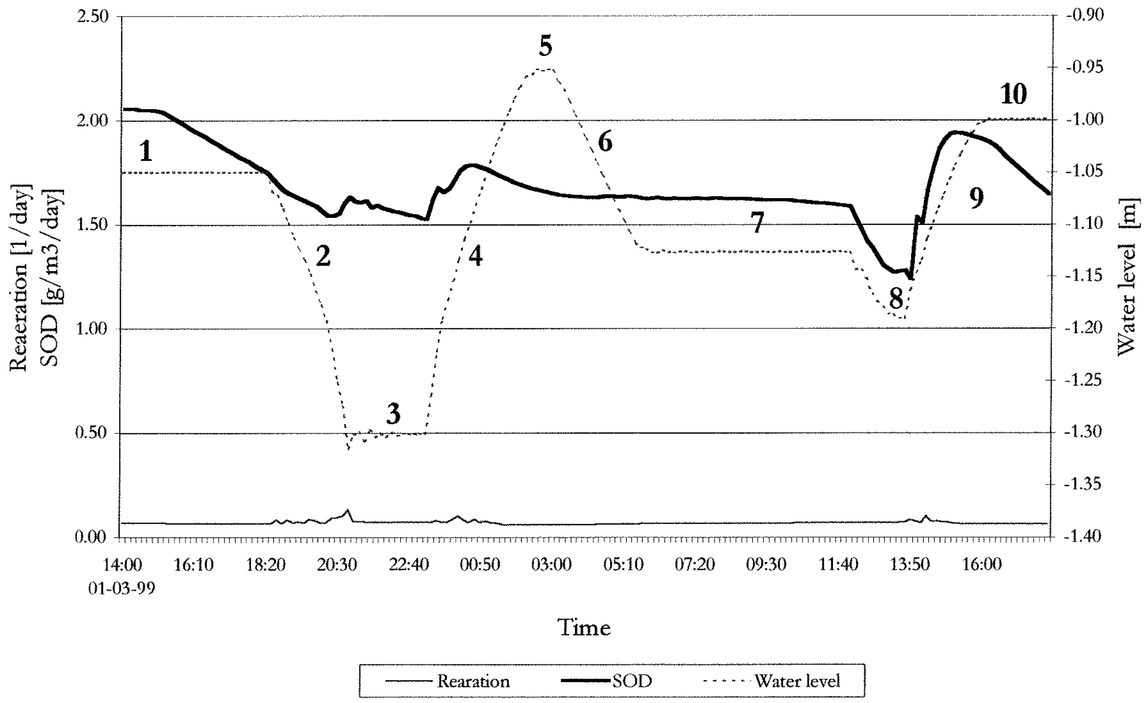


Figure 44: Reaeration, SOD and water level in section 9

The references made in this discussion of the output of section 9 refer to figure 43 and 44 unless mentioned otherwise.

Due to the differences in the water depth between the sections, the values of the reaeration in this section are lower here. To obtain the value of reaeration in the vertical water column the value is divided by the water depth. Section 9 has the lowest bottom level and so the largest water depth causing the lower values of the reaeration. The highest values of reaeration were found in the forest sections due to the smallest water depths.

» The DO-concentration also changed during the period before the first measured exchange of water (1). However, the DO-concentration decreased more rapidly compared to the normal decrease (DO-1) caused by SOD (SOD-1). Besides diffusion, the reason must be that water with a low DO-concentration entered this section. Discussing section 24 it was seen that water was flowing from section 9 into section 24 through structure S9 due to a height difference caused by the rounding of the calculated water levels in Duflow. Figure 45 shows the discharge of the other structure, S13 that connected the two sections at the other end.

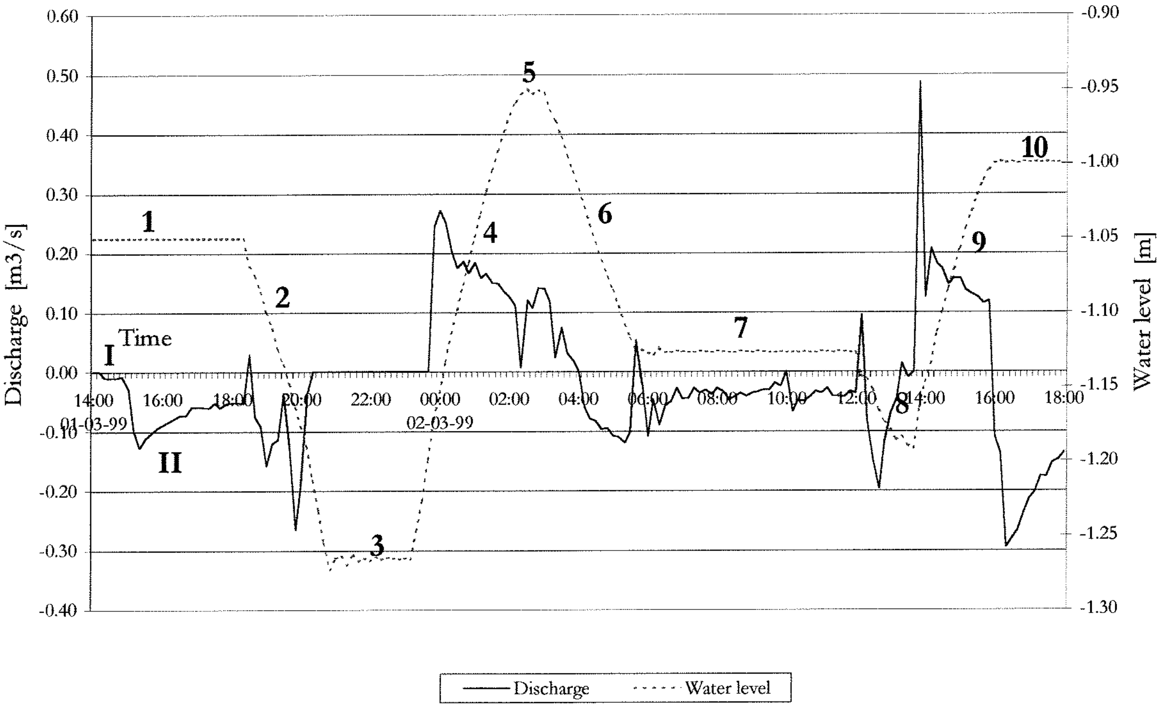


Figure 45: The discharge and water level structure S13

First, the discharge was 0 m^3/s (I) and then becoming negative (II) meaning that water was flowing from section 24, containing a lower DO-concentration into section 9 causing a more rapid decrease of the DO-concentration (DO-1). As discussed in paragraph 8.4.2 this discharge was caused by the rounding of the water levels in Duflow. Due to the decrease of the DO-concentration causing a lower Monod-factor the SOD decreased (SOD-1).

» During the outlet of water, the water level dropped (2, 6 and 8) causing water with a lower DO-concentration to flow from the forest into section 9 (DO-2, DO-6 and DO-8). The water diluted causing a decrease of the DO-concentration in the channels.

» The DO-concentration increased (DO-4 and DO-9) during the inlet of water (4 and 9) mainly because of the water with a high DO-concentration that entered the pond coming from sea.

8.4.3 Describing section 19 with 34

These sections were chosen because they are positioned far from the sluices showing the influence the water exchange has at the sections further situated.

- Section 34

Section 34 represents a part of the forest. Figure 46 shows the DO-concentration combined with the water level in section 34. Figure 47 shows the functions reaeration and SOD that influence the DO-concentration in combination with the water level.

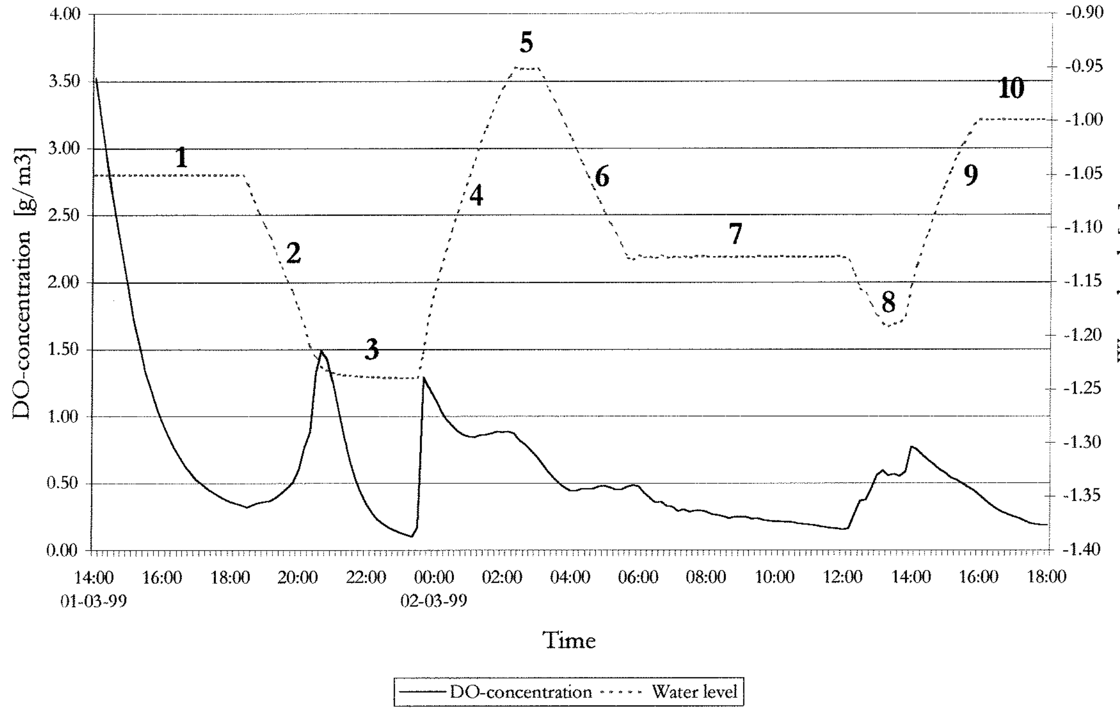


Figure 46: The DO-concentration and water level in section 34

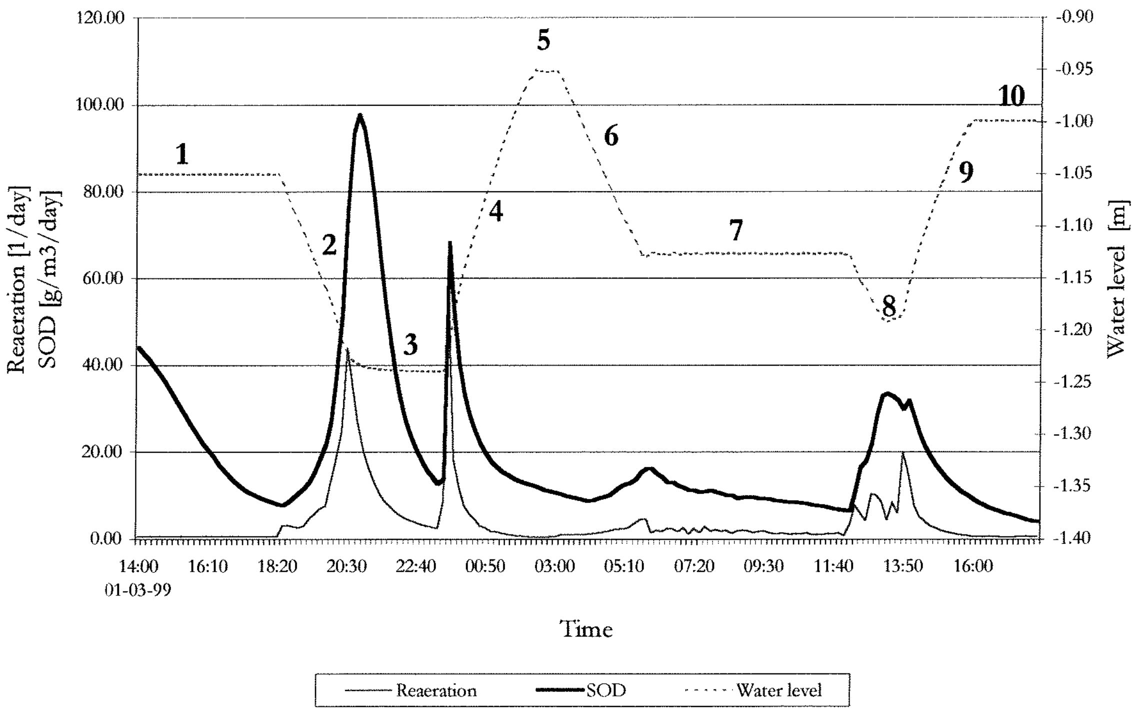


Figure 47: Reaeration, SOD and water level in section 34

Both figures show the same phenomena that were seen discussing the previous sections and will not be further explained. The initial value of the DO-concentration is a lot higher than DO-concentrations found later and was defined probably too high. A check was made to see if the initial water quality condition had any influence on the development of the DO-concentration in time. The initial conditions in the forest were lowered meaning that in section 34 the initial water quality condition was changed from 5.49 g/m^3 into 2.00 g/m^3. Figure 48 compares the DO-concentrations calculated with the high and low initial water quality conditions.

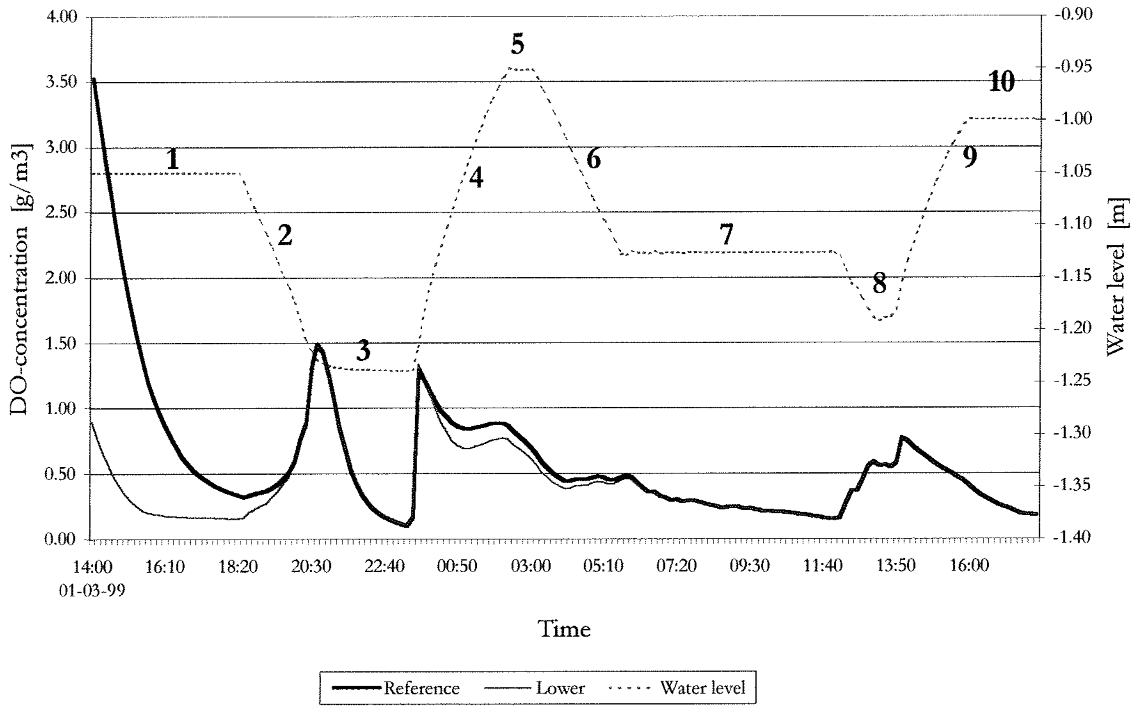


Figure 48: The influence of lower initial water quality conditions in section 34

As seen in figure 48, the DO-concentrations were different in the beginning but after the first outlet, the maximum DO-concentrations were the same. Small differences were seen during the first inlet (4) but after the second outlet (6), the DO-concentrations became identical. The higher initial water quality conditions have only a little influence on the DO-concentrations. In both situations, the same maximum DO-concentrations were found. The defined initial water quality conditions in the forest influence the DO-concentrations a little bit but they do not cause considerable differences.

During the inlet of water (4 and 9), water with a high DO-concentration coming from sea did not influence the DO-concentration like it did in section 22 and 24. The assumption was made that decreasing the influence of the water coming from the forest and the increase of the DO-concentration was caused by the reaeration. Due to the exchange of water, the water started flowing increasing the reaeration. During the outlet of water (2, 6 and 8) the reaeration increased that much (Rea-2, Rea-6 and Rea-8) increasing the DO-concentration (DO-2, DO-6 and DO-8) and decreasing the influence of the water form the forest. Water that entered the pond did not have major influence on the DO-concentration in section 34.

- Section 19

Section 19 represents a part of the channels. Figure 49 describes the DO-concentration and water level in section 19.

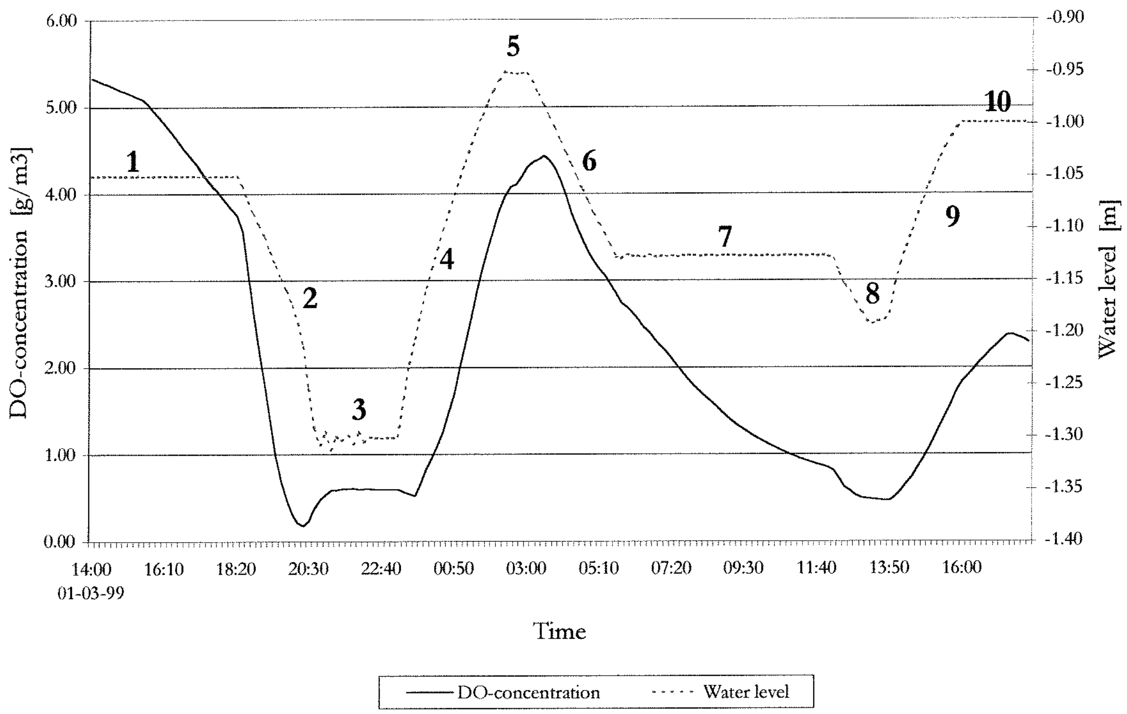


Figure 49: The DO-concentration and water level in section 19

Figure 50 shows together with the water level the functions that influence the DO-concentration, SOD and reaeration.

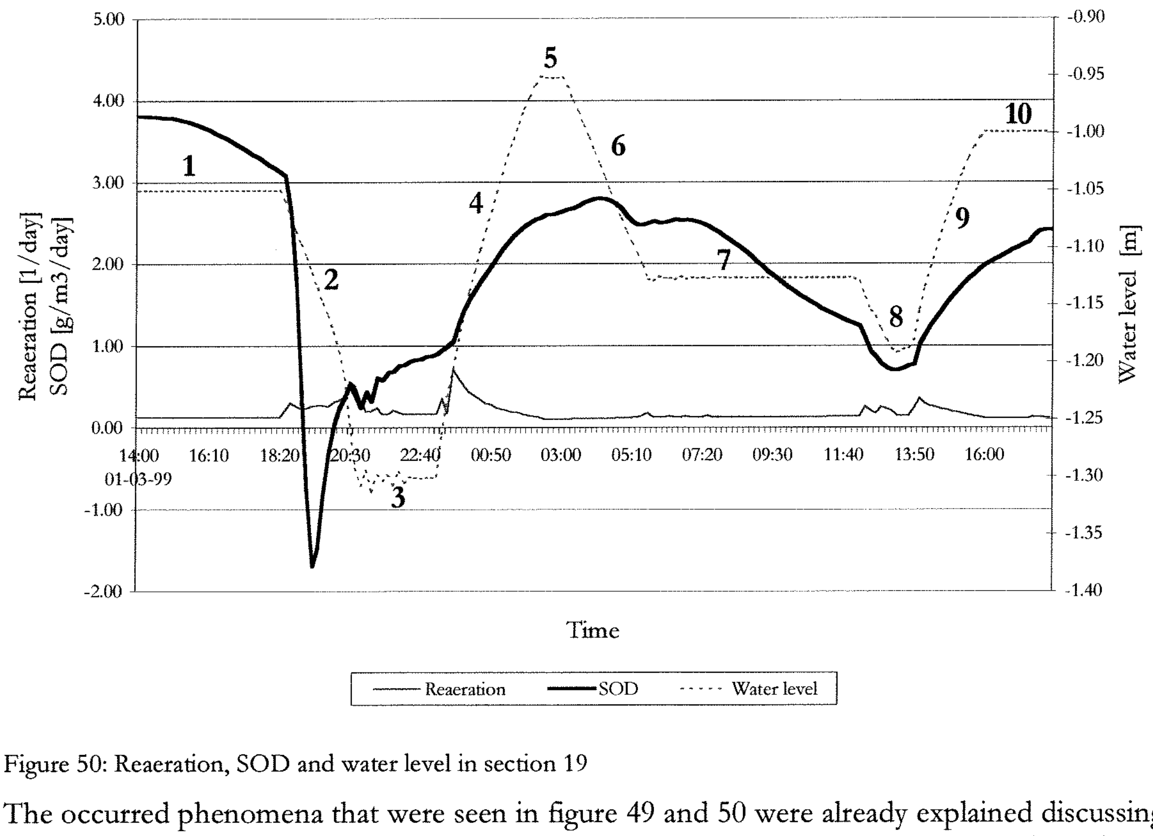


Figure 50: Reaeration, SOD and water level in section 19

The occurred phenomena that were seen in figure 49 and 50 were already explained discussing the previous sections. Only one strange value of SOD (SOD-2) was seen, the negative values and can be caused by numerical problems due to the sudden change of the DO-concentration when water was let out. Water with a low DO-concentration flowed from the forest into the channel.

At this point, the Monod-factor was also negative. Besides this strange value everything that was seen in these figures were already discussed.

Also looking at figure 49 it was seen that during water inlet (4 and 9) the DO-concentration did not reach as high as in the sections closer to the sluices (especially at 9). Due to the first inlet of water (4), the maximum DO-concentration was reached after some time when the sluices were closed. This assumes that it took some time before the water with the higher DO-concentration reached those parts of the pond that were situated further away from the sluices. It was also assumed that before this water reached section 19 a high amount of DO was already consumed by SOD causing the DO-concentration in section 19 to increase less.
Figure 51 shows the DO-concentrations in one channel, the sections 11, 15 and 19 (for positions see figure 35) in combination with the water level inside to see the times the water was exchanged. Section 11 closest positioned to a sluice had the most increase of the DO-concentration compared to the sections situated further.
The development of the DO-concentration in time will not be discussed here because all the phenomena were already discussed.

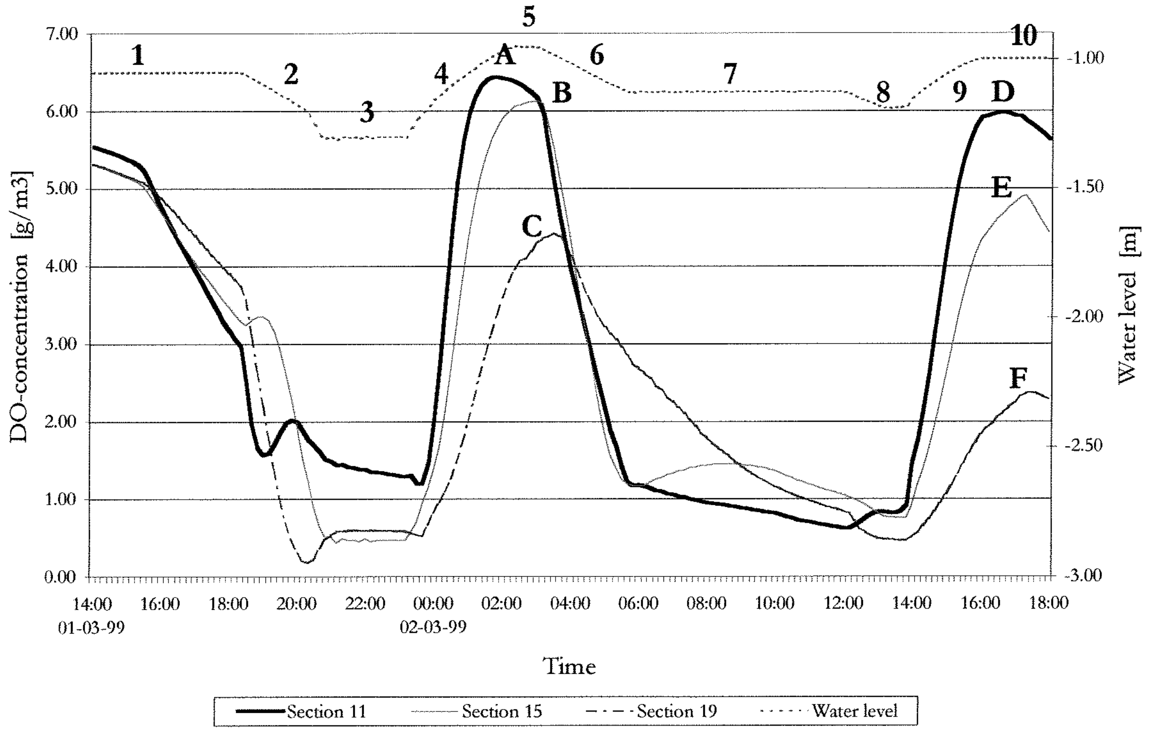


Figure 51: DO-concentration in one channel

For all three sections an increase of DO-concentration can be seen when the water was let in (4 and 9). It can be seen that the maximum DO-concentrations after inlet were reached at a later time in the sections further from the sluice (A, B, C and D, E, F), caused by the time it took for the water to reach these further positioned sections.
The further situated from the sluices the less the DO-concentration increased (C and F). The section closest to the sluice was influenced the most by the DO-concentration during inlet (A and D). The reason is that during the time the water with the higher DO-concentration was flowing towards the sections further away from the sluices the SOD consumed DO. By the time the water reached the sections far from the sluice the DO-concentration in the water had already decreased, which resulted in a smaller increase of the DO-concentration in these sections (C and F).

The reason that the (C) was higher than (F) was because of the volume of water that was let in. During the first inlet (4) more water was let in compared to volume of water entering the pond during the second inlet (9). More water means more DO entering the pond causing more DO to reach the sections further situated from the sluices so a higher DO-concentrations was seen. Maybe the initial conditions in section 19 were set too high. To check this the initial water quality conditions were lowered and gave the results as shown in figure 52.

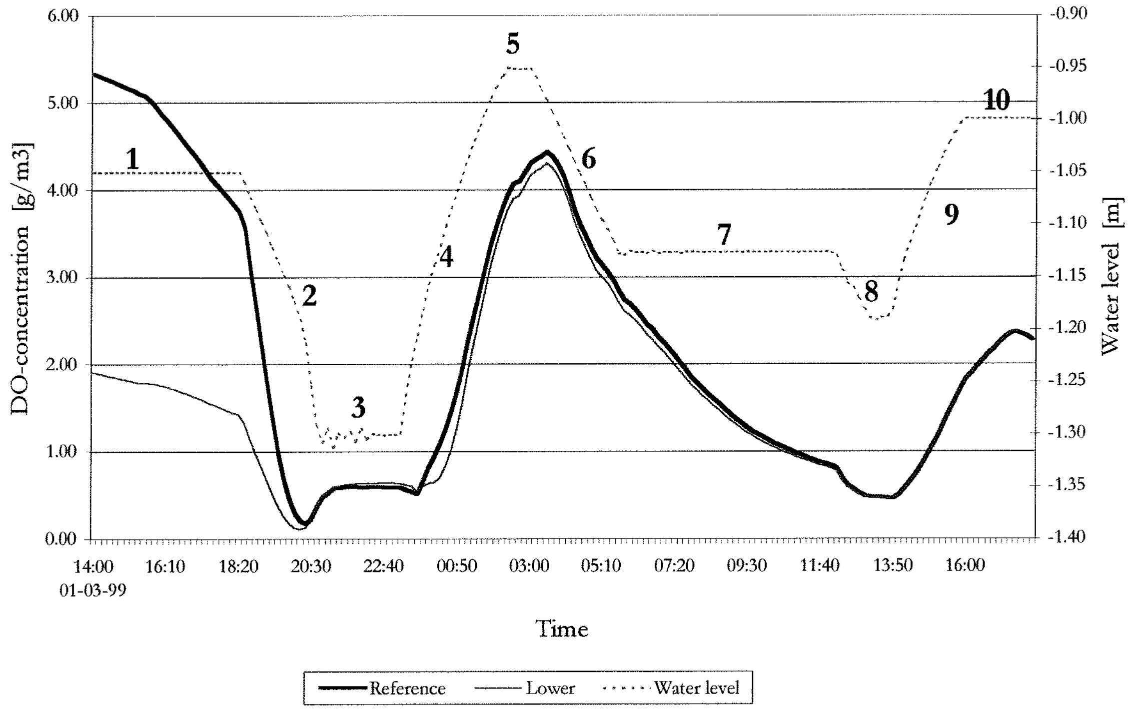


Figure 52: The influence of lower initial water quality conditions in section 19

Some small differences were seen between the two different definitions of the initial water quality conditions but for both values the differences between the first and second inlet were still visible and almost the same.
The cause of the difference in DO-concentration between C and F was not the cause of the defined initial water quality condition that were defined too high but due to the volume of water that was exchanged.

8.5 Summary of the output

This paragraph describes the most important phenomena that were seen discussing the water quality output of the model in paragraph 8.4.

Due to the assumptions made defining this model, the output can not be compared with the critical values that influence the shrimp. DO-concentrations calculated in Duflow were lower compared to the measured concentrations during the two fieldtrips. Still the model was not adjusted because low DO-concentrations were measured during earlier fieldtrips (*M. Zitzen, 1998; Roozen and Rosenboom, 1997*). The low DO-concentrations in Duflow were caused by the high consumption of DO by the sediment, the SOD.

During outlet a decrease of the DO-concentration in the channels was seen. Water from the forest, containing a very low DO-concentration flowed into the channels where it diluted causing the DO-concentration in the channels to decrease rapidly.

During inlet, the water starts to flow causing the reaeration to increase. Reaeration in combination with the inlet of the water from sea, containing a higher DO-concentration the DO-concentration inside the pond increased rapidly.

Sections situated further from the sluices were not well refreshed causing the DO-concentrations to be lower there compared with the sections situated closer to the sluices. During the time the water flowed from the in direction from the sections further situated, the SOD consumed DO lowering the DO-concentration in the water. Water with lower DO-concentrations reached the sections situated further causing the DO-concentrations to be lower compared to the sections closer to the sluices.

Exchanging more water caused the flow velocity to increase inside the pond. These higher flow velocities caused the reaeration to increase so more DO was provided to the system. Due to the value of SOD, sometimes this increase of the DO-concentration was seen and sometimes not. When the SOD was low the reaeration caused an increase of the DO-concentration, the reaeration was dominant compared to the consumption of DO by SOD. Other times the SOD was high just before the reaeration increased, the extra DO provided by reaeration was immediately consumed, so the DO-concentration did not increase.

When the DO-concentration increased due to the increase of reaeration, or water with a higher DO-concentration entered the pond, the SOD also increased. A higher DO-concentration in the system causes the Monod-factor to be higher too resulting in an increase of the rate of the SOD process. Due to the higher value of the SOD more DO is consumed causing the DO-concentration to decrease causing the Monod-factor to become lower too. A lower Monod-factor means a lower value of SOD. The SOD and DO-concentration influence each other.

9 Improving the system

This chapter first describes why this system needs to be improved (paragraph 9.1) followed by several options that show how to influence the system. The discussed options are described in paragraph 9.2, 9.3 and 9.4. At the end of this chapter a summary of the most important changes seen in the system is given (paragraph 9.5).

9.1 Why improving this system

During previous fieldtrips, DO-concentrations below the critical level of 4.3 g/m^3 were measured. DO-concentrations below the critical value may cause stress to the shrimp, stress influences the production in a negative way.
Due to the assumptions made, calibrating the model as defined in chapter 8 was not useful. The model gave lower DO-concentrations than measured. With the differences between the model and reality, this model can be used only to see how to influence the DO-concentrations, instead of comparing the output with the critical values. Results of the different options to improve are compared with the output of the model defined in chapter 8, the reference situation.

As seen in chapter 8, due to the high values of $SOD_{T.P.}$ a lot of DO was consumed causing the low DO-concentrations. The high values of $SOD_{T.P.}$ were caused by the high amount of leaf litter from the forest lying on the bottom. The forest, due to the leaf litter strongly influenced the DO-concentrations in the system, and was the main cause of the low DO-concentrations.
Decreasing the influence of the forest to improve the DO-concentrations, several options are discussed. Paragraph 9.2 describes options how to influence the DO-concentrations by increasing the influence of the DO providers, the water coming from the sea and the reaeration process. Paragraph 9.3 describes how to influence the DO-concentration by decreasing the influence of the DO consumer, SOD. The option of removing the sluices, letting the water level inside the pond to follow the tide at sea is discussed in paragraph 9.4.

9.2 The influence of the DO providers

Reaeration and the water from sea that entered the pond during inlet provided the system of DO.
During fieldtrip 2, every high and low water was used to exchange water, more periods to exchange water were not possible.
The changes made to increase the influence of the DO providers to improve the DO-concentration were:

- Changing the sluice management (paragraph 9.2.1)
- Increasing the number of sluices (paragraph 9.2.2)
- Creating more side connections (paragraph 9.2.3)
- Combining several options (paragraph 9.2.4)

9.2.1 Changing the sluice management

During the fieldtrips, it was seen that during every high and low water, water was exchanged, more periods of exchanging water could not be defined. Changing the sluice management, the water was forced to flow to have a better circulation, increasing the reaeration. The following option, option 1 concerning the sluice management is discussed:

1) using sluice A for the inlet and sluice B for outlet of water

Forcing the water to flow from one side of the pond to the other side and could result in a better circulation and a change of reaeration.

Option 1:
Figure 53 and 54 compares the DO-concentrations of the reference situation (Reference) with the found results of option 1 for section 7 and 19.

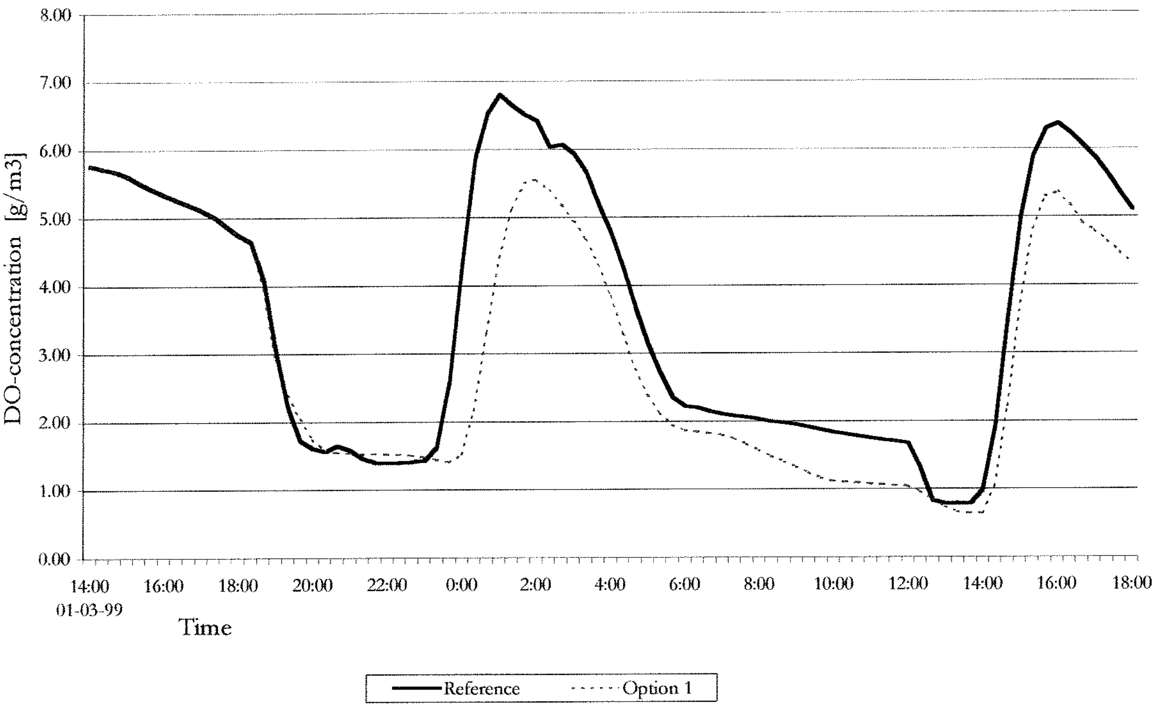


Figure 53: Comparing the reference situation with option 1 in section 7

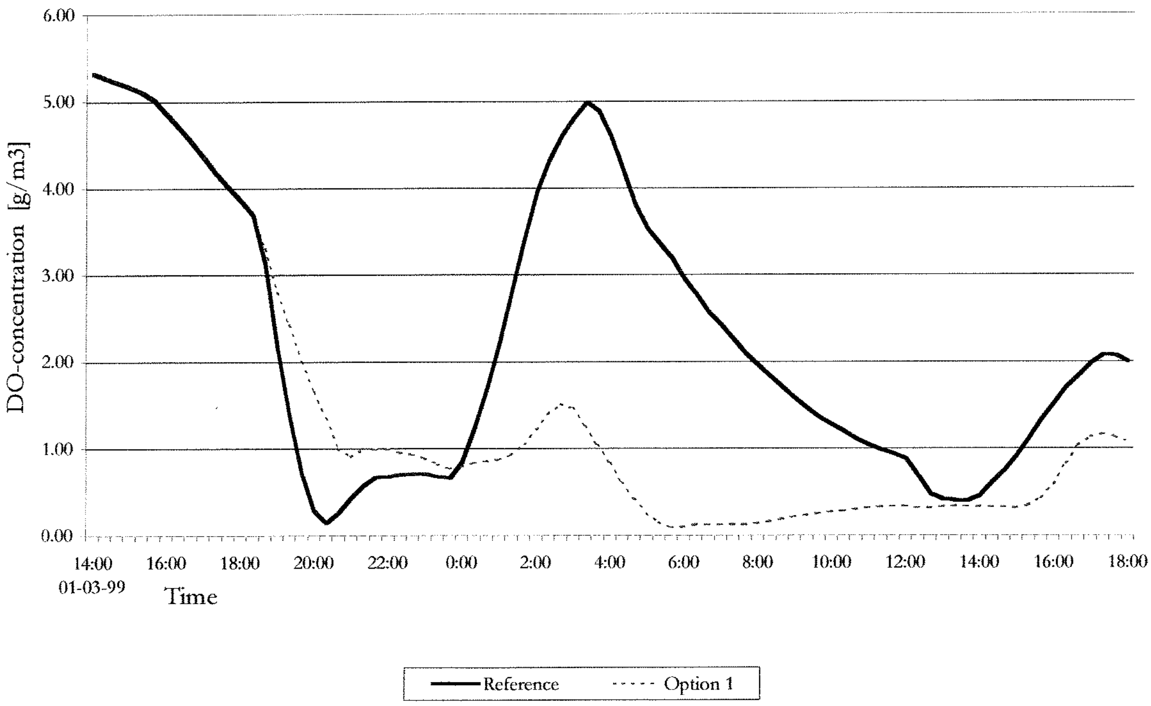


Figure 54: Comparing the reference situation with option 1 in section 19

Using sluice A for inlet and sluice B for the outlet of water resulted in a decrease of the reaeration compared with the reference situation causing lower DO-concentrations.

Using sluice B for outlet, the water was forced to flow in the direction of this sluice. Only using one sluice for outlet caused less water to be let out during the same period causing the flow velocity inside the pond to become lower compared to the reference situation. The lower flow velocity caused the reaeration and the DO-concentrations to be lower compared to the reference situation. Due to the smaller volume of water that was let out, the water level inside dropped less causing a smaller volume of water to flow from the forest into the channels. In spite of less water coming from the forest, the DO-concentrations in the channels still decreased rapidly.
When water was let in, an increase of the DO-concentrations near sluice A was seen. Due to the lower DO-concentrations after outlet, before inlet, lower DO-concentrations were found after inlet compared with the reference situation.
Discussing channel section 19 (paragraph 8.4.3) it was seen that it took time for the water to reach those parts of the pond further situated from the sluices. During that time the SOD consumed DO causing water with a lower DO-concentration to reach the sections situated further from the sluices. The same was seen here. Water let in through sluice A, had to refresh the whole pond, some sections were situated further than channel section 19. The time it took the inlet water to reach the further situated sections, in combination with the DO consumption by SOD during that time, the DO-concentrations in the sections at the other side of the pond were not influenced.
When the channel sections showed worse DO-concentrations, compared with the reference situation the parallel channels representing the forest also gave lower DO-concentrations.

The opposite of option 1 was also looked at, using sluice A for outlet and sluice B for inlet. The same phenomena were seen at the opposite side of the pond compared with the results of option 1. The only difference was see during inlet, the DO-concentration near sluice B increased more due to the larger dimensions of the sluice causing more water with a higher DO-concentration to enter the pond. Still these DO-concentrations near sluice B were lower compared to the reference situation.

Using one sluice for inlet and one for the outlet of water caused the flow velocity inside the pond to be lower compared to the reference situation. Due to the lower velocity in the pond, the reaeration and the DO-concentrations were lower. Using only one sluice for the inlet of water was not enough to refresh the whole pond. Sections close to the sluices also gave lower DO-concentration compared to the reference situation.

9.2.2 Changing the number of sluices

As seen from the results of paragraph 9.2.1, the sluice dimensions influence the DO-concentration inside the pond. Larger dimensions or more sluices cause more water to enter the pond causing a higher increase of the DO-concentration. This option, option 2 discusses the influence of an extra sluice.

2) define an extra sluice with the dimensions of sluice A, situated between sluice A and B

All the sluices were used to let water in and out. Increasing the number of sluices made sure that more water would be exchanged causing the flow velocity to become higher, and during inlet, more DO will enter the pond.

Option 2:
The network with the new defined sluice, sluice C is shown in figure 55. Sluice A has in this option the same dimensions as in the reference situation. The new defined sluice (sluice C) has the same dimensions as sluice A. Besides the same dimensions also the times of water exchange

for both sluices were the same. Sluice C is connected with the channel outside the pond. Figure 55 shows that the new sluice was defined more to the center of the pond.

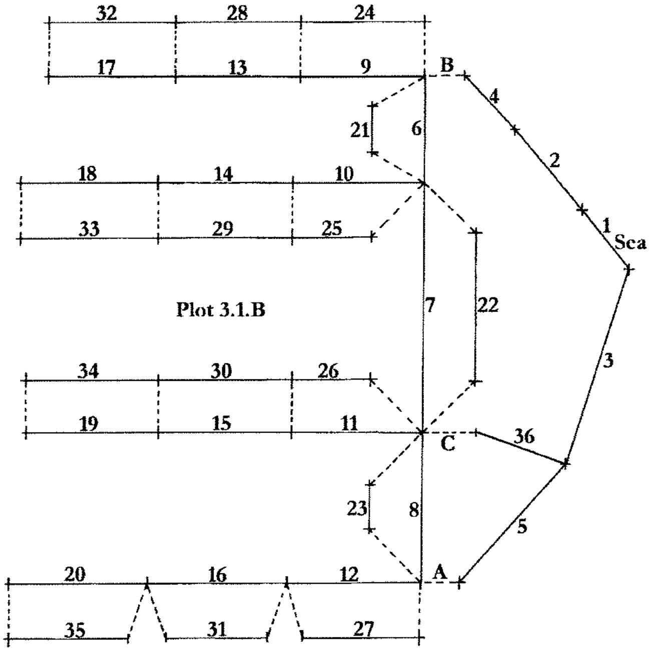


Figure 55: New network option 2

Figure 56 and 57 compares the results of option 2 with the reference situation for respectively section 7 and 19.

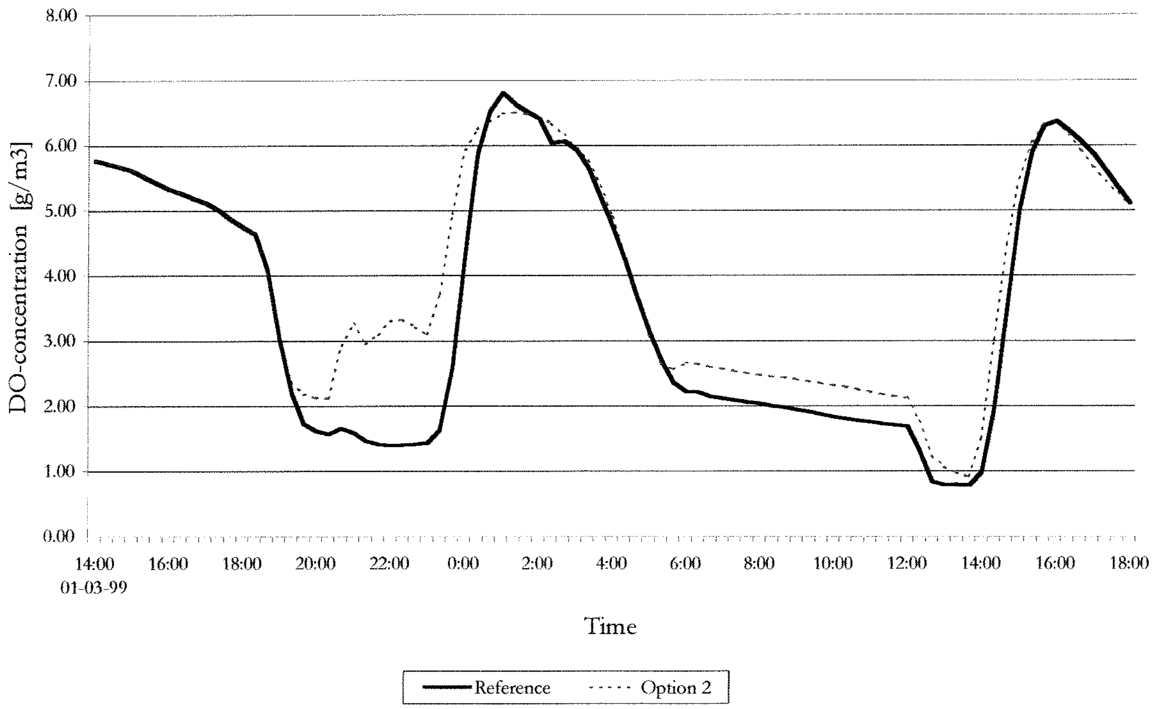


Figure 56: Comparing the reference situation with option 2 in section 7

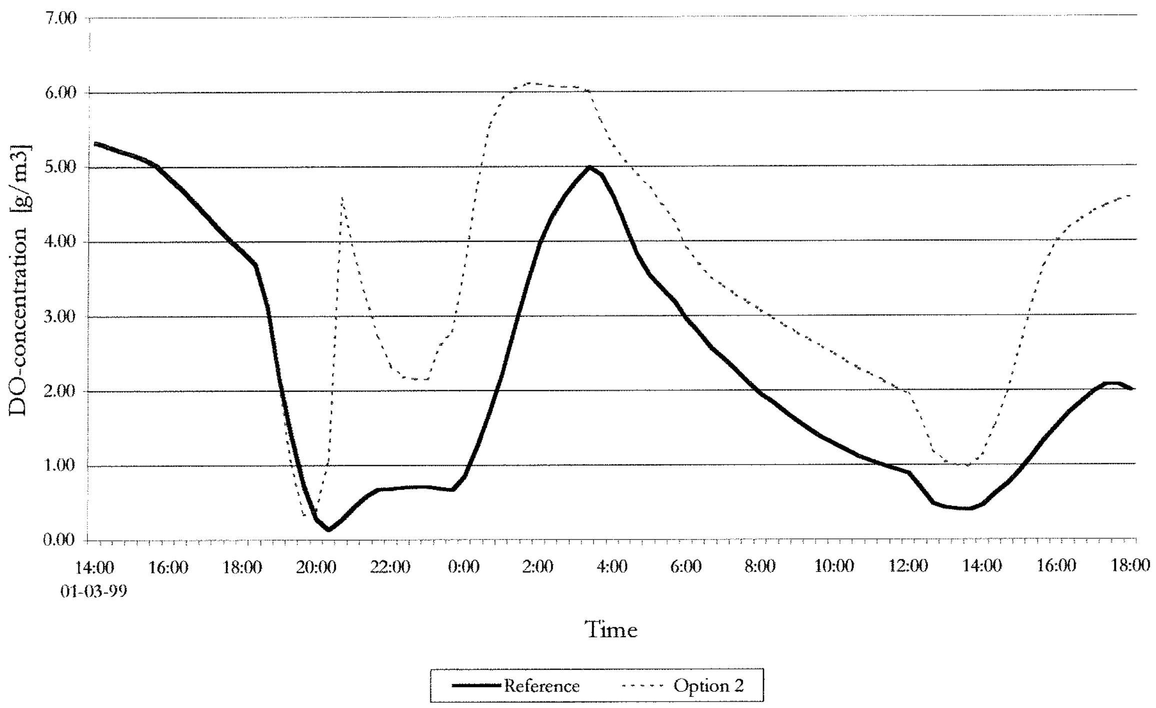


Figure 57: Comparing the reference situation with option 2 in section 19

The DO-concentrations were higher compared with the reference situation. Due to exchanging more water, the flow velocity inside the pond increased causing the reaeration to increase too. The higher values of reaeration in combination with the water from sea containing a higher DO-concentration that entered the pond during inlet, caused the DO-concentrations to become higher compared to the reference situation.
The new sluice was defined at the beginning of the channel that ends with section 19. The shorter distance between section 19 and a sluice more DO reached this section causing the DO-concentration to become higher compared to the reference situation.
Due to the higher reaeration during outlet more DO was provided to the system causing a decrease of the influence of the water flowing form the forest into the channels, containing a lower DO-concentration. The DO-concentrations in the channels decreased less compared to the reference situation.

Looking at this option it was seen that the DO-concentrations were higher compared with the reference situation. More water was exchanged causing higher flow velocities and thus an increase of reaeration, and during inlet more DO entered the pond. Defining a new sluice in the middle made sure that the sections further situated from sluice A and B in the reference situation were better influenced. Exchanging more water also cause more shrimp to enter the pond.

9.2.3 Creating more side connections

At the end of the four parallel channels dams were constructed that divide plot 3.1 into two parts. These dams (figure 3) prevent the water to circulate in plot 3.1.B, influencing the circulation and so the reaeration. To see the influence the dams have this paragraph describes what happens if the water could circulate better, option 3. More connections between the four parallel channels were defined. The changes made in option 3, compared with the reference situation were:

3) defining three extra connecting sections at positions the dams are situated

Option 3:
Figure 58 shows the position of the new defined channels (I, II and III) to increase the reaeration.

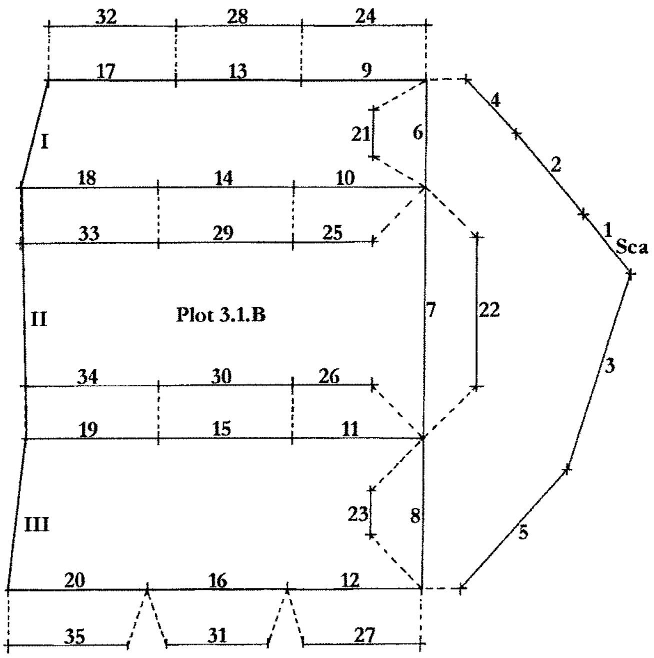


Figure 58: New network of option 3

Figure 59 and 60 shows the results of option 3 in section 7 and 19 compared with the reference situation.

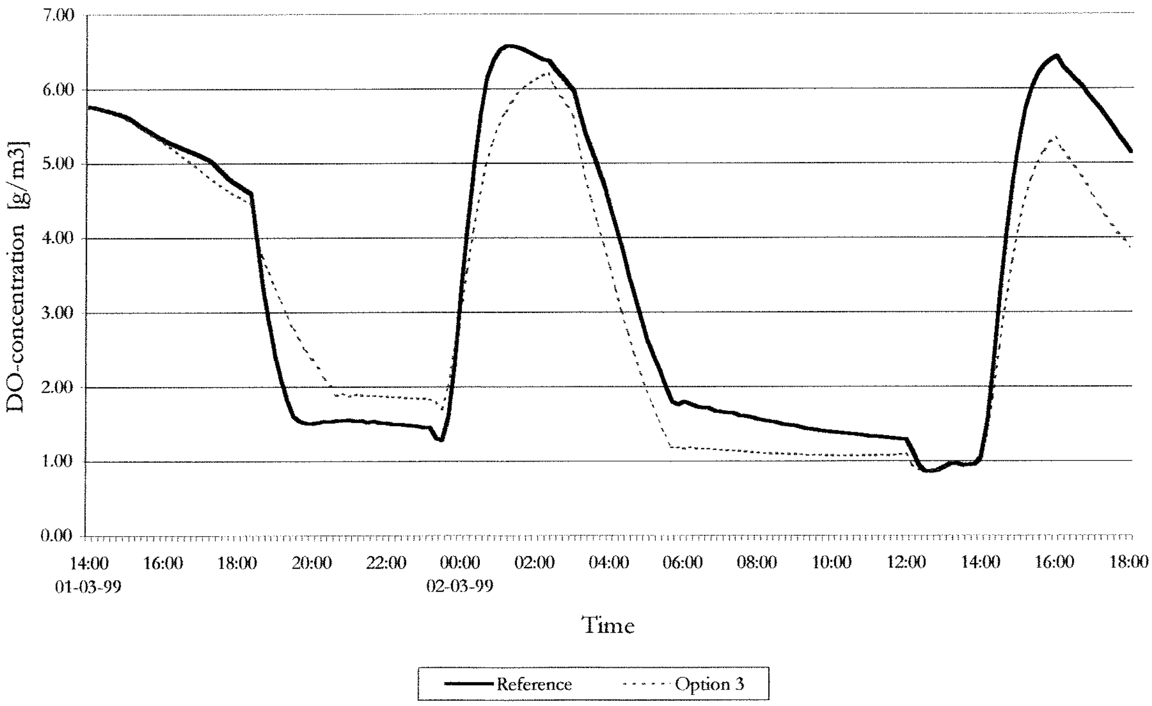


Figure 59: Comparing the reference situation with option 3 in section 7

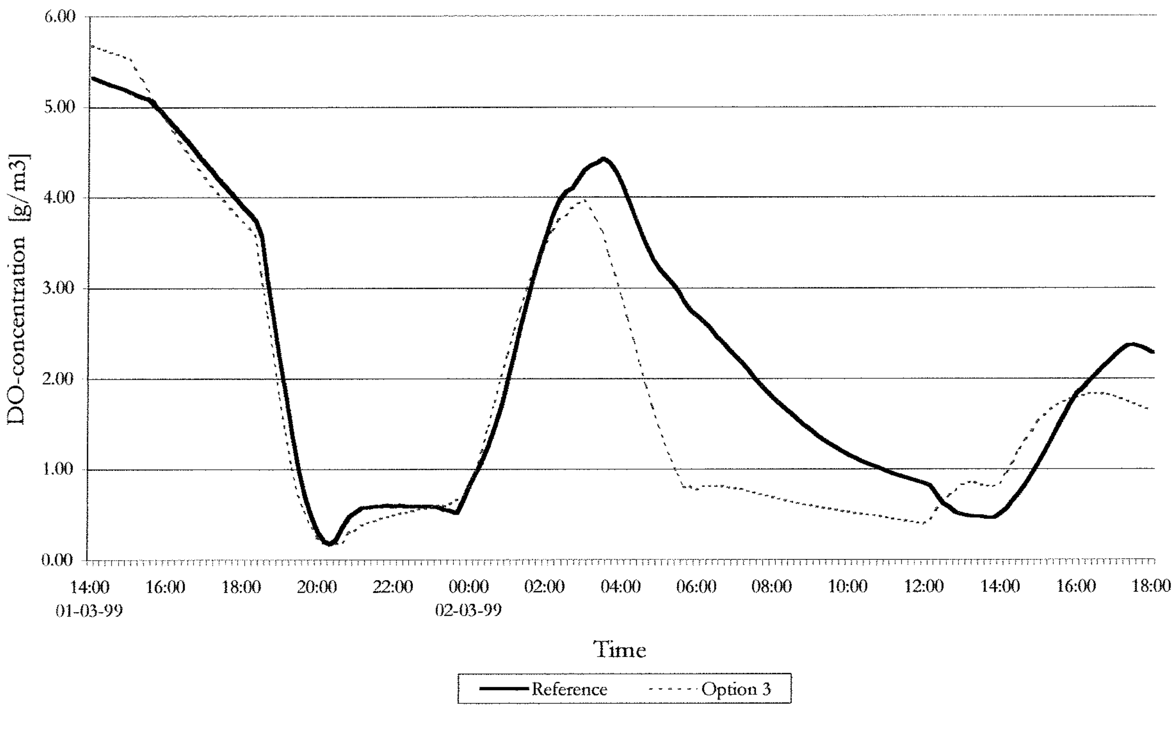


Figure 60: Comparing the reference situation with option 3 in section 19

Defining extra side connections, the reaeration was influenced in both a negative and positive way, compared to the reference situation. In the reference situation, due to the fewer connections, the water was forced to flow through certain sections, now due to the new defined connections the water could flow also in other directions. In the reference situation, water coming from the two inside channels (section 10, 11, 14, 15, 18 and 19, figure 58) flowed through section 7. Due to the new defined connections, the water could now also flow towards the sluices along a different way. Less water would flow through section 7 causing the reaeration to become lower compared to the reference situation. Due to the new defined connections more water flowed through other sections increasing the reaeration there.
Less water flowed through section 7 in option 3, so less water with a lower DO-concentration coming from the forest flowed through section 7 causing the DO-concentration to be less influenced compared to the reference situation. Higher DO-concentrations were found in section 7 after the first outlet.

Some sections showed an increase of reaeration but not an increase of the DO-concentration. The increase of reaeration provided the system of more DO, but also increased the SOD (higher Monod-factor). Sometimes the consumption of DO by SOD was dominant compared to the amount of DO provided by reaeration, causing the DO-concentration not to increase.
Higher DO-concentrations in the channel sections caused the DO-concentrations in the forest sections to be higher too. Nevertheless, very low DO-concentrations were seen in the forest sections.

9.2.4 Combining several options

From previous options proved that exchanging a larger volume of water caused the reaeration to increase inside the pond so higher DO-concentrations were found. Also exchanging more water, more water with a higher DO-concentration will enter the pond during inlet. Creating more connections between the channels influenced the flowing of the water but influenced the reaeration in a both negative and positive way. Here the previous options, to influence the DO-concentration are combined.

To exchange more water, two extra sluices, sluice C and D were defined at the opposite side of where sluice A and B are situated. The new sluices have the same dimensions as sluice B (a sluice width of 2,10 m). Also the sluice width of sluice A was changed from 1,20 m into 2,10 m. To improve the circulation three extra channels were defined (section 36, 37 and 38). Figure 61 shows the new defined network. The boundary conditions (tide and the DO-concentration) were defined at the beginning of the sections that were connected with sluice C and D, sections 39 and 40 (see figure 61). The boundary conditions, the tide and the DO-concentration were the same as defined at sea.

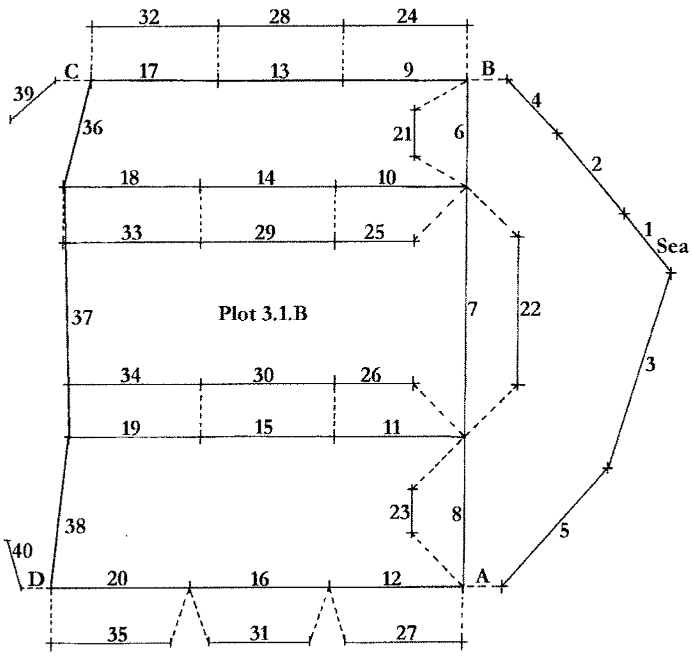


Figure 61: New network option 4 and 5

Besides defining extra sluices and channels, the influence of sluice management is checked here. Two different options, option 4 and 5 to improve the DO-concentration are discussed. These were:

4) all sluices (A, B, C and D) were used for the inlet and outlet of water
5) sluice A and B were used for outlet, sluice C and D for the inlet of water

Figure 62 and 63 compares the results of option 4 and 5 in section 15 and 17 with each other, and with the reference situation.

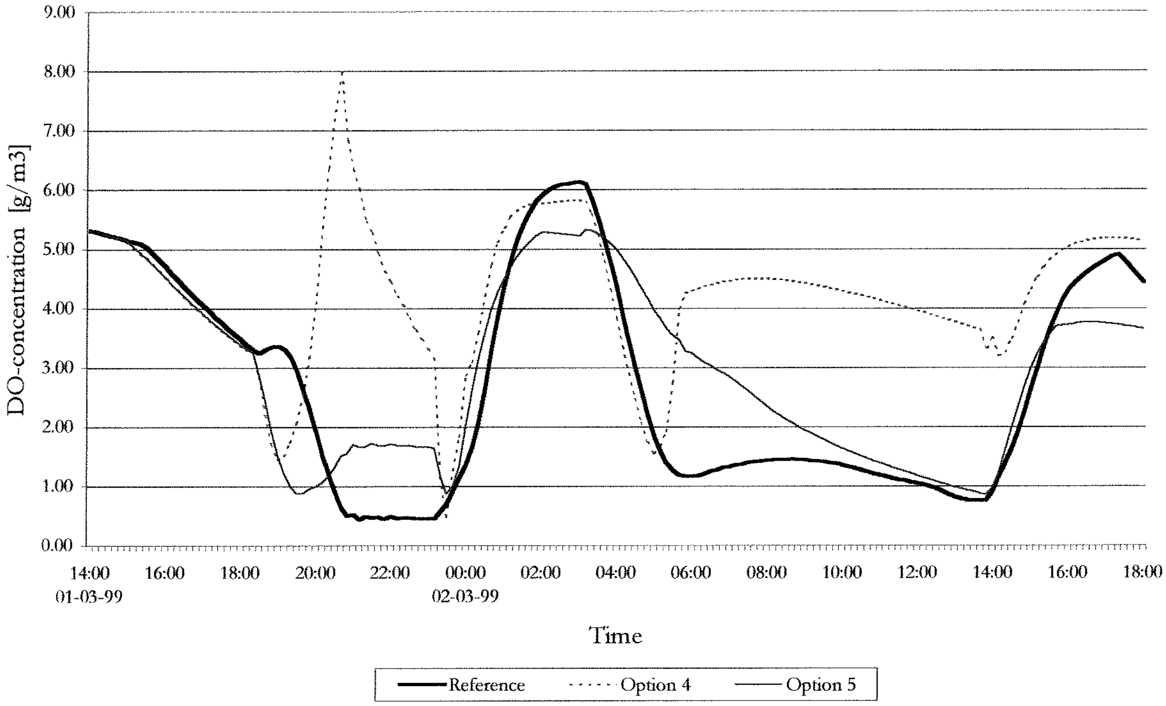


Figure 62: Comparing the reference situation with option 4 and 5 in section 15

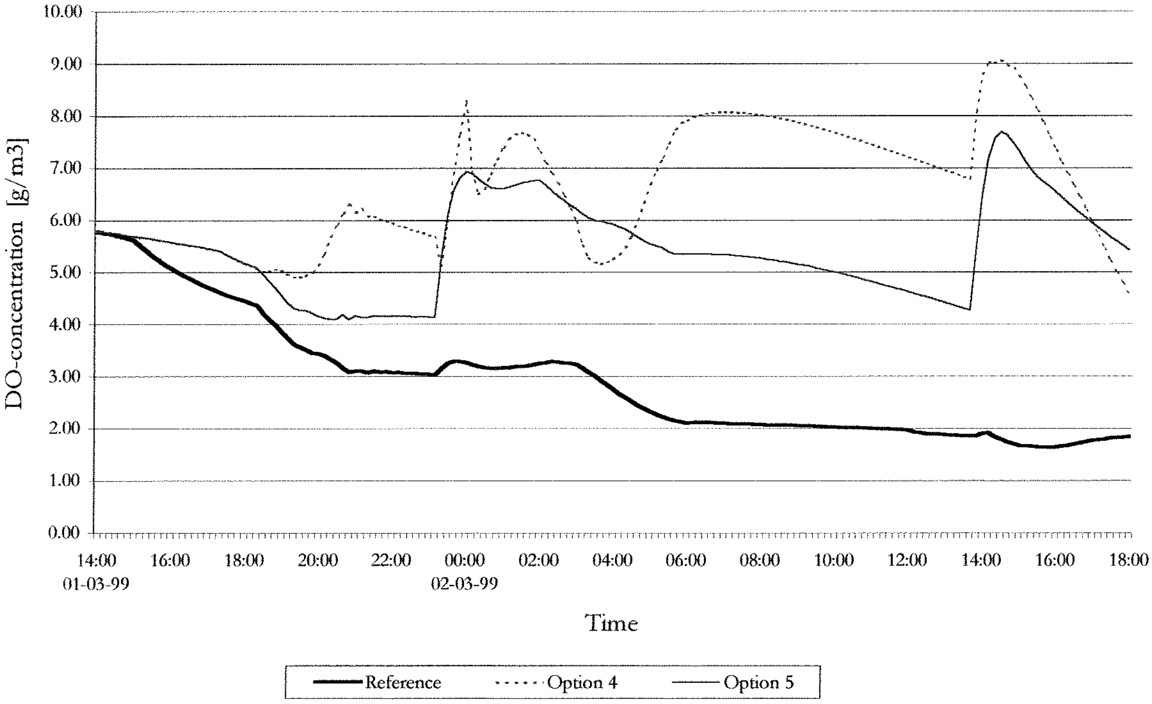


Figure 63: Comparing the reference situation with option 4 and 5 in section 17

The output of section 15 was chosen to show because this section is now the worst situated, looking at its position in comparison with the positions of the sluices section in the pond.

Option 4:
The times of water exchange during outlet were slightly adapted here. Due to using more sluices to exchange water, more water was exchanged during the same period of time causing the water level inside the pond to drop more rapidly. This caused the water levels in- and outside the pond

to be equal sooner. The outside water level still rose causing that the outside water level during the last period of an outlet to became higher than the inside water level so water was let in again. To avoid this, the times of water exchange during outlet were defined shorter.
All four sluices were used to exchange water causing more water to be exchanged compared with the reference situation. Due to more exchanging water, the flow velocity inside the pond became higher causing the reaeration also to be higher compared to the reference situation. As well as during inlet as outlet the reaeration increased, even during periods when no water was exchanged the reaeration was higher compared to the reference situation. During the outlet of water the flow velocity inside the pond increased causing the water to circulate with a high velocity. This circulation was so strong it still continued after the sluices were closed causing the higher values of reaeration during the period of no water exchange. Defining the two new sluices, the sections in the reference situation far situated from a sluice (section 19) were now closer to a sluice and better influenced. This better influence caused the DO-concentrations in these sections to be higher compared to the reference situation. Section 15, now the worst situated section in this new network was negative and positive influenced. During outlet, due to the more connections between the channels, water flowed in more directions. More water flowed in the system causing the reaeration to be higher compared to the reference situation. During inlet, water reached other sections and the DO was more divided over the system causing the DO-concentration in section 15 to be lower compared to the reference situation.
During the first outlet, a very high DO-concentration was seen, a numerical problem can be the cause of this, due to the rapid changes. Reaeration increased quickly causing the SOD to increase too. This quick increase could cause the DO-concentration to decrease rapidly.

Exchanging more water, the flow velocity inside the pond increased causing a higher reaeration compared to the reference situation. Also more DO entered the pond during inlet causing higher DO-concentrations. Using more sluices in combination with the extra connections between the channels, the DO-concentrations were higher compared to the reference situation.

Option 5:
Using sluice A and B for outlet, C and D for the inlet of water gave the following results. During the outlet of water, the reaeration was higher near the sluices A and B compared to the reference situation but higher values were also seen near the sluices C and D. The higher values were the result of a better circulation. The increase of reaeration during outlet decreased the influence of the water with a low DO-concentration coming from the forest. First a decrease of the DO-concentration was seen but after a short period the reaeration was high enough to provide enough DO to prevent the water, coming from the forest to decrease the DO-concentration in the channels. Higher DO-concentrations were found after outlet compared to the reference situation.
Sections, like section 17 and 19 further situated from the sluices in the reference situation, were now better influenced, due to the distance between the new defined sluices C and D and those sections. Only small differences between section 19 and the reference situation were seen.
Comparing this option with option 4 it was seen that during the periods the sluices were closed the reaeration was lower and almost the same as in the reference situation. The smaller volume of water that was exchanged in this option caused the flow velocity in the pond to be lower. This lower flow velocity was not able to maintain the strong circulation, like it did in option 4 so the high values of reaeration after the sluices were closed were not seen here.
Section 15 showed higher DO-concentrations during the periods between the water exchange but lower DO-concentrations during water inlet compared to the reference situation.

From the discussed options (4 and 5) above it was seen that exchanging more water, increases the flow velocities inside the pond causing an increase of reaeration. The increase of reaeration caused the DO-concentrations to become higher compared to the reference situation.

Option 4 shows that exchanging water using all sluices a circulation was induced being so strong it continued after the sluices were closed causing higher values of reaeration after the sluices were closed compared to the reference situation
With the defined sluices at the other side of the pond, the sections that were first situated far from a sluice were now better influenced, due to the shorter distance to the new sluices. The sections now worse situated as section 15 showed higher DO-concentrations compared with the reference situation. In spite of the improvements caused by exchanging more water and more side connections still low DO-concentrations were found.
Letting more water in, more shrimp will enter the pond.

9.3 The influence of the DO consumer

The only DO consumer modeled was the SOD. The high $SOD_{T.P.}$ value was the result of the decomposition of leaf litter on the pond bottom coming from the mangroves. To decrease the influence of SOD something had to be done about the high amount of organic material coming from leaf from the forest.
To influence the $SOD_{T.P.}$ two options will be discussed in paragraph 9.3.1. In paragraph 9.3.2 the influence of $SOD_{T.P.}$ during the period of the lunar month (7 days) when no water was exchanged and the influence on the next period of water exchange (7 days) is discussed.

9.3.1 Decrease the influence of SOD

Two options will be discussed that describe how to decrease the influence of the SOD. The high values of $SOD_{T.P.}$ were caused the decomposition of organic material from the high amount of leaf from the forest. To decrease the influence of leaf the following options are discussed:

6) cleaning the channels or preventing leaf to enter the channels
7) separating the forest from the channels

Decreasing the amount of leaf in the channels will decrease the value of $SOD_{T.P.}$ in the channels. Option 6 will discuss the influence of leaf that enter the channels and option 7 will discuss the influence of the forest. Figure 64 and 65 will compare the DO-concentrations found with option 6 and 7 with the reference situation for section 7 and 19.

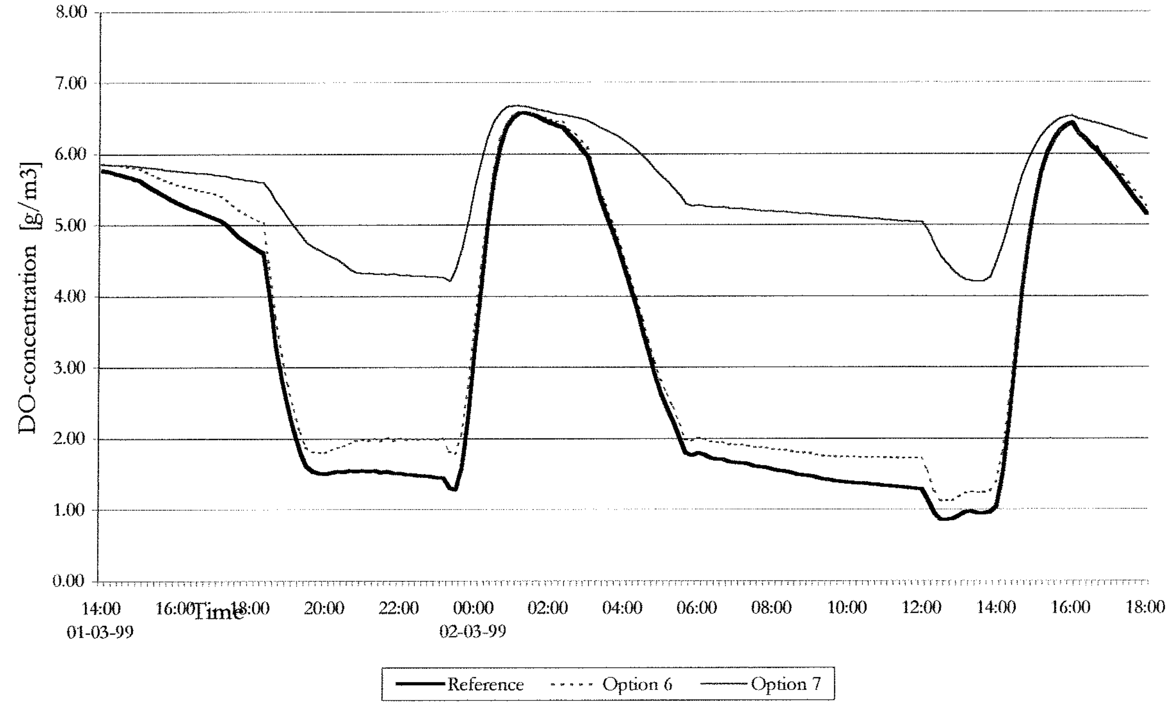


Figure 64: Comparing the reference situation with option 6 and 7 in section 7

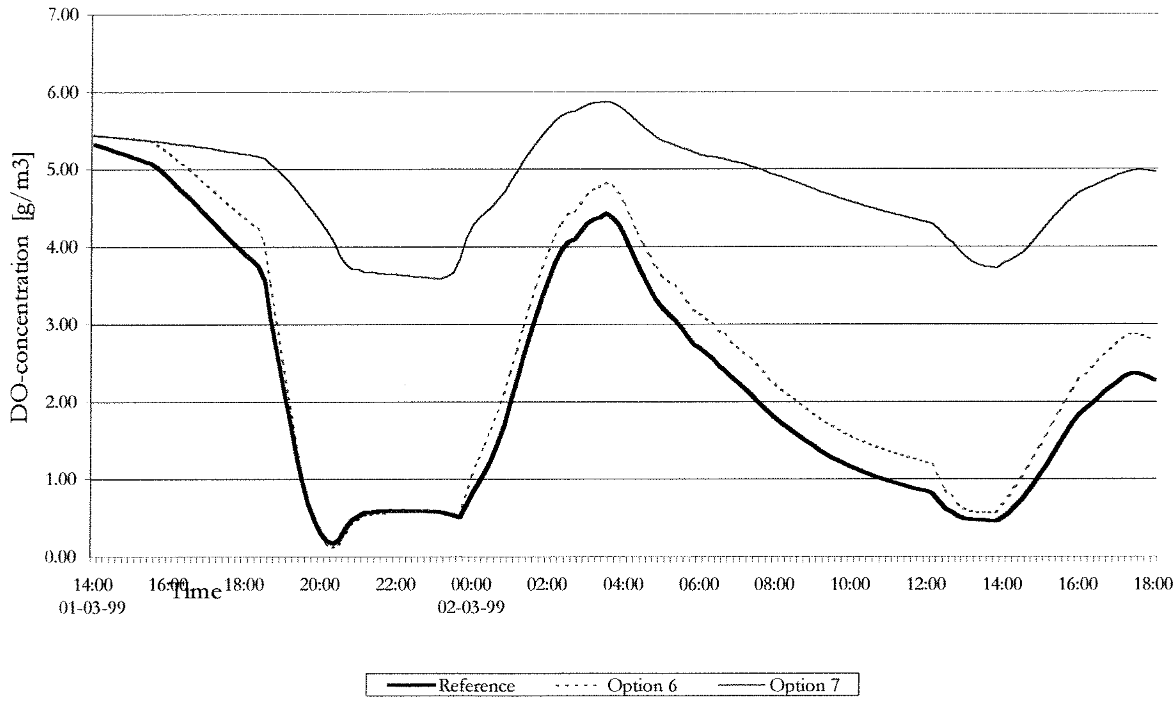


Figure 65: Comparing the reference situation with option 6 and 7 in section 19

Option 6:

As written before leaf were decomposed using DO causing high values of $SOD_{T.P.}$. Lowering the $SOD_{T.P.}$ in the channels can be done preventing leaf to enter the channels. This can be done by:

a) cleaning the channels more often
b) prevent the leaf from entering the channels

Cleaning the channels more often causes that leaf lying on the bottom will be removed. Cleaning the forest by hand to remove all leaf is impossible.
Preventing leaf to enter the channels can be done using wire netting. Water can enter and leave the forest during water exchange but the leaf will, due to the wire netting be prevented to enter the channels.
Making sure less leaf enter the channels the value of $SOD_{T.P.}$ will become lower. The $SOD_{T.P.}$ value in the channels was defined at 0.75 $g/m^2 \cdot day$ (instead of 3 $g/m^2 \cdot day$). This value contained the influence of the SS, 0.45 $g/m^2 \cdot day$ (15% of the total SOD; *M. Zitzen, 1998*) raised to 0.75 $g/m^2 \cdot day$, leaf will always fall in the water because of for instance wind. This raise is arbitrary.
Lowering the $SOD_{T.P.}$ less DO was consumed, resulting in a slower decrease of the DO-concentrations during the periods between the water exchange compared to the reference situation. During water outlet, water with a lower DO-concentration flowed from the forest into the channels still causing a rapid decrease of the DO-concentrations.
Section 19 shows an increase of the DO-concentration during inlet. Due to the lower sediment oxygen demand in the channels, less DO was consumed during the time the water flowed from the sluices towards section 19. Water with a higher DO-concentration reached section 19 so higher DO-concentrations were found compared with the reference situation.
In spite of the fact that the $SOD_{T.P.}$ in the forest was the same a little increase was seen in certain sections describing the forest caused by the higher DO-concentrations in the channels.

Option 7:
In option 6 still low DO-concentrations were found in the forest and in the channels after outlet of water, caused by the water with a low DO-concentration that flowed from the forest into the channels. To decrease the influence of the forest, the channels and forest must be separated from each other. Separating the forest from the channels can be done on several ways. The forest can be removed but also other options like reconstructing the farm in such way that the water from the forest can not enter the channels. Option 7 will describe the influence when the forest is removed. The area where the forest was is still used as storage area.

Removing the forest resulted in a lower $SOD_{T.P.}$ value in the sections that used to describe the forest. SS, containing organic material still enters this area the $SOD_{T.P.}$ was defined at 0.75 $g/m^2 \cdot day$, the same value used in option 6 for the channel sections. Wind could still cause leaf from surrounding forests to fall in the water.
All sections showed a strong increase of the DO-concentration. The lowest concentration in the sections that used to describe the forest was approximately 3 g/m^3. In the reference situation DO-concentration of 0.7 g/m^3 were seen. Lowering the $SOD_{T.P.}$ caused a considerable increase of the DO-concentrations.

Option 7 shows that the forest due to leaf litter, strongly influences the DO-concentrations in the pond. Removing the forest was the only option that showed a considerable improvement of the DO-concentrations.

9.3.2 The influence of no water exchange

As seen discussing option 7, the forest strongly influences the DO-concentration. As written before (paragraph 2.1) water is only exchanged during two periods of the lunar month. The 7 days between these periods no water is exchanged. Here three scenarios (a, b and c) are discussed that show the influence of the seven days period of not exchanging water on the DO-concentrations. The three scenarios are:

a) the reference situation; what happens to the DO-concentration during that period when the pond would not be changed

b) option 6; what happens when the channels were cleaned to the DO-concentration during the period of no water exchange
c) option 7; what happens to the DO-concentration during the period of no water exchange when there was no forest

- The sections describing the forest:

From the calculations the following results were found, see table 40. This table shows after how many hours the DO-concentration did not differ anymore (time). Not all the sections had the same DO-concentration so a minimum and maximum value is given. The values are not exact but approximations. The used figures describing the output of Duflow is shown in appendix E.2.

Table 40: Influence of no water exchange in the forest sections

Scenario	Time [hours]	Minimum DO-concentration [g/m^3]	Maximum DO-concentration [g/m^3]
a	30	0.1	0.4
b	30	0.1	0.4
c	150	1.1	2.3

After respectively 30 and 150 hours, the DO-concentrations became very low. Not decreasing the influence of the $SOD_{T.P.}$ cause extreme low DO-concentrations after one day of not exchanging. Even the best scenario, scenario c with the lowest $SOD_{T.P.}$ showed that before the 7 days were over the DO-concentrations were extreme low.
Due to all assumptions made and the differences with the real system, the model output can not be compared to the critical values that influence the shrimp. Still a check was made to see after how many hours the DO-concentration in the best scenario, scenario c would be lower than the critical value of 4.3 g/m^3. The $SOD_{T.P.}$ in this scenario was set on 0.75 g/m^2·day, low compared with the measured and assumed values of $SOD_{T.P.}$. Working with this scenario a good indication of the influence of the period of not exchanging water can be given. The first section was below the critical DO-concentration after approximately 4 hours and the last section passed this limit was after almost 33 hours. Not exchanging water for a short period (1.5 days), the DO-concentrations in the pond are lower than the critical DO-concentration.

- The sections describing the channels

Table 41 shows after how many hours the DO-concentration remained constant. From the results it was seen that two sections gave higher DO-concentrations compared with the rest. In spite of these two sections, the other parts of the pond showed similar results. The figure used describing the output of Duflow is shown in appendix E.2.

Table 41: Influence of no water exchange in the channel sections

Scenario	Time [hours]	Minimum DO-concentration [g/m^3]	Maximum DO-concentration [g/m^3]
a	45	0.1	0.4
b	90	0.3	0.7
c	180	1.1	1.8

Looking after what time the DO-concentrations became under the critical concentration of 4.3 g/m^3 only the best scenario; scenario c was looked at. After 13 and 40 hours, respectively the first and last section became lower the critical DO-concentration.

Due to the high values of $SOD_{T.P.}$, the forest strongly influences the system. During the period of 7 days between water exchange, very low DO-concentrations were found. No shrimp were

farmed during those periods making the situation inside the pond of minor importance to the farmers. Still it strongly influences the period of water exchange followed to the period of not exchanging water. A calculation was made to see the influence of these low DO-concentrations on the period of water exchange that followed. The initial water quality conditions were defined at the highest value of the best scenario, scenario c (removing the forest) after 7 days of not exchanging water. The lowest DO-concentration was found, see table 41, was 1.8 g/m^3.
After the first inlet the DO-concentration increased to a maximum of 6.6 g/m^3 followed by a quick decrease caused by the exchanging of water with other sections. Not all sections were well refreshed and still very low DO-concentrations, especially in the sections far situated from the sluices were seen. It took time before these sections had higher DO-concentrations. After 21 hours, the DO-concentrations in most of the channel sections were below the critical value of 4.3 g/m^3. Even values around the 2.0 g/m^3 were seen.
To create an environment for the shrimp were the can life after a long period of not exchanging water takes time. During the first days of exchanging water, the DO-concentrations will be too low for the shrimp to life in.
The period of 7 days of not exchanging water, strongly influences the DO-concentrations, especially the first few days, of the period when water will be exchanged. Exchanging water during this period of 7 days can solve this problem. However, during this period, due to neap tide the tidal range is smaller compared to the tidal range in the period of water exchange (spring tide). Due to the smaller tidal range (approximately 1 m smaller compared to the spring tide) the water levels in the outside channels are too low to be used to let water in.

9.4 The natural mangrove-shrimp system

From the above discussed options it was seen that improving the DO-concentrations changing the DO providers can do, but still very low DO-concentrations would occur. To obtain high DO-concentrations, separating the forest from the channels is the best option (option 7). This indicates that the combination of growing mangroves with farming shrimp is not a good one. In spite of it, many mangrove-shrimp systems exist in nature because it is a natural combination. Not exchanging water (paragraph 9.2.3) caused the DO-concentrations to become very low. Separating the system from its natural environment where the water levels follow the tide can be the cause of the problems. To check this the following option, option 8 is discussed:

8) removing the sluices and let the inside water level to follow the tide

Removing the sluices A and B the pond was connected directly with the sea and the tide could enter the pond. The measurements done in Vietnam were done during spring tide. Due to the high tidal range, the pond dried up during certain periods of the day, causing problems in Duflow but also in reality problems can occur when the channels dry up. The inside channels in the pond are wide and not sheltered from the sun by the mangroves, causing the pond bottom to dry in the sun. Often these ponds are built on an Acid-Sulfate-soil (*M. Zitzen, 1999*), and when these types of bottoms dry in the sun, acids (cat's clay) can be released having a bad influence on the environment. During neap tide, when the tidal range is approximately 1 m smaller the pond also dries up in the sun and it is assumed that during neap tide the forest will not be refreshed.

To see the influence on the DO-concentrations when the water levels inside the pond follow the tide, several adjustments were made to the model to avoid problems in the water quality output. Removing the sluices, changing the mean level of the tide from –1.8 m to 1.0 m, and the bottoms of two channels inside the pond (section 10, 11, 14, 15, 18 and 19) were lowered to avoid drying up.

Figure 65, 66 and 67 compares the DO-concentrations of the reference situation with option 8, in section 7, 17 and 22. The same values of $SOD_{T.P.}$ as used in the reference situation were used here; in the forest sections 10 g/m^2·day and in the channels sections 3 g/m^2·day.

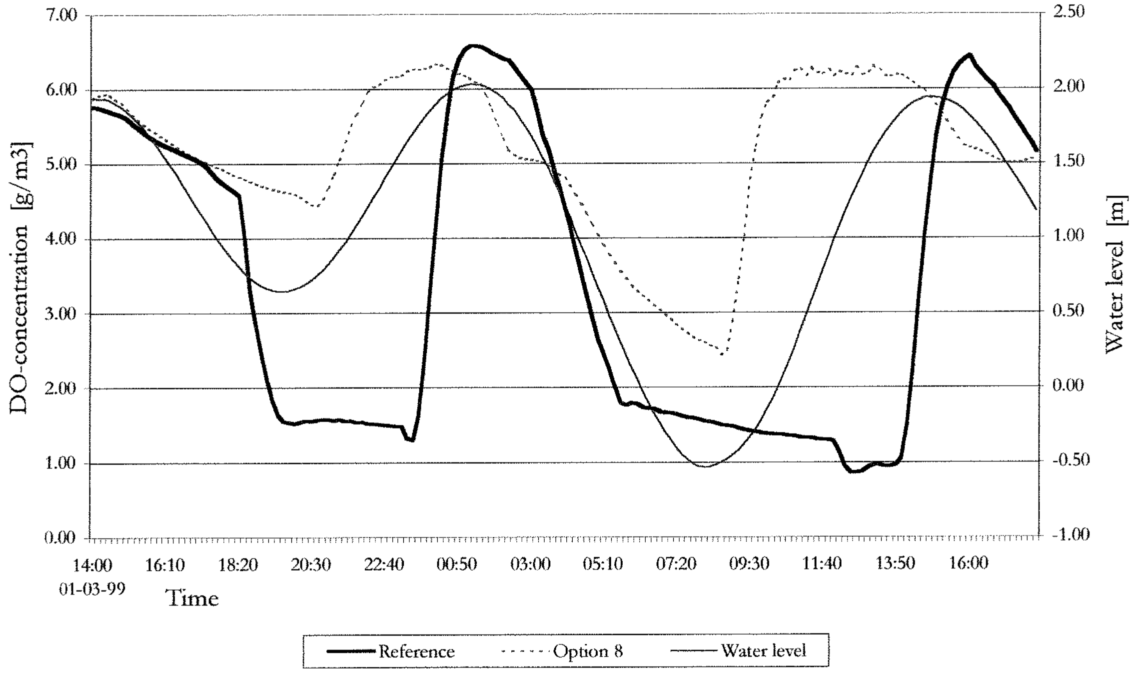


Figure 66: Comparing the reference situation with option 8 in section 7

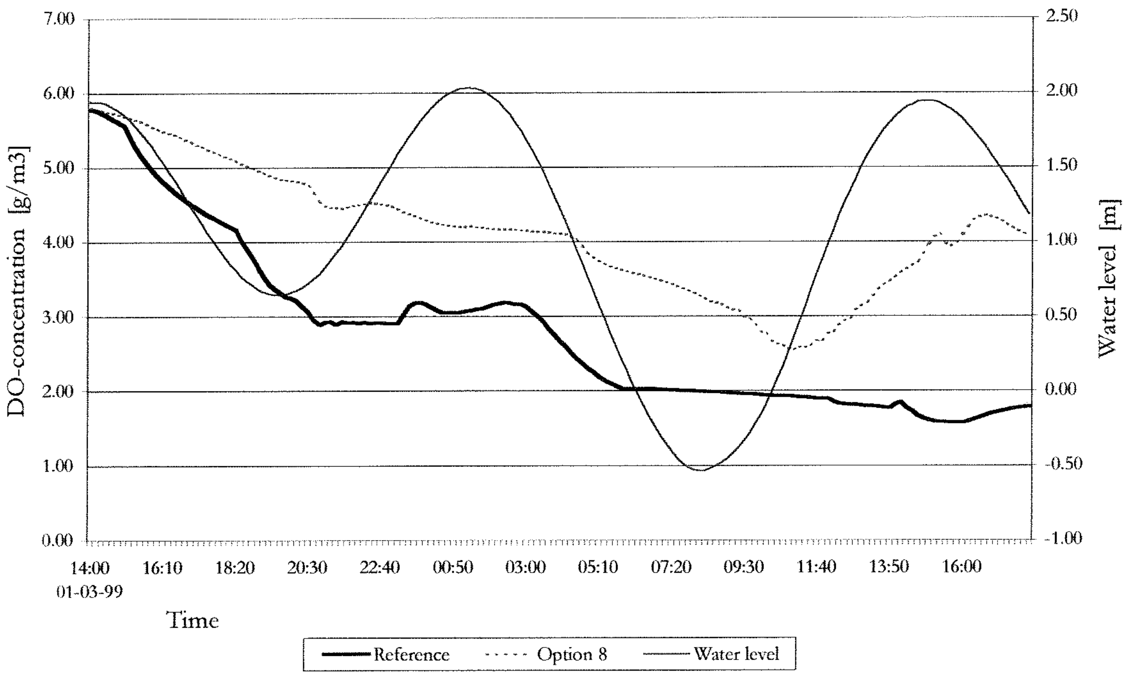


Figure 67: Comparing the reference situation with option 8 in section 17

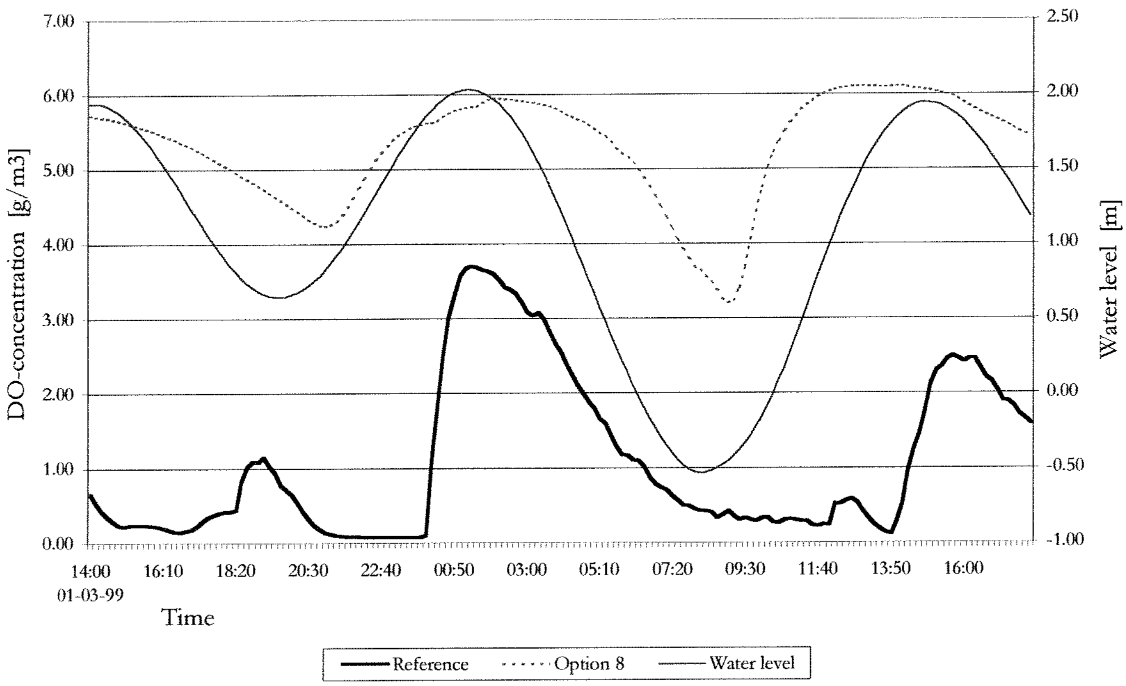


Figure 68: Comparing the reference situation with option 8 in section 22

In most sections the changing of the DO-concentration followed the tide. During the period the water level dropped no DO entered the pond and the SOD consumed DO causing the decrease of the DO-concentration. During the rise of the water level, water from the sea with a higher DO-concentration flowed into the pond causing the increase of the DO-concentration. The DO-concentrations changed smoothly compared to the reference situation where they increased rapidly during the inlet of water. These rapid changes may cause stress to the shrimp.
Due to the slower rising and dropping of the water, the flow velocity was lower compared to the reference situation, causing the reaeration to be lower too.
Section 17, further situated for the pond entrance; the first rise of water did not show an increase of the DO-concentration. The second rise of the water did show an increase of the DO-concentration caused by the larger height difference between low and high tide. During the second inlet, more water entered the pond. In spite of the consumption of SOD, more water with a higher DO-concentration reached the sections further situated causing a higher increase of the DO-concentration. In the reference situation these further situated sections were almost not influenced.

The DO-concentrations were higher compared to the reference situation. Adjusting the model to be able to show the influence of the tide, the water depths in the model increased too meaning that more DO is present in the system and it takes longer to lower the DO-concentrations. To see the influence of the water depth, the bottoms in the reference situation were lowered. To show both options, lower bottom level and no sluices using one model with the same geometry was not possible. When the model with the sluices present worked it became unstable when the sluices were removed, and the other way around. Therefor it was chosen to lower the bottom in the reference situation 2 meters. The average depth in both situations (no sluices and lowering the bottoms in the reference situation) was almost the same. The water depth in the channels was deeper the influence of the water from the forest was less. Figure 69 and 70 compares the situation of the reference with the lowered bottom levels and the adjusted model when the sluices were removed in section 7 and 17.

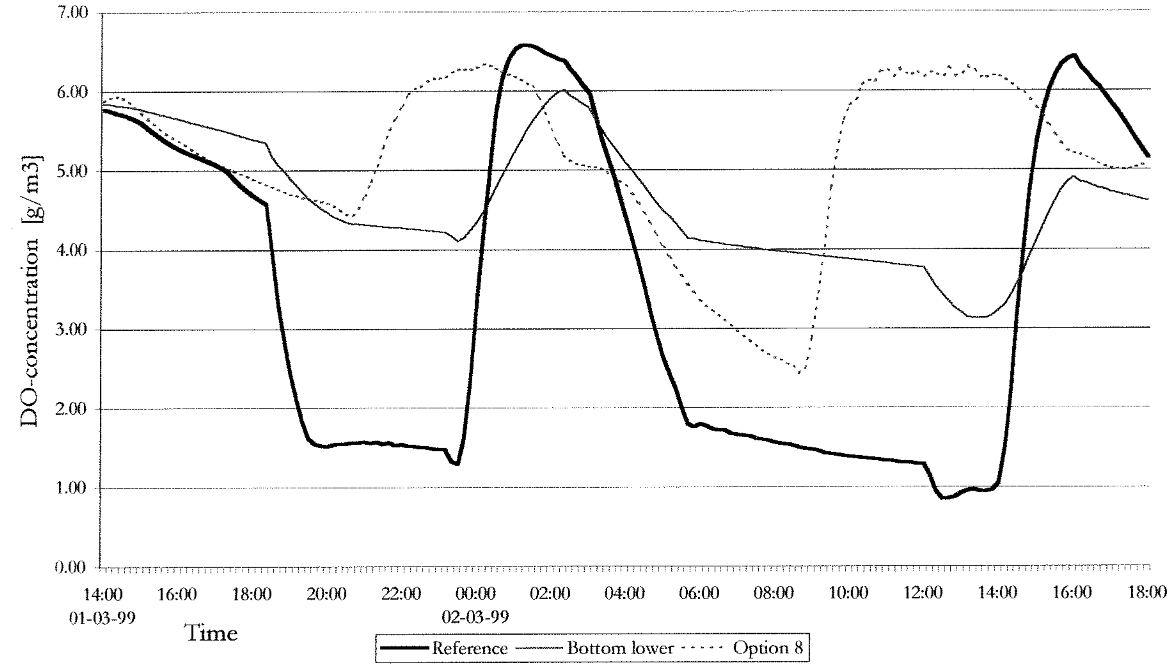


Figure 69: Comparing no sluices with a lower bottom in section 7

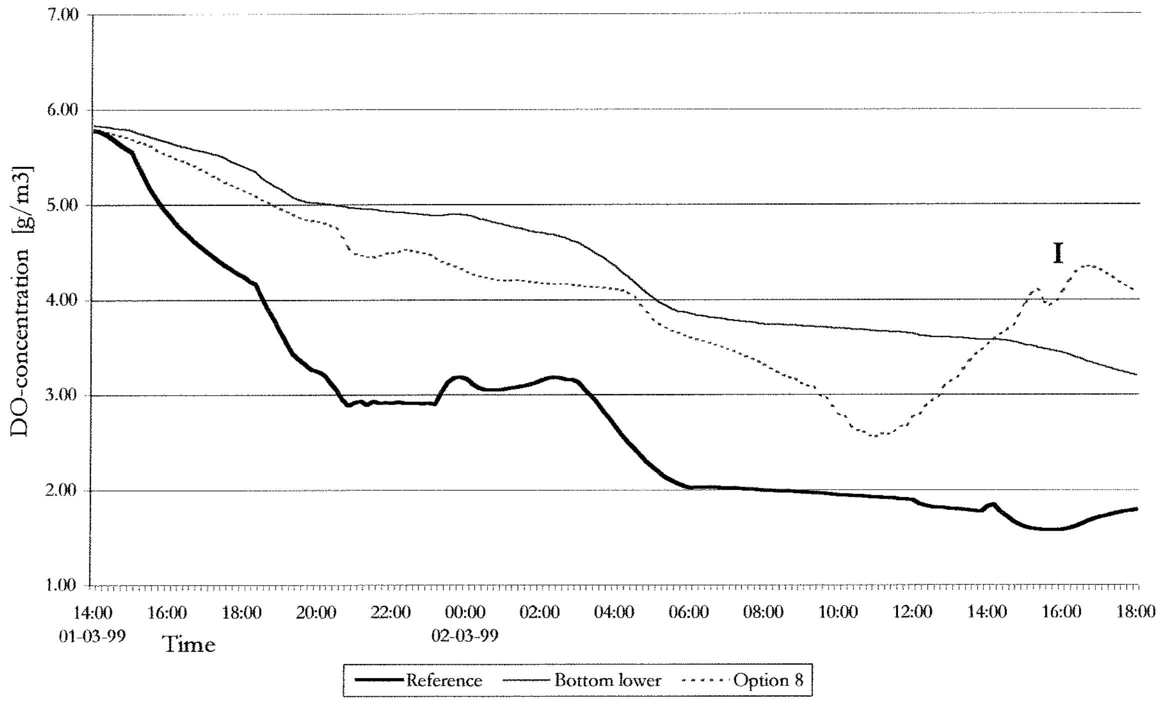


Figure 70: Comparing no sluices with lower bottom in section 17

Lowering the bottoms in the channels of the reference situation caused the DO-concentrations to be higher. In section 7, the option without sluices gave longer periods of higher DO-concentrations. Deeper channels or letting the water level rise slower caused less rapid changes in the system, which is good for the shrimp. Rapid changes may cause stress to them. Section 17, far situated from the pond entrance showed an increase of the DO-concentration during the second rise of the water (I in figure 70). The DO-concentrations were not influenced by the options with the sluices used. Letting the water level follow the tide, higher differences between the water levels were seen causing more water to enter the pond. In spite of the high consumption of DO by SOD, more DO reached the sections further situated causing an increase in the DO-concentrations.

Due to the problems concerning the water quality output that occur in Duflow when the channels dry up, it is difficult to show the differences between the natural system and the insulated system in Thanh Phu.
Letting this system work like its natural way, by letting the water level inside the pond to follow the tide, and not regulating it with sluices, the SOD would become lower. Due to the constant changing of the water level, a flow is constant present in the system. The larger height differences between the water levels mean that more water is exchanged with the sea. Exchanging more water during a longer period in combination with the permanent flow it was assumed that leaf would flow out of the pond towards sea, causing the pond to clean itself. Less leaf in the system means less decomposition of organic material causing the value of $SOD_{T.P.}$ to be lower compared to the reference situation and higher DO-concentrations are found.
More water to let in more shrimp will also enter the pond. Letting the water levels follow the tide the maximum volume of water is exchanged causing the maximum amount of shrimp to enter the pond.

Letting the water levels inside the pond in Thanh Phu to follow the tide is not possible. The pond is situated too high above the sea level causing that during periods of the day, during spring tide, the pond will dry up. During neap tide, when the tidal range is approximately 1 m smaller it is even expected that the water level is too low to refresh the water in the forest. The mangroves do not cover the channels and when the channels dry up they dry in the sun, which can cause the release of acids (cat's clay) having a bad influence on the environment.
As written before it was assumed that when the water level inside the pond follows the tide the pond will clean itself causing the $SOD_{T.P.}$ values to become lower.
In the natural system, the water level rises slowly meaning that slowly water is entering the pond causing the DO-concentrations to change slowly. Slow changes of the water quality variables are good for the shrimp.

Letting the water levels inside the pond to follow the tide, the pond will clean itself lowering the influence of SOD. In addition, the less rapid change of the DO-concentrations is god for the shrimp. Letting more water in the pond, more shrimp will enter the pond too. Letting the water levels follow the tide, the maximum volume of water is exchanged and so the maximum amount of shrimp enters the pond. From these arguments, it was assumed the mangrove-shrimp system works better when they are not insulated.

9.5 Summary of the influences

Several influences were seen discussing the different options. The pond is too large to be influenced by only one sluice. One sluice can not refresh the water at the other side of the pond.

Exchanging more water caused the flow velocity in the pond to become higher compared to the reference situation. These higher velocities caused higher values of reaeration causing higher DO-concentrations. Due to exchanging more water, more water from sea will enter the pond during inlet. The more water with the high DO-concentration that entered the pond in combination with the increase of reaeration, higher DO-concentrations were found compared to the reference situation.
Still, due to the high values of $SOD_{T.P.}$ the DO-concentration decreased rapidly after inlet.

Separating the forest from the channels caused, due to the less amount of leaf litter present in the system the $SOD_{T.P.}$ values to decrease causing the DO-concentrations to become a lot higher compared to the reference situation. Due to the leaf litter from the forest, the forest strongly influences the DO-concentration. Separating the forest from the channels gave the best results compared with the other options.

During the period of not water exchanging, 7 days between two periods of water exchanging, it was seen that the best option when no forest is present and the SOD values are lower that the DO-concentrations were very low. Knowing that the model could not be compared with the critical values, still a check was made and it was seen that after 21 hours the DO-concentrations in the channels were below the critical value.
Exchanging water can do solving the problem of the low DO-concentrations in this period. It is assumed that this is not possible due to the small tidal range, neap tide. During this period, neap tide the tidal range is approximately 1 m smaller compared to the measured tide. This caused the water levels in the outside channels to be too low to let water in.

From the above seen phenomena it looks like that the combination of growing mangroves with farming shrimp is not a good one. Still this combination is normal and is seen in nature. Preventing the water level inside the pond to follow the tide by installing sluices to control the exchange of water could be the cause of the low DO-concentrations.
To check this the sluices were removed and after adjusting the model, the water levels inside the pond followed the tide. Due to the adjustments made the water depths were larger. To compare and to see if these higher water depths are of influence, the bottoms of the channel sections in the reference situation were lowered. It was not possible to have the same geometry used for both situations, with and without sluices. The DO-concentrations were closer together. The water depth influenced the DO-concentration. Due to the deeper channels more water is present and so more DO, causing more time to decrease the DO-concentration.
A high tidal range caused the DO-concentrations to increase in the sections further situated. Longer periods of higher DO-concentrations were seen in the situation where there were no sluices.
It was assumed that because of the constant changing of the water level, when no sluices are present, the tide would clean the pond. The constant flow together with the higher volume of water that is exchanged will transport more leaf litter out of the pond lowering the $SOD_{T.P.}$ value.
The changes in the DO-concentrations were less rapid. Slow changes are good for the shrimp because otherwise the shrimp may be stressed.
The more water is let in, the more shrimp will enter the pond. Letting the water levels inside the pond to follow the tide, the maximum volume of water is exchanged causing the maximum amount of shrimp to enter the pond during inlet.

Letting the water levels in Thanh Phu to follow the tide, some problems occur. The pond is situated too high above the sea level and together with the high tidal range measured, the pond would dry up during certain periods of the day. During those periods, the sun will dry the pond bottom, which can cause the release of acids (cat's clay). These acids are a bad influence to the environment.
When the no acids are released, during drying the pond bottom in the sun, another problem will occur. These tide measurements were done during spring tide, during neap tide the tidal range is approximately 1 m smaller and will cause lower water levels. When these water levels are high enough to let water in the channels they are probably too low to refresh the water in the forest. During the period of neap tide the water in the forest will not be refreshed causing the water in the forest to contain a very low DO-concentration. This will negatively influence the DO-concentration in the channels when the tidal range is large enough to refresh the forest again.

10. Conclusions and recommendations

This research concentrated on the DO-concentrations inside the pond and how to improve them. To see how the DO-concentrations could be influenced a computer model was made describing the most important water quality process in the pond, the changing of the DO-concentration in time. Due to the assumptions made, like the storage area and the $SOD_{T.P.}$ values, the model was not very accurate in describing the DO-concentrations and could only be used to see how to influence the DO-concentrations. Lower DO-concentrations were calculated compared to the measured DO-concentrations during fieldtrip 2 and 3. Low DO-concentrations were measured during previous fieldtrips.

From the model without improvements it was seen that:

- The high values of $SOD_{T.P.}$ caused the DO-concentrations to decrease rapidly. Due to the higher values of $SOD_{T.P.}$ in the forest, the DO-concentrations in the forest were lower compared to the DO-concentrations in the channels.
- During outlet, water having a lower DO-concentration flowed from the forest into the channels and diluted there causing the DO-concentrations in the channels to decrease rapidly. The increase of reaeration during outlet, due to the flowing of the water could not prevent this decrease of the DO-concentration in the channels.
- During inlet, water coming from the sea having a higher DO-concentration, in combination with the increase of reaeration caused the DO-concentrations to increase rapidly. Rapid changes of the water quality variables may cause stress to the shrimp.
- The parts of the pond further situated from the sluices were influenced worse compared to the sections closer to the sluices. During the time it took the water to reach these parts situated further, the SOD consumed DO causing water with a lower DO-concentration (compared with the DO-concentration of the inlet water) to reach these parts. Due to the lower DO-concentration, the increase was also lower.

Several options were discussed improving the DO-concentrations. The DO-concentrations were influenced by:

- Exchanging more water in combination with more side connections, cause higher DO-concentrations in the system. The new defined connections made sure the water could flow better. The dams that divide plot 3.1 into two parts prevented this good circulation of the water. The positive aspect of the dams was that it reduced the pond area. A smaller pond area is better influenced using these sluices. Having a larger pond area, as before the dams were constructed, sections further situated from the sluices will not be good influenced having a negative effect on the system. On the other hand, the dams decreased the area of the pond and so decreasing the volume of water to be exchanged. Letting less water in causes also less shrimp to enter the pond. Exchanging more water and more connections caused the reaeration to increase. Besides a higher reaeration, more DO entered the pond during the inlet of water. The stronger influence of reaeration and the more DO that entered the pond gave higher DO-concentrations compared to the reference situation.
- During inlet the DO-concentrations increased rapidly, which may cause stress to the shrimp.
- Increasing the volume of water to be exchanged and creating side connections, still very low DO-concentrations were found caused by the high consumption of DO by SOD.

- The high values of the SOD were caused by the high amount of leaf litter from the forest. Separating the forest from the channels will decrease the $SOD_{T.P.}$ value, causing the DO-concentration to increase and become a lot higher compared to the reference situation and other options.

- During the period of 7 days not exchanging water, the DO-concentrations decreased to very low values. These low concentrations strongly influence the DO-concentrations during the following period of water exchange. The first few days of exchanging water have to be used to increase the DO-concentrations to a level the shrimp can survive in.

The best option to improve was separating the forest from the channels, indicating that the combination of mangroves and shrimp farming is not good. Still this combination is normal and often seen in nature. Managing the pond with sluices can be the cause of the problem. To see the influence of preventing the water levels inside the pond to follow the tide, what happens in their natural environment, the sluices were removed. The found results are:

- The high tidal range, exchanging more water caused the DO-concentrations further in the pond to be influenced. From the options using the sluices, the further situated sections were almost not influenced.
- Besides having the sections better influenced also longer periods of higher DO-concentrations were seen.
- The water level rose and dropped slower causing the DO-concentrations to change less rapidly. The slower change is good for shrimp because they may get stressed when exposed to rapid changes.
- It is assumed that the $SOD_{T.P.}$ value in a natural system will be lower compared to the reference situation when the water levels could not follow the tide. When the water level follows the tide it changes constantly causing a permanent flow to be present in the system. Also the water level changed more compared to the reference situation causing more water to leave the pond. The more water that is let out together with the permanent flow in the system it is assumed that more leaf litter is transported out of the pond. Less leaf litter present in the system compared to the reference situation cause less decomposition of organic material causing the $SOD_{T.P.}$ value to be lower. The lower $SOD_{T.P.}$ causes less consumption of DO resulting in a higher DO-concentration. Letting the water levels inside follow the tide, the system cleans itself.
- It is assumed that the amount of shrimp that entered the pond is related with the volume of water that enters the pond. The more water that is let in the more shrimp will enter too. Letting the water levels follow the tide the water exchange is maximum (the tidal range) causing the maximum amount of shrimp to enter the pond.

The option to let the water levels inside the pond to follow the tide is not a good option here. The pond in Thanh Phu is situated too high above mean sea level causing, due to the high tidal range the channels to dry up during parts of the day. The bottoms of the channels will dry in the sun because the mangroves do not cover the channels. This can cause a release of acids (cat's clay), which is not good for the environment.
These tide measurements were done during spring tide, during neap tide the tidal range will be approximately 1 m lower causing the water levels to be lower too. These lower water levels probably will not refresh the water levels in the mangrove forest. When the tidal range is large enough the forest will be refreshed again. However, first the water that was already present in the forest having a low DO-concentration (not refreshed for a long time) will be diluted with the water in the channels causing a decrease of the DO-concentration.

From this research the following conclusions and recommendations were made:

- The reason for the diminishing harvest can be the reason of the low DO-concentrations caused by the sediment oxygen demand. These high values are caused by the high amount of organic material coming from leaf of the mangroves that fall on the pond bottom. Some years ago, when the harvest was still good the trees were just planted and were still small producing less leaf litter. The organic material coming from the forest was less causing a lower influence of the sediment oxygen demand. During the years the mangroves have grown and became larger containing more leaf. Due to more leaf on the trees, more leaf litter became present in the system causing the influence of the sediment oxygen demand to increase during the years. The high $SOD_{T.P.}$ value now decreases the DO-concentrations making it for the shrimp not suitable to life in the pond. The forest has, because of the high amount of leaf litter a very negative influence on the DO-concentrations.

- Improving the DO-concentration in the system can be done influencing the DO providers but due to the high value of $SOD_{T.P.}$ still very low DO-concentrations were found. Making the channels deeper gave higher DO-concentrations, more water so more DO is present in the system. Still the sediment oxygen demand will increase in time due to the growing of the mangroves causing more leaf litter and in the future the same problems of low DO-concentrations will occur. Deepening the channels is a short-term option to improve. Using pumps to increase the circulation can do but the costs of the pumps are maybe too high compared with the yield. Also no electricity is available in near the pond.
- Cleaning the pond to lower the amount of leaf litter and so the amount of organic material, less material needs to be decomposed. Less decomposition of organic material causes the $SOD_{T.P.}$ value to become lower, which is a good for improving the DO-concentrations. Cleaning the forest in Thanh Phu by hand or machine is not possible due to the high density of mangroves. It is assumed that cleaning of the pond (forest and channels) can be done by letting the water levels inside the pond follow the tide. Nature cleans itself.
  Following the tide, the water level inside the pond change more, so more water is exchanged. The higher volume of water that was let out in combination with the permanent flow, due to the continuos changing of the water level it is assumed that leaf litter will be transported out of the pond towards the sea. Therefore, less leaf litter will be present in the system causing the $SOD_{T.P.}$ value to decrease resulting in higher DO-concentrations. Letting the water levels inside the pond to follow the tide the pond will clean itself causing the DO-concentrations to become higher.
- The water levels inside the pond follow the tide so the maximum volume of water is exchanged, more than in the reference situation. The amount of shrimp that enter the pond is related with the volume of water that is let in. The more water that is let in the more shrimp will enter. Letting the water levels follow the tide causes more water to be let in, so also more shrimp will enter the pond.
- If the pond is managed using sluices, the combination of mangrove and shrimp decreases the amount of water daily exchanged and so decreases the self-cleaning of the system. Less cleaning of the pond caused a higher amount of leaf litter and so organic material to be present in the system causing lower DO-concentrations. Due to the less volume of water was let in, so fewer shrimp enter the pond.
  Managing the pond with sluices, the pond is not cleaned properly so the influence of the forest will remain high causing the low DO-concentrations and less shrimp will enter the pond. A combination of mangroves and shrimp managed with sluices is not a good one.
- The option of letting the water levels inside the pond to follow the tide is not an option in Thanh Phu because the pond is situated too high above the mean sea level. The high tidal range causes the channels inside to dry up causing the channel bottoms to dry in the sun, which can cause the release of an acid, also known as cat's clay. During neap tide, when the tidal range is approximately 1 m lower it is assumed due to the lower water levels the forest will not be refreshed. The pond in Thanh Phu is situated too high above mean sea level to be improved using only the tide.

- From this research conclusions and recommendations were made about the system in Thanh Phu, Vietnam. Still important answers to questions about the system in Thanh Phu, which are not available, must be found. Answers about to questions like:

- » Is the harvest of shrimp decreasing?
  - » When the harvest of shrimp is decreasing, how much is this decrease?
  - » How much must the harvest of shrimp be for the farmers to survive?
  - » How much is the harvest of shrimp now?

  Answering these questions, with numbers obtained by doing research, something can be said about if there is a problem or not! Until now, no research is done providing the answers to the questions.
- When there is a problem and the harvest is decreasing, more information must be found from the shrimp point of view. Questions must be asked like:
  - » Do shrimp enter the pond, and when they do how long will they stay there?
  - » What do shrimp do when they enter the pond?
  - » Do the shrimp stay in the pond for a longer period to grow or spawn, or do they leave the pond during the following outlet?

  These questions are important because tell something about the system working as nursery or shrimp trap. When shrimp enter the pond but they do not stay in it and leave the pond one or two outlets later the shrimp will not grow or spawn. When the shrimp leave the pond one or two outlets later, the pond works as a shrimp trap instead of a nursery. Working as a shrimp trap, the presence of shrimp in the pond is of no importance to the harvest. Harvesting the shrimp during inlet, the shrimp will not enter the pond and will not be influenced by the low DO-concentrations inside the pond. Making the water quality inside the pond is of no importance anymore.

  Still the inside of the pond should not be made smaller due to the relation between the volume of water that is let in and the amount of shrimp that enter the pond. Having a larger area more water is exchanged and more shrimp enter the pond and are harvested during inlet.
- Besides looking at influence of the water quality and finding answers for the mentioned questions above, also other possible causes of the decrease of the harvest of shrimp must be researched, like the:
  - » Decrease of the population in the sea.
  - » Death during residence in the system. Whether this plays a role is not known. Possible causes of mortality are: asphyxiation, poisoning, e.g. by ammonia, hydrogen sulfide, plant toxins from the mangroves, pesticides, industrial and urban pollution upstream the river, consumption of shrimp by fish and other animals (large crabs and aquatic snakes were observed) in the system, viral infections and other diseases.
- Because of all the assumptions made the model did not give accurate results compared to the measurements and were only used to compare different situations. Wanting to have a more accurate description of the pond the model can be used as a starting-point. Doing more measurements concerning the water movement can do verifying the assumptions made in the water movement part. And doing more measurements using more reliable instruments (SOD measurements) can do improving the water quality part of the model.

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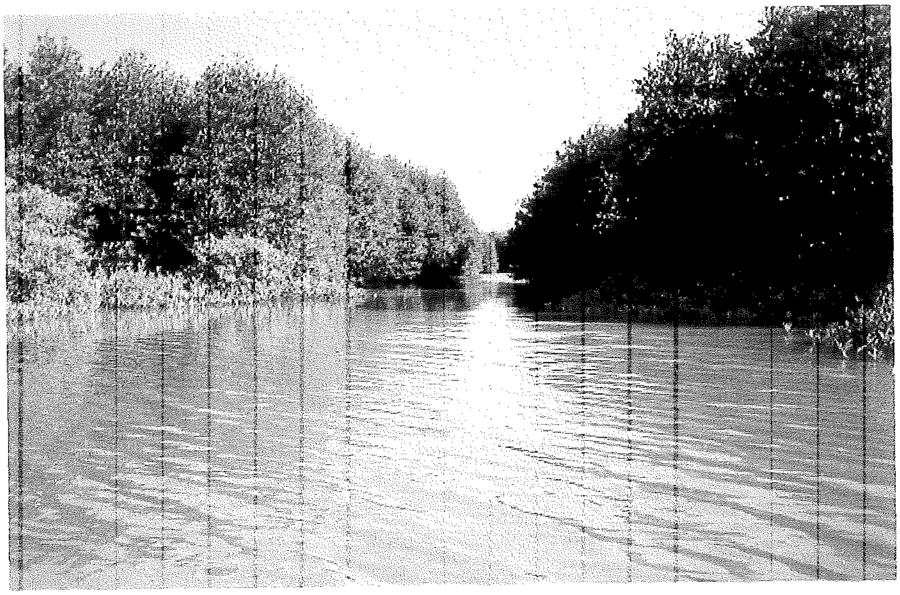

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Modeling
the water movement and water quality of a mangrove-shrimp system in Vietnam

APPENDIXES

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List of symbols

Symbol	**Description**	**Dimension**
α	correction factor non-uniformity of the velocity distribution	m^2
μ	discharge coefficient	-
$\phi(x)$	direction channel axis, measured clockwise from the north	°
$\Phi(t)$	wind direction	°
$\gamma(x)$	wind conversion coefficient	-
Δh	height difference between the in- and outside water levels	m
η_{ott}	number of revolutions per second	rev./s
$A(x,H)$	cross-sectional flow area	m^2
$A_{sl.}$	cross-section sluice	m^2
A_{tot}	total cross-sectional area	m^2
$B(x,H)$	cross sectional storage width	m
$b(x,H)$	cross-sectional flow width	m
BOD^5_{20}	biochemical oxygen demand after 5 days and at 20°C	g/m^3
$C(x,H)$	Chézy coefficient	$m^{½}/s$
Co	constituent concentration	g/m^3
D	dispersion coefficient	m^2/s
DO	dissolved oxygen concentration	g/m^3
$DO_{average}$	average dissolved oxygen concentration	g/m^3
DO_{bottom}	dissolved oxygen concentration at the bottom	g/m^3
$DO_{surface}$	dissolved oxygen concentration at the surface	g/m^3
g	acceleration of gravity	m/s^2
$H(x,t)$	water level with respect to reference level	m
k_0	zero order reaction coefficient	-
k_1	first order reaction coefficient	-
P	production of the constituent per unit length of the section	g/m·s
pH	acidic or alkaline character of water	-
Q	discharge	m^3/s
$Q(x,t)$	discharge	m^3/s
$R(x,H)$	hydraulic radius of the cross-section	m
Sal.	salinity	‰
SOD	sediment oxygen demand	g/m^3
$SOD_{T.P.}$	sediment oxygen demand found in Thanh Phu	g/m^2·day
SS	suspended solids	g/m^3
t	time	s
temp.	temperature	°C
$v(x,t)$	mean velocity	m/s
$v_{meas.}$	measured velocity with the Ott-meter	m/s
$v_{sub.}$	measured velocity of a sub-measurement	m/s
$w(t)$	wind velocity	m/s
x	distance measured along the channel axis	m

Introduction

In front of you lies, the second part of the report concerning the research done in Vietnam containing the appendixes where referred was to in the report: Modeling the water movement and water quality of a mangrove-shrimp system in Vietnam.

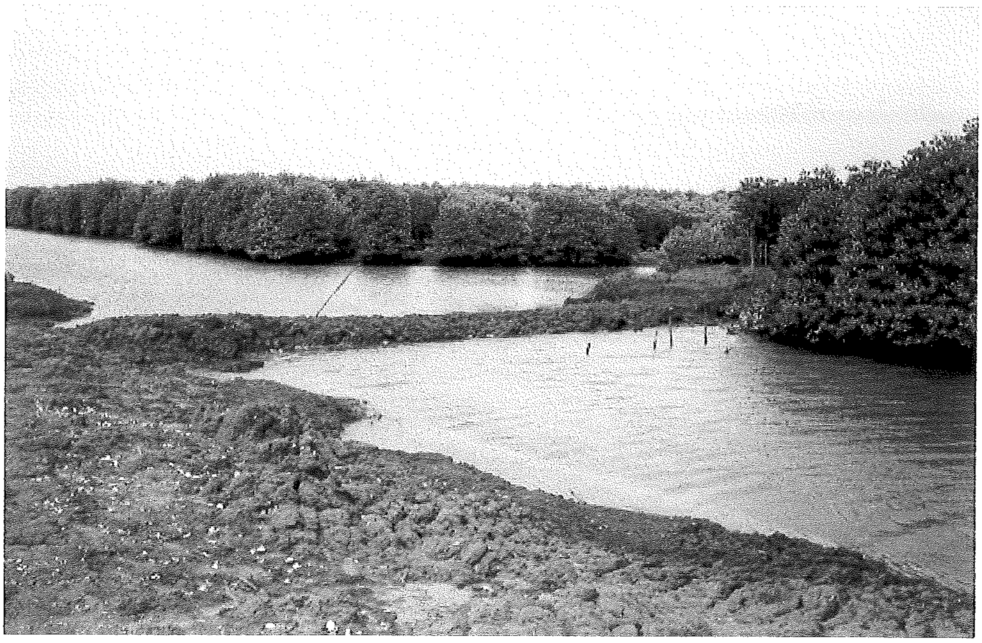
This part of the report gives a more detailed description of the fieldwork (appendix A). An explanation of the computer program Duflow that was used to model the water movement and water quality is given in appendix B. The results of the measurements and the analysis are shown (appendix C). Only the final results of the water quality measurements are shown. For a more derailed description of the water quality measurements reference is made to: *Water quality changes in a sluice gate controlled extensive mangrove-cum-shrimp system at Thanh Phu, Ben Tre province, Viet Nam; (M. Zitzen, 1999)*.
The definitions of the models in Duflow describing the water movement and water quality are shown in appendix D.
The last part of this report, appendix E shows several figures describing the differences between the Duflow output and the measured DO-concentrations and it what happens when for several days no water was exchanged.

Appendixes

A The fieldwork

This appendix shows pictures of the research area to get an impression of it. Besides the pictures, the fieldtrips are discussed including a description of the equipment used and some actions that were done.

A.1 Pictures of the research area



Picture 1: One of the dams that divide the pond into two parts.

Picture 2: Sluice B with its two entrances; measuring during outlet.

Picture 3: Sluice A is closed, one entrance. A fishing net is positioned at the left side against the sluice.

Picture 4: View into the mangrove forest. It shows the high density of the mangrove, making it impossible to do measurements in the forest.

Picture 5: Steel pump with the concrete foundation. The white spot made on the on the pump was chosen to be the zero-level for the leveling, the reference level.

Picture 6: Measuring the cross-sections of the channels.

A.2 The water movement measurements

Fieldtrip 1:
This fieldtrip was used for measuring the geometry of the pond.

- Length measurements

Length measurements were done using a measuring tape of thirty meters in combination with wooden sticks to mark the beginning and end. Starting at the steel pump and ending there the whole outline was measured. A compass was used to define the angles the channels had with the North, to be able to draw a map of the pond.

- Leveling

For leveling a Nokia leveling machine together with two leveling rods was used. A circle leveling was done starting and ending at the same point, the steel pump (see picture 5, appendix A.1). A point on the steel pump was chosen as reference level. This pump had a concrete foundation and would not move during the period of research. During the circle leveling that was done several marks were painted on a concrete part of the sluices. The gauges that needed to be installed near the sluices were not available at that moment, and still had to be made. Knowing the level of the marks on the sluices and using the leveling machine a link between them and the gauges positioned nearby the sluices and sluice bottoms were made. The leveling machine was still needed but a new circle leveling is avoided.

- Gauges

During this trip it became clear that only one gauge was available, the other five (in this phase the whole pond was examined) had to be made ourselves. These gauges were made of wood with the length-scale painted on it. Because the gauges were finished later, first wooden sticks were installed at the places the gauges would come. To avoid time-loss, nails were made on these sticks, and were leveled using the marks on the sluices. A link was made, using the leveling machine between the marks on the sluices and the nails in the wooden sticks. After the gauges were finished they were attached to the sticks and the number that was at the same height as the nails was written down. The gauges were now leveled.

- Cross-sections

The last part of this fieldtrip was used to measure the cross-sections of the channels. This was done with a rope and a self-made measuring stick of 2.05 m. On the rope at every 1.50 m ti-ripes were attached. At these points, the cross-sections were measured. The rope was stretched over the cross-section, inside 10 cm above the water and outside 50 cm. At every point the depth was measured (see picture 6, appendix A.1).

Also the sluice dimensions were measured using the measuring stick.

Fieldtrip 2 and 3:
Both of these trips were used to collect data to calibrate the computer model. During these trips the same measurements were done and will be discussed together.

- Level measurements inside and outside

Divers were used to register the water levels. These Divers were of the type D1212 having a diameter of 22 mm and a length of 23 cm. The Diver has a memory for 16.000 registrations. The frequency of measuring can be defined from every 0.5 second till every 99 hours. Using an optical reading device and the appropriate software, the collected data was read into a computer. The

Diver measured the total pressure, water and air expressing it in cm water column. Wanting to now the water depth, the air-pressure had to be known during the measurements.
Two of these Divers were used. One to measure the tide outside the pond and one to measure the inside water levels. The Diver outside was tied to a stick and to some trees close to the installation point. The stick was put in the ground near the sea, sheltered from waves. The Diver hanged just above the bottom level. The same was also done during the last trip but in the other outside channel. During that trip the Diver was stolen!
The Diver inside was also tied to a stick that were used for previous water quality measurements. For both trips, the same place inside the pond was used to install the Diver.
With the Diver not in the water, it only registers the air-pressure, working as barometer. Using the gauge readings, a link between the reference level and the Diver-data was made.

- Velocity measurements

The velocity measurements, done using an Ott-meter of the type C31 to predict the discharge coefficients of the sluices. An Ott-meter has a propeller that rotates due to the flow of the water. The number of revolutions measured during a known period was used to calculate the velocity of the water. The Dutch Rijkswaterstaat donated this Ott-meter.
Measuring the revolutions during a defined period, the revolutions per second were calculated. Using the formula for this Ott-meter, calibrated by the Dutch Rijkswaterstaat, the velocity of the water was calculated. In every entrance (sluice A: 1 and sluice B: 2) four measurements were done, two near the bottom and two near the surface.
During fieldtrip 2, the Ott-meter was tied with iron-wire to a large wooden stick. Due to the strong force of the water on the Ott-meter, it was difficult to keep the Ott-meter in the direction of the flow. During the last fieldtrip, an iron-stick was used bought in Can Tho but did not resist the strong force of the water causing the stick to break during the last measurement done.
The velocity measurements were done only in the sluices because the velocities in the pond were very low and of no interest.

- Cross-sections

More cross-sections of the outer channels were measured. During modeling after the first two fieldtrips, it was seen that these outside channels especially near sluice B, where heading up of water during outlet was seen, strongly influences the water movement. The method of measuring was the same as discussed measurements of the cross-sections during fieldtrip 1 except the rope was now only 10 cm above the water.

- Other readings

Water level readings were done reading the gauges. These readings were used to link the data from the Divers with the reference level. Readings of the water levels in- and outside were taken. Barometer readings were done using a normal barometer. During the analysis, it became clear that the barometer was not reliable caused by the transportation from the Statefarm to the research area. Barometer readings of the Diver were not the same as the readings of the other barometer.

A.3 The water quality measurements

No water quality measurements were done during fieldtrip 1. The official calibration measurements were done during fieldtrip 2 and 3.

- pH, temperature, DO-concentration

These values were measured using an electrode. For the pH and temperature the Multiline P4 universal meter, and for the DO-concentration the oxi 330 was used. The pH and temperature measurements were taken at the surface of the water. The DO measurements were done at the surface and near the bottom, to see the difference of DO-concentration in the vertical water column. During the exchange of water, measurements were done in the sluices. Due to the high velocities during water exchange, it was assumed that because of the mixing the DO-concentrations would be the same for the bottom as for the surface. During the water exchange, only DO-concentration measurements were done at the surface. The measurements during inlet were important because they show the quality of the water that was let in.

- Salinity

The salinity measurements were done with the use of a hand-refractometer, Atago. Light passes through a tin layer of water and was refracted. The salinity can be read on a scale in the eyepiece by the observer.

- Biochemical oxygen demand (BOD)

Measure of DO consuming properties of water, often a test to see how polluted the water sample is. During each BOD measurement, two sample bottles were filled with water. The bottles were filled at a depth of 30 cm from the surface. To one bottle, of 125 ml, 1 ml $MnSO_4$ and 1 ml Winklerreagens were added. The second bottle of 300 ml was stored in the dark. The rest of the Winkler analysis to calculate the DO-concentration was done in the laboratory. The second bottle was stored in the dark for 5 days with a constant temperature of 20°C. After 5 days 1 ml $MnSO_4$ and 1 ml Winklerreagens were added. In addition, the DO-concentration was defined. The total BOD^5_{20} was defined by calculating the difference between the two bottles.

- Suspended solids (SS)

A sample of 125 ml was taken. This sample was stored on ice and taken to the laboratory to be analyzed. There the sample was shaken, poured into a beaker and stirred. Immediately the absorbency was measured using a spectrophotometer, Hach DR2010.

- Organic materials

Several measurements were done to estimate the organic material.

First: measuring the total leaf fall in the forest. Using four baskets each 50 cm above the ground. Each basket catching leaves. Because of thievery of three baskets (first two and later one) were stolen. The remaining leafs were taken to the lab and weighted after heating to 105 °C and also after heating to 520 °C. The difference was the mass of organic compound of the fallen leaves.
Second: the organic compound of the top layer (25 cm) was investigated. At the sample points x1, x2', x3 and x4 the measurements were done in the forest, at the border of the forest and in the channel. After heating the samples to 105 °C and 520 °C, the mass difference was taken representing the organic material.
Third: an estimation of sedimentation was done by putting near each inside sample point three buckets in the ground. The upper level of the bucket was 5 – 10 cm above the bottom. After 48 days, 4 periods of exchange of water, the buckets were removed and the sediment in the buckets was estimated. One problem was that in some buckets crabs were living. These crabs ate the sediment. Because the crabs were trapped, they ate the sediment in the buckets. These buckets were neglected during the analysis.

- Hydrogen sulfide (H_2S)

Samples of 125 ml were taken in the outside channels near the sluices. One ml of 2% $CdCl_2$ was immediately added. The samples were stored on ice and in the laboratory they stood for 48 hours. After these 48 hours, the precipitation was dissolved in 5 ml of iodine solution and 5 ml HCl. The excess iodine that was added was titrated with $H_2S_2O_3$.

- Ammonium

Samples of 125 with immediately three drops of 98% H_2SO_4 added, put on ice, taken to the lab, and further analyzed. With the indophenol-blue method, the amount of ammonium was estimated. It made use of the coloration of ammonium with phenol and hypo-chlorite in alkaline solution. The color is intensified by sodium nitroprusside.

- Sediment oxygen demand (SOD)

No measurements were done during the two fieldtrips but some measurements were done in a previous fieldtrip (28/01/1999 – 29/01/1999). Because of the importance of these SOD-values they were discussed here.
The SOD was measured using a self-made instrument that contained a bucket with a propeller inside to stir the water in it. During the stirring the DO-concentration was measured with the same electrode used during the DO measurements. The propeller had to be hand driven and no data-logger was available to measure the DO-concentration. The cable of the electrode was short making it only possible to measure in shallow water. After analyzing the data the value of $SOD_{T.P.}$ was defined.

B Duflow

This appendix gives an introduction of the computer program, Duflow that was used for modeling the water movement and water quality of a shrimp pond in Thanh Phu, Vietnam. Duflow is developed by several institutions, mentioned later when the different parts of the model, water movement and water quality will be discussed.

Duflow is a PC-program package for unsteady flow computations in networks and open channels. The package is very suitable for modeling the relationship between the water movement and water quality and is therefor a useful tool for Water Quality Management. Duflow is designed for many different applications. Some of them are:

- propagation of tidal waves in estuaries
- flood waves in rivers
- operating drainage and irrigation networks

Different structures like pumps and weirs can be modeled in Duflow.
Duflow is a 1-dimensional model so calculations are only made in the direction of the axis of the channels.

B.1 Modeling the water movement

The institutions IHE Delft; the Rijkswaterstaat, Tidal Waters Division, The Hague and the Delft University of Technology, faculty of Civil Engineering, developed the water movement part of Duflow.
The flow (water movement) calculations are based on the one-dimensional partial equations that describe the non-stationary flow in open channels. These are the equations of the conservation of mass (equation B.1) and the conservation of momentum (equation B.2)

$$B \cdot \frac{\partial H}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad \text{(Equation B.1)}$$

$$\frac{\partial Q}{\partial t} + gA\frac{\partial H}{\partial x} + \frac{\partial(\alpha Q v)}{\partial x} + \frac{g|Q|Q}{C^2AR} = b\gamma w^2 \cos(\Phi - \phi) \qquad \text{(Equation B.2)}$$

Where:

α	correction factor non-uniformity of the velocity distribution	m^2
$\Phi(t)$	wind direction	°
$\phi(x)$	direction channel axis, measured clockwise from the north	°
$\gamma(x)$	wind conversion coefficient	-
A(x,H)	cross-sectional flow area	m^2
b(x,H)	cross-sectional flow width	m
B(x,H)	cross-sectional storage width	m
C(x,H)	Chézy coefficient	$m^{1/2}/s$
g	acceleration of gravity	m/s^2
H(x,t)	water level with respect to reference level	m
Q(x,t)	discharge	m^3/s
R(x,H)	hydraulic radius of the cross-section	m
t	time	s
v(x,t)	mean velocity	m/s
w(t)	wind velocity	m/s
x	distance measured along the channel axis	m

During this modeling the influence of the wind was neglected. Equation B.2 was rewritten into equation B.3.

$$\frac{\partial Q}{\partial t} + gA\frac{\partial H}{\partial x} + \frac{\partial(\alpha Qv)}{\partial x} + \frac{g|Q|Q}{C^2AR} = 0 \qquad \text{(Equation B.3)}$$

The plot will be modeled using nodes connected by sections. Every section is defined by two cross-sections. Boundary conditions are defined and can be tide or discharges. Besides the boundary, initial conditions are needed. Initial conditions are discharges and water levels in the pond when the calculation starts.

B.2 Modeling the water quality

During a later phase, this part was added to Duflow. This part was designed by the Agricultural University of Wageningen, Department of Nature Conservation in co-operation with IHE Delft. The water quality calculations are based on the one-dimensional partial transport equation (equation B.4).

$$\frac{\partial(A_{tot}Co)}{\partial t} = -\frac{\partial(QCo)}{\partial x} + \frac{\partial\left(AD\frac{\partial Co}{\partial x}\right)}{\partial s} + P \qquad \text{(Equation B.4)}$$

Where:

Co	constituent concentration	g/m^3
Q	discharge	m^3/s
A(x,H)	cross-sectional flow area	m^2
A_{tot}	cross-sectional area	m^2
D	dispersion coefficient	m^2/s
x	x-coordinate	m
t	time	s
P	production of the constituent per unit length of the section	g/m·s

Beside the transport of variables, also different processes can be modeled. Duflow contains an editor that can be used to program different water quality processes like the changing of the DO-concentration in time. The most important statement used to program the processes is the formula-statement. These processes represent the P in equation B.4. P can be expressed in Co (concentration [g/m^3]) as shown in equation B.5.

$$P = A_{tot} \cdot \frac{dCo}{dt} \qquad \text{(Equation B.5)}$$

Where:

$$\frac{dCo}{dt} = k_1 Co + k_0 \qquad \text{(Equation B.6)}$$

Where:

k_1 first order reaction coefficient, depended on Co

k_0 zero order reaction coefficient

k_1 and k_0 are found rewriting the used equation in the form of equation B.6. Everything that is dependent on Co will be expressed k_1. The rest of the formula is expressed by k_0.
Besides the formula statement an if- and iteration statement can be used to program the processes.

C Results of the measurements

This appendix gives a description of the collected data and the results of the analysis of it.

C.1 Geometry measurements

The geometry measurements done during the first fieldtrip contained:

- The length measurements

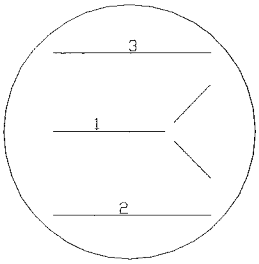
Beside the length of the channels, an angle that referred the position of the channels with the North was measured. The angle can be used to draw a map of the pond. The measurements and remarks are shown in table 1.

Table 1: Length measurements

Number	Angle [°]	Length [m]	Remarks
1	88	315.60	From well to dam
2	88	1.60	Dam
3	88	409.72	From dam to beginning curve
4	17	49.95	From beginning curve to sluice
5	350	107.53	From sluice to the house
6	350	57.70	From the house to the center of the channel
7	350	209.75	From center channel to center channel
8	350	142.32	From center channel to center channel
9	350	20.05	From center channel to start curve
10	332	13.22	From start curve to sluice
11	332	15.65	Over the sluice
12	316	14.86	From the sluice to the house
13	310	30.00	Curve
14	286	30.00	Curve
15	264	51.64	From the curve to the center of the channel
16	264	288.30	From center channel to the dam
17	264	1.00	The dam
18	264	308.75	From the dam to the center of the channel
19	264	60.00	From the center of the channel to start curve
20	222	31.70	From curve to the sluice
21	222	1.60	Sluice
22	222	168.20	From sluice to the center of the channel
23	222	112.40	From the center of the channel to the curve
24	218	34.00	From the curve to the center of the channel
25	218	189.90	From the center of the channel to the sluice
26	218	2.20	The sluice
27	148	160.20	From the sluice to the center of the channel
28	148	78.80	From the center of the channel to the curve
29	88	253.30	From the curve to the center of the channel
30	88	104.20	From the center of the channel to the well

- Leveling

First, the whole pond was leveled doing a circle leveling. Marks were made on the sluices during this round, later used to level the gauges and the bottoms of the sluices. Still the leveling machine was used but a new circle leveling was avoided. After doing the circle leveling the results were checked doing some control calculations to see if the leveling was accurate enough. These calculations are shown after table 2. Table 2 shows the results of the circle leveling. The adjustments were already processed in this table. To avoid problems of definition, figure 1 shows the lens of the leveling machine together with the words used in table 2 and during the analysis of the data.



With:
1: Leveling rod
2: Distance line bottom or distance bottom
3: Distance line top or distance top

Figure 1: Lens of the leveling machine

- The circle leveling

Table 2: Measurements circle leveling

No.	Distance lines [mm]				Leveling rod [mm]		Delta H [m]	Level [m]	Remarks
	Behind		Front						
	Top	Bottom	Top	Bottom	Behind	Front			
1	1485	823			1164			0.000	Starting point, the pump
			1750	1080		1410	-0.246	-0.246	
2	1756	1480			1618				
			1455	1190		1322	0.296	0.049	
3	1910	1540			1730				
			1900	1461		1680	0.050	0.099	Near the dam
4	1950	1554			1751				Near the dam
			1626	1266		1447	0.304	0.403	
5	1535	1265			1405				
			1930	1530		1730	-0.325	0.077	
6	2180	1780			1980				
			2300	1845		2070	-0.090	-0.013	
7	1980	1560			1770				
			1935	1463		1700	0.070	0.056	
8	950	550			750				
			1825	1345		1585	-0.835	-0.779	
9	1695	1310			1505				
			1835	1565		1700	-0.195	-0.974	Ref.point sluice A (front)
D6	1800	1400			1600				Ref.point sluice A (behind)
			1410	1050		1230	0.370	-0.605	Near sluice A

No.	Distance lines [mm] Behind Top	Behind Bottom	Front Top	Front Bottom	Leveling rod [mm] Behind	Front	Delta H [m]	Level [m]	Remarks
C4	1895	1315			1605				Placed stick
			1450	910		1180	0.425	-0.262	
16	1720	1160			1440				
			2035	1675		1855	-0.415	-0.678	
17	1650	1190			1420				
			1025	550		785	0.635	-0.043	
18	1085	475			780				
			1035	505		770	0.010	-0.033	Near Tuan's house
C6	1175	605			890				Near Tuan's house
			1250	610		930	-0.040	-0.074	Ref.point near sluice C (front)
D6	1400	940			1170				Ref.point near sluice C (behind)
			1800	1240		1520	-0.350	-0.424	
19	2090	1550			1820				
			2165	1495		1830	-0.010	-0.434	
20	1380	683			1032				
			1120	324		722	0.310	-0.125	
21	2410	1790			2100				
			2055	1225		1640	0.460	0.335	
22	1240	420			820				
			1345	735		1040	-0.220	0.115	Ref.point sluice D (front)
23	1420	760			1090				Ref.point sluice D (behind)
			1922	1185		1554	-0.464	-0.350	Stick for reference
24	1530	880			1205				Stick for reference
			1480	885		1182	0.023	-0.327	
25	1320	710			1015				
			910	835		647	0.368	0.040	
26	1110	610			860				
			1230	570		900	-0.040	0.000	Endpoint, the pump

The used formulae to check the accuracy of the leveling were:

$$\frac{\left(\sum \text{distance lines top} + \sum \text{distance lines bottom}\right)_{\text{behind}}}{\left(\sum \text{leveling rod}\right)_{\text{behind}}} \approx 2 \qquad \text{(Formula C.1)}$$

$$\frac{\left(\sum \text{distance lines top} + \sum \text{distance lines bottom}\right)_{\text{front}}}{\left(\sum \text{leveling rod}\right)_{\text{front}}} \approx 2 \qquad \text{(Formula C.2)}$$

$$\sum \left(\text{leveling rod}\right)_{\text{behind}} = \sum \left(\text{leveling rod}\right)_{\text{front}} \qquad \text{(Formula C.3)}$$

The calculated values are:
Distance lines behind top : 50.038 mm
Distance lines behind bottom : 33.728 mm
Distance lines front top : 49.037 mm
Distance lines front bottom : 33.834 mm
Leveling rod behind : 41.892 mm
Leveling rod front : 41.880 mm

Results:
Formula C.1 : 2.00
Formula C.2 : 1.98
Formula C.3 : 12 mm

According to *A.M. Sluis, 1979* an error of maximum of 17,9 mm was allowed. The error here was 12 mm. An adjustment on every front readings of the leveling rod of 0.375 mm (difference/number of readings) was made, already processed in table 2. The most important elements were leveled. The marks on the sluices were used to link the gauges with the reference level.

- Leveling the gauges

"Level" in this section means the level of the readings of the gauge, where the nails were placed, referring to the reference level. The 0-level was the position of the zero on the gauge referring to the reference level.
The results of the gauges that were used during this research are shown below.

Gauge 1
Position: Outside near sluice A
Reading gauge: 0.85 m
Ref. level sluice A: -0.97 m

Leveling	Ref.point [mm]	Gauge [mm]	Delta H [m]	Level [m]	0-level [m]
Distance top	1876	1813			
Leveling rod	1852	1732	0.12	-0.85	-1.70
Distance bottom	1828	1652			

Gauge 2
Position: Inside near sluice A
Reading gauge: 0.85 m
Ref. level sluice A: -0.97 m

Leveling	Ref.point [mm]	Gauge [mm]	Delta H [m]	Level [m]	0-level [m]
Distance top	1876	1840			
Leveling rod	1852	1728	0.12	-0.85	-1.70
Distance bottom	1828	1615			

Gauge 3

Position: Outside near sluice B

Reading gauge: 0.75 m

Ref. level sluice B: 0.16 m

Leveling	Ref.point [mm]	Gauge [mm]	Delta H [m]	Level [m]	0-level [m]
Distance top	1623	2728			
Leveling rod	1585	2654	-1.07	-0.91	-1.66
Distance bottom	1548	2579			

- Measuring the cross-sections

Cross-sections in both parts of the pond were measured. Only those cross-sections useful for this project, of sub-plot 3.1.B, are shown here. Figure 2 shows the positions of the measured cross-sections.

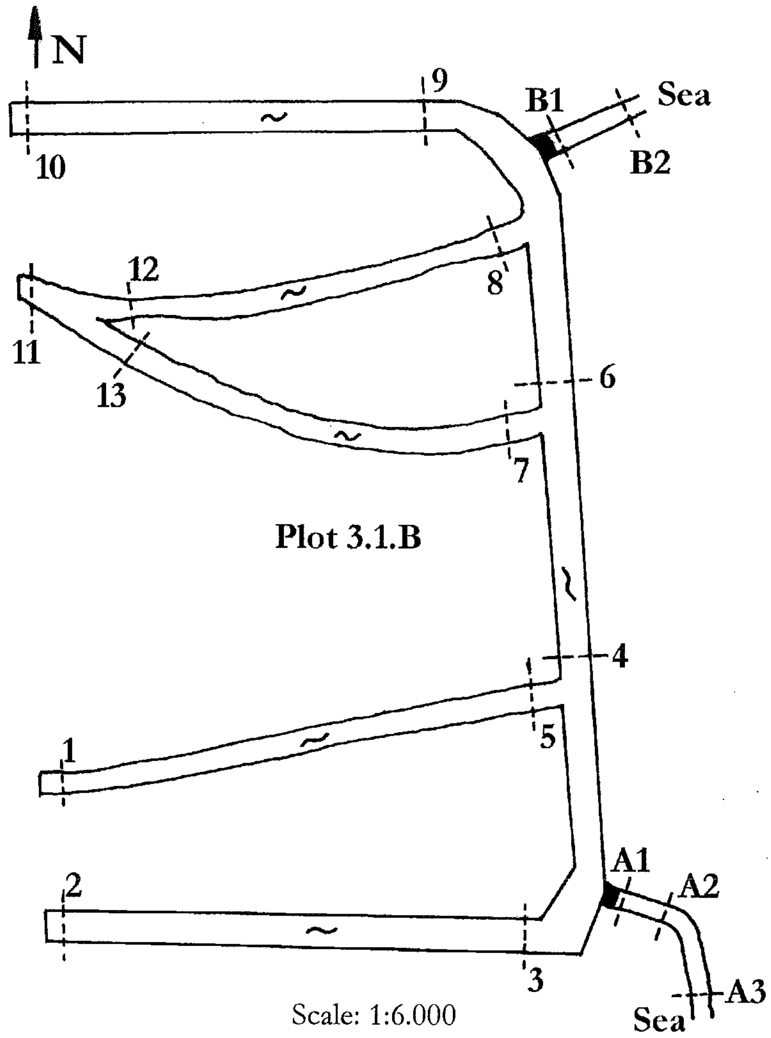


Figure 2: Positions measured cross-sections

The water level during measurements of the inside sections was, with reference to the reference level, –1.17 m. Sometimes a value describing the height difference between land and water is shown. These values can give insight in the storage area. No measurements of the storage area could be done because of the high density of mangrove trees (see picture 4, appendix A.1).

Cross-section 1 land > water: 0.30 m

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	16.45
Distance to rope [m]	0.10	0.65	0.80	0.92	0.95	0.97	0.90	0.83	0.74	0.75	0.45	0.10
Water-depth [m]	0.00	0.55	0.70	0.82	0.85	0.87	0.80	0.73	0.64	0.65	0.35	0.00
Bottom-depth [m]	**-1.17**	**-1.72**	**-1.87**	**-1.99**	**-2.02**	**-2.04**	**-1.97**	**-1.90**	**-1.81**	**-1.82**	**-1.52**	**-1.17**

Cross-section 2

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	13.65
Distance to rope [m]	0.10	0.89	1.16	1.25	1.36	1.35	1.34	1.31	0.68	0.18	0.10
Water-depth [m]	0.00	0.79	1.06	1.15	1.26	1.25	1.24	1.21	0.58	0.08	0.00
Bottom-depth [m]	**-1.17**	**-1.96**	**-2.23**	**-2.32**	**-2.43**	**-2.42**	**-2.41**	**-2.38**	**-1.75**	**-1.25**	**-1.17**

Cross-section 3

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	13.55
Distance to rope [m]	0.10	1.05	1.40	1.54	1.60	1.63	1.79	1.69	1.24	0.12	0.10
Water-depth [m]	0.00	0.95	1.30	1.44	1.50	1.53	1.69	1.59	1.14	0.02	0.00
Bottom-depth [m]	**-1.17**	**-2.12**	**-2.47**	**-2.61**	**-2.67**	**-2.70**	**-2.86**	**-2.76**	**-2.31**	**-1.19**	**-1.17**

Cross-section 4

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	15.11
Distance to rope [m]	0.10	0.91	1.16	1.23	1.26	1.40	1.50	1.46	1.48	1.30	0.15	0.10
Water-depth [m]	0.00	0.81	1.06	1.13	1.16	1.30	1.40	1.36	1.38	1.20	0.05	0.00
Bottom-depth [m]	**-1.17**	**-1.98**	**-2.23**	**-2.30**	**-2.33**	**-2.47**	**-2.57**	**-2.53**	**-2.55**	**-2.37**	**-1.22**	**-1.17**

Cross-section 5 land = water

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	16.00
Distance to rope [m]	0.10	0.55	0.58	0.66	0.72	0.77	0.80	0.90	0.92	0.80	0.74	0.10
Water-depth [m]	0.00	0.45	0.48	0.56	0.62	0.67	0.70	0.80	0.82	0.70	0.64	0.00
Bottom-depth [m]	**-1.17**	**-1.62**	**-1.65**	**-1.73**	**-1.79**	**-1.84**	**-1.87**	**-1.97**	**-1.99**	**-1.87**	**-1.81**	**-1.17**

Cross-section 6

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00
Distance to rope [m]	0.10	0.65	1.05	1.20	1.30	1.42	1.45	1.56	1.48	1.10	0.10
Water-depth [m]	0.00	0.55	0.95	1.10	1.20	1.32	1.35	1.46	1.38	1.00	0.00
Bottom-depth [m]	**-1.17**	**-1.72**	**-2.12**	**-2.27**	**-2.37**	**-2.49**	**-2.52**	**-2.63**	**-2.55**	**-2.17**	**-1.17**

Cross-section 7 land = water

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	15.34
Distance to rope [m]	0.10	0.35	0.42	0.53	0.60	0.61	0.62	0.60	0.55	0.40	0.30	0.10
Water-depth [m]	0.00	0.25	0.32	0.43	0.50	0.51	0.52	0.50	0.45	0.30	0.20	0.00
Bottom-depth [m]	**-1.17**	**-1.42**	**-1.49**	**-1.60**	**-1.67**	**-1.68**	**-1.69**	**-1.67**	**-1.62**	**-1.47**	**-1.37**	**-1.17**

Cross-section 8 land > water: 0.05 m

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	16.50
Distance to rope [m]	0.10	0.41	0.53	0.56	0.60	0.81	0.73	0.65	0.60	0.58	0.54	0.39
Water-depth [m]	0.00	0.31	0.43	0.46	0.50	0.71	0.63	0.55	0.50	0.48	0.44	0.29
Bottom-depth [m]	**-1.17**	**-1.48**	**-1.60**	**-1.63**	**-1.67**	**-1.88**	**-1.80**	**-1.72**	**-1.67**	**-1.65**	**-1.61**	**-1.46**

Cross-section 9 land > water: 0.25 m

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	14.90
Distance to rope [m]	0.10	0.85	1.22	1.42	1.65	1.85	1.86	1.75	1.28	0.40	0.10
Water-depth [m]	0.00	0.75	1.12	1.32	1.55	1.75	1.76	1.65	1.18	0.30	0.00
Bottom-depth [m]	**-1.17**	**-1.92**	**-2.29**	**-2.49**	**-2.72**	**-2.92**	**-2.93**	**-2.82**	**-2.35**	**-1.47**	**-1.17**

Cross-section 10 land < water: 0.10 m

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	15.59
Distance to rope [m]	0.10	1.16	1.38	1.48	1.55	1.58	1.60	1.75	1.55	1.35	0.26	0.10
Water-depth [m]	0.00	1.06	1.28	1.38	1.45	1.48	1.50	1.65	1.45	1.25	0.16	0.00
Bottom-depth [m]	**-1.17**	**-2.23**	**-2.45**	**-2.55**	**-2.62**	**-2.65**	**-2.67**	**-2.82**	**-2.62**	**-2.42**	**-1.33**	**-1.17**

Cross-section 11 land < water: 0.10 m

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	13.85
Distance to rope [m]	0.10	0.62	0.65	0.68	0.69	0.68	0.60	0.55	0.45	0.35	0.10
Water-depth [m]	0.00	0.52	0.55	0.58	0.59	0.58	0.50	0.45	0.35	0.25	0.00
Bottom-depth [m]	**-1.17**	**-1.69**	**-1.72**	**-1.75**	**-1.76**	**-1.75**	**-1.67**	**-1.62**	**-1.52**	**-1.42**	**-1.17**

Cross-section 12 land < water 0.10 m

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	12.31
Distance to rope [m]	0.10	0.35	0.41	0.45	0.48	0.58	0.61	0.59	0.50	0.10
Water-depth [m]	0.00	0.25	0.31	0.35	0.38	0.48	0.51	0.49	0.40	0.00
Bottom-depth [m]	**-1.17**	**-1.42**	**-1.48**	**-1.52**	**-1.55**	**-1.65**	**-1.68**	**-1.66**	**-1.57**	**-1.17**

Cross-section 13 land < water: 0.10 m

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	14.18
Distance to rope [m]	0.10	0.38	0.45	0.50	0.63	0.60	0.56	0.52	0.38	0.35	0.10
Water-depth [m]	0.00	0.28	0.35	0.40	0.53	0.50	0.46	0.42	0.28	0.25	0.00
Bottom-depth [m]	**-1.17**	**-1.45**	**-1.52**	**-1.57**	**-1.70**	**-1.67**	**-1.63**	**-1.59**	**-1.45**	**-1.42**	**-1.17**

Cross-section A1
Water-level -1.13 m

Width [m]	0.00	0.75	1.50	2.25	3.00	3.75	4.50	5.34
Distance to rope [m]	0.50	1.43	1.81	2.44	1.95	1.95	1.60	0.50
Water-depth [m]	0.00	0.93	1.31	1.94	1.45	1.45	1.10	0.00
Bottom-depth [m]	**-1.13**	**-2.06**	**-2.44**	**-3.07**	**-2.58**	**-2.58**	**-2.23**	**-1.13**

Cross-section A2

Water-level -0.86 m

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	9.00
Distance to rope [m]	0.40	1.35	2.06	2.40	2.15	0.80	0.34
Water-depth [m]	0.30	1.25	1.96	2.30	2.05	0.70	0.24
Bottom-depth [m]	**-1.16**	**-2.11**	**-2.82**	**-3.16**	**-2.91**	**-1.56**	**-1.10**

Cross-section A3

Water-level -0.86 m

Width [m]	0.00	1.50	3.00	4.50	6.00	7.50	8.10
Distance to rope [m]	0.65	1.56	2.25	2.20	2.20	1.25	0.98
Water-depth [m]	0.55	1.46	2.15	2.10	2.10	1.15	0.88
Bottom-depth [m]	**-1.41**	**-2.32**	**-3.01**	**-2.96**	**-2.96**	**-2.01**	**-1.74**

Cross-section B1

Water-level -1.03 m

Width [m]	0.00	0.75	1.50	2.25	3.00	3.93
Distance to rope [m]	0.50	1.75	1.73	1.64	1.62	0.50
Water-depth [m]	0.00	1.25	1.23	1.14	1.12	0.00
Bottom-depth [m]	**-1.03**	**-2.28**	**-2.26**	**-2.17**	**-2.15**	**-1.03**

Cross-section B2

Water-level -0.94 m

Width [m]	0.00	0.75	1.50	2.25	3.00	3.84
Distance to rope [m]	0.25	1.34	1.63	1.89	1.34	0.19
Water-depth [m]	0.15	1.24	1.53	1.79	1.24	0.09
Bottom-depth [m]	**1.09**	**2.18**	**2.47**	**2.73**	**2.18**	**1.03**

C.2 Sluice dimensions

The dimensions of the sluices are discussed here.

- Sluice A

Sluice A was constructed out of concrete and wood. The sluice gate and the turning mechanism were made of wood. The sluice had one entrance, opening and closing the sluice was managed by hand. During the inlet and outlet of water, the sluice gate was completely out of the water. Figure 3 shows a view of sluice a from above.

The bottom level of the sluice is at: -2.39 m. During the exchange of water, water was heading up against the beams of the sluice.

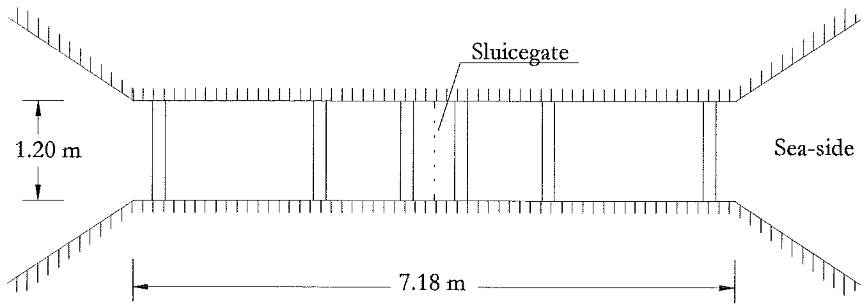


Figure 3: View of sluice A

- Sluice B

Sluice B was also constructed of concrete and wood and was almost a replica of sluice A. The difference was that this sluice had two entrances. In figure 4 a view of sluice B from above with the dimensions is given.

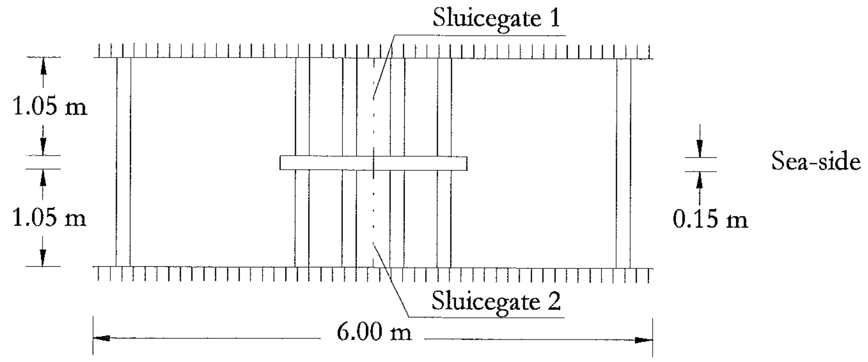


Figure 4: View of sluice B

The bottom level of the sluice is, referring to the reference level at: -2.26 m. During the exchange of water, water was heading up against the beams of the sluice. During the outlet of water heading up in the channel outside near sluice B was seen.

C.3 Velocity measurements

Every measurement will be shown here together with the water levels during the measurements. For every measurement the velocity was calculated using the following formula:

$$v_{meas.} = 0.257 \cdot \eta_{ott} + 0.007 \qquad \text{(Formula C.4)}$$

η_{Ott} are the number of revolutions per second. Formula C.4 is instrument dependent. The Dutch Rijkswaterstaat, who donated, this Ott-meter, calibrated it and found formula C.4 to must be used to calculate the velocity when this Ott-meter was used.

The time of measurement was 50 seconds. One entrance contained four sub-measurements, two near the bottom and two near the surface. Sluice A had one entrance so four sub-measurements to complete one total measurement. Sluice B had two entrances so eight sub-measurements to complete one total measurement.

- Velocity measurements sluice A

Points for measurement, looking from inside to outside:

3	4	Surface
2	1	Bottom

1 – 4 were the positions the measurements were done. All four together, one entrance, was one complete measurement.

Measurement 1A Date: 01-03-1999

	Time	Reading [m]	Level [m]	Remarks
Inside the plot	19:13	0.57	-1.13	
Outside the plot	19:11	-0.15	-1.85	Global reading. low water level

Point [-]	Time [hhmm]	Revolutions [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	19:06	352	7.04	1.82	**1.78**
2	19:08	370	7.40	1.91	
3	19:09	343	6.86	1.77	
4	19:10	314	6.28	1.62	

Remarks: Water was outgoing
High velocity and a lot of turbulence

Measurement 2A Date: 02-03-1999

	Time	Reading [m]	Level [m]	Remarks
Inside the plot	0:40	0.60	-1.11	Between 0.59 and 0.60
Outside the plot	0:38	....	....	Can't reach the gauge

Point [-]	Time [hhmm]	Revolutions [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	0:33	356	7.12	1.84	**1.67**
2	0:36	284	5.68	1.47	
3	0:37	335	6.70	1.73	
4	0:38	317	6.34	1.64	

Remarks: Water was incoming
High velocity

Measurement 3A Date: 02-03-1999

	Time	Reading [m]	Level [m]	Remarks
Inside the plot	....	0.53	-1.17	Before 14:00
Outside the plot	....	0.74	-0.96	Before 14:00

Point [-]	Time [hhmm]	Revolutions [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	13:58	288	5.76	1.49	**1.56**
2	13:59	346	6.92	1.79	
3	14:01	266	5.32	1.37	
4	14:03	308	6.16	1.59	

Remarks: Water was incoming with high velocity
Extra data:

	Time	Reading [m]	Level [m]	Remarks
Inside the plot	14:04	0.54	-1.16	
Outside the plot	13:54	0.77	-0.94	Between 0.76 and 0.77

Measurement 4A Date: 02-03-1999

	Time	Reading [m]	Level [m]	Remarks
Inside the plot	14:28	0.58	-1.12	
Outside the plot	14:30	0.85	-0.85	

Point [-]	Time [hhmm]	Revolutions [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	14:33	344	6.88	1.78	**1.70**
2	14:34	377	7.54	1.94	
3	14:35	288	5.76	1.49	
4	14:37	305	6.10	1.57	

Remarks: Water was incoming
High velocity
Extra data:

	Time	Reading [m]	Level [m]	Remarks
Inside the plot	14:39	0.59	-1.11	
Outside the plot	14:38	0.87	-0.83	

Measurement 5A Date: 16-03-1999

	Time	Reading [m]	Level [m]	Remarks
Inside the plot	18:48	0.60	-1.10	
Outside the plot	18:49	-0.15	-1.85	Global reading. low water-level

Point [-]	**Time** [hhmm]	**Revolutions** [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	18:52	301	6.02	1.55	**1.67**
2	18:53	289	5.78	1.49	
3	18:55	355	7.10	1.83	
4	18:56	353	7.06	1.82	

Remarks: Water was going out
Extra reading:

	Time	Reading [m]	Level [m]	Remarks
Inside the plot	18:57	0.59	-1.11	
Outside the plot	18:57	-0.15	-1.85	Global reading, low water-level

Measurement 6A Date: 17-03-1999

	Time	Reading [m]	Level [m]	Remarks
Inside the plot	14:03	0.60	-1.10	
Outside the plot	14:04	0.88	-0.82	

Point [-]	**Time** [hhmm]	**Revolutions** [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	14:07	361	7.22	1.86	**1,66**
2	14:08	343	6.86	1.77	
3	14:09	297	5.94	1.53	
4	14:11	288	5.76	1.49	

Remarks: Water was coming in
During measuring of point 1 the stick of the Ott-meter broke.
Measurements were done a little bit higher than before.
Extra reading:

	Time	Reading [m]	Level [m]	Remarks
Inside the plot	14:13	0.61	-1.09	
Outside the plot	14:12	0.88	-0.82	Global reading, low water-level

- Velocity measurements sluice B

Points for measurements (looking from inside to outside):

7	8	3	4	Surface
6	5	2	1	Bottom

1-8 show the positions of the measuring points. Together they form two entrances, and one complete measurement.

Measurement 1B Date: 01-03-1999

	Time	Reading [m]	Level [m]	Remarks
Outside the plot	14:42	0.67	-0.99	

Point [-]	Time [hhmm]	Revolutions [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	14:54	115	2.30	0.60	**0,72**
2	14:56	147	2.94	0.76	
3	14:57	165	3.30	0.86	
4	14:58	136	2.72	0.71	
5	14:59	140	2.80	0.73	
6	15:00	118	2.36	0.61	
7	15:01	142	2.84	0.74	
8	15:02	148	2.96	0.77	

Remarks: Water was outgoing

Measurement 2B Date: 01-03-1999

	Time	Reading [m]	Level [m]	Remarks
Outside the plot	19:37	0.30	-1.36	After measuring

Point [-]	Time [hhmm]	Revolutions [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	19:26	166	3.32	0.86	**1,09**
2	19:27	226	4.52	1.17	
3	19:28	270	5.40	1.39	
4	19:29	146	2.92	0.76	
5	19:31	182	3.64	0.94	
6	19:33	174	3.48	0.90	
7	19:34	249	4.98	1.29	
8	19:35	272	5.44	1.41	

Remarks: Water was outgoing

Measurement 3B Date: 02-03-1999

	Time	Reading [m]	Level [m]	Remarks
Outside the plot	0:17	0.61	-1.05	Between 0.60 and 0.62, after measuring

Point [-]	Time [hhmm]	Revolutions [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	0:04	180	3.60	0.93	**1.17**
2	0:05	224	4.48	1.16	
3	0:07	236	4.72	1.22	
4	0:09	209	4.18	1.08	
5	0:10	227	4.54	1.17	
6	0:12	180	3.60	0.93	
7	0:13	242	4.84	1.25	
8	0:15	312	6.24	1.61	

Remarks: Water was incoming

Measurement 4B Date: 02-03-1999

	Time	Reading [m]	Level [m]	Remarks
Outside the plot	12:45	0.35	-1.31	

Point [-]	Time [hhmm]	Revolutions [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	12:46	154	3.08	0.80	**0.81**
2	12:48	140	2.80	0.73	
3	12:49	134	2.68	0.70	
4	12:51	143	2.86	0.74	
5	12:52	140	2.80	0.73	
6	12:54	175	3.50	0.91	
7	12:55	177	3.54	0.92	
8	12:56	190	3.80	0.98	

Remarks: Water was outgoing

Extra water levels, translation golf

Time	Reading [m]	Level [m]
12:54	0.41	-1.25
12:57	0.43	-1.23
12:59	0.35	-1.31
13:00	0.41	-1.25
13:01	0.28	-1.38

Measurement 5B

Date: 02-03-1999

	Time	Reading [m]	Level [m]	Remarks
Outside the plot	14:48	0.65	-1.01	

Point [-]	Time [hhmm]	Revolutions [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	14:51	206	4.12	1.07	**1.31**
2	14:53	260	5.20	1.34	
3	14:55	247	4.94	1.28	
4	14:56	248	4.96	1.28	
5	14:58	187	3.74	0.97	
6	14:59	227	4.54	1.17	
7	15:01	316	6.32	1.63	
8	15:02	342	6.84	1.76	

Remarks: Water was incoming
Level outside: 15:03 0.68-0.70 m

Measurement 6B Date: 16-03-1999

	Time	Reading [m]	Level [m]	Remarks
Outside the plot	18:11	0.35-0.40	-1.31	Fast and turbulent water
			-1.26	Between these values

Point [-]	Time [hhmm]	Revolutions [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	18:13	172	3.44	0.89	**1.04**
2	18:14	170	3.40	0.88	
3	18:16	210	4.20	1.09	
4	18:17	170	3.40	0.88	
5	18:19	178	3.56	0.92	
6	18:20	201	4.02	1.04	
7	18:22	250	5.00	1.29	
8	18:23	258	5.16	1.33	

Remarks: Water was outgoing
At 18:18 extra measurement point 3: Revolutions were 205
Water level was rising quick
Extra reading:

	Time	Reading [m]	Level [m]	Remarks
Outside the plot	18:24	0.40	-1.26	Fast and turbulent water

Measurement 7B Date: 17-03-1999

	Time	Reading [m]	Level [m]	Remarks
Outside the plot	13:25	0.59-0.61	Between -1.07 and -1.06	

Point [-]	Time [hhmm]	Revolutions [-]	η_{ott} [rev/sec]	$v_{sub.}$ [m/s]	$v_{meas.}$ [m/s]
1	13:26	208	4.16	1.08	**1.16**
2	13:27	205	4.10	1.06	
3	13:28	250	5.00	1.29	
4	13:30	212	4.24	1.10	
5	13:31	220	4.40	1.14	
6	13:33	203	4.06	1.05	
7	13:34	235	4.70	1.21	
8	13:35	265	5.30	1.37	

Remarks: Water was coming in
Look at drawings of the sluice, turbulence.
Extra reading:

	Time	Reading [m]	Level [m]	Remarks
Outside the plot	13:37	0.60-0.62	**-1.06**	Fast and turbulent water
			-1.04	Between these values

From the calculated velocities, an estimation of the discharge coefficients was made. The discharge coefficient μ can be calculated using formula C.5.

$$\mu = \frac{Q}{A_{sl.} \cdot \sqrt{2 \cdot g \cdot \Delta h}} \quad \text{where } g = 9.81 \text{ m/s}^2 \qquad \text{(Formula C.5)}$$

Table 3 shows the used values and the results. $v_{meas.} = Q/A_{sl.}$.

Table 3: Calculating the discharge coefficients

Sluice A incoming				
Measurement	$v_{meas.}$ **[m/s]**	**Δh [m]**	**√(2·g·Δh) [m/s]**	**μ [-]**
2A	0.72	0.27	2.30	0.72
3A	0.76	0.21	2.03	0.76
4A	0.73	0.27	2.30	0.73
6A	0.70	0.28	2.34	0.70
		Average μ		**0.73**

Sluice A outgoing				
Measurement	$v_{meas.}$ **[m/s]**	**Δh [m]**	**√(2·g·Δh) [m/s]**	**μ [-]**
1A	1.78	0.72	3.76	0.47
5A	1.67	0.75	3.84	0.44
		Average μ		**0.46**

Sluice B incoming				
Measurement	$v_{meas.}$ **[m/s]**	**Δh [m]**	**√(2·g·Δh) [m/s]**	**μ [-]**
3B	1.17	0.08	1.25	0.93
5B	1.31	0.09	1.33	0.99
		Average μ		**0.96**

Sluice B outgoing				
Measurement	$v_{meas.}$ [m/s]	**Δh [m]**	**√(2·g·Δh) [m/s]**	**μ [-]**
2B	1.09	0.20	1.98	0.55
4B	0.81	0.13	1.60	0.51
		Average μ		**0.53**

C.4 Water level measurements

The Diver gave during the second fieldtrip output every 10 minutes for the in- and outside water levels. Besides the measured data, the results of the analysis of it are shown here. The measured data was transferred into useful water levels. A description of the calculations was given in paragraph 6.1. Gauge readings (referring to the reference level) were used to link the Diver-data with the reference level. The data of the Diver just before it entered the water was used as the first air-pressure value because the barometer did not gave reliable readings. The barometer was disordered probably caused by the transport from Statefarm to the research plot.
The Diver outside the pond was stolen during the last fieldtrip so no outside data was available during that period. The data of the inside Diver was available and are shown and analyzed here. In addition, a few registrations before the divers entered the water will be given.
First, some explanation will be given about the used titles of several columns

- Total pressure: the pressure of air and water measured by the Diver [cm water column].
- Corrected pressure: the measured data corrected with a density factor of 1,018 because of brackish/salt water.
- Total pressure: the total pressure of air and water [mbar].
- Air-pressure: the air-pressure, most of the times assumed because of the not reliable readings of the barometer.

- Fieldtrip 2

- ***Diver with inside water levels:***

Figure 5 shows the registered levels of the Diver inside the pond followed by the analysis of it.

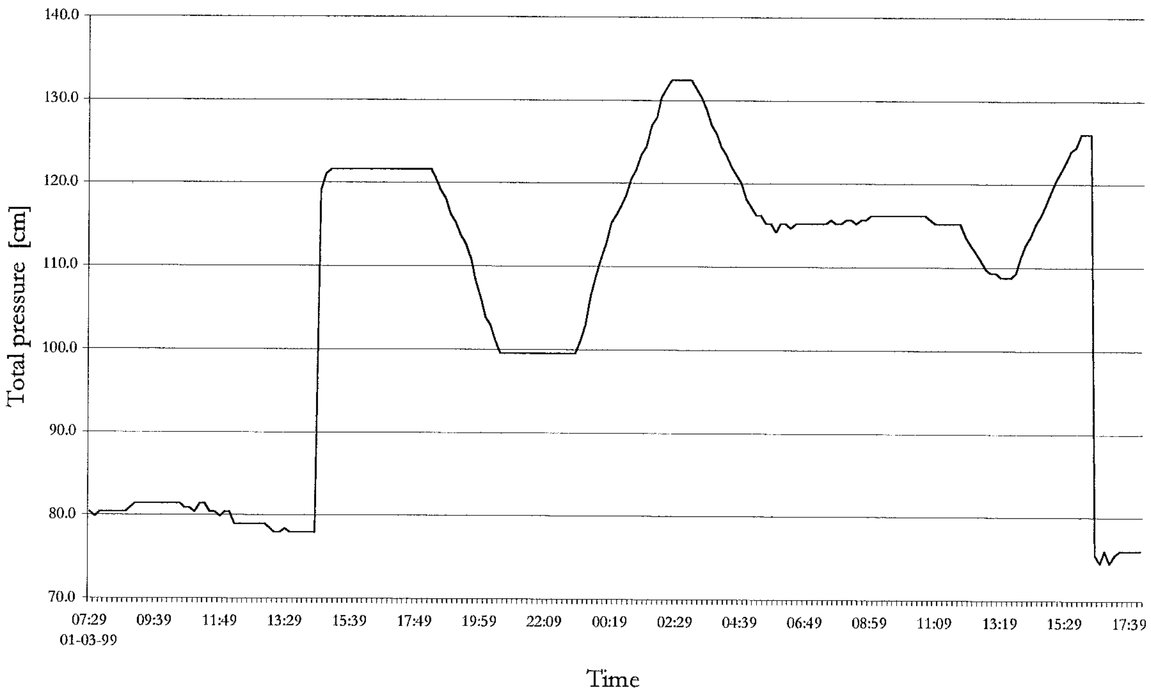


Figure 5: Diver readings inside, fieldtrip 2

The output and the analysis of the data are shown in table 4.

Table 4: Inside water level analysis, fieldtrip 2

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
37	01-03-99	13:29	78.4	78.4	1008.9			
38	01-03-99	13:39	77.9	77.9	1008.4			
39	01-03-99	13:49	77.9	77.9	1008.4	1003.0	5.5	-1.41
40	01-03-99	13:59	77.9	77.9	1008.4	1008.4	0.0	-1.47
41	01-03-99	14:09	77.9	77.9	1008.4	1008.4	0.0	-1.47
42	01-03-99	14:19	77.9	77.9	1008.4	1008.4	0.0	-1.47
43	01-03-99	14:29	77.9	77.9	1008.4	1008.4	0.0	-1.47
44	01-03-99	14:39	119.1	117.0	1046.7	1008.4	39.1	-1.07
45	01-03-99	14:49	121.1	119.0	1048.6	1008.4	41.0	-1.05
46	01-03-99	14:59	121.6	119.4	1049.1	1008.4	41.5	-1.05
47	01-03-99	15:09	121.6	119.4	1049.1	1008.4	41.5	-1.05
48	01-03-99	15:19	121.6	119.4	1049.1	1008.4	41.5	-1.05
49	01-03-99	15:29	121.6	119.4	1049.1	1008.4	41.5	-1.05
50	01-03-99	15:39	121.6	119.4	1049.1	1008.4	41.5	-1.05
51	01-03-99	15:49	121.6	119.4	1049.1	1008.4	41.5	-1.05
52	01-03-99	15:59	121.6	119.4	1049.1	1008.4	41.5	-1.05
53	01-03-99	16:09	121.6	119.4	1049.1	1008.4	41.5	-1.05
54	01-03-99	16:19	121.6	119.4	1049.1	1008.4	41.5	-1.05
55	01-03-99	16:29	121.6	119.4	1049.1	1008.4	41.5	-1.05
56	01-03-99	16:39	121.6	119.4	1049.1	1008.4	41.5	-1.05
57	01-03-99	16:49	121.6	119.4	1049.1	1008.4	41.5	-1.05
58	01-03-99	16:59	121.6	119.4	1049.1	1008.4	41.5	-1.05
59	01-03-99	17:09	121.6	119.4	1049.1	1008.4	41.5	-1.05
60	01-03-99	17:19	121.6	119.4	1049.1	1008.4	41.5	-1.05
61	01-03-99	17:29	121.6	119.4	1049.1	1008.4	41.5	-1.05
62	01-03-99	17:39	121.6	119.4	1049.1	1008.4	41.5	-1.05
63	01-03-99	17:49	121.6	119.4	1049.1	1008.4	41.5	-1.05
64	01-03-99	17:59	121.6	119.4	1049.1	1008.4	41.5	-1.05
65	01-03-99	18:09	121.6	119.4	1049.1	1008.4	41.5	-1.05
66	01-03-99	18:19	121.6	119.4	1049.1	1008.4	41.5	-1.05
67	01-03-99	18:29	120.6	118.5	1048.2	1008.4	40.5	-1.06
68	01-03-99	18:39	119.1	117.0	1046.7	1008.4	39.1	-1.07
69	01-03-99	18:49	118.1	116.0	1045.8	1008.4	38.1	-1.08
70	01-03-99	18:59	116.2	114.1	1043.9	1008.4	36.2	-1.10
71	01-03-99	19:09	115.2	113.2	1043.0	1008.4	35.2	-1.11
72	01-03-99	19:19	113.7	111.7	1041.5	1008.4	33.8	-1.13
73	01-03-99	19:29	112.7	110.7	1040.6	1008.4	32.8	-1.14
74	01-03-99	19:39	110.8	108.8	1038.7	1008.4	30.9	-1.16
75	01-03-99	19:49	108.3	106.4	1036.3	1008.4	28.5	-1.18
76	01-03-99	19:59	106.4	104.5	1034.5	1008.4	26.6	-1.20

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
77	01-03-99	20:09	103.9	102.1	1032.1	1008.5	24.0	-1.22
78	01-03-99	20:19	102.9	101.1	1031.1	1008.5	23.0	-1.23
79	01-03-99	20:29	101.0	99.2	1029.3	1009.0	20.7	-1.26
80	01-03-99	20:39	99.5	97.7	1027.8	1011.0	17.2	-1.29
81	01-03-99	20:49	99.5	97.7	1027.8	1011.0	17.2	-1.29
82	01-03-99	20:59	99.5	97.7	1027.8	1011.0	17.2	-1.29
83	01-03-99	21:09	99.5	97.7	1027.8	1011.0	17.2	-1.29
84	01-03-99	21:19	99.5	97.7	1027.8	1011.0	17.2	-1.29
85	01-03-99	21:29	99.5	97.7	1027.8	1011.0	17.2	-1.29
86	01-03-99	21:39	99.5	97.7	1027.8	1011.0	17.2	-1.29
87	01-03-99	21:49	99.5	97.7	1027.8	1011.0	17.2	-1.29
88	01-03-99	21:59	99.5	97.7	1027.8	1011.0	17.2	-1.29
89	01-03-99	22:09	99.5	97.7	1027.8	1011.0	17.2	-1.29
90	01-03-99	22:19	99.5	97.7	1027.8	1011.0	17.2	-1.29
91	01-03-99	22:29	99.5	97.7	1027.8	1011.0	17.2	-1.29
92	01-03-99	22:39	99.5	97.7	1027.8	1011.0	17.2	-1.29
93	01-03-99	22:49	99.5	97.7	1027.8	1011.0	17.2	-1.29
94	01-03-99	22:59	99.5	97.7	1027.8	1011.0	17.2	-1.29
95	01-03-99	23:09	99.5	97.7	1027.8	1011.0	17.2	-1.29
96	01-03-99	23:19	101.0	99.2	1029.3	1010.9	18.7	-1.28
97	01-03-99	23:29	102.9	101.1	1031.1	1010.8	20.7	-1.26
98	01-03-99	23:39	106.4	104.5	1034.5	1010.7	24.2	-1.22
99	01-03-99	23:49	108.8	106.9	1036.8	1010.6	26.7	-1.20
100	01-03-99	23:59	110.8	108.8	1038.7	1010.5	28.8	-1.18
101	02-03-99	00:09	112.7	110.7	1040.6	1010.4	30.7	-1.16
102	02-03-99	00:19	115.2	113.2	1043.0	1010.3	33.3	-1.13
103	02-03-99	00:29	116.2	114.1	1043.9	1010.2	34.4	-1.12
104	02-03-99	00:39	117.2	115.1	1044.9	1010.1	35.5	-1.11
105	02-03-99	00:49	118.6	116.5	1046.2	1010.0	36.9	-1.10
106	02-03-99	00:59	120.6	118.5	1048.2	1009.9	39.0	-1.08
107	02-03-99	01:09	121.6	119.4	1049.1	1009.8	40.1	-1.06
108	02-03-99	01:19	123.5	121.3	1051.0	1009.7	42.1	-1.04
109	02-03-99	01:29	124.5	122.3	1051.9	1009.6	43.1	-1.03
110	02-03-99	01:39	127.0	124.8	1054.3	1009.5	45.7	-1.01
111	02-03-99	01:49	127.9	125.6	1055.2	1009.4	46.7	-1.00
112	02-03-99	01:59	130.4	128.1	1057.6	1009.3	49.2	-0.97
113	02-03-99	02:09	131.4	129.1	1058.6	1009.2	50.3	-0.96
114	02-03-99	02:19	132.4	130.1	1059.5	1009.1	51.4	-0.95
115	02-03-99	02:29	132.4	130.1	1059.5	1009.3	51.2	-0.95
116	02-03-99	02:39	132.4	130.1	1059.5	1009.0	51.5	-0.95
117	02-03-99	02:49	132.4	130.1	1059.5	1009.0	51.5	-0.95
118	02-03-99	02:59	132.4	130.1	1059.5	1009.1	51.4	-0.95

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
119	02-03-99	03:09	131.4	129.1	1058.6	1009.0	50.5	-0.96
120	02-03-99	03:19	130.4	128.1	1057.6	1009.0	49.6	-0.97
121	02-03-99	03:29	128.9	126.6	1056.2	1009.0	48.1	-0.98
122	02-03-99	03:39	127.0	124.8	1054.3	1009.0	46.2	-1.00
123	02-03-99	03:49	126.0	123.8	1053.4	1009.0	45.2	-1.01
124	02-03-99	03:59	124.5	122.3	1051.9	1009.0	43.8	-1.03
125	02-03-99	04:09	123.5	121.3	1051.0	1009.0	42.8	-1.04
126	02-03-99	04:19	122.1	119.9	1049.6	1009.0	41.4	-1.05
127	02-03-99	04:29	121.1	119.0	1048.6	1009.0	40.4	-1.06
128	02-03-99	04:39	120.1	118.0	1047.7	1009.0	39.4	-1.07
129	02-03-99	04:49	118.1	116.0	1045.8	1009.0	37.5	-1.09
130	02-03-99	04:59	117.2	115.1	1044.9	1009.0	36.6	-1.10
131	02-03-99	05:09	116.2	114.1	1043.9	1009.0	35.6	-1.11
132	02-03-99	05:19	116.2	114.1	1043.9	1009.0	35.6	-1.11
133	02-03-99	05:29	115.2	113.2	1043.0	1009.0	34.6	-1.12
134	02-03-99	05:39	115.2	113.2	1043.0	1010.0	33.6	-1.13
135	02-03-99	05:49	114.2	112.2	1042.0	1009.0	33.6	-1.13
136	02-03-99	05:59	115.2	113.2	1043.0	1010.0	33.6	-1.13
137	02-03-99	06:09	115.2	113.2	1043.0	1010.0	33.6	-1.13
138	02-03-99	06:19	114.7	112.7	1042.5	1010.0	33.1	-1.13
139	02-03-99	06:29	115.2	113.2	1043.0	1010.0	33.6	-1.13
140	02-03-99	06:39	115.2	113.2	1043.0	1010.0	33.6	-1.13
141	02-03-99	06:49	115.2	113.2	1043.0	1010.0	33.6	-1.13
142	02-03-99	06:59	115.2	113.2	1043.0	1010.0	33.6	-1.13
143	02-03-99	07:09	115.2	113.2	1043.0	1010.0	33.6	-1.13
144	02-03-99	07:19	115.2	113.2	1043.0	1010.0	33.6	-1.13
145	02-03-99	07:29	115.2	113.2	1043.0	1010.0	33.6	-1.13
146	02-03-99	07:39	115.7	113.7	1043.4	1010.0	34.1	-1.12
147	02-03-99	07:49	115.2	113.2	1043.0	1010.0	33.6	-1.13
148	02-03-99	07:59	115.2	113.2	1043.0	1010.0	33.6	-1.13
149	02-03-99	08:09	115.7	113.7	1043.4	1011.0	33.1	-1.13
150	02-03-99	08:19	115.7	113.7	1043.4	1011.0	33.1	-1.13
151	02-03-99	08:29	115.2	113.2	1043.0	1011.0	32.6	-1.14
152	02-03-99	08:39	115.7	113.7	1043.4	1011.0	33.1	-1.13
153	02-03-99	08:49	115.7	113.7	1043.4	1011.0	33.1	-1.13
154	02-03-99	08:59	116.2	114.1	1043.9	1011.0	33.6	-1.13
155	02-03-99	09:09	116.2	114.1	1043.9	1011.0	33.6	-1.13
156	02-03-99	09:19	116.2	114.1	1043.9	1011.0	33.6	-1.13
157	02-03-99	09:29	116.2	114.1	1043.9	1011.0	33.6	-1.13
158	02-03-99	09:39	116.2	114.1	1043.9	1011.0	33.6	-1.13
159	02-03-99	09:49	116.2	114.1	1043.9	1011.0	33.6	-1.13
160	02-03-99	09:59	116.2	114.1	1043.9	1011.0	33.6	-1.13

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
161	02-03-99	10:09	116.2	114.1	1043.9	1011.0	33.6	-1.13
162	02-03-99	10:19	116.2	114.1	1043.9	1011.0	33.6	-1.13
163	02-03-99	10:29	116.2	114.1	1043.9	1011.0	33.6	-1.13
164	02-03-99	10:39	116.2	114.1	1043.9	1011.0	33.6	-1.13
165	02-03-99	10:49	116.2	114.1	1043.9	1011.0	33.6	-1.13
166	02-03-99	10:59	115.7	113.7	1043.4	1011.0	33.1	-1.13
167	02-03-99	11:09	115.2	113.2	1043.0	1010.0	33.6	-1.13
168	02-03-99	11:19	115.2	113.2	1043.0	1010.0	33.6	-1.13
169	02-03-99	11:29	115.2	113.2	1043.0	1010.0	33.6	-1.13
170	02-03-99	11:39	115.2	113.2	1043.0	1010.0	33.6	-1.13
171	02-03-99	11:49	115.2	113.2	1043.0	1010.0	33.6	-1.13
172	02-03-99	11:59	115.2	113.2	1043.0	1009.7	33.9	-1.13
173	02-03-99	12:09	113.7	111.7	1041.5	1010.0	32.1	-1.14
174	02-03-99	12:19	112.7	110.7	1040.6	1010.0	31.1	-1.15
175	02-03-99	12:29	111.8	109.8	1039.7	1010.0	30.3	-1.16
176	02-03-99	12:39	110.8	108.8	1038.7	1010.0	29.3	-1.17
177	02-03-99	12:49	109.8	107.9	1037.8	1010.0	28.3	-1.18
178	02-03-99	12:59	109.3	107.4	1037.3	1010.0	27.8	-1.19
179	02-03-99	13:09	109.3	107.4	1037.3	1010.0	27.8	-1.19
180	02-03-99	13:19	108.8	106.9	1036.8	1010.0	27.3	-1.19
181	02-03-99	13:29	108.8	106.9	1036.8	1010.0	27.3	-1.19
182	02-03-99	13:39	108.8	106.9	1036.8	1010.0	27.3	-1.19
183	02-03-99	13:49	109.3	107.4	1037.3	1010.0	27.8	-1.19
184	02-03-99	13:59	111.3	109.3	1039.2	1009.8	30.0	-1.17
185	02-03-99	14:09	112.7	110.7	1040.6	1009.0	32.2	-1.14
186	02-03-99	14:19	113.7	111.7	1041.5	1009.0	33.1	-1.13
187	02-03-99	14:29	115.2	113.2	1043.0	1009.0	34.6	-1.12
188	02-03-99	14:39	116.2	114.1	1043.9	1009.0	35.6	-1.11
189	02-03-99	14:49	117.6	115.5	1045.3	1009.0	37.0	-1.10
190	02-03-99	14:59	119.1	117.0	1046.7	1009.0	38.5	-1.08
191	02-03-99	15:09	120.6	118.5	1048.2	1009.0	39.9	-1.07
192	02-03-99	15:19	121.6	119.4	1049.1	1009.0	40.9	-1.06
193	02-03-99	15:29	122.6	120.4	1050.1	1009.0	41.9	-1.05
194	02-03-99	15:39	124.0	121.8	1051.4	1009.0	43.3	-1.03
195	02-03-99	15:49	124.5	122.3	1051.9	1009.0	43.8	-1.03
196	02-03-99	15:59	126.0	123.8	1053.4	1007.0	47.3	-0.99
197	02-03-99	16:09	126.0	123.8	1053.4	1007.0	47.3	-0.99
198	02-03-99	16:19	126.0	123.8	1053.4	1006.0	48.3	-0.98
199	02-03-99	16:29	75.5	75.5	1006.0	1006.0	0.0	-1.47
200	02-03-99	16:39	74.5	74.5	1005.0	1005.0	0.0	-1.46
201	02-03-99	16:49	76.0	76.0	1006.5	1006.5	0.0	-1.47
202	02-03-99	16:59	74.5	74.5	1005.0	1005.0	0.0	-1.47

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
203	02-03-99	17:09	75.5	75.5	1006.0	1006.0	0.0	-1.47
204	02-03-99	17:19	76.0	76.0	1006.5	1006.5	0.0	-1.47
205	02-03-99	17:29	76.0	76.0	1006.5	1006.5	0.0	-1.47
206	02-03-99	17:39	76.0	76.0	1006.5	1006.5	0.0	-1.47
207	02-03-99	17:49	76.0	76.0	1006.5	1006.5	0.0	-1.47
208	02-03-99	17:59	76.0	76.0	1006.5	1006.5	0.0	-1.47

- ***Diver with outside water levels (tide)***

The assumptions made for the barometer readings during the analysis of the inside water levels were used to calculate the outside water levels. It was assumed that the assumptions made for the air-pressure were correct. Figure 6 shows the readings of the Diver outside. After this figure, the results will be analyzed.

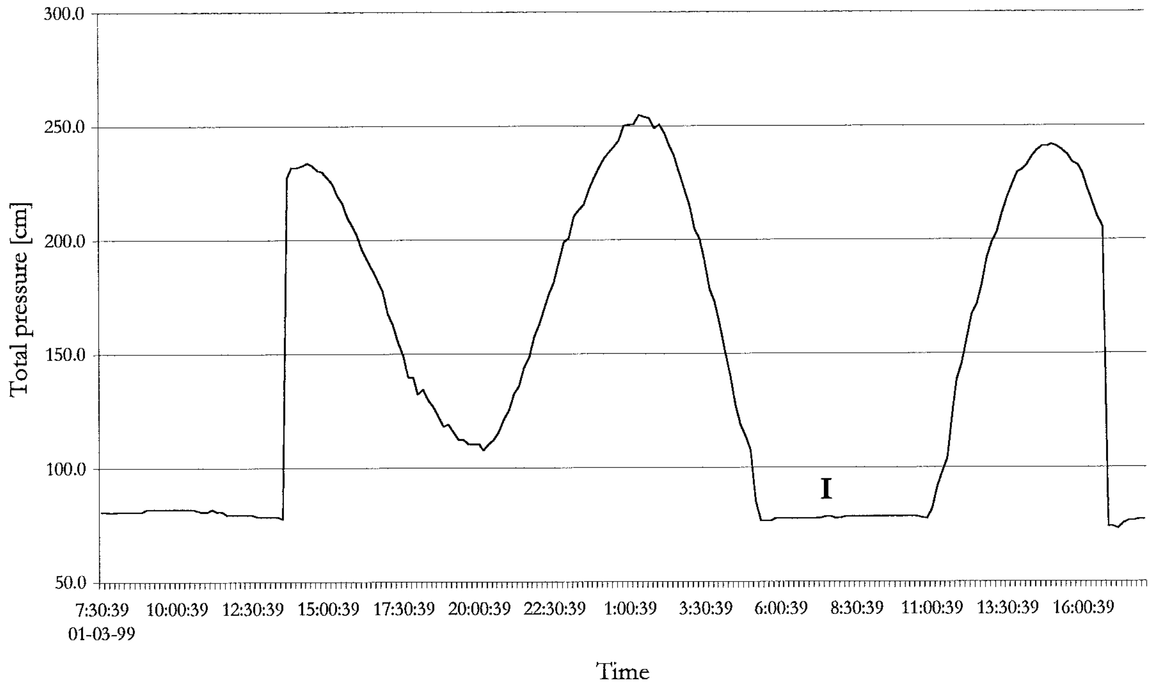


Figure 6: Diver readings outside, fieldtrip 2

The period when the level (I, see figure 6) is horizontal means that the Diver was hanging above the water level, measuring only the air-pressure.

The reason for this was the high tidal range causing the channel to dry up during certain periods of the day. The analysis of the data is shown in table 5.

Table 5: Outside water level analysis, fieldtrip 2

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
39	01-03-99	13:50	231.9	227.8	1155.4	1003.0	155.4	-0.89
40	01-03-99	14:00	231.9	227.8	1155.4	1008.4	149.9	-0.94

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
41	01-03-99	14:10	232.8	228.7	1156.3	1008.4	150.8	-0.93
42	01-03-99	14:20	233.8	229.7	1157.3	1008.4	151.7	-0.92
43	01-03-99	14:30	232.8	228.7	1156.3	1008.4	150.8	-0.93
44	01-03-99	14:40	230.4	226.3	1154.0	1008.4	148.4	-0.96
45	01-03-99	14:50	229.9	225.8	1153.5	1008.4	147.9	-0.96
46	01-03-99	15:00	227.5	223.5	1151.2	1008.4	145.5	-0.99
47	01-03-99	15:10	225.0	221.0	1148.8	1008.4	143.1	-1.01
48	01-03-99	15:20	219.6	215.7	1143.6	1008.4	137.8	-1.06
49	01-03-99	15:30	216.2	212.4	1140.3	1008.4	134.4	-1.10
50	01-03-99	15:40	209.8	206.1	1134.1	1008.4	128.2	-1.16
51	01-03-99	15:50	206.4	202.8	1130.8	1008.4	124.8	-1.19
52	01-03-99	16:00	202.0	198.4	1126.6	1008.4	120.5	-1.24
53	01-03-99	16:10	195.6	192.1	1120.4	1008.4	114.2	-1.30
54	01-03-99	16:20	191.2	187.8	1116.2	1008.4	109.9	-1.34
55	01-03-99	16:30	186.8	183.5	1112.0	1008.4	105.6	-1.39
56	01-03-99	16:40	182.4	179.2	1107.7	1008.4	101.2	-1.43
57	01-03-99	16:50	177.5	174.4	1103.0	1008.4	96.4	-1.48
58	01-03-99	17:00	167.6	164.6	1093.5	1008.4	86.7	-1.57
59	01-03-99	17:10	162.7	159.8	1088.7	1008.4	81.9	-1.62
60	01-03-99	17:20	155.4	152.7	1081.7	1008.4	74.7	-1.69
61	01-03-99	17:30	149.5	146.9	1076.0	1008.4	68.9	-1.75
62	01-03-99	17:40	139.7	137.2	1066.6	1008.4	59.3	-1.85
63	01-03-99	17:50	139.7	137.2	1066.6	1008.4	59.3	-1.85
64	01-03-99	18:00	132.4	130.1	1059.5	1008.4	52.1	-1.92
65	01-03-99	18:10	134.3	131.9	1061.4	1008.4	54.0	-1.90
66	01-03-99	18:20	129.9	127.6	1057.1	1008.4	49.7	-1.94
67	01-03-99	18:30	127.0	124.8	1054.3	1008.4	46.8	-1.97
68	01-03-99	18:40	122.6	120.4	1050.1	1008.4	42.5	-2.02
69	01-03-99	18:50	118.1	116.0	1045.8	1008.4	38.1	-2.06
70	01-03-99	19:00	119.1	117.0	1046.7	1008.4	39.1	-2.05
71	01-03-99	19:10	115.7	113.7	1043.4	1008.4	35.7	-2.08
72	01-03-99	19:20	112.3	110.3	1040.2	1008.4	32.4	-2.12
73	01-03-99	19:30	112.3	110.3	1040.2	1008.4	32.4	-2.12
74	01-03-99	19:40	110.3	108.3	1038.2	1008.4	30.4	-2.14
75	01-03-99	19:50	110.3	108.3	1038.2	1008.4	30.4	-2.14
76	01-03-99	20:00	110.3	108.3	1038.2	1008.4	30.4	-2.14
77	01-03-99	20:10	107.8	105.9	1035.8	1008.5	27.9	-2.16
78	01-03-99	20:20	110.3	108.3	1038.2	1008.5	30.3	-2.14
79	01-03-99	20:30	112.3	110.3	1040.2	1009.0	31.8	-2.12
80	01-03-99	20:40	115.7	113.7	1043.4	1011.0	33.1	-2.11
81	01-03-99	20:50	121.1	119.0	1048.6	1011.0	38.4	-2.06
82	01-03-99	21:00	125.0	122.8	1052.4	1011.0	42.2	-2.02

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
83	01-03-99	21:10	132.4	130.1	1059.5	1011.0	49.5	-1.95
84	01-03-99	21:20	135.8	133.4	1062.8	1011.0	52.8	-1.91
85	01-03-99	21:30	144.1	141.6	1070.8	1011.0	61.0	-1.83
86	01-03-99	21:40	148.5	145.9	1075.1	1011.0	65.3	-1.79
87	01-03-99	21:50	157.4	154.6	1083.6	1011.0	74.0	-1.70
88	01-03-99	22:00	162.7	159.8	1088.7	1011.0	79.2	-1.65
89	01-03-99	22:10	169.1	166.1	1094.9	1011.0	85.5	-1.59
90	01-03-99	22:20	176.0	172.9	1101.6	1011.0	92.3	-1.52
91	01-03-99	22:30	181.4	178.2	1106.8	1011.0	97.6	-1.46
92	01-03-99	22:40	190.2	186.8	1115.2	1011.0	106.3	-1.38
93	01-03-99	22:50	199.0	195.5	1123.7	1011.0	114.9	-1.29
94	01-03-99	23:00	201.0	197.4	1125.6	1011.0	116.9	-1.27
95	01-03-99	23:10	210.3	206.6	1134.6	1011.0	126.0	-1.18
96	01-03-99	23:20	213.2	209.4	1137.4	1010.9	129.0	-1.15
97	01-03-99	23:30	215.7	211.9	1139.8	1010.8	131.5	-1.13
98	01-03-99	23:40	222.1	218.2	1146.0	1010.7	137.9	-1.06
99	01-03-99	23:50	227.5	223.5	1151.2	1010.6	143.3	-1.01
100	02-03-99	00:00	231.9	227.8	1155.4	1010.5	147.7	-0.96
101	02-03-99	00:10	235.8	231.6	1159.2	1010.4	151.7	-0.92
102	02-03-99	00:20	238.2	234.0	1161.5	1010.3	154.1	-0.90
103	02-03-99	00:30	240.7	236.4	1163.9	1010.2	156.7	-0.87
104	02-03-99	00:40	243.6	239.3	1166.7	1010.1	159.6	-0.84
105	02-03-99	00:50	250.0	245.6	1172.9	1010.0	166.0	-0.78
106	02-03-99	01:00	250.5	246.1	1173.3	1009.9	166.6	-0.77
107	02-03-99	01:10	251.0	246.6	1173.8	1009.8	167.2	-0.77
108	02-03-99	01:20	254.9	250.4	1177.6	1009.7	171.1	-0.73
109	02-03-99	01:30	253.9	249.4	1176.6	1009.6	170.3	-0.74
110	02-03-99	01:40	253.4	248.9	1176.1	1009.5	169.9	-0.74
111	02-03-99	01:50	249.0	244.6	1171.9	1009.4	165.6	-0.78
112	02-03-99	02:00	250.5	246.1	1173.3	1009.3	167.2	-0.77
113	02-03-99	02:10	246.6	242.2	1169.6	1009.2	163.5	-0.81
114	02-03-99	02:20	241.7	237.4	1164.9	1009.1	158.8	-0.85
115	02-03-99	02:30	236.8	232.6	1160.1	1009.3	153.8	-0.90
116	02-03-99	02:40	229.4	225.3	1153.0	1009.0	146.8	-0.97
117	02-03-99	02:50	222.1	218.2	1146.0	1009.0	139.6	-1.04
118	02-03-99	03:00	215.2	211.4	1139.3	1009.1	132.8	-1.11
119	02-03-99	03:10	204.4	200.8	1128.9	1009.0	122.2	-1.22
120	02-03-99	03:20	200.0	196.5	1124.7	1009.0	117.9	-1.26
121	02-03-99	03:30	191.2	187.8	1116.2	1009.0	109.3	-1.35
122	02-03-99	03:40	178.4	175.2	1103.9	1009.0	96.7	-1.47
123	02-03-99	03:50	172.6	169.5	1098.3	1009.0	91.0	-1.53
124	02-03-99	04:00	162.7	159.8	1088.7	1009.0	81.3	-1.63

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
125	02-03-99	04:10	151.0	148.3	1077.5	1009.0	69.8	-1.74
126	02-03-99	04:20	139.7	137.2	1066.6	1009.0	58.7	-1.85
127	02-03-99	04:30	127.9	125.6	1055.2	1009.0	47.1	-1.97
128	02-03-99	04:40	119.1	117.0	1046.7	1009.0	38.5	-2.06
129	02-03-99	04:50	113.7	111.7	1041.5	1009.0	33.1	-2.11
130	02-03-99	05:00	107.8	105.9	1035.8	1009.0	27.4	-2.17
131	02-03-99	05:10	85.3	83.8	1014.1	1009.0	5.2	-2.39
132	02-03-99	05:20	76.5	76.5	1007.0	1009.0	-2.0	-2.46
133	02-03-99	05:30	76.5	76.5	1007.0	1009.0	-2.0	-2.46
134	02-03-99	05:40	76.5	76.5	1007.0	1010.0	-3.1	-2.47
135	02-03-99	05:50	77.5	77.5	1008.0	1009.0	-1.0	-2.45
136	02-03-99	06:00	77.5	77.5	1008.0	1010.0	-2.1	-2.46
137	02-03-99	06:10	77.5	77.5	1008.0	1010.0	-2.1	-2.46
138	02-03-99	06:20	77.5	77.5	1008.0	1010.0	-2.1	-2.46
139	02-03-99	06:30	77.5	77.5	1008.0	1010.0	-2.1	-2.46
140	02-03-99	06:40	77.5	77.5	1008.0	1010.0	-2.1	-2.46
141	02-03-99	06:50	77.5	77.5	1008.0	1010.0	-2.1	-2.46
142	02-03-99	07:00	77.5	77.5	1008.0	1010.0	-2.1	-2.46
143	02-03-99	07:10	77.5	77.5	1008.0	1010.0	-2.1	-2.46
144	02-03-99	07:20	77.9	77.9	1008.4	1010.0	-1.7	-2.46
145	02-03-99	07:30	78.4	78.4	1008.9	1010.0	-1.2	-2.45
146	02-03-99	07:40	78.4	78.4	1008.9	1010.0	-1.2	-2.45
147	02-03-99	07:50	77.5	77.5	1008.0	1010.0	-2.1	-2.46
148	02-03-99	08:00	77.9	77.9	1008.4	1010.0	-1.7	-2.46
149	02-03-99	08:10	78.4	78.4	1008.9	1011.0	-2.2	-2.46
150	02-03-99	08:20	78.4	78.4	1008.9	1011.0	-2.2	-2.46
151	02-03-99	08:30	78.4	78.4	1008.9	1011.0	-2.2	-2.46
152	02-03-99	08:40	78.4	78.4	1008.9	1011.0	-2.2	-2.46
153	02-03-99	08:50	78.4	78.4	1008.9	1011.0	-2.2	-2.46
154	02-03-99	09:00	78.4	78.4	1008.9	1011.0	-2.2	-2.46
155	02-03-99	09:10	78.4	78.4	1008.9	1011.0	-2.2	-2.46
156	02-03-99	09:20	78.4	78.4	1008.9	1011.0	-2.2	-2.46
157	02-03-99	09:30	78.4	78.4	1008.9	1011.0	-2.2	-2.46
158	02-03-99	09:40	78.4	78.4	1008.9	1011.0	-2.2	-2.46
159	02-03-99	09:50	78.4	78.4	1008.9	1011.0	-2.2	-2.46
160	02-03-99	10:00	78.4	78.4	1008.9	1011.0	-2.2	-2.46
161	02-03-99	10:10	78.4	78.4	1008.9	1011.0	-2.2	-2.46
162	02-03-99	10:20	78.4	78.4	1008.9	1011.0	-2.2	-2.46
163	02-03-99	10:30	78.4	78.4	1008.9	1011.0	-2.2	-2.46
164	02-03-99	10:40	77.9	77.9	1008.4	1011.0	-2.7	-2.47
165	02-03-99	10:50	77.5	77.5	1008.0	1011.0	-3.1	-2.47
166	02-03-99	11:00	81.9	80.5	1010.9	1011.0	-0.1	-2.44

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
167	02-03-99	11:10	91.7	90.1	1020.3	1010.0	10.5	-2.34
168	02-03-99	11:20	98.0	96.3	1026.4	1010.0	16.7	-2.27
169	02-03-99	11:30	103.9	102.1	1032.1	1010.0	22.5	-2.22
170	02-03-99	11:40	123.5	121.3	1051.0	1010.0	41.8	-2.02
171	02-03-99	11:50	138.7	136.2	1065.6	1010.0	56.7	-1.87
172	02-03-99	12:00	145.6	143.0	1072.3	1009.7	63.8	-1.80
173	02-03-99	12:10	156.4	153.6	1082.7	1010.0	74.1	-1.70
174	02-03-99	12:20	167.2	164.2	1093.1	1010.0	84.7	-1.59
175	02-03-99	12:30	171.6	168.6	1097.3	1010.0	89.0	-1.55
176	02-03-99	12:40	180.4	177.2	1105.8	1010.0	97.6	-1.46
177	02-03-99	12:50	192.2	188.8	1117.2	1010.0	109.2	-1.35
178	02-03-99	13:00	199.0	195.5	1123.7	1010.0	115.9	-1.28
179	02-03-99	13:10	203.4	199.8	1128.0	1010.0	120.2	-1.24
180	02-03-99	13:20	211.8	208.1	1136.1	1010.0	128.5	-1.16
181	02-03-99	13:30	218.6	214.7	1142.6	1010.0	135.2	-1.09
182	02-03-99	13:40	224.0	220.0	1147.8	1010.0	140.5	-1.04
183	02-03-99	13:50	229.4	225.3	1153.0	1010.0	145.8	-0.98
184	02-03-99	14:00	230.4	226.3	1154.0	1009.8	147.0	-0.97
185	02-03-99	14:10	232.8	228.7	1156.3	1009.0	150.1	-0.94
186	02-03-99	14:20	236.3	232.1	1159.7	1009.0	153.6	-0.91
187	02-03-99	14:30	239.2	235.0	1162.5	1009.0	156.4	-0.88
188	02-03-99	14:40	240.7	236.4	1163.9	1009.0	157.9	-0.86
189	02-03-99	14:50	240.7	236.4	1163.9	1009.0	157.9	-0.86
190	02-03-99	15:00	241.7	237.4	1164.9	1009.0	158.9	-0.85
191	02-03-99	15:10	240.7	236.4	1163.9	1009.0	157.9	-0.86
192	02-03-99	15:20	239.2	235.0	1162.5	1009.0	156.4	-0.88
193	02-03-99	15:30	237.3	233.1	1160.6	1009.0	154.6	-0.90
194	02-03-99	15:40	233.8	229.7	1157.3	1009.0	151.1	-0.93
195	02-03-99	15:50	232.8	228.7	1156.3	1009.0	150.1	-0.94
196	02-03-99	16:00	229.4	225.3	1153.0	1007.0	148.8	-0.95
197	02-03-99	16:10	222.6	218.7	1146.5	1007.0	142.2	-1.02
198	02-03-99	16:20	216.2	212.4	1140.3	1006.0	136.9	-1.07
199	02-03-99	16:30	209.8	206.1	1134.1	1006.0	130.6	-1.13
200	02-03-99	16:40	205.4	201.8	1129.9	1005.0	127.3	-1.17
201	02-03-99	16:50	74.0	74.0	1004.5	1006.5	-2.0	-2.46
202	02-03-99	17:00	74.0	74.0	1004.5	1005.0	-0.5	-2.45
203	02-03-99	17:10	73.0	73.0	1003.6	1006.0	-2.5	-2.47
204	02-03-99	17:20	75.5	75.5	1006.0	1006.5	-0.5	-2.45
205	02-03-99	17:30	76.5	76.5	1007.0	1006.5	0.5	-2.44
206	02-03-99	17:40	76.5	76.5	1007.0	1006.5	0.5	-2.44
207	02-03-99	17:50	77.0	77.0	1007.5	1006.5	1.0	-2.43
208	02-03-99	18:00	77.0	77.0	1007.5	1006.5	1.0	-2.43

- Fieldtrip 3

- ***Diver with inside water levels***

As told before the Diver outside the plot was stolen so only data of the inside Diver was available. The water levels were registered every minute but did not give any extra insight in the process due to the fluctuations of the air-pressure that had to be assumed. This appendix shows only the levels every 10 minutes. Figure 7 shows the diver readings followed by the analysis, table 6, of the measurements.

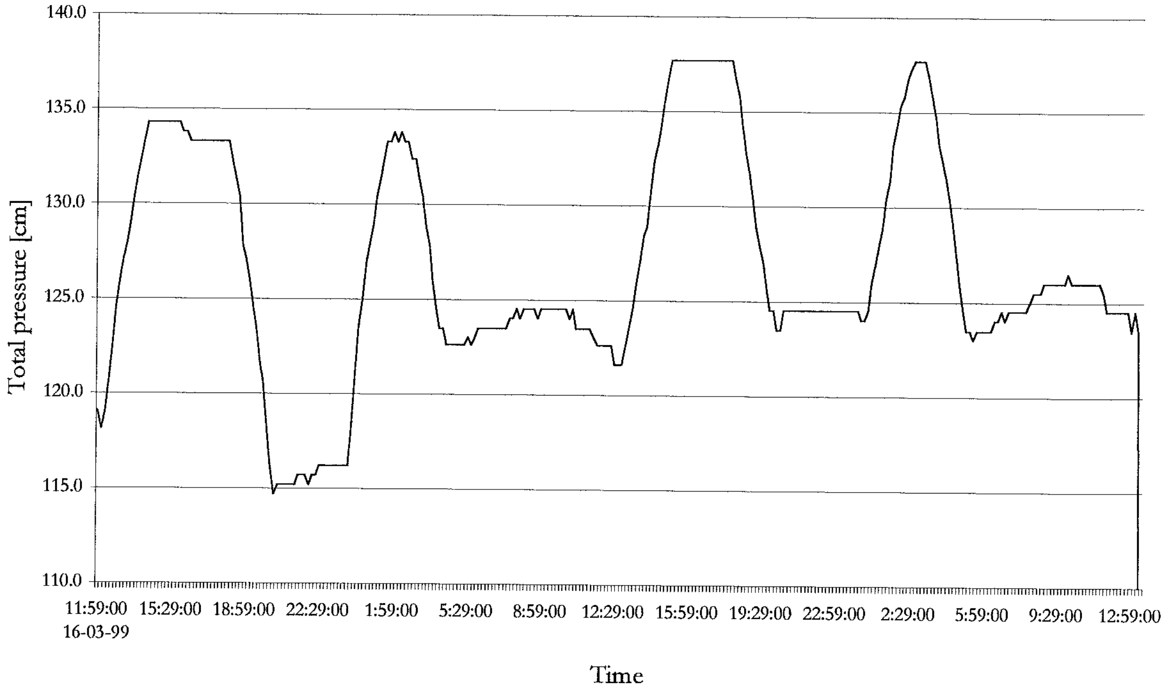


Figure 7: Diver readings outside, fieldtrip 3

Table 6: Inside water level analysis, fieldtrip 3

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water level [m]
1770	16-03-99	11:59	119.1	117.0	1046.7	1007.5	40.0	-1.26
1780	16-03-99	12:09	118.1	116.0	1045.8	1007.0	39.5	-1.27
1790	16-03-99	12:19	119.1	117.0	1046.7	1006.5	41.0	-1.25
1800	16-03-99	12:29	120.6	118.5	1048.2	1006.0	43.0	-1.23
1810	16-03-99	12:39	122.6	120.4	1050.1	1005.5	45.5	-1.21
1820	16-03-99	12:49	124.5	122.3	1051.9	1005.0	47.8	-1.18
1830	16-03-99	12:59	126.0	123.8	1053.4	1004.5	49.8	-1.16
1840	16-03-99	13:09	127.0	124.8	1054.3	1004.0	51.3	-1.15
1850	16-03-99	13:19	127.9	125.6	1055.2	1003.5	52.7	-1.13
1860	16-03-99	13:29	128.9	126.6	1056.2	1003.0	54.2	-1.12
1870	16-03-99	13:39	130.4	128.1	1057.6	1002.5	56.2	-1.10
1880	16-03-99	13:49	131.4	129.1	1058.6	1002.0	57.7	-1.08
1890	16-03-99	13:59	132.4	130.1	1059.5	1001.5	59.2	-1.07
1900	16-03-99	14:09	133.3	130.9	1060.4	1001.0	60.6	-1.05

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
1910	16-03-99	14:19	134.3	131.9	1061.4	1001.0	61.5	-1.05
1920	16-03-99	14:29	134.3	131.9	1061.4	1001.0	61.5	-1.05
1930	16-03-99	14:39	134.3	131.9	1061.4	1001.0	61.5	-1.05
1940	16-03-99	14:49	134.3	131.9	1061.4	1001.0	61.5	-1.05
1950	16-03-99	14:59	134.3	131.9	1061.4	1001.0	61.5	-1.05
1960	16-03-99	15:09	134.3	131.9	1061.4	1001.0	61.5	-1.05
1970	16-03-99	15:19	134.3	131.9	1061.4	1001.0	61.5	-1.05
1980	16-03-99	15:29	134.3	131.9	1061.4	1001.0	61.5	-1.05
1990	16-03-99	15:39	134.3	131.9	1061.4	1001.0	61.5	-1.05
2000	16-03-99	15:49	134.3	131.9	1061.4	1001.0	61.5	-1.05
2010	16-03-99	15:59	133.8	131.4	1060.9	1001.0	61.0	-1.05
2020	16-03-99	16:09	133.8	131.4	1060.9	1001.0	61.0	-1.05
2030	16-03-99	16:19	133.3	130.9	1060.4	1001.0	60.6	-1.05
2040	16-03-99	16:29	133.3	130.9	1060.4	1001.0	60.6	-1.05
2050	16-03-99	16:39	133.3	130.9	1060.4	1001.0	60.6	-1.05
2060	16-03-99	16:49	133.3	130.9	1060.4	1001.0	60.6	-1.05
2070	16-03-99	16:59	133.3	130.9	1060.4	1001.0	60.6	-1.05
2080	16-03-99	17:09	133.3	130.9	1060.4	1001.0	60.6	-1.05
2090	16-03-99	17:19	133.3	130.9	1060.4	1001.0	60.6	-1.05
2100	16-03-99	17:29	133.3	130.9	1060.4	1001.0	60.6	-1.05
2110	16-03-99	17:39	133.3	130.9	1060.4	1001.0	60.6	-1.05
2120	16-03-99	17:49	133.3	130.9	1060.4	1001.0	60.6	-1.05
2130	16-03-99	17:59	133.3	130.9	1060.4	1001.0	60.6	-1.05
2140	16-03-99	18:09	133.3	130.9	1060.4	1001.0	60.6	-1.05
2150	16-03-99	18:19	132.4	130.1	1059.5	1001.2	59.5	-1.07
2160	16-03-99	18:29	131.4	129.1	1058.6	1001.4	58.3	-1.08
2170	16-03-99	18:39	130.4	128.1	1057.6	1001.6	57.1	-1.09
2180	16-03-99	18:49	127.9	125.6	1055.2	1001.6	54.6	-1.11
2190	16-03-99	18:59	127.0	124.8	1054.3	1001.6	53.8	-1.12
2200	16-03-99	19:09	126.0	123.8	1053.4	1001.8	52.6	-1.13
2210	16-03-99	19:19	124.5	122.3	1051.9	1002.0	50.9	-1.15
2220	16-03-99	19:29	123.5	121.3	1051.0	1002.2	49.7	-1.16
2230	16-03-99	19:39	121.6	119.4	1049.1	1002.4	47.6	-1.18
2240	16-03-99	19:49	120.6	118.5	1048.2	1002.6	46.4	-1.20
2250	16-03-99	19:59	118.1	116.0	1045.8	1002.8	43.8	-1.22
2260	16-03-99	20:09	116.2	114.1	1043.9	1003.0	41.7	-1.24
2270	16-03-99	20:19	114.7	112.7	1042.5	1004.0	39.2	-1.27
2280	16-03-99	20:29	115.2	113.2	1043.0	1004.0	39.7	-1.26
2290	16-03-99	20:39	115.2	113.2	1043.0	1004.0	39.7	-1.26
2300	16-03-99	20:49	115.2	113.2	1043.0	1004.0	39.7	-1.26
2310	16-03-99	20:59	115.2	113.2	1043.0	1004.0	39.7	-1.26
2320	16-03-99	21:09	115.2	113.2	1043.0	1004.0	39.7	-1.26

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
2330	16-03-99	21:19	115.2	113.2	1043.0	1004.0	39.7	-1.26
2340	16-03-99	21:29	115.7	113.7	1043.4	1004.0	40.2	-1.26
2350	16-03-99	21:39	115.7	113.7	1043.4	1004.0	40.2	-1.26
2360	16-03-99	21:49	115.7	113.7	1043.4	1004.0	40.2	-1.26
2370	16-03-99	21:59	115.2	113.2	1043.0	1004.0	39.7	-1.26
2380	16-03-99	22:09	115.7	113.7	1043.4	1004.0	40.2	-1.26
2390	16-03-99	22:19	115.7	113.7	1043.4	1004.0	40.2	-1.26
2400	16-03-99	22:29	116.2	114.1	1043.9	1005.0	39.7	-1.26
2410	16-03-99	22:39	116.2	114.1	1043.9	1005.0	39.7	-1.26
2420	16-03-99	22:49	116.2	114.1	1043.9	1005.0	39.7	-1.26
2430	16-03-99	22:59	116.2	114.1	1043.9	1005.0	39.7	-1.26
2440	16-03-99	23:09	116.2	114.1	1043.9	1005.0	39.7	-1.26
2450	16-03-99	23:19	116.2	114.1	1043.9	1005.0	39.7	-1.26
2460	16-03-99	23:29	116.2	114.1	1043.9	1005.0	39.7	-1.26
2470	16-03-99	23:39	116.2	114.1	1043.9	1005.0	39.7	-1.26
2480	16-03-99	23:49	116.2	114.1	1043.9	1005.0	39.7	-1.26
2490	16-03-99	23:59	118.1	116.0	1045.8	1004.6	42.0	-1.24
2500	17-03-99	00:09	121.1	119.0	1048.6	1004.2	45.3	-1.21
2510	17-03-99	00:19	123.5	121.3	1051.0	1003.8	48.1	-1.18
2520	17-03-99	00:29	125.0	122.8	1052.4	1003.4	50.0	-1.16
2530	17-03-99	00:39	127.0	124.8	1054.3	1003.0	52.3	-1.14
2540	17-03-99	00:49	127.9	125.6	1055.2	1002.6	53.6	-1.12
2550	17-03-99	00:59	128.9	126.6	1056.2	1002.2	55.0	-1.11
2560	17-03-99	01:09	130.4	128.1	1057.6	1001.8	56.9	-1.09
2570	17-03-99	01:19	131.4	129.1	1058.6	1001.4	58.3	-1.08
2580	17-03-99	01:29	132.4	130.1	1059.5	1001.0	59.7	-1.06
2590	17-03-99	01:39	133.3	130.9	1060.4	1001.0	60.6	-1.05
2600	17-03-99	01:49	133.3	130.9	1060.4	1001.0	60.6	-1.05
2610	17-03-99	01:59	133.8	131.4	1060.9	1001.0	61.0	-1.05
2620	17-03-99	02:09	133.3	130.9	1060.4	1001.0	60.6	-1.05
2630	17-03-99	02:19	133.8	131.4	1060.9	1001.0	61.0	-1.05
2640	17-03-99	02:29	133.3	130.9	1060.4	1001.0	60.6	-1.05
2650	17-03-99	02:39	133.3	130.9	1060.4	1001.0	60.6	-1.05
2660	17-03-99	02:49	132.4	130.1	1059.5	1002.0	58.7	-1.07
2670	17-03-99	02:59	132.4	130.1	1059.5	1003.0	57.6	-1.08
2680	17-03-99	03:09	131.4	129.1	1058.6	1003.0	56.7	-1.09
2690	17-03-99	03:19	130.4	128.1	1057.6	1003.0	55.7	-1.10
2700	17-03-99	03:29	128.9	126.6	1056.2	1003.0	54.2	-1.12
2710	17-03-99	03:39	127.9	125.6	1055.2	1003.0	53.2	-1.13
2720	17-03-99	03:49	126.0	123.8	1053.4	1003.0	51.3	-1.15
2730	17-03-99	03:59	124.5	122.3	1051.9	1003.0	49.9	-1.16
2740	17-03-99	04:09	123.5	121.3	1051.0	1003.0	48.9	-1.17

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
2750	17-03-99	04:19	123.5	121.3	1051.0	1003.0	48.9	-1.17
2760	17-03-99	04:29	122.6	120.4	1050.1	1003.0	48.0	-1.18
2770	17-03-99	04:39	122.6	120.4	1050.1	1003.0	48.0	-1.18
2780	17-03-99	04:49	122.6	120.4	1050.1	1003.0	48.0	-1.18
2790	17-03-99	04:59	122.6	120.4	1050.1	1003.0	48.0	-1.18
2800	17-03-99	05:09	122.6	120.4	1050.1	1003.0	48.0	-1.18
2810	17-03-99	05:19	122.6	120.4	1050.1	1003.0	48.0	-1.18
2820	17-03-99	05:29	123.0	120.8	1050.5	1003.5	47.9	-1.18
2830	17-03-99	05:39	122.6	120.4	1050.1	1003.0	48.0	-1.18
2840	17-03-99	05:49	123.0	120.8	1050.5	1003.5	47.9	-1.18
2850	17-03-99	05:59	123.5	121.3	1051.0	1004.0	47.9	-1.18
2860	17-03-99	06:09	123.5	121.3	1051.0	1004.0	47.9	-1.18
2870	17-03-99	06:19	123.5	121.3	1051.0	1004.0	47.9	-1.18
2880	17-03-99	06:29	123.5	121.3	1051.0	1004.0	47.9	-1.18
2890	17-03-99	06:39	123.5	121.3	1051.0	1004.0	47.9	-1.18
2900	17-03-99	06:49	123.5	121.3	1051.0	1004.0	47.9	-1.18
2910	17-03-99	06:59	123.5	121.3	1051.0	1004.0	47.9	-1.18
2920	17-03-99	07:09	123.5	121.3	1051.0	1004.0	47.9	-1.18
2930	17-03-99	07:19	123.5	121.3	1051.0	1004.0	47.9	-1.18
2940	17-03-99	07:29	124.0	121.8	1051.4	1004.0	48.4	-1.18
2950	17-03-99	07:39	124.0	121.8	1051.4	1004.0	48.4	-1.18
2960	17-03-99	07:49	124.5	122.3	1051.9	1005.0	47.8	-1.18
2970	17-03-99	07:59	124.0	121.8	1051.4	1004.5	47.9	-1.18
2980	17-03-99	08:09	124.5	122.3	1051.9	1005.0	47.8	-1.18
2990	17-03-99	08:19	124.5	122.3	1051.9	1005.0	47.8	-1.18
3000	17-03-99	08:29	124.5	122.3	1051.9	1005.0	47.8	-1.18
3010	17-03-99	08:39	124.5	122.3	1051.9	1005.0	47.8	-1.18
3020	17-03-99	08:49	124.0	121.8	1051.4	1004.5	47.9	-1.18
3030	17-03-99	08:59	124.5	122.3	1051.9	1005.0	47.8	-1.18
3040	17-03-99	09:09	124.5	122.3	1051.9	1005.0	47.8	-1.18
3050	17-03-99	09:19	124.5	122.3	1051.9	1005.0	47.8	-1.18
3060	17-03-99	09:29	124.5	122.3	1051.9	1005.0	47.8	-1.18
3070	17-03-99	09:39	124.5	122.3	1051.9	1005.0	47.8	-1.18
3080	17-03-99	09:49	124.5	122.3	1051.9	1004.5	48.3	-1.18
3090	17-03-99	09:59	124.5	122.3	1051.9	1004.5	48.3	-1.18
3100	17-03-99	10:09	124.5	122.3	1051.9	1004.5	48.3	-1.18
3110	17-03-99	10:19	124.0	121.8	1051.4	1004.5	47.9	-1.18
3120	17-03-99	10:29	124.5	122.3	1051.9	1004.5	48.3	-1.18
3130	17-03-99	10:39	123.5	121.3	1051.0	1004.3	47.6	-1.18
3140	17-03-99	10:49	123.5	121.3	1051.0	1004.2	47.7	-1.18
3150	17-03-99	10:59	123.5	121.3	1051.0	1004.2	47.7	-1.18
3160	17-03-99	11:09	123.5	121.3	1051.0	1004.0	47.9	-1.18

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
3170	17-03-99	11:19	123.5	121.3	1051.0	1003.5	48.4	-1.18
3180	17-03-99	11:29	123.0	120.8	1050.5	1003.0	48.4	-1.18
3190	17-03-99	11:39	122.6	120.4	1050.1	1003.0	48.0	-1.18
3200	17-03-99	11:49	122.6	120.4	1050.1	1003.0	48.0	-1.18
3210	17-03-99	11:59	122.6	120.4	1050.1	1003.0	48.0	-1.18
3220	17-03-99	12:09	122.6	120.4	1050.1	1003.0	48.0	-1.18
3230	17-03-99	12:19	122.6	120.4	1050.1	1002.5	48.5	-1.18
3240	17-03-99	12:29	121.6	119.4	1049.1	1002.0	48.0	-1.18
3250	17-03-99	12:39	121.6	119.4	1049.1	1002.0	48.0	-1.18
3260	17-03-99	12:49	121.6	119.4	1049.1	1002.0	48.0	-1.18
3270	17-03-99	12:59	122.6	120.4	1050.1	1002.0	49.0	-1.17
3280	17-03-99	13:09	123.5	121.3	1051.0	1002.0	49.9	-1.16
3290	17-03-99	13:19	124.5	122.3	1051.9	1002.0	50.9	-1.15
3300	17-03-99	13:29	126.0	123.8	1053.4	1002.0	52.4	-1.14
3310	17-03-99	13:39	127.0	124.8	1054.3	1002.0	53.3	-1.13
3320	17-03-99	13:49	128.4	126.1	1055.7	1002.0	54.7	-1.11
3330	17-03-99	13:59	128.9	126.6	1056.2	1002.0	55.2	-1.11
3340	17-03-99	14:09	130.9	128.6	1058.1	1002.0	57.2	-1.09
3350	17-03-99	14:19	132.4	130.1	1059.5	1002.0	58.7	-1.07
3360	17-03-99	14:29	133.3	130.9	1060.4	1002.0	59.5	-1.07
3370	17-03-99	14:39	134.3	131.9	1061.4	1002.0	60.5	-1.06
3380	17-03-99	14:49	135.8	133.4	1062.8	1002.0	62.0	-1.04
3390	17-03-99	14:59	136.8	134.4	1063.8	1002.0	63.0	-1.03
3400	17-03-99	15:09	137.7	135.3	1064.6	1002.0	63.9	-1.02
3410	17-03-99	15:19	137.7	135.3	1064.6	1002.0	63.9	-1.02
3420	17-03-99	15:29	137.7	135.3	1064.6	1002.0	63.9	-1.02
3430	17-03-99	15:39	137.7	135.3	1064.6	1002.0	63.9	-1.02
3440	17-03-99	15:49	137.7	135.3	1064.6	1002.0	63.9	-1.02
3450	17-03-99	15:59	137.7	135.3	1064.6	1002.0	63.9	-1.02
3460	17-03-99	16:09	137.7	135.3	1064.6	1002.0	63.9	-1.02
3470	17-03-99	16:19	137.7	135.3	1064.6	1002.0	63.9	-1.02
3480	17-03-99	16:29	137.7	135.3	1064.6	1002.0	63.9	-1.02
3490	17-03-99	16:39	137.7	135.3	1064.6	1002.0	63.9	-1.02
3500	17-03-99	16:49	137.7	135.3	1064.6	1002.0	63.9	-1.02
3510	17-03-99	16:59	137.7	135.3	1064.6	1002.0	63.9	-1.02
3520	17-03-99	17:09	137.7	135.3	1064.6	1002.0	63.9	-1.02
3530	17-03-99	17:19	137.7	135.3	1064.6	1002.0	63.9	-1.02
3540	17-03-99	17:29	137.7	135.3	1064.6	1002.0	63.9	-1.02
3550	17-03-99	17:39	137.7	135.3	1064.6	1002.0	63.9	-1.02
3560	17-03-99	17:49	137.7	135.3	1064.6	1002.0	63.9	-1.02
3570	17-03-99	17:59	137.7	135.3	1064.6	1002.0	63.9	-1.02
3580	17-03-99	18:09	136.8	134.4	1063.8	1002.0	63.0	-1.03

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
3590	17-03-99	18:19	135.8	133.4	1062.8	1002.0	62.0	-1.04
3600	17-03-99	18:29	134.3	131.9	1061.4	1002.0	60.5	-1.06
3610	17-03-99	18:39	132.8	130.5	1059.9	1002.0	59.0	-1.07
3620	17-03-99	18:49	131.9	129.6	1059.1	1002.0	58.2	-1.08
3630	17-03-99	18:59	130.4	128.1	1057.6	1002.0	56.7	-1.09
3640	17-03-99	19:09	128.9	126.6	1056.2	1002.0	55.2	-1.11
3650	17-03-99	19:19	127.9	125.6	1055.2	1002.0	54.2	-1.12
3660	17-03-99	19:29	127.0	124.8	1054.3	1002.0	53.3	-1.13
3670	17-03-99	19:39	126.0	123.8	1053.4	1002.0	52.4	-1.14
3680	17-03-99	19:49	124.5	122.3	1051.9	1002.0	50.9	-1.15
3690	17-03-99	19:59	124.5	122.3	1051.9	1002.0	50.9	-1.15
3700	17-03-99	20:09	123.5	121.3	1051.0	1002.0	49.9	-1.16
3710	17-03-99	20:19	123.5	121.3	1051.0	1002.0	49.9	-1.16
3720	17-03-99	20:29	124.5	122.3	1051.9	1002.0	50.9	-1.15
3730	17-03-99	20:39	124.5	122.3	1051.9	1002.0	50.9	-1.15
3740	17-03-99	20:49	124.5	122.3	1051.9	1002.0	50.9	-1.15
3750	17-03-99	20:59	124.5	122.3	1051.9	1002.0	50.9	-1.15
3760	17-03-99	21:09	124.5	122.3	1051.9	1002.0	50.9	-1.15
3770	17-03-99	21:19	124.5	122.3	1051.9	1002.0	50.9	-1.15
3780	17-03-99	21:29	124.5	122.3	1051.9	1002.0	50.9	-1.15
3790	17-03-99	21:39	124.5	122.3	1051.9	1002.0	50.9	-1.15
3800	17-03-99	21:49	124.5	122.3	1051.9	1002.0	50.9	-1.15
3810	17-03-99	21:59	124.5	122.3	1051.9	1002.0	50.9	-1.15
3820	17-03-99	22:09	124.5	122.3	1051.9	1002.0	50.9	-1.15
3830	17-03-99	22:19	124.5	122.3	1051.9	1002.0	50.9	-1.15
3840	17-03-99	22:29	124.5	122.3	1051.9	1002.0	50.9	-1.15
3850	17-03-99	22:39	124.5	122.3	1051.9	1002.0	50.9	-1.15
3860	17-03-99	22:49	124.5	122.3	1051.9	1002.0	50.9	-1.15
3870	17-03-99	22:59	124.5	122.3	1051.9	1002.0	50.9	-1.15
3880	17-03-99	23:09	124.5	122.3	1051.9	1002.0	50.9	-1.15
3890	17-03-99	23:19	124.5	122.3	1051.9	1002.0	50.9	-1.15
3900	17-03-99	23:29	124.5	122.3	1051.9	1002.0	50.9	-1.15
3910	17-03-99	23:39	124.5	122.3	1051.9	1002.0	50.9	-1.15
3920	17-03-99	23:49	124.5	122.3	1051.9	1002.0	50.9	-1.15
3930	17-03-99	23:59	124.5	122.3	1051.9	1002.0	50.9	-1.15
3940	18-03-99	00:09	124.0	121.8	1051.4	1001.0	51.4	-1.15
3950	18-03-99	00:19	124.0	121.8	1051.4	1001.5	50.9	-1.15
3960	18-03-99	00:29	124.5	122.3	1051.9	1001.5	51.4	-1.15
3970	18-03-99	00:39	126.0	123.8	1053.4	1001.5	52.9	-1.13
3980	18-03-99	00:49	127.0	124.8	1054.3	1001.5	53.9	-1.12
3990	18-03-99	00:59	127.9	125.6	1055.2	1001.5	54.7	-1.11
4000	18-03-99	01:09	128.9	126.6	1056.2	1001.5	55.7	-1.10

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
4010	18-03-99	01:19	130.4	128.1	1057.6	1001.5	57.2	-1.09
4020	18-03-99	01:29	131.4	129.1	1058.6	1001.5	58.2	-1.08
4030	18-03-99	01:39	133.3	130.9	1060.4	1001.5	60.0	-1.06
4040	18-03-99	01:49	134.3	131.9	1061.4	1001.5	61.0	-1.05
4050	18-03-99	01:59	135.3	132.9	1062.3	1001.5	62.0	-1.04
4060	18-03-99	02:09	135.8	133.4	1062.8	1001.5	62.5	-1.04
4070	18-03-99	02:19	136.8	134.4	1063.8	1001.5	63.5	-1.03
4080	18-03-99	02:29	137.3	134.9	1064.3	1001.5	64.0	-1.02
4090	18-03-99	02:39	137.7	135.3	1064.6	1001.5	64.4	-1.02
4100	18-03-99	02:49	137.7	135.3	1064.6	1001.5	64.4	-1.02
4110	18-03-99	02:59	137.7	135.3	1064.6	1001.5	64.4	-1.02
4120	18-03-99	03:09	137.7	135.3	1064.6	1001.5	64.4	-1.02
4130	18-03-99	03:19	136.8	134.4	1063.8	1001.5	63.5	-1.03
4140	18-03-99	03:29	135.8	133.4	1062.8	1001.5	62.5	-1.04
4150	18-03-99	03:39	134.8	132.4	1061.9	1001.5	61.5	-1.05
4160	18-03-99	03:49	133.3	130.9	1060.4	1001.5	60.0	-1.06
4170	18-03-99	03:59	132.4	130.1	1059.5	1001.5	59.2	-1.07
4180	18-03-99	04:09	131.4	129.1	1058.6	1001.5	58.2	-1.08
4190	18-03-99	04:19	130.4	128.1	1057.6	1001.5	57.2	-1.09
4200	18-03-99	04:29	128.9	126.6	1056.2	1001.5	55.7	-1.10
4210	18-03-99	04:39	127.5	125.2	1054.8	1001.5	54.3	-1.12
4220	18-03-99	04:49	126.0	123.8	1053.4	1001.5	52.9	-1.13
4230	18-03-99	04:59	124.5	122.3	1051.9	1001.5	51.4	-1.15
4240	18-03-99	05:09	123.5	121.3	1051.0	1001.5	50.4	-1.16
4250	18-03-99	05:19	123.5	121.3	1051.0	1001.5	50.4	-1.16
4260	18-03-99	05:29	123.0	120.8	1050.5	1001.5	49.9	-1.16
4270	18-03-99	05:39	123.5	121.3	1051.0	1001.5	50.4	-1.16
4280	18-03-99	05:49	123.5	121.3	1051.0	1001.5	50.4	-1.16
4290	18-03-99	05:59	123.5	121.3	1051.0	1001.5	50.4	-1.16
4300	18-03-99	06:09	123.5	121.3	1051.0	1001.5	50.4	-1.16
4310	18-03-99	06:19	123.5	121.3	1051.0	1001.5	50.4	-1.16
4320	18-03-99	06:29	124.0	121.8	1051.4	1002.0	50.4	-1.16
4330	18-03-99	06:39	124.0	121.8	1051.4	1002.0	50.4	-1.16
4340	18-03-99	06:49	124.5	122.3	1051.9	1002.5	50.4	-1.16
4350	18-03-99	06:59	124.0	121.8	1051.4	1002.0	50.4	-1.16
4360	18-03-99	07:09	124.5	122.3	1051.9	1002.5	50.4	-1.16
4370	18-03-99	07:19	124.5	122.3	1051.9	1002.5	50.4	-1.16
4380	18-03-99	07:29	124.5	122.3	1051.9	1002.5	50.4	-1.16
4390	18-03-99	07:39	124.5	122.3	1051.9	1002.5	50.4	-1.16
4400	18-03-99	07:49	124.5	122.3	1051.9	1002.5	50.4	-1.16
4410	18-03-99	07:59	124.5	122.3	1051.9	1002.5	50.4	-1.16
4420	18-03-99	08:09	125.0	122.8	1052.4	1003.0	50.4	-1.16

No.	Date	Time	Total Pressure [cm]	Corrected Pressure [cm]	Total Pressure [mbar]	Air Pressure [mbar]	Water column [cm]	Water Level [m]
4430	18-03-99	08:19	125.5	123.3	1052.9	1003.5	50.3	-1.16
4440	18-03-99	08:29	125.5	123.3	1052.9	1003.5	50.3	-1.16
4450	18-03-99	08:39	125.5	123.3	1052.9	1003.5	50.3	-1.16
4460	18-03-99	08:49	126.0	123.8	1053.4	1004.0	50.3	-1.16
4470	18-03-99	08:59	126.0	123.8	1053.4	1004.0	50.3	-1.16
4480	18-03-99	09:09	126.0	123.8	1053.4	1004.0	50.3	-1.16
4490	18-03-99	09:19	126.0	123.8	1053.4	1004.0	50.3	-1.16
4500	18-03-99	09:29	126.0	123.8	1053.4	1004.0	50.3	-1.16
4510	18-03-99	09:39	126.0	123.8	1053.4	1004.0	50.3	-1.16
4520	18-03-99	09:49	126.0	123.8	1053.4	1004.0	50.3	-1.16
4530	18-03-99	09:59	126.5	124.3	1053.9	1004.5	50.3	-1.16
4540	18-03-99	10:09	126.0	123.8	1053.4	1004.0	50.3	-1.16
4550	18-03-99	10:19	126.0	123.8	1053.4	1004.0	50.3	-1.16
4560	18-03-99	10:29	126.0	123.8	1053.4	1004.0	50.3	-1.16
4570	18-03-99	10:39	126.0	123.8	1053.4	1004.0	50.3	-1.16
4580	18-03-99	10:49	126.0	123.8	1053.4	1004.0	50.3	-1.16
4590	18-03-99	10:59	126.0	123.8	1053.4	1004.0	50.3	-1.16
4600	18-03-99	11:09	126.0	123.8	1053.4	1004.0	50.3	-1.16
4610	18-03-99	11:19	126.0	123.8	1053.4	1004.0	50.3	-1.16
4620	18-03-99	11:29	126.0	123.8	1053.4	1004.0	50.3	-1.16
4630	18-03-99	11:39	125.5	123.3	1052.9	1004.0	49.8	-1.16
4640	18-03-99	11:49	124.5	122.3	1051.9	1003.0	49.9	-1.16
4650	18-03-99	11:59	124.5	122.3	1051.9	1003.0	49.9	-1.16
4660	18-03-99	12:09	124.5	122.3	1051.9	1003.0	49.9	-1.16
4670	18-03-99	12:19	124.5	122.3	1051.9	1003.0	49.9	-1.16
4680	18-03-99	12:29	124.5	122.3	1051.9	1003.0	49.9	-1.16
4690	18-03-99	12:39	124.5	122.3	1051.9	1003.0	49.9	-1.16
4700	18-03-99	12:49	124.5	122.3	1051.9	1003.0	49.9	-1.16
4710	18-03-99	12:59	123.5	121.3	1051.0	1002.0	49.9	-1.16
4720	18-03-99	13:09	124.5	122.3	1051.9	1003.0	49.9	-1.16
4730	18-03-99	13:19	123.5	121.3	1051.0	1002.0	49.9	-1.16
4740	18-03-99	13:29	74.5	74.5	1005.0	1005.0	0.0	-1.66

C.5 Other readings

These readings were also used for the analysis. The water levels from the gauges were used to link the Diver-data with the reference level. The barometer readings should be used to calculate the water levels from the Diver-data, but the barometer was not reliable. Still they will be shown in this appendix. The data for fieldtrip 2 and 3 will be combined here.

- Water levels inside

The water level readings from the gauge inside the pond are shown in table 7.

Table 7: Water levels readings inside

Date	Time	Reading [m]	Level [m]	Date	Time	Reading [m]	Level [m]
01-03-99	12:10	0.54	-1.16	02-03-99	14:04	0.54	-1.16
	14:26	0.61	-1.09		14:28	0.58	-1.12
	16:25	0.65	-1.05		14:39	0.59	-1.11
	16:36	0.65	-1.05	16-03-99	12:17	0.48	-1.22
	17:40	0.65	-1.05		13:43	0.59-0.60	....
	19:15	0.57	-1.13		15:30	0.65	-1.05
	20:41	0.41	-1.29		17:47	0.65	-1.05
	22:33	0.41	-1.29	17-03-99	09:07	0.52	-1.18
02-03-99	00:40	0.59-0.60	....		11:07	0.52	-1.18
	05:00	0.60	-1.10	18-03-99	09:01	0.54	-1.16
	09:51	0.57	-1.13		10:45	0.54	-1.16
	13:54	0.53	-1.17				

- The water levels outside near sluice A

The water level readings near sluice A from the inside gauge are shown in table 8.

Table 8: Water levels outside near sluice A

Date	Time	Reading [m]	Level [m]	Date	Time	Reading [m]	Level [m]
01-03-99	12:06	0.20	-1.50	02-03-99	13:59	0.77	-0.94
	14:28	0.77	-0.93		14:30	0.85	-0.85
	16:27	0.34	-1.36		14:38	0.87	-0.83
	17:12	0.07	-1.63	16-03-99	13:41	0.84	-0.86
	17:43	-0.15	-1.85*1		15:28	0.54	-1.16
	19:11	-0.15	-1.85*1		17:48	-0.15	-1.85*1
	22:35	0.26	-1.44	17-03-99	09:05	-1.00	-2.70*2
02-03-99	13:54	0.74	-0.96		11:08	-0.25	-1.95*3

*1 : Assumption because water level below lowest value on gauge.
*2 : Assumption, level about 1.1 m under the number 1 on the gauge.
*3 : Assumption, level about 0.35 m under the number 1 on the gauge.

- The outside water levels near sluice B

The outside water level readings of the gauge near sluice B are shown in table 9.

Table 9: Outside water levels near sluice B

Date	Time	Reading [m]	Level [m]	Date	Time	Reading [m]	Level [m]
01-03-99	13:19	0.52	-1.14	02-03-99	13:00	0.41	-1.25
	13:48	0.58	-1.08		13:01	0.28	-1.38
	14:42	0.67	-0.99		13:43	0.58	-1.08
	15:10	0.65	-1.01		13:45	0.53	-1.13
	16:16	0.36	-1.30		14:48	0.65	-1.01
	16:39	0.22	-1.44		15:03	0.69	-0.97
	17:31	-0.11	-1.77	16-03-99	16:14	0.23	-1.43

Date	Time	Reading [m]	Level [m]	Date	Time	Reading [m]	Level [m]
01-03-99	19:37	0.30	-1.36	16-03-99	16:36	0.09	-1.57
	22:15	0.04	-1.62		17:39	-0.06	-1.72
02-03-99	00:16	0.61	-1.05	17-03-99	11:30	0.05	-1.61
	12:45	0.35	-1.31		11:45	0.1	-1.56
	12:54	0.41	-1.25		12:10	0.15	-1.51
	12:57	0.43	-1.23		13:53	0.64-0.66	....
	12:59	0.35	-1.31				

- The barometer readings

The barometer readings are shown in table 10.

Table 10: The barometer readings

Date	Time	Reading [mbar]	Date	Time	Reading [mbar]
01-03-99	07:30	1011.0	15-03-99	13:23	999.0
	09:26	1010.0		16:50	1001.0
	12:23	1003.0		22:26	1004.0
	13:45	1003.0	16-03-99	06:30	1006.0
	14:15	1004.0		08:24	1005.9
	15:05	1004.5		11:35	1003.0
	16:15	1005.0		16:47	1001.0
	17:00	1005.5		17:38	1002.0
	17:55	1004.0	17-03-99	09:18	1003.0
	20:10	1008.5		09:26	1005.0
	20:15	1008.5		09:45	1004.5
	22:06	1009.1		10:00	1004.5
02-03-99	02:33	1009.3	17-03-99	10:15	1004.5
	03:00	1009.1		10:30	1004.5
	08:07	1009.0		10:45	1004.5
	09:14	1009.0		11:00	1004.2
	10:36	1009.0		11:15	1004.2
	12:10	1009.0		11:30	1004.0
	12:49	1007.0		11:45	1003.9
	13:30	1006.0		12:00	1003.0
	15:26	1005.0		12:15	1002.9
	15:53	1005.0		12:30	1002.0
	16:39	1005.2		14:46	999.5
15-03-99	10:00	1003.0		15:26	1000.0
	10:41	1003.0		18:43	1002.0
	11:41	999.5	18-03-99	06:30	1003.0
	12:19	1000.5		07:36	1004.0

C.6 Water quality measurements

The same water quality measurements were done during fieldtrip two and three and will be discussed here together. The results of the water quality analysis are discussed here.

- The dissolved oxygen (DO)

These measurements are shown in table 11.

Table 11: Measurements DO-concentration

Date	Time	Position	$DO_{surface}$ [g/m^3]	DO_{bottom} [g/m^3]	$DO_{average}$ [g/m^3]
01-03-99	17:45	x1	5.9	5.8	5.9
01-03-99	23:51	x1	5.0	4.8	4.9
02-03-99	03:46	x1	6.3	6.3	6.3
02-03-99	11:44	x1	5.7	5.6	5.6
16-03-99	14:40	x1	6.5	6.3	6.4
18-03-99	09:39	x1	5.5	5.0	5.3
01-03-99	15:02	x2'	5.6	5.1	5.4
01-03-99	23:32	x2'	4.3	4.3	4.3
02-03-99	04:08	x2'	4.1	3.9	4.0
02-03-99	11:16	x2'	4.0	3.9	3.9
16-03-99	15:00	x2'	6.5	6.3	6.4
18-03-99	10:00	x2'	4.6	4.6	4.6
01-03-99	15:40	x3	6.2	4.8	5.4
01-03-99	23:19	x3	4.3	3.8	4.1
02-03-99	04:24	x3	4.9	5.4	5.2
02-03-99	10:50	x3	5.1	4.3	4.7
16-03-99	15:18	x3	6.7	5.9	6.3
18-03-99	10:15	x3	4.8	3.6	4.2
01-03-99	16:11	x4	6.0	5.9	5.9
01-03-99	23:01	x4	5.1	4.6	4.9
02-03-99	04:41	x4	4.7	5.7	5.2
02-03-99	10:16	x4	5.0	4.7	4.8
16-03-99	15:35	x4	6.7	6.6	6.7
18-03-99	10:27	x4	5.1	5.1	5.1

Sluice A			
Date	**Time**	**$DO_{surface}$ [g/m^3]**	**Direction**
02-03-99	04:56	5.5	Outlet
02-03-99	14:18	6.6	Inlet
16-03-99	12:45	6.6	Inlet
16-03-99	18:55	6.2	Outlet
17-03-99	14:05	6.4	Inlet
18-03-99	13:30	7.1	Inlet

Sluice B			
Date	**Time**	**$DO_{surface}$ [g/m^3]**	**Direction**
01-03-99	18:20	5.4	Outlet
02-03-99	13:52	6.5	Inlet
02-03-99	14:18	6.7	Inlet
16-03-99	13:35	6.6	Inlet
16-03-99	18:25	6.5	Outlet
17-03-99	13:40	6.5	Inlet

- Temperature

Table 12 shows the readings of the temperature.

Table 12: Temperature readings

Date	Time	Position	temp. [°C]	Date	Time	Position	temp. [°C]
01-03-99	17:42	x1	28.3	01-03-99	15:37	x3	28.9
01-03-99	23:49	x1	27.1	01-03-99	23:18	x3	27.0
02-03-99	03:42	x1	26.2	02-03-99	04:22	x3	25.9
02-03-99	11:42	x1	27.5	02-03-99	10:47	x3	27.6
16-03-99	14:40	x1	30.8	16-03-99	15:18	x3	31.0
18-03-99	09:39	x1	29.0	18-03-99	10:15	x3	30.8
01-03-99	14:57	x2'	29.50	01-03-99	16:08	x4	28.9
01-03-99	23:30	x2'	26.70	01-03-99	22:57	x4	27.5
02-03-99	04:06	x2'	25.80	02-03-99	04:37	x4	26.2
02-03-99	11:15	x2'	28.10	02-03-99	10:13	x4	26.7
16-03-99	15:00	x2'	31.30	16-03-99	15:35	x4	30.8
18-03-99	10:00	x2'	29.40	18-03-99	10:27	x4	29.6

Sluice A				Sluice B			
Date	**Time**	**temp. [°C]**	**Direction**	**Date**	**Time**	**temp. [°C]**	**Direction**
02-03-99	04:56	26.0	Outlet	01-03-19	18:20	28.2	Outlet
02-03-99	14:18	28.0	Inlet	02-03-19	13:52	28.5	Inlet
16-03-99	12:45	30.1	Inlet	16-03-19	13:35	30.0	Inlet
16-03-99	18:55	29.7	Outlet	16-03-19	18:25	29.9	Outlet
17-03-99	14:05	30.1	Inlet	17-03-19	13:40	30.5	Inlet
18-03-99	13:30	30.1	Inlet				

- The salinity

The results of the measurements are shown in table 13.

Table 13: Measurements salinity

Date	Time	Position	Sal. [‰]	Date	Time	Position	Sal. [‰]
01-03-99	17:43	x1	29.0	01-03-99	15:38	x3	26.5
01-03-99	23:49	x1	31.0	01-03-99	23:19	x3	31.0
02-03-99	03:43	x1	32.0	02-03-99	04:23	x3	32.0
02-03-99	11:42	x1	29.0	02-03-99	10:48	x3	29.0
16-03-99	14:40	x1	22.0	16-03-99	15:18	x3	24.5
18-03-99	09:39	x1	26.0	18-03-99	10:15	x3	26.5
01-03-99	14:58	x2'	26.0	01-03-99	16:09	x4	28.0
01-03-99	23:32	x2'	31.0	01-03-99	22:59	x4	31.0
02-03-99	04:07	x2'	32.0	02-03-99	04:38	x4	32.0
02-03-99	11:15	x2'	29.5	02-03-99	10:14	x4	28.0
16-03-99	15:00	x2'	24.0	16-03-99	15:35	x4	25.5
18-03-99	10:00	x2'	26.0	18-03-99	10:27	x4	26.0

Sluice A				**Sluice B**			
Date	**Time**	**Sal. [‰]**	**Direction**	**Date**	**Time**	**Sal. [‰]**	**Direction**
01-03-99	17:00	27.0	Outlet (1h)	01-03-99	18:20	30.0	Outlet
01-03-99	22:43	30.0	Inlet (0.5 h)	01-03-99	22:20	30.0	Inlet (1h)
02-03-99	14:18	27.0	Inlet	02-03-99	12:47	29.5	Inlet (1h)
16-03-99	12:45	25.0	Inlet	02-03-99	13:52	27.0	Inlet
16-03-99	18:55	26.5	Outlet	16-03-99	13:35	21.0	Inlet
17-03-99	14:05	25.0	Inlet	16-03-99	18:25	26.5	Outlet
				17-03-99	13:40	25.0	Inlet

- The pH

The results of the pH measurements are shown in table 14.

Table 14: pH measurements

Date	Time	Position	pH [-]	Date	Time	Position	pH [-]
01-03-99	17:42	x1	8.00	01-03-99	15:36	x3	8.06
01-03-99	23:49	x1	7.73	01-03-99	23:17	x3	7.65
02-03-99	03:42	x1	8.13	02-03-99	04:22	x3	7.81
02-03-99	11:42	x1	7.92	02-03-99	10:47	x3	7.69
16-03-99	14:40	x1	8.15	16-03-99	15:18	x3	8.15
18-03-99	09:39	x1	7.79	18-03-99	10:15	x3	8.12
01-03-99	14:55	x2'	7.79	01-03-99	16:07	x4	7.94
01-03-99	23:30	x2'	7.60	01-03-99	22:57	x4	7.75
02-03-99	04:05	x2'	7.62	02-03-99	04:37	x4	7.85
02-03-99	11:15	x2'	7.55	02-03-99	10:13	x4	7.63
16-03-99	15:00	x2'	8.02	16-03-99	15:35	x4	8.12
18-03-99	10:00	x2'	7.41	18-03-99	10:27	x4	7.62

Sluice A			
Date	Time	pH [-]	Direction
02-03-99	04:56	7.97	Outlet
02-03-99	14:18	8.11	Inlet
16-03-99	12:45	8.06	Inlet
16-03-99	18:55	8.10	Outlet
17-03-99	14:05	8.16	Inlet
18-03-99	13:30	7.98	Inlet

Sluice B			
Date	Time	pH [-]	Direction
01-03-99	18:20	7.84	Outlet
02-03-99	13:52	8.08	Inlet
16-03-99	13:35	8.12	Inlet
16-03-99	18:25	8.11	Outlet
17-03-99	13:40	8.12	Inlet

- Biological oxygen demand (BOD)

From the samples taken during the fieldtrips, the biological oxygen demand was calculated. The results are shown here, table 15.

Table 15: Results of BOD^5_{20} analysis

Date	Time	Position	BOD^5_{20} [g/m³]
01-03-1999	17:54	x1	2.3
02-03-1999	11:50	x1	1.4
01-03-1999	15:11	x2'	4.5
02-03-1999	11:25	x2'	0.9

Date	Time	Position	BOD^5_{20} [g/m³]
01-03-99	15:50	x3	2.4
02-03-99	11:00	x3	2.1
01-03-99	16:18	x4	6.0
02-03-99	10:30	x4	2.0

Sluice A			
Date	Time	BOD^5_{20} [g/m³]	Direction
01-03-1999	17:00	5.3	Outlet (1h)
02-03-1999	14:18	3.6	Inlet
16-03-1999	12:45	6.1	Inlet
17-03-1999	14:05	5.2	Inlet
18-03-1999	13:30	5.8	Inlet

Sluice B			
Date	Time	BOD^5_{20} [g/m³]	Direction
01-03-99	18:20	7.7	Outlet
02-03-99	13:52	2.4	Inlet
16-03-99	13:35	5.0	Inlet
17-03-99	13:40	4.3	Inlet

- The suspended solids (SS)

The results of the suspended solids (SS) analysis are shown in table 16.

Table 16: Results of SS-analysis

Date	Time	Position	SS [g/m³]
01-03-99	17:45	x1	52.3
02-03-99	11:50	x1	142.0
16-03-99	14:45	x1	164.7
18-03-99	09:40	x1	40.0
01-03-99	15:20	x2'	203.0
02-03-99	11:25	x2'	61.7
16-03-99	15:05	x2'	72.7
18-03-99	10:00	x2'	33.3

Date	Time	Position	SS [g/m³]
01-03-99	15:54	x3	102.3
02-03-99	11:00	x3	74.7
16-03-99	15:22	x3	94.3
18-03-99	10:15	x3	57.3
01-03-99	16:20	x4	62.3
02-03-99	10:32	x4	74.7
16-03-99	15:38	x4	73.3
18-03-99	10:30	x4	54.0

Sluice A				Sluice B			
Date	**Time**	**SS [g/m^3]**	**Direction**	**Date**	**Time**	**SS [g/m^3]**	**Direction**
01-03-99	17:00	153.7	Outlet (1h)	01-03-99	18:20	73.0	Outlet
02-03-99	14:18	400.7	Inlet	02-03-99	12:47	63.7	Inlet (1h)
16-03-99	12:45	289.0	Inlet	02-03-99	13:52	327.7	Inlet
16-03-99	18:55	146.3	Outlet	16-03-99	13:10	302.0	Inlet
17-03-99	14:05	80.0	Inlet	16-03-99	18:25	80.0	Outlet
18-03-99	13:30	90.0	Inlet	17-03-99	13:40	204.0	Inlet

- Hydrogen sulfide (H_2S)

During fieldtrip 3 a few measurements were done. These measurements, see table 17, were done in the outer channels near the sluices.

Table 17: Results of H_2S analysis

Sluice A	
Measurement	**H_2S [g/m^3]**
1	0.62
2	0.03
Average	**0.32**

Sluice B	
Measurement	**H_2S [g/m^3]**
1	0.09
2	0.05
3	0.11
Average	**0.08**

- Ammonium

The results of the ammonium (NH_4^+) are shown in table 18.

Table 18: Results of NH_4^+ analysis

Sluice A	
Measurement	**NH_4^+ [g/m^3]**
1	0.010
2	0.000
3	0.000
4	0.016
Average	**0.007**

Sluice B	
Measurement	**NH_4^+ [g/m^3]**
1	0.013
2	0.019
3	0.000
Average	**0.011**

- Organic material (C)

Three different experiments were done to estimate the organic material. The results of these experiments will be shown here.

Leaffall:

Four baskets were used but two of them were stolen, and thus only the results of two baskets are shown in table 19.

Table 19: Organic material of leaf fall

Basket	Measurement 1 [g-C/m^2·day]	Measurement 2 [g-C/m^2·day]	Measurement 3 [g-C/m^2·day]
Basket 1	2.55	2.67	1.78
Basket 2	1.75	1.37	-

The average value is 2.03 g-C/ m^2·day.

Top-layer sediment:
At each sample point (x1-x4), three ground samples were taken, one in the forest, one at the border of the forest and one in the channel. The **average** results are shown in table 20.

Table 20: Organic material from sediment layer

Sediment depth [cm]	Forest [g-C/m^2·day]	Border forest [g-C/m^2·day]	Channel [g-C/m^2·day]
0 – 5	0.099	0.085	0.085
10 – 15	0.086	0.063	0.071
20 – 25	0.078	0.073	0.064

Sedimentation:
A problem with his experiment was that crabs were found in some sediment-traps and ate the sediment. These sediment-traps were neglected.
In table 21 the average results of the analysis are shown.

Table 21: Average values sedimentation organic material

Sample point	Volume sedimentation [ml/day·m^2]	Organic content [g/g]	Sedimentation [g-C/m^2·day]
x1	130.0	0.08	4.01
x2	126.4	0.13	8.37
x3	93.5	0.090	3.26
x4	104.0	0.11	4.92
Average	**113.5**	**0.101**	**5.14**

- Sediment oxygen demand (SOD)

The results of the SOD-calculations are shown in table 22.

Table 22: Results of $SOD_{T.P.}$

Sample point	$SOD_{T.P.}$ [g-DO/m^2·day]
x1 (8 meters in the forest)	9.4
x1 (3 meters in the forest)	9.2
x1 (at the side of the forest)	4.4
x2 (6 meters in the forest)	63.1
x2 (at the side of the forest)	7.7
x2 (in the channel)	12.5
x3 (8 meters in the forest)	52.6
x3 (5 meters in the forest)	11.3
x3 (at the side of the forest)	1.7

D The final models

This appendix gives the definition of the model describing fieldtrip 2 (Model 3) and 3 after calibration. The steps taken to reach this result were discussed in the report, chapter 7 and 8. Both the water movement definition and the water quality definition are discussed here. Before starting with the definition of the models, a calculation of the storage width was made that was used to make a first estimation of the storage width in the model.

D.1 The storage width

This appendix gives a calculation to estimate the storage area to be used as a first estimation in the Duflow model describing the water movement. First, the surface area of the channels was calculated. Not all the dimensions inside the pond were known for instance the little sub-channels everywhere. For that reason, the channel surface was raised 10%. The choice of the 10% raise was arbitrary. A calculation of the total area of the pond followed. The difference between the two values was the storage area. Estimations were made dividing the land between the channels equally to each channel. For instance: between two channels, there is land of 100 m width meaning that each channel has 50 m of storage width. Figure 8 shows the names used in this appendix and the dimensions.

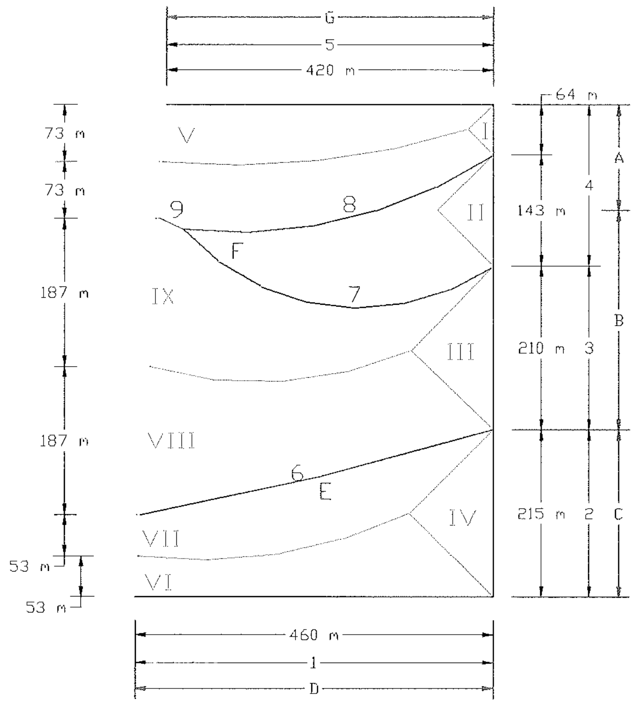


Figure 8: Estimation of the storage area

The channels were divided into 9 parts (1 - 9). The results of calculation are shown in table 23. The "length" is the length measured during fieldtrip 1. The channel width is the average width for that part calculated from the nearest measured cross-sections (measured during fieldtrip 1).

Table 23: Surface area channels

Part	Length [m]	Width [m]	Surface area [m^2]
1	458	13.60	6.229
2	166	14.30	2.374
3	210	15.05	3.161

Part	Length [m]	Width [m]	Surface area [m²]
4	264	15.95	3.947
5	340	15.25	5.185
6	441	16.25	7.166
7	435	15.00	6.525
8	404	15.50	6.262
9	15	13.50	203
		Total	**41.051**

Raising this value, 41.051 m^2 with 10% the surface area of the channels becomes: **45.156 m^2**. The total area was calculated making a map on scale using the measurements of the first fieldtrip. This map with the calculation is not given here. The total pond area is: **262.688 m^2**. This made the storage area: **217.532 m^2**.

The first definition of the model contained 7 sections (A – G) that described the model inside, see figure 8. The land was divided in 9 areas (I – IX). The sections A, B, and C also had some storage area. With an angle of 45° going inland this area was defined. Being only an estimation of the storage area, difficult calculations were avoided and everything was schematized.

Simple calculations were done to calculate the surface area of each defined area. The found results are shown in table 24.

Table 24: Storage areas

Area	Surface area [m²]
I	1.024
II	5.112
III	11.025
IV	11.557
V	23.638

Area	Surface area [m²]
VI	31.021
VII	29.501
VIII	59.976
IX	44.678

To obtain the average storage width of a section the total storage area, concerning that section was divided by the length of it. The average values are shown in table 25.

Table 25: Average storage width for each section

Section	Storage area [m²]	Length [m]	Width [m]
A	3.580	120	30
B	13.581	281	49
C	11.557	166	70
D	31.021	460	68
E	89.477	441	203
F	44.678	450	100
G	23.638	420	57

Section F is a combination of channel 7, 8 and 9

D.2 Modeling the network and geometry

The results of the network and geometry are shown here and are for both fieldtrips, two and three the same. Table 26 shows the definition of the sections. S stand for sluice, for instance S1 means sluice 1.

Table 26: Definition of the sections

Section	Node begin	Node end	Section	Node begin	Node end
1	1	2	32	37	41
2	2	4	33	38	42
3	1	3	34	39	43
4	4	5	35	40	44
5	3	6	S1	6	10
6	7	8	S2	5	7
7	8	9	S3	7	23
8	9	10	S4	8	24
9	7	11	S5	8	25
10	8	12	S6	9	26
11	9	13	S7	9	27
12	10	14	S8	10	28
13	11	15	S9	7	29
14	12	16	S10	8	30
15	13	17	S11	9	31
16	14	18	S12	10	32
17	15	19	S13	11	33
18	16	20	S14	12	34
19	17	21	S15	13	35
20	18	22	S16	14	36
21	23	24	S17	15	37
22	25	26	S18	16	38
23	27	28	S19	17	39
24	29	33	S20	18	40
25	30	34	S21	19	41
26	31	35	S22	20	42
27	32	36	S23	21	43
28	33	37	S24	22	44
29	34	38	S25	14	36
30	35	39	S26	18	46
31	45	46			

Table 27 shows the coordinates of the nodes. These coordinates were not the same as in reality and a correction is made in table 28 when the defining the channel lengths. The angle referring to the north was not important because the wind influence was neglected. No catchment area was defined because the measurements were done during dry season and it did not rain.

Table 27: Coordinates of the nodes

Node	x-coord. [m]	y-coord. [m]	Catchment-area [m^2]	Run-off factor
1	0	0	0.000	1.000
2	-50	50	0.000	1.000
3	-75	-150	0.000	1.000

Node	x-coord. [m]	y-coord. [m]	Catchment-area [m²]	Run-off factor
4	-125	125	0.000	1.000
5	-180	180	0.000	1.000
6	-180	-250	0.000	1.000
7	-180	180	0.000	1.000
8	-180	72	0.000	1.000
9	-180	-143	0.000	1.000
10	-180	-250	0.000	1.000
11	-320	180	0.000	1.000
12	-330	72	0.000	1.000
13	-328	-143	0.000	1.000
14	-333	-250	0.000	1.000
15	-460	180	0.000	1.000
16	-480	72	0.000	1.000
17	-476	-143	0.000	1.000
18	-486	-250	0.000	1.000
19	-600	180	0.000	1.000
20	-630	72	0.000	1.000
21	-625	-143	0.000	1.000
22	-640	-250	0.000	1.000
23	-180	180	0.000	1.000
24	-180	72	0.000	1.000
25	-180	72	0.000	1.000
26	-180	-143	0.000	1.000
27	-180	-143	0.000	1.000
28	-180	-250	0.000	1.000
29	-180	180	0.000	1.000
30	-180	72	0.000	1.000
31	-180	-143	0.000	1.000
32	-180	-250	0.000	1.000
33	-320	180	0.000	1.000
34	-330	72	0.000	1.000
35	-328	-143	0.000	1.000
36	-333	-250	0.000	1.000
37	-460	180	0.000	1.000
38	-480	72	0.000	1.000
39	-476	-143	0.000	1.000
40	-486	-250	0.000	1.000
41	-600	180	0.000	1.000
42	-630	72	0.000	1.000
43	-625	-143	0.000	1.000
44	-640	-250	0.000	1.000
45	-333	-250	0.000	1.000
46	-486	-250	0.000	1.000

After defining the nodes the network layout is known and the dimensions of the sections were defined. Table 28 shows the definition of the dimensions of the sections. This table contains the length of the sections, the bottom levels at the beginning and end, and the Chézy-factor.

Table 28: Parameters sections

Section	Length section [m]	Angle to N [°]	Bottom begin [m]	Bottom end [m]	Chézy pos. dir. [$m^{½}/s$]	Chézy neg. dir. [$m^{½}/s$]	windconv 10^-6 [-]
1	50	315.00	-3.43	-3.43	50.00	50.00	3.600
2	75	315.00	-3.43	-2.73	50.00	50.00	3.600
3	175	207.00	-3.43	-3.58	50.00	50.00	3.600
4	70	315.00	-2.73	-2.26	30.00	30.00	3.600
5	50	226.00	-3.58	-3.43	50.00	50.00	3.600
6	120	180.00	-2.93	-2.63	50.00	50.00	3.600
7	281	180.00	-2.63	-2.57	50.00	50.00	3.600
8	166	180.00	-2.57	-2.86	50.00	50.00	3.600
9	140	270.00	-2.93	-2.89	50.00	50.00	3.600
10	150	270.00	-1.80	-1.77	50.00	50.00	3.600
11	148	270.00	-1.99	-2.01	50.00	50.00	3.600
12	153	270.00	-2.86	-2.72	50.00	50.00	3.600
13	140	270.00	-2.89	-2.86	50.00	50.00	3.600
14	150	270.00	-1.77	-1.73	50.00	50.00	3.600
15	148	270.00	-2.01	-2.02	50.00	50.00	3.600
16	153	270.00	-2.72	-2.57	50.00	50.00	3.600
17	140	270.00	-2.86	-2.82	50.00	50.00	3.600
18	150	270.00	-1.73	-1.70	50.00	50.00	3.600
19	149	270.00	-2.02	-2.04	50.00	50.00	3.600
20	154	270.00	-2.57	-2.43	50.00	50.00	3.600
21	120	180.00	-1.33	-1.30	50.00	50.00	3.600
22	281	180.00	-1.27	-1.21	50.00	50.00	3.600
23	166	180.00	-1.29	-1.31	50.00	50.00	3.600
24	140	270.00	-1.32	-1.28	50.00	50.00	3.600
25	150	270.00	-1.22	-1.19	50.00	50.00	3.600
26	148	270.00	-1.29	-1.31	50.00	50.00	3.600
27	153	270.00	-1.52	-1.38	50.00	50.00	3.600
28	140	270.00	-1.31	-1.28	50.00	50.00	3.600
29	150	270.00	-1.23	-1.19	50.00	50.00	3.600
30	148	270.00	-1.29	-1.30	50.00	50.00	3.600
31	153	270.00	-1.53	-1.40	50.00	50.00	3.600
32	140	270.00	-1.32	-1.28	50.00	50.00	3.600
33	150	270.00	-1.22	-1.19	50.00	50.00	3.600
34	149	270.00	-1.29	-1.31	50.00	50.00	3.600
35	154	270.00	-1.52	-1.38	50.00	50.00	3.600

Section 1 till 5 : The outside channels
Section 6 till 20 : The inside channels
Section 21 till 35 : The channels representing the forest

After defining the sections the cross-sections were defined. The cross-sections were derived from the cross-section measurements done during fieldtrip 1. The defined cross-sections were not identical like those who were measured. Table 29 shows the cross-sections.

Table 29: The cross-sections

Section	Depth to bottom [m]	Flow width begin [m]	Flow width end [m]	Storage width begin [m]	Storage width end [m]
1,2	0.00	3.00	1.50	3.00	1.50
	0.55	3.50	2.25	3.50	2.25
	2.10	4.00	4.00	4.00	4.00
3	0.00	3.00	1.00	3.00	1.00
	1.00	6.00	3.50	6.00	3.50
	2.10	9.00	9.00	9.00	9.00
	2.50	9.00	20.00	9.00	20.00
4	0.00	1.50	1.50	1.50	1.50
	0.55	2.25	2.25	2.25	2.25
	1.80	4.00	4.00	4.00	4.00
5	0.00	1.00	1.00	1.00	1.00
	1.00	3.50	3.50	3.50	3.50
	2.10	9.00	9.00	9.00	9.00
	2.50	20.00	20.00	20.00	20.00
6	0.00	3.00	3.00	3.00	3.00
	1.60	15.00	15.00	15.00	15.00
	1.65	15.00	15.00	15.00	15.00
	1.70	15.00	15.00	15.00	15.00
7	0.00	3.00	3.00	3.00	3.00
	1.45	15.00	15.00	15.00	15.00
	1.50	15.00	15.00	15.00	15.00
	1.55	15.00	15.00	15.00	15.00
8	0.00	3.00	3.00	3.00	3.00
	1.55	15.00	15.00	15.00	15.00
	1.60	15.00	15.00	15.00	15.00
	1.65	15.00	15.00	15.00	15.00
9, 13, 17	0.00	3.00	3.00	3.00	3.00
	1.00	12.00	12.00	12.00	12.00
	1.70	15.00	15.00	15.00	15.00
	1.75	15.00	15.00	15.00	15.00
	1.80	15.00	15.00	15.00	15.00
10, 14, 18	0.00	8.00	8.00	8.00	8.00
	0.65	30.00	30.00	30.00	30.00
	0.70	30.00	30.00	30.00	30.00
	0.75	30.00	30.00	30.00	30.00
11, 15, 19	0.00	5.00	5.00	5.00	5.00
	0.80	16.00	16.00	16.00	16.00
	0.85	16.00	16.00	16.00	16.00
	0.90	16.00	16.00	16.00	16.00

Section	Depth to bottom [m]	Flow width begin [m]	Flow width end [m]	Storage width begin [m]	Storage width end [m]
12, 16, 20	0.00	5.00	5.00	5.00	5.00
	1.25	13.00	13.00	13.00	13.00
	1.50	14.00	14.00	14.00	14.00
	1.55	14.00	14.00	14.00	14.00
	1.60	14.00	14.00	14.00	14.00
21	0.00	0.00	0.00	0.00	0.00
	0.05	20.00	20.00	20.00	20.00
	0.10	30.00	30.00	30.00	30.00
22	0.00	0.00	0.00	0.00	0.00
	0.10	29.00	29.00	29.00	29.00
	0.15	45.00	45.00	45.00	45.00
23	0.00	0.00	0.00	0.00	0.00
	0.30	53.00	53.00	53.00	53.00
	0.35	70.00	70.00	70.00	70.00
24	0.00	0.00	0.00	0.00	0.00
	0.14	46.00	46.00	46.00	46.00
	0.19	46.00	46.00	46.00	46.00
25	0.00	0.00	0.00	0.00	0.00
	0.12	70.00	70.00	70.00	70.00
	0.17	100.00	100.00	100.00	100.00
26	0.00	0.00	0.00	0.00	0.00
	0.15	120.00	120.00	120.00	120.00
	0.20	180.00	180.00	180.00	180.00
27	0.00	0.00	0.00	0.00	0.00
	0.21	31.00	31.00	31.00	31.00
	0.26	70.00	70.00	70.00	70.00
28	0.00	0.00	0.00	0.00	0.00
	0.17	46.00	46.00	46.00	46.00
	0.22	46.00	46.00	46.00	46.00
29	0.00	0.00	0.00	0.00	0.00
	0.16	70.00	70.00	70.00	70.00
	0.21	100.00	100.00	100.00	100.00
30	0.00	0.00	0.00	0.00	0.00
	0.13	120.00	120.00	120.00	120.00
	0.18	180.00	180.00	180.00	180.00
31	0.00	0.00	0.00	0.00	0.00
	0.36	31.00	31.00	31.00	31.00
	0.41	70.00	70.00	70.00	70.00
32	0.00	0.00	0.00	0.00	0.00
	0.21	46.00	46.00	46.00	46.00
	0.26	46.00	46.00	46.00	46.00
33	0.00	0.00	0.00	0.00	0.00
	0.19	70.00	70.00	70.00	70.00
	0.24	100.00	100.00	100.00	100.00
34	0.00	0.00	0.00	0.00	0.00
	0.12	120.00	120.00	120.00	120.00
	0.17	180.00	180.00	180.00	180.00

Section	Depth to bottom [m]	Flow width		Storage width	
		begin [m]	end [m]	begin [m]	end [m]
35	0.00	0.00	0.00	0.00	0.00
	0.50	31.00	31.00	31.00	31.00
	0.55	70.00	70.00	70.00	70.00

The last part of the network and geometry definition was defining the weirs. Two types of weirs were used. Weir with underflow was defined as the sluices used for the exchange water. The other type, weir with overflow, was used as a connection between the forest and channel sections. Table 30 shows the parameters of the structures of the type weir with underflow and table 31 describes the other weirs.

Table 30: Parameters weir with underflow

Parameter	Sluice A	Sluice B
Number	S1	S2
Width (m)	1.20	2.10
Sill level (m)	-2.39	-2.26
Gate level (m)	2.00	2.00
Mu pos. dir. free	0.70	0.70
Mu neg. dir. free	0.55	0.53
Mu pos. dir. subm.	0.80	0.80
Mu neg. dir. subm.	0.80	0.80

Table 31: Parameters weir with overflow

Structure	Width [m]	Sill level [m]	Mu pos. dir. [-]	Mu neg. dir. [-]
S3	60.00	-1.25	1.00	1.00
S4	60.00	-1.11	1.00	1.00
S5	140.50	-1.16	1.00	1.00
S6	140.50	-1.13	1.00	1.00
S7	83.00	-1.09	1.00	1.00
S8	83.00	-1.24	1.00	1.00
S9	70.00	-1.23	1.00	1.00
S10	75.00	-1.14	1.00	1.00
S11	74.00	-1.20	1.00	1.00
S12	76.50	-1.33	1.00	1.00
S13	140.00	-1.19	1.00	1.00
S14	150.00	-1.12	1.00	1.00
S15	148.00	-1.21	1.00	1.00
S16	76.50	-1.25	1.00	1.00
S17	140.00	-1.16	1.00	1.00
S18	150.00	-1.08	1.00	1.00
S19	148.50	-1.22	1.00	1.00
S20	74.00	-1.03	1.00	1.00
S21	70.00	-1.13	1.00	1.00
S22	75.00	-1.06	1.00	1.00
S23	74.50	-1.24	1.00	1.00
S24	77.00	-1.00	1.00	1.00
S25	76.50	-1.18	1.00	1.00
S26	76.50	-1.11	1.00	1.00

D.3 Modeling the water movement

This appendix describes the parameters of the model concerning the water movement. These parameters were, unlike the similar parameters defined in appendix D.2, different for each fieldtrip. For both fieldtrips, these are discussed here.

- Fieldtrip 2

The following parameters are defined here: the structure control, the initial and boundary conditions.

- The structure control

The structure control was used to control the opening and closing of the structures. These structures are the sluices of the type weirs with underflow; sluice A (structure S1) and sluice B (structure S2). The other weirs do not need structure control. Table 32 shows the structure control of the sluices.

Table 32: Structure control, fieldtrip 2

Type of operation	Continues
Operational parameter	Gate level [m]
Structure number	1and 2
Type of function	Time series
Start time (yymmdd)	990301
Start time (hhmm)	1300
Time step (hhmm)	0010
Number of values	175

Sluice A, structure S1		
Time begin [hhmm]	**Time end [hhmm]**	**Parameter [m]**
1300	1820	-2.39
1830	2040	2.00
2050	2310	-2.39
2320	0210	2.00
0220	0300	-2.39
0310	0530	2.00
0540	1340	-2.39
1350	1550	2.00
1600	1800	-2.39

Sluice B, structure S2		
Time begin [hhmm]	**Time end [hhmm]**	**Parameter [m]**
1300	1820	-2.26
1830	2030	2.00
2040	2310	-2.26
2320	0210	2.00
0220	0300	-2.26
0310	0530	2.00
0540	1200	-2.26
1210	1310	2.00
1320	1340	-2.26
1350	1550	2.00
1600	1800	-2.26

- The initial conditions

The initial conditions were those conditions in the pond when the calculations started. Table 33 shows the defined initial conditions.

Table 33: Initial conditions, fieldtrip 2

Node	Level [m]	Node	Level [m]	Node	Level [m]	Node	Level [m]
1	-0.99	13	-1.05	25	-1.05	36	-1.05
2	-0.99	14	-1.05	26	-1.05	37	-1.05
3	-0.99	15	-1.05	27	-1.05	38	-1.05
4	-0.99	16	-1.05	28	-1.05	39	-1.05
5	-0.99	17	-1.05	29	-1.05	40	-1.05
6	-0.99	18	-1.05	30	-1.05	41	-1.05
7	-1.05	19	-1.05	31	-1.05	42	-1.05
8	-1.05	20	-1.05	32	-1.05	43	-1.05
9	-1.05	21	-1.05	33	-1.05	44	-1.05
10	-1.05	22	-1.05	34	-1.05	45	-1.05
11	-1.05	23	-1.05	35	-1.05	46	-1.05
12	-1.05	24	-1.05				

The initial discharges are 0 m^3/s (The sluices were closed).

- The boundary condition

The boundary condition used for the model of fieldtrip 2 is shown in table 34.

Table 34: Boundary condition, fieldtrip 2

Type	Level [m]
Node(s)	1
Condition number	1
Type of function	Fourier series
Start date (yymmdd)	990301
Start time (hhmm)	1300
Cycle 1th component (hhmm)	2450
Number of sine shaped comp.	2

Comp.	Amplitude [m]	Phase [°]
0	-1.80	-
1	0.59	101
2	0.94	13

- Fieldtrip 3

The same parameters were defined for modeling fieldtrip 3. The defined boundary condition was found after calibrating the model of fieldtrip 3. The reason was the stolen Diver.

- The structure control

The same sluices were controlled (S1 and S2). Table 35 shows the parameters used for controlling the structure.

Table 35: Structure control, fieldtrip 3

Type of operation	Continues
Operational parameter	Gate level [m]
Structure number	1 and 2
Type of function	Time series

Start time (yymmdd)	990316
Start time (hhmm)	1300
Time step (hhmm)	0005
Number of values	583

Sluice A, structure S1		
Time begin [hhmm]	**Time end [hhmm]**	**Parameter [m]**
1300	1810	-2.39
1815	2010	2.00
2015	2345	-2.39
2350	0130	2.00
0135	0240	-2.39
0245	0420	2.00
0425	1250	-2.39
1255	1455	2.00
1500	1800	-2.39
1805	1955	2.00
2000	0010	-2.39
0015	0225	2.00
0230	0310	-2.39
0315	0510	2.00
0515	1330	-2.39

Sluice B, structure S2		
Time begin [hhmm]	**Time end [hhmm]**	**Parameter [m]**
1300	1810	-2.26
1815	2010	2.00
2015	2345	-2.26
2350	0130	2.00
0135	0240	-2.26
0245	0420	2.00
0425	1250	-2.26
1255	1455	2.00
1500	1800	-2.26
1805	1955	2.00
2000	0010	-2.26
0015	0225	2.00
0230	0310	-2.26
0315	0510	2.00
0515	1330	-2.26

- The initial conditions

The initial conditions used are shown in table 36.

Table 36: Initial conditions, fieldtrip 3

Node	Level [m]	Node	Level [m]	Node	Level [m]	Node	Level [m]
1	-0.87	13	-1.05	25	-1.05	36	-1.05
2	-0.87	14	-1.05	26	-1.05	37	-1.05
3	-0.87	15	-1.05	27	-1.05	38	-1.05
4	-0.87	16	-1.05	28	-1.05	39	-1.05
5	-0.87	17	-1.05	29	-1.05	40	-1.05
6	-0.87	18	-1.05	30	-1.05	41	-1.05
7	-1.05	19	-1.05	31	-1.05	42	-1.05
8	-1.05	20	-1.05	32	-1.05	43	-1.05
9	-1.05	21	-1.05	33	-1.05	44	-1.05
10	-1.05	22	-1.05	34	-1.05	45	-1.05
11	-1.05	23	-1.05	35	-1.05	46	-1.05
12	-1.05	24	-1.05				

The initial discharges were 0 m^3/s (The sluices were closed).

- The boundary condition

The boundary condition was found calibrating the model describing fieldtrip 3. The found parameters are shown in table 37.

Table 37: Boundary condition, fieldtrip 3

Type	Level [m]
Node(s)	1
Condition number	1
Type of function	Fourier series
Start date (yymmdd)	990316
Start time (hhmm)	1300
Cycle 1th component (hhmm)	2450
Number of sine shaped comp.	2

Comp.	Amplitude [m]	Phase [°]
0	-1.80	
1	0.655	89
2	0.930	11

D.4 Modeling the water quality

This appendix describes the modeling of the processes together with the other definitions like initial and boundary conditions, external variables and parameters.

- The model listing

```
/*                Graduation 1999                */
/*                                               */
/*             Simple quality model for          */
/*            Thanh Phu, plot 3.1.B              */
/*                  Vietnam                      */
/*                                               */
/*                    by                         */
/*                                               */
/*                                               */
/*               E.T.M. Klaassen                 */
/*                                               */

water  O2    [6.600] g/m3         ; Oxygen concentration

parm   Tsod  [1.060] -            ; Temp. coeff. SOD
parm   Tre   [1.024] -            ; Temp. coef. Reaeration
parm   kmin  [0.100] m/day        ; Minimum oxygen mass constant
parm   Ksod  [2.000] g/m2.day     ; Monod factor SOD

xt     SOD   [6.580] g/m2.day     ; Sediment oxygen demand
xt     T     [27.35] oC           ; Temperature
xt     Sal   [29.80] g/m3         ; Salinity

flow   z     [2.000] m            ; Water depth
flow   Q     [5.000] m3/s         ; Discharge
flow   As    [20.00] m2           ; Flow area
```

```
{
IF    (z>=0.00)
      {
      u=ABS(Q/As);
      }
ELSE IF (z<0.00)
      {
      u=0.00;
      }

dep=z;

lnOsat=-173.4292+(249.6339*(100/(T+273.15)))+(143.3482*(ln((T+273.15)/100)))
-(21.8492*((T+273.15)/100))+(Sal*((-0.033096)+(0.014259*((T+273.15)/100))+
(-0.0017000*(((T+273.15)/100)^2))));

Osat=exp(lnOsat);

Kl20=((2.33)*(u^(0.67))*((ABS(z))^(-0.85)));

IF              ((Kl20<kmin) && (z>=0.00))
                {
                Kl20=kmin;
                }
ELSE IF         ((Kl20<kmin) && (z<0.00))
                {
                Kl20=0.00;
                }

KlT=(Kl20)*(Tre^(T-20));

Kre=KlT/z;

fsod=O2/(O2+Ksod);

IF              (z>=0.00)
                {
                Sed=((SOD*(Tsod^(T-20)))/z);
                }
ELSE IF         (z<0.00)
                {
                Sed=0.00;
                }

SedO2=Sed*fsod;
k1(O2)=-Kre;
k0(O2)=(Kre*Osat)-(SedO2);
```

- The initial conditions

The initial conditions were those conditions in the pond when the calculation started. Because not every position in the pond was measured, assumptions were made. Initial water quality conditions only influence the start of the model. The initial water quality conditions are shown in table 38.

Table 38: Initial water quality conditions

Node [-]	DO concentration [g/m³]	Node [-]	DO-concentration [g/m³]	Node [-]	DO-concentration [g/m³]
1	6.60	17	5.49	32	5.91
2	6.60	18	5.91	33	5.88
3	6.60	19	5.88	34	5.36
4	6.60	20	5.36	35	5.49
5	6.60	21	5.49	36	5.91
6	6.60	22	5.91	37	5.88
7	5.88	23	5.88	38	5.36
8	5.89	24	5.89	39	5.49
9	5.90	25	5.89	40	5.91
10	5.91	26	5.90	41	5.88
11	5.88	27	5.90	42	5.36
12	5.36	28	5.91	43	5.49
13	5.49	29	5.88	44	5.91
14	5.91	30	5.89	45	5.91
15	5.88	31	5.90	46	5.91
16	5.36				

- The boundary condition

The boundary condition was used to define the constant input of DO from sea. Table 39 shows the used boundary condition.

Table 39: Quality boundary condition

Description	Definition
Type	Concentration
Variable	o2 unit: g/m3
Node(s)	1
Condition number	1
Type of function	Constant
Constant value	6.600

- External variables

Table 40, 41 and 42 show the defined external parameters of respectively salinity, temperature and SOD.

Table 40: The external parameter salinity

Description	Definition
Type	Salinity unit: g/m3
Node(s)	All
Condition number	1
Type of function	Constant
Constant value	29.200

Table 41: The external variable temperature

Description	Definition	
Type	t unit: oC	
Node(s)	All	
Condition number	1	
Type of function	non eq. series	
number of values	5	
Date	**Time**	**Value**
990301	1300	29.250
990301	1500	29.250
990302	0415	25.900
990302	1500	28.600
990302	1800	27.750

Table 42: The external variables $SOD_{T.P.}$

Description	Definition
Type	SOD unit: g/m2.day
Condition number	1
Type of function	Constant
Node(s)	**Value**
1-6	0.000
7-22	3.000
23-46	10.000

- Parameters

The parameters used in the definition of the processes are shown in table 43.

Table 43: Defined parameters

Name	Description	Default	Value	Unit
kmin	minimum oxygen mass constant	0.100	0.100	m/day
ksod	monod factor SOD	2.000	2.000	g/m2.day
tre	temp. coef. reaeration	1.024	1.024	-
tsod	temp. coef. SOD	1.060	1.060	-

E The model output

This appendix describes the model output. First the output of the first model is compared with the measured data followed by the figures that show the influence of the period when no water is exchanged (7 days).

E.1 Comparing the Duflow data with the measured data

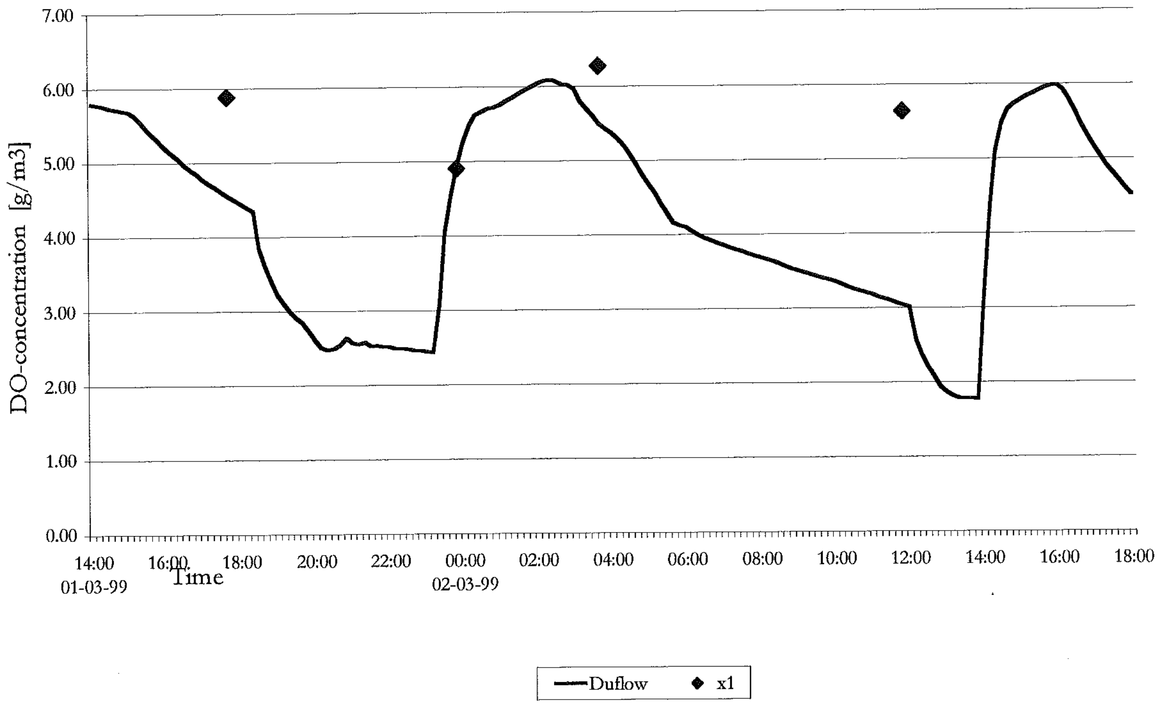


Figure 9: Comparing Duflow with the measured data at position x1

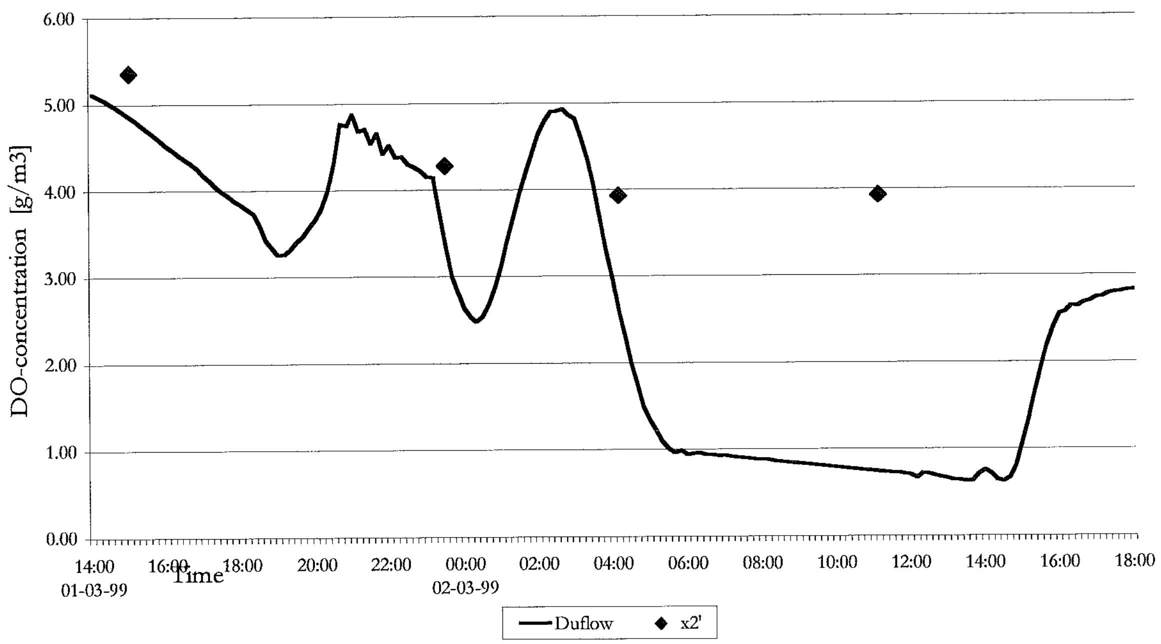


Figure 10: Comparing Duflow with the measured data at x2'

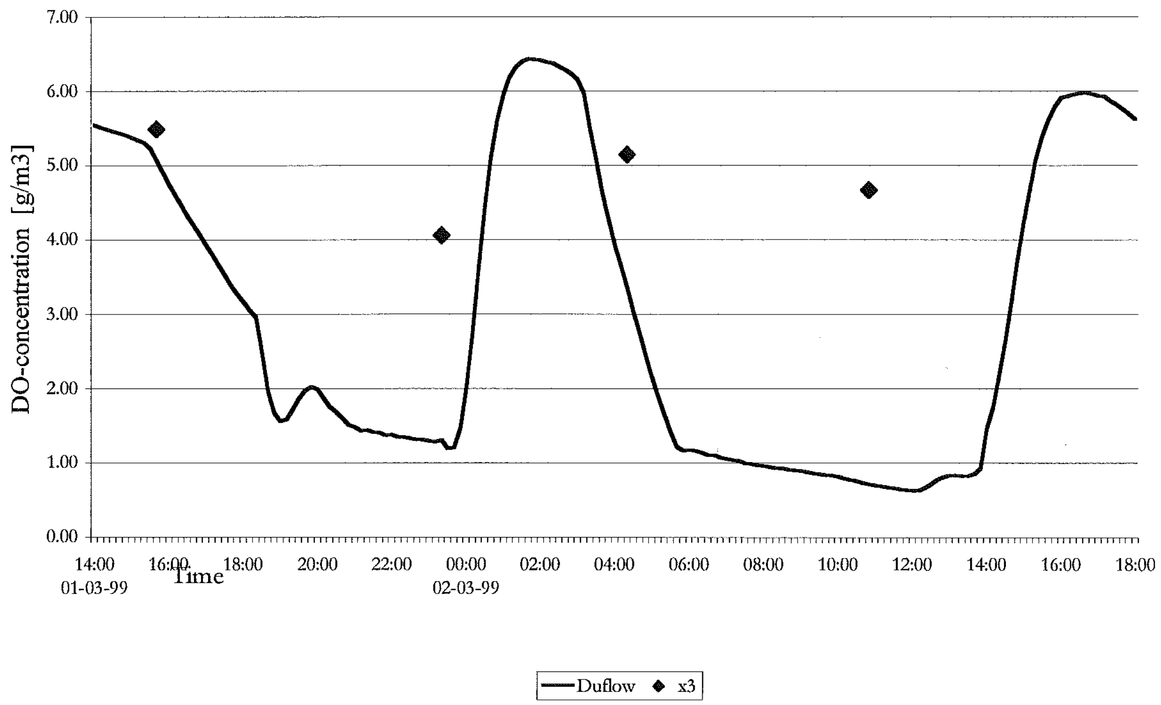


Figure 11: Comparing Duflow with the measured data at position x3

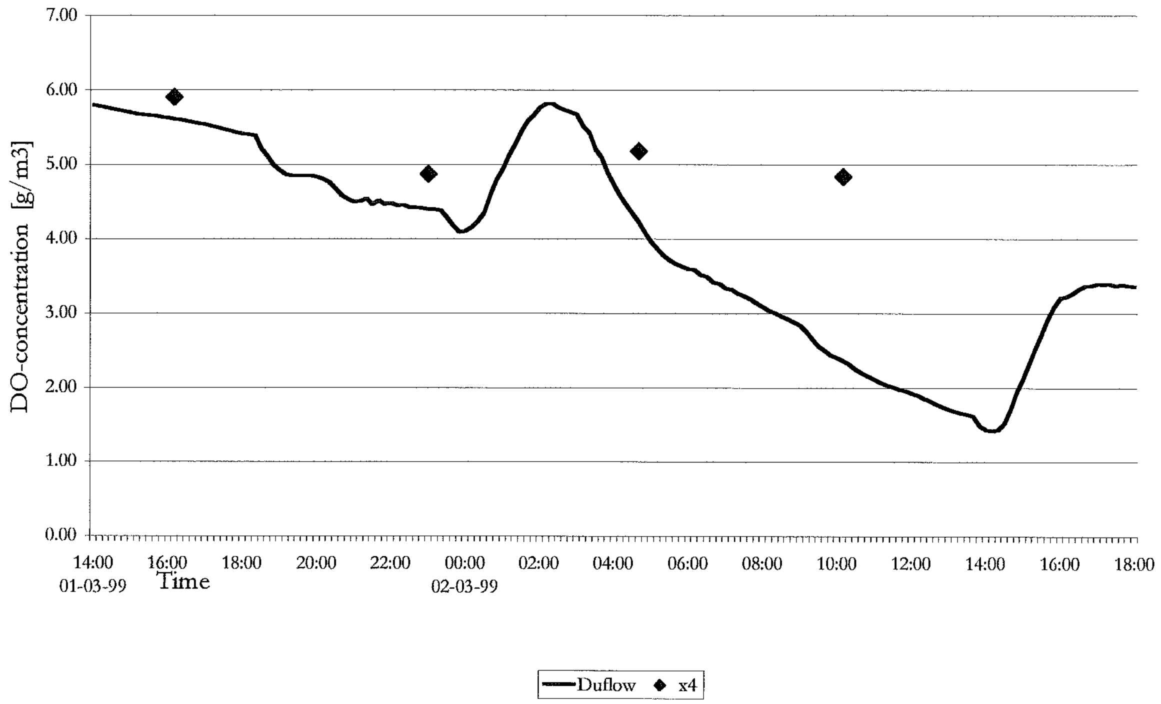


Figure 12: Comparing Duflow with the measured data at position x4

The figures shown in appendix E.1 showed the DO-concentration without improving the system.

E.2 DO-concentrations during the period of no water exchange

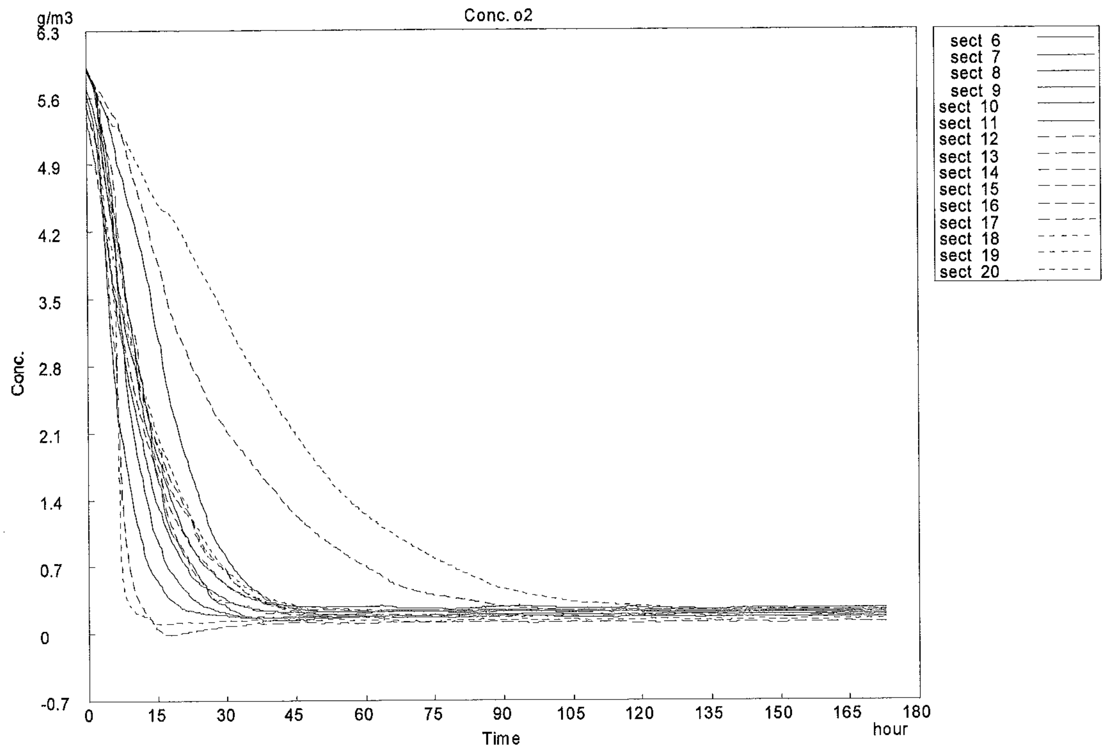


Figure 13: Influence of not exchanging water in the reference situation, channel sections

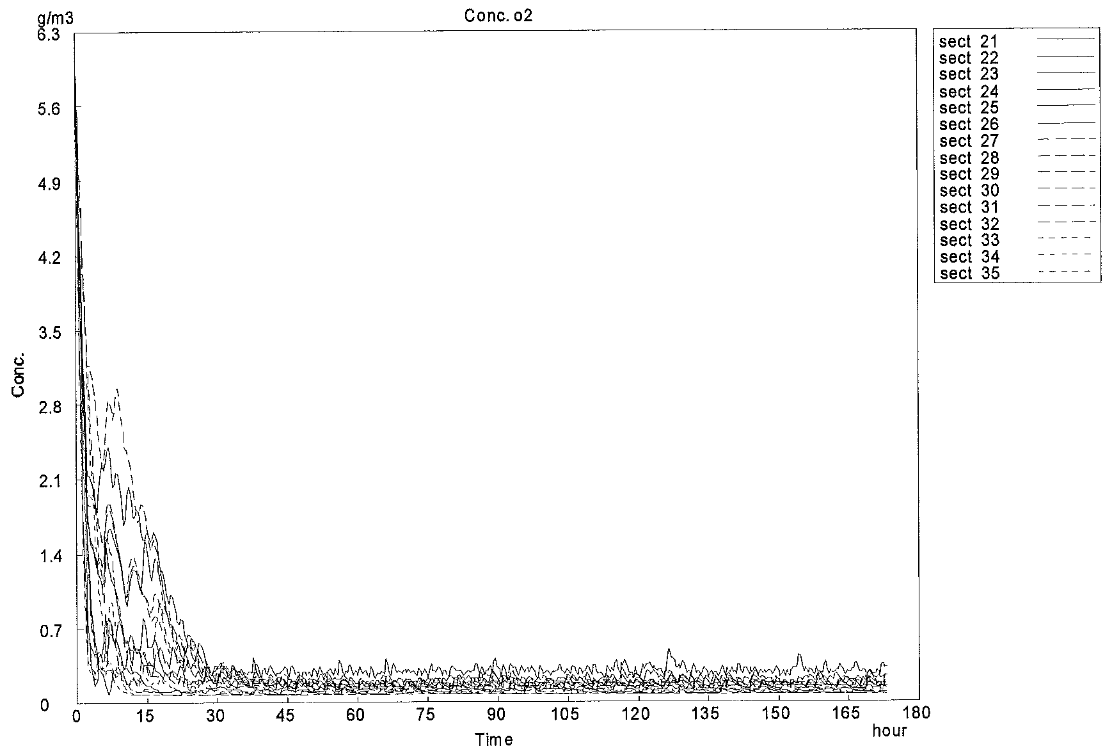


Figure 14: Influence of not exchanging water in the reference situation, forest sections

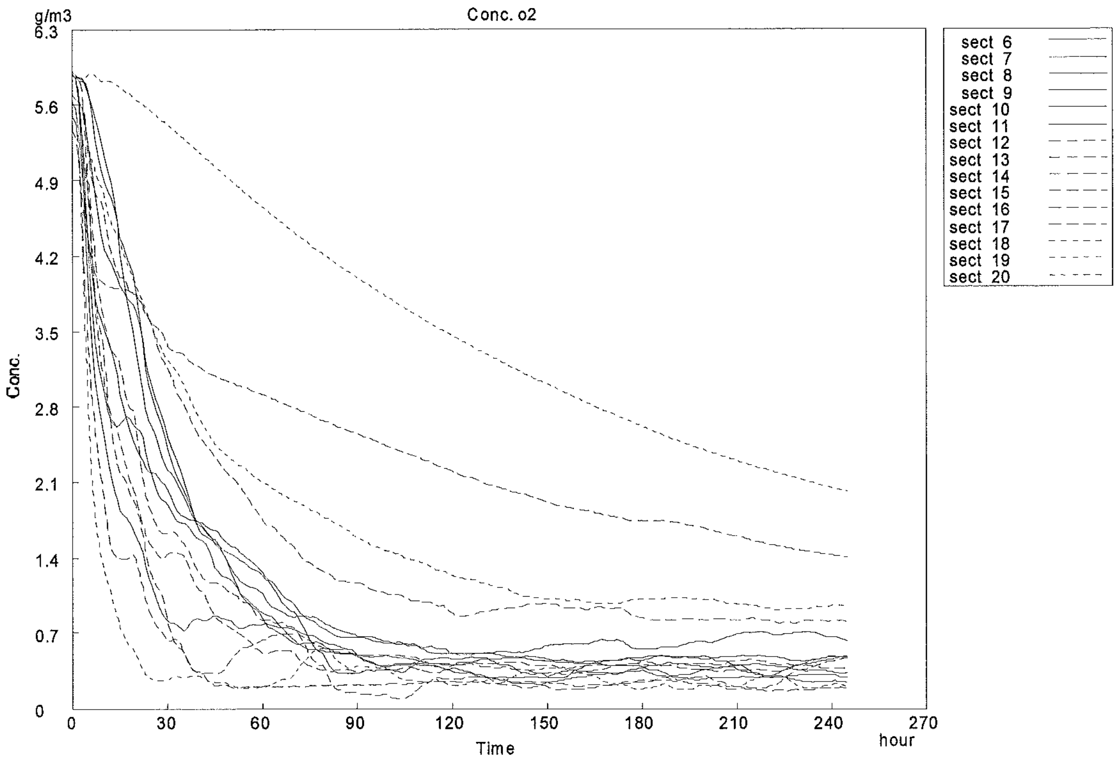


Figure 15: Influence of not exchanging water in option 6, channel sections

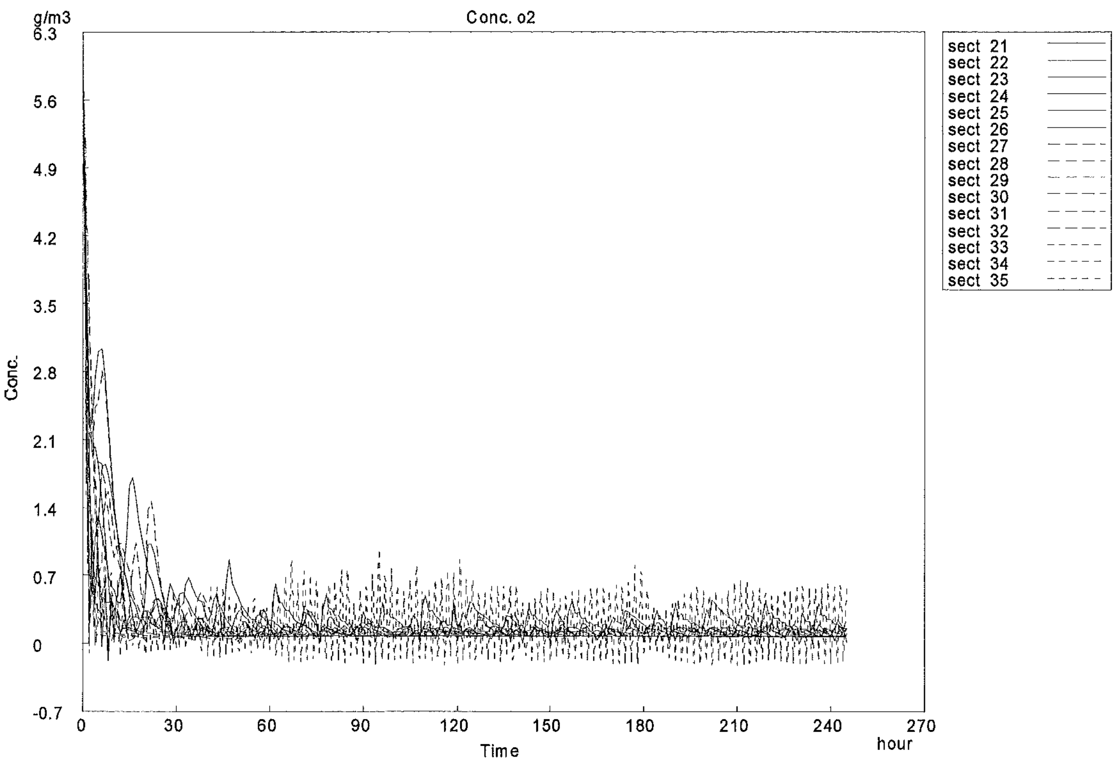


Figure 16: Influence of not exchanging water in option 6, forest sections

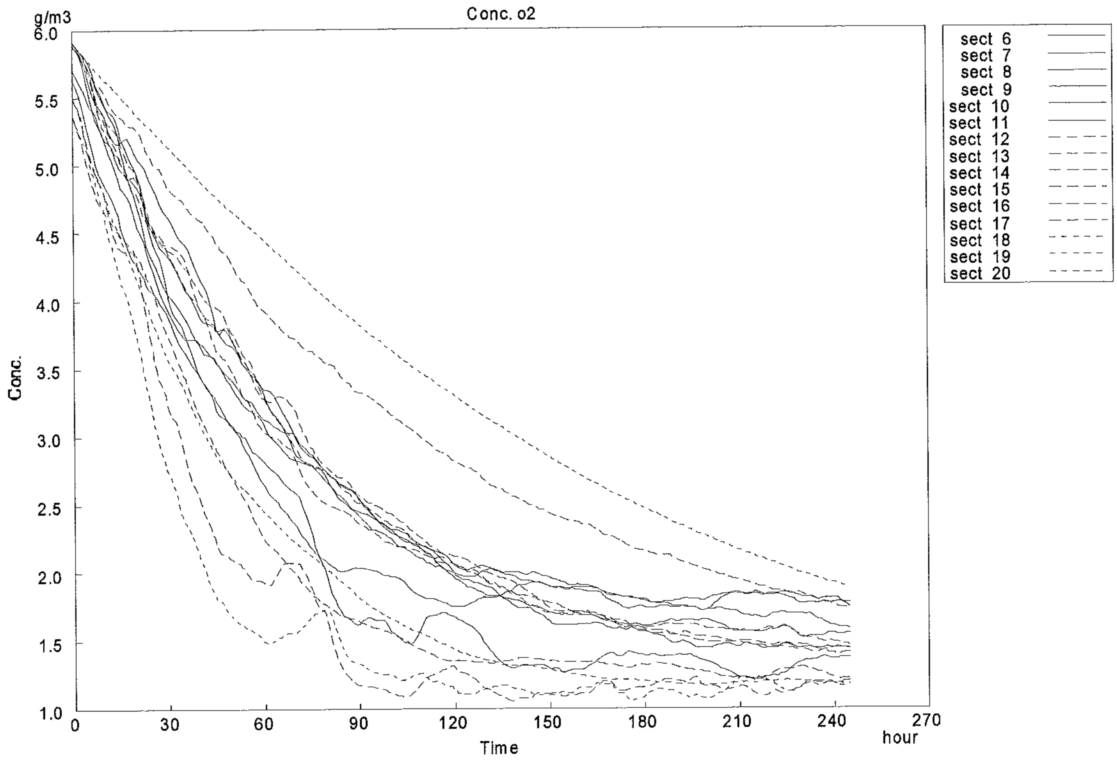


Figure 17: Influence of not exchanging water in option 7, channel sections

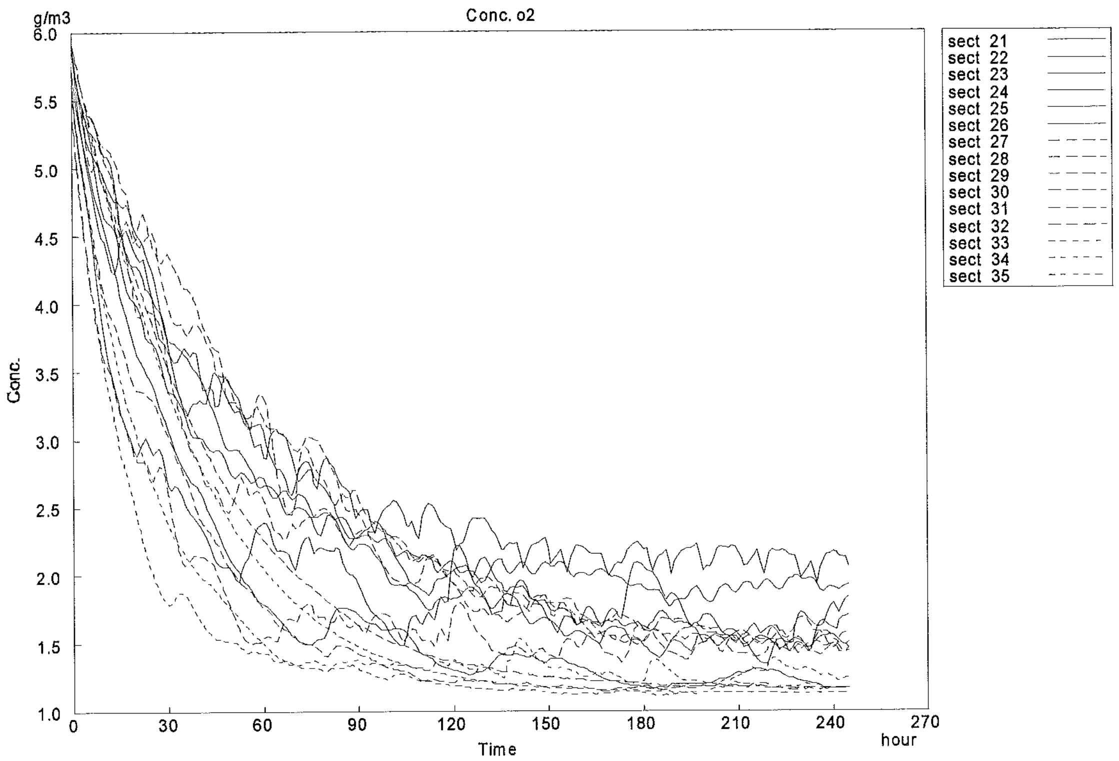


Figure 18: Influence of not exchanging water in option 7, forest sections

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