EVALUATION AND SIMULATION OF THE NUTRIENT REMOVAL FUNCTION OF A CONSTRUCTED WETLAND: THE KRISTALBAD CASE, ENSCHEDE, NL

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Abstract

This research is about monitoring and analyzing the nutrient removal capacity of a constructed wetland, an urban water infrastructure near Enschede, NL. The Kristalbad, west of Enschede, is a new (>2012) multifunctional water management infrastructure, constructed to reduce urban storm runoff peaks, impacts of CSO (combined sewer overflows) from the urban waste water treatment plant of Enschede-west and to improve downstream water quality of the Elsbeek and Bornse beek systems. Wetlands are known to remove nutrient loadings (N, P) from runoff waters. At first, a nutrient mass balance and simple process model approach will be used, using existing data and own measurements to evaluate the nutrient flows and behavior in the wetland system. In second instance, an eco-hydraulic model (using DMS/Duflow) will be set-up to simulate the flows, water levels and nutrient biogeochemical processes in the wetland. Detailed geospatial high resolution imagery (0.5 – 8 m) and geospatial data will be used to build the georeferenced water quality simulation modelling scheme. The modelling system, when calibrated will improve our understanding of the functioning of the complex wetland and help to design and analyze scenarios and nutrient removal efficiencies of this water infrastructure. The model suitability will also be critically evaluated.

Keywords

Constructed wetland; Kristalbad; nutrients; Duflow; eco-hydraulic model; nitrogen, phosphorus

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1 Introduction

1.1 background

The “Kristalbad” is a recently constructed artificial wetland infrastructure which came operational in 2012-2013. It is located between Hengelo and Enschede (Figure 1). It is a complex but challenging water management project because multiple water functions and ecosystem services are combined in a limited area, such as storm water retention, water quality improvement, ecological connection, recreation and landscape management. The water in the Kristalbad comes largely from the urban sewage treatment plant effluent of Enschede-West which flows upstream in the Elsbeek. This "water machine" was built for storm water retention, but is also intended to improve the water quality of the Elsbeek and downstream Bornse beek systems. The system was inspired by proven methods of the Wetland Research Centre at the University of Halmstad in Sweden. The pond compartments of Kristalbad fill up alternately, and undergo a diurnal filling and drainage cycle. Under the influence of light and air, biogeochemical processes in the water and sediment and aquatic vegetation will have a purifying effect, e.g. breaking down and converting nutrients, carbon and other substances. However, several questions in relation to its functioning, sustainability and impact still need to be answered.

How does the hydraulic management (cycles) affect the purification capacity of the system, growth of aquatic vegetation, retention of other substances such as nutrients, dissolved and particulate carbon? What will happen in the medium long term to the suspended matter coming from the Elsbeek and settling in the ponds, decomposition of aquatic weeds, etc.? Which aquatic plants grow well under the local circumstances and are more optimal in removing certain substances? How sensitive and resilient is the system to externalities such as different weather events, high or low chemical loadings? What use can be made of geospatial and satellite data for remote monitoring these water systems?

The present MSc studies will address a number of specific questions as phrased above. The research will be done in close cooperation with the regional water authority “Waterschap Vechstromen” and the municipality (Enschede city) in relation to the WWTP management.

In this study, focus was given to nutrients in the wetland. Nutrients in a water body, such as nitrogen and phosphorus, become pollutants when their concentrations reach too high (Daniel et al., 1998). Eutrophication is one of the effects of excessive nutrients, which will lead to excessive algae growth in water body. Nutrient levels in water are important indicators of environmental water conditions (Piatek, Christopher, & Mitchell, 2008; Mulholland, Houser, & Maloney, 2005; ARHEIMER & BRANDT, 1998). The overabundance of nutrients in the water can occasionally lead to an excessive growth of algae. The excess algae has an impact on the water quality, other plants and animals that live in and around the water. The excessive use of manure in agriculture is a significant source of nitrogen and phosphate in the environment. Discharges from factories and urban residual waste water effluent releases and nitrogen from exhaust gases are important source of nutrients (Yevenes & Mannaerts, 2011; Ventura et al., 2008).

How does the nutrients distribute in the wetland, and how does the wetland perform in breaking down the nutrients, this research would use the Duflow model to check it and evaluate the wetland’s performance. Check the result from Duflow to evaluate the model suitability for simulating the Kristalbad wetland system.

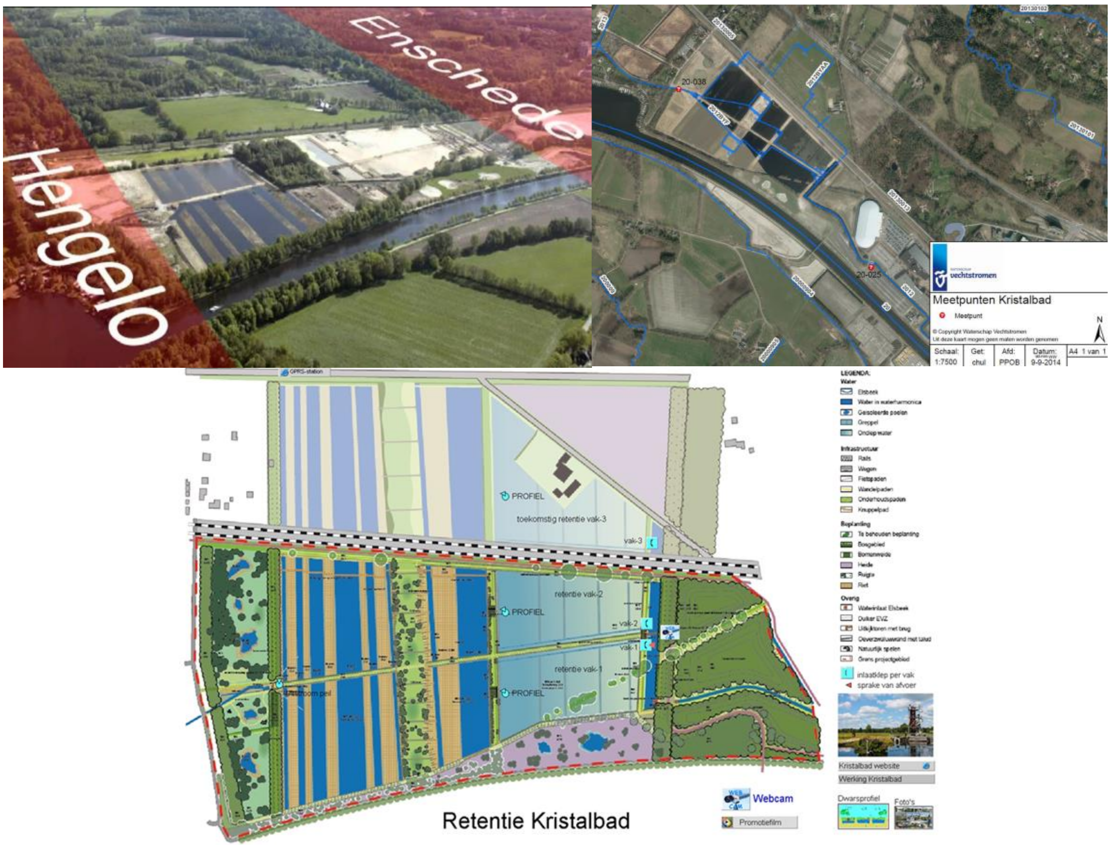


Figure 1 Kristalbad

1.2 Research objectives

- analyze the nutrient behavior and effect of the Kristalbad wetland system on (N, P) removal in the water flows of the Elsbeek (carrying the effluents from the WWTP Enschede-west and draining through the wetland), using a simple mass balance and water quality process approach;
- design an eco-hydraulic model for analyzing flow and nutrient behavior in the Kristalbad, based on high resolution (0.5 – 8 m) satellite and other geospatial data and generate a detailed geo-referenced physical eco-hydraulic modelling scheme of the wetland system;
- evaluate the model suitability for simulating the Kristalbad wetland system and use the modelling system to evaluate flow and water management scenarios

1.3 Research Hypothesis

The wetland system (consisting of three large ponds) is hydraulically managed and alternating filling and drying of the wetland ponds and diurnal water level changes occur in the system. Our hypothesis is that wetland ponds is constant filling.

1.4 Research questions

The following research questions can be phrased in relation to the objectives and hypothesis:

- What impact has the Kristalbad on nutrients (C, N, and P) levels in waters of the Elsbeek draining the effluents from the WWTP Enschede-west?
- What major biogeochemical water quality processes occur in the wetland system respectively in relation to nitrogen and phosphorus?
- What's the contribution of aquatic plants to breaking down and converting nutrients?
- Is DMS suitable to simulate the nutrient behavior and function of the artificial wetland?

- What impact has the different discharge condition on nutrient (C, N, and P) removal?
- What impact has the spill condition (sudden increase on nutrients concentration) on nutrients (C, N, and P) removal?

2 Literature review

2.1 Reviews on wetlands for water purification

People have a long history in conducting experiments aimed at the possibility of wastewater treatment. Käthe Seidel finish the first experiment in Germany in the early 1950s at the Max Planck Institute in Plön(Seidel, 1955).Then he make numerous tries with various types of wastewater such as phenol wastewaters(Seidel, 1966), dairy wastewaters (Seidel, 1976) and livestock wastewater (Seidel, 1941). Due to his experiment, subsurface flow constructed wetlands prevailed through Europe in the 1980s and 1990s(Vymazal, J.; Kröpfelová, 2008).

However, in North America, free water surface CWs are more popular. It started for all kinds of wastewaters treatment at the end of the 1960s and beginning of the 1970s ((Ewel, K.C.; Odum, 1984),(Odum, H.T.; Ewel, K.C.; Mitsch, W.J.; Ordway, 1977),(Kadlec, Robert H., Donald L. Tilton, 1979)).

Now, constructed wetlands (CWs) are increasingly accepted and used through the whole world for water storage and removing contaminants from waste water. Comparing to the conventional biological wastewater treatment systems, it has many superiority, such as moderater capital cost, low energy consumption, less maintenance requirement(Arroyo, Blanco, Cortijo, De Luis Calabuig, & Ansola, 2013),straightforward operation((García, Soto, González, & Bécares, 2008))higher efficiency(Vymazal, 2010).With the more attention paid to this field, more and more different kinds of CWs are implement in the real world to improve the mankind ’ s living environment.

2.2 Reviews on Hydrologic Models

During the last two decades a couple of models were developed for constructed wetlands with differing purposes. Generally some groups of models can be distinguished: on one hand mechanistic models try to display the complex and diffuse interaction of occurring processes, on the other hand the same kind of models are used to investigate single processes (Daniel Meyer et al., 2015) (Table 1).

Table 1 Hydrologic Models

Contributing modelling/simulation study	Model used	Water flow	Biochemical processes		Additional processes	D
			Species considered	Reactions		
Pálfy & Langergraber, 2013	**HYDRUS/CW2D**	**Saturated and unsaturated (Richards eq.)**	**12, incl. forms of COD, N and P**	**9**		**2D**
Morvannou, Choubert, Vanclooster, & Molle, 2014	**HYDRUS/CW2D**	**Saturated and unsaturated (Richards eq.)**	**12, incl. forms of COD, N and P**	**9**	**Ammonium adsorption**	**2D**
Pálfy & Langergraber, 2014	**HYDRUS/CWM1**	**Saturated and unsaturated**	**16, incl. forms of**	**17**	**Heat transfer**	**2D**

		(Richards eq.)	**COD, N and S**		**and root effects**	
Rizzo et al., 2014	**HYDRUS/CWM1**	**Saturated and unsaturated (Richards eq.)**	**16, incl. forms of COD, N and S**	**17**	**Ammonium adsorption**	**2D**
Samsó & Garcia, 2013, and Samsó & García, 2013	**BIO_PORE (COMSOL Multiphysics™)**	**Saturated (Darcy + adapting water table level)**	**18, incl. forms of COD, N and S**	**17**	**Root effects**	**2D**
Forquet, Wanko, Molle, Mosé, & Sadowski, 2009, and Petitjean et al., 2012	**Diph_M (MATLAB)**	**Unsaturated (two-phase flow)**	**forms of COD, NH4-N, oxygen**	**5**		**1D**
Morvannou, Forquet, Vanclooster, & Molle, 2012	**Dual-porosity model (DPM) in HYDRUS-1D**	**Saturated, unsaturated and preferential (Richards eq. + dual porosity)**	**0**	**0**	**Non-reactive tracer transport**	**1D**
Claveau-Mallet, Wallace, & Comeau, 2012	**PHREEQCP-hydroslag**	**Saturated**	**post treatment, no biochemical model**	**0**	**4 inorganic reactions**	**1D**
Sani, Scholz, Babatunde, & Wang, 2013	**Wang-Scholz-Model (COMSOL)**	**Vertical-flow wetlands with uniform water flow**	**no biochemical model**	**0**	**Clogging processes (particle setting)**	**1D**
Zeng, Soric, Ferrasse, & Roche, 2013	**RTD/GPS-X**	**Tanks in series with recycle and dead volumes under variable water content**	**12, incl. forms of COD, N (only soluble)**	**11**	**Interaction with biofilm growth**	**2D**
D Meyer & Dittmer, 2014	**RSF_Sim**	**Tanks in series with variable water content**	**no biochemical model**	**0**	**transport, filtration, adsorption, degradation**	**1D,1.5 D in future?**

The most advanced reaction models are implemented in the Wetland Module of the HYDRUS software package (Langergraber & Šimuunek, 2005), based again on the mathematical formulation of the ASMs (Henze, 2000).

Duflow surface water hydrodynamic model aims to describe the behavior of rivers in their natural conditions or state. As in all natural conditions in homogeneities and inconsistencies do prevail, thus proving difficult to integrate all sub systems making up a single system. Despite that, Duflow within its limits generate results that can be applied in real life situations such as planning and construction of engineering structures, decision-making, and environmental conservation and wetlands management. The objective of this case study was to establish a design flood recommendable for mitigation by using Duflow surface hydrodynamic model. Various design flows are simulated against the different proposed structures hence, the optimal structure is finally recommended when economic, social and environmental constraints are considered in the decision making process. The measure of building a green-storage is the best and optimal structure for flood mitigation (Joleha, 2009).

2.3 Reviews on nutrients models

Nutrients is an important part of water quality. The concentration of nutrients largely impact the environment of the water body. Too much nutrients could cause the pollution problems, such as algal bloom and eutrophication(Daniel, Sharpley, & Lemunyon, 1998).Then will impact the growth of the plant in water body and make the water quality worse again(Pease, Oduor, & Padmanabhan, 2010;Sims, Simard, & Joern, 1998).So it significant to get the knowledge of the distribution of nutrients in water body. Many researches focus on it and many models were settled to simulation the nutrients.

The SWAT model provides a continuous time simulations with daily time−step. It is designed to evaluate management effects on water quality in large, ungauged basins. SWAT simulates several forms of nitrogen and phosphorus within soil profiles and through surface and lateral subsurface flows. (Saleh & Du, 2004).The SWAT is made up by many components(Neitsch, Arnold, Kiniry, & Williams, 2011) and needed man input parameters.

HSPF is a comprehensive, continuous, lumped parameter, watershed−scale model that simulates the movement of water and nutrients on pervious and impervious surfaces(Bicknell, Imhoff, Kittle, Jr., Jobes, & Donigian, Jr., 2005). While it was less user−friendly, had numerous parameters to input and adjust, and required a long and strenuous calibration process. And due to the inability of this model to incorporate detailed farm management practices, the underprediction of nutrients always be with HSPF model(Saleh & Du, 2004).

The Annualized Agricultural Nonpoint Source Pollution (AnnAGNPS)model is developed by a cooperation between many organizations which include the United States Department of Agriculture (USDA), Agricultural Research Service (ARS) and USDA Natural Resources Conservation Service (NRCS).It intend to evaluate NPS pollution from agricultural watersheds (Bingner, Theurer, & Yuan, 2001;Young & Onstad, 1990;Yuan, Bingner, & Rebich, 2001). N,P are considered in the pollution. The nitrogen estimation usually get a good result. But it performed bed in the phosphorus simulation(Li et al., 2015).

Above all, theses model differ in complexity, considered processer, and required data for calibration and validation(Shamshad, Leow, Ramlah, Wan Hussin, & Mohd. Sanusi, 2008).Actually there is no single best model for all application. Thus, the most appropriate model will depend on the intended use and characteristics of the watershed under study(Li et al., 2015).

Duflow is the simple 1-D hydraulic model. The process it simulated and the parameter it enquired is simple and easy understanding. What's more it is suitable for the small scale water area which the Kristalbad is. So Duflow is a good choice for this research.

2.4 Research problem

Kristalbad is a relatively new wetland. It has multiple functions in a limited area. There is still not many research on its functioning as it is a new system. We do not have a good knowledge of how does the wetland perform in processing nutrients. Different types of plants in the wetland may have various contribution to breaking down and converting nutrients. The contribution are also influenced the light and air .All of above are important to the assessment of function of Kristalbad.

3 Data and methods

3.1 Description of the study area

Enschede is a city with 160,000 population and 142.71km2 area in the Twente region. It is in the province of Overijssel, eastern Netherlands.

Hengelo city is northwest of Enschede. Coming to the elevation, Hengelo is around 18-22 m above mean sea level while Enschede is 35- 45 m above sea level.

The Kristalbad lies on the border of the municipalities of Enschede and Hengelo, north of the Twente Canal and south of the Hengelosestraat / Enschedesestraat. It is situated from latitudes 52° 14’29” N to 52°14’50” N. The elevation ranges from 21 m to 24 m above sea level. The railway Hengelo-Enschede cuts through the area. The area is named after the former nearby pool here with that name, now the site “Zwaaikom”. Contrary to what the name suggests, the new Kristalbad does not allow for swimming.

Kristalbad project is a unique project because it offers a solution for:

To reduce peak rainfall - runoffs from Enschede towards Hengelo

To improve water quality by natural purification

An ecological connection between Driene and Twekkelo

Accommodation for nature recreation (bird watching, etc.)

The project has been of interest from various parties for many years. The redesign of Enschede North offered the chance to develop a multifunctional area. It is a complex but challenging project because so many features are combined in a limited area. The Kristalbad is achieved through intensive cooperation with various organizations and was completed in 2014.

Water retention

In Enschede and Hengelo is a little space to store excess rainwater. There is quite a difference in height between the two cities and in heavy rain, the water runs too fast to Hengelo. In order to keep the feet dry in Hengelo, the water must be collected temporarily. The Kristalbad accommodate 187,000 cubic meters of water.

Clear water

The water in the Kristalbad comes largely from the sewage treatment plant Enschede and flows through the Elsbeek within the area. Clean purified water, but little biologically active. To improve the environmental quality of the water, the "water machine" built. Inspired by proven methods of the Wetland Research Centre at the University of Halmstad in Sweden, the Regge & Dinkel this ingenious organic hiring and promotion system used. The compartments of Kristalbad are filled alternately, drain and dry. Under the influence of light, air and vegetation, the sediment does its purifying effect: breaking down and converting nutrients.

Ecological connection

It is expected that the ecological corridor is suitable for important species. These include frogs, salamanders and lizards, water shrew, pine martens, polecats and badgers.

Landscape quality the designer also was instructed to put down a firm and clear landscape structure, but one with respect for the elements that were present. With this in mind, the concept of the 'barcode' arise. Thereby Kristalbad receive a clear and recognizable style. The marks given shape by a variety of wooded strips, reeds and open water; a variety of wet and dry areas and in different widths. This design also gives literally shape the ecological corridor Twekkelo-Drienerlo whose Kristalbad part. The 'bar' is also reflected in the banks, boards, plank bridges and the two viewpoints.

Recreation

It is notable that between the watchtowers a sight line is kept open. Along the walking area people can do few cycling and hiking trails. On the water is a plank arranged. Those paths are clearly visible places with different water levels.

3.2 Research methods

Flowchart (Figure 2):

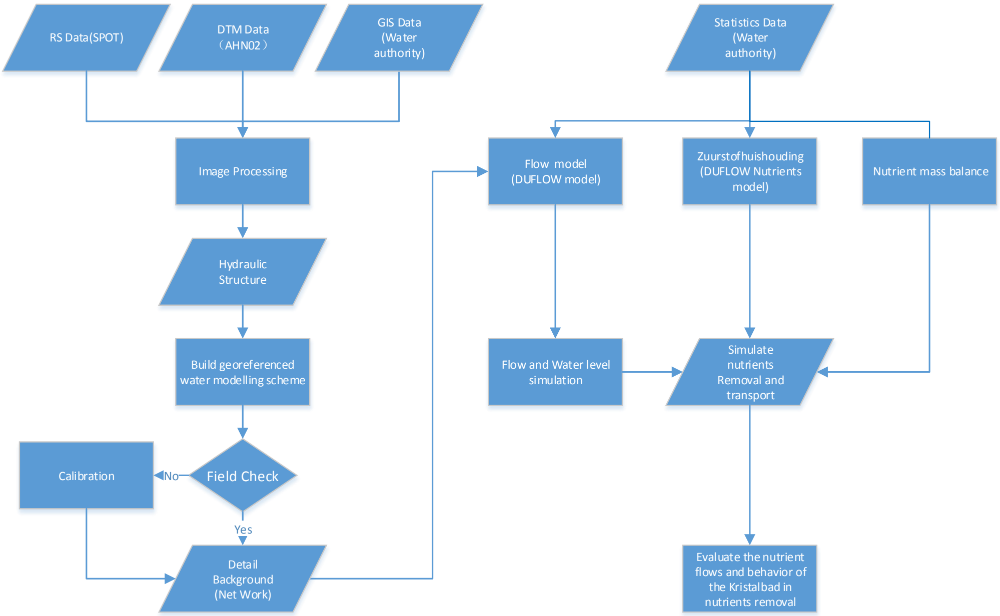


Figure 2 Flow chart of methods

3.3 Geospatial Data

Geospatial data includes Remote sensing data, DTM data and GIs data. Detailed geospatial high resolution imagery and geospatial data will be used to build the georeferenced water quality simulation modeling scheme.

3.3.1 Remote sensing data

SPOT6 –Pan and SPOT6-MS are used as RS Data. The spatial resolution is 1.5m and 6m respectively. The high resolution data can give a good help for the detail background. The digital aerial image data is from Geoweb (©RWS, 2013]) (Figure 3). After the band composite, the image presents in the true color, which is easy for classification. Mark the indicator of surface feature.

Figure 3 Remote sensing image background

3.3.2 GIS data

GIS data we collected from the "Vechtstromen" Water authority (aan- afvoervakken) (Figure 4).

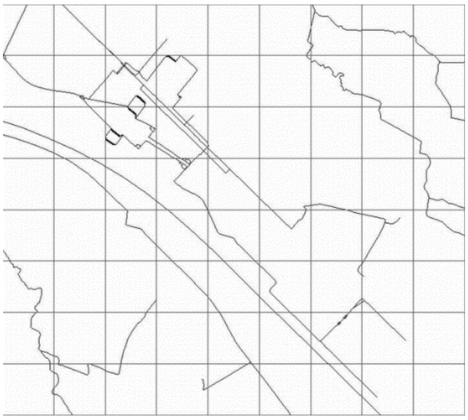


Figure 4 GIS data

The geospatial data is used to get the geo-information of the wetland. It can indicate the x, y coordinate of the note and more detail information of section. The network was built based on GIS data information and accompanying files in combination with a detailed image background using. The flow section lengths, width and depth were derived from the GIS data and background; the cross sections were derived based on field on-site visits and other information. Hydraulic structure can also be obtained from the GIS data. All of these can help us to build the network and provide geo-information to model building.

3.3.3 AHN2 data

The floor level and surface level data are collected from AHN (Actueel Hoogtebestand Nederland) web and previous research. Every cross section are set the floor level and surface level(Figure 5).

Figure 5 AHN2 data

3.4 Field work

Getting information from GIS data and remote sensing image can make the simple schematization of the flow network in DMS. Many data of the flow can be got from the GIS data. Field work are need to ensure the schematization precision. Section length, section width are checked with the GIS data to wonder if the data from GIS data is precise. Data of cross section and hydraulic structure are also recorded during the field work and are used to do the schematization calibration.

3.5 Data Collection

The data of the inflow and outflow are needed. The concentration of elements in water (such as oxygen, BOD, NH4, PO4), the data of flow (such as Discharge, water temperature), and other external variables are detailedly recorded by the local water authority. They record it as statistics. Some statistics can also get from previous research (see appendix 1).The water level is also gotten from the previous research.

3.6 Model descriptions

3.6.1 DUFLOW Flow

Duflow is a flexible one-dimensional water movement and water quality package for unsteady flows and forms the heart of the Duflow Modelling Studio (DMS). DMS is a complete model instruments that are easy to use, but that comprehensive, integrated water studies can be performed.

The Duflow Modelling Studio consists of the following modules: Duflow (quantity and quality), RAM - Rain Drain Module, TEWOR and MoDuflow.

The Duflow Modeling Studio provides the modeler a very user friendly graphical user interface (GUI). In this environment model data can be entered easily; with the Network Editor, a network can be constructed by dragging and clicking of objects. The Scenario Manager makes it possible scenarios, calculating and results of various interventions in the water system to compare.

Duflow water movement

With the aid of Duflow, it is possible to calculate the non-stationary flow in a network of canals, rivers and channels. Example: Prediction Over discharge waves;

Assessing the impact of infrastructure development on water resources;

Examining the consequences of proposed changes in water level management.

The network can be entered easily using the Network Editor with a geographical background as a basis. The results of calculations can be presented in graphs and tables. By making use of the Presentation mode, the results can also be displayed in the network itself.

These equations, which are the mathematical translation of the laws of conservation of mass and of momentum, read:

Equation (1):

$$\frac{\partial \mathrm{B}}{\partial \mathrm{t}}+\frac{\partial Q}{\partial x}=0$$

and

Equation (2):

$$\frac{\partial \mathrm{Q}}{\partial \mathrm{t}}+gA\frac{\partial H}{\partial x}+\frac{\partial(\alpha Qv)}{\partial x}+\frac{g|Q|Q}{C^2AR}=a\gamma w^2\cos(\Phi-\emptyset)$$

While the relation:

Equation (3):

$$\mathrm{Q}=\mathrm{v}\cdot\mathrm{A}$$

Holds and where:

t : time [s]

x: distance as measured along the channel axis [m]

H (x, t): water level with respect to reference level [m]

$v\ (x, t)$: mean velocity (averaged over the cross-sectional area) [m/s]
Q (x, t): discharge at location x and at time t [m^3/s]
R (x, H): hydraulic radius of cross-section [m]
$\alpha\ (x, H)$: cross-sectional flow width [m]
A (x, H): cross-sectional flow area [m^2]
$b(x, H)$: cross-sectional storage width [m]
B (x, H): cross-sectional storage area [m^2]
g: acceleration due to gravity [m/s^2]
C (x, H): coefficient of De Chézy [$m^{1/2}/s$]
$w\ (t)$: wind velocity [m/s]
$\Phi\ (t)$: wind direction in degrees [degrees]
$\emptyset\ (x)$: direction of channel axis in degrees, measured clockwise from the north [degrees]
$\gamma\ (x)$: wind conversion coefficient [-]

α: correction factor for non-uniformity of the velocity distribution in the advection term, defined as:

$$\alpha = \frac{A}{Q^2} \int v(y, z)^2 dydz$$

where the integral is taken over the cross-section A. [m^2]
The mass equation (Equation (1) states that if the water level changes at some location there will be the net result of local inflow minus outflow. The momentum equation (Equation (2) expresses that the net change of momentum is the result of interior and exterior the forces like friction, wind and gravity.
For the derivation of these equations it has been assumed that the fluid is well-mixed and hence the density may be considered to be constant.

The advection term in the momentum equation $\frac{\partial(\alpha Q v)}{\partial x}$ can be broken into $\alpha \left(2 \frac{Q}{A} \frac{\partial Q}{\partial x} - \frac{Q^2}{A^2} \frac{\partial A}{\partial x}\right)$.

The first term represents the impact of the change in discharge. The second term which expresses the effect of change in cross-sectional flow area is called the Froude term. In case of abrupt changes in cross-section this Froude term may lead to computational instabilities.
Equation (1 and Equation (2 are discretized in space and time using the four-point implicit Preissmann scheme.
A mass conservative scheme for water movement is essential for proper water quality simulation. If the continuity equation is not properly taken into account, the calculated concentration will not match the actual concentration. The mass conservative scheme is based on the fact that the error made in the continuity equation will be corrected in the next time step. Mass conservation is therefore guaranteed.
For a unique solution of the set of equations additional conditions have to be specified at the physical boundaries of the network and at the sections defined as hydraulic structures. The user-defined conditions at the physical boundaries may be specified as levels, discharges or a relation between both, for instance a (tidal) elevation H, a discharge Q, or a so-called QH relation.
At internal junctions the (implicit) condition states that the water level is continuous over such a junction node, and that the flows towards the junction are in balance since continuity requires:
Equation (4):

$$\sum_{J=1}^{JJ} Q_{i,j} + Q_i = 0$$

Where:
I: indication for the junction node
$Q_{i,j}$: discharge from node j to node i
q_i: additional or lateral flow to node i

The above equations are solved at each time step. They are transformed into a system of (linear) equations for the water levels. Equation (4 is not used in nodes where a water level is prescribed as boundary condition. In such a node no equation is needed because the water level is already known. Discharge boundary conditions are taken into account as the additional flow q_i.

To start the computations, initial values for H and Q are required. These initial values must be provided by the user; they may be historical measurements, obtained from former computations or just a first reasonable guess.

Additionally wind stress and rainfall conditions can be specified.

Various types of control structures can be defined such as weirs, culverts, siphons and pumping stations. Here in this study, weirs, culverts and general structures are defined for the network. At weirs and other structures discharges and levels can be controlled by manipulating the gates. DUFLOW allows for specification of such an operation using the so-called trigger conditions: depending on flow conditions at specified locations in the network, parameters such as the width of the weir, the level of the sill etc. can be adjusted during the computation. A common characteristic of structures is that the storage of water inside the structure is negligible compared with the storage in the open channels. The definition of flow direction in a structure is the same as the definition in ordinary channel sections, flow from the begin node to the end node is assumed to be positive. The discharge over a weir depends on the water level at both sides, the level of the sill, type of structures and the flow condition.

3.6.2 DUFLOW water quality

The water quality Duflow module is suitable for simulating the transport of substances into the surface up to and including the simulation of extensive water quality processes.

In Duflow-water quality, a distinction is made between substances that move along with the water phase, for example, the dissolved substances, and the substances which do not move along with the water phase, but which, as it were, to the bottom are connected. This distinction, the user, for example, also offers the possibility to include the water bottom in the quality model to model and the exchange of substances between the aqueous phase and the water bottom.

3.6.3 Oxygen model (DUFLOW model)

The model describes the variation in the oxygen concentration as a result of a number of processes which in turn are dependent on environmental conditions such as temperature, light irradiation, flow etc.

3.6.3.1 Processes

The oxygen concentration varies in time and place by three types of processes:

[1] Transport processes in (with) water. These are automatically calculated in Duflow in the transport modules. It is advective transport (with the bulk flow) and dispersive transport.

[2] Transport processes across interfaces. This relates to the interface water-air: reaeration and the interface soil-water: sediment oxygen consumption, SOD.

[3] Processes in the water itself. There are oxygen-producing processes, such as primary production by aquatic plants and / or algae, and oxygen-consuming processes, whereby substances are oxidized, usually through the intermediary of micro-organisms. Therefore the latter process is usually summarizes as the term: BOD (biological oxygen consumption).

Not all descriptions are included in the Duflow model. Which describes processes and how much detail to take with it, will depend on the available input data, the significance of the calculations, and the desired precision of the properties of the water system.
Here is the equation of the oxygen model:

$$\frac{dO_2}{dt} = --v \cdot \frac{\partial O_2}{\partial x} + \mathrm{D} \cdot \frac{\partial^2 O_2}{\partial x^2} + \frac{\mathrm{d\Phi}}{\mathrm{dt}} - \frac{\mathrm{d(NH4)}}{\mathrm{dt}} - \frac{\mathrm{dBOD}}{\mathrm{dt}} - \frac{\mathrm{dSOD}}{\mathrm{dt}} + \frac{\mathrm{dP}}{\mathrm{dt}}$$

Where Φ is the reaeration, P is oxygen from primary production. The equation concludes the process of advection, dispersion, reaeration, nutrients consumption, BOD, SOD and primary production.

3.6.3.2 Application

The model for the oxygen levels can be used, in principle, both for free-flowing and semi-stagnant waters. Application possibilities can be found in the simulation of effects of point source on the oxygen content of the receiving water. The model can predicted, for example, the effect of an overflow from a combined sewer system, or an effluent discharge. In addition, the model can be used for the analysis of measures to improve the oxygen levels, such as the flushing of a system or the removal of an oxygen-consuming sludge layer from the bottom. The latter can be simulated by reducing the sediment oxygen consumption. In a simple manner, the production of oxygen by algae and water plants as described in the model, so that possibly also the day / night rhythm in the oxygen content can be taken into account.

3.6.3.3 Limitation

While it is assumed that the water over the vertical is homogeneously mixed. For flowing water, this is usually the case. In stagnant waters, however, stratification may occur. Conditions under which this particular happens to be calm and high insolation (lots of sun) and especially in the somewhat deeper systems. In such situations, this model cannot be applied and a two-layer model is required.
Also with duckweed-covered waters, the model is not simply applicable. Cover with duckweed affects reaeration and the solar radiation and thus the production of oxygen by the primary producers. In whole-covered systems may optionally be switched off and the production of oxygen reaeration be made equal to zero. For systems that are only partially covered a simple solution is not readily available, and additional studies will be necessary to determine the contribution of the affected processes.
If one wants to achieve with the model, the day / night rhythm in the oxygen concentration, one must realize that the parameters held constant in these descriptions. In reality, these are not. Certainly over longer periods, this will vary. Among other things, by changes in the species composition of the algal population and the adaptation of the algae at ambient conditions. This allows the use of this option of the model only over a relatively short time scales as possible. Consideration should be given simulation periods of several days to a week.

3.6.3.4 Required entry

The input of the Duflow consists of following parts:
Initial conditions
Preconditions including point releases
Parameters
External variables

Here are the parameters the model needed (table2).

Table 2 Parameters of Oxygen model

Type	Name	Source	Typical value
initial condition	O2 water Column	Measurement	
	BOD1		
	BOD2		
	NH4		
Boundary conditions	O2 system boundary	Measurement	
	BOD1		
	BOD2		
	NH4		
	O2 point Discharges	Measurement	
	BOD1		
	BOD2		
	NH4		
Parameters	Kl,min Minimum mass transfer constant flow systems	literature	0.1 m.dag-1
	θKl Temperature coefficient mass transfer	literature	1.024
	Kd1 Constant speed Bod1 demolition	literature calibration experimental	0.4-0.8 dag-1
	Kd2 Constant speed Bod2 demolition	literature calibration experimental	0.1-0.3 dag-1
	Vs1 sedimentation BOD1	literature experimental	1-5 m.dag-1
	Vs2 sedimentation BOD2	literature experimental	<1 m.dag-1
	fd1 Group resolved BOD1	literature experimental	0.3-0.4(overflow)
	fd2 Group resolved BOD2	literature experimental	0.8-1.0
	KO2 Monod constant O2 inhibition BOD degradation	literature	1MG O2 L-1
	Θkd Temperature coefficient BOD degradation	literature	1.03-1.05
	Knit Constant speed nitrification	literature calibration	0.1-1.0 day-1
	Θknit Temperature coefficien nitrification	literature	1.05-1.10
	KNO2 Monod constant O2 inhibit nitrification	literature	1.0-2.0 mg O2 L-1
Parameters	βOxygen Production constant	literature calibration	10-4-10-3 G O2 DAY-1 MG CHL-1(WM-2)-1
	Θszv Temperature coefficient szv	literature	1.06
	OPTKl Mass transfer option (0 = stagnant; 1 = flowing)		
External variables	D Dispersion constant	Literature/exper.	See Chapter 1.3.4
	T Watertemperature	Measurement / Estimation	
	SBOD1 Diffuse tax BOD1	Estimation	system Specific Memory
	SBOD2 Diffuse tax BOD2	Estimation	system Specific Memory
	SNH4 Diffuse TAX NH4	Measurement / Estimation	system Specific Memory
	I0 Irradiance [PAR] surface	KNMI	
	A Algae Biomass	Measurement	10-200 g .l-1
	SZV Sediment Oxygen Demand	Literature/exper.	0,5-2,0 g.m-2.dag-1
	W Wind Speed	KNMI	

The model care the NH4 mostly, we will ignore the influence of phosphorus.

3.6.4 EUTROF1A model (DUFLOW model)

Within the series eutrophication models in Duflow EUTROF1A is the most basic model. The set process descriptions EUTROF1A derived from a model that is supplied with Duflow. Compared to this existing model is the set of process descriptions simplified. The main change concerns the description of the phosphate metabolism. This is adjusted to provide the preconditions for the state quantities more in line with the field measurements. Another important difference is that it is no longer described the oxygen levels in EUTROF1A. This allows all processes in EUTROF1A have become implicit insensitive to oxygen. Thus EUTROF1A has become a simple model, which focuses on the description of nutrient cycles and algal biomass. As well as being the exchange of nutrients between the sediment and the water column above is not described in EUTROF1A.

The starting point for EUTROF1A is a model as simple as possible to put down, which in practice can be obtained a reasonable estimate of the algal biomass and which can be predicted levels of nutrients. This set-up in order to reduce the number of parameters and variables, so that the ease of use is increased, while the estimate remains sufficiently reliable.

3.6.4.1 Processes

In the model, the following state variables are distinguished:
A Algae Biomass
DP Dissolved phosphate (represents the orto-P)
PP particulate phosphate
Norg Organically bound nitrogen
NH4 Ammonium Nitrogen
NO3 Nitrate Nitrogen
In Figure 6 provides an overview of the interactions between the state variables in the model. The model describes alongside the algal biomass cycles of nitrogen and phosphate.

The nitrogen balance are three processes underlying these are mineralization, nitrification and denitrification.

- In the first process, mineralization, organic nitrogen is degraded to ammonium. This process is also called ammonification.
- The second process, nitrification, actually proceeds in two steps, under aerobic conditions in which ammonium is converted to nitrate by bacteria. Intermediate is nitrite (NO2). Since the conversion of nitrite to nitrate much faster than the conversion of ammonium to nitrite, the nitrification process in EUTROF1A described as a one step process.
- Finally, nitrate can be converted into free nitrogen (N2). This process is known as denitrification and proceeds under oxygen-poor conditions, making denitrification in the water column is usually negligible. Denitrification occurs mainly in sedimentary layers and in biofilms.

In practice, concentrations are often presented to Kjeldahl nitrogen and total nitrogen. The Kjeldahl nitrogen concentration is equal to the sum of organically bound nitrogen, the nitrogen in the algae and the ammonium nitrogen. Total nitrogen is the sum of all the various forms of nitrogen. Both variables can be calculated after selection as an output variable (Figure 6).

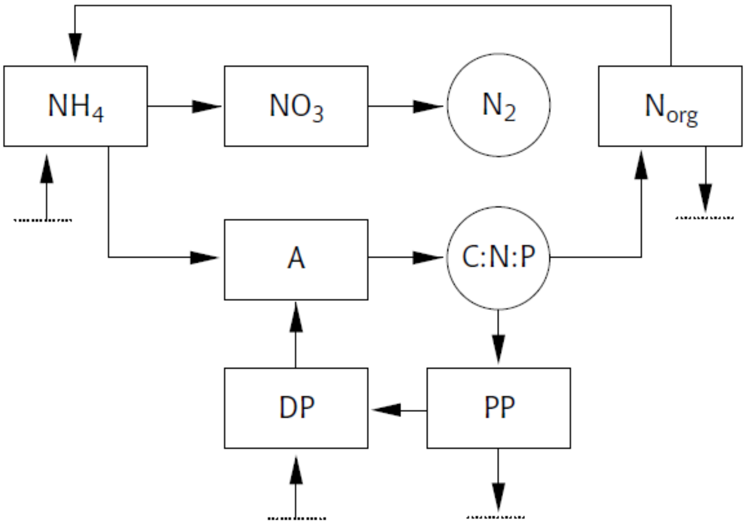


Figure 6 Interactions between the state variables

In the phosphate metabolism makes the model only distinction between two types of phosphate. These are the dissolved phosphate (DP), representative of the ortho-phosphate measured in practice, and the particulate bound phosphate (PP). The DP is other than PP incorporated by algae. In addition, sedimentation and resuspension influence the fate of PP in contrast to DP which is only influenced by dispersion and advection. Sedimentation in this model is the net difference between sedimentation and resuspension and is entered as a constant. In EUTROF2a model both processes have been described separately.

The subsequent delivery of phosphate from the sediment is not described in this model. However, the user can specify a backorder flux, assuming that the subsequently delivered phosphate released in solution. One must realize that in this way the chosen description for the phosphate metabolism only a simplified representation of reality. For a more complex description, reference is made to the EUTROF2a model.

In practice often reported total phosphate (P-to). Within EUTROF1A this quantity is an output variable, the total phosphate content is the sum of DP, PP, and the phosphate in the algae.

Here is the equation of the nutrients model:

$$\frac{dN_{org}}{dt} = - - v \cdot \frac{\partial N_{org}}{\partial x} + \mathrm{D} \cdot \frac{\partial^2 N_{org}}{\partial x^2} - k_{min}\theta_{min}^{(T-20)} N_{org} - \frac{V_{so}}{z} N_{org} + k_{loss}\alpha_{NC}A$$

Wherein: k_{min} rate constant for the mineralization of organic matter (day^{-1})
θ_{min} temperature coefficient for the mineralization of organic matter (-)
V_{so} sedimentation of organic matter (m.dag^{-1})
Z water depth (m)
k_{loss} rate constant for loss (day 1)
α_{NC} constant nitrogen / carbon ratio in the algae (g N. g C^{-1})

$$\frac{dNH_4}{dt} = - - v \cdot \frac{\partial NH_4}{\partial x} + \mathrm{D} \cdot \frac{\partial^2 NH_4}{\partial x^2} - k_{nit}\theta_{nit}^{(T-20)} NH_4 + k_{min}\theta_{min}^{(T-20)} N_{org} - \alpha_{NC}A + \frac{N_{flux}}{Z}$$

Wherein: k_{nit} nitrification rate constant (day^{-1})
θ_{nit} temperature coefficient for the nitrification (-)
N_{flux} subsequent delivery flux of ammonium from the sediment (gm -2 .day -1)

$$\frac{dNO_3}{dt} = - - v \cdot \frac{\partial NO_3}{\partial x} + \mathrm{D} \cdot \frac{\partial^2 NO_3}{\partial x^2} - k_{den}\theta_{den}^{(T-20)} NO_3 - k_{nit}\theta_{nit}^{(T-20)} NH_4$$

Wherein: k_{den} denitrification rate constant (day^{-1})
θ_{den} temperature coefficient for the denitrification (-)

$$\frac{dPP}{dt} = - - v \cdot \frac{\partial PP}{\partial x} + \mathrm{D} \cdot \frac{\partial^2 PP}{\partial x^2} - k_{min}\theta_{min}^{(T-20)} PP - \frac{V_{so}}{z} PP + k_{loss}\alpha_{PC}A$$

Wherein: α_{PC} constant phosphate / carbon ratio in the algae (g P. g C^{-1})

$$\frac{dDP}{dt} = - - v \cdot \frac{\partial DP}{\partial x} + \mathrm{D} \cdot \frac{\partial^2 DP}{\partial x^2} + k_{min}\theta_{min}^{(T-20)} PP - \alpha_{PC}A + \frac{P_{flux}}{Z}$$

Wherein: P_{flux} subsequent delivery flux of phosphate from the sediment (gm -2 .day -1)

3.6.4.2 Application

The simple design of EUTROF 1A, the number of applications are limited. Below, the application and the constraints of the model are displayed.

Applications for the model:
- Simulations of algae and nutrients on small time scales (from a few weeks to a month).
- Evaluation of measures, such as flushing and the deepening of water.
- To assess the effect of nutrient limitation on the system.

3.6.4.3 Limitation

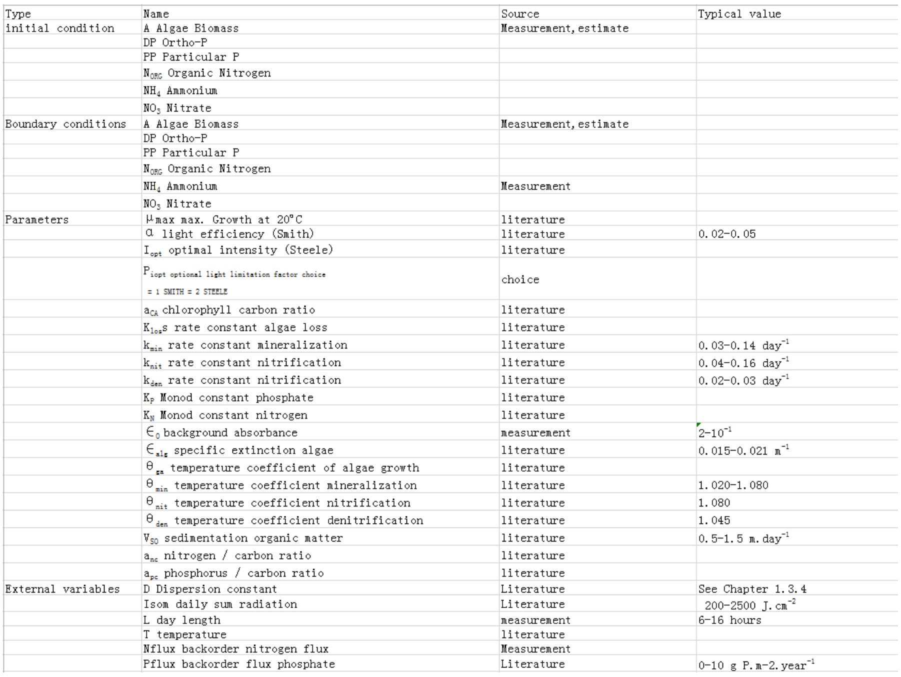
Limitations of the model:
- When used on small time scales should be realized that EUTROF1A is a simple model, and the reality is much more complex. For example, it is known that, inter alia, algae adapt to changing light conditions, and mixing regimes, and may have a variable C / Chl-a relationship. Processes, none of which are included in this model.
- The model is not designed to simulate the long-term effect of reduced external load, in that the sediment-water interaction is not dynamic described.
- EUTROF1A describes the growth of one type of alga, which is representative of the entire phytoplankton community. In particular, in an area where succession occurs this is a very rough approximation.

- Finally, the net sedimentation in the dynamic model has not been described. Changes in the flow variables such as flow rate thereby do not have any impact on the net sedimentation.

3.6.4.4 Required entry

The input of the Duflow consists of following parts:
Initial conditions
Preconditions including point releases
Parameters
External variables
Here are the parameters the model needed (table 3).

Table 3 Parameters of Eutrof1a model



Type	Name	Source	Typical value
initial condition	A Algae Biomass	Measurement, estimate	
	DP Ortho-P		
	PP Particular P		
	N_{ORG} Organic Nitrogen		
	NH_4 Ammonium		
	NO_3 Nitrate		
Boundary conditions	A Algae Biomass	Measurement, estimate	
	DP Ortho-P		
	PP Particular P		
	N_{ORG} Organic Nitrogen		
	NH_4 Ammonium	Measurement	
	NO_3 Nitrate		
Parameters	μmax max. Growth at 20°C	literature	
	α light efficiency (Smith)	literature	0.02-0.05
	I_{opt} optimal intensity (Steele)	literature	
	P_{iopt} optional light limitation factor choice = 1 SMITH = 2 STEELE	choice	
	a_{CA} chlorophyll carbon ratio	literature	
	K_{los}s rate constant algae loss	literature	
	k_{min} rate constant mineralization	literature	0.03-0.14 day^{-1}
	k_{nit} rate constant nitrification	literature	0.04-0.16 day^{-1}
	k_{den} rate constant nitrification	literature	0.02-0.03 day^{-1}
	K_P Monod constant phosphate	literature	
	K_N Monod constant nitrogen	literature	
	ϵ_0 background absorbance	measurement	$2\text{-}10^{-1}$
	ϵ_{alg} specific extinction algae	literature	0.015-0.021 m^{-1}
	θ_{ga} temperature coefficient of algae growth	literature	
	θ_{min} temperature coefficient mineralization	literature	1.020-1.080
	θ_{nit} temperature coefficient nitrification	literature	1.080
	θ_{den} temperature coefficient denitrification	literature	1.045
	V_{SO} sedimentation organic matter	literature	0.5-1.5 $m.day^{-1}$
	a_{nc} nitrogen / carbon ratio	literature	
	a_{pc} phosphorus / carbon ratio	literature	
External variables	D Dispersion constant	Literature	See Chapter 1.3.4
	Isom daily sum radiation	Literature	200-2500 $J.cm^{-2}$
	L day length	measurement	6-16 hours
	T temperature	literature	
	Nflux backorder nitrogen flux	Measurement	
	Pflux backorder flux phosphate	Literature	0-10 g P.m-2.$year^{-1}$

3.7 Data analysis and results

After running the model, the change of concentration of nutrients with the distance from entrance and with time can be simulated. We used the past data to compare with the model simulated data. Evaluate the efficiency of the simulation. If the result of the simulation is not acceptable, then change the scenario parameters of the model to get a better result. Until the result can be acceptable, use the model to predict the change in concentration of nutrients in the future.

3.8 Expected outputs

Analyzing the data from entry and exit of the flow with mass balance, we can find the how much the nutrients get in the flow and how much go out. Then we can find how much of the nutrients stay and break down in in the wetland. Get an evaluation of the behavior of wetland in nutrients.
After building the models, we set the scenarios. Put the parameters we collect form the water authority and previous research and literatures into the model. We got the nutrients removal in each wetlands parts and the efficiencies of wetland about the nutrients removal. With the

comparison with past data, the suitability of the model can be evaluated. It also help us get a good understanding of the function of the complex process in the wetland.

4. Hydrodynamic modeling

4.1 Simplified Steady state model_1 (M1)

This very simplified model is used for a first approximation and evaluation of the flow and transport rates in the system. It assumes:
Realistic dimensions of channels and pond volumes, lengths, derived from high resolution geo data and field checks;
steady state (constant flow Qadd inputs; QH or QL out)
No gravity bed slope (zero bottom level; piston flow Qadd;)
No implementation of flow regulating structures
It is used for the initial evaluation of flow rates and velocities, residence times and substance concentrations using
Steady state flow conditions
Different discharges (from RWZI EnsWest) and
a simple tracer 1D ADR transport model of a substance
And as training purposes (in order to get more familiar) with the real and modelling system
In second instance, a number of water quality processes sub-models were build and evaluated using this simplified model:
tracer substance (no decay)
substance with decay (a/o constant diffuse source)
oxygen model with CBOD and N-Amm (NOD)
Nutrient (eutrophication-type) model (light, temp, mineralisations, nutrients, denitrification …).

4.1.1 Description of the modelling system

Schematization of the flow network in DMS

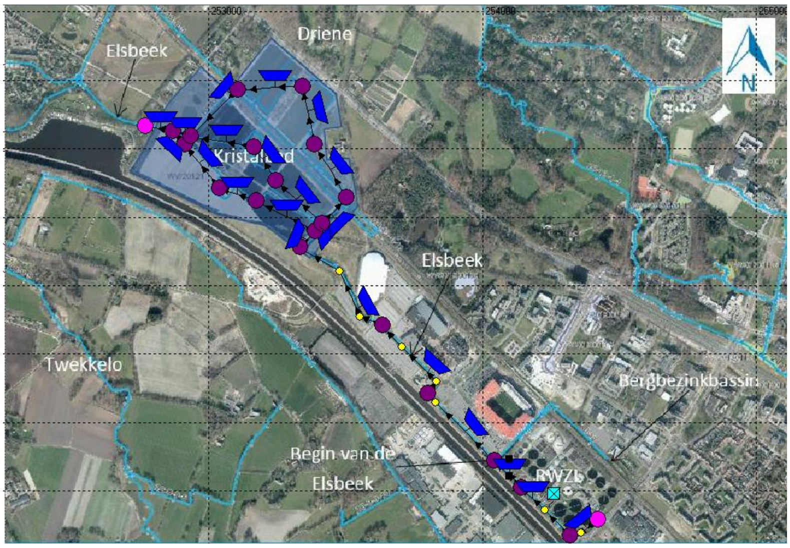


Figure 7 Schematization of the flow network in DMS

The network was built based on GIS data information from the “Vechtstromen” Water authority (aan- afvoervakken) and accompanying files in combination with a detailed image background using (digital aerial image data from Geoweb (©RWS, 2013]). (Figure 7-8)
The flow section lengths were derived from the GIS data and background; the cross sections were derived based on field on-site visits and other information.

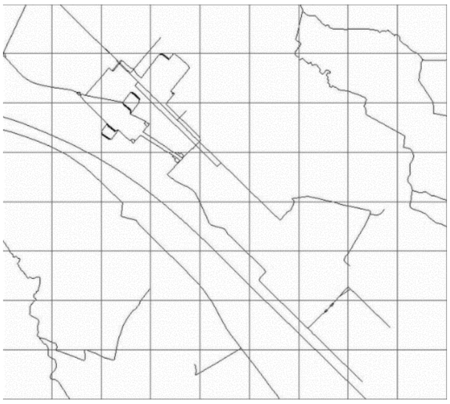


Figure 8 network of the flow

Hereafter, the network objects are succinctly described and how they were implemented in Duflow DMS

4.1.1.1 Network schematization: part A (RWZI EnschedeWest)

Figure 9 Schematization of the part A in DMS

The part A (Figure 9) includes 5 nodes(NOD 00000,00001, 00015 ,00004, 000023), 4 sections(SEC 00000,00003,00008), 3 cross section(CSC 00000,00001,00019), 2scheme point(SCH 00005,00009), 1 discharge point(DIS 00000).
NOD 00004 is the start points of the flow model (Figure 10).

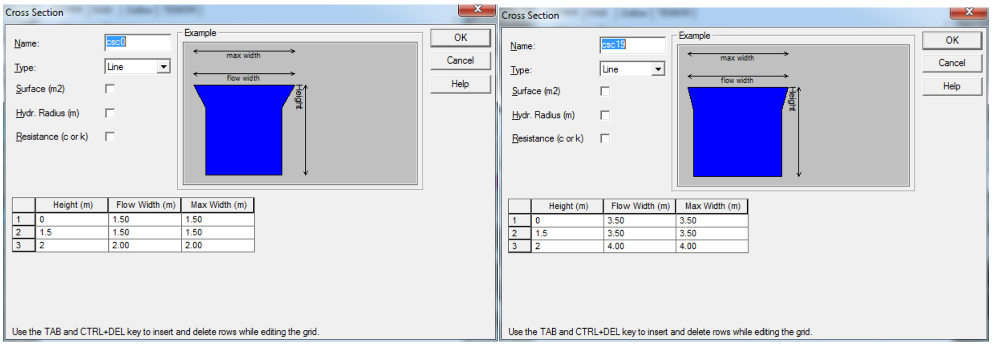
Figure 10 Start Node -NOD 00004

Figure 11 Discharge point-DIS 00000

The discharge point discharges the water from the effluent treatment plant (Figure 11). SEC00003, SEC00000 and SEC00008 connect one of the start point NOD0004 to the joint node NOD0001 with the respective lengths of 48m, 193m and 60m. (Figure 12)

Figure 12 Section 00003, Section 00000 and Section 00008

Cross section 00000, 00001 are in section 00003, section 00000. These two cross sections have the same structure. The cross sections (CSC00000 and CSC00001) for this part are both set as scheme *csc 0*. Cross section 00019 is in section 00008. *Csc 19* is set as the scheme of cross section 00019(Figure 13).



Cross Section

Name: csc0

Type: Line

Surface (m2) ☐

Hydr. Radius (m) ☐

Resistance (c or k) ☐

	Height (m)	Flow Width (m)	Max Width (m)
1	0	1.50	1.50
2	1.5	1.50	1.50
3	2	2.00	2.00

Use the TAB and CTRL+DEL key to insert and delete rows while editing the grid.

Cross Section

Name: csc19

Type: Line

Surface (m2) ☐

Hydr. Radius (m) ☐

Resistance (c or k) ☐

	Height (m)	Flow Width (m)	Max Width (m)
1	0	3.50	3.50
2	1.5	3.50	3.50
3	2	4.00	4.00

Use the TAB and CTRL+DEL key to insert and delete rows while editing the grid.

Figure 13 Scheme csc 0 and Scheme csc19

4.1.1.2 Network schematization: part B (middle part and weir)

Figure 14 Schematization of Part B

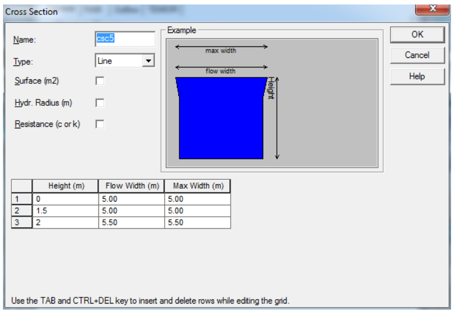
The part B (Figure 14) includes 4 nodes(NOD 00001,00003,00018,00022), 3 sections(SEC 00002, 00014, 00015), 3 cross section(CSC 00003,00004,00005), 5 scheme point(SCH 00000, 00001, 00002, 00003, 00004). The part B starts as a confluence from NOD00001 passing by NOD00022 and NOD00018 and ends at NOD00003. Sections 00002 (150m) and 00014 (118m) involve the same cross section settings as cross section 00019. Cross section 00003 and 00004 are set as scheme *csc19*. Cross section of Section 00015 (103m) is different from the other two. The scheme of cross section 00005 is named as *csc5*. (Figure 15-19)

Figure 15 NOD 00001

Figure 16 Section 00002

Figure 17 Section 00015

Figure 18 Section 00014



Name: csc5

Type: Line

Surface (m2) ☐

Hydr. Radius (m) ☐

Resistance (c or k) ☐

	Height (m)	Flow Width (m)	Max Width (m)
1	0	5.00	5.00
2	1.5	5.00	5.00
3	2	5.50	5.50

Use the TAB and CTRL+DEL key to insert and delete rows while editing the grid.

Figure 19 Scheme csc5

4.1.1.3 Network schematization: part C: Kristalbad wetlands

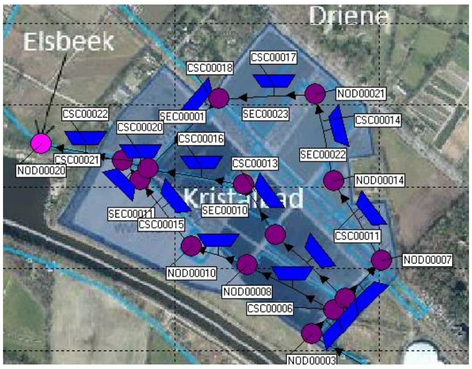


Figure 20 Schematization of Part C

There are Intake channel, 3 pond systems and an outlet system involved in this part (Figure 20-21). Along the direction of the flow from the south to the north are respectively pond system No.1, No.2 and No.3.

Intake channel

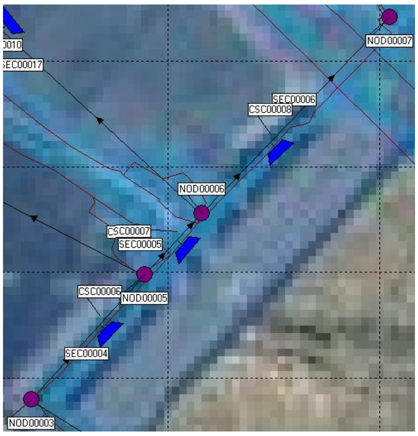
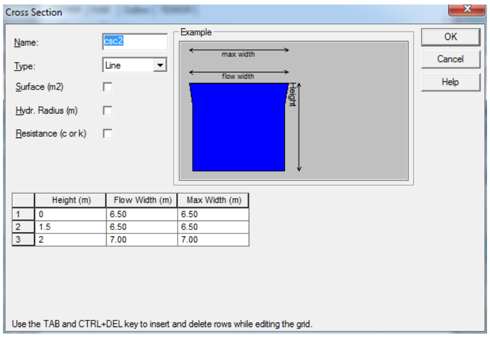


Figure 21 Schematization of Intake channel

The intake channel includes 4 nodes(NOD 00003,00005,00006,00007), 3 sections(SEC 00004, 00005,00006), 3 cross section(CSC 00006,00007,00008).The confluence flows into ponds systems through the intake channel which connects the beginning points (NOD00003, NOD00006 and NOD00007) of 3 ponds with SEC00004 (48m), SEC00005 (23m) and SEC00006 (48m). Cross section 00006, 00007, 00008 are in these sections, these three cross sections have the same structure. The cross section scheme settings for this channel are scheme *csc2*. (Figure 22-24)

Figure 22 Node 00003

Figure 23 Section 00004,Section 00005 and Section 00006



Name: csc2

Type: Line

Surface (m2) ☐

Hydr. Radius (m) ☐

Resistance (c or k) ☐

	Height (m)	Flow Width (m)	Max Width (m)
1	0	6.50	6.50
2	1.5	6.50	6.50
3	2	7.00	7.00

Use the TAB and CTRL+DEL key to insert and delete rows while editing the grid.

Figure 24 Scheme River 2

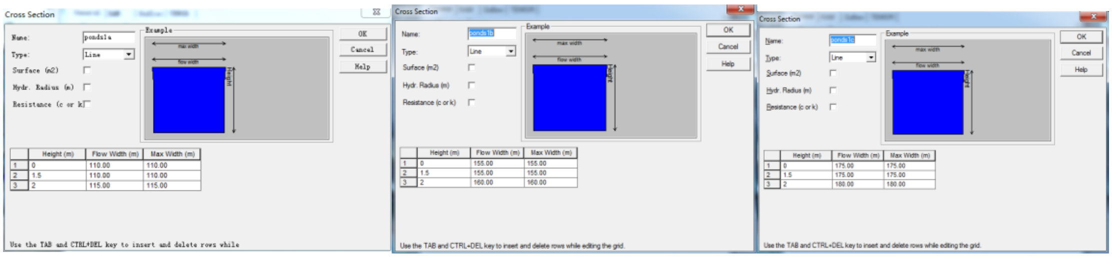
Pond system 1 (vak_1): Pond_11 - Pond_12 – Pond_13

Figure 25 Schematization of Ponds system 1

The Pond system 1 (Figure 25-26) includes 4 nodes(NOD 00005,00008,00010,00012), 3 sections(SEC 00009,00011,00016), 3 cross section(CSC 00009,00012,00015).

Figure 26 Pond system 1

Pond_11 is between NOD00005 and NOD00008. The length here (SEC00016) is about 114m with cross section CSC00009. Pond_12 is from NOD00008 to NOD00010 as long as 75m (Section 00009) with the cross section simulated as CSC00012. Pond_13 begins at NOD00010 and ends at NOD00012 with the length of 118m (Section 00011) and a cross section named CSC00015.Scheme 'Ponds 1a' i, 'Ponds 1b' and 'Ponds 1c' are presented cross section 00009, 00012 and 00015 respectly. Here are the structures(Figure 27).



Name: ponds1a
Type: Line
Surface (m2) ☐
Hydr. Radius (m) ☐
Resistance (c or k) ☐

	Height (m)	Flow Width (m)	Max Width (m)
1	0	110.00	110.00
2	1.5	110.00	110.00
3	2	115.00	115.00

Use the TAB and CTRL+DEL key to insert and delete rows while

Name: ponds1b
Type: Line
Surface (m2) ☐
Hydr. Radius (m) ☐
Resistance (c or k) ☐

	Height (m)	Flow Width (m)	Max Width (m)
1	0	155.00	155.00
2	1.5	155.00	155.00
3	2	160.00	160.00

Use the TAB and CTRL+DEL key to insert and delete rows while editing the grid.

Name: ponds1c
Type: Line
Surface (m2) ☐
Hydr. Radius (m) ☐
Resistance (c or k) ☐

	Height (m)	Flow Width (m)	Max Width (m)
1	0	175.00	175.00
2	1.5	175.00	175.00
3	2	180.00	180.00

Use the TAB and CTRL+DEL key to insert and delete rows while editing the grid.

Figure 27 Cross Section scheme for pond_11, pond_12, pond_13

Pond system 2 (Vak_2): Pond_21-Pond_22-Pond_23

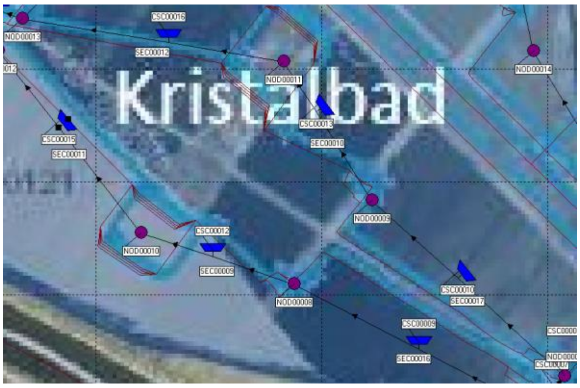
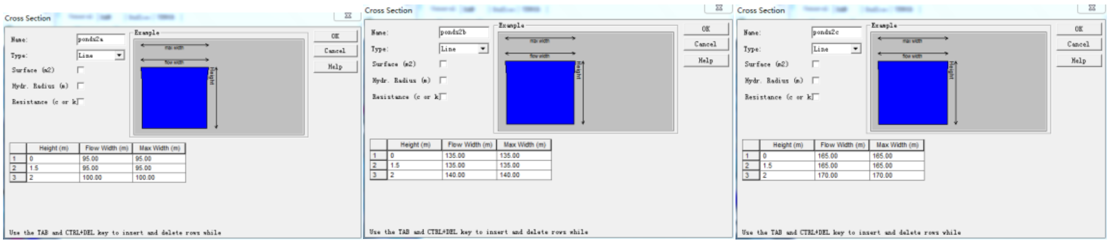


Figure 28 Schematization of Ponds system 2

The Pond system 2 (Figure 28-29) includes 4 nodes (NOD 00006,00009,00011,00013), 3 sections(SEC 00010,00012,00017), 3 cross section(CSC 00010,00013,00016).

Figure 29 Pond system 2

Pond_21 is between NOD00006 and NOD00009. The length here is about 128m (Section 00017) with cross section CSC00010. 'Ponds 2a' is used for presenting this pond. Pond_22 is from NOD00009 to NOD00011 as long as 92m (Section 00010) with the cross section simulated as CSC00013. Cross section 00013 is definded as scheme 'Ponds 2b'. Pond_23 begins at NOD00011 and ends at NOD00013 with the length of 103m (Section 00012) and a cross section named CSC00016. Cross section 00016 is in this section. 'Ponds 2c' is used for presenting this pond. Here are the structures. (Figure 30)



Cross Section

Name: ponds2a
Type: Line
Surface (m2) ☐
Hydr. Radius (m) ☐
Resistance (c or k) ☐

	Height (m)	Flow Width (m)	Max Width (m)
1	0	95.00	95.00
2	1.5	95.00	95.00
3	2	100.00	100.00

Use the TAB and CTRL+DEL key to insert and delete rows while

Cross Section

Name: ponds2b
Type: Line
Surface (m2) ☐
Hydr. Radius (m) ☐
Resistance (c or k) ☐

	Height (m)	Flow Width (m)	Max Width (m)
1	0	135.00	135.00
2	1.5	135.00	135.00
3	2	140.00	140.00

Use the TAB and CTRL+DEL key to insert and delete rows while

Cross Section

Name: ponds2c
Type: Line
Surface (m2) ☐
Hydr. Radius (m) ☐
Resistance (c or k) ☐

	Height (m)	Flow Width (m)	Max Width (m)
1	0	165.00	165.00
2	1.5	165.00	165.00
3	2	170.00	170.00

Use the TAB and CTRL+DEL key to insert and delete rows while

Figure 30 Cross Section scheme for pond_21, pond_22 and pond_23

Pond system 3 (Vak_3): Pond_31-Pond_32-Pond_33-Pond_34

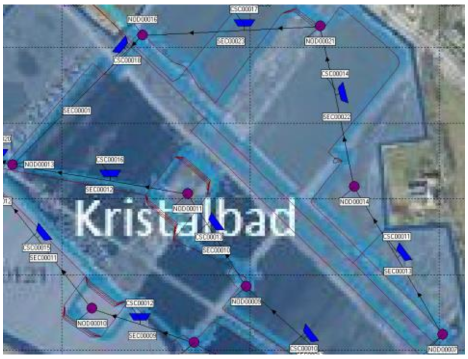
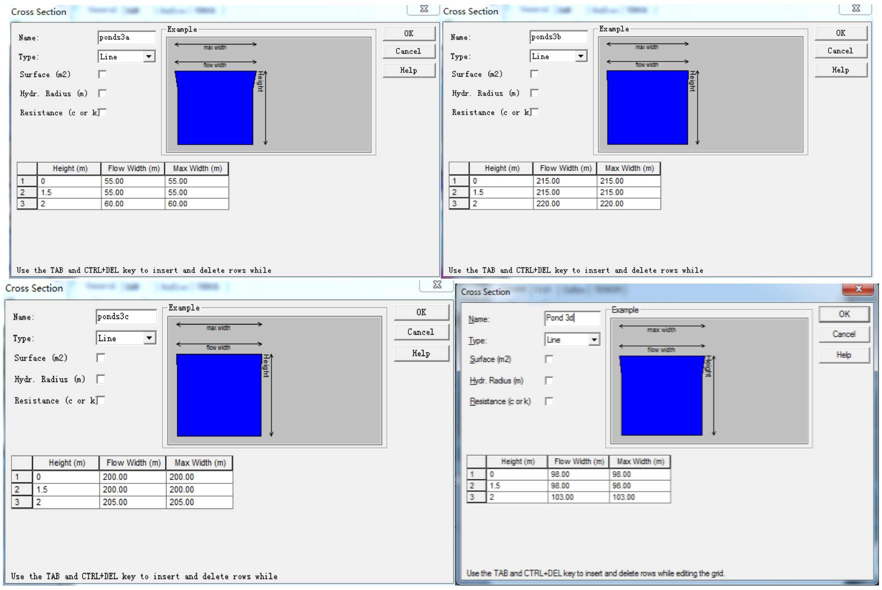


Figure 31 Schematization of Ponds system 3

The Pond system 3 (Figure 31-32) includes 5 nodes (NOD 00007,00013,00014,00021,00016), 4 sections(SEC 00001,00013,00022,00023), 4 cross section(CSC 00011,00014,00017,00018).

Figure 32 Pond system 3

Pond_31 is between NOD00007and NOD00014 with cross section CSC00011.The length here is about 114m (Section 00013). Pond_32 is from NOD00014 to NOD00021 as long as 123m (Section 00022) with the cross section simulated as CSC00014. Pond_33 begins at NOD00021 and ends at NOD00016 with the length of 103m (Section 00023) and a cross section modeled like CSC00017. Pond_34 begins at NOD00016 and ends at NOD00013 with the length of 28m (Section 00001) and a cross section modeled like CSC00018. Actually Pond_34 is the same ponds as Pond_23 except the different flow direction. 'Ponds 3a', 'Ponds 3b' and 'Ponds 3d' are used for presenting cross section 00011,00014,00017 and 00018 respectly. Here are the structures(Figure 34).



Cross Section

Name: ponds3a

Type: Line

	Height (m)	Flow Width (m)	Max Width (m)
1	0	55.00	55.00
2	1.5	55.00	55.00
3	2	60.00	60.00

Use the TAB and CTRL+DEL key to insert and delete rows while

Cross Section

Name: ponds3b

Type: Line

	Height (m)	Flow Width (m)	Max Width (m)
1	0	215.00	215.00
2	1.5	215.00	215.00
3	2	220.00	220.00

Use the TAB and CTRL+DEL key to insert and delete rows while

Cross Section

Name: ponds3c

Type: Line

	Height (m)	Flow Width (m)	Max Width (m)
1	0	200.00	200.00
2	1.5	200.00	200.00
3	2	205.00	205.00

Use the TAB and CTRL+DEL key to insert and delete rows while

Cross Section

Name: Pond 3d

Type: Line

	Height (m)	Flow Width (m)	Max Width (m)
1	0	98.00	98.00
2	1.5	98.00	98.00
3	2	103.00	103.00

Use the TAB and CTRL+DEL key to insert and delete rows while editing the grid.

Figure 33 Cross Section scheme for pond_31, pond_32, pond_33 and pond_34

Outlet system

Flow from Pond 3 and Pond 2 join at NOD 00013 and then join the flow from Pond 1 at NOD00019.Finally the water flow to the end node (NOD 00020). (Figure 34)

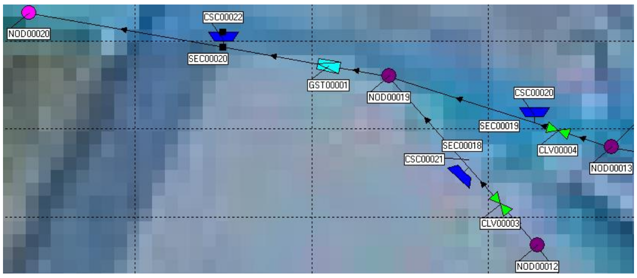
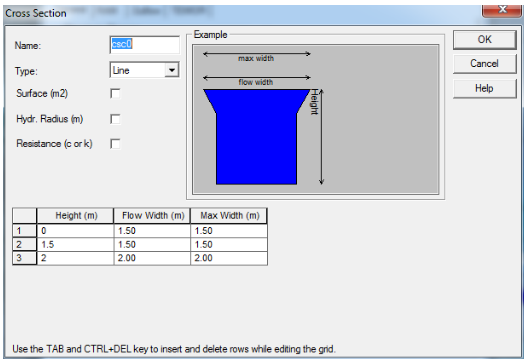


Figure 34 Schematization of the outlet system of Kristalbad

Distance between NOD00013 and NOD00019 is 20m (Section 00019), between NOD00012 and NOD00019 is 29m (Section 00018) and between last 2 nodes is 93m (Section 00020). All of the rest cross sections including CSC00020, CSC00021 and CSC00022 are all set as Scheme *csc0*. (Figure 35-37)

Figure 35 End Node-NOD 00020

Figure 36 Section 00018, Section 00019 and Section 00020



Name: csc0

Type: Line

Surface (m2) ☐

Hydr. Radius (m) ☐

Resistance (c or k) ☐

	Height (m)	Flow Width (m)	Max Width (m)
1	0	1.50	1.50
2	1.5	1.50	1.50
3	2	2.00	2.00

Use the TAB and CTRL+DEL key to insert and delete rows while editing the grid.

Figure 37 Scheme *csc0*

4.1.2 Quality model

There are four water quality processes sub-models build and evaluated using this simplified model. They are named M1-TRAC, M1-DEC, M1-OXY, and M1-NUT.

To make a Quality Model out of an existing Flow model, the following actions need to be carried out;

-Define Quality Description file,

-Define Initial Conditions for Quality,

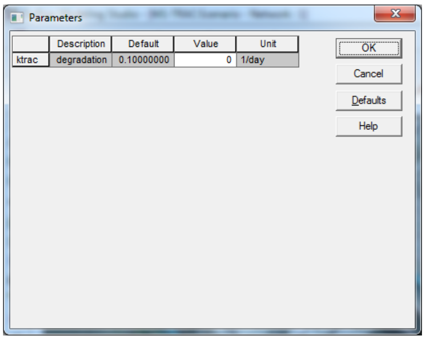
-Define Boundary Conditions for Quality

-Define External Variables,

-Configure the Calculation.

4.1.2.1 M1-TRAC

M1-TRAC is a simple water quality processes sub-model about the tracer substance. To ignore the decay, the degradation is set 0. (Figure 38)



	Description	Default	Value	Unit
ktrac	degradation	0.10000000	0	1/day

Figure 38 Parameter of M1-TRAC

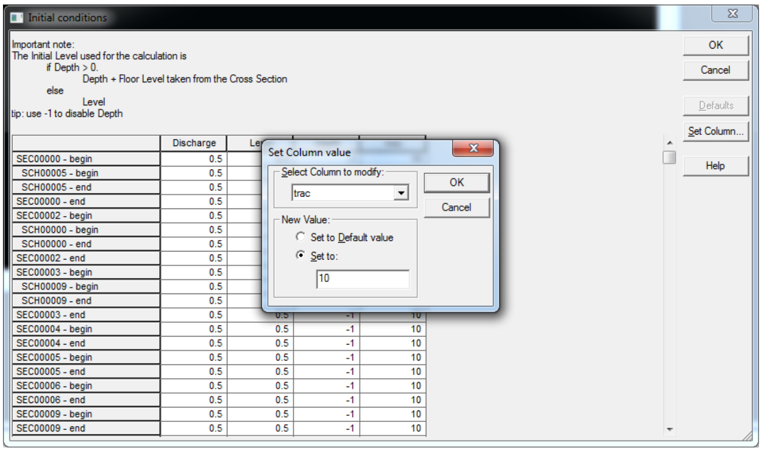
The simple quality model description file like below contains the definition of a tracer:

1. Definition of the quality description file

```
water TRAC [0.000] mg/l       ; TRACER
parm ktrac [0.000] 1/day              ;degradation constant
{
k1(TRAC)=-ktrac;
}
```

2. Initial Conditions

To evaluate the simple model, the initial concentration for Trac is set 10mg/l for all nodes and schematization points. (Figure 39)



Initial conditions

Important note:
The Initial Level used for the calculation is
if Depth > 0.
Depth + Floor Level taken from the Cross Section
else
Level
tip: use -1 to disable Depth

	Discharge	Le		
SEC00000 - begin	0.5			
SCH00005 - begin	0.5			
SCH00005 - end	0.5			
SEC00000 - end	0.5			
SEC00002 - begin	0.5			
SCH00000 - begin	0.5			
SCH00000 - end	0.5			
SEC00002 - end	0.5			
SEC00003 - begin	0.5			
SCH00009 - begin	0.5			
SCH00009 - end	0.5			
SEC00003 - end	0.5	0.5	-1	10
SEC00004 - begin	0.5	0.5	-1	10
SEC00004 - end	0.5	0.5	-1	10
SEC00005 - begin	0.5	0.5	-1	10
SEC00005 - end	0.5	0.5	-1	10
SEC00006 - begin	0.5	0.5	-1	10
SEC00006 - end	0.5	0.5	-1	10
SEC00009 - begin	0.5	0.5	-1	10
SEC00009 - end	0.5	0.5	-1	10

Set Column value

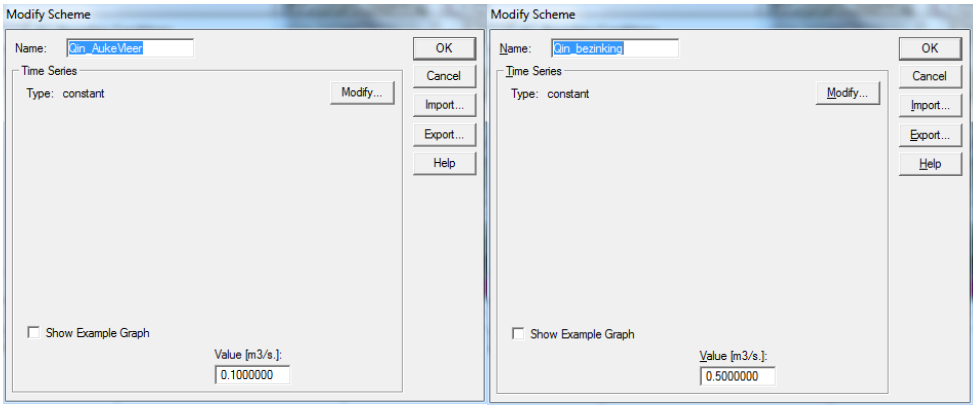
Select Column to modify: trac

New Value:
○ Set to Default value
● Set to: 10

Figure 39 Initial condition of M1-TRAC

3. Boundary Conditions

This model assumes the river in a steady state, so concentration of the substance, Qadd scheme of start nodes and level scheme of end node are set as a constant value. Qadd scheme in start node (NOD00004) is 0.1 m^3/s and in another start node (NOD00015) is 0.5 m^3/s. The level scheme of end node (NOD00020) is 0.5 m^3/s. This model assumes the concentration of the tracer in the start node is set 10 mg/l constantly. Repeat these actions to define a constant concentration of 10mg/l as a boundary condition on the end of the Network. (Figure 40)



Modify Scheme

Name: Qin_AukeVleer

Time Series

Type: constant

☐ Show Example Graph

Value [m3/s.]: 0.1000000

Modify Scheme

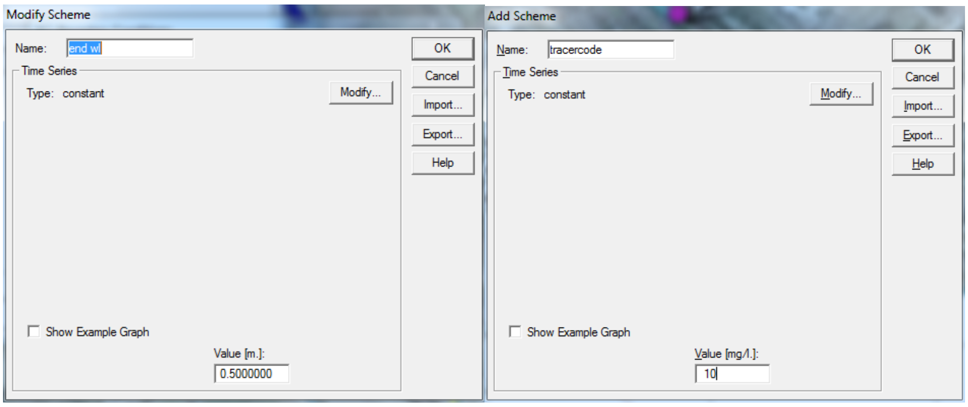
Name: Qin_bezinking

Time Series

Type: constant

☐ Show Example Graph

Value [m3/s.]: 0.5000000



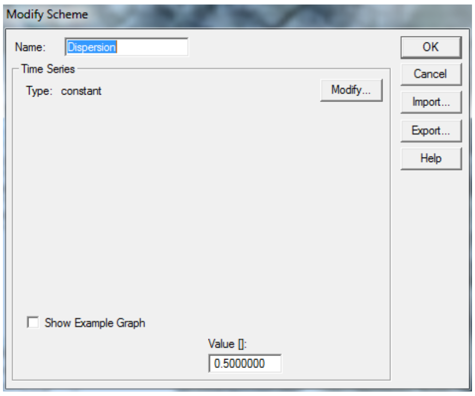
Name: end wl
Time Series
Type: constant
Value [m.]: 0.5000000

Name: tracercode
Time Series
Type: constant
Value [mg/l.]: 10

Figure 40 Boundary of M1-TRAC

4. External Variables

Dispersion is an external variable, which has to be defined in every quality model. In this test model, dispersion is set for 0.5. (Figure 41)

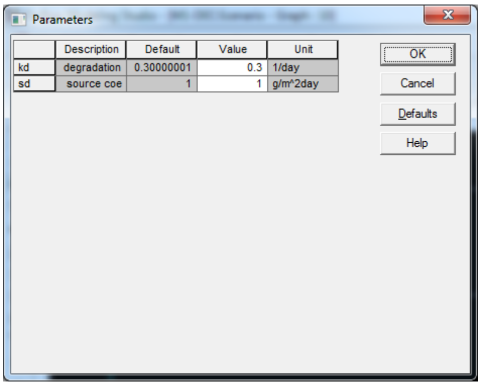


Name: Dispersion
Time Series
Type: constant
Value []: 0.5000000

Figure 41 External variables of M1-TRAC

4.1.2.2 M1-DEC

M1-DEC is also a simple water quality processes sub-model about the Chemical substance. What's more, this model consider the decay of the substance. The degradation is set 0.3 and source coefficient is set 1g/m²day. (Figure 42)



	Description	Default	Value	Unit
kd	degradation	0.30000001	0.3	1/day
sd	source coe	1	1	g/m^2day

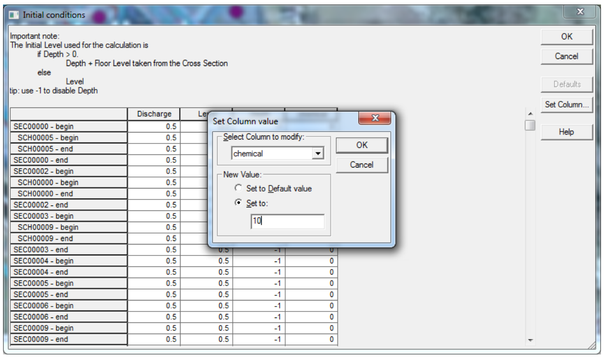
Figure 42 Parameter of M1-DEC

1. Definition of the quality description file

```
water chemical [0.000] mg/l        ; chemical concentration
parm kd [0.300] 1/day              ;degradation constant
parm Sd [1.00] g/m^2day     ; source coefficient (release)
flow z [2.000] m                   ;water depth
{
k1(chemical)=-kd;
k0(chemical)=Sd/z;
}
```

2. Initial Conditions

To evaluate the simple model, the initial concentration for chemical is set 10mg/l for all nodes and schematization points. (Figure 43)



Important note:
The Initial Level used for the calculation is
if Depth > 0.
Depth + Floor Level taken from the Cross Section
else
Level
tip: use -1 to disable Depth

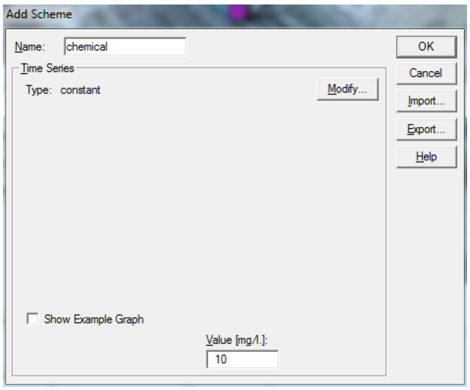
	Discharge	Le		
SEC00000 - begin	0.5			
SCH00005 - begin	0.5			
SCH00005 - end	0.5			
SEC00000 - end	0.5			
SEC00002 - begin	0.5			
SCH00000 - begin	0.5			
SCH00000 - end	0.5			
SEC00002 - end	0.5			
SEC00003 - begin	0.5			
SCH00009 - begin	0.5			
SCH00009 - end	0.5			
SEC00003 - end	0.5	0.5	-1	0
SEC00004 - begin	0.5	0.5	-1	0
SEC00004 - end	0.5	0.5	-1	0
SEC00005 - begin	0.5	0.5	-1	0
SEC00005 - end	0.5	0.5	-1	0
SEC00006 - begin	0.5	0.5	-1	0
SEC00006 - end	0.5	0.5	-1	0
SEC00009 - begin	0.5	0.5	-1	0
SEC00009 - end	0.5	0.5	-1	0

Set Column value
Select Column to modify: chemical
New Value:
○ Set to Default value
● Set to: 10

Figure 43 Initial condition of M1-DEC

3. Boundary Conditions

This model assumes the river in a steady state, so concentration of the chemical in the start node is set 10 mg/l constantly. Repeat these actions to define a constant concentration of 10mg/l as a boundary condition on the end of the Network. Qadd scheme of start nodes and level scheme of end node are also set as a constant value which is the same with value in M1-TRAC model. (Figure 44)



Name: chemical
Time Series
Type: constant
☐ Show Example Graph
Value [mg/l.]: 10

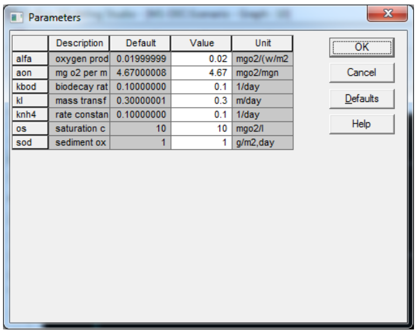
Figure 44 Boundary condition of M1-DEC

4. External Variables

Dispersion is an external variable, which has to be defined in every quality model. In this test model, dispersion is set for 0.5 which is same with value in M1-TRAC.

5.1.2.3 M1-OXY

M1-OXY is a water quality processes sub-model about the CBOD and N-Amm (ammonium). This model consider the decay of the substance. The degradation is set 0.1. (Figure 45)



	Description	Default	Value	Unit
alfa	oxygen prod	0.01999999	0.02	mgo2/(w/m2
aon	mg o2 per m	4.67000008	4.67	mgo2/mgn
kbod	biodecay rat	0.10000000	0.1	1/day
kl	mass transf	0.30000001	0.3	m/day
knh4	rate constan	0.10000000	0.1	1/day
os	saturation c	10	10	mgo2/l
sod	sediment ox	1	1	g/m2,day

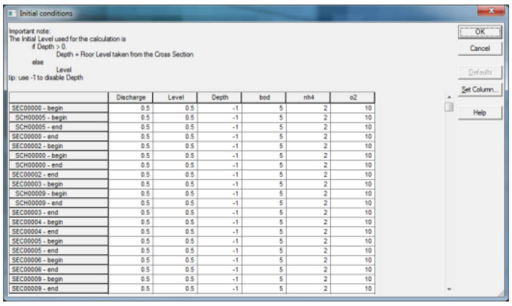
Figure 45 Parameter of M1-OXY

1．Definition of the quality description file

```
WATER   BOD    [ 5.000]    mg O2/l      ; CARBON BIOCHEMICAL OXYGEN DEMAND
WATER   NH4    [ 2.000]    mg N/l       ; AMMONIUM-N CONCENTRATION
WATER   O2     [10.000]    mg O2/l      ; OXYGEN CONCENTRATION
PARM    Kbod   [0.1000]    1/day        ; BIODECAY RATE CONSTANTE BOD
PARM    Knh4   [0.1000]    1/day        ; RATE CONSTANTE NITRIFICATION
PARM    Kl     [0.3000]    m/day        ; MASS TRANSFER CONSTANTE OXYGEN
PARM    Os     [10.000]    mg O2/l   ; SATURATION CONCENTRATION OXYGEN (f(T))
PARM    Aon    [4.6700]    mg O2/mg N; MG O2 PER MG N
PARM    ALFA   [0.0200]    mg O2/ (W/m2);OXYGEN PRODUCTION CONSTANTE(plants, algae)
PARM    SOD    [1.0000]    g/m2, day     ; SEDIMENT OXYGEN DEMAND
XT      I0     [100.00]    W/m2         ; IRRADIATION
FLOW    Z      [2.0000]    m             ; WATERDEPTH
{
K1(NH4)=-Knh4;
K1(BOD)=-Kbod;
K1(O2)=-Kl/Z;
K0(O2)=Kl*Os/Z-Kbod*BOD-Aon*Knh4*NH4-SOD/Z+ALFA*I0;
}
```

2．Initial Conditions

To evaluate the simple model, the initial concentration for BOD is set 5mg/l for all nodes and schematization points. For NH4, the concentration is 2mg/l. The concentration of O2 is set as 10 mg/l. (Figure 46)



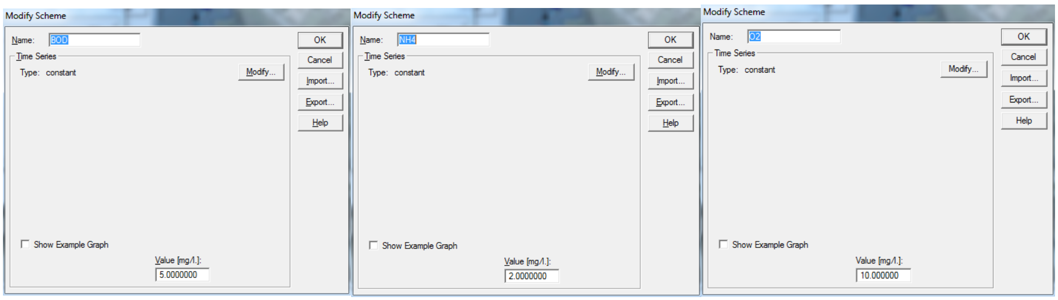
Important note:
The Initial Level used for the calculation is
if Depth > 0.
Depth + Floor Level taken from the Cross Section
else
Level
tip: use -1 to disable Depth

	Discharge	Level	Depth	bod	nh4	o2
SEC00000 - begin	0.5	0.5	-1	5	2	10
SCH00005 - begin	0.5	0.5	-1	5	2	10
SCH00005 - end	0.5	0.5	-1	5	2	10
SEC00000 - end	0.5	0.5	-1	5	2	10
SEC00002 - begin	0.5	0.5	-1	5	2	10
SCH00000 - begin	0.5	0.5	-1	5	2	10
SCH00000 - end	0.5	0.5	-1	5	2	10
SEC00002 - end	0.5	0.5	-1	5	2	10
SEC00003 - begin	0.5	0.5	-1	5	2	10
SCH00009 - begin	0.5	0.5	-1	5	2	10
SCH00009 - end	0.5	0.5	-1	5	2	10
SEC00003 - end	0.5	0.5	-1	5	2	10
SEC00004 - begin	0.5	0.5	-1	5	2	10
SEC00004 - end	0.5	0.5	-1	5	2	10
SEC00005 - begin	0.5	0.5	-1	5	2	10
SEC00005 - end	0.5	0.5	-1	5	2	10
SEC00006 - begin	0.5	0.5	-1	5	2	10
SEC00006 - end	0.5	0.5	-1	5	2	10
SEC00009 - begin	0.5	0.5	-1	5	2	10
SEC00009 - end	0.5	0.5	-1	5	2	10

Figure 46 Initial condition of M1-OXY

3. Boundary Conditions

This model assumes the river in a steady state, so concentration of the substance, Qadd scheme of start nodes and level scheme of end node are set as a constant value. Qadd scheme of start nodes and level scheme of end node are also set as the same value in M1-TRAC model. In the start nodes the concentrations of BOD, NH4 and O2 are 5mg/l, 2mg/l and 10mg/l respectively. Repeat these set to define constant concentrations of BOD, NH4 and O2 as a boundary condition on the end of the Network. (Figure 47)



Name: BOD
Type: constant
Value [mg/l]: 5.0000000

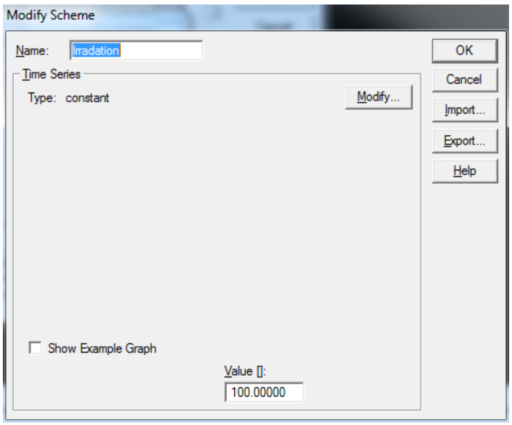
Name: NH4
Type: constant
Value [mg/l]: 2.0000000

Name: O2
Type: constant
Value [mg/l]: 10.000000

Figure 47 Boundary condition of M1-OXY

4. External Variables

Dispersion is an external variable, which has to be defined in every quality model. In this test model, dispersion is set for 0.5 which is same with value in M1-TRAC. And the irradiation is set as 100w/m². (Figure 48)

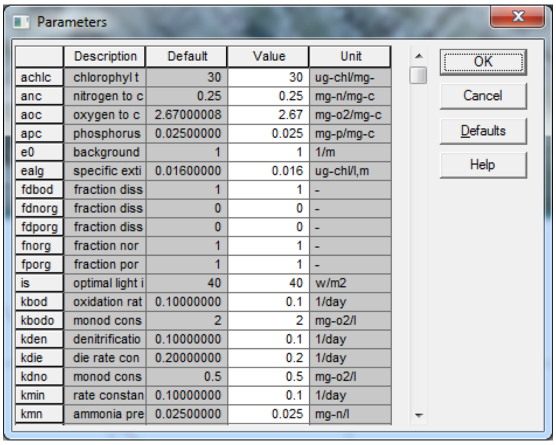


Name: Irradiation
Type: constant
Value []: 100.00000

Figure 48 External variables of M1-OXY

5.1.2.3 M1-EUT

M1-EUT is the complicated water quality processes model. It considers many influence factors, such as light, temp, mineralization, nutrients, denitrification. These parameters are set as below. (Figure 49)



	Description	Default	Value	Unit
achlc	chlorophyl t	30	30	ug-chl/mg-
anc	nitrogen to c	0.25	0.25	mg-n/mg-c
aoc	oxygen to c	2.67000008	2.67	mg-o2/mg-c
apc	phosphorus	0.02500000	0.025	mg-p/mg-c
e0	background	1	1	1/m
ealg	specific exti	0.01600000	0.016	ug-chl/l,m
fdbod	fraction diss	1	1	-
fdnorg	fraction diss	0	0	-
fdporg	fraction diss	0	0	-
fnorg	fraction nor	1	1	-
fporg	fraction por	1	1	-
is	optimal light i	40	40	w/m2
kbod	oxidation rat	0.10000000	0.1	1/day
kbodo	monod cons	2	2	mg-o2/l
kden	denitrificatio	0.10000000	0.1	1/day
kdie	die rate con	0.20000000	0.2	1/day
kdno	monod cons	0.5	0.5	mg-o2/l
kmin	rate constan	0.10000000	0.1	1/day
kmn	ammonia pre	0.02500000	0.025	mg-n/l

Figure 49 Parameter of M1-NUT

1．Definition of the quality description file

```
water         A      [ 2.000]     mg-C/l          ;Algal biomass
water         PORG       [ 0.110]     mg-P/l          ;Organic Phosphorus
water         PANORG     [ 0.040]     mg-P/l          ;Inorganic Phosphorus
water         NH4  [ 0.300]     mg-N/l          ;Ammonia
water         NO3  [ 3.000]     mg-N/l          ;Nitrate
water         NORG       [ 0.800]     mg-N/l          ;Organic Nitrogen
water         O2    [10.000]     mg/l        ;Oxygen
water         BOD  [ 5.000]     mg-O2/l         ;BOD-5
water         SS     [ 5.000]     mg/l        ;Suspended Solids
parm     kp     [ 0.005]     mg-P/l          ;Monod constant Phosphorus
parm     kn     [ 0.010]     mg-N/l          ;Monod constant Nitrogen
parm     ealg  [ 0.016]     ug-Chl/l,m       ;Specific extinction chlorophyl
parm     e0     [ 1.000]     1/m        ;Background extinction
parm     achlc     [30.000]          ug-Chl/mg-C       ;Chlorophyl to Carbon ratio
parm     is     [40.000]     W/m2          ;Optimal Light Intensity
parm     umax[ 4.000]     1/day          ;Unlimited algal growth rate
parm     tga    [ 1.047]     -          ;Temperature coefficient algal growth
parm     tra    [ 1.047]     -          ;Temperature coefficient algal respiration
parm     kres  [ 0.100]     1/day          ;Respiration rate constant
parm     kdie        [ 0.200]     1/day          ;Die rate constant
parm     fporg [ 1.000]     -          ;Fraction PORG released by respiration
parm     apc    [ 0.025]     mg-P/mg-C;Phosphorus to Carbon ratio
parm     anc    [ 0.250]     mg-N/mg-C       ;Nitrogen to Carbon ratio
parm     kmin  [ 0.100]     1/day          ;Rate constant mineralisation
parm     tmin  [ 1.047]     -          ;Temperature coefficient mineralisation
```

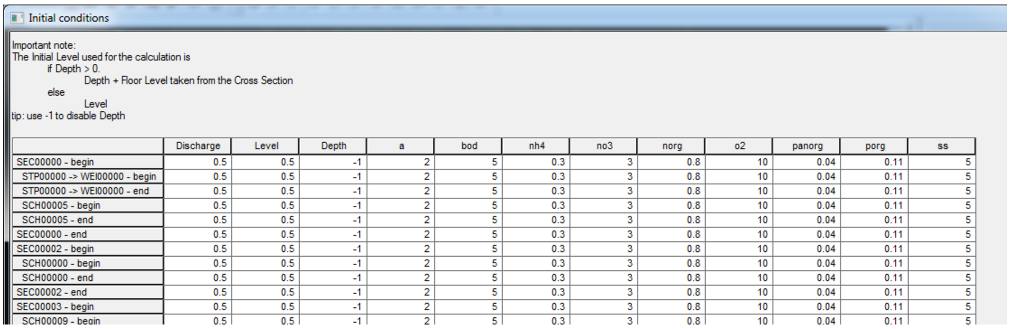
```
parm    vso    [ 0.100]    m/day          ;Nett sedimentatie rate organic matter
parm    fdporg    [ 0.000]    -          ;Fraction dissolved organic Phosphorus
parm    fdnorg    [ 0.000]    -          ;Fraction dissolved organic Nitrogen
parm    kpip   [ 0.010]    l/mg-SS        ;Phosphorus Partition coefficient
parm    fnorg [ 1.000]    -          ;Fraction NORG released by respiration
parm    kmn   [ 0.025]    mg-N/l         ;Ammonia preference factor
parm    tnit   [ 1.080]    -          ;Temperature coefficient nitrification
parm    knit   [ 0.100]    1/day          ;Nitrification rate constant
parm    kno    [ 2.000]    mg-O2/l        ;Monod constant nitrification
parm    kden  [ 0.100]    1/day          ;Denitrification rate constant
parm    tden  [ 1.045]    -          ;Temperature coefficient denitrification
parm    kdno [ 0.500]    mg-O2/l        ;Monod constante denitrification
parm    kbod [ 0.100]    1/day          ;Oxidation rate constant BOD
parm    tbod  [ 1.047]    -          ;Temperature coefficient oxidation BOD
parm    kbodo     [ 2.000]    mg-O2/l        ;Monod constante oxidation BOD
parm    fdbod     [ 1.000]    -          ;Fraction dissolved BOD
parm    aoc    [ 2.670]    mg-O2/mg-C     ;Oxygen to Carbon ratio
parm    trea   [ 1.024]    -          ;Temperaturecoefficient reaeration
parm    krmin     [ 0.100]    m/day          ;Minimum oxygen mass transfer constant
parm    vss    [ 0.100]    m/day          ;Sedimentation rate Suspended Solids
xt          sod    [ 1.000]    g-O2/m2.day    ;Sediment Oxygen Demand
xt          i0[ 10.00]    W/m2           ;Surface Light Intensity
xt          t  [ 20.00]    oC          ;Temperature
xt          resf    [   0.50]    g/m2.day  ;Resuspension flux Suspended Solids
xt       pflux    [    0.00]        g P/m2,day       ;Phosphorus release flux from sediment
xt       nflux    [    0.00]        g N/m2,day       ;Ammonia release flux from sediment
flow    z   [    2.00]        m               ;Water depth
flow    Q  [    0.10]        m3/day         ;Flow
flow  As    [ 10.00]    m2         ;Crossectional Area
{
fdpano=1/(1+kpip*SS);
PORTO=PANORG*fdpano;
Chla=achlc*A;
fn=MIN(PORTO/(PORTO+kp),(NH4+NO3)/(NH4+NO3+kn));
etot=e0+ealg*Chla;
ister=i0/is;
fl=2.71*(exp(-1*ister*exp(-1*etot*z))-exp(-ister))/(etot*z);
ft=tga^(t-20);
Groei=umax*fn*fl*ft;
Resp=kres*tra^(t-20)+kdie;
k1(A)=Groei-Resp;
mino=kmin*tmin^(t-20);
sedo=vso/z;
k0(PORG)=fporg*Resp*apc*A;
```

```
k1(PORG)=-1*mino-sedo*(1-fdporg);
k0(PANORG)=mino*PORG-Groei*A*apc+(1-fporg)*Resp*apc*A+pflux/z;
k1(PANORG)=-1*vss/z*(1-fdpano);
k0(NORG)=fnorg*Resp*anc*A;
k1(NORG)=-1*mino-1*sedo*(1-fdnorg);
if (NO3==0.0 && NH4==0.0)
        {
        pnh4=0.;
        }
else
        {
        pnh4=NH4*NO3/((kmn+NH4)*(kmn+NO3))+NH4*kmn/((NH4+NO3)*(kmn+NO3));
        }

nitr=knit*tnit^(t-20)*O2/(O2+kno);
k0(NH4)=mino*NORG-Groei*anc*A*pnh4+(1-fnorg)*Resp*anc*A+nflux/z;
k1(NH4)=-1*nitr;
denit=kden*tden^(t-20)*kdno/(kdno+O2);
k0(NO3)=nitr*NH4-Groei*anc*A*(1-pnh4);
k1(NO3)=-1*denit;
oxid=kbod*tbod^(t-20)*O2/(O2+kbodo);
conv=(1-exp(-5*kbod));
k1(BOD)=-1*oxid-1*sedo*(1-fdbod);
k0(BOD)=(kdie*aoc*A-5/4*32/14*denit*NO3)*conv;
u=ABS(Q/As);
kmas=3.94*u^0.5*z^(-0.5);
if (kmas<krmin)
            {
            kmas=krmin;
            }
kre=(kmas*trea^(t-20))/z;
cs=14.5519-0.373484*t+0.00501607*t*t;
k1(O2)=-1.0*kre;
k0(O2)=kre*cs-oxid*BOD/conv-64/14*nitr*NH4-32/12*kres*tra^(t-20)*A-sod/z+Groei*A*(32/12+48/14*anc*(1-
pnh4)*NO3);
k1(SS)=-1*vss/z;
k0(SS)=resf/z;
Ptot=PORG+PANORG+A*apc;
Nkj=NORG+NH4+anc*A;
Ntot=Nkj+NO3;}
```

2. Initial Conditions

To evaluate the simple model, the initial concentration for Algal biomass, BOD(biochemical oxygen demand), NH4(ammonium), NO3(nitrate) organic N, O2, organic P, inorganic P and suspended solids are set as 2mg/l, 5mg/l, 0.3mg/l, 3mg/l, 0.8mg/l, 10mg/l, 0.04mg/l, 0.1mg/l and 5mg/l respectively. (Figure 50)



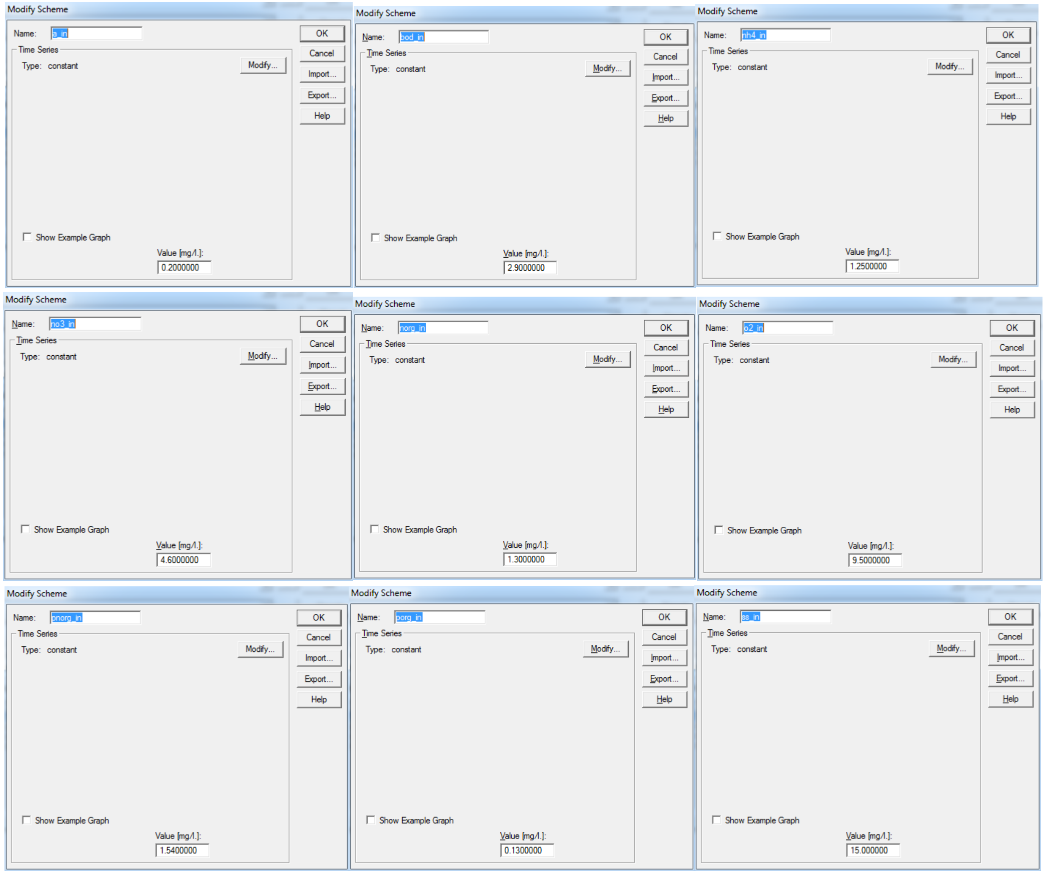
Important note:
The Initial Level used for the calculation is
if Depth > 0.
Depth + Floor Level taken from the Cross Section
else
Level
tip: use -1 to disable Depth

	Discharge	Level	Depth	a	bod	nh4	no3	norg	o2	panorg	porg	ss
SEC00000 - begin	0.5	0.5	-1	2	5	0.3	3	0.8	10	0.04	0.11	5
STP00000 -> WEI00000 - begin	0.5	0.5	-1	2	5	0.3	3	0.8	10	0.04	0.11	5
STP00000 -> WEI00000 - end	0.5	0.5	-1	2	5	0.3	3	0.8	10	0.04	0.11	5
SCH00005 - begin	0.5	0.5	-1	2	5	0.3	3	0.8	10	0.04	0.11	5
SCH00005 - end	0.5	0.5	-1	2	5	0.3	3	0.8	10	0.04	0.11	5
SEC00000 - end	0.5	0.5	-1	2	5	0.3	3	0.8	10	0.04	0.11	5
SEC00002 - begin	0.5	0.5	-1	2	5	0.3	3	0.8	10	0.04	0.11	5
SCH00000 - begin	0.5	0.5	-1	2	5	0.3	3	0.8	10	0.04	0.11	5
SCH00000 - end	0.5	0.5	-1	2	5	0.3	3	0.8	10	0.04	0.11	5
SEC00002 - end	0.5	0.5	-1	2	5	0.3	3	0.8	10	0.04	0.11	5
SEC00003 - begin	0.5	0.5	-1	2	5	0.3	3	0.8	10	0.04	0.11	5
SCH00009 - begin	0.5	0.5	-1	2	5	0.3	3	0.8	10	0.04	0.11	5

Figure 50 Initial condition of M1-EUT

3. Boundary Conditions

This model assumes the river in a steady state, so concentration of the substance, Qadd scheme of start nodes and level scheme of end node are set as a constant value. Qadd scheme of start nodes and level scheme of end node are also set as the same value in M1-TRAC model. In the start nodes the concentrations of Algal biomass, BOD, NH4, NO3 organic N, O2, organic P, inorganic P and suspended solids are set as 0.2mg/l,2.9mg/l, 1.25mg/l, 4.6mg/l, 1.3mg/l, 9.5mg/l, 0.13mg/l, 1.54mg/l and 15mg/l respectively. Repeat these set to define constant concentrations as a boundary condition on the end of the Network. (Figure 51)



Name: a_in
Type: constant
Value [mg/l.]: 0.2000000

Name: bod_in
Type: constant
Value [mg/l.]: 2.9000000

Name: nh4_in
Type: constant
Value [mg/l.]: 1.2500000

Name: no3_in
Type: constant
Value [mg/l.]: 4.6000000

Name: norg_in
Type: constant
Value [mg/l.]: 1.3000000

Name: o2_in
Type: constant
Value [mg/l.]: 9.5000000

Name: pnorg_in
Type: constant
Value [mg/l.]: 1.5400000

Name: porg_in
Type: constant
Value [mg/l.]: 0.1300000

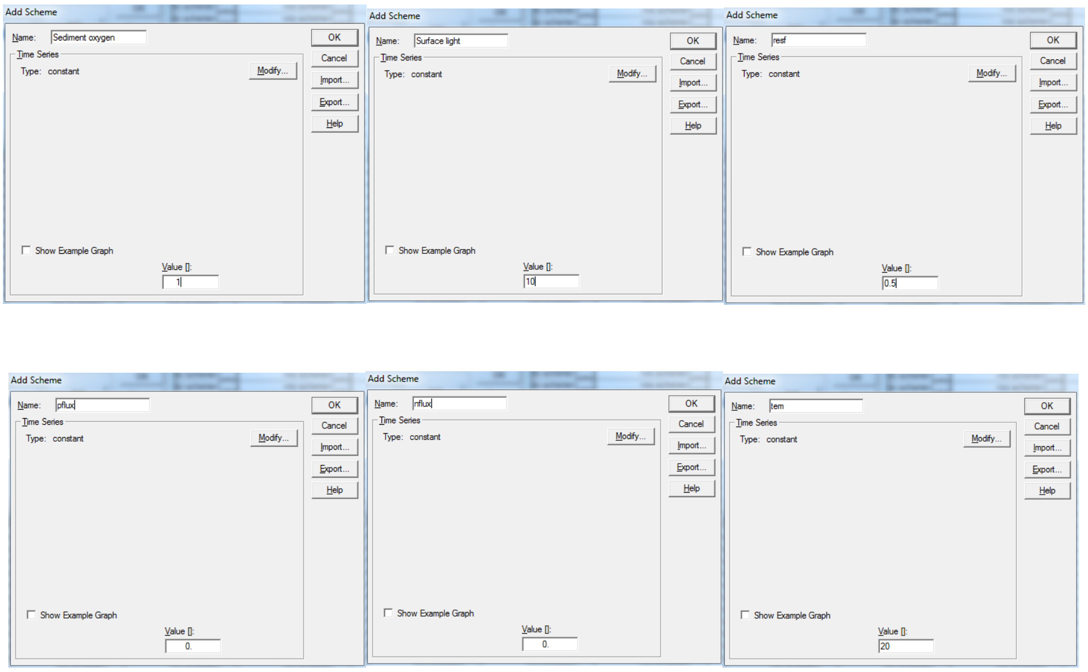
Name: ss_in
Type: constant
Value [mg/l.]: 15.000000

Figure 51 Boundary condition of M1-EUT

4. External Variables

Dispersion is an external variable, which has to be defined in every quality model. In this test model, dispersion is set for 0.5 which is same with value in M1-TRAC. Sediment oxygen demand is1 g-O_2/m^{2}day. Surface light intensity is 10 W/m2. Resuspension flux suspended solids is 0.5

g/m²day. Phosphorus release flux from sediment is 0 g-P/m²day. Ammonia release flux from sediment is 0 g-N/m²day. Temperature is 20 ºC. (Figure 52)



Name: Sediment oxygen
Type: constant
Value []: 1

Name: Surface light
Type: constant
Value []: 10

Name: resf
Type: constant
Value []: 0.5

Name: pflux
Type: constant
Value []: 0.

Name: nflux
Type: constant
Value []: 0.

Name: tem
Type: constant
Value []: 20

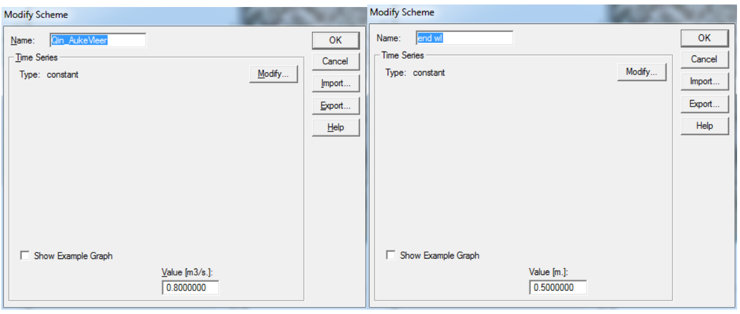
Figure 52 External Variables of M1-EUT

4.1.3 Scenario

The condition of the flow often changes as a result of many factors, such as precipitation, weather and climate. When heavy rain comes, the water level of the flow must rise. The flow model is not only make for the normal condition. Scenario can simulate different flow condition. Three scenario are set to simulate the dry condition, wet condition and extreme (spill) condition. All flow models are check the performance under the different scenarios.

4.2.1.1 Normal condition

Sometimes there is not a constantly condition, many reason can cause a sudden change. When heavy rain comes suddenly, there is a sharp increase in discharge. According to the previous, discharge of start node (NOD 00004) is set from 0.8 m³/s and the water level of end node (NOD 00020) is set 0.5m.



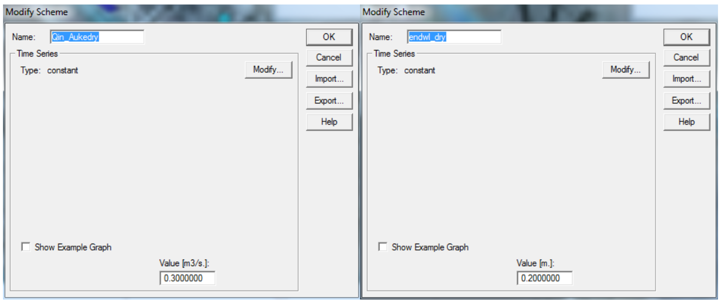
Name: Qin_AukeVleer
Type: constant
Value [m3/s.]: 0.8000000

Name: end wl
Type: constant
Value [m.]: 0.5000000

Figure 53 Setting of normal scenario

4.2.1.2 Dry condition

The dry condition is usually used to simulate the condition when there is not much water in the flow. The reason may be less precipitation, much evaporation or the dry climate. In this scenario, the discharge and water level usually get low values. According to the previous, discharge of start node (NOD 00004) is set 0.3m³/s and the water level of end node (NOD 00020) is set 0.2m. (Figure 54)



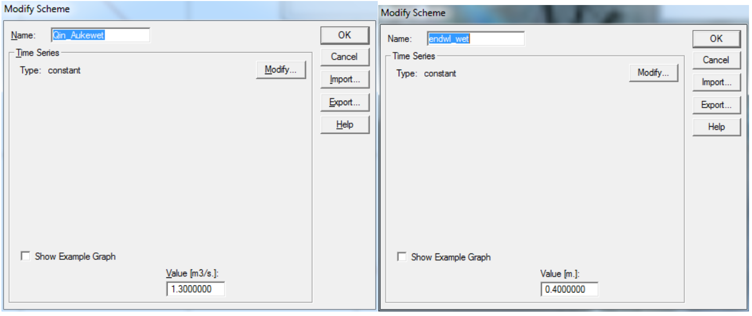
Name: Qin_Aukedry
Time Series
Type: constant
Value [m3/s.]: 0.3000000

Name: endwl_dry
Time Series
Type: constant
Value [m.]: 0.2000000

Figure 54 Setting of dry scenario

4.2.1.3 Wet condition

When there is much water in the flow, the wet condition is suitable to simulate this condition. Much precipitation and wet climate usually are the major reason. In this scenario, the discharge and water level usually get high values. According to the previous, discharge of start node (NOD 00004) is set 1.3m³/s and the water level of end node (NOD 00020) is set 0.4m. (Figure 55)



Name: Qin_Aukewet
Time Series
Type: constant
Value [m3/s.]: 1.3000000

Name: endwl_wet
Time Series
Type: constant
Value [m.]: 0.4000000

Figure 55 Setting of wet scenario

4.2.1.4 Spill scenario

In daily life, many accidents often happen. May be some waste water be poured into the river. May be many nutrients leak from a chemical plant. All these can make a sudden increase of the nutrients in the river. It is necessary to see how the Kristalbad perform under the accidents. The discharge of the flow is same as the normal condition. The difference is the concentration of nutrients will increase 10 times at 8:00,14th October and back to normal level at 15:00.

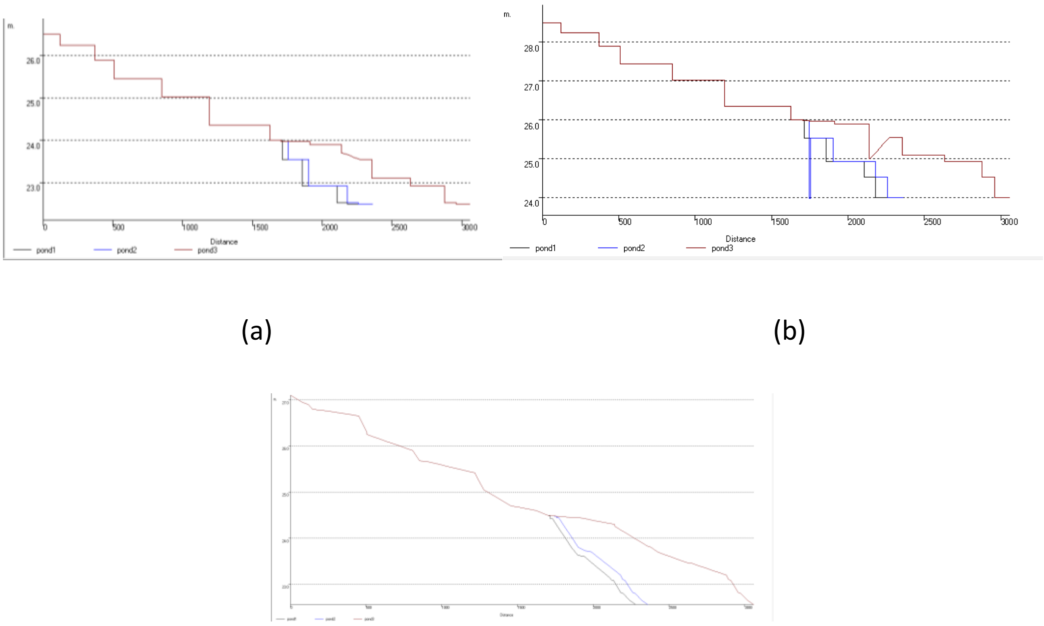
4.2 Steady state model_2 (M2)

In this model, topography (i.e. floor and surface levels) is implemented, as well as major flow regulating structures (weirs, culverts).

Flow and water levels according gravity slope and structure contractions, crown, crest heights, Approx. Steady state conditions (e.g. dry weather flow and constant discharges)
In this model, evaluation of more realistic water levels, flow rates and residence times is pursued. In this second instance, water quality processes are evaluated (same as M1 quality model).

4.2.1 Topography

In the M2, topography is added in the model. In other world, the realistic floor and surface levels are added in the model. The floor level and surface level data are collected from AHN (Actueel Hoogtebestand Nederland) web and previous research (figure 56-a, b).The water level is gotten from previous research (figure 56-c).Every cross section are set the floor level and surface level.



(a) (b)

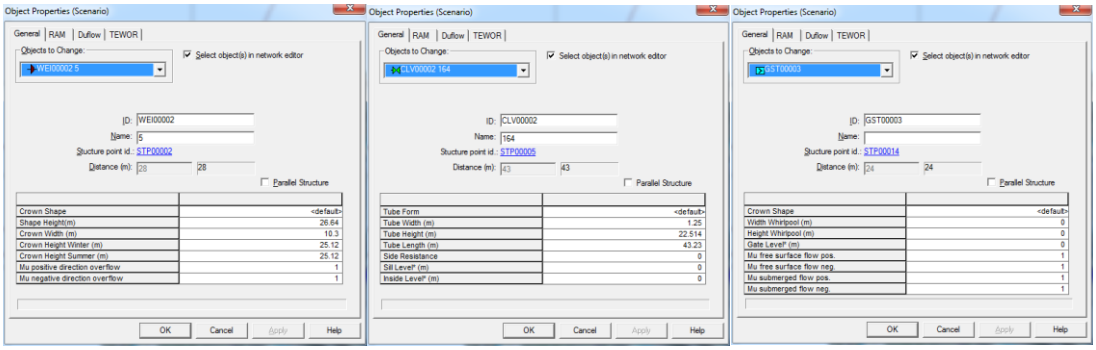
(c)

Figure 56 Topography of flow model (a: floor level, b: surface level, c: water level)

4.2.2 Hydraulic structure

There are many regulating structures (weir, culvert, general structure) in the flow (figure 57, 58). They are all recorded in the GIS data. After check in the field work, the GIS data are proved available.

Figure 57 Hydraulic structure (weir, culvert, general structure)



Objects to Change: WEI00002 5
☑ Select object(s) in network editor
ID: WEI00002
Name: 5
Stucture point id.: STP00002
Distance (m): 28 28
☐ Parallel Structure

Crown Shape	<default>
Shape Height(m)	26.64
Crown Width (m)	10.3
Crown Height Winter (m)	25.12
Crown Height Summer (m)	25.12
Mu positive direction overflow	1
Mu negative direction overflow	1

Objects to Change: CLV00002 164
☑ Select object(s) in network editor
ID: CLV00002
Name: 164
Stucture point id.: STP00005
Distance (m): 43 43
☐ Parallel Structure

Tube Form	<default>
Tube Width (m)	1.25
Tube Height (m)	22.514
Tube Length (m)	43.23
Side Resistance	0
Sill Level* (m)	0
Inside Level* (m)	0

Objects to Change: GST00003
☑ Select object(s) in network editor
ID: GST00003
Name:
Stucture point id.: STP00014
Distance (m): 24 24
☐ Parallel Structure

Crown Shape	<default>
Width Whirlpool (m)	0
Height Whirlpool (m)	0
Gate Level* (m)	0
Mu free surface flow pos.	1
Mu free surface flow neg.	1
Mu submerged flow pos.	1
Mu submerged flow neg.	1

Figure 58 Setting of weir, culvert and general structure

4.3 Dynamic model_3 (M3)

In this third model, using the schematization of M2, varying flow conditions will be simulated and evaluated. The varying flow condition is according to the varying flow data. The data is the realistic data of the flow. The water quality changes are also evaluated in the vary flow condition.

5 Scenario analysis

To check the model accuracy and suitability, three flow conditions are set. Normal condition, dry condition and wet condition present different flow condition. These conditions are present by three scenarios (normal scenario, dry scenario and wet scenario). Different scenarios

In the normal condition, entry the collected flow and nutrients data of inlet, run the flow and water quality model and get the results of flow and nutrients of outlet. Comparing to the collected outlet data got from the previous research, find the difference between these two sets of data. Change the parameters of water quality to decrease the difference and record the parameters when the difference becomes smallest. Entry the parameters into model and finish the parameters calibration on water quality model.

After parameters calibration, put the parameters (initial condition, discharge point boundary condition) into dry condition and wet condition. Run the model in different scenarios and check the changes of ammonium, nitrate, total nitrate and total phosphorus. According to the results, evaluate the Kristalbad performance in nutrients removal.

When the model begin running, it needs some time to become a stable state. In the stable state the data is dependable. The data from the figure below, all recorded from the stable state.

5.1 Concentration change from start node to inlet

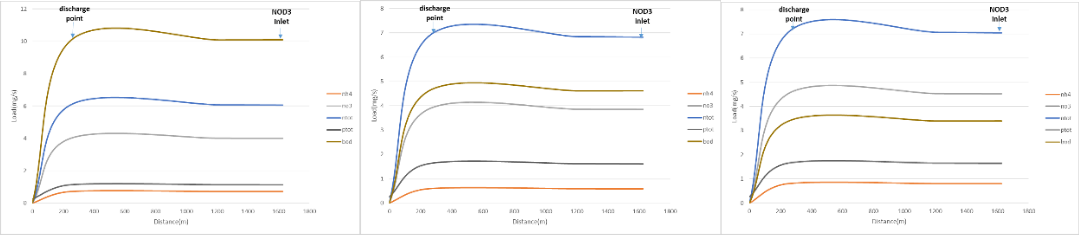


Figure 59 Concentration of nutrients from start node to inlet in different condition (left to right: dry, normal, wet condition)

From the figure 59, we find the there is no obvious change of nutrients concentration from the start node to the inlet (node 3). The efficiency is so small (0.2%-0.6%).And the main object is to find the Kristalbad impact on the nutrients transport. So we make detail analysis on Kristalbad part (include inlet, ponds and outlet)

5.2 Normal condition scenario

In normal condition, initial condition, boundary condition and flow data are both from previous research and model default. Flow rate is set as 0.8m³/s in river and discharge point. The table 4 below is the initial condition which conclude many substance.

Table 4 Initial condition setting

Initial condition item	value
Discharge	0.5m3/s
Level	0.5 m
Depth	-1
A	2 mg-C/l
Bod	5mg-O2/l
Nh4	0.3mg-N/l
No3	3mg-N/l
Organic N	0.8mg-N/l
O2	10mg/l
Inorganic P	0.04mg-P/l
Organic P	0.11 mg-P/l
Suspended solids	5mg/l

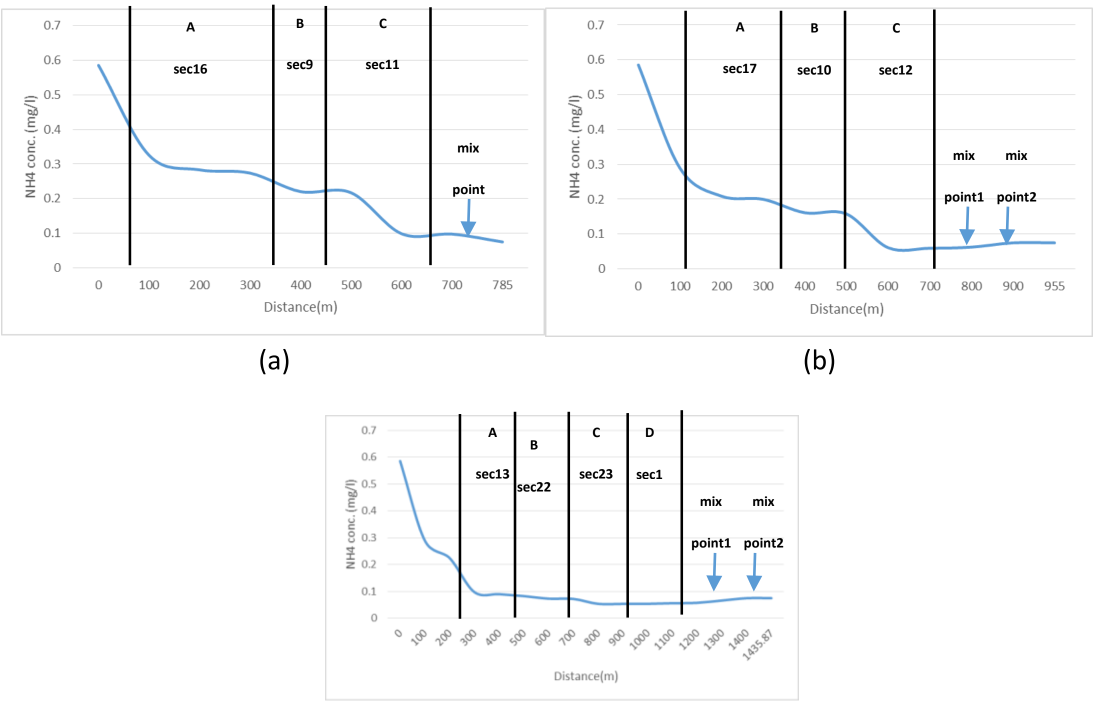
Discharge point the main source where nutrients come from. Boundary condition is only set at the discharge point to make a simple simulate. Boundary condition data is simulated by the observed data at inlet and outlet of the Kristalbad (table5). It is set as table 6. Boundary condition is a constant value. In different scenario (discharge), the constant concentration will be transfer to the same load. After simulation, the EUTROF model export the process of the content of nutrients in every pond.

Table 5 observed data at inlet and outlet

item	inlet	outlet
Algal biomass	0.2mg/l	0.12mg/l
BOD	2.9mg/l	3.7mg/l
NH4	1.25mg/l	1.05mg/l
NO3	4.6mg/l	3.2mg/l
organic N	1.3mg/l	0.7mg/l
O2	9.5mg/l	11.2mg/l
Organic P	0.13mg/l	0.2mg/l
Inorganic P	1.54mg/l	1.05mg/l
Suspended solids	15mg/l	6mg/l

Table 6 Boundary condition setting

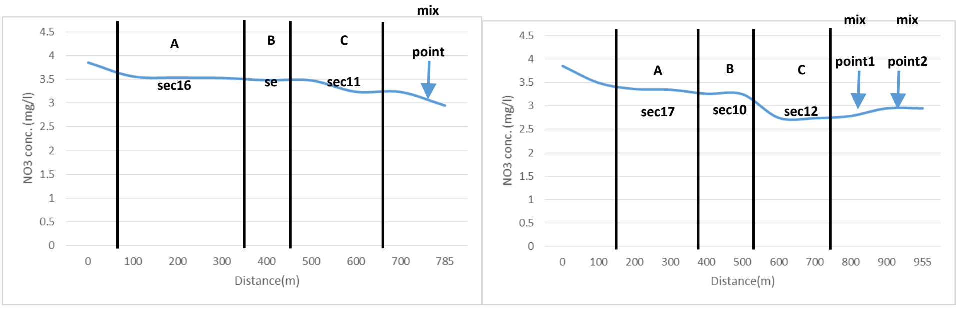
Boundary condition item	value
Algal biomass	0.19mg/l
BOD	2.75mg/l
NH4	1.30mg/l
NO3	4.8mg/l
organic N	1.25mg/l
O2	9 mg/l
Organic P	0.12mg/l
Inorganic P	1.4mg/l
Suspended solids	2.2mg/l



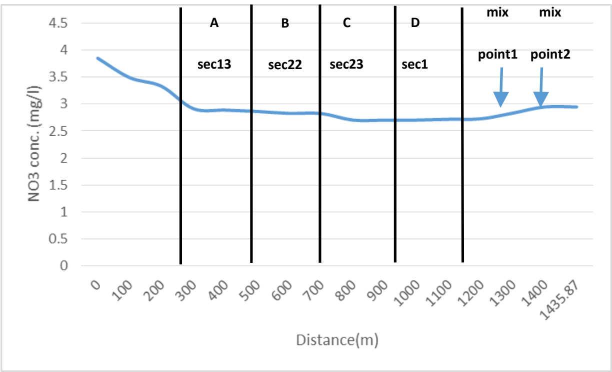
(a) (b)

(c)

Figure 60 Concentration of NH₄ in normal condition (a through pond1, b though pond 2, c through pond3)

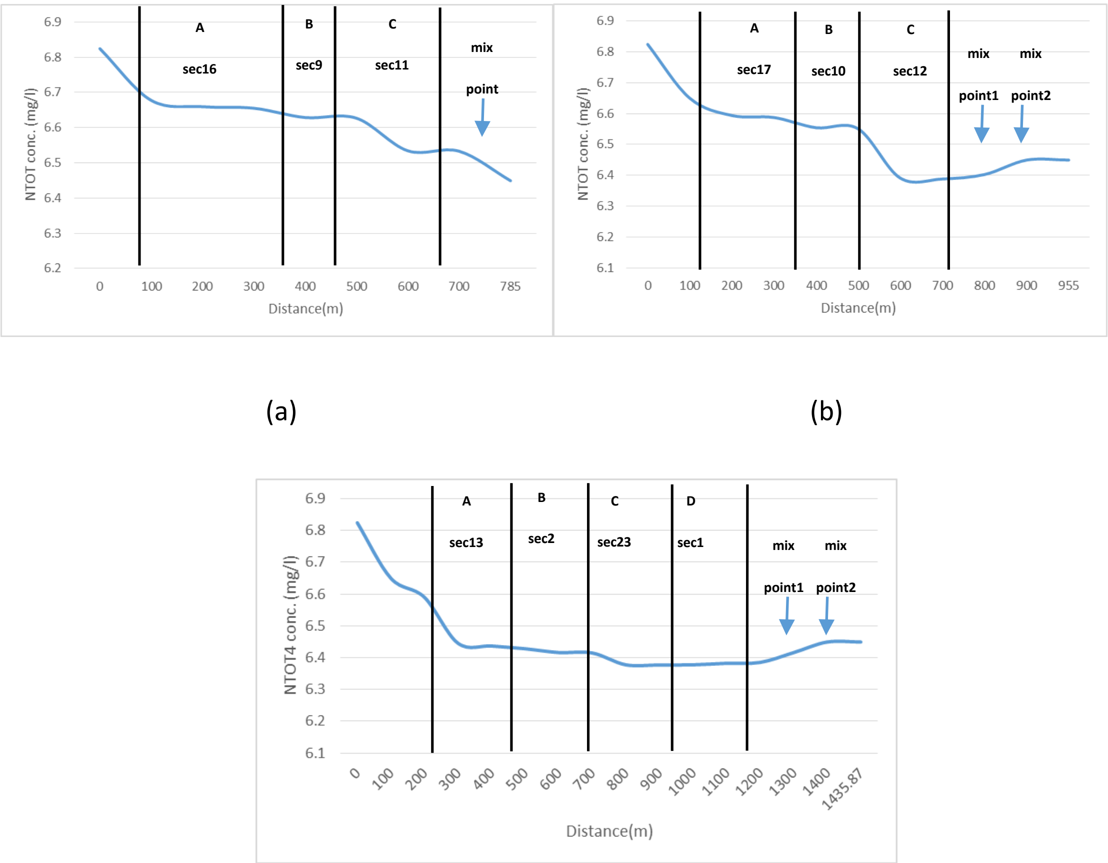


(a) (b)



(c)

Figure 61 Concentration of NO_3 in normal condition (a through pond1, b through pond 2, c through pond3)



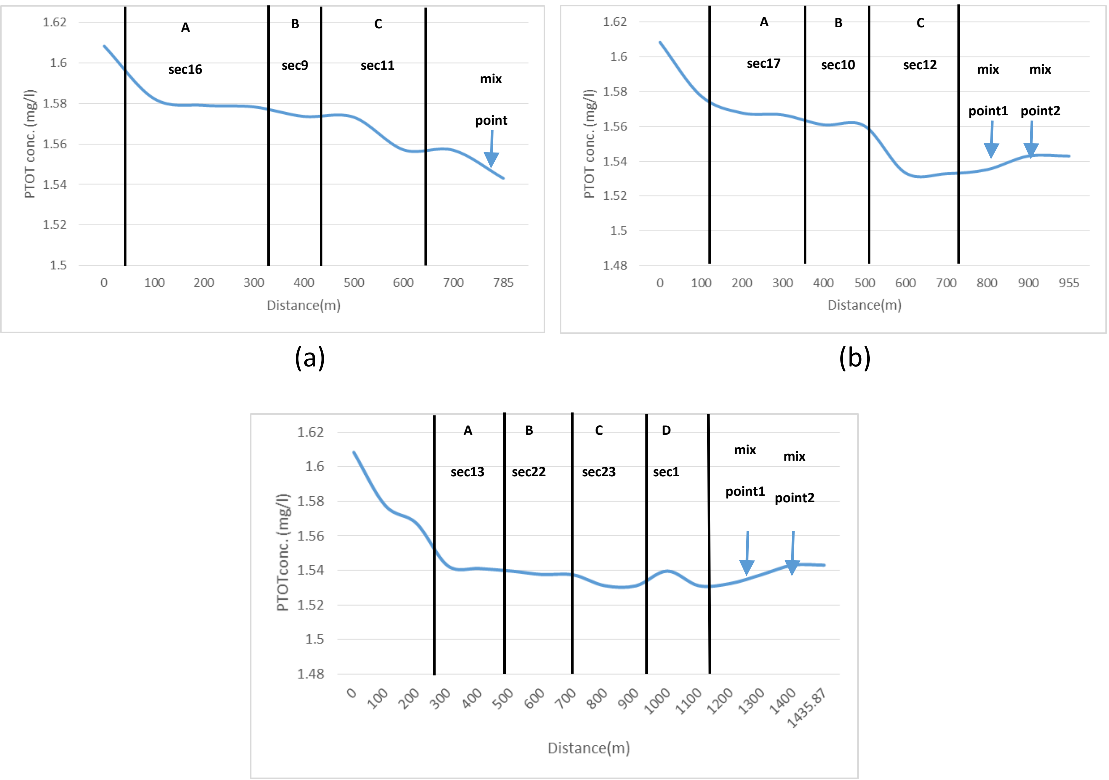
(a)

(b)

(c)

Figure 62 Concentration of total nitrogen in normal condition (a through pond1, b through pond 2, c through pond3)

NOD3

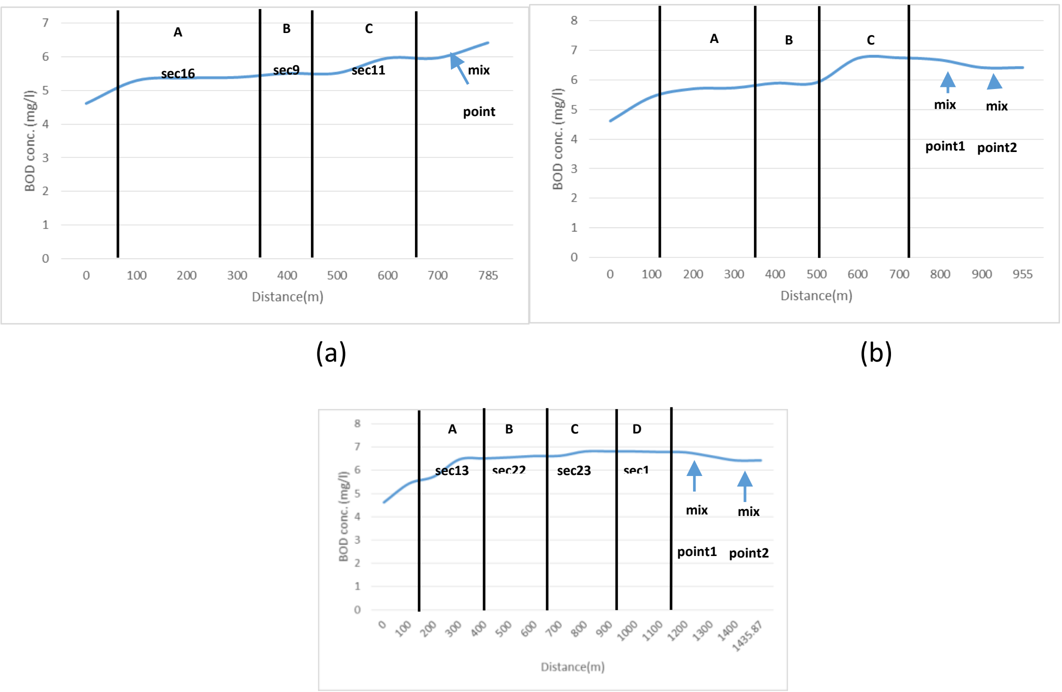


(a)

(b)

(c)

Figure 63 Concentration of total Phosphorus in normal condition (a through pond1, b through pond 2, c through pond3)



(a)

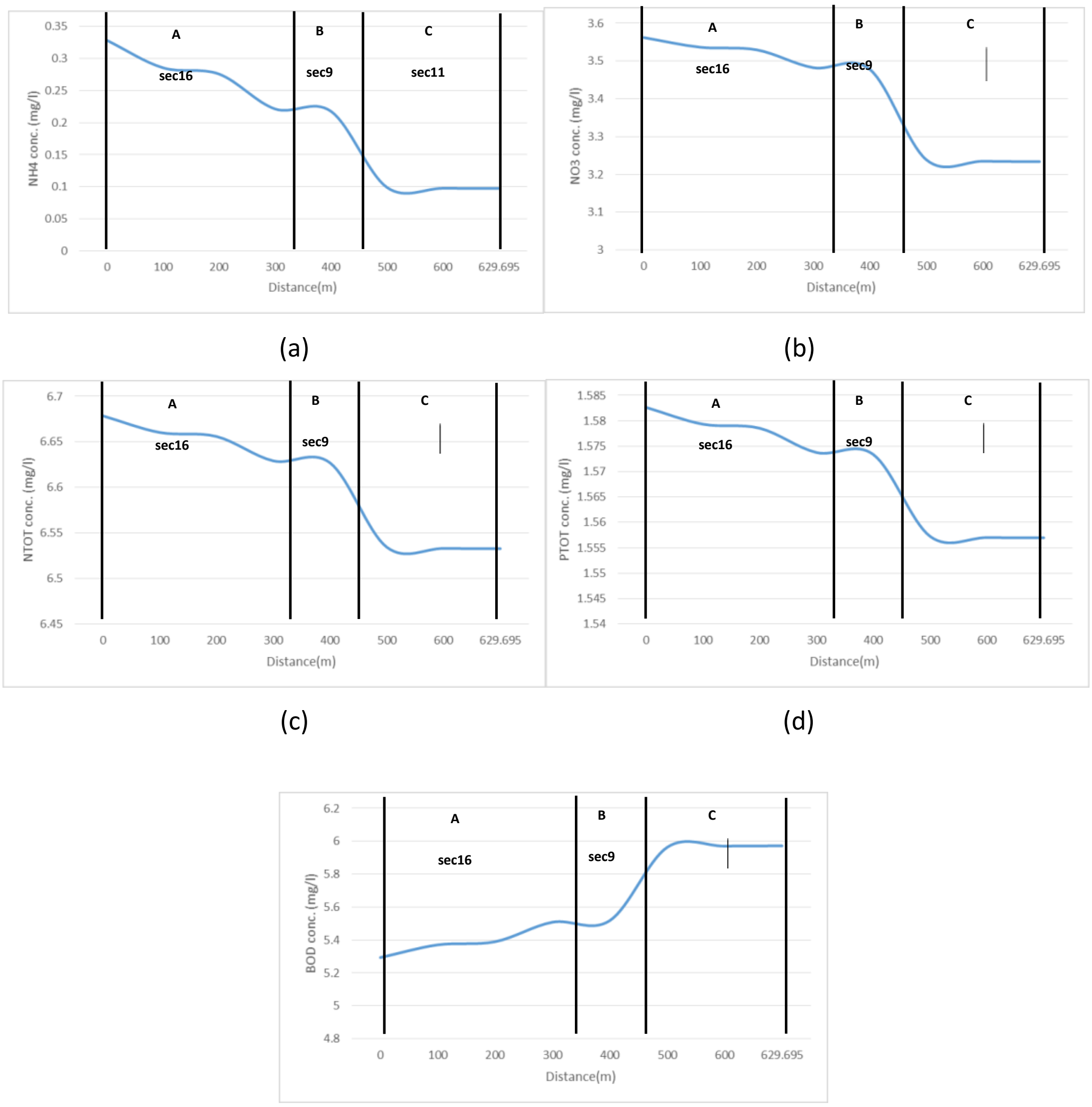
(b)

(c)

Figure 64 Concentration of BOD in normal condition (a through pond1, b through pond 2, c through pond3)

The results are shown in Figures 60-64. Simulated is under the effect of normal inlet flow rate ($0.8m^3/s$). In the initial situation, NH4 content is 0.3 mg/l, NO3 is 4 mg/l. In upstream sections substantially NH4 is equal to 0.59mg/l, NO3 is 3.85 mg/l, total N is 6.82 mg/l, and total P is 1.61 mg /l. Normal flow rate leads to a reduction of all concentrations up to 0.07mg/l,2.95 mg/l,6.45mg/l and 1.54 mg/l respectively. The removal efficiencies for the nutrients of the Kristalbad are 87.20% (NH4), 23.48% (NO3), 5.45% (Total N), and 4.07% (Total P).Bod increases form 4.62 mg/l to 6.42 mg/l (39.11%).

There are three ponds in the Kristalbad. It’s important to check the nutrients removal efficiencies in different ponds.



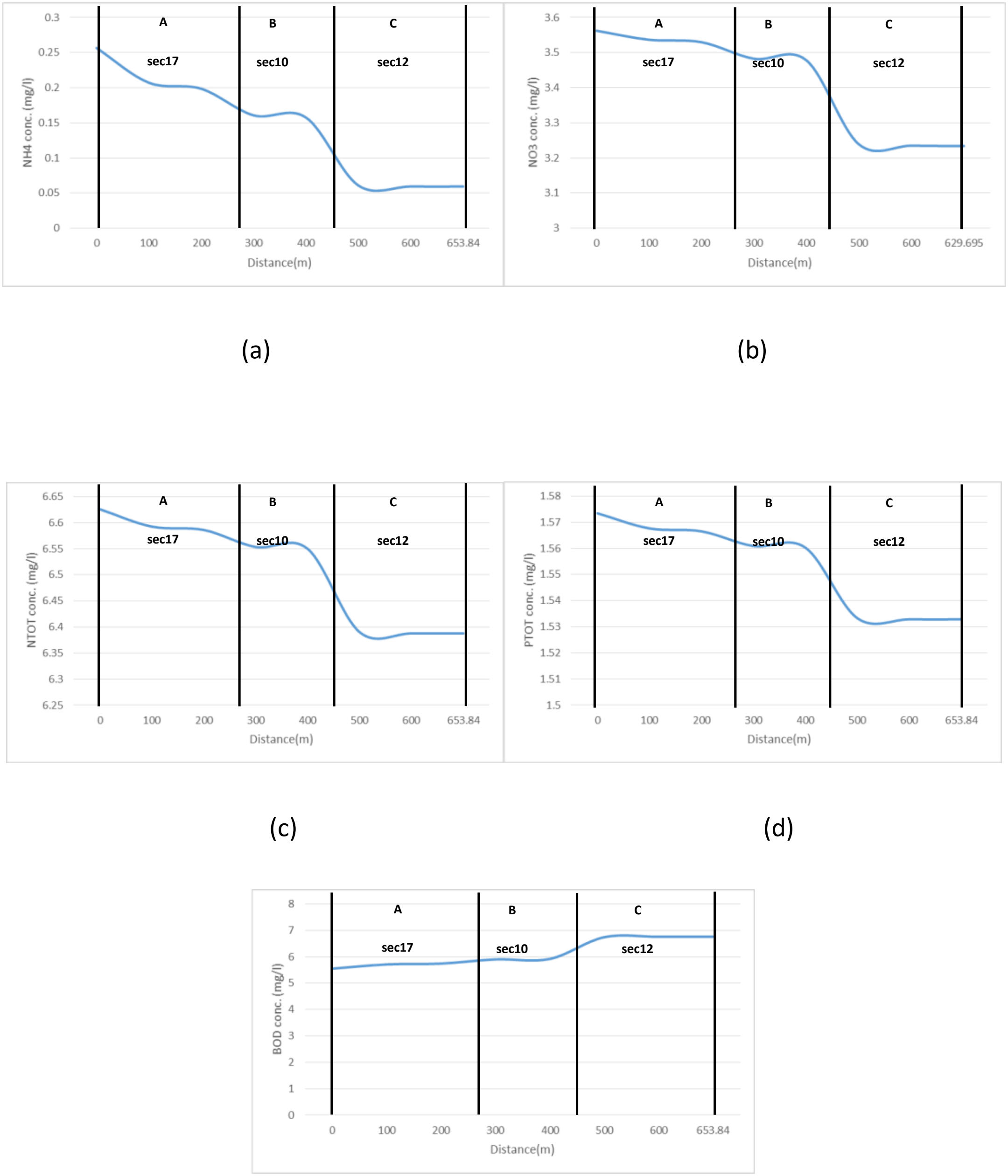
(a) (b)

(c) (d)

(e)

Figure 65 Concentration of Nutrients in normal condition in Pond1 (a for NH4, b for NO3, c for total N, d for total P, e for BOD)

The results are shown in Figures 65. In entrance of pond1 substantially NH4 is equal to 0.33mg/l, NO3 is 3.56 mg/l, total N is 6.68 mg/l, and total P is 1.58 mg /l. Normal flow rate leads to a reduction of all concentrations up to 0.10mg/l,3.23 mg/l,6.53mg/l and 1.56 mg/l respectively. The removal efficiencies for the nutrients of the pond 1 are 70.26% (NH4), 9.22% (NO3), 2.18% (Total N), and 1.62% (Total P). Bod increases form 5.29 mg/l to 5.97 mg/l (12.82%).



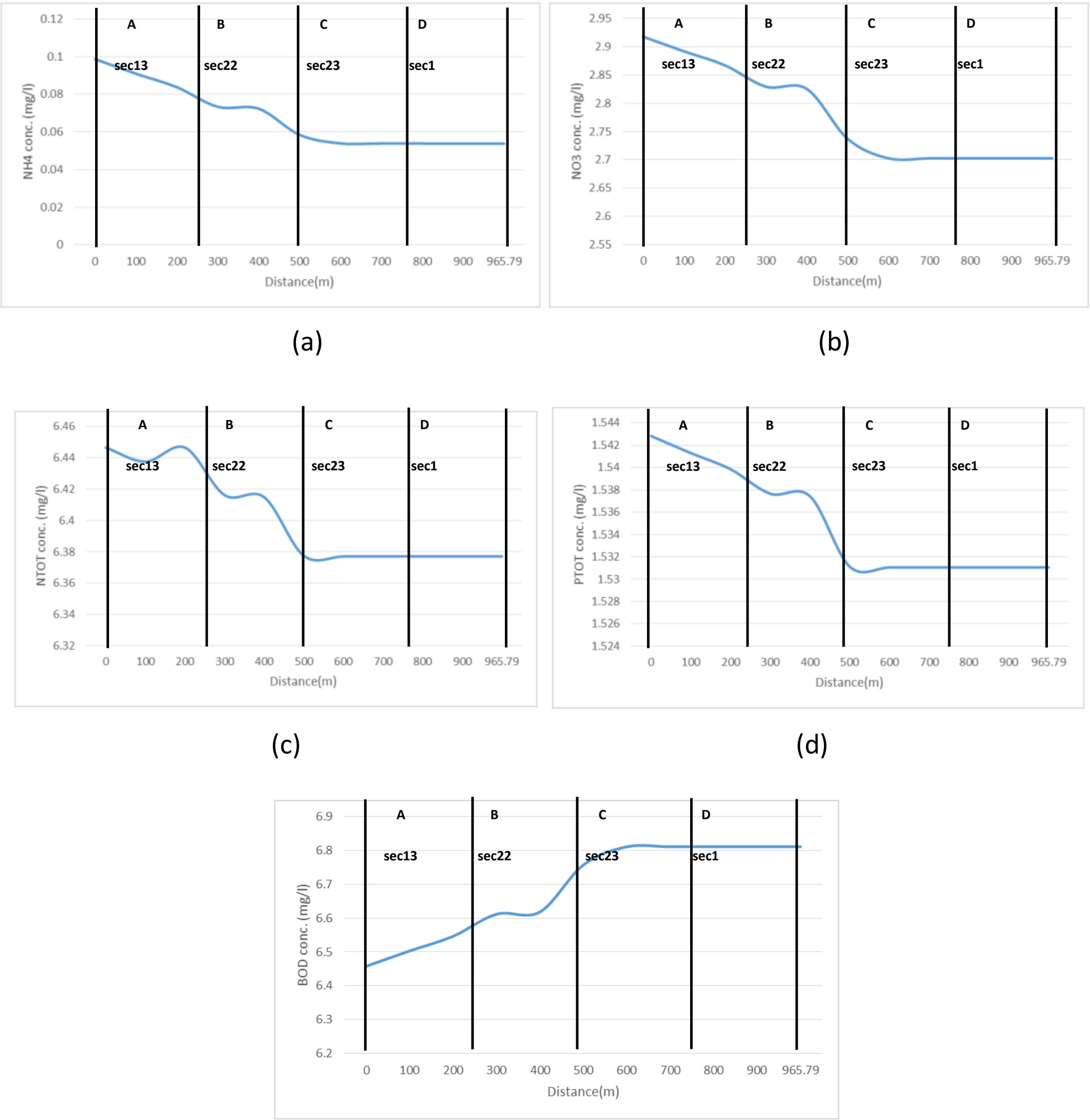
(a) (b)

(c) (d)

(e)

Figure 66 Concentration of Nutrients in normal condition in Pond2 (a for NH4, b for NO3, c for total N, d for total P, e for BOD)

The results are shown in Figures 66. In entrance of pond2 substantially NH4 is equal to 0.26mg/l, NO3 is 3.43 mg/l, total N is 6.63 mg/l, and total P is 1.57 mg /l. Normal flow rate leads to a reduction of all concentrations up to 0.06mg/l,2.74 mg/l,6.39mg/l and 1.53 mg/l respectively. The removal efficiencies for the nutrients of the pond 2 are 76.89% (NH4), 20.31% (NO3), 3.59% (Total N), and 2.58% (Total P). Bod increases form 5.55 mg/l to 6.76 mg/l (21.82%).



(a) (b) (c) (d) (e)

Figure 67 Concentration of Nutrients in normal condition in Pond3 (a for NH4, b for NO3, c for total N, d for total P, e for BOD)

The results are shown in Figures 67. In entrance of pond 3 substantially NH4 is equal to 0.10mg/l, NO3 is 2.92 mg/l, total N is 6.45 mg/l, and total P is 1.54 mg /l. Normal flow rate leads to a reduction of all concentrations up to 0.05mg/l,2.70 mg/l,6.38mg/l and 1.53 mg/l respectively. The removal efficiencies for the nutrients of the pond 3 are 45.49% (NH4), 7.38% (NO3), 1.08% (Total N), and 0.76% (Total P). Bod increases form 6.46 mg/l to 6.81 mg/l (5.47%).

5.3 Dry condition scenario

In dry condition, it sets the same initial condition and boundary condition as normal scenario. The difference is the discharge.

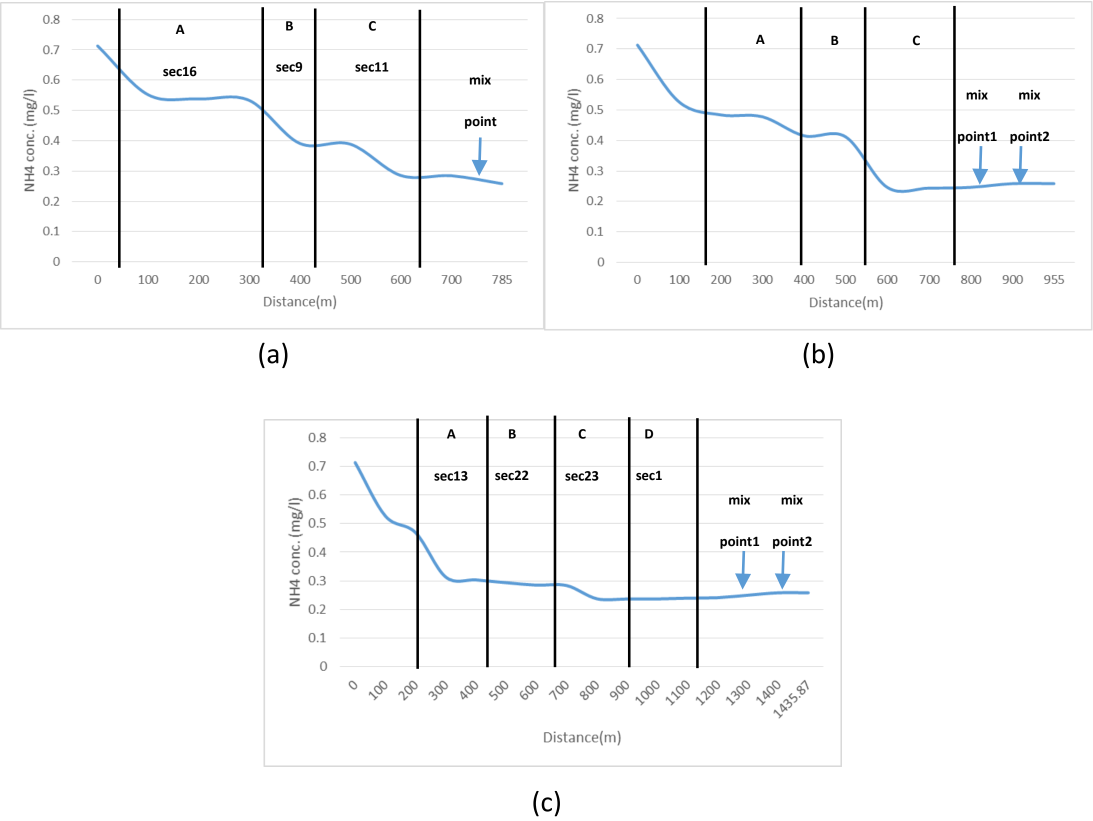


Figure 68 Concentration of NH₄ in dry condition (a through pond1, b though pond 2, c through pond3)

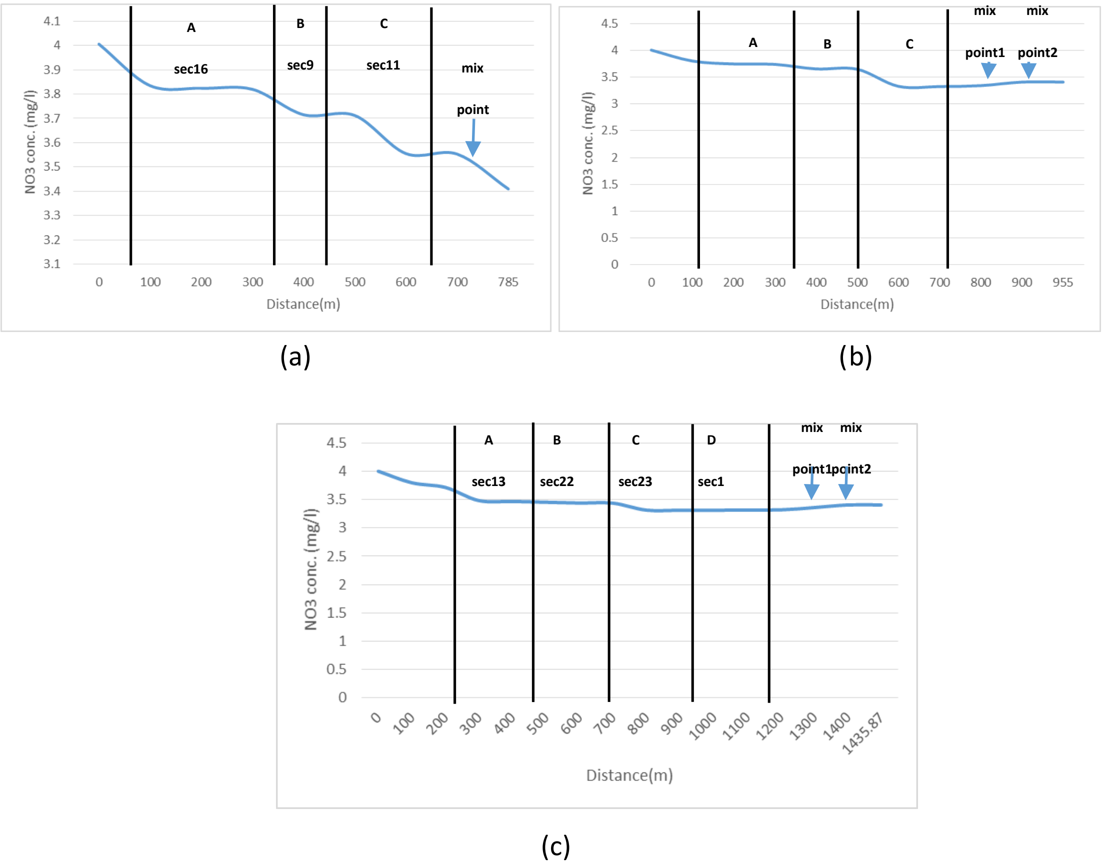
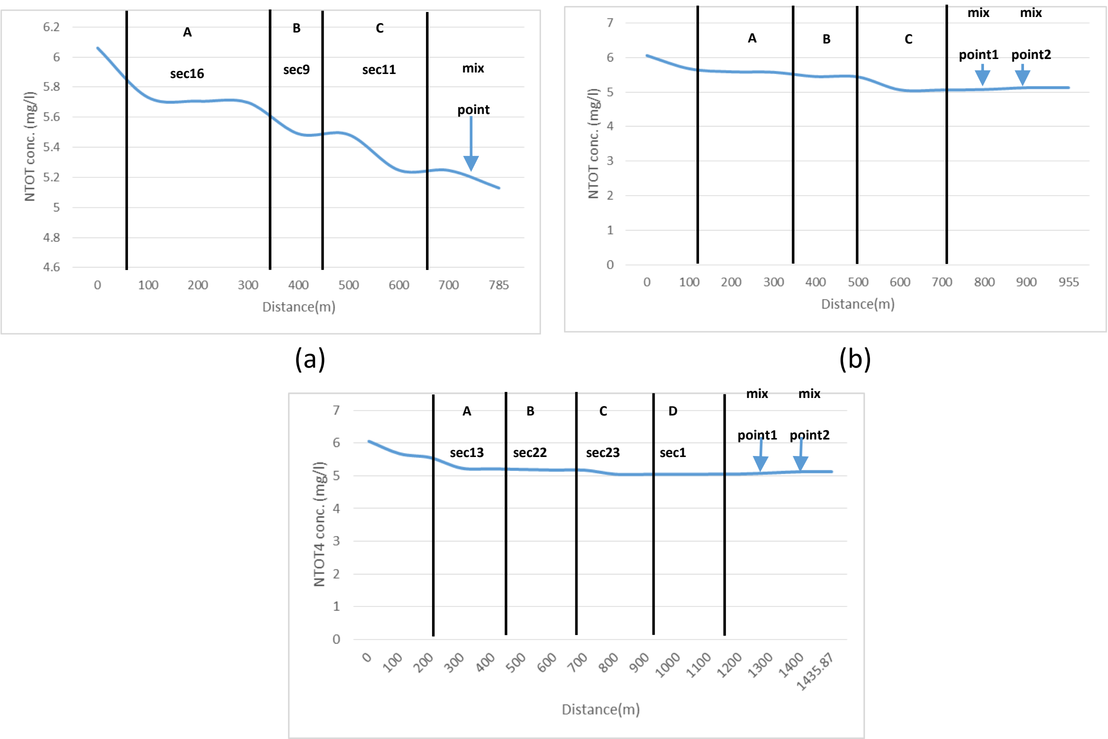


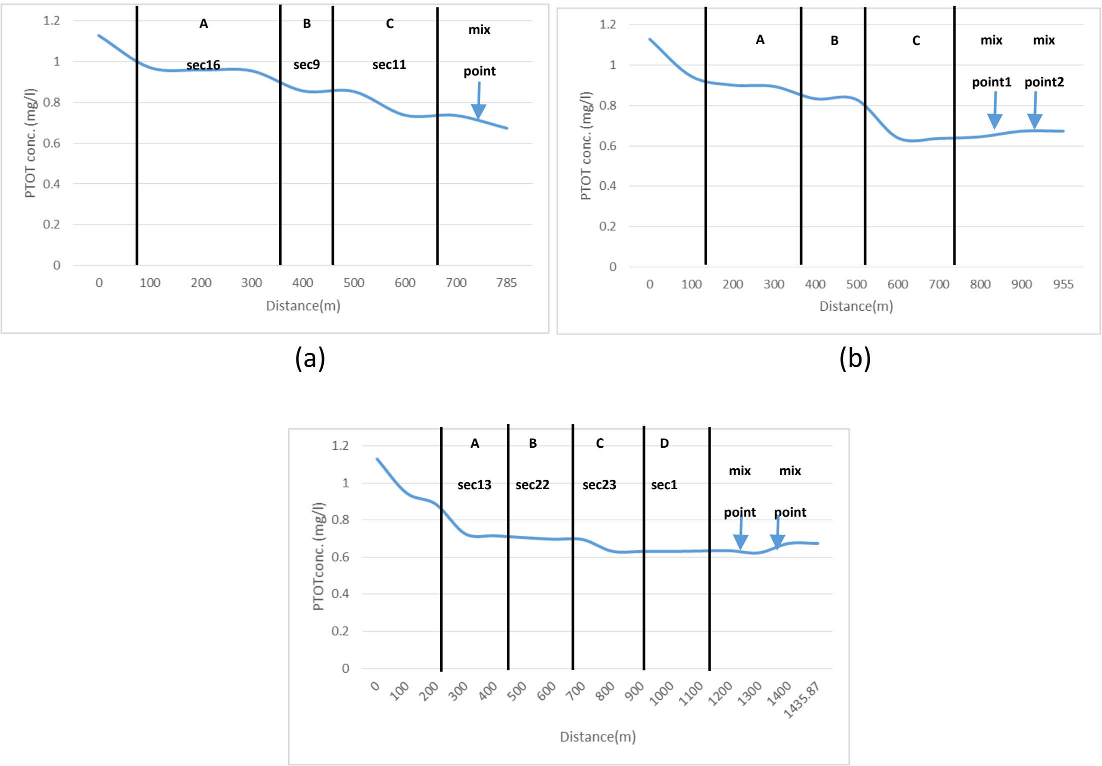
Figure 69 Concentration of NO₃ in dry condition (a through pond1, b through pond 2, c through pond3)



(a) (b)

(c)

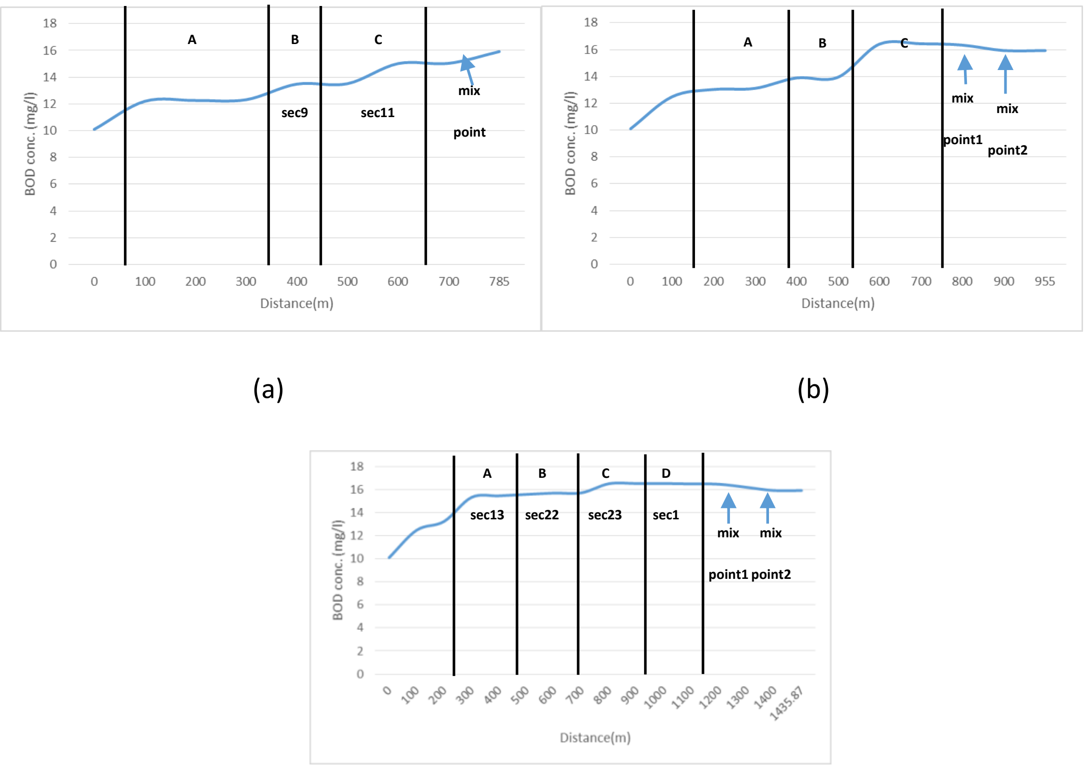
Figure 70 Concentration of total Nitrogen in dry condition (a through pond1, b through pond 2, c through pond3)



(a) (b)

(c)

Figure 71 Concentration of total Phosphorus in dry condition (a through pond1, b through pond 2, c through pond3)



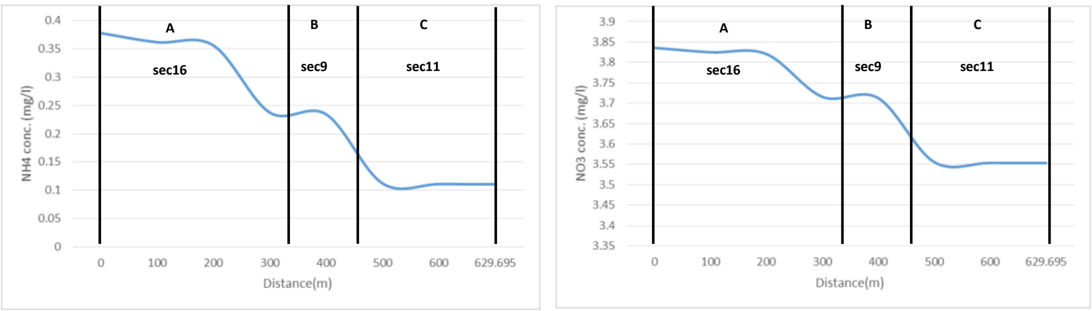
(a)

(b)

(c)

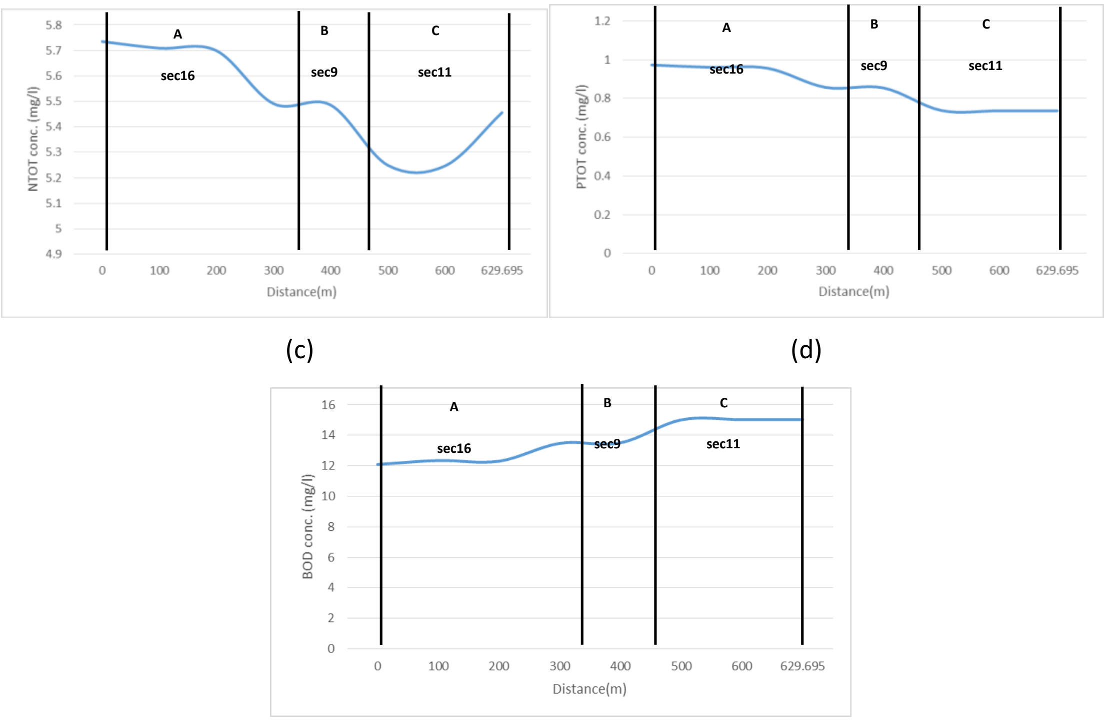
Figure 72 Concentration of BOD in dry condition (a through pond1, b through pond 2, c through pond3)

The results are shown in Figures 68-72. Simulated is under the effect of normal inlet flow rate (0.3m³/s). In the initial situation, NH4 content is 0.3 mg/l, NO3 is 4 mg/l. In upstream sections substantially NH4 is equal to 0.71 mg/l, NO3 is 4.01 mg/l, total N is 6.06 mg/l, and total P is 1.13mg /l. Normal flow rate leads to a reduction of all concentrations up to 0.26mg/l,3.41 mg/l, 5.13 mg/l and 0.67 mg/l respectively. The removal efficiencies for the nutrients of the Kristalbad are 63.75% (NH4), 14.89% (NO3), 15.38% (Total N), and 40.35% (Total P). Bod increases form 10.01 mg/l to 15.83 mg/l (5.78%).



(a)

(b)



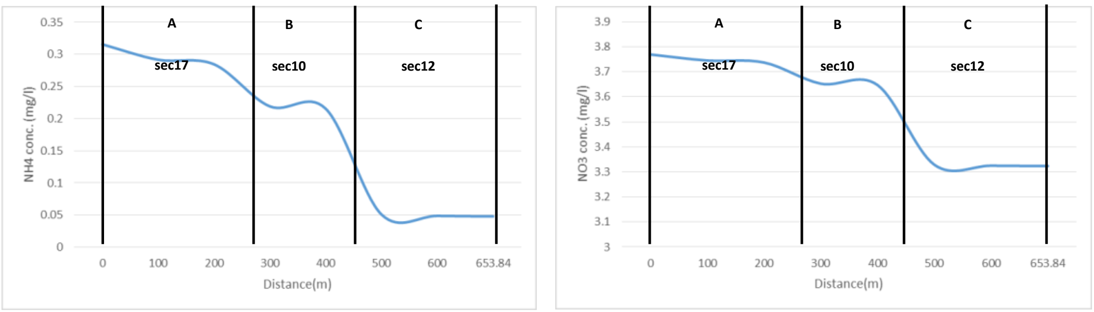
(c)

(d)

(e)

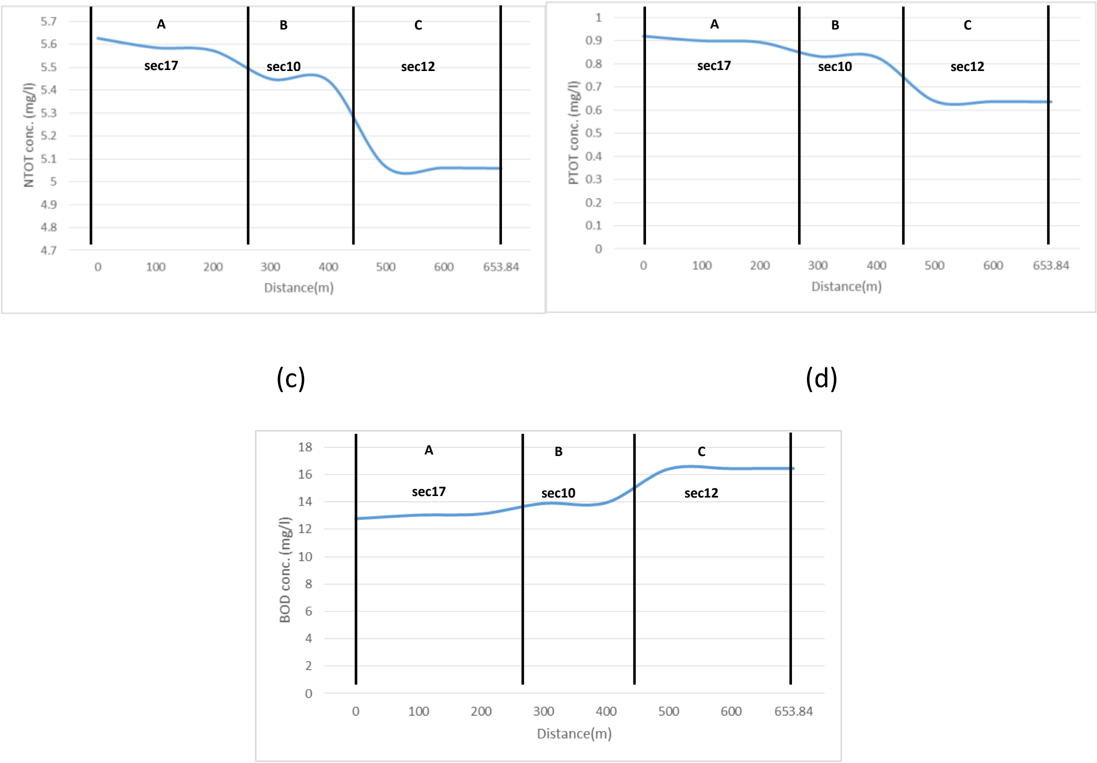
Figure 73 Concentration of Nutrients in dry condition in Pond1 (a for NH4, b for NO3, c for total N, d for total P, e for BOD)

The results are shown in Figures 73. In entrance of pond1 substantially NH4 is equal to 0.38mg/l, NO3 is 3.84 mg/l, total N is 5.74 mg/l, and total P is 0.97 mg /l. Normal flow rate leads to a reduction of all concentrations up to 0.11mg/l,3.55 mg/l,5.46mg/l and 0.74 mg/l respectively. The removal efficiencies for the nutrients of the pond 1 are 70.73% (NH4), 7.37% (NO3), 4.86% (Total N), and 24.3% (Total P). Bod increases form 12.09 mg/l to 15.04 mg/l (24.35%).



(a)

(b)

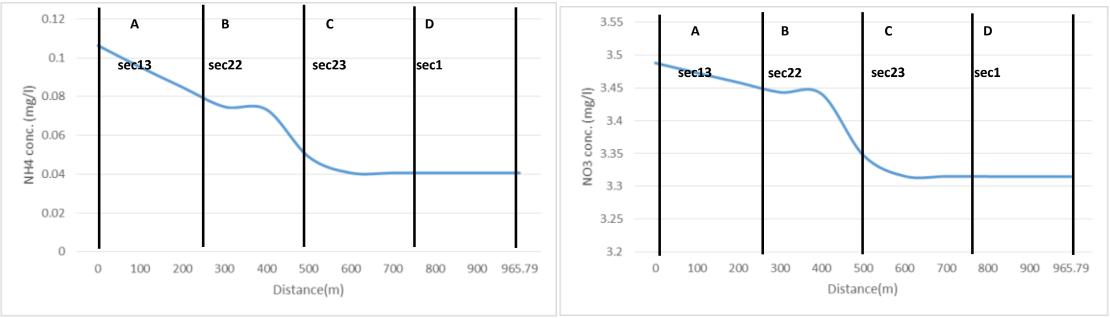


(c) (d)

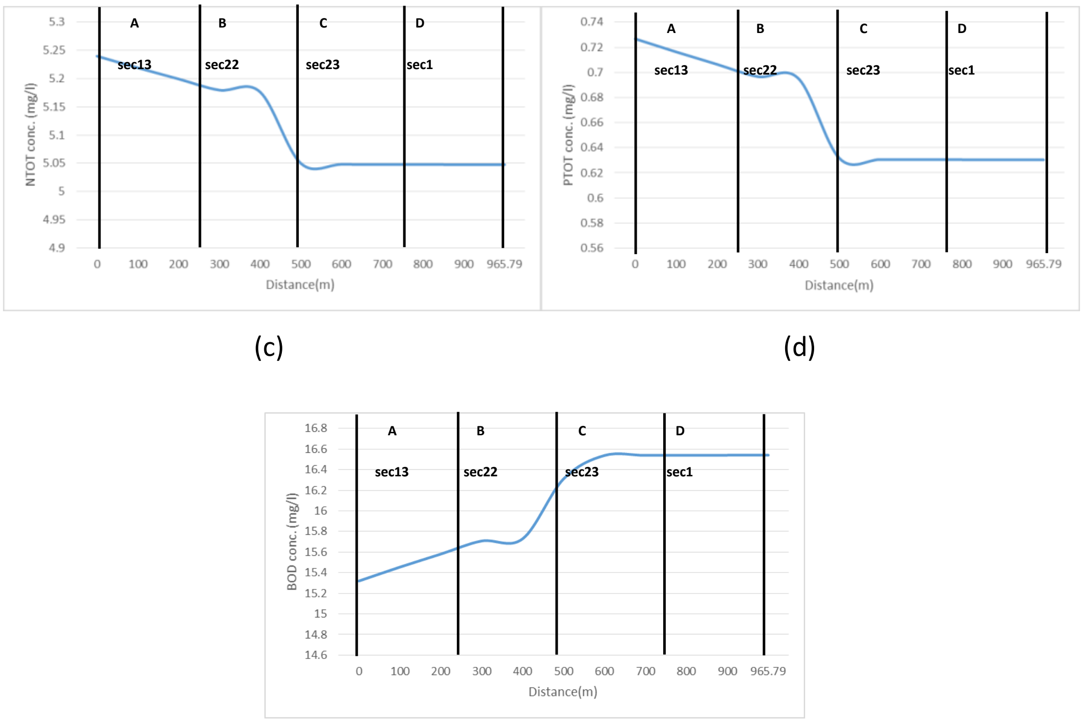
(e)

Figure 74 Concentration of Nutrients in dry condition in Pond2 (a for NH4, b for NO3, c for total N, d for total P, e for BOD)

The results are shown in Figures 74. In entrance of pond2 substantially NH4 is equal to 0.32mg/l, NO3 is 3.77 mg/l, total N is 5.63 mg/l, and total P is 0.92 mg /l. Normal flow rate leads to a reduction of all concentrations up to 0.05mg/l,3.32 mg/l,5.06mg/l and 0.64 mg/l respectively. The removal efficiencies for the nutrients of the pond 2 are 84.81% (NH4), 11.83% (NO3), 10.09% (Total N), and 30.87% (Total P). Bod increases form 12.78 mg/l to 16.49mg/l (28.74%).



(a) (b)



(c)

(d)

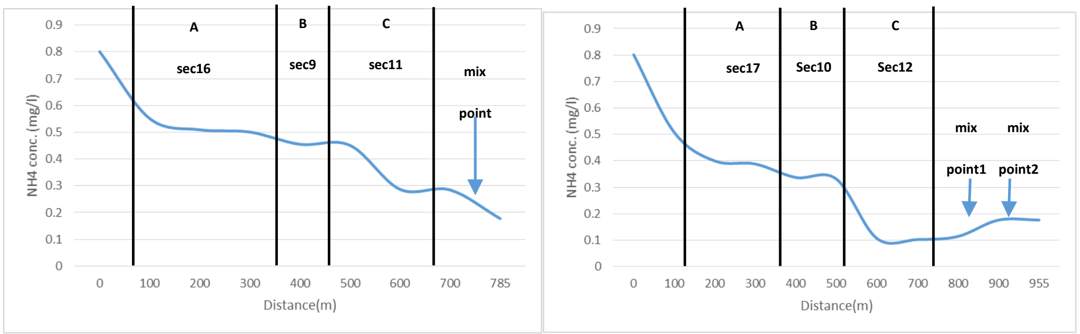
(e)

Figure 75 Concentration of Nutrients in dry condition in Pond3 (a for NH4, b for NO3, c for total N, d for total P, e for BOD)

The results are shown in Figures 75. In entrance of pond 3 substantially NH4 is equal to 0.11mg/l, NO3 is 3.49 mg/l, total N is 5.24 mg/l, and total P is 0.73 mg /l. Normal flow rate leads to a reduction of all concentrations up to 0.04mg/l,3.31 mg/l,5.05mg/l and 0.63 mg/l respectively. The removal efficiencies for the nutrients of the pond 3 are 61.79% (NH4), 4.97% (NO3), 3.67% (Total N), and 13.26% (Total P). Bod increases form 15.32 mg/l to 16.54mg/l (7.98%).

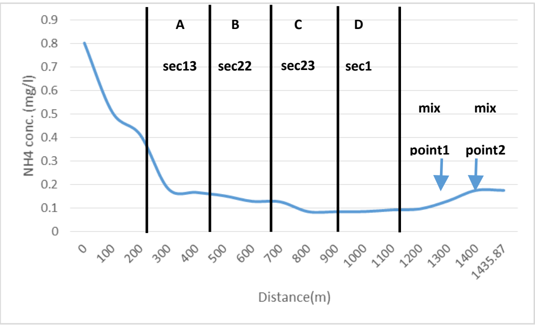
5.4 Wet condition scenario

In wet condition, it sets the same initial condition and boundary condition as normal scenario. The difference is the discharge.



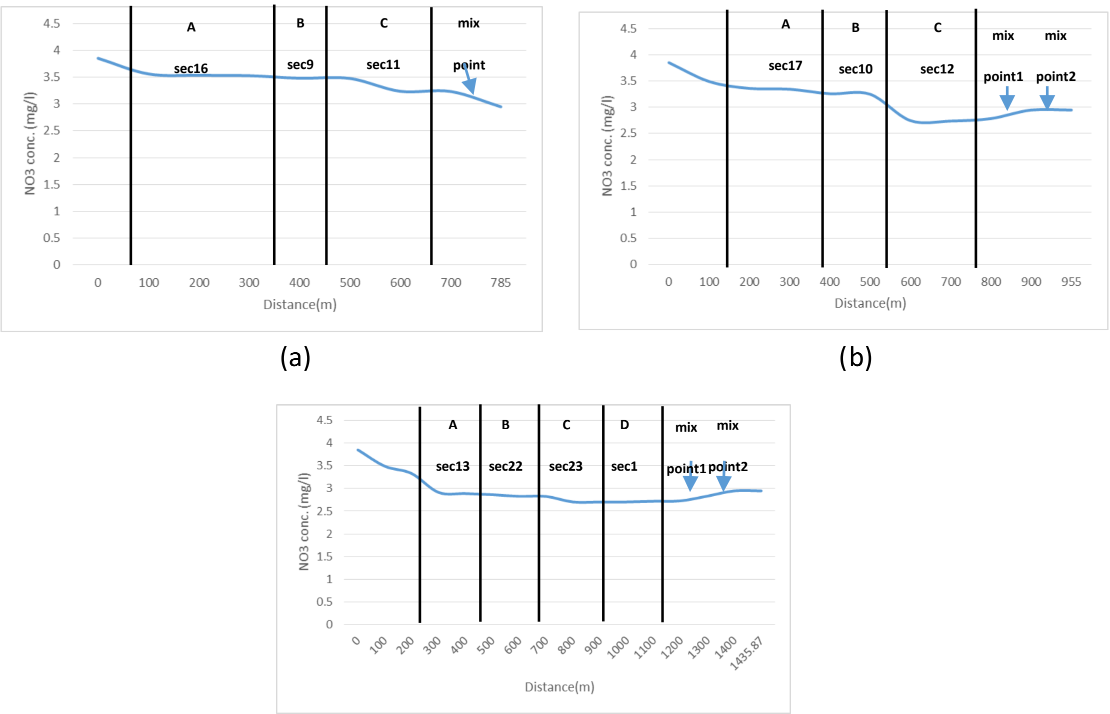
(a)

(b)



(c)

Figure 76 Concentration of in wet condition (a through pond1, b though pond 2, c through pond3)

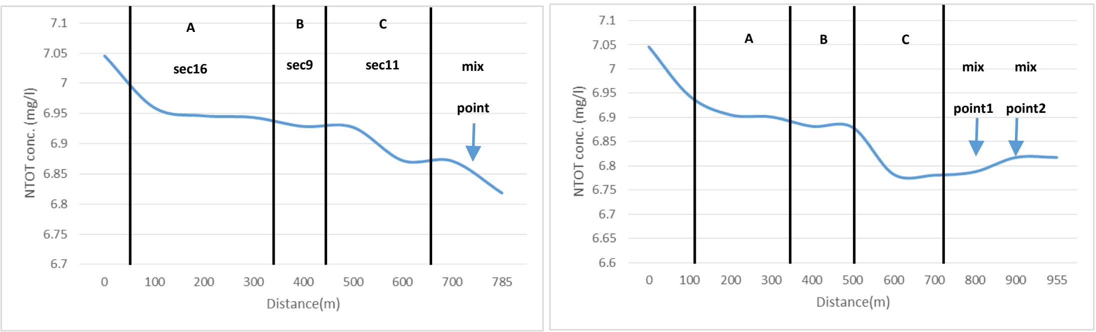


(a)

(b)

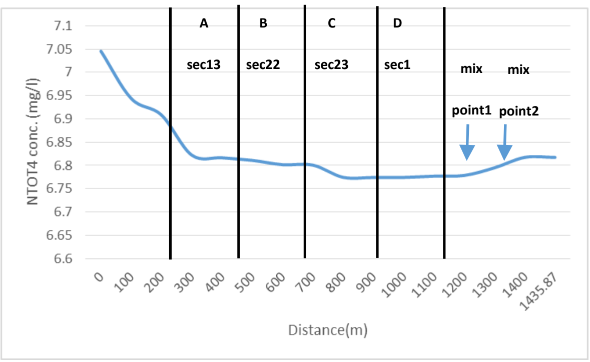
(c)

Figure 77 Concentration of NO_3 in wet condition (a through pond1, b through pond 2, c through pond3)



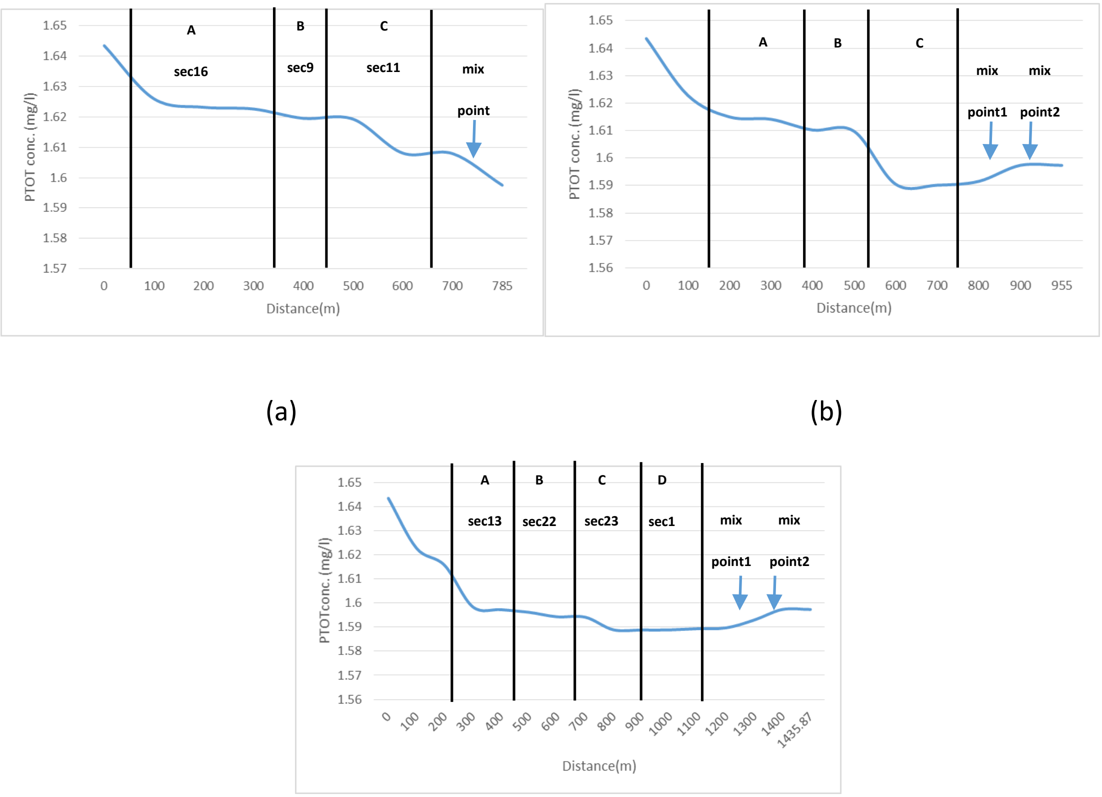
(a)

(b)



(c)

Figure 78 Concentration of total Nitrogen in wet condition (a through pond1, b through pond 2, c through pond3)

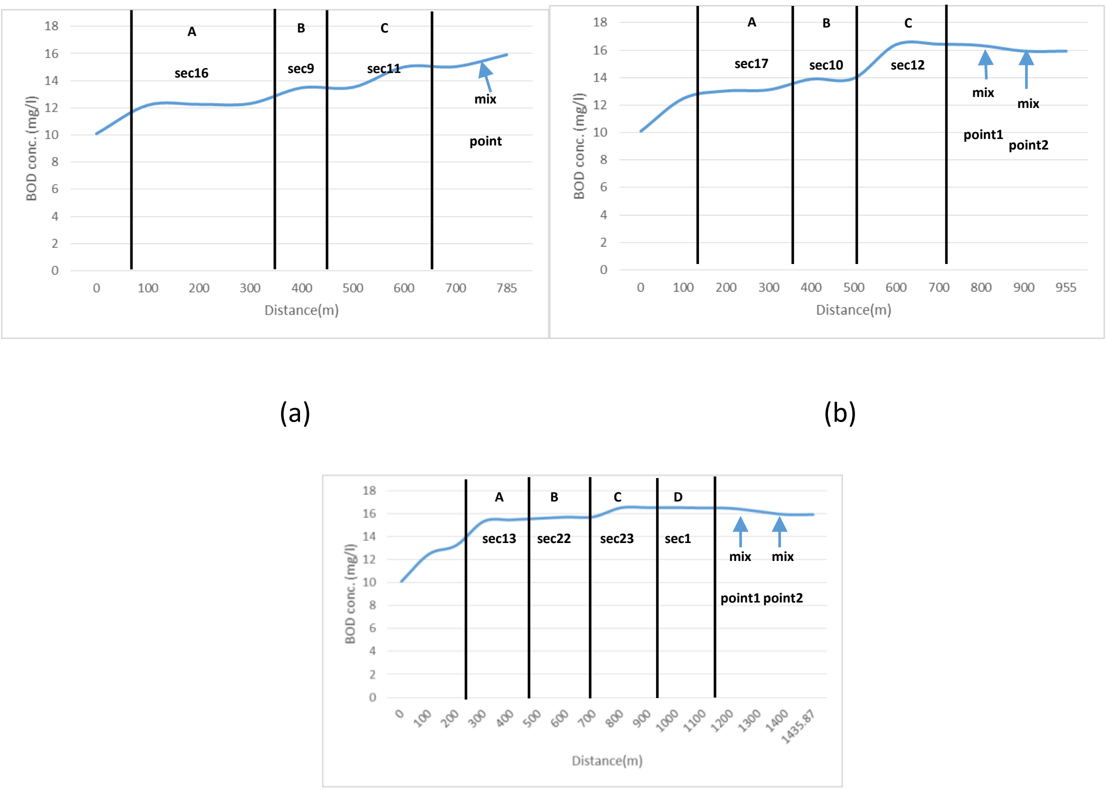


(a)

(b)

(c)

Figure 79 Concentration of total Phosphorus in wet condition (a through pond1, b through pond 2, c through pond3)



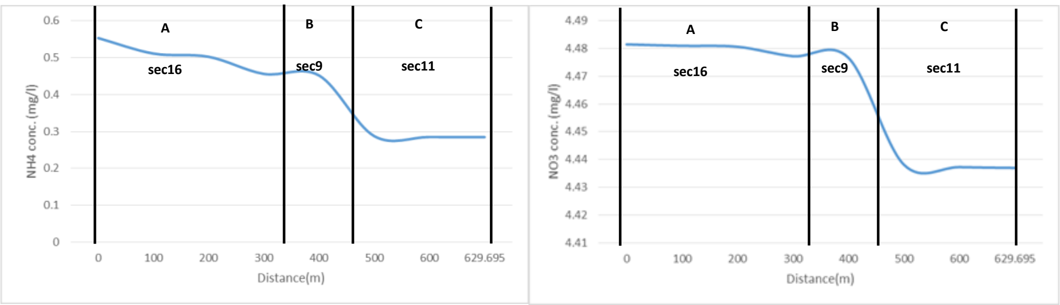
(a)

(b)

(c)

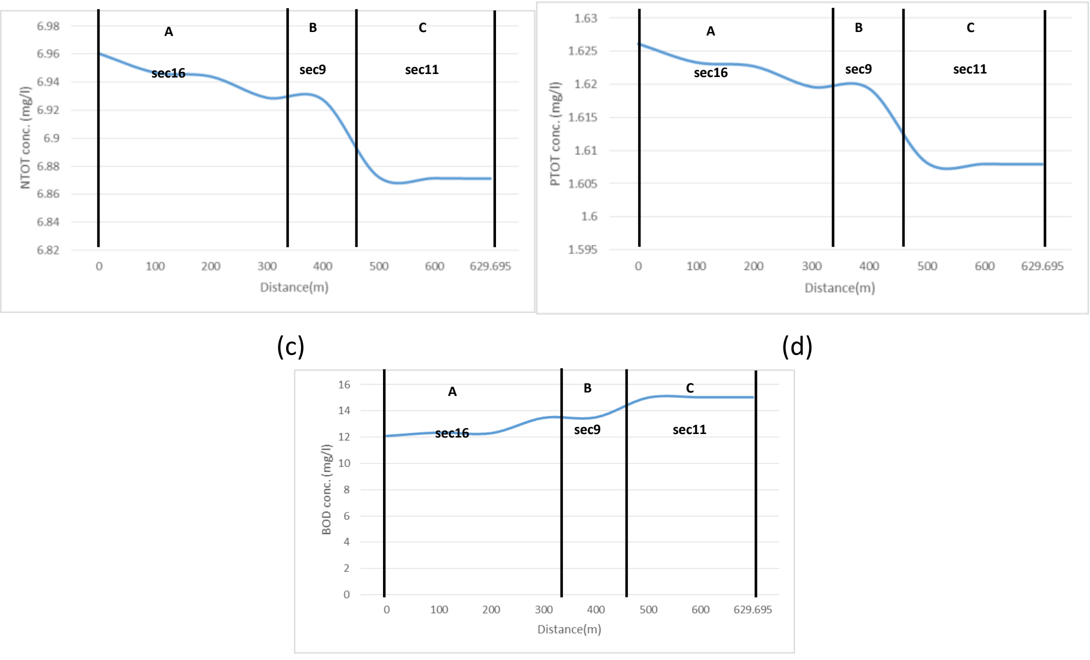
Figure 80 Concentration of BOD in wet condition (a through pond1, b through pond 2, c through pond3)

The results are shown in Figures 76-80. Simulated is under the effect of normal inlet flow rate (1.3m³/s). In the initial situation, NH4 content is 0.3 mg/l, NO3 is 4 mg/l. In upstream sections substantially NH4 is equal to 0.80 mg/l, NO3 is 4.52 mg/l, total N is 7.05 mg/l, and total P is 1.64mg /l. Normal flow rate leads to a reduction of all concentrations up to 0.18mg/l,4.33 mg/l, 6.82 mg/l and 1.59 mg/l respectively. The removal efficiencies for the nutrients of the Kristalbad are 77.82% (NH4), 4.32% (NO3), 3.23% (Total N), and 2.80% (Total P). Bod increases form 3.40 mg/l to 4.23mg/l (24.34%).



(a)

(b)

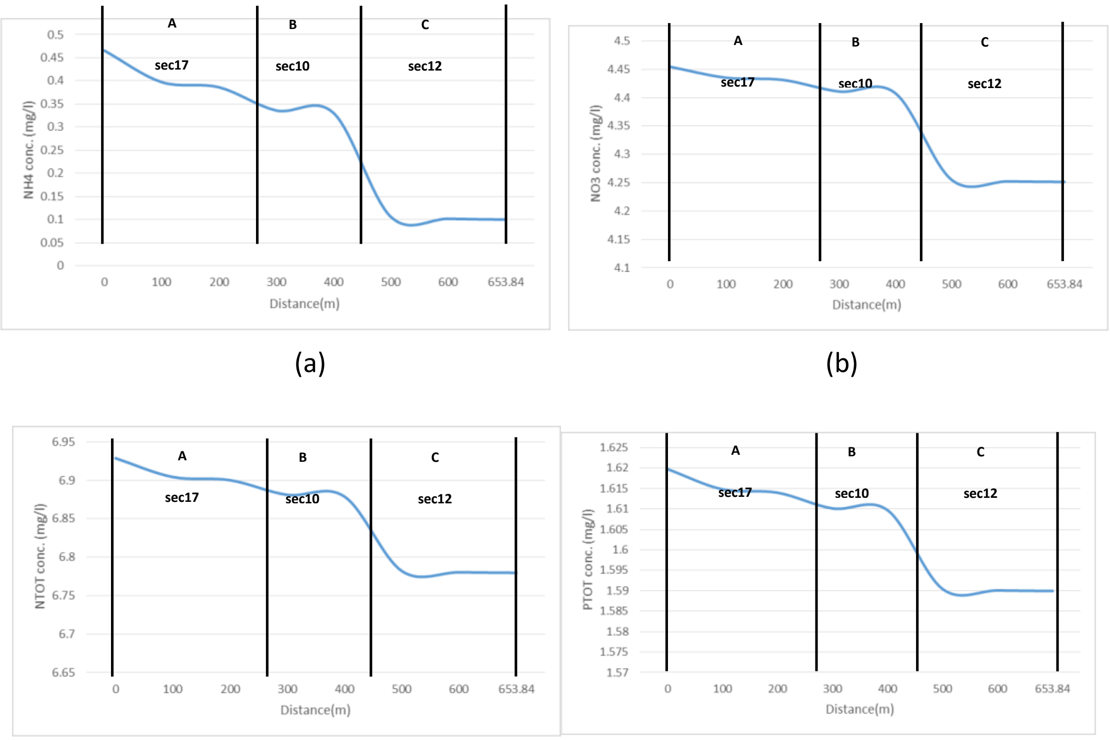


(c) (d)

(e)

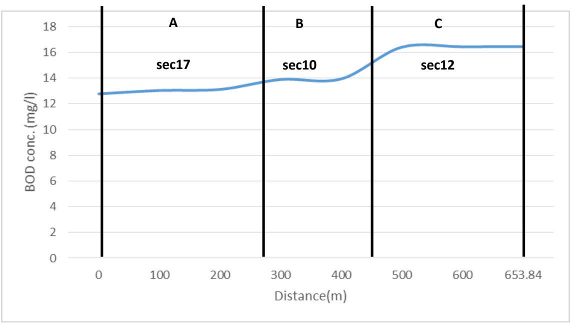
Figure 81 Concentration of Nutrients in wet condition in Pond1 (a for NH4, b for NO3, c for total N, d for total P, e for BOD)

The results are shown in Figures 81. In entrance of pond1 substantially NH4 is equal to 0.55mg/l, NO3 is 4.48 mg/l, total N is 6.96 mg/l, and total P is 1.63 mg /l. Normal flow rate leads to a reduction of all concentrations up to 0.28mg/l,4.44 mg/l,6.87mg/l and 1.61 mg/l respectively. The removal efficiencies for the nutrients of the pond 1 are 48.55% (NH4), 0.99% (NO3), 1.28% (Total N), and 1.12% (Total P). Bod increases form 3.68 mg/l to 3.98mg/l (8.07%).



(a) (b)

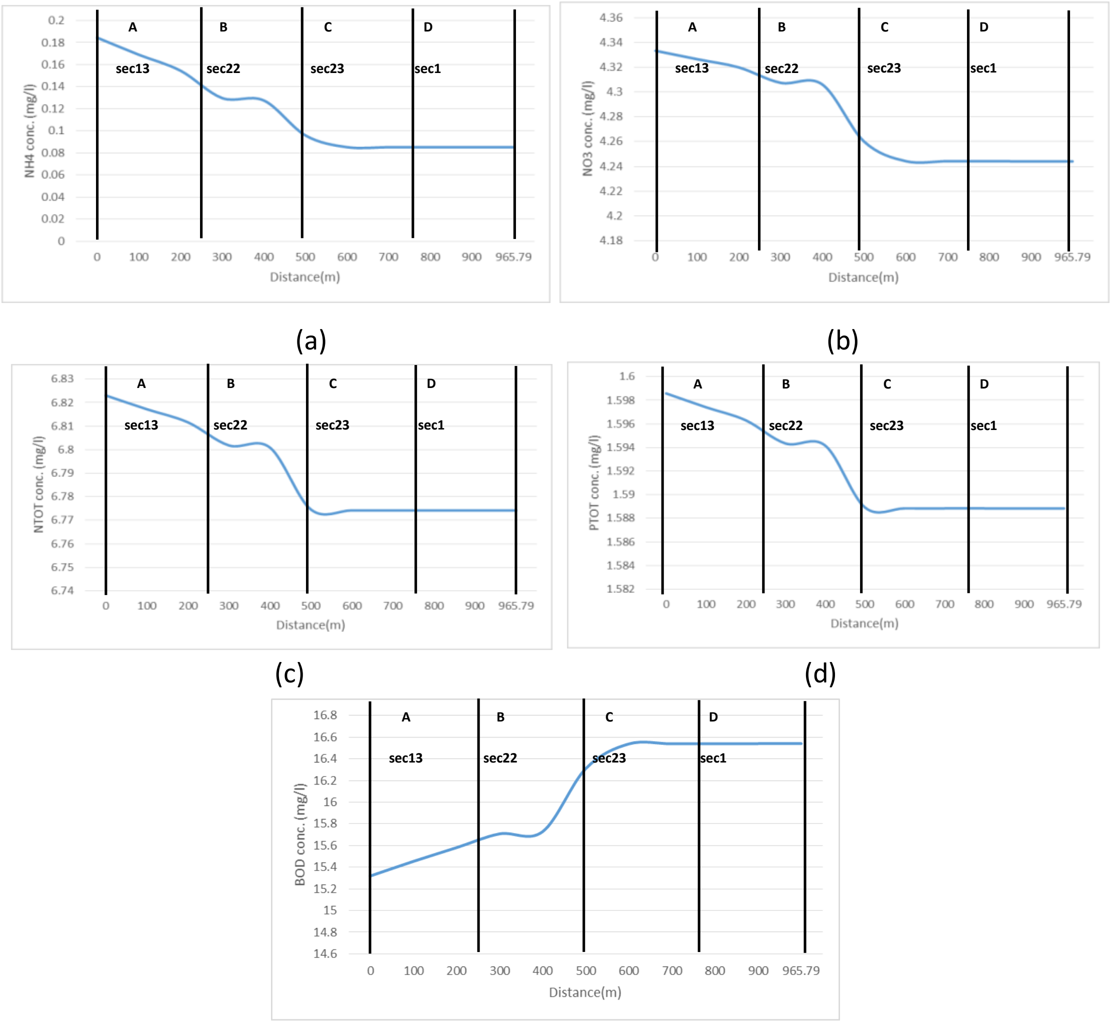
(c) (d)



(e)

Figure 82 Concentration of Nutrients in wet condition in Pond2 (a for NH4, b for NO3, c for total N, d for total P, e for BOD)

The results are shown in Figures 2. In entrance of pond2 substantially NH4 is equal to 0.47mg/l, NO3 is 4.45 mg/l, total N is 6.93 mg/l, and total P is 1.62 mg /l. Normal flow rate leads to a reduction of all concentrations up to 0.1mg/l,4.25 mg/l,6.78mg/l and 1.59 mg/l respectively. The removal efficiencies for the nutrients of the pond 2 are 78.53% (NH4), 4.56% (NO3), 2.15% (Total N), and 0.02% (Total P). Bod increases form 3.68 mg/l to 3.98mg/l (8.07%). Bod increases form 3.80 mg/l to 4.41mg/l (16.13%).



(a)

(b)

(c)

(d)

(e)

Figure 83 Concentration of Nutrients in wet condition in Pond3 (a for NH4, b for NO3, c for total N, d for total P, e for BOD)

The results are shown in Figures 83. In entrance of pond 3 substantially NH4 is equal to 0.18mg/l, NO3 is 4.33 mg/l, total N is 6.82 mg/l, and total P is 1.60 mg /l. Normal flow rate leads to a reduction of all concentrations up to 0.09mg/l,4.24 mg/l,6.77mg/l and 1.59 mg/l respectively. The removal efficiencies for the nutrients of the pond 3 are 53.80% (NH4), 2.06% (NO3), 0.72% (Total N), and 6.10% (Total P). Bod increases form 4.23 mg/l to 4.43mg/l (4.85%)

5.5 Spill scenario

In spill condition, it sets the same initial condition and discharge as normal scenario. The difference is the discharge point boundary condition. .

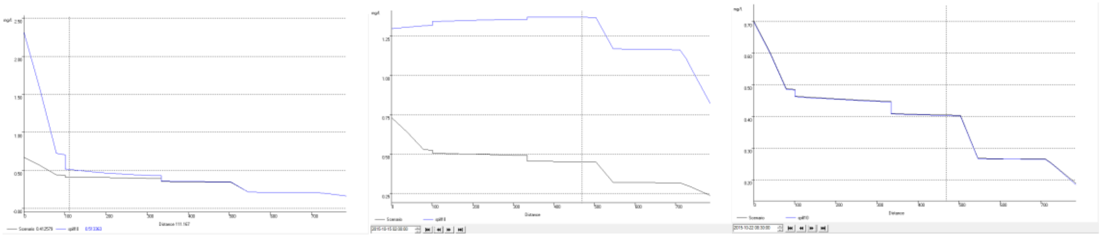


Figure 84 concentration of NH4 change under the spill scenario

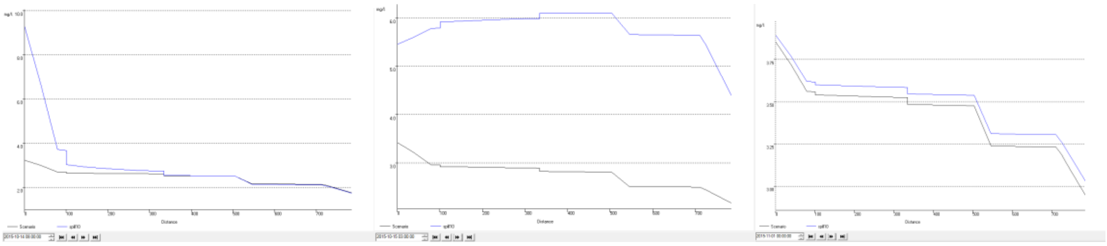


Figure 85 concentration of NO3 change under the spill scenario

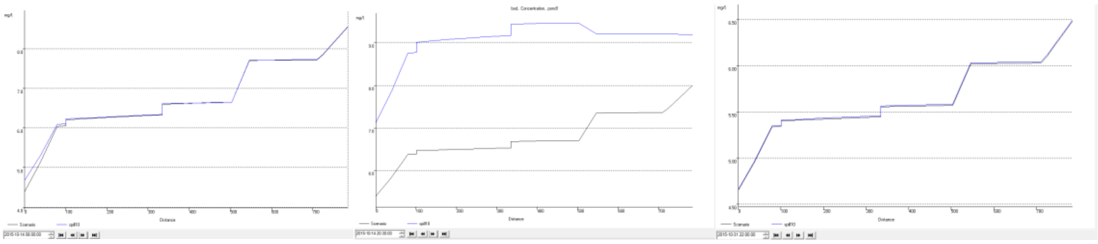


Figure 86 concentration of BOD change under the spill scenario

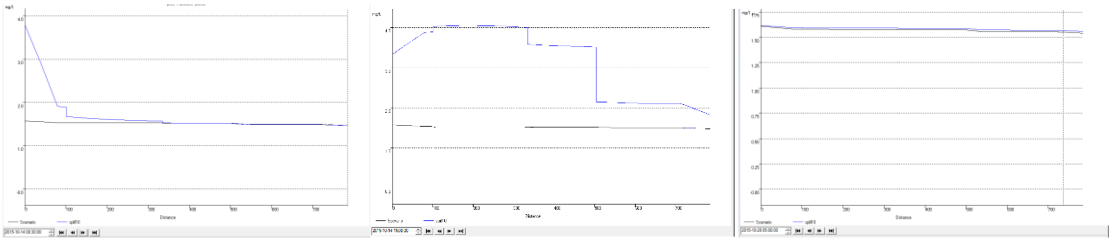


Figure 87 concentration of Total phosphorus change under the spill scenario

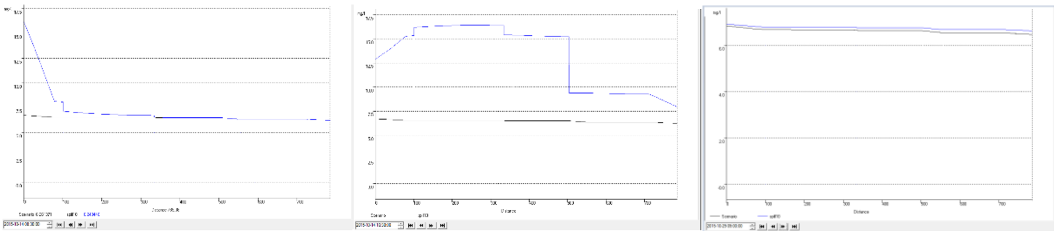


Figure 88 concentration of Total Nitrogen change under the spill scenario

From figure 84-88,it is can be find that different substance need different period to come back to normal level. For example, ammonium increases to the maximum at 2:00 15th and back to normal level at 8:30 22th. At 2:00 15th, the whole flow is affected by the spill ammonium. While Total phosphorus increases to the maximum at 14:00 15th, and back to normal level at 5:00 28th. Total nitrogen increases to the maximum at 16:00 14th, and back to normal level at 9:00 29th. The back period depends the removal efficiency and many other factors. For nitrate is 18 days and for bod is 17days.

6 Conclusions and recommendations

6.1 Conclusions

A prototype modelling system for analyzing the behavior of heavy metals loadings of a WWTP was developed. A semi-detailed system was designed, incorporating the channels and ponds and also a number of the more important hydraulic structures were represented.

The sizing of the system, was done using real dimensions, and making use of digital aerial photo background, the AHN accurate elevation model (1m), and detailed GIS geodatabase information for the water authority. Field work and surveying was also done to verify the system dimensions and functioning.

The Eutrof1a water quality model permits to analyze the behavior of some nutrients i.e. C,NH_4, NO_3, Total N, Total P in water, and the sediment phase of the channels and ponds.

Use was made of measurements of (2013, 2014) nutrients concentrations in water done by the Water authority. This permitted to use realistic values for model initial and boundary quality conditions for concentrations.

Also observed average dry and wet weather flows were used in the model runs.

Using this prototype model, the releases of nutrients in the residual effluent from the Enschede West WWTP municipal waste water treatment plant were simulated. Aim was to analyze the behavior of the metals and to investigate the retention in the Kristalbad, and the removal efficiency.

The three main nutrients (C, N, P) were initially used. We observed a quite different behavior among the three nutrients which can be explained by their chemical reactivity and behavior of these three elements in aqueous and sediment media.

Due to renewal works of the ITC Geoscience or GS laboratory (incl. retirement of lab head) and installation of new equipment's, no active field sampling and lab measurement data could be gathered and executed during the MSc period. Therefore, a number of theoretical (but with realistic parameter settings) scenario's were run in Duflow.

After running the model in all scenarios, we collect the removal efficiencies in different ponds for nutrients under the three scenarios. Here is the figure about all efficiencies.

Table 7 Nutrients removal efficiency

		Whole flow (%)	Pond 1 (%)	Pond 2 (%)	Pond 3 (%)
Normal	NH4	87.2	70.26	76.89	45.49
	NO3	23.48	9.22	20.31	7.38
	NTOT	5.45	2.18	3.59	1.08
	PTOT	4.07	1.62	2.58	0.76
	BOD	39.11(+)	12.82(+)	21.82(+)	5.47(+)
Dry	NH4	63.75	70.73	84.81	61.79
	NO3	14.89	7.37	11.83	4.97
	NTOT	15.38	4.86	10.09	3.67
	PTOT	40.35	24.3	30.87	13.26
	BOD	57.76(+)	24.35(+)	28.74(+)	7.98(+)
Wet	NH4	77.82	48.55	78.53	53.8
	NO3	4.32	0.99	4.56	2.06
	NTOT	3.23	1.28	2.15	0.72

	PTOT	2.8	1.12	1.84	0.61
	BOD	24.34(+)	8.07(+)	16.13(+)	4.85(+)

According to the table 7, we can find the Kristalbad has a good performance on ammonium removal in all flow conditions (63.75%-87.2%), especially in normal condition. Three ponds have different performance in three scenarios. For example, among all scenarios, all ponds have highest efficiencies in dry scenario (70.73%, 84.81% and 61.79%). Pond 1 gets lowest efficiencies in wet condition (48.55%). While pond 2 pond 3 gets lowest in dry condition (76.89%, 45.49%). In all scenarios, Pond 2 is the best among three ponds (76.89%-84.81%). In wet condition, pond 1 perform worst. Pond 3 has the lowest efficiency in normal and dry condition.

Comparing the other nutrients, nitrate has the second best removal efficiency in flow in normal (23.48%) and wet scenario (4.32%). But in the dry scenario, efficiency becomes lowest (14.89%). Among all the ponds, pond 2 still has the highest removal efficiency (20.31%, 11.83%, and 4.56%) in nitrate among all ponds. Pond 3 is the lowest one (7.38%, 4.97%, and 2.06%). All ponds get the best nitrate removal efficiency in normal condition and the lowest on in wet condition.

Among all nutrients, total nitrogen is the third highest flow removal efficiency in all conditions (5.45%, 15.38% and 3.23%). Comparing the other ponds, Pond 2 still has the highest removal efficiency (3.59%, 10.09%, and 2.15%) in nitrate. Pond 3 is the lowest one (1.08%, 3.67%, and 0.72%). As the same as nitrate, normal condition is the best for total nitrogen removal and the wet condition is the worst one for all ponds.

The flow has the worst removal of total Phosphorus in normal condition (4.07%) and wet condition (2.8%). But at dry condition, it increase to 40.35%, better than total nitrogen and nitrate. Pond 2 has better performance than the other two ponds in all conditions (2.58%, 30.87% and 1.84%). Pond 3 has is the lowest on (0.76%, 13.26% and 0.61%). For all ponds, dry condition is the best for total phosphorus removal and the wet condition is the worst one

BOD is related to the organic matter and carbon. More BOD means more organic matter and carbon. So Bod is good indicator for the carbon. In dry condition, in the flow, Bod increases mostly (57.76%). While in wet condition Bod increase least (23.34%). It is the same performance for all ponds (7.98%, 24.35%, 28.74% in dry condition, 4.85%, 8.07%, and 16.13% in wet condition).Among all ponds, pond 2 performs best in all condition (16.13%, 21.82%, and 28.74%). While pond 3 has the worst performance (4.85%, 5.47%, and 7.98%).

According to the efficiency analysis, we can find the Kristalbad has a good performance in ammonium removal in all conditions. In normal condition, the flow have a good removal performance of ammonium and nitrate. Actually although in dry scenario the efficiency of ammonium and nitrate get a little decrease, the other removal get higher increase, especially for total phosphorus. In dry condition, with low discharge, total phosphorus and total nitrogen get a best removal. In wet condition, with high discharge, there is no good removal for nutrients comparing to the other condition.

Among all the nutrients, Kristalbad has the highest removal efficiency in ammonium. Total Phosphorus is the hardest nutrients to be removed in Kristalbad. Carbon increase when pass by the Kristalbad. All this changes make the water quality better. So the Kristalbad has a good performance in improve the water quality of the river and water from WWTP.

According to the analysis result, we can provide advices for the water authority. We can improve our plan on Kristalbad use in the future. For example, in dry weather, with the lower discharge, the nitrate and ammonium gets high value. It is better to let the pond 2 bear more removal task and pond 3 bear less removal task. And in wet weather with high discharge, pond 2 should bear more nitrate and ammonium removal task and pond 1 bear less removal task.

Pond 2 has the best removal for all nutrients in all conditions. Although Pond 3 has the longest flow length, the performance is not match the length. Maybe it because the build work of pond 3 is not totally finish. It is important to increase the nutrient removal of pond 3 in the future.

2. Come to the spill model, it can help us to evaluate the nutrients recovery period of Kristalbad. It will be easy to know how long the river will come back to normal nutrients condition after the accident events. In this model, if a sudden event happens, the Kristal bad can deal the excess nutrients in 20 days.
3. The nitrogen balance are three processes underlying these are mineralization, nitrification and denitrification.
4. In the phosphate metabolism makes the model only distinction between two types of phosphate. These are the dissolved phosphate (DP), representative of the ortho-phosphate measured in practice, and the particulate bound phosphate (PP). Sedimentation and resuspension influence the fate of PP in contrast to DP which is only influenced by dispersion and advection.
5. Plants are included in water quality model. It absorb the ammonium and dissolved phosphate.

6.2 Recommendations

1. Because of the observed data limit, we presented only simple simulate. More data are needed for model calibration and further test for the suitability and removal performance. M3 model only focus on the variable water quality data. It is better finish under a variable good quality flow data.

2. We can recommend the use of mass balances (over the ponds) combined with measurements (field and laboratory) of nutrients to verify the modelling system and confirm the removal efficiencies. Also detailed flow (effluent) data from the WWTP and level data (from the water authority) in the Kristalbad system can be used to further optimize the model.

3. Nutrients are included in many biogeochemical or physical process. Detail process analysis can be made with more data to get the nutrients transport process in the further research. The focus only on the ammonium and nitrate and total nitrogen, which ignore the organic nitrogen. Description for the phosphate metabolism phosphorus a simplified representation of reality. The subsequent delivery of phosphate from the sediment is not described in this model. A more complex description can be set in further model. One difficulty in the detailed water quality model process of nutrients will be the effect of hydraulic structures on the element behavior. Although, some processes (e.g. extra oxygen intake at weirs) can be simulated in Duflow, it will remain a challenge to verify all effects (incl. sediment) of the different structures in the system on the overall behavior of the water quality in the system.

4. In this model, aquatic plants are assumed as an easy factor. It is a simplified representation of reality. There are many kinds of plants live in the water and around the water. More varieties mean more kinds of plants impact on nutrients removal. The detail of the different impacts can be researched on the further study.

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Appendix 1 measurement results of Kristalbad

Alkalinity						
Points	Number of measurement [n]	measured years	Min [meq/l]	Max [meq/l]	Average [meq/l]	Mode [meq/l]
IN	2	2011, 2012	3,6	5,2	4,4	3,6 - 5,2
OUT	2	2011, 2012	3,0	4,8	3,9	3,0 - 4,8

PH						
Points	Number of measurement [n]	measured years	Min [-l]	Max [-]	Average [-]	Mode [-]
IN	52	2012, 2013, 2014	7,0	7,6	7,27	7,2
OUT	52	2012, 2013, 2014	6,9	8,6	7,82	7,6

Salinity						
Points	Number of measurement [n]	measured years	Min [mmo/l]	Max [mmo/l]	Average [mmo/l]	Mode [mmo/l]
IN	2	2011, 2012	15	23	19	15 - 23
OUT	2	2011, 2012	16	24	20	16 - 24

Chlorinity

Points	Number of measurement [n]	measured years	Min [mg/l]	Max [mg/l]	Average [mg/l]	Mode [mg/l]
IN	2	2011, 2012	115	185	150	115 - 185
OUT	38	2011, 2012, 2013, 2014	63	330	169,37	170

Sulphate

Points	Number of measurement [n]	measured years	Min [mg/l]	Max [mg/l]	Average [mg/l]	Mode [mg/l]
IN	2	2011, 2012	86	92	89	86 - 92
OUT	2	2011, 2012	67	86	76,5	67 - 86

Calcium

Points	Number of measurement [n]	measured years	Min [mg/l]	Max [mg/l]	Average [mg/l]	Mode [mg/l]
IN	2	2011, 2012	60	73	66,5	60 - 73
OUT	2	2011, 2012	45	63	54	45 - 63

Magnesium						
Points	Number of measurement [n]	measured years	Min [mg/l]	Max [mg/l]	Average [mg/l]	Mode [mg/l]
IN	2	2011, 2012	7,5	9,1	8,3	7,5 - 9,1
OUT	2	2011, 2012	5,9	8,4	7,15	5,9 - 8,4

Sodium						
Points	Number of measurement [n]	measured years	Min [mg/l]	Max [mg/l]	Average [mg/l]	Mode [mg/l]
IN	2	2011, 2012	97	167	132	97 - 167
OUT	2	2011, 2012	130	190	160	130 - 190

Potassium						
Points	Number of measurement [n]	measured years	Min [mg/l]	Max [mg/l]	Average [mg/l]	Mode [mg/l]
IN	2	2011, 2012	15	23	19	15 - 23
OUT	2	2011, 2012	18	26	22	18 - 26

Iron						
Points	Number of measurement [n]	measured years	Min [mg/l]	Max [mg/l]	Average [mg/l]	Mode [mg/l]
IN	52	2012, 2013, 2014	0,09	0,62	0,31	0,31
OUT	52	2012, 2013, 2014	0,10	0,84	0,34	0,24

Phosphate						
Points	Number of measurement [n]	measured years	Min [mg/l]	Max [mg/l]	Average [mg/l]	Mode [mg/l]
IN	52	2012, 2013, 2014	0,11	7,1	1,54	1,0
OUT	52	2012, 2013, 2014	0,02	3,2	1,05	0,62

Nitrate						
Points	Number of measurement [n]	measured years	Min [mg/l]	Max [mg/l]	Average [mg/l]	Mode [mg/l]
IN	52	2012, 2013, 2014	1,0	8,0	4,6	3,7
OUT	52	2012, 2013, 2014	1,1	6,7	3,2	3,9

Ammonium						
Points	Number of measurement [n]	measured years	Min [mg/l]	Max [mg/l]	Average [mg/l]	Mode [mg/l]
IN	52	2012, 2013, 2014	< 0,06	8,9	1,25	0,4
OUT	52	2012, 2013, 2014	< 0,06	4,2	0,50	0,1

Ammoniac						
Points	Number of measurement [n]	measured years	Min [mg/l]	Max [mg/l]	Average [mg/l]	Mode [mg/l]
IN	52	2012, 2013, 2014	< 0,01	0,04	0,013	< 0,01
OUT	52	2012, 2013, 2014	< 0,01	0,03	0.011	< 0,01

Point data project Kristalbad water sample inlet

Nutrients	**Concentration(mg/l)**
Ammonium	0.96
Nitrite	0.21
Sum of nitrate and nitrite	5.0
Nitrate	4.8
Total phosphorus	0.87