SUPPORTING REPORT E

Integrated River Basin Analysis Model

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E INTEGRATED RIVER BASIN ANALYSIS MODEL

E.1 General

In the present supporting report, integrated river basin analysis model that has been developed in the study is described in detail. Chapter E.2 introduces the modeling concept that is applied in the Study. Chapter E.3 summarizes the activities related modeling during the study. Chapter E.4 and E.5 shows the detail of MIKE11 water quantity model and water quality model, respectively. Finally, simple model is introduced in Chapter E.6.

E.2 Modeling Concept

E.2.1 General

Figure E.2.1 shows the data treated in the study. There are several kinds of data to be handled as follows.

- Level 1: Core Data
- Level 2: Waterbodies Data
- Level 3: Monitoring Data
- Level 4: Basic Analysis Data
- Level 5: Spatial Distribution Analysis Data
- Level 6: Water Management Plan Data

The model developed in the study will be mainly used to produce the Level 5 and Level 6 data using the other level data. In other words, the model can be utilized for the following purposes.

- Assessment for existing condition
    - Observed point data to spatially distributed presentation with some assumptions
- Planning such as long term strategy for water management, program measures
    - Checking effectiveness of some of program measures
    - Reference for permission based on long term strategy for water management

The model developed in the study is not suitable for the following purposes due to insufficient data and information so far.

- Operational decision such as daily reservoir operation and flood warning
    - It requires additional data, information and model development with additional modules and so on (or different types of model might be required).

Some hydrological process models for water quantity and quality have been developed in Bulgaria as follows.

- MIKE11 Model in JICA Study on the Maritsa River Basin[1)]
  - Water Quantity and Quality
  - MIKE11-RR, HD, WQ model
  - Time scale: Daily
- HEC-HMS Model in Mesta River Basin[2)]
  - Water Quantity
  - HEC-HMS ver2.2.2 (special treatment on snow process)
  - Time Scale: Daily
- Struma River Basin Distributed Hydrological Model[3)]
  - Water Quantity
  - GIS-based Simplified Distributed Hydrological Model
  - Time Scale: Monthly
- Distributed Hydrological Model by Plovdiv Branch of NIMH[4)]
  - Water Quantity
  - Distributed Hydrological Model
  - Time Scale: Daily
- BISTRA Model in Yantra River Basin[5)]
  - Water Quantity
  - GIS-based hydrological model
  - Time Scale: Monthly
- MONERIS Model in Lesnovsaka River in the Iskar River Basin by IWP[6)]
  - Water Quantity and Quality
  - GIS-based Emission model for calculating nutrient emissions

There are general notes regarding a model as follows.

- Model is not perfect. It is simplified representation of actual world. However, it can help thinking of what happens and what will happen.
- If a model is used for decision support, it is not necessary for the model to be perfect. However, it should be transparent in its assumption and methodology. Conesus on the model is important.

The present study proposes the model that will be directly handled by Basin Directorates and will support their river basin management activity. Transparency of the model with clear explanation on assumptions for the model will be important for this purpose.

E.2.2 Two Different Types of Model

(1) Simple Model and MIKE11 Model

In the present study, two different types of model are proposed. One is “Simple Model”, which is based on basically simple mass balance and can be working in general software such as MS-Excel. Another one is “MIKE11 Model” which is well-known but requires specific software for implementing the simulation. Characteristics of the two models are summarized as below (see also Figure E.2.2).

- Simple Model
  - No specific modeling software
  - Spread sheet calculation only
  - Point representation at key points for management
  - Time scale: Monthly or Average in whole year and/or summer time
  - Reference for permission
  - Scenario setting for improvement plan

- MIKE11 Model
  - Specific software (MIKE11& MIKE BASIN)
  - Physical process-based model
  - Spatio-temporal representation along river network
  - Time scale: Daily
  - Detailed simulation for confirming effects of improvement plan

As for MIKE11 model, the following modules are introduced in the present study.

- Rainfall-Runoff Module (MIKE11-RR)
  - Conversion of Precipitation *to* Runoff in Catchment
  - NAM model has been selected.

- Hydro Dynamic Module (MIKE11-HD)
  - Conversion of Inflow (Runoff in Catchment) *to* Flow Condition along River

- Water Quality Module (MIKE11-AD & Eco-Lab)
  - Conversion of Flow Condition and pollution load in River *to* Water Quality Condition along River

It is noted that MIKE11 can run the above components simultaneously.

MIKE11 model is selected because of its integrated treatment on water quantity and quality. HEC model, which is public domain software and thus could be one of alternatives, does not have water quality module in the current version. The Pollution Load Calculator as a part of MIKE11 model in the present study, which is an extension of ArcGIS, can be also integrated in order to prepare some of input files on pollution load for MIKE11 model simulation in a transparent way on GIS platform. Furthermore, MIKE11 model was introduced in the previous JICA Study on the Maritsa River Basin. The concept and parameter setting developed in the previous JICA Study will be referred in the present study so that the model in the present study will be efficiently developed in a limited timeframe.

(2) Structure of Modeling Environment

Figure E.2.3 shows the proposed structure of modelling environment. The GIS-DB, which is described in *Supporting Report A*, is a base of the modelling environment.

MIKE11 model development and simulation are implemented within MIKE ZERO platform, which is provided by DHI as a native platform for MIKE11 model.

For development of a model, some layers in the GIS-DB such as river network and catchment can be imported to MIKE ZERO platform.

MIKE11 model requires a lot of time series data for input, although format of input file is special format for MIKE11 model. For smooth implementation of the simulation using the GIS-DB, MIKE BASIN Temporal Analyst and Pollution Load Calculator, which are extensions of ArcGIS, as well as Excel sheet, are utilized for preparing input files for MIKE11 simulation. Conversion of .xls file, .txt file and/or Geodatabase (.mdb) to .dfs0 (MIKE11 time series format) will be easily implemented by using the Temporal Analyst (See example shown in Figure E.2.4).

MIKE View on MIKE ZERO platform can be used for visualization of the simulation result of MIKE11 model. However, output files can also be imported to ArcGIS using MIKE BASIN Temporal Analyst, and then result presentation and analysis would be conducted in GIS environment. For example, linear reference system in ArcGIS may be utilized for the analysis and presentation on the result of the simulation in GIS environment.

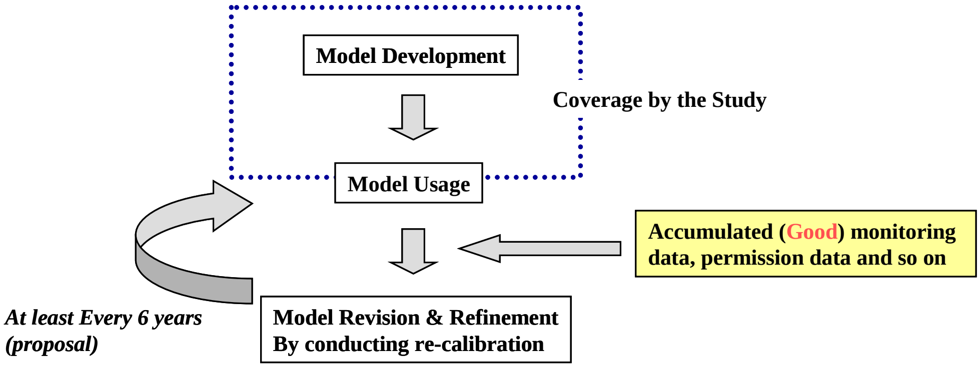
As for Simple model, input data for the model are extracted from the GIS-DB. Some model parameters such as runoff volume are set using the result of MIKE11 model. Simple model is rather independent from GIS software so that user can use it without any knowledge of specific GIS software.

E.2.3 Modeling Cycle

There are three stages for the modeling, which consists of modeling cycle, as follows.

- Model development stage
- Model usage stage
- Model revision and refinement stage

The present study covers model development stage and a part of model usage stage. It is expected that model usage will be continued by Basin Directorate after the study. Model revision and refinement is proposed to be conducted after sufficient data and information will be accumulated in future. The best timing for model revision and refinement seems to be just before the river basin management plan will be revised.



Modeling Cycle

The following table summarizes the activities which have been conducted in the model development and usage stages in the present study and which are expected to be conducted in model revision and refinement stage after the study.

Activities in Each Modeling Stage

Stage	MIKE11 Model	Simple Model
Model development stage	-Calibration of parameters for rainfall-runoff module for MIKE11 model (2001 – 2005: 5 years) -Setting river-network for hydro dynamic module for MIKE11 model -Calibration of parameters for water quality module for MIKE11 model (2004: a representative year)	-Preparation of Excel sheets (incl. Macros) as templates
Model usage stage	-To run the developed model by changing water use, pollution load based on scenarios	-Checking of water balance for different water use conditions -Examination on effect of pollution load reduction on water quality
Model revision and refinement stage (after the study)	-Re-calibration of model parameters using accumulated data and information.	-Re-input of calibrated model parameters and reservoir operation pattern using accumulated data and information.

E.2.4 Target Users

Target users for Simple model and MIKE11 model are proposed as shown in the following table. There will be two kinds of users. One is the users who will run the model for different scenarios only. Another is the users who will maintain the model. Model run for MIKE11 model and model maintenance for both models require detailed knowledge on the model. It is thus recommended that Basin Directorate keep a few responsible persons for model maintenance, who will conduct model maintenance and model run for MIKE11 model, and model maintenance for Simple model.

Trainings for the model have been conducted for the appropriate persons according to the proposed target users during the Phase II of the Study.

Target Users

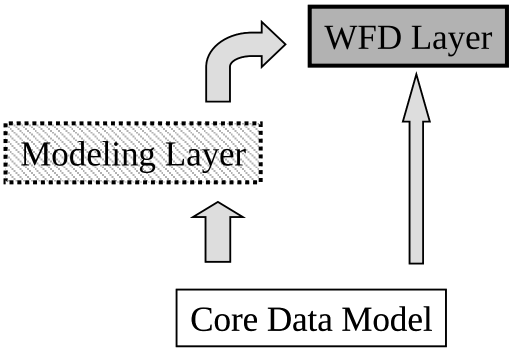
User	Simple Model	MIKE 11 Model
Model Run	Planning & Monitoring & Permission Dept.	Responsible person for model maintenance in RBD with discussion among Planning & Monitoring & Permission Dept.
Model Maintenance	Responsible person for model maintenance in RBD with discussion among Planning & Monitoring & Permission Dept.	Responsible person for model maintenance in RBD with discussion among Planning & Monitoring & Permission Dept.

E.2.5 Modeling Layer

Modeling layer has been prepared as one of supporting layers beside core data model and WFD layer discussed in GIS-DB as shown in the following figure and Table. The modeling layer will be utilized for:

- Reference for preparing WFD layer, and
- Base for preparing basin management plan.

Each object in the modeling layer has its ID for modeling purpose. To avoid confusion with WFD code for waterbodies, it is totally different from the WFD code.



Modeling Layer

Prepared Modeling Layer

Layer	Explanation
Catchment	Base unit for modeling, same as Core data, but has unique ID for modeling
NAMCatchment	Base unit for Rainfall-Runoff modeling, which is prepared by aggregation of Catchment
MainRiverSegment	Selected river segment corresponding to Catchment One Catchment has one MainRiverSegment basically.
SignificantLake	Selected reservoir and lake for modeling purpose Significant reservoirs specified by Water Act and lakes whose surface area is more than $5km^2$ are selected.

(1) River

Figure E.2.5 shows the relationship among core data model, modeling layer and WFD layer for river.

Core data for rivers is basically based on 1/100,000 topography map, which includes many small rivers and canals. 550 Rivers selected by MoEW[7)] are extracted as MainRiverSegment from the core data model for analysis purpose. MainRiverRoute that uses linear reference system and has same geometry with MainRiverSegment is also prepared. As explained in Section (4), important MainRiverSegment is selected for MIKE11 modelling as RiverNetworkMIKE11. Results of analysis expressed in MainRiverRoute can be reflected to sub-division and description of status on RiverSegment for WFD layer.

RiverSegment for WFD layer may include more rivers and canals, according to judgement by Basin Directorate on importance of the rivers and canals.

(2) Lake

Figure E.2.6 shows the relationship among core data model, modeling layer and WFD layer for lakes.

Core data for lakes is basically based on 1/100,000 topography map, which includes many small lakes. Significant reservoirs specified by Water Act and a lake whose surface area is more than $5km^2$ are extracted as SignificantLake for analysis purpose. Among the SignificantLake, important ones are selected for MIKE11 simulation.

LakeWaterBody for WFD layer may include more lakes, according to judgement by Basin Directorate on importance of the lake.

(3) Catchment

Figure E.2.7 shows the relationship among catchment, sub-basin and basin. Catchment is not WFD layer. It is determined by only hydrological point of view. On the other hand, Basin and SubBasin are WFD layers. Both SubBasin and Basin will be prepared by aggregating catchments.

Criteria on delineation of catchment are as follows.

- Confluence of MainRiverSegment
- Junction between MainRiverSegment and SignificantLake

Examples for delineation of catchment are shown in Figure E.2.8.

Watershed (Catchment) for 550 rivers which has been delineated by NIMH is basically utilized for catchment after verified using 1/100,000 and 1/25,000 topographic map. However, it has been modified considering own-catchment for SignificantLake. Figure E.2.9 shows an example for modifying the catchment around SignificantLake. In EABD and WABD, totally about 600 catchments have been delineated.

Figure E.2.10 and E.2.11 show the MainRiverSegement, SignificantLake and delineated catchment for EABD and WABD, respectively.

In the present study, it is proposed that catchment is a basic unit for analysis and modelling. Spatially-distributed parameter is basically represented as one parameter or pivot table (matrix) in a catchment. Spatially-distributed parameter may include the followings.

- Precipitation
- Evapo-transpiration
- Water resources potential
- Water user & water demand
- Pollution load (Non-point source and point source)
- Other natural and socio-economical conditions related to modeling
  - Land use, Soil condition, Geology, Population etc.

Some characteristics on small rivers and lakes within a catchment may be also summarized as one parameter or pivot table (matrix) in a catchment.

(4) Rainfall-Runoff Catchment (NAM Catchment) for MIKE11 Modeling

To model for all MainRiverSegment and those catchments is possible. It is however time-consuming. It is better to select important MainRiverSegment for the modeling from view point of management. The selected MainRiverSegment will be modeled as a river-network. The non-selected MainRiverSegment will be treated as a part of modeling catchment.

In the present study, NAM model is used for rainfall-runoff model as a part of MIKE11 model. NAM model assumes that hydrological property is similar within a modelling catchment which is called as NAM catchment. NAM catchment will be prepared by aggregating catchments (see Figure E.2.12).

It is noted that hydrological process related to small lakes, reservoirs and local rivers in NAM catchment is represented by model parameters of NAM model.

(5) Watershed for Specific Point

Watershed is here defined as total upstream area for a specific point. For assessment of pressure & impact for the specific point such as a lake, a monitoring point (HMS, Physco-Chemical St, HydroBiological St) along a river, watershed will be delineated as one of analysis layers beside Catchment, when necessary (see Figure E.2.13).

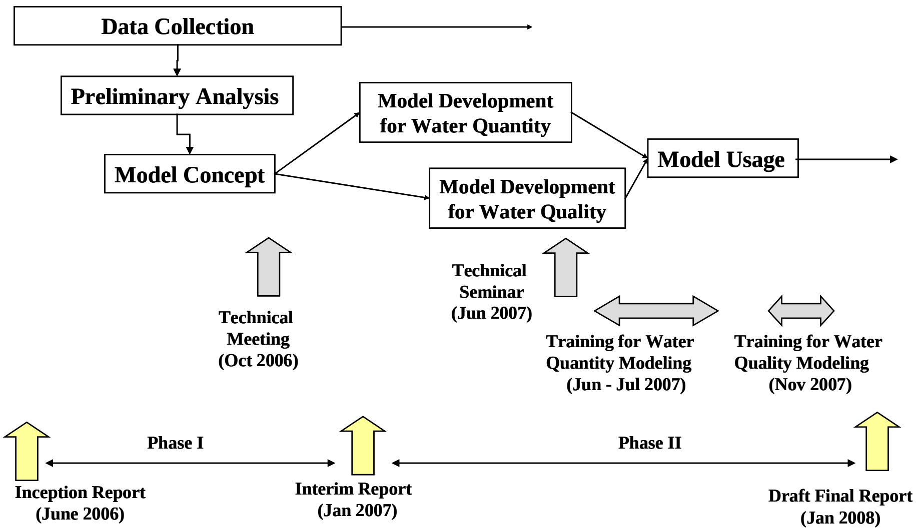
E.2.6 Definition of Terms Related to Water Quantity in the Model

In Bulgaria, many of observed water quantity are heavily affected by human activities such as water transfer, abstraction and discharge. Considering this situation, in the model, the following terms that are related to water quantity are defined to avoid any misunderstandings.

- Quasi-Natural Flow
    - Flow without human disturbances such as abstraction, discharge, transfer
    - Likely natural, however, not exactly natural.
    - In the model, regime change of local reservoir is not taken into account.
- Potential Flow with Significant Reservoir
    - Flow with influence of significant reservoir, but no abstraction from reservoir
    - Potentially usable water amount after regime change by significant reservoir
- Disturbed Flow
    - Existing condition
    - It can be expressed as follows
        - (Potential Flow) – (Total abstracted water) + (Total discharged water)

E.3 Modeling Activities during the Study

Outline of modeling activities during the study is shown in the following figure.



In Phase I of the study, data collection and preliminary analysis on the data were done. Based on the preliminary analysis, modeling concept was developed and presented at technical meeting on October 2006.

After the seminar, selection of MIKE11 river network and setting of NAM catchment for each river basin was conducted. Firstly, the initial idea was proposed by the Study Team based on the following information.

- Sensitive Area Study in 2003[8)] for EABD and WABD
- On-going Risk Assessment provided by EABD and WABD
- Available information incl. pollution source data, water use data, HMS and cross-sec.

The initial idea was modified by the discussion with C/P in EABD and WABD. Some rivers are added and some are excluded. Finally, the draft version of MIKE11 river network and NAM catchment was agreed between C/P in EABD, WABD and the Study Team.

In Phase II of the Study, data collection was continued because of delay of data collection in Phase I. Actual model development was also conducted. The developed model was used for scenario simulations for formulation of river basin management plan (draft).

Technical seminar was held on June 2007 to present progress of model development. Consequently, training for water quantity model, which is total 6 days with once a week, was conducted in June to July 2007. Training for water quality model, which is total 3 days, was also conducted in November 2007. The contents of the training for water quantity modeling are as follows.

- 1) Introduction (June 20)
  - Overall structure of model
  - Software(MIKE11) installation & trial run (simple tutorial)

- 2) Dealing with Time Series (June 27)
  - Discussion on time series data
  - Introduction of Temporal Analyst for ArcGIS and its exercise
- 3) Rainfall-runoff model (July 4)
  - Discussion on hydrological process (mainly surface water)
  - Introduction of NAM model and its exercise
- 4) Hydro Dynamic model (July 11)
  - Discussion on hydro dynamic model
  - Introduction of MIKE11-HD and its exercise
- 5) Model set-up for EABD and WABD rivers (July 18)
  - Explanation of model set-up
  - Exercise for Model Run and Post-processing
- 6) Simple model (July 25)
  - Explanation on Simple Model
  - Exercise for using Simple Model
  - Preparation of some of MIKE11 input files

The training was rather practical. Biala River Basin in EABD and Pirinska Bistritsa River Basin in WABD were used for pilot basins for training purpose. The contents of the training for water quality modeling are as follows.

- 1) Introduction (November 15)
  - General introduction to water quality modeling and the MIKE 11 concept
  - Refreshment of the memory on the HD-modeling
  - Presentation of Results
- 2) Structure of WQ-boundary file in the model set-up in question (November 21)
  - Changing pollution load -scenarios simulation
  - Making boundary files for new scenarios from excel files
- 3) Further working with the actual full set-up on the different rivers in WADB and EABD (November 27)
  - Scenario simulation
  - Sensitivity analysis
  - Evaluation of model result and model limitation

There were totally about 10 participants from not only EABD and WABD but also MoEW, EEA, DRBD and BSBD for trainings for both water quantity and quality modeling.

E.4 MIKE11 Model for Water Quantity

E.4.1 Outline of Water Quantity Model

MIKE11 model for water quantity consists of MIKE11-RR (Rainfall-Runoff module) and MIKE11-HD (Hydrodynamic module). There are several options for the modules in MIKE11. In the present study, the options described below are applied.

(1) MIKE11-RR

Several different rainfall-runoff models are prepared for MIKE11-RR. Among those, NAM model is selected in the present study. NAM model is one of the most suitable and handy model for long-term simulation. NAM model is lumped conceptual hydrological model, which represents spatially averaged phenomena within a rainfall-runoff catchment.

NAM model simulates rainfall-runoff processes by continuously accounting for the water content in four different and mutually interrelated storages that represent different physical elements of the catchment. These storages are (see FigureE.4.1):

- Snow storage
- Surface storage
- Lower or Root Zone storage
- Groundwater storage
- Lower groundwater storage

The meteorological input data to the model are precipitation, PET and temperature (only if the snow routine is used). On this basis, it produces, as its main results, catchment runoff and groundwater level values as well as information about other elements of the land phase of the hydrological cycle, such as the temporal variation of the soil moisture content and the groundwater recharge. The resulting catchment runoff is split conceptually into overland flow, interflow and baseflow components.

The primary model parameters in NAM model are shown in Figure E.4.2. It is necessary for the parameters to be calibrated using observed data.

In the present study, snow routine for MIKE11-RR is considered, because snow melting process in mountain region is one of key hydrological processes. In the snow routine, totally 15 elevation zones were considered.

NAM model has additionally the following two options.

- Irrigation routine
- Ground water abstraction routine

In the present study, however, these additional routines are not used. The reasons are as follows.

- Irrigation routine introduces different model parameters. To keep model structure simple, it was judged for the irrigation module not to be included.

- The ground water abstraction module in NAM model is too simple to express the effect of abstraction of ground water on ground water behavior in the study area.

(2) MIKE11-HD

MIKE11-HD module is to simulate river flow process. One dimensional version of governing equations for momentum transfer and continuity of fluid flow is basic equations for MIKE11-HD.

(a) Solver Option

There are three options to solve the basic equations in MIKE11-HD as follows.

- Dynamic Wave Model
  - Momentum equations for water flow are fully solved.
  - Mainly for flat area and low slope channel
- Diffusion Wave Model
  - Simplified expression of momentum equations for water flow
  - Mainly for mountain area and high slope channel
- Kinematic Wave Model
  - No momentum equation is considered. Only resistance law is considered, instead of momentum equations

In the present study, dynamic wave model is selected. For time and space steps, dx = 2,000m, dt =3 -10 min (mostly 5min) are selected, considering necessary resolution, calculation time and stability of the model.

(b) Resistance Law

Constant roughness for entire cross-section was assumed. In the present study, Manning's n was set as 0.04 for entire reach basically. There are exceptional cases as follows.

- Reservoir
  - To avoid high frequency fluctuation with time-step by time-step, which is not suitable for AD calculation, relatively high Manning's n within a reservoir was given to damper out the high frequency fluctuation.
- Small and high slope channel
  - To prevent drying -up of channel during dry period, relatively high Manning's n was given to the bottom portion of river bed. The high Manning's n at the bottom of river bed is interpreted as transition zone to porous layer composed of gravel or pebble.

(c) Boundary Conditions

MIKE11-HD has several kinds of boundary conditions. Figure E.4.3 demonstrates them.

(d) RR-HD Link

Rainfall-runoff model (MIKE11-RR) is linked with MIKE11-HD. There are two options for the link. One is distributed link. Another one is link at a point. Figure E.4.4 shows an example of RR-HD link. In case of distributed link, runoff amount from rainfall-runoff catchment is equally distributed along river network specified. Link at a point is used when outlet of rainfall-runoff catchment connect to river network at a point.

(e) Transfer by Feeder channel

When there are feeder channels in rainfall-runoff catchment, quasi-natural runoff without influence of the feeder channels is firstly given as a input for river network by RR-HD link. Then, abstracted water amount by feeder channel is subtracted as point or distributed source, one of boundary condition types, with negative value. Figure E.4.5 shows an example of model for transfer by feeder channels.

(f) Reservoir

There are two options for dealing with reservoirs in MIKE11-HD.

- Option 1
    - Simulation model is disconnected at a reservoir. The reservoir is treated as only boundary condition.
- Option 2
    - Continuous simulation with reservoir. The water retention in a reservoir is also solved.

In case of option 2, reservoir is modelled as shown in Figure E.4.6. A weir is put on dam with actual dimension and a virtual weir which has very low height is put on the upstream end of the reservoir to get stable HD solution. Regulating structure is set on the dam to control released water amount from dam. Abstracted water amount from reservoir is given by distributed source, one of boundary condition types, with negative value. Figure E.4.6 shows an example of model for reservoir.

(g) Water Abstraction

The permission data includes the transferred water from reservoir. The effect of reservoir operation including water transfer is considered as reservoir operation in MIEK11-HD. To avoid double account for the amount of abstracted water, permission data whose source is reservoir that is treated in MIKE11-HD are excluded. The permission data are aggregated in each catchment and/or NAM Catchment, and then the aggregated amount is subtracted from the adjoining river segment (see Figure E.4.7).

(h) Discharge

For domestic discharge, the discharge from settlements whose PE is more than 2000 are treated as point sources. The discharge from smaller settlements are aggregated in a catchment and treated as distributed source (see Figure E.4.8).

For industrial discharge, all of permissions are treated as point sources (see Figure E.4.9).

E.4.2 Input Data for Water Quantity Model

(1) General

The following data are necessary for modeling in the present study.

- Meteo-Hydrological Data
  - Precipitation
  - Potential evapo-transpiration (PET)
  - Air Temperature
  - Water quantity at key HMSs
- Water Transfer, Abstraction, Discharge Data
  - Reservoir operation (for significant reservoir)
  - Water abstraction
    - Irrigation water use
    - Domestic & Industrial water use
  - Water discharge (waste water)
- River Condition Data
  - Cross-section data

(2) Meteo-Hydrological Data

(a) Precipitation

Daily precipitation data at 253 NIMH precipitation station in Bulgaria during 2000-2005 are available without missing duration in MoEW. Theissen Polygons of the precipitation stations are prepared (see *Supporting Report B*), and is used for estimating spatially-averaged precipitation.

Long-term data are available only from Statistical Year Book issued by NSI, which includes 13 meteorological stations during 1990-2005 and 8 meteorological stations during 1960-2005.

Average precipitation over a catchment is estimated by the following equations.

$$P_{ave} = C_{elc} P_{ave0} \qquad \text{(E.4.1)}$$

$$C_{ele} = exp\left[0.0003\left(E_{ave} \quad E_{ave\_P}\right)\right] \qquad (E.4.2)$$

$$P_{ave0} = \sum C_{pn} P_n \qquad (E.4.3)$$

$$E_{ave\_p} = \sum C_{pn} E_n \qquad (E.4.4)$$

where P_{ave} = average precipitation (mm), P_{ave0} = average precipitation before correction for elevation difference (mm), C_{ele} = correction coefficient for elevation difference between average elevation of catchment and one for precipitation sts. (-), E_{ave} = average elevation of catchment (m), E_{ave_p} = average elevation of precipitation stations (m), P_n = precipitation at station "n" (mm), C_{pn} = Thiessen coefficient for station "n" (-), E_n = elevation at station "n" (m).

Equation (E.4.2) is an empirical curve based on observation data (see *Supporting Report B*). Average elevation of catchment is derived from digital elevation model.

(b) Potential Evapo-Transpiration (PET)

To get enough amount of meteorological data at NIMH climatic sts. is difficult, because of high cost of data. Alternative freely available source, WORLDCLIM database, in which includes 1km mesh monthly averaged air temperature for whole world, is used. WORLDCLIM database shows average value during 1950-2000 based on observed data at several climatic stations considering altitude distribution. Thornthwaite equation is used for converting air temperature to PET.

When NIMH data will be available in future, they may be utilized to increase the accuracy of estimation of PET.

(c) Daily Air Temperature

To simulate melting process of snow, it is necessary to give daily air temperature. It is again very difficult to get daily temperature for a lot of meteorological stations, because of their high cost. In the study, data for daily temperature during 2000-2005 for the following five meteorological stations are purchased from NIMH, considering the limitation of budget of the study.

- Kustendil
- Sandanski
- Kazanlak
- Haskovo
- Pazardjik

(d) Water Quantity at Key HMSs

Daily discharge data at 204 NIMH HMSs in Bulgaria during 2000-2005 are available in MoEW.

As for long-term data, monthly data before 1975 are available in well-known Hydrological Reference Book. Monthly data in 1975 - 1983 are available in Bulletin issued from NIMH. However, it is necessary to purchase the data in 1983 – 1999 from NIMH, which is the only available way to get data except that the other studies, such as previous JICA study for Maritsa river basin, have already collected the data and they are opened to public. They are extremely high cost, considering the limitation of budget of the study. The study team therefore gave up getting the long term data in 1983-1999.

(3) Water Transfer, Abstraction, Discharge Data

(a) Reservoir Operation (for Significant Reservoir)

MoEW receives and stores monthly water balance data for some of significant reservoirs. The monthly water balance data include the followings.

- Reservoir Volume
- Total Inflow
- Total Outflow
- Used water amount for HPP, Irrigation, domestic & industrial use
- Release to downstream river (discharge pipe and/or overflow)

It is necessary to get permission to utilize the above data from MoEW. The study team finally got the permission to utilize the data for 2000-2005 from MoEW on April 2007.

Monthly water balance data for irrigation reservoirs have been also got from Irrigation Systems Ltd.

The monthly water balance data sometimes do not show clearly how much water is released to downstream river as instream flow. In such case, the amount of water is estimated by expert judgment with considering scheme of water use and possible water balance by measured water quantity at hydrometric stations (see *Supporting Report B* for the detail)

(b) Water Abstraction

(i) Irrigation Data

- Data for annually abstracted water volume for each irrigation branch (2000-2005) are purchased from Irrigation Systems Ltd.
- Data for monthly used water volume for each irrigation branch (2000-2005) are purchased from Irrigation Systems Ltd.
- Permission data for irrigation use were obtained from EABD & WABD.
- Actually abstracted water volume by Irrigation Systems Ltd. is much smaller than the amount described in the Permission in general.
- In the model, actually abstracted water amount by Irrigation Systems Ltd. is used for analysis (except in case that water is abstracted from significant reservoirs). Spatial distribution of water abstraction within each irrigation branch is estimated by permission data for assessment of existing condition.

(ii) Domestic and Industrial Data

- Permission data for domestic and industrial use are obtained from EABD & WABD. Annual permitted water volume is used for analysis for assessing existing condition.

(c) Discharge (Waste water)

- Permission and monitoring data for domestic and industrial discharge are obtained from EABD & WABD.
- On the other hand, population equivalent (PE) is also calculated based on population data.
- In the present study, PE for domestic discharge and permission data for industrial discharge are utilized, respectively.

(4) River Condition Data

(a) Cross-section

MIKE11-HD requires cross-section data of the rivers to be modelled. In the present study, the following cross-section data are available.

- NIMH HMS sts. data (Purchased by the Study Team): 20 sections
- Data used in the previous JICA Maritsa River Basin Study: 61 sections
- Surveyed data in the present study: 25 sections

Location of available cross-section data is shown in Figures E.4.10 and E.4.11.

In addition to the actual cross-section data, simplified version of cross-section data will also be utilized in MIKE11-HD modelling, based on the width and elevation of the river that will be estimated by other sources such as Google Earth and DEM.

It should be remind that considering the currently available cross-section data, the simulation result of water level may not be reliable for assessment of flood condition.

(b) Hydraulic Structure

There exist many hydraulic structures such as weir along the rivers to be modelled. However, the existence of such hydraulic structure will be basically ignored in MIKE11-HD, because of lack of the detailed information.

E.4.3 MIKE11 River Network and Rainfall-Runoff (NAM) Catchment

The outline of the model set-up is shown in the followimg table.

Outline of MIKE11 River Network and Rainfall-Runoff (NAM) Catchment

River Basin	Total Modeling Catchment Area (km^2)	Number of Rainfall-Runoff (NAM) Catchment	Total Length of Modeling River Network (km)	Number of Branch
Struma	8667.18	25	343.14	6
Mesta & Dospat	3397.71	14	141.80	3
Arda & Biala	5811.84	12	332.10	5
Tundzha	7890.93	20	409.46	5
Maritsa	21272.27	34	954.98	20

Figures E.4.12 – E.4.16 show MIKE11 river network and rainfall-runoff (NAM) catchment for each river basin.

The detailed model set-up is described in *Annex E.1*.

E.4.4 Calibration

The rainfall-runoff (NAM) model has many model parameters to be calibrated. In the present study, the model parameters were calibrated using the water quantity during 2001-2005. During this period, there were both extremely dry and wet years. The calibration was conducted to reproduce reasonable hydrograph with such wide range of precipitation conditions. Therefore, it is expected that the calibrated model parameters can be valid against relatively wide range of precipitation condition.

When the calibration was conducted, it was set for duration of simulation to be from the beginning of August 2000 to the end of 2005 so as to avoid including significant influence of initial condition for the model parameters on the simulated results. Duration from the beginning of August 2000 to the end of 2000 was regarded as initial running period, which should not be used for further analysis.

The model parameters were basically calibrated against estimated quasi-natural runoff from the watershed that was determined by calibrated points and/or rainfall-runoff catchment. The quasi-natural runoff was estimated by using observed flow and estimated transferred water, abstracted water and discharged water within the watershed as shown in Figure E.4.17.

It should be noted that the effect of regime change by local reservoirs was not taken into account for estimating quasi-natural runoff in the present study, because of lack of the information.

The data used for the estimation of quasi-natural flow were sometimes monthly data. The monthly data were converted to daily data, assuming same fluctuation pattern as the reference daily data with keeping mass balance for monthly basis. The reference daily data were selected from the observed data which were recorded at the HMS nearby same river. The details for the estimation of quasi-natural runoff are described in *Annex E.2*.

During the calibration, the following priority was considered.

- 1st Priority: Total mass balance during 2001-2005
- 2nd Priority: Overall fitness during 2001- 2005
- 3rd Priority: Low flow condition

Figure E.4.18 shows an example of calibration. In almost all cases, it was very difficult to get satisfactory hydrograph without including lower ground water storage, especially for recession process. It was thereby decided to include the lower ground water storage in the present study. When the lower ground water storage is included, it is necessary to use very small time scale for base flow component (ground water) to get good fitting. The time scale is 200 to 500 hours, which is almost same as one for interflow usually. Therefore, it should be careful to interpret the model result. The simulated ground water component is very quick one, which is almost like interflow. The simulated lower ground water component could be more suitable to be regarded as ground water, which stays longer time under ground.

The calibrated model parameters as well as the parameters characterizing elevation zones for the snow module are shown in *Annex E.3*.

Water balance for quasi-natural condition by calibrated NAM model is shown in Table E.4.1. It can be seen that runoff rate (RO/P) ranges 20 to 45%. The storage shown in the table is mainly because of large time scale of retention in lower ground water storage. The detailed water balance by Rainfall-runoff (NAM) catchment is presented in *Annex E.4.*

Figure E.4.19 shows the calibrated quasi-natural specific runoff by rainfall-runoff (NAM) catchment in 2001-2005. It can be clarified that mountain area produces higher runoff.

Figure E.4.20 shows the percentage of overland flow component in 2001-2005 by the calibrated NAM model. Southern part of EABD such as Arda river basin has higher percentage of overland flow component compared to other areas. This may be mainly because of climatic condition affected by Meditation Sea.

Figure E.4.21 shows relationship between total unit runoff and overland flow runoff component. MONERIS model[6)] uses an empirical equation for estimating the percentage of overland flow component. The result by the present study implies that the empirical equation gives lower estimation for the percentage of overland flow when it is applied to the catchments in some parts of Bulgaria, especially for southern part of Bulgaria.

Hydro dynamic simulation, in which water transfer, abstraction and discharge are taken into account, was tested using the calibrated parameters for Rainfall-runoff (NAM) model. Figures E.4.22 – E.4.26 show comparison between observed (disturbed flow) and simulated hydrograph at a representative HMS for each river basin. It can be seen that the simulated results agree fairly with the observed ones. More comparisons can be seen in *Annex E.5*.

E.4.5 Presentation and Analysis of Simulated Results

As an output of the study, an environment that users in river basin directorates can easily see and analyze the results of MIKE11 have been prepared. Simulated results by MIKE11 water quantity model have been linked to ArcGIS platform using Temporal Analyst for ArcGIS. Figure E.4.27 shows an example of presentation of results of MIKE11 model using Temporal Analyst. Many kinds of statistical analysis such as calculation of average, maximum and minimum value for the output of MIKE11 can be conducted and those results can be presented in ArcGIS platform.

The simulated results by MIKE11 water quantity model are utilized further for MIKE11 water quality analysis directly. Furthermore, the outputs of Rainfall-runoff model are utilized for Simple Model for water quantity.

E.5 MIKE11 Model for Water Quality

E.5.1 Outline of Water Quality Model

A MIKE 11 Water Quality Model (MIKE 11 EcoLab) is set up for all the water bodies described by the MIKE 11HD Hydraulic Model for water quantity.

The water quality and environmental models in MIKE 11 consist of a transport model for dissolved substances (the AD module) and various processes modules describing the biological and chemical processes in the water and bed sediments (the ECOLab). These are described briefly below.

As shown in Figure E.5.1 the MIKE 11 AD and MIKE 11 EcoLab utilize and are depending on the result from the MIKE 11 HD and are fully integrated. Building on a calibrated hydrodynamic model ensures that the dilution of pollutant and other substances discharged into the rivers is described in as sound way. Dynamic variation over time created by changes in water level, velocity and discharges can therefore be described correctly by the model complex.

The MIKE 11 AD module is based on the one-dimensional equation of conservation of mass of a dissolved or suspended material (e.g. salt or cohesive sediments). The behaviour of conservative materials that decay linearly can be simulated. The module runs in parallel with the hydrodynamic module.

The MIKE 11 system includes a well-proven water quality module. It is coupled to the advection-dispersion (AD) module and simulates the reaction processes of multi-compound systems. The mass balances for the parameters involved are calculated for all grid points at all time steps using a rational extrapolation method in an integrated two-step procedure with the AD module.

In addition to the AD-module the water quality/environmental modules of the MIKE 11 system consist of several types of modules describing the bio-chemical turnover processes. These modules are in the modelling system called EcoLab Templates. This is predefined water quality models to be used for different purposed and water quality problems. There exist EcoLab templates for impact of organic pollution (WQ Templates), nutrient and algae growth problems (Eutrophication Templates), heavy metal pollution (HM Templates) and others. These predefined module or templates can be modified by the user according to the specific study. The use can also defined a complete new and local specific type of water quality model. This is done through a relative user friendly menu system.

The Ecolab Template that has been selected for use under this project is a

- WQ-Template including BOD oxygen and nutrients (Figure E.5.2)

The selected template is basic the so-called MIKE 11 WQ level 4 Template (for details see the MIKE 11 Manual). The templates have been slightly modified to meet the exactly need for this study. The modification concerns primarily that the template are simplified only to include the below mention variable. This has been done to reduce the calculation time for the models. Further more is included a post-processing of result data to calculated Total N and Total P concentrations, which were not included in the original template. Finally the templates have for some of the rivers been modified to include local re-aeration processes (the exchange of oxygen with the atmosphere).

The selected module is designed for the study of the water quality in the rivers where the focus is on degradation of organic matter, transformation of N-components and the consequences for the oxygen concentrations. The selected model includes in addition phosphorus compounds.

The BOD, oxygen and N-transformation processes is outlined in Figure E.5.2. Form the figure it can be seen that the model include both the transformation processes for the substances flowing in to the rivers as well as processes as photosynthesis and respiration of plants animals and sediment.

The Phosphorus processes are outlined in Figure E.5.3. The Phosphorus Model is a relative simple absorption-desorption model expanded with relevant processes related to plant, animal and sediment.

The WQ-module describes the following concentration (State Variables):

- BOD (Biological Oxygen Demand ~ Organic matter)
- Diluted Oxygen (DO)
- Total Ammonium (NH_4-N)
- Nitrate (NO_3-N)
- Phosphate (PO_4-P)
- Phosphor bound to particulate material (Particulate –P)
- Temperature

The most important processes included concerns:

- BOD degradation and following oxygen consumption
- Re-aeration processes, (the exchange of oxygen with the atmosphere)
- Ammonification, (ammonium production during BOD degradation)
- Nitrification, (transformation of ammonium to nitrate under oxygen consumption)
- Denitrification (transformation of nitrate into free atmospheric nitrogen- N_2)
- Phosphate adsorption/desorption to particles.
- Phosphate production during BOD degradation, (mineralization).
- Oxygen production and consumption from the ecosystem (sediment, plants, animals)
- Nutrient (N and P) uptake and exchange by the ecosystem (sediment, plants, animals)
- Sedimentation and resuspension processes.

E.5.2 Input Data for Water Quality Model

The most significant part of the input data for the MIKE 11 Water quality Model (ECOLab) has been created during the pollution load estimation. The basis and assumption for this estimated is additionally described in *Supporting Report C*. Below is give a description the data used for the MIKE11 water quality model.

(1) Domestic Pollution

For including domestic pollution in the MIKE 11 Water Quality Model there has been distinguished between towns above 2000 person equivalents (PE) and towns and villages below 2000 PE.

The towns above 2000 PE have been included as individual point sources. The pollution input to the MIKE 11 model used for these towns is for the present situation given in *Annex E.6*.

Towns below 2000 PE have been included as distributed sources flowing into the rivers equally distributed along the river branched within each NAM-Catchment. The load from each NAM catchments for the present situation is given in *Annex E.6*.

For the estimation of the pollution load for the domestic pollution sources is used the unit load representing one person equivalent (PE) shown in the following table.

Unit load (PE) that is Assumed to Reach the Rivers from Domestic Pollution Sources (WWTP:Waste Water Treatment Plants)

g/day/person	BOD	NH4-N	NO3-N	PO4-P	Part P	TP	Org. N	TN	l/day
Raw Sewage	60	8	0	1.7	0.1	1.8	3	11	200
Severed without treatment	60	8	0	1.7	0.1	1.8	3	11	200
With secondary WWTP	10	1	2.5	0.9	0.1	1	0.5	4	200
With primary WWTP	35	9	0	1.7	0.1	1.8	2	11	200
Without sewage system	15	1	2	0.9	0.1	1	0	3	200

From the Table it can be seen that the pollution per PE that reach the river is assumed lower in case no sewage system exist compared to the situation where all are severed. The argument for this is that a significant amount of especially BOD and Ammonium is depredated on its way to the river through drains, ditches and infiltration through soil matrices.

(2) Industrial Pollution

Industrial pollution sources with separate discharges directly into the river have been included as separate point sources in the MIKE 11 WQ model setup. The pollution has been estimated based on data made available from EABD and WABD. The data originate partly form monitoring programs and partly from license (information card) data. In several cases that only data for discharge have been available, concentration of pollution variables was roughly estimated based on data from other industrial sources of the same general type. The industrial pollution load estimates is highly uncertain and it is highly recommendable to improve this part of the model input data.

The used discharges and concentrations are given in *Annex E.6.*

A part of the industrial pollution has not been possible to describe separately and has been include in the person equivalent form urban area. This part of the industrial pollution is discharged into the MIKE 11 model together with the above mention domestic sources. For more details please refer to *Supporting Report C*.

(3) Livestock Farm Pollution

Two different groups of livestock pollution sources have been include in the MIKE11 model setup.

- Livestock Farms – included as point sources
- Distributed livestock spread in the catchments - includes as non-point sources

The pollution form Livestock Farm has been based on information collected from the EABD and WADB. The farms includes together with discharged values are given in *Annex E.6*.

Estimation of the non-point livestock sources have been based on statistical information about animals in each municipality. For further description, see below in section (4).

(4) Non-Point Load using the LOAD CALCULATOR

Non-point pollution load from fertilizers and livestock spread in the catchments have been quantified and input data for the modeling have been created using the MIKE BASIN / MIKE 11 LOAD CALCULATOR. This section describes the input data used for this purpose. Additional description of the use of this facility is given in *Guideline for the Integrated River Basin Analysis Model*.

The MIKE LOAD CALCULATOR is a tool for assisting in determining the pollution loads within river basins. The tool can be applied as a stand-alone tool for calculating average mass fluxes of pollutants for individual sub-catchments (e.g. kg/catchment/year) or on a raster grid basis (e.g. kg/grid/year). Optionally the tool can provide the pollution load input data for the MIKE BASIN Water Quality model and for MIKE 11 ECOLab models.

Pollution loads may include both point and non-point sources. All loads are initially calculated as constant mass fluxes for each sub-catchment, e.g. kg/year, however when applying the Load Calculator together with the MIKE BASIN WQ or the MIKE 11 RR (Rainfall-Runoff/NAM) model there are several options for translating the constant mass fluxes into mass flux time series depending on e.g. runoff time series or any other known temporal variations.

The main LOAD CALCULATOR dialog consists of three parts:

- Sources - for specifying pollution sources,

- Transport - for specifying the transport and retention of pollutants
- Output - for specifying how the output is to be stored

Within these model set-up the source part and the output part are utilized. The transport in the modeling area is described in the MIKE 11 model and the retention of the non-point pollution in the catchment before ending up in the river is described using a runoff coefficient.

In the Sources section all pollution sources are defined and specified individually. An unlimited number of sources can be specified. Each source can have a unique set of required input data or groups of sources may have similar input data. In any case the data input is very similar in all four cases. The sources input data is divided into

- a Shape file attributes section
- a Time distribution (alfa time series) section, and
- a source specific section that in three of the four methods includes a Runoff Coefficients.

Sources are divided into four different groups:

- Fertiliser Sources
- Livestock Sources
- Domestic Sources
- Point Sources.

In the model set-up used in this study only the facilities for pollution estimates from the use of fertilizers and from livestock spread in the catchments have been utilized. The pollution load from different kind of point sources (domestic, industrial, livestock farms) have been included in the model set-up based on calculation carried out in different Excel sheets. For more details on this please consult *Guideline for the Integrated River Basin Analysis Model – chapter on MIKE 11 Water Quality Model*.

(a) Fertilizer Sources

The Fertilizer source type typically represents artificial fertilizers, such as nitrogen and/or phosphorous. Other pollutant components may also be included as a fertilizer source. This have however not been utilized in the specific set-up for the rivers in question.

For these model set-ups it assumed that the used of fertilizers result in a runoff to the rivers of

- Nitrate-Nitrogen (NO_3-N)
- Phosphate - Diluted Ortho Phosphate (PO_4-P)

A fertilizer sources must be specified individually for each type of pollutant. For example, to simulate both nitrogen and phosphorus two fertilizer sources are required - one called "Fertilizer Nitrogen" and the other called "Fertilizer Phosphorous".

The input data has been stored in a polygon shape file with field(s) in the associated attribute table representing the amount of fertilizer applied per polygon (e.g. farm, district or county). Data used in these setups are achieved from statistical information stored in ArcGIS in a directory named: *"Bulagria_fertilser-byDistrict"*. In Table E.5.1 is given the statistical information about the average use of fertilizers district by district for the period 1999-2005 that have been utilized for the estimation of the non-point pollution from this source. These values are found in the attribute table for the shape file (ArcGIS-layer) named "Bg_District" within the directory *"Bulagria_fertilser-byDistrict"*. More details on the use of fertilizers the individual years is shown in *Annex E.6*.

For the calculation of the pollution input to the rivers a runoff coefficient of 10 % has been assumed.

The concentrations in the input to the modeled rivers have been assumed constant through the year. However the transport to the river is not constant as this non-point pollution follows the runoff of water described by the Rainfall-Runoff (NAM) model.

(b) Livestock Sources

The Livestock Source type typically represents pollutants derived from manure or slurry from cattle, bovines, pigs, sheep, goats, horses, poultry, etc.

For each livestock source several different types of pollutants can be specified via a *Source Load per Head*. For each pollutant component a value must be specified representing the average production or field application of manure or slurry, e.g. kg N /year/animal head. Available components for livestock sources in the LOAD CALCULATOR are:

- BOD - Biological Oxygen Demand
- Ntot - Total Nitrogen
- NH4 - Ammonia-Nitrogen
- NO3 - Nitrate-Nitrogen
- Ptot - Total Phosphorous (or PO_4-P)
- EColi - E-Coli Bacteria
- User Def - User defined substance

In this model set-up the pollution from non-point pollution from livestock contribute with

- BOD - Biological Oxygen Demand
- NH_4-N - Ammonia-Nitrogen
- PO_4-P – Diluted Ortho Phosphate

This mean that all nitrogen contribution from this source is assume to reach the rivers as Ammonium and all phosphorus contribution is assumed to reach the rivers as phosphate (PO_4-P). The Total Phosphorous component of the LOAD CALCULATOR is redefined (or interpretated) in the MIKE 11 ECOLab models as Phosphate (PO_4-P).

Input data are stored as an ArcGIS layer of the type polygon shape file with field(s) in the associated attribute table representing the number of heads per polygon (e.g. farm, district or county). Data have been made available from the statistical year book 2005 /Agricultural census of Bulgaria 2003/. The data used as input for the LOAD CALCULATOR for livestock is shown in Table E.5.2.

The pollution produced by each animal has been calculated using unit load per hear as outlined in the following table.

Levels of Pollution per Head from Different Domestic Animals

Species	BOD kg/year/head	TN kg N/year/head	TP kg P/year/head
Milk producing (Dairy) cows	360	118	17.5
Bovine cows / cattles	55	27.5	17.5
Mother pigs (sows)	33	5.8	4.0
Slaughter pigs (up to100 kg)	8.6	2.8	1.6
Sheeps /goats	7.3	3.25	2.0
Poultry (average)	0.7	0.25	0.18

It is assumed for the calculation of the pollution to the rivers that only 5% of the produced pollution load for livestock spread in catchment will reach the rivers. The rest of the pollution produced is assumed to be retained and turned over within the catchments areas before washed out into the rivers. This assumption is rather rough and the correct level of retention is difficult to estimate and very uncertain.

(5) Inflow with Groundwater

The MIKE 11 Hydrodynamic (HD) model used for describing the water quantity (water levels, discharges and velocities) receive inflow from the Rainfall Runoff model (MIKE 11 RR). The MIKE 11 RR describes the Surface or Overland Flow, the Rootzone or Interflow and the Baseflow.

The Baseflow is the water flowing into the river from the Groundwater. In case no specification of concentration or temperature is made for this inflow the model will regard it as pure water with no constituents and zero degree.

Periodically an important part of the flow in some river is generated by the Baseflow.

The condition in the inflowing groundwater is described based on available data on groundwater concentration from the different NAM Catchments. For some NAM Catchments no information has been available and a global average from neighboring catchments has been used.

E.5.3 Calibration of Water Quality Models

The below sections presents the results of the calibration for the five rivers, for which MIKE11 WQ models have been setup under the project. The calibration constant differ some extent for the rivers and minor changes have been made in the modeling templates. However for all rivers the above general description of the used model is valid.

The pollution load has been relative roughly quantified and there exist significant uncertainties on domestic, industrial, as well as agricultural load. This concerns both the described point sources and the non-point sources. For many of the sources the pollutants travel some distance through the catchments before they end up in the rivers. During the load estimation awareness have been on this issue and estimates on the possible turnover before discharging into rives was taken into account. However the pollution estimates can only be taken as estimations of levels and no details have been available on the distribution over time. Some industries are seasonal and are continuously changing production. For some industries only licensed data have been available or no pollution load estimate exists. For the domestic pollution there are significant uncertainties on variation through the year, decay, turnover and loss before it reach the river. Finally for the non-point pollution no fine tuning of the seasonal inflow have been possible. It assumed that it follow the water flow with a constant concentration.

The year 2004 has been chosen as the hydraulic basis for the calibration. These in spite that the pollution loads to a higher extent represent the level in the period 2005-2007. The year 2004 has been selected as hydraulic basis, because this year has been characterized closed to an average year between those for which hydrological data was available.

All together this mean that it can’t be expected to achieve very precise simulation of the monitored concentration and especially not the suddenly peaks and variation through the year. Further more there are significant uncertainties on the monitored vales. For these reason it has during the calibration process been aimed to achieve a representation of the measured level not only in 2004 but also that measured other resent years.

(1) Struma River

The model constants used for the Struma River Basin is shown in Table E.5.3. Local sedimentation rates have been used in the reservoirs to describe the settling of suspended material here.

In the Figures E.5.5 – E.5.32 are shown calibration result for the variables BOD, Oxygen (DO), Ammonium (NH_4-N) and Phosphate-P (PO_4-P) from the stations outlined in Figure E.5.4. Time series of water quality data have not been available from all stations. The station for presentation of model results has been selected to achieve a broad representation of the different part of the Struma Rives as possible based on available water quality time series data.

Generally the simulated concentration levels downstream the Pchelina Reservoir corresponds to the measured although some of the dynamic variation is not described too well. To achieve an improved simulation of the dynamic in the river system requires at least better estimations of the variation in pollution load. No such data have been available.

The model does not simulate the upstream part of the river system (e.g. upstream Pchelina Reservoir) correctly. The simulated concentrations are general much too high. In general the HD-model simulates relative low discharges here. This, together with the estimated pollution load, result in these too high concentrations. The model description of these river stretches have to be re-evaluated before the model is used for management purposes for this part of the river system.

(2) Mesta River

The model constants used for the Mesta River Basin is shown in Table E.5.4. Local sedimentation rates have been used in the reservoirs to describe the settling of suspended material here.

Below is shown in Figures E.5.34 – E.5.48 calibration result for the variables BOD, Oxygen (DO), Ammonium (NH_4-N) and Phosphate-P (PO_4-P) from the stations outlined in Figure E.5.33. Time series of water quality data have not been available from all stations. The station for presentation of model results has been selected to achieve the best possible representation of the different part of the Mesta/Dospat Rivers based on available water quality time series data.

Generally the simulated concentration corresponds to the measured although some of the dynamic variation is not described too well. To achieve an improved simulation of the dynamic in the river system requires at least better estimations of the variation in pollution load. No such data have been available.

There is a tendency to simulation too high phosphate levels. A pure AD-simulation without any transformation or decay have shown that much higher concentration can not be simulated based on the existing HD-model and the estimated pollution loads. To improve the model with this respect a re-evaluation of especially the pollution load is recommended.

(3) Arda River

The calibrated model constants are shown in Table E.5.5.

The result of the calibration of the MIKE 11 water quality model for the variables BOD, Oxygen (DO), Ammonium (NH4-N) and Phosphate-P (PO4-P) in the Arda River system is shown in Figures E.5.50 - E.5.73 for the selected stations (Figure E.5.49).

In general the model simulated the measures concentration levels satisfying taking into account that no detailed information has been available about the time variation in the load from the main sources.

However the model does not simulate the concentrations in upstream part of the model (see below BOD and Ammonium for chainage 127,068 / St. 397) too well especially in periods with very low discharges (e.g. last month of 2004). In such periods the model overestimates the concentration of pollutants in the river compared to the measured values. More detailed information and investigation of the pollution load in this part of the catchment can be recommended.

(4) Tundzha River

The Tundzha River has been calibrated for the reached downstream Koprinka Reservoir, e.g. downstream station 269 shown in Figure E.5.74. The reason for excluding the upstream part was model technical difficulties with achieving a sound and stable AD-model due to periodically drying out of certain cross sections and structures. Furthermore the Koprinka reservoir as the other reservoirs is not well represented by the MIKE 11 WQ model. MIKE 11 EU (Eutrophication) model would have been more applicable. However due to time and resource constrains it was not possible to solve these within this project and it was decided to restrict the MIKE 11 WQ modelling to the reached downstream the Koprinka Reservoir. For long periods (e.g. most of 2004), no water or only very little water flow into the Tundzha River from the Koprinka Reservoir because nearly all water is diverted for other purposes.

During the setup of Tundzha River a modification of the ECOLab Template, (which includes the description of the water quality processes), has been made. Special local description for reaeration relationship were found necessary when measured combination of concentration levels for BOD, Ammonium and Oxygen should be simulated for the Mochuritsa Tributary flowing from Karnobat region to the confluence with Tundzha River at Yambol (in Figur*e* E.5.74 the tributary with the monitoring stations 297, 269, 298).

The model constants achieved during calibration is shown in Table E.5.6.

Figures E.5.75 - E.5.103 show the calibration result for the variables BOD, Oxygen (DO), Ammonium (NH_4-N) and Phosphate-P (PO_4-P) from the stations outlined in Figure E.5.74.

The model describes in general the measured levels satisfactory. However in the most upstream part of the WQ-model area the model overestimates the concentration to some extent. More detailed information has to be collected concerning the pollution load especially for dry periods if the significant improved simulation of the measured valued have to be achieved here.

In addition the variation in oxygen concentration in and just downstream reservoir are less well represented by the model simulation. This is due the algae growth processes (Eutrophication), which are not included in the MIKE 11 WQ-ECOLab Templated used (modified WQ-template level 4 – see MIKE11 Manual and the delivered Ecolab-files for addition information).

(5) Martisa River

Figures E.5.105 - E.5.134 show the calibration result for the variables BOD, Oxygen (DO), Ammonium (NH_4-N) and Phosphate-P (PO_4-P) from the stations outlined in Figure E.5.104. The calibrated model constants are given in Table E.5.7.

The concentration of BOD is simulated in general at the same level as measured. This conclusion is also based on comparison with measurement from other years (2002-2005) that the simulated 2004. This is done because the information about the load is not specifically representing one specific year but has to be regarded as a general pollution level of the present situation. The main BOD polluters are described with a constant discharge which is true in reality. No data for variation is available. As a consequence the model does not simulate the variation correctly at all station. This is especially pronounced in the upstream part of the rivers.

The oxygen level and variation are in general described satisfying taking into account the above comment in relation to the simulated BOD.

The ammonium concentration levels and variations are in general described well although some peaks of ammonium are not fully represented by the model.

The phosphate levels are in general simulated too low. However even without any transformation or decay (e.g. using a pure AD-simulation) shows lower concentration than measures. More attention is recommended to be paid to the estimation of P load. The model simulation indicates that the load input to the model is underestimated.

E.5.4 Scenario Simulation

The calibrated water quality models have been used for simulation of the scenarios:

- Present situation (corresponds to the calibration simulation)
- Near Future
- Near Future with 10 % loss
- High Priority Future
- High and Medium Priority Future

For description of the pollution load scenarios please see *Main Report* and *Supporting Report C*: *Water Quality* of this project.

For all of the scenarios the hydrological and hydraulic condition from year 2004 has been used as was done for the calibration. The time axis on all plots are therefore showing dates in 2004 although the represent different future years / scenarios.

The results of the scenario simulation are for selected cross sections shown in *Annex E.6*. The results are in addition illustrated with plan plots of the rivers with colours corresponding to the Bulgarian Water Quality Classes with respect to BOD concentrations in Figures E.5.135 - E.5.159. Further more the BOD concentration has been shown as profiles along the main river. The plots have been selected at a time during the year which is close to the most critical situation e.g. at the time where the impact is most severe. Because this do not occur exactly at the same time in all river branches there may at some river stretches where concentrations have been simulated higher for short periods than illustrated in the following figures. However, the figures give in general pictures that represent the overall impression of the simulation results.

E.6 Simple Model

E.6.1 General

The Simple model is basically based on monthly mass balance calculation and empirical relationship between total load and water quality. The calculation is implemented on spread sheet such as Ms-Excel. This chapter describes the basic idea of the simple model for water quantity and water quality.

E.6.2 Simple Model for Water Quantity

(1) Basic Ideas of Model

Unit of analysis in space for the simple model for water quantity is a catchment. Water movement and balance among the catchments are analyzed by the simple model. To develop the simple model for water quantity, connectivity of the catchments is examined and an additional attribute for modeling catchment layer is recorded using GIS environment as shown in Figure E.6.1.

The additional attribute for the catchment connectivity allows analyzing easily affected catchments by a source catchment. An example of the affected catchments is shown in Figure E.6.2.

"Matrix for contribution" can also be prepared based on the additional attribute table. An example of the "matrix for contribution" is shown in Figure E.6.3. Using this matrix, one can easily calculate the total accumulated value at an observation point from all of upstream catchments.

In the present study, the matrix of contribution for each river basin has been prepared and stored in the Excel sheet as a part of the simple model.

In a catchment, the following sources are estimated.

- Catchment Area
- Run-off from Catchment
- Abstraction from Catchment
- Discharge from Catchment
- Transfer from Catchment

For example, the simple model of water quantity utilizes the results of calibrated rainfall-runoff (NAM) model. To estimate quasi-natural runoff from each catchment, the following is assumed (see Figure E.6.4).

- Runoff from each catchment inside a rainfall-runoff (NAM) catchment is proportional to: (Cacthment Area) x (Precipitation – Evapo-transpiration)

The other sources such as abstraction, discharge and transfer from a catchment are estimated by using same methodology for MIKE11 water quantity model.

When the sources from catchments are given, accumulated values without influence of significant reservoir such as quasi-natural flow and total abstracted water at an observation point are calculated using the matrix of contribution (See Figure E.6.5).

Influence of operation of significant reservoir is taken into account by introducing "matrix for reservoir influence". At the catchments which are affected by specific reservoir, modified water quantity by the operation of the reservoir is substituted by quasi-natural water quantity to get disturbed water quantity as show in Figure E.6.6.

All of the calculation is implemented in Excel sheet with Macros which have been prepared in the present study.

(2) Versions of Simple Model for Water Quantity

The simple model for water quantity has the following four versions.

Versions for Simple Model for Water Quantity

Version	Purpose
SimpleModel_ver_Existing	-To estimate existing condition -Developed in the study (No need to change until RR model will be revised.)
SimpleModel_ver_Potential	-To estimate probable water quantity for quasi-natural and potential flows -Developed in the study (No need to change until RR model will be revised.)
SimpleModel_ver_Permit	-To examine the effect of permitted water amount -Local + Existing water abstraction by Significant Reservoir -Local + Permitted water abstraction for Significant Reservoir
SimpleModel_ver_Demand	-To estimate water demand with several scenarios

An example of the presentation of simple model_ver_Existing is shown in Figure E.6.7. The user can specify any observation points to see the time series of water balance.

The results of ver_Exitsing and ver_Potential are shown and discussed in detail in *Supporting Report B.* Those results are basis for the draft basin management plan prepared by the present study.

The simple model_ver_Permit and ver_Demand have been prepared rather for Decision Support Tools for proper water management by Basin Directorate itself. Main features for each version are as follows:

- Ver_Permit
  - Entering permission data for hydropower, irrigation, drinking water supply and industrial water supply.
  - Selection of reference points for management
  - Summary table for annual average and average during summer time (Jul. to Sep.) for year 2001 -2005 for each catchment/segment and reference point
  - Longitudinal plot of the summarized results along main channel

- Time series plot for each reference point and/or catchment/segment
- Globally and locally changeable coefficient for permitted water amount
- Preparation of an input file related to local water abstraction for each NAM catchment for MIKE11 water quantity model

- Ver_Demand
  - Entering parameters for estimation of water demand for irrigation, drinking water supply and industrial water supply
  - Selection of reference points for management
  - Summary table for annual average and average during summer time (Jul. to Sep.) for each catchment/segment and reference point
  - Longitudinal plot of the summarized results along main channel
  - Time series plot for each reference point and/or catchment/segment
  - Preparation of an input file related to local water abstraction for each NAM catchment for MIKE11 water quantity model

Manuals for ver_Permit and ver_Demand are shown in *Annex E.7* and *E.8*, respectively.

E.6.3 Simple Model for Water Quality

In order to facilitate the formulation of water quality management plan and for future use for water quality management, simple model for water quality was developed in the Study.

(1) Basic Concept of Simple Model for Water Quality (WQL Simple Model)

- The WQL Simple Model will simulate the effect of reducing pollution loads to the river water quality in terms of BOD5.
- The simulation will be done at key calculation points along the rivers.
- The calculation will be done by MS-Excel.
- The model can be utilized for quick review of the conditions of BOD loads in the river basins comparing the future required BOD loads to attain good status of water (such as Class II with BOD5 3.0 mg/l).

(2) Procedure of Developing the WQL Simple Model

Figure E.6.8 shows the procedure for developing the WQL Simple Model.

- First to check the general co-relation between the present accumulated catchment BOD loads from the upstream of the calculation points and the river BOD loads at the calculation points. If there is junction of tributary, the calculation points are set at the upstream side of the main stream. If there is no tributary, the calculation point is just on the main stream at that point. Figure E.6.9 shows the calculation points for EABD and WABD with NAM catchments. There are clear co-relation between the accumulated catchment BOD loads and the river BOD loads as shown in *Supporting Report C*.

- The existing sewer networks in EABD and WABD have significant loss of pollutants such as at least 50 % loss for the Maritsa and Tundzha River Basin, 40 % in the Arda River Basin, and 60 % in the Struma and Mesta River Basin. The current loss percentage to the domestic BOD load and industrial BOD load discharged into the sewerage system is applied for calculating their inflow BOD loads to the river. This assumption is more or less acceptable because the domestic loads without sewerage system are calculated with smaller unit loads (15 g/day/PE) compared to the generated unit load of 60 g/day/PE, and it may reach to the river through ditch or gulley.
- Ratios between the inflow BOD loads and river BOD loads are calculated at every calculation point.
- Under the assumed condition of reducing the loss from the sewer networks up to 10 % in the long time future, inflow BOD loads based on the Near Future BOD load including under constructed WWTPs or committed for constructing WWTPs in EABD and WABD are calculated. Corresponding to this, River BOD load and the BOD concentration in the near future condition with loss of sewerage with 10% are calculated.
- In order to attain the good status of water, which is better than Class II with BOD5 of 3.0 mg/l, required inflow BOD load and corresponding accumulated catchment BOD load is calculated.
- Setting the pollution reduction plan such as construction of WWTPs in the future, future accumulated catchment BOD load is calculated, and compared with the required accumulated catchment BOD load.

(3) Results of the Calculation

Based on the procedure described above, following tables and figures show the results of the calculations by the WQL Simple Model.

Table / Figure	Contents
Table E.6.1	Present Accumulated Catchment BOD Loads and River BOD Loads in EABD
Table E.6.2	Required Accumulated Catchment BOD Loads and Proposed Future BOD Loads with the High Priority Towns for WWTPs in EABD
Table E.6.3	Required Accumulated Catchment BOD Loads and Proposed Future BOD Loads with the High and Medium Priority Towns for WWTPs in EABD
Table E.6.4	Present Accumulated Catchment BOD Loads and River BOD Loads in WABD
Table E.6.5	Required Accumulated Catchment BOD Loads and Proposed Future BOD Loads with the High Priority Towns for WWTPs in WABD
Table E.6.6	Required Accumulated Catchment BOD Loads and Proposed Future BOD Loads with the High and Medium Priority Towns for WWTPs in WABD
Figure E.6.10	Present Accumulated Catchment BOD Loads and River BOD Loads in EABD
Figure E.6.11	Required Accumulated Catchment BOD Loads and River BOD Loads in EABD with High Priority Towns for WWTPs
Figure E.6.12	Required Accumulated Catchment BOD Loads and River BOD Loads in EABD with High and Medium Priority Towns for WWTPs
Figure E.6.13	Present Accumulated Catchment BOD Loads and River BOD Loads in WABD
Figure E.6.14	Required Accumulated Catchment BOD Loads and River BOD Loads in WABD with High Priority Towns for WWTPs
Figure E.6.15	Required Accumulated Catchment BOD Loads and River BOD Loads in WABD with High and Medium Priority Towns for WWTPs

Effects of reduction of BOD loads in EABD by the high priority towns for WWTPs as well as the high and medium priority towns for WWTPs are rather good along the Maritsa and Tundzha Main Rivers in general. However, for the upstream to mid-stream part of the Tundzha River, reduction rate is slightly lower than the downstream. This reaches of the Tundzha River might have more influence from the medium and smaller settlements. Therefore, in the future, it will be necessary for reduction of pollution loads in this part from medium to smaller settlements as well.

Overall effects for reducing BOD Loads by the high priority towns for WWTPs as well as the high and medium priority towns for the Struma and Mesta Rivers are generally good. However, for the Struma River, reduction rate of the pollution loads is insufficient especially from upstream to mid-stream part. Therefore in the future, it may be necessary to treat medium and smaller settlements in the upstream to the mid-stream parts as well.

References in Chapter E

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Supporting Report E

Tables

Table E.4.1 Water Balance for Quasi-Natural Condition during 2001-2005 by Calibrated NAM Model

Source: JICA Study Team

	Struma	Mesta	Dospat	Arda	Biala	Tundzha	Maritsa
Catchment Area (km^2)	8541	2785	613	5213	599	7891	21272
Average Elevation (m)	919	1225	1330	639	418	386	569
Precipitation (P) (mm/y)	761	844	875	902	833	710	723
PET (mm/y)	629	577	552	671	717	689	669
ET (mm/y)	483	442	490	511	567	513	488
Total Runoff (RO) (mm/y)	231	349	321	371	232	158	173
Lower Base Flow (LBF)	28	56	81	14	12	27	41
OverlandFlow (OF) (mm/y)	25	26	30	165	99	26	31
Storage (ST) (mm/y)	48	53	64	20	35	39	62
ET/P (%)	63.5	52.4	56.0	56.7	68.1	72.3	67.5
RO/P (%)	30.4	41.4	36.7	41.1	27.9	22.3	23.9
LBF/P (%)	3.7	6.6	9.3	1.6	1.4	3.8	5.7
OF/P (%)	3.3	3.1	3.4	18.3	11.9	3.7	4.3
ST/P (%)	6.3	6.3	7.3	2.2	4.2	5.5	8.6
ET/PET (%)	76.8	76.6	88.8	76.2	79.1	74.5	72.9
Total Runoff (m^3/s)	62.6	30.8	6.2	61.3	4.4	39.5	116.7
Specific Total Runoff ($l/s/km^2$)	7.325	11.067	10.179	11.764	7.357	5.010	5.486
Remarks	1) Catchment area is only for modelled area in Bulgarian teritory. 2) Two catchments are disturbed condtion. 3) Precipitation is modified considering elevation in the model.	1) Catchment area is only for modelled area. 2) Precipitation is modified considering elevation in the model.	1) Catchment area is only for modelled area. 2) Precipitation is modified considering elevation in the model.	1) Catchment area is only for modelled area. 2) Precipitation is modified considering elevation in the model.	1) Catchment area is only for modelled area. 2) Precipitation is modified considering elevation in the model.	1) Catchment area is only for modelled area. 2) Precipitation is modified considering elevation in the model.	1) Catchment area is only for modelled area. 2) Precipitation is modified considering elevation in the model.

Table E.5.1 Information about Use of Fertilizer within Each District Unitized for Estimation of the Non-point Load from This Source (Average Use in the Period 1999-2005)

District Name	kgN/year	kgN/km^2/year	kgP/year	kgP/km^2/year
Plovdiv	7366998.0	9389.9	234338.8	298.7
Burgas	8189751.6	8610.5	81044.8	85.2
Blagoevgrad	1743345.5	9699.3	103835.6	577.7
Pazardzhik	2350963.6	8363.6	164106.3	583.8
Kardzhali	633215.7	5229.5	1365.7	11.3
Kyustendil	760438.4	7648.5	20776.3	209.0
Sofia	2093932.5	7733.4	94664.5	349.6
Stara Zagora	7857140.9	8535.4	141729.9	154.0
Haskovo	4740221.7	8746.5	75957.8	140.2
Smolyan	1648177.7	9049.6	209222.1	1148.8
Sliven	4183851.4	7501.9	28152.9	50.5
Yambol	6222461.3	8166.6	86336.6	113.3
Pernik	710138.3	6651.0	3531.3	33.1
Gabrovo	903477.8	8576.1	17075.2	162.1
Veliko Tarnovo	6806923.4	8218.5	78291.3	94.5

Table E.5.2 Livestock Input Data for the LOAD CALCULATOR

(1/2)

MUNICIP Code no.	NAME Municipals	Bovine Buffalos	Dairy cows	Slaughter pigs	Breeding sows	sheep + goat	Tot. poultry
935	Chernoochene	5066	2736	29	9	7755	47722
908	Dzhebel	4487	2827	80	16	6992	22820
921	Momchilgrad	7753	3689	55	14	18409	36626
916	Kardzhali	10913	6448	1120	358	19656	237322
638	Chepelare	2126	1271	240	39	2250	7404
858	Chelopech	196	140	322	149	442	3804
857	Chavdar	335	247	273	183	1068	3398
853	Yakoruda	3590	1865	15	0	6566	13600
632	Strelcha	606	395	1350	120	4803	12172
841	Sapareva banya	788	498	1091	35	2993	13291
855	Pirdop	728	472	955	114	2199	8766
621	Peshtera	749	482	4153	482	4218	148189
620	Panagyurishte	2123	1254	1908	65	9314	24628
619	Pazardzhik	4164	1981	25980	2762	26862	276731
618	Nedelino	2180	1825	111	13	959	1177
614	Lesichovo	545	271	1312	55	6357	41120
838	Rila	338	222	586	27	1640	4968
624	Rakitovo	1337	817	335	18	3828	8796
837	Razlog	1937	1026	1858	94	7395	21173
836	Radomir	2850	1858	18171	1649	7599	87170
813	Garmen	3675	1897	239	0	8474	25400
818	Etropole	0	0	0	0	0	0
854	Anton	515	313	454	40	1186	5057
807	Botevgrad	0	0	0	0	0	0
811	Gotse Delchev	3283	1972	2659	226	10481	30321
851	Tran	1261	664	1121	183	4950	16190
803	Blagoevgrad	1754	1006	22253	3457	13079	32457
806	Bozhurishte	0	0	0	0	0	0
804	Bobov dol	268	179	1002	289	3979	21674
606	Bratsigovo	1034	549	845	11	4859	23193
603	Batak	1269	874	17	0	632	128
801	Bansko	1286	810	1879	45	6809	21562
608	Velingrad	6095	3678	106	15	6946	16022
827	Kocherinovo	939	568	1774	241	5662	21560
805	Boboshevo	333	151	755	67	3425	16533
902	Ardino	4934	3635	123	11	5948	20258
822	Kovachevtsi	611	345	596	85	1416	14572
848	Dupnitsa	974	662	1885	277	7065	39849
820	Ihtiman	1917	1160	1286	81	5282	28300
825	Kostenets	542	287	1141	39	5505	22756
629	Septemvri	1278	663	3398	91	10309	96492
604	Belovo	364	208	911	63	5794	17710
839	Samokov	3815	2606	3270	307	11257	46079
859	Dolna banya	169	104	203	9	2253	6188
808	Breznik	1392	798	2043	302	6838	30996
832	Pernik	2628	1659	3279	248	11167	54892
833	Petrich	1377	807	7915	925	30821	71192
849	Strumyani	438	222	1707	66	10218	16024
850	Treklyano	416	265	468	249	1372	5005
829	Kyustendil	2411	1576	5892	1318	8967	91011
831	Nevestino	824	543	2196	576	4906	26113
844	Simitli	1436	824	3551	491	11534	26906
828	Kresna	608	340	1205	80	6085	11391
914	Kirkovo	12302	6607	29	0	10329	64083
915	Krumovgrad	10025	4974	119	0	20577	44454
840	Sandanski	2682	1495	4266	318	23774	55742
852	Hadzhidimovo	2562	1445	958	54	8819	27266
842	Satovcha	4871	2674	13	0	8688	6396
610	Dospat	2681	1660	0	0	2149	576

Table E.5.2 Livestock Input Data for the LOAD CALCULATOR

(2/2)

MUNICIP Code no.	NAME Municipals	Bovine Buffalos	Dairy cows	Slaughter pigs	Breeding sows	sheep + goat	Tot. poultry
605	Borino	1647	878	109	17	1661	1939
609	Devin	2849	1745	314	44	6875	5269
611	Zlatograd	1877	1437	64	10	1295	3184
616	Madan	2197	1750	0	0	564	10255
802	Belitsa	2528	1490	91	0	6714	14780
602	Banite	2105	1623	71	0	3306	8319
631	Smolyan	6405	3979	868	106	9527	273339
627	Rudozem	1918	1449	86	0	1202	2038
819	Zemen	742	394	700	91	3253	12754
856	Mirkovo	834	478	480	18	3294	11646
847	Zlatitsa	1056	754	724	112	2361	19899
936	Chirpan	4653	2539	6578	707	7418	1817153
225	Tundzha	9477	4947	23433	1664	42877	284478
224	Tvarditsa	3094	1634	3736	253	8883	41953
933	Harmanli	3621	1482	3467	263	17429	93585
930	Stambolovo	3116	1629	667	49	7339	62679
931	Stara Zagora	8674	4563	26040	3338	26172	263598
923	Opan	1376	698	2439	214	5039	47267
216	Nova Zagora	6846	3723	23870	1780	23376	251189
919	Mineralni bani	2814	1677	593	51	4199	32555
927	Radnevo	3278	1712	16608	738	10792	442493
907	Galabovo	1329	718	3038	271	6493	68705
209	Karnobat	3395	1625	28357	2508	34647	87416
912	Kazanlak	4527	2325	3195	271	12576	52380
223	Sungurlare	1929	1100	3322	261	16370	84215
918	Madzharovo	2248	1017	311	14	7125	15583
226	Tundzha	1109	595	13012	1270	2345	27339
929	Simeonovgrad	1735	848	2367	126	5445	35600
934	Haskovo	8749	4838	5505	420	17897	554834
909	Dimitrovgrad	7291	3944	9803	956	10458	151830
220	Sliven	9804	5489	23318	2272	47621	271097
633	Saedinenie	2756	1609	5410	504	10333	122932
622	Maritsa	546	340	1299	142	1268	207381
617	Maritsa	6091	3196	22165	1260	14292	326307
615	Laki	637	418	33	0	629	1326
612	Kaloyanovo	4432	2271	20819	1502	11110	132705
626	Maritsa	3660	2023	3267	350	10954	212782
626	Maritsa	596	315	612	78	1438	9784
625	Rakovski	5564	3076	6485	439	9208	144508
628	Sadovo	2319	1328	2288	267	3933	82834
607	Brezovo	3627	1712	1920	0	7247	70782
637	Hisarya	3667	1932	3767	463	12637	64177
924	Pavel banya	2972	1676	1121	44	8896	31828
222	Straldzha	3359	1670	8487	804	21588	110113
938	Nikolaevo	358	235	664	51	1778	9498
937	Gurkovo	867	426	1374	234	3223	11726
922	Maglizh	1794	901	1533	171	6734	27657
641	Stamboliyski	539	354	977	67	2915	27831
639	Krichim	264	176	120	0	996	4940
640	Perushtitsa	25	12	139	55	595	18356
917	Lyubimets	1163	513	2362	134	7214	57255
932	Topolovgrad	2525	1234	3223	245	19812	88987
203	Bolyarovo	1603	642	2052	107	14274	47553
911	Ivaylovgrad	2564	1302	1663	134	13493	30572
928	Svilengrad	1982	981	5335	488	16928	87254
207	Elhovo	3312	1661	4425	374	19279	73499
904	Bratya Daskalovi	3477	1785	2647	228	6784	67287
613	Karlovo	7235	4166	4121	200	28235	98794
601	Asenovgrad	8078	4826	3049	426	10042	54515
623	Parvomay	8796	5085	4863	529	9549	101519

Table E.5.3 MIKE 11 WQ Model Constants for Struma River Basin

Struma, Final calibration - Constants, Global	Unit	Value
Temperature: Latitude	Degrees	42
Temperature: Maximum absorbed solar radiation	per day	4992
Temperature: Displacement of solar radiation max. from 12 pm	hours	1
Temperature: Emitted heat radiation	per day	1608
Oxygen Processes: No. of reaeration expression	dimensionless	3
Oxygen Processes: Reaeration temperature coefficient	dimensionless	1.02
Oxygen Processes: Respiration of animals and plants	per day	3
Oxygen Processes: Respiration temperature coefficient	dimensionless	1.05
Oxygen Processes: Max. oxygen production by photosynthesis	per day	3.5
Oxygen Processes: Production/respiration per m2 (=1) or per m3 (=2)		2
Degradation: 1. order BOD decay rate at 20 deg. C	per day	0.4
Degradation: Temperature coefficient for decay rate	dimensionless	1.02
Degradation: Half-saturation oxygen concentration	mg/l	2
Oxygen Processes: Own #1 Reaeration constant	per day	1
Oxygen Processes: Own #1 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #1 Exponent, water depth	dimensionless	0
Oxygen Processes: Own #1 Exponent, river slope	dimensionless	0
Oxygen Processes: Own #2 Reaeration constant	per day	1
Oxygen Processes: Own #2 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #2 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #2 Exponent, river slope	dimensionless	0
Oxygen Processes: Own #3 Reaeration constant	per day	1
Oxygen Processes: Own #3 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #3 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #3 Exponent, river slope	dimensionless	0
Sediment processes: Sediment oxygen demand	g/m2/day	0.5
Sediment processes: Temperature coefficient SOD	Dimensionless	1
Sediment processes: Resuspension of organic matter	g/m2/day	0.5
Sediment processes: sedimentation rate for organic matter	m/day	0.2
Sediment processes: Critical flow velocity	m/s	1
Nitrogen Content: Ratio of ammonia released at BOD decay	gNH4/gBOD	0.08
Nitrogen Content: Uptake of ammonia in plants	Dimensionless	0.066
Nitrogen Content: Uptake of ammonia in bacteria	Dimensionless	0.109
Nitrification: Reaction order 1 = first order process, 2 = half order process	Dimensionless	1
Nitrification: Ammonia decay rate at 20 deg Celcius	per day	1.54
Nitrification: Temperature coefficient for nitrification	dimensionless	1.13
Denitrification: Oxygen demand by nitrification	gO2/gHN4	4.47
Denitrification: Half saturation constant	mg/l	0.05
Denitrification: Reaction order 1 = 1st. order process, 2 = ½ order process	Dimensionless	1
Denitrification: Denitrification rate, conversion of nitrate into free N2	1/day	1
Denitrification: Temperature coefficient for denitrification	Dimensionless	1.16
Coliforms: Arrhenius temperature coefficient	Dimensionless	1.09
Coliforms: Salinity coefficient of decay rate	Dimensionless	1.01
Coliforms: Light coefficient of decay rate	Dimensionless	7.4
Coliforms: Light Extinction Coefficient	1/m	1.4
Phosphorus content: Ratio of phosphorus released at BOD decay	gP/gBOD	0.009
Phosphorus content: Uptake of P in plants	Dimensionless	0.009
Phosphorus exchange with bed: Resuspension of particulate phosphorus	g/m2/day	0.5
Phosphorus exchange with bed: Deposition of particulate phosphorus	m/day	0.8
Phosphorus exchange with bed: Critical velocity of flow	m/s	1
Phosphorus processes: Decay constant for particulate phosphorus	per day	0.1
Phosphorus processes: Temperature coefficient for decay	Dimensionless	1
Phosphorus processes: Formation constant for particulate phosphorus	per day	0.1
Phosphorus processes: Temperature coefficient for formation	Dimensionless	1

Struma, Final calibration - Constants, Local	Value	Branch	Chainage
Sediment processes: sedimentation rate for organic matter	0.2	ST_M	200848
Sediment processes: sedimentation rate for organic matter	2.5	ST_M	199780
Sediment processes: sedimentation rate for organic matter	2.5	ST_M	192681
Sediment processes: sedimentation rate for organic matter	0.2	ST_M	191228

Table E.5.4 MIKE 11 WQ Model Constants for Mesta River Basin

Mesta, Final calibration - Constants, Global	Unit	Value
Temperature: Latitude	Degrees	42
Temperature: Maximum absorbed solar radiation	per day	4992
Temperature: Displacement of solar radiation max. from 12 pm	hours	1
Temperature: Emitted heat radiation	per day	1608
Oxygen Processes: No. of reaeration expression	dimensionless	3
Oxygen Processes: Reaeration temperature coefficient	dimensionless	1.02
Oxygen Processes: Respiration of animals and plants	per day	3
Oxygen Processes: Respiration temperature coefficient	dimensionless	1.05
Oxygen Processes: Max. oxygen production by photosynthesis	per day	3.5
Oxygen Processes: Production/respiration per m2 (=1) or per m3 (=2)		2
Degradation: 1. order BOD decay rate at 20 deg. C	per day	0.3
Degradation: Temperature coefficient for decay rate	dimensionless	1.02
Degradation: Half-saturation oxygen concentration	mg/l	2
Oxygen Processes: Own #1 Reaeration constant	per day	1
Oxygen Processes: Own #1 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #1 Exponent, water depth	dimensionless	0
Oxygen Processes: Own #1 Exponent, river slope	dimensionless	0
Oxygen Processes: Own #2 Reaeration constant	per day	1
Oxygen Processes: Own #2 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #2 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #2 Exponent, river slope	dimensionless	0
Oxygen Processes: Own #3 Reaeration constant	per day	1
Oxygen Processes: Own #3 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #3 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #3 Exponent, river slope	dimensionless	0
Sediment processes: Sediment oxygen demand	g/m2/day	0.5
Sediment processes: Temperature coefficient SOD	Dimensionless	1
Sediment processes: Resuspension of organic matter	g/m2/day	0.5
Sediment processes: sedimentation rate for organic matter	m/day	0.1
Sediment processes: Critical flow velocity	m/s	1
Nitrogen Content: Ratio of ammonia released at BOD decay	gNH4/gBOD	0.08
Nitrogen Content: Uptake of ammonia in plants	Dimensionless	0.066
Nitrogen Content: Uptake of ammonia in bacteria	Dimensionless	0.109
Nitrification: Reaction order 1 = first order process 2 = half order pro	Dimensionless	1
Nitrification: Ammonia decay rate at 20 deg Celcius	per day	1.54
Nitrification: Temperature coefficient for nitrification	dimensionless	1.13
Denitrification: Oxygen demand by nitrification	gO2/gHN4	4.47
Denitrification: Half saturation constant	mg/l	0.05
Denitrification: Reaction order 1 = 1st. order process 2 = ½ order pro	Dimensionless	1
Denitrification: Denitrification rate, conversion of nitrate into free N_2	1/day	1
Denitrification: Temperature coefficient for denitrification	Dimensionless	1.16
Coliforms: Arrhenius temperature coefficient	Dimensionless	1.09
Coliforms: Salinity coefficient of decay rate	Dimensionless	1.01
Coliforms: Light coefficient of decay rate	Dimensionless	7.4
Coliforms: Light Extinction Coefficient	1/m	1.4
Phosphorus content: Ratio of phosphorus released at BOD decay	gP/gBOD	0.009
Phosphorus content: Uptake of P in plants	Dimensionless	0.009
Phosphorus exchange with bed: Resuspension of particulate phosph	g/m2/day	0.5
Phosphorus exchange with bed: Deposition of particulate phosphoru	m/day	0.8
Phosphorus exchange with bed: Critical velocity of flow	m/s	1
Phosphorus processes: Decay constant for particulate phosphorus	per day	0.1
Phosphorus processes: Temperature coefficient for decay	Dimensionless	1
Phosphorus processes: Formation constant for particulate phosphor	per day	0.1
Phosphorus processes: Temperature coefficient for formation	Dimensionless	1

Table E.5.5 MIKE 11 WQ Model Constants for Arda River Basin

Arda Final calibration - Constants, Global	Unit	Values
Temperature: Latitude	Degrees	42
Temperature: Maximum absorbed solar radiation	per day	4992
Temperature: Displacement of solar radiation max. from 12 pm	hours	1
Temperature: Emitted heat radiation	per day	1608
Oxygen Processes: No. of reaeration expression	dimensionless	2
Oxygen Processes: Reaeration temperature coefficient	dimensionless	1.02
Oxygen Processes: Respiration of animals and plants	per day	1.8
Oxygen Processes: Respiration temperature coefficient	dimensionless	1.05
Oxygen Processes: Max. oxygen production by photosynthesis	per day	3.5
Oxygen Processes: Production/respiration per m2 (=1) or per m3 (=2)		2
Degradation: 1. order BOD decay rate at 20 deg. C	per day	0.3
Degradation: Temperature coefficient for decay rate	dimensionless	1.02
Degradation: Half-saturation oxygen concentration	mg/l	2
Oxygen Processes: Own #1 Reaeration constant	per day	1
Oxygen Processes: Own #1 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #1 Exponent, water depth	dimensionless	0
Oxygen Processes: Own #1 Exponent, river slope	dimensionless	0
Oxygen Processes: Own #2 Reaeration constant	per day	1
Oxygen Processes: Own #2 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #2 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #2 Exponent, river slope	dimensionless	0
Oxygen Processes: Own #3 Reaeration constant	per day	1
Oxygen Processes: Own #3 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #3 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #3 Exponent, river slope	dimensionless	0
Sediment processes: Sediment oxygen demand	g/m2/day	0.5
Sediment processes: Temperature coefficient SOD	Dimensionless	1
Sediment processes: Resuspension of organic matter	g/m2/day	0.9
Sediment processes: sedimentation rate for organic matter	m/day	0.1
Sediment processes: Critical flow velocity	m/s	1
Nitrogen Content: Ratio of ammonia released at BOD decay	gNH4/gBOD	0.29
Nitrogen Content: Uptake of ammonia in plants	Dimensionless	0.066
Nitrogen Content: Uptake of ammonia in bacteria	Dimensionless	0.109
Nitrification: Reaction order 1 = first order process 2 = half order process	Dimensionless	1
Nitrification: Ammonia decay rate at 20 deg Celcius	per day	0.3
Nitrification: Temperature coefficient for nitrification	dimensionless	1.13
Denitrification: Oxygen demand by nitrification	gO2/gHN4	4.47
Denitrification: Half saturation constant	mg/l	0.05
Denitrification: Reaction order 1 = 1st order process 2 = ½ order process	Dimensionless	1
Denitrification: Denitrification rate, conversion of NO3 into free nitrogen N2	1/day	0.8
Denitrification: Temperature coefficient for denitrification	Dimensionless	1.16
Coliforms: Arrhenius temperature coefficient	Dimensionless	1.09
Coliforms: Salinity coefficient of decay rate	Dimensionless	1.01
Coliforms: Light coefficient of decay rate	Dimensionless	7.4
Coliforms: Light Extinction Coefficient	1/m	1.4
Phosphorus content: Ratio of phosphorus released at BOD decay	gP/gBOD	0.009
Phosphorus content: Uptake of P in plants	Dimensionless	0.009
Phosphorus exchange with bed: Resuspension of particulate phosphorus	g/m2/day	0.5
Phosphorus exchange with bed: Deposition of particulate phosphorus	m/day	0.5
Phosphorus exchange with bed: Critical velocity of flow	m/s	1
Phosphorus processes: Decay constant for particulate phosphorus	per day	0.08
Phosphorus processes: Temperature coefficient for decay	Dimensionless	1
Phosphorus processes: Formation constant for particulate phosphorus	per day	0.05
Phosphorus processes: Temperature coefficient for formation	Dimensionless	1

Arda Final Calibration - Constants, Local	Value	River name	Chainage
Degradation: 1. order BOD decay rate at 20 deg. C	0.8	AR_KRU	0
Degradation: 1. order BOD decay rate at 20 deg. C	0.8	AR_KRU	26630
Degradation: 1. order BOD decay rate at 20 deg. C	0.8	AR_VAR	2900
Degradation: 1. order BOD decay rate at 20 deg. C	0.8	AR_VAR	66000
Degradation: 1. order BOD decay rate at 20 deg. C	0.8	AR_CHE	0
Degradation: 1. order BOD decay rate at 20 deg. C	0.8	AR_CHE	18700
Oxygen Processes: Max. oxygen production by photosynthesis	4.5	AR_M	125573
Oxygen Processes: Max. oxygen production by photosynthesis	4.5	AR_M	103161
Oxygen Processes: Max. oxygen production by photosynthesis	4	AR_M	97672
Oxygen Processes: Max. oxygen production by photosynthesis	4	AR_M	71958

Table E.5.6 MIKE 11 WQ Model Constants for Tundzha River Basin

(1/2)

Tundzha Final calibration - Constants, Global	Unit	Value
Temperature: Latitude	Degrees	42
Temperature: Maximum absorbed solar radiation	per day	4992
Temperature: Displacement of solar radiation max. from 12 pm	hours	1
Temperature: Emitted heat radiation	per day	1608
Oxygen Processes: No. of reaeration expression	dimensionless	3
Oxygen Processes: Reaeration temperature coefficient	dimensionless	1.02
Oxygen Processes: Respiration of animals and plants	per day	1.8
Oxygen Processes: Respiration temperature coefficient	dimensionless	1.05
Oxygen Processes: Max. oxygen production by photosynthesis	per day	3.5
Oxygen Processes: Production/respiration per m2 (=1) or per m3 (=2)		2
Degradation: 1. order BOD decay rate at 20 deg. C	per day	0.3
Degradation: Temperature coefficient for decay rate	dimensionless	1.02
Degradation: Half-saturation oxygen concentration	mg/l	2
Oxygen Processes: Own #1 Reaeration constant	per day	1
Oxygen Processes: Own #1 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #1 Exponent, water depth	dimensionless	0
Oxygen Processes: Own #1 Exponent, river slope	dimensionless	0
Oxygen Processes: Own #2 Reaeration constant	per day	1
Oxygen Processes: Own #2 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #2 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #2 Exponent, river slope	dimensionless	0
Oxygen Processes: Own #3 Reaeration constant	per day	1
Oxygen Processes: Own #3 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #3 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #3 Exponent, river slope	dimensionless	0
Sediment processes: Sediment oxygen demand	g/m2/day	0.5
Sediment processes: Temperature coefficient SOD	Dimensionless	1
Sediment processes: Resuspension of organic matter	g/m2/day	0.5
Sediment processes: sedimentation rate for organic matter	m/day	0.1
Sediment processes: Critical flow velocity	m/s	1
Nitrogen Content: Ratio of ammonia released at BOD decay	gNH4/gBOD	0.15
Nitrogen Content: Uptake of ammonia in plants	Dimensionless	0.066
Nitrogen Content: Uptake of ammonia in bacteria	Dimensionless	0.109
Nitrification: Reaction order 1 = first order process 2 = half order process	Dimensionless	1
Nitrification: Ammonia decay rate at 20 deg Celcius	per day	1.54
Nitrification: Temperature coefficient for nitrification	dimensionless	1.13
Denitrification: Oxygen demand by nitrification	gO2/gHN4	4.47
Denitrification: Half saturation constant	mg/l	0.05
Denitrification: Reaction order 1 = 1st order process 2 = ½ order process	Dimensionless	1
Denitrification: Denitrification rate, conversion of NO3 into free nitrogen N2	1/day	1
Denitrification: Temperature coefficient for denitrification	Dimensionless	1.16
Coliforms: Arrhenius temperature coefficient	Dimensionless	1.09
Coliforms: Salinity coefficient of decay rate	Dimensionless	1.01
Coliforms: Light coefficient of decay rate	Dimensionless	7.4
Coliforms: Light Extinction Coefficient	1/m	1.4
Phosphorus content: Ratio of phosphorus released at BOD decay	gP/gBOD	0.009
Phosphorus content: Uptake of P in plants	Dimensionless	0.009
Phosphorus exchange with bed: Resuspension of particulate phosphorus	g/m2/day	0.5
Phosphorus exchange with bed: Deposition of particulate phosphorus	m/day	0.8
Phosphorus exchange with bed: Critical velocity of flow	m/s	1
Phosphorus processes: Decay constant for particulate phosphorus	per day	0.1
Phosphorus processes: Temperature coefficient for decay	Dimensionless	1
Phosphorus processes: Formation constant for particulate phosphorus	per day	0.1
Phosphorus processes: Temperature coefficient for formation	Dimensionless	1

Table E.5.6 MIKE 11 WQ Model Constants for Tundzha River Basin

(2/2)

Tundzha Final calibration - Constants, Local	Value	Branch	Chainage
Sediment processes: Sediment oxygen demand	0.7	TU_M	0
Sediment processes: Sediment oxygen demand	0.7	TU_M	110535.8
Nitrification: Ammonia decay rate at 20 deg Celcius	1.7	TU_M	0
Nitrification: Ammonia decay rate at 20 deg Celcius	1.7	TU_M	110535.8
Oxygen Processes: Respiration of animals and plants	2.4	TU_M	0
Oxygen Processes: Respiration of animals and plants	2.4	TU_M	110535.8
Degradation: 1. order BOD decay rate at 20 deg. C	0.7	TU_MOC	0
Degradation: 1. order BOD decay rate at 20 deg. C	0.7	TU_MOC	46835.17
Oxygen Processes: No. of reaeration expression	4	TU_MOC	0
Oxygen Processes: No. of reaeration expression	4	TU_MOC	46835.17
Oxygen Processes: Own #1 Reaeration constant	8000	TU_MOC	0
Oxygen Processes: Own #1 Reaeration constant	8000	TU_MOC	46835.17
Oxygen Processes: Own #1 Exponent, flow velocity	0.931	TU_MOC	0
Oxygen Processes: Own #1 Exponent, flow velocity	0.931	TU_MOC	46835.17
Oxygen Processes: Own #1 Exponent, water depth	-0.692	TU_MOC	0
Oxygen Processes: Own #1 Exponent, water depth	-0.692	TU_MOC	46835.17
Oxygen Processes: Own #1 Exponent, river slope	1.09	TU_MOC	0
Oxygen Processes: Own #1 Exponent, river slope	1.09	TU_MOC	46835.17
Oxygen Processes: Own #1 Reaeration constant	8000	TU_M	0
Oxygen Processes: Own #1 Reaeration constant	8000	TU_M	110535.8
Oxygen Processes: Own #1 Exponent, flow velocity	0.931	TU_M	0
Oxygen Processes: Own #1 Exponent, flow velocity	0.931	TU_M	110535.8
Oxygen Processes: Own #1 Exponent, water depth	-0.692	TU_M	0
Oxygen Processes: Own #1 Exponent, water depth	-0.692	TU_M	110535.8
Oxygen Processes: Own #1 Exponent, river slope	1.09	TU_M	0
Oxygen Processes: Own #1 Exponent, river slope	1.09	TU_M	110535.8
Oxygen Processes: No. of reaeration expression	4	TU_M	0
Oxygen Processes: No. of reaeration expression	4	TU_M	110535.8
Phosphorus processes: Formation constant for particulate P	0.8	TU_M	206787
Phosphorus processes: Formation constant for particulate P	0.8	TU_M	191511

Table E.5.7 MIKE 11 WQ Model Constants for Maritsa River Basin

Maritsa Final calibration - Constants, Global	**Unit**	**Value**
Temperature: Latitude	Degrees	42
Temperature: Maximum absorbed solar radiation	per day	4992
Temperature: Displacement of solar radiation max. from 12 pm	hours	1
Temperature: Emitted heat radiation	per day	1608
Oxygen Processes: No. of reaeration expression	dimensionless	3
Oxygen Processes: Reaeration temperature coefficient	dimensionless	1.02
Oxygen Processes: Respiration of animals and plants	per day	3
Oxygen Processes: Respiration temperature coefficient	dimensionless	1.05
Oxygen Processes: Max. oxygen production by photosynthesis	per day	3.5
Oxygen Processes: Production/respiration per m2 (=1) or per m3 (=2)		2
Degradation: 1. order BOD decay rate at 20 deg. C	per day	0.3
Degradation: Temperature coefficient for decay rate	dimensionless	1.02
Degradation: Half-saturation oxygen concentration	mg/l	2
Oxygen Processes: Own #1 Reaeration constant	per day	1
Oxygen Processes: Own #1 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #1 Exponent, water depth	dimensionless	0
Oxygen Processes: Own #1 Exponent, river slope	dimensionless	0
Oxygen Processes: Own #2 Reaeration constant	per day	1
Oxygen Processes: Own #2 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #2 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #2 Exponent, river slope	dimensionless	0
Oxygen Processes: Own #3 Reaeration constant	per day	1
Oxygen Processes: Own #3 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #3 Exponent, flow velocity	dimensionless	0
Oxygen Processes: Own #3 Exponent, river slope	dimensionless	0
Sediment processes: Sediment oxygen demand	g/m2/day	0.5
Sediment processes: Temperature coefficient SOD	Dimensionless	1
Sediment processes: Resuspension of organic matter	g/m2/day	0.5
Sediment processes: sedimentation rate for organic matter	m/day	0.2
Sediment processes: Critical flow velocity	m/s	1
Nitrogen Content: Ratio of ammonia released at BOD decay	gNH4/gBOD	0.08
Nitrogen Content: Uptake of ammonia in plants	Dimensionless	0.066
Nitrogen Content: Uptake of ammonia in bacteria	Dimensionless	0.109
Nitrification: Reaction order 1 = first order process 2 = half order process	Dimensionless	1
Nitrification: Ammonia decay rate at 20 deg Celcius	per day	1.54
Nitrification: Temperature coefficient for nitrification	dimensionless	1.13
Denitrification: Oxygen demand by nitrification	gO2/gHN4	4.47
Denitrification: Half saturation constant	mg/l	0.05
Denitrification: Reaction order 1 = 1st order process 2 = ½ order process	Dimensionless	1
Denitrification: Denitrification rate, conversion of NO3 into free nitrogen N2	1/day	1
Denitrification: Temperature coefficient for denitrification	Dimensionless	1.16
Coliforms: Arrhenius temperature coefficient	Dimensionless	1.09
Coliforms: Salinity coefficient of decay rate	Dimensionless	1.01
Coliforms: Light coefficient of decay rate	Dimensionless	7.4
Coliforms: Light Extinction Coefficient	1/m	1.4
Phosphorus content: Ratio of phosphorus released at BOD decay	gP/gBOD	0.009
Phosphorus content: Uptake of P in plants	Dimensionless	0.009
Phosphorus exchange with bed: Resuspension of particulate phosphorus	g/m2/day	0.5
Phosphorus exchange with bed: Deposition of particulate phosphorus	m/day	0.8
Phosphorus exchange with bed: Critical velocity of flow	m/s	1
Phosphorus processes: Decay constant for particulate phosphorus	per day	0.1
Phosphorus processes: Temperature coefficient for decay	Dimensionless	1
Phosphorus processes: Formation constant for particulate phosphorus	per day	0.1
Phosphorus processes: Temperature coefficient for formation	Dimensionless	1

Maritsa Final calibration - Constants, Local	**Unit**	**Branch**	**Chainage**
Sediment processes: sedimentation rate for organic matter	0.2	MA_TOP	57221
Sediment processes: sedimentation rate for organic matter	5	MA_TOP	55545
Sediment processes: sedimentation rate for organic matter	5	MA_TOP	45793
Sediment processes: sedimentation rate for organic matter	0.2	MA_TOP	44227

Calculation Point		Discharge of River		Present Catchment BOD Load			Present Water Quality Condition in the River					Present River BOD Load				Assumed R. BOD with normal loss		
Point Name	Accumulat. Upstream Catchment Area (km2)	Annual Average (upstream side) (m3/s)	Average of July to Sep. (upstream side): Q0 (m3/s)	Acc. catchment BOD load (PA) (kg/day)	Inflow BOD load to the river with current loss of SW (PA') (kg/day)	Runoff rate: a=PA'/PA (%)	Representative Pysico-chemical monitoring point	BOD normal maximum (mg/l)	BOD Class	Water quality based on bio-index	Bio-index (BI) water quality class	Applied BOD value in the river (C0) (Note: yellow color=assumed) (mg/l)	River BOD load (PR=C0 x Q0) (kg/day)	a0=PR/PA	a1=PR/PA'	Inflow BOD load with normal loss of SW 10 % (PA'1) (kg/day)	River BOD load (PR1=PA'1 x a1) (kg/day)	BOD in the river (C1= PR1/Q0) (mg/l)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	16	17	18
1. Maritsa River Basin																		
	0			0	0								0			0		
MA1	173	1.38	1.46	64	51	80	St.313	6	III	high	I	6	757	11.88	14.83	61	898	7
MA2	1,032	10.60	7.60	2,098	1,330	63	St.315	9	IV	poor	IV	9	5,907	2.82	4.44	1,906	8,465	13
MA3	5,066	26.74	23.65	25,255	16,485	65	St.336	6	III	poor	IV	6	12,262	0.49	0.74	23,063	17,154	8
MA4	9,969	57.49	44.87	51,237	33,466	65	St.354	10	IV	moderate	III	10	38,763	0.76	1.16	46,794	54,201	14
MA5	13,718	73.25	53.96	63,586	42,286	67	St.363	4	III	poor	IV	4	18,650	0.29	0.44	58,261	25,696	6
MA6	15,322	79.91	57.30	70,160	46,945	67	St.369	6	III	poor	IV	6	29,702	0.42	0.63	64,356	40,719	8
MA7	21,272	108.37	76.72	99,128	61,042	62	St.387	5	III	poor	IV	5	33,143	0.33	0.54	84,024	45,621	7
MAI1	978	4.73	4.46	4,119	2,584	63	St.323	6	III	poor	IV	6	2,312	0.56	0.89	3,735	3,342	9
MAT1	338	3.41	2.73	442	286	65	St.327	3	II	moderate	III	3	706	1.60	2.47	403	995	4
MAT2	947	3.46	3.63	2,177	1,419	65	S.329	6	III	bad	V	6	1,881	0.86	1.33	1,987	2,636	8
MAT3	1,434	9.22	8.15	3,991	3,059	77	St.331	5	III	poor	IV	5	3,519	0.88	1.15	3,758	4,324	6
MAT4	1,775	6.11	8.75	4,260	3,244	76	St.334	6	III	poor	IV	6	4,538	1.07	1.40	4,006	5,605	7
MAU1	674	1.99	1.13	2,142	1,388	65	St.342	10	IV	poor	IV	10	979	0.46	0.71	1,953	1,378	14
MAV1	1,679	16.00	8.66	2,700	1,765	65	St.351	3	II	moderate	III	3	2,245	0.83	1.27	2,466	3,138	4
MAP1	453	0.16	0.11	304	238	78	not avail.	-	-	moderate	III	5	48	0.16	0.20	287	58	6
MAL1	442	9.12	8.56	709	470	66	not avail.	-	-	good	II	3	2,218	3.13	4.72	649	3,063	4
MAL2	1,017	10.30	9.58	5,286	3,345	63	St.358	9	IV	bad	V	9	7,450	1.41	2.23	4,801	10,691	13
MAS1	1,074	9.70	9.32	3,657	2,305	63	St.360	3	II	moderate	III	3	2,415	0.66	1.05	3,319	3,477	4
MAS2	1,491	9.87	8.26	5,264	3,495	66	St.361	3	II	moderate	III	3	2,142	0.41	0.61	4,821	2,955	4
MAZ1	1,143	6.42	6.10	14,937	9,479	63	not avail.	-	-	bad	V	10	5,270	0.35	0.56	13,573	7,546	14
MAZ2	3,366	14.39	13.44	18,109	11,843	65	St.379	10	IV	poor	IV	10	11,612	0.64	0.98	16,542	16,220	14
MAZ3	642	2.93	2.74	1,571	1,225	78	St.375	8	IV	poor	IV	8	1,895	1.21	1.55	1,484	2,297	10
MAH1	963	4.92	2.40	7,837	306	4	St.384	-	-	bad	V	8	1,661	0.21	5.43	372	2,018	10
2. Tundzha River Basin																		
	0			0	0								0			0		
TU1	469	4.33	4.79	448	304	68	St.268	5	III	moderate	III	5	2,070	4.62	6.81	412	2,803	7
TU2	1,092	2.76	3.28	1,997	1,355	68	St.270	4	-	poor	IV	4	1,133	0.57	0.84	1,836	1,536	5
TU3	1,984	8.55	8.10	2,651	1,819	69	St.284	5	III	poor	IV	5	3,498	1.32	1.92	2,443	4,700	7
TU4	2,230	10.37	9.27	2,850	1,960	69	St.286	3	II	poor	IV	3	2,402	0.84	1.23	2,628	3,220	4
TU5	2,904	4.50	3.10	3,462	2,423	70	St.292	5	III	poor	IV	5	1,341	0.39	0.55	3,202	1,772	7
TU6	3,575	6.43	4.44	5,269	3,675	70	St.294	-	-	poor	IV	5	1,920	0.36	0.52	4,871	2,544	7
TU7	6,202	17.67	10.62	11,872	8,173	69	St.304	6	III	poor	IV	6	5,505	0.46	0.67	10,947	7,374	8
TU8	7,891	21.99	12.03	13,417	9,311	69	St.309	6	III	moderate	III	6	6,236	0.46	0.67	12,390	8,298	8
TUM1	1,294	3.11	2.27	2,705	1,880	70	St.298	8	IV	poor	IV	8	1,569	0.58	0.83	2,499	2,086	11
3. Arda River Basin																		
	0			0	0								0			0		
AR1	517	9.33	3.64	1,475	903	61	St.389	6	III	moderate	III	6	1,886	1.28	2.09	1,361	2,841	9
AR2	1,432	21.78	8.02	6,168	3,524	57	St.397	4	III	good	II	4	2,772	0.45	0.79	5,639	4,435	6
AR3	1,907	27.50	9.95	6,674	3,919	59	St.400	4	III	poor	IV	4	3,437	0.52	0.88	6,123	5,370	6
AR4	3,741	45.28	22.65	14,458	8,599	59	St.403	3	II	good	II	3	5,871	0.41	0.68	13,287	9,070	5
AR5	5,130	55.86	27.14	15,948	9,714	61	St.412	3	II	good	II	3	7,036	0.44	0.72	14,701	10,648	5
AR6	5,213	53.95	26.31	16,158	9,819	61	St.412	3	II	good	II	3	6,819	0.42	0.69	14,890	10,341	5
ARC1	270	4.47	1.57	3,719	1,985	53	St.391	10	IV	poor	IV	10	1,358	0.37	0.68	3,372	2,306	17
ARV1	1,190	16.13	2.98	3,260	2,173	67	St.407	3	II	moderate	III	3	774	0.24	0.36	3,043	1,083	4
ARK1	673	9.55	2.62	945	631	67	St.408	0.5	I	good	II	0.5	113	0.12	0.18	883	158	1
4. Byala River Basin																		
BI1	599	4.47	0.47	243	185	76	St.414	3	II	high	I	3	122	0.50	0.66	232	152	4

Table E.6.1 Present Accumulated Catchment BOD Loads and River BOD Loads in EABD

Calculation Point		Discharge of river		Near Future BOD Load		River BOD		Target Water Quality and Load in the			Rate	Required Catchment BOD Load				Future Catch. BOD	
Point Name	Accumulat. Upstream Catchment Area (km2)	Annual Average (upstream side) (m3/s)	Average of July to Sep. (upstream side): Q0 (m3/s)	Acc. catchment BOD load: PB (kg/day)	Acc. inflow BOD load with current loss: PB' (kg/day)	Present BOD (mg/l)	Estimated Near Future BOD with normal loss of Catchment Load (mg/l)	Target BOD class in the river	Target BOD value: C3 (mg/l)	Target River BOD load: PR3 = C3 x Q0 (kg/day)	Present River load (PR) / Catch. load with current loss (PA') = a	Required inflow BOD load with normal loss of SW 10 %: PC' = PR3/a (kg/day)	Required acc. catchment BOD load: PC= PC'/0.9 (kg/day)	Percent PC'/PB (%)	Provisionally required catchment BOD load with current loss: PD = PC'/0.4 (kg/day)	Future accu. Catchment BOD load: PC (kg/day)	Percent PC/PB (%)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Maritsa River Basin																	
	0			0	0					0		0	0		0	0	
MA1	173	1.38	1.46	64	51	6	7	II	3	378	14.83	26	28	45%	43	64	100%
MA2	1,032	10.60	7.60	2,098	1,330	9	13	II	3	1,969	4.44	443	493	23%	739	1,246	59%
MA3	5,066	26.74	23.65	15,918	10,882	6	5	II	3	6,131	0.74	8,242	9,158	58%	13,737	12,421	78%
MA4	9,969	57.49	44.87	41,899	27,864	10	11	II	3	11,629	1.16	10,040	11,155	27%	16,733	26,805	64%
MA5	13,718	73.25	53.96	54,248	36,683	4	5	II	3	13,987	0.44	31,714	35,238	65%	52,857	35,024	65%
MA6	15,322	79.91	57.30	57,965	39,627	6	7	II	3	14,851	0.63	23,472	26,080	45%	39,120	38,740	67%
MA7	21,272	108.37	76.72	70,567	46,641	5	5	II	3	19,886	0.54	36,625	40,694	58%	61,042	48,517	69%
MAI1	978	4.73	4.46	4,119	2,584	6	9	II	3	1,156	0.89	1,292	1,436	35%	2,154	2,663	65%
MAT1	338	3.41	2.73	278	188	3	3	II	3	706	2.47	286	318	114%	477	278	100%
MAT2	947	3.46	3.63	2,013	1,320	6	8	II	3	941	1.33	709	788	39%	1,182	2,013	100%
MAT3	1,434	9.22	8.15	3,828	2,961	5	6	II	3	2,112	1.15	1,835	2,039	53%	3,059	3,710	97%
MAT4	1,775	6.11	8.75	4,096	3,145	6	7	II	3	2,269	1.40	1,622	1,802	44%	2,703	3,979	97%
MAU1	674	1.99	1.13	2,142	1,388	10	14	II	3	294	0.71	416	463	22%	694	1,070	50%
MAV1	1,679	16.00	8.66	2,700	1,765	3	4	II	3	2,245	1.27	1,765	1,961	73%	2,941	2,700	100%
MAP1	453	0.16	0.11	304	238	5	6	II	3	29	0.20	143	159	52%	238	304	100%
MAL1	442	9.12	8.56	709	470	3	4	II	3	2,218	4.72	470	522	74%	783	709	100%
MAL2	1,017	10.30	9.58	5,286	3,345	9	13	II	3	2,483	2.23	1,115	1,239	23%	1,859	1,764	33%
MAS1	1,074	9.70	9.32	3,657	2,305	3	4	II	3	2,415	1.05	2,305	2,561	70%	3,842	1,725	47%
MAS2	1,491	9.87	8.26	5,264	3,495	3	4	II	3	2,142	0.61	3,495	3,883	74%	5,824	3,331	63%
MAZ1	1,143	6.42	6.10	3,131	2,396	10	3	II	3	1,581	0.56	2,844	3,160	101%	4,740	3,131	100%
MAZ2	3,366	14.39	13.44	6,303	4,759	10	5	II	3	3,484	0.98	3,553	3,948	63%	5,921	6,047	96%
MAZ3	642	2.93	2.74	1,571	1,225	8	10	II	3	711	1.55	459	510	32%	766	1,315	84%
MAH1	963	4.92	2.40	3,278	306	8	10	II	3	623	5.43	115	127	4%	191	2,094	64%
2. Tundzha River Basin																	
	0			0	0					0		0	0		0	0	
TU1	469	4.33	4.79	448	304	5	7	II	3	1,242	6.81	182	203	45%	304	293	65%
TU2	1,092	2.76	3.28	1,997	1,355	4	5	II	3	850	0.84	1,016	1,129	57%	1,694	1,842	92%
TU3	1,984	8.55	8.10	2,651	1,819	5	7	II	3	2,099	1.92	1,091	1,212	46%	1,819	2,496	94%
TU4	2,230	10.37	9.27	2,850	1,960	3	4	II	3	2,402	1.23	1,960	2,177	76%	3,266	2,695	95%
TU5	2,904	4.50	3.10	3,462	2,423	5	7	II	3	804	0.55	1,454	1,615	47%	2,423	3,307	96%
TU6	3,575	6.43	4.44	4,868	3,434	5	6	II	3	1,152	0.52	2,205	2,450	50%	3,675	4,713	97%
TU7	6,202	17.67	10.62	11,471	7,932	6	8	II	3	2,752	0.67	4,086	4,540	40%	6,811	8,089	71%
TU8	7,891	21.99	12.03	13,016	9,070	6	8	II	3	3,118	0.67	4,655	5,173	40%	7,759	9,633	74%
TUM1	1,294	3.11	2.27	2,705	1,880	8	11	II	3	589	0.83	705	783	29%	1,175	1,463	54%
3. Arda River Basin																	
	0			0	0					0		0	0		0	0	
AR1	517	9.33	3.64	812	572	6	5	II	3	943	2.09	452	502	62%	903	812	100%
AR2	1,432	21.78	8.02	2,526	1,703	4	3	II	3	2,079	0.79	2,643	2,937	116%	5,286	2,526	100%
AR3	1,907	27.50	9.95	3,032	2,098	4	3	II	3	2,578	0.88	2,939	3,266	108%	5,879	3,032	100%
AR4	3,741	45.28	22.65	10,342	6,541	3	3	II	3	5,871	0.68	8,599	9,555	92%	17,199	7,196	70%
AR5	5,130	55.86	27.14	11,831	7,655	3	3	II	3	7,036	0.72	9,714	10,793	91%	19,427	8,685	73%
AR6	5,213	53.95	26.31	12,042	7,760	3	3	II	3	6,819	0.69	9,819	10,910	91%	19,637	8,895	74%
ARC1	270	4.47	1.57	740	496	10	3	II	3	407	0.68	596	662	89%	1,191	740	100%
ARV1	1,190	16.13	2.98	2,786	1,936	3	4	II	3	774	0.36	2,173	2,415	87%	4,347	2,786	100%
ARK1	673	9.55	2.62	945	631	1	1	II	3	680	0.18	3,788	4,209	445%	7,577	945	100%
4. Byala River Basin																	
BI1	599	4.47	0.47	243	185	3	4	II	3	122	0.66	185	206	85%	370	243	100%

Table E.6.2 Required Accumulated Catchment BOD Loads and Proposed Future BOD Loads with the High Priority Towns for WWTPs in EABD

Calculation Point		Discharge of river		Near Future BOD Load		River BOD		Target Water Quality and Load in the River			Rate	Required Catchment BOD Load				Future Catch. BOD Load	
Point Name	Accumulat. Upstream Catchment Area (km2)	Annual Average (upstream side) (m3/s)	Average of July to Sep. (upstream side): Q0 (m3/s)	Acc. catchment BOD load: PB (kg/day)	Acc. inflow BOD load with current loss: PB' (kg/day)	Present BOD (mg/l)	Estimated Near Future BOD with normal loss of Catchment Load (mg/l)	Target BOD class in the river	Target BOD value: C3 (mg/l)	Target River BOD load: PR3 = C3 x Q0 (kg/day)	Present River load (PR) / Catch. load with current loss (PA') = a	Required inflow BOD load with normal loss of SW 10 %: PC' = PR3/a (kg/day)	Required acc. catchment BOD load: PC= PC'/0.9 (kg/day)	Percent PC/PB (%)	Provisionally required catchment BOD load with current loss: PD = PC'/0.4 (kg/day)	Future accu. Catchment BOD load: PC (kg/day)	Percent PC/PB (%)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Maritsa River Basin																	
	0			0	0					0		0	0		0	0	
MA1	173	1.38	1.46	64	51	6	7	II	3	378	14.83	26	28	45%	43	64	100%
MA2	1,032	10.60	7.60	2,098	1,330	9	13	II	3	1,969	4.44	443	493	23%	739	944	45%
MA3	5,066	26.74	23.65	15,918	10,882	6	5	II	3	6,131	0.74	8,242	9,158	58%	13,737	9,819	62%
MA4	9,969	57.49	44.87	41,899	27,864	10	11	II	3	11,629	1.16	10,040	11,155	27%	16,733	22,165	53%
MA5	13,718	73.25	53.96	54,248	36,683	4	5	II	3	13,987	0.44	31,714	35,238	65%	52,857	28,991	53%
MA6	15,322	79.91	57.30	57,965	39,627	6	7	II	3	14,851	0.63	23,472	26,080	45%	39,120	32,323	56%
MA7	21,272	108.37	76.72	70,567	46,641	5	5	II	3	19,886	0.54	36,625	40,694	58%	61,042	41,108	58%
MAI1	978	4.73	4.46	4,119	2,584	6	9	II	3	1,156	0.89	1,292	1,436	35%	2,154	1,452	35%
MAT1	338	3.41	2.73	278	188	3	3	II	3	706	2.47	286	318	114%	477	278	100%
MAT2	947	3.46	3.63	2,013	1,320	6	8	II	3	941	1.33	709	788	39%	1,182	1,217	60%
MAT3	1,434	9.22	8.15	3,828	2,961	5	6	II	3	2,112	1.15	1,835	2,039	53%	3,059	2,915	76%
MAT4	1,775	6.11	8.75	4,096	3,145	6	7	II	3	2,269	1.40	1,622	1,802	44%	2,703	3,183	78%
MAU1	674	1.99	1.13	2,142	1,388	10	14	II	3	294	0.71	416	463	22%	694	828	39%
MAV1	1,679	16.00	8.66	2,700	1,765	3	4	II	3	2,245	1.27	1,765	1,961	73%	2,941	1,460	54%
MAP1	453	0.16	0.11	304	238	5	6	II	3	29	0.20	143	159	52%	238	304	100%
MAL1	442	9.12	8.56	709	470	3	4	II	3	2,218	4.72	470	522	74%	783	403	57%
MAL2	1,017	10.30	9.58	5,286	3,345	9	13	II	3	2,483	2.23	1,115	1,239	23%	1,859	1,459	28%
MAS1	1,074	9.70	9.32	3,657	2,305	3	4	II	3	2,415	1.05	2,305	2,561	70%	3,842	1,105	30%
MAS2	1,491	9.87	8.26	5,264	3,495	3	4	II	3	2,142	0.61	3,495	3,883	74%	5,824	1,938	37%
MAZ1	1,143	6.42	6.10	3,131	2,396	10	3	II	3	1,581	0.56	2,844	3,160	101%	4,740	3,131	100%
MAZ2	3,366	14.39	13.44	6,303	4,759	10	5	II	3	3,484	0.98	3,553	3,948	63%	5,921	5,538	88%
MAZ3	642	2.93	2.74	1,571	1,225	8	10	II	3	711	1.55	459	510	32%	766	1,315	84%
MAH1	963	4.92	2.40	3,278	306	8	10	II	3	623	5.43	115	127	4%	191	2,094	64%
2. Tundzha River Basin																	
	0			0	0					0		0	0		0	0	
TU1	469	4.33	4.79	448	304	5	7	II	3	1,242	6.81	182	203	45%	304	293	65%
TU2	1,092	2.76	3.28	1,997	1,355	4	5	II	3	850	0.84	1,016	1,129	57%	1,694	1,803	90%
TU3	1,984	8.55	8.10	2,651	1,819	5	7	II	3	2,099	1.92	1,091	1,212	46%	1,819	2,419	91%
TU4	2,230	10.37	9.27	2,850	1,960	3	4	II	3	2,402	1.23	1,960	2,177	76%	3,266	2,618	92%
TU5	2,904	4.50	3.10	3,462	2,423	5	7	II	3	804	0.55	1,454	1,615	47%	2,423	3,195	92%
TU6	3,575	6.43	4.44	4,868	3,434	5	6	II	3	1,152	0.52	2,205	2,450	50%	3,675	4,583	94%
TU7	6,202	17.67	10.62	11,471	7,932	6	8	II	3	2,752	0.67	4,086	4,540	40%	6,811	7,884	69%
TU8	7,891	21.99	12.03	13,016	9,070	6	8	II	3	3,118	0.67	4,655	5,173	40%	7,759	9,198	71%
TUM1	1,294	3.11	2.27	2,705	1,880	8	11	II	3	589	0.83	705	783	29%	1,175	1,388	51%
3. Arda River Basin																	
	0			0	0					0		0	0		0	0	
AR1	517	9.33	3.64	812	572	6	5	II	3	943	2.09	452	502	62%	903	812	100%
AR2	1,432	21.78	8.02	2,526	1,703	4	3	II	3	2,079	0.79	2,643	2,937	116%	5,286	2,526	100%
AR3	1,907	27.50	9.95	3,032	2,098	4	3	II	3	2,578	0.88	2,939	3,266	108%	5,879	3,032	100%
AR4	3,741	45.28	22.65	10,342	#VALUE!	3	#VALUE!	II	3	5,871	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	6,876	66%
AR5	5,130	55.86	27.14	11,831	#VALUE!	3	#VALUE!	II	3	7,036	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	8,158	69%
AR6	5,213	53.95	26.31	12,042	#VALUE!	3	#VALUE!	II	3	6,819	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	8,368	69%
ARC1	270	4.47	1.57	740	496	10	3	II	3	407	0.68	596	662	89%	1,191	740	100%
ARV1	1,190	16.13	2.98	2,786	#VALUE!	3	#VALUE!	II	3	774	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	2,466	89%
ARK1	673	9.55	2.62	945	631	1	1	II	3	680	0.18	3,788	4,209	445%	7,577	738	78%
4. Byala River Basin																	
BI1	599	4.47	0.47	243	185	3	4	II	3	122	0.66	185	206	85%	370	243	100%

Table E.6.3 Required Accumulated Catchment BOD Loads and Proposed Future BOD Loads with the High and Medium Priority Towns for WWTPs in EABD

Calculation Point		Discharge of River		Present Catchment BOD Load			Present Water Quality Condition in the River					Present River BOD Load				Assumed R. BOD with normal loss		
Point Name	Accumulat. Upstream Catchment Area (km2)	Annual Average (upstream side) (m3/s)	Average of July to Sep. (upstream side): Q0 (m3/s)	Acc. catchment BOD load (PA) (kg/day)	Inflow BOD load to the river with current loss of SW (PA') (kg/day)	Runoff rate: a=PA'/PA (%)	Representative Pysico-chemical monitoring point	BOD normal maximum (mg/l)	BOD Class	Water quality based on bio-index	Bio-index (BI) water quality class	Applied BOD value in the river (C0) (Note: yellow color=assumed) (mg/l)	River BOD load (PR=C0 x Q0) (kg/day)	a0=PR/PA	a1=PR/PA'	Inflow BOD load with normal loss of SW 10 % (PA'1) (kg/day)	River BOD load (PR1=PA'1 x a1) (kg/day)	BOD in the river (C1= PR1/Q0) (mg/l)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	16	17	18
1. Struma River Basin																		
	0			0	0								0					
ST1	102	1.14	0.68	27	24	89	St.433	4	III	not avail.	-	4	234	8.83	9.91	26	258	4
ST2	791	2.05	1.79	3,622	2,365	65	St.437	7	III	poor	IV	7	1,083	0.30	0.46	3,412	1,562	10
ST3	1,394	2.47	2.03	3,953	2,586	65	not avail.	-	-	poor	IV	6	1,052	0.27	0.41	3,725	1,516	9
ST4	2,202	7.55	3.35	4,170	2,733	66	St.444	5	III	poor	IV	5	1,448	0.35	0.53	3,930	2,083	7
ST5	3,649	20.32	8.52	5,972	3,845	64	St.449	6	III	good	II	6	4,417	0.74	1.15	5,618	6,454	9
ST6	5,106	31.58	14.58	9,185	5,977	65	St.455	6	III	not avail.	-	6	7,557	0.82	1.26	8,650	10,938	9
ST7	6,195	40.45	17.81	15,840	8,806	56	St.457	5	III	not avail.	-	5	7,693	0.49	0.87	14,668	12,814	8
ST8	6,390	42.76	18.91	15,868	8,827	56	not avail.	-	-	not avail.	-	4	6,534	0.41	0.74	14,694	10,878	7
ST9	7,216	51.53	21.35	16,790	9,236	55	not avail.	-	-	poor	IV	4	7,379	0.44	0.80	15,531	12,407	7
ST10	8,667	71.35	30.05	26,531	14,620	55	St.464	4	III	not avail.	-	4	10,385	0.39	0.71	24,546	17,436	7
STD1	770	4.28	2.67	2,701	1,818	67	St.453	8	IV	moderate	III	8	1,843	0.68	1.01	2,554	2,589	11
2. Mesta River Basin																		
	0			0	0								0					
ME1	262	2.61	1.89	223	143	64	St.420	2	I	high	I	2	326	1.46	2.29	210	480	3
ME2	550	5.40	3.32	1,061	537	51	St.422	3	II	good	II	3	862	0.81	1.61	974	1,563	5
ME3	1,523	18.11	9.78	4,216	2,025	48	St.431	3	II	good	II	3	2,536	0.60	1.25	3,851	4,821	6
ME4	1,810	20.82	8.57	5,098	2,452	48	not avail.	-	-	good	II	4	2,961	0.58	1.21	4,657	5,624	8
ME5	2,300	24.67	11.11	7,889	3,792	48	St.432	5	III	moderate	III	5	4,800	0.61	1.27	7,206	9,122	10
ME6	2,785	27.69	11.72	8,667	4,220	49	St.432	5	III	not avail.	-	5	5,061	0.58	1.20	7,926	9,506	9
MEI1	449	7.06	4.15	2,584	1,183	46	St.423	-	-	poor	IV	4	1,433	0.55	1.21	2,350	2,847	8
3. Dospat River Basin																		
DO1	237	5.87	2.78	388	209	54	St.417	7	III	poor	IV	7	1,683	4.34	8.07	358	1,833	8
DO2	376	2.41	1.53	779	400	51	St.419	20	V	not avail.	-	20	2,643	3.39	6.60	716	2,643	20

Table E.6.4 Present Accumulated Catchment BOD Loads and River BOD Loads in WABD

Calculation Point		Discharge of river		Near Future BOD Load		River BOD		Target Water Quality and Load in the River			Rate	Required Catchment BOD Load				Future Catch. BOD Load	
Point Name	Accumulat. Upstream Catchment Area (km2)	Annual Average (upstream side) (m3/s)	Average of July to Sep. (upstream side): Q0 (m3/s)	Acc. catchment BOD load (PB) (kg/day)	Acc. inflow BOD load with current loss (PB') (kg/day)	Present BOD (mg/l)	Estimated Near Future BOD with normal loss of Catchment Load (mg/l)	Target BOD class in the river	Target BOD value (C3) (mg/l)	Target River BOD load (PR3 = C3 x Q0) (kg/day)	Present River load (PR) / Catch. load with current loss (PA') = a	Required inflow BOD load with normal loss of SW 10 %(PC' = PR3/a) (kg/day)	Required acc. catchment BOD load (PC= PC'/0.9) (kg/day)	Percent PC'/PB (%)	Provisionally required catchment BOD load with current loss (PD = PC'/0.4) (kg/day)	Future accu. Catchment BOD load: PC (kg/day)	Percent PC/PB (%)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Struma River Basin																	
	0			0	0					0		0	0		0	0	
ST1	102	1.14	0.68	27	24	4	4	II	3	176	9.91	18	20	74%	44	27	100%
ST2	791	2.05	1.79	3,622	2,365	7	10	II	3	464	0.46	1,014	1,126	31%	2,534	3,032	84%
ST3	1,394	2.47	2.03	3,953	2,586	6	9	II	3	526	0.41	1,293	1,437	36%	3,233	3,364	85%
ST4	2,202	7.55	3.35	4,170	2,733	5	7	II	3	869	0.53	1,640	1,822	44%	4,099	3,581	86%
ST5	3,649	20.32	8.52	5,664	3,722	6	8	II	3	2,209	1.15	1,923	2,136	38%	4,807	5,075	90%
ST6	5,106	31.58	14.58	8,877	5,854	6	8	II	3	3,779	1.26	2,988	3,320	37%	7,471	8,052	91%
ST7	6,195	40.45	17.81	10,884	6,823	5	6	II	3	4,616	0.87	5,283	5,870	54%	13,209	9,413	86%
ST8	6,390	42.76	18.91	10,912	6,844	4	5	II	3	4,901	0.74	6,620	7,356	67%	16,550	9,440	87%
ST9	7,216	51.53	21.35	11,834	7,254	4	5	II	3	5,534	0.80	6,927	7,697	65%	17,318	10,363	88%
ST10	8,667	71.35	30.05	21,576	12,638	4	5	II	3	7,789	0.71	10,965	12,183	56%	27,413	15,020	70%
STD1	770	4.28	2.67	2,701	1,818	8	11	II	3	691	1.01	682	758	28%	1,705	2,465	91%
2. Mesta River Basin																	
	0			0	0					0		0	0		0	0	
ME1	262	2.61	1.89	223	143	2	3	II	3	490	2.29	214	238	107%	535	223	100%
ME2	550	5.40	3.32	1,061	537	3	5	II	3	862	1.61	537	596	56%	1,341	1,061	100%
ME3	1,523	18.11	9.78	3,217	1,626	3	4	II	3	2,536	1.25	2,025	2,251	70%	5,064	2,601	81%
ME4	1,810	20.82	8.57	4,099	2,053	4	6	II	3	2,221	1.21	1,839	2,044	50%	4,598	3,483	85%
ME5	2,300	24.67	11.11	6,890	3,392	5	8	II	3	2,880	1.27	2,275	2,528	37%	5,688	4,724	69%
ME6	2,785	27.69	11.72	7,668	3,820	5	8	II	3	3,037	1.20	2,532	2,813	37%	6,329	5,502	72%
MEI1	449	7.06	4.15	1,584	783	4	5	II	3	1,075	1.21	887	986	62%	2,218	968	61%
3. Dospat River Basin																	
DO1	237	5.87	2.78	388	209	7	12	II	3	721	8.07	89	99	26%	223	388	100%
DO2	376	2.41	1.53	779	400	20	36	II	3	396	6.60	60	67	9%	150	605	78%

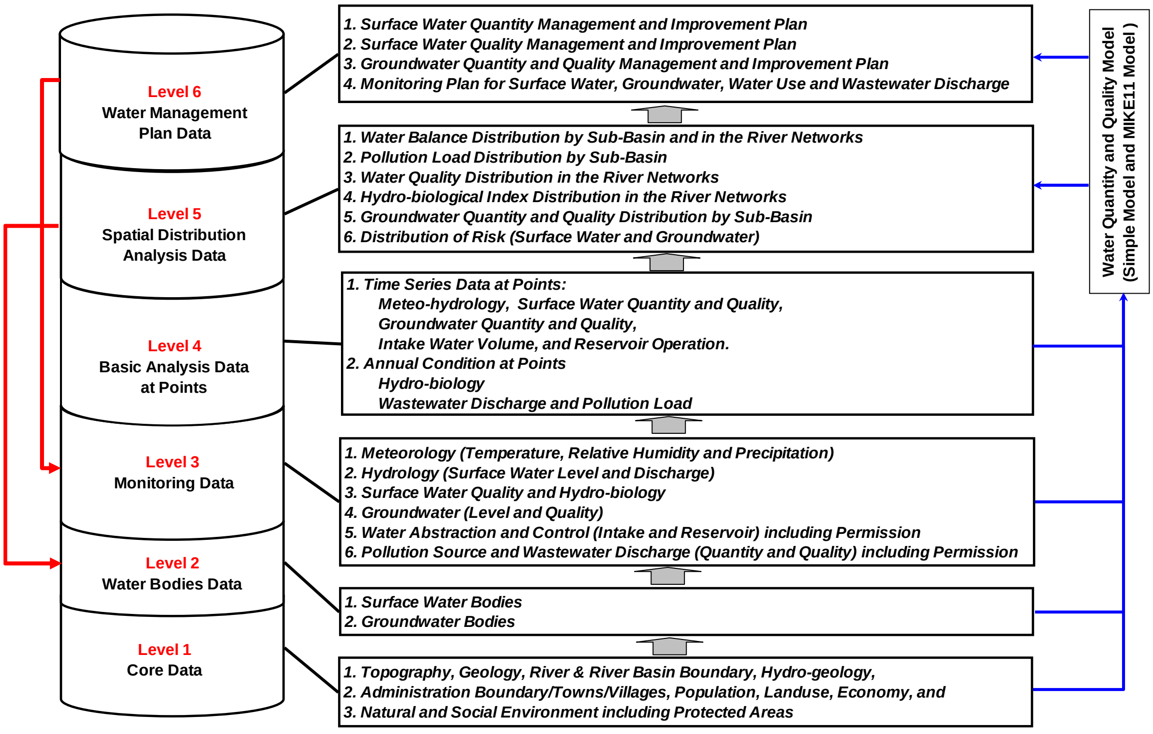
Table E.6.5 Required Accumulated Catchment BOD Loads and Proposed Future BOD Loads with the High Priority Towns for WWTPs in WABD

Calculation Point		Discharge of river		Near Future BOD Load		River BOD		Target Water Quality and Load in the			Rate	Required Catchment BOD Load				Future Catch. BOD	
Point Name	Accumulat. Upstream Catchment Area (km2)	Annual Average (upstream side) (m3/s)	Average of July to Sep. (upstream side): Q0 (m3/s)	Acc. catchment BOD load (PB) (kg/day)	Acc. inflow BOD load with current loss (PB') (kg/day)	Present BOD (mg/l)	Estimated Near Future BOD with normal loss of Catchment Load (mg/l)	Target BOD class in the river	Target BOD value (C3) (mg/l)	Target River BOD load (PR3 = C3 x Q0) (kg/day)	Present River load (PR) / Catch. load with current loss (PA') = a	Required inflow BOD load with normal loss of SW 10 %(PC' = PR3/a) (kg/day)	Required acc. catchment BOD load (PC= PC'/0.9) (kg/day)	Percent PC'/PB (%)	Provisionally required catchment BOD load with current loss (PD = PC'/0.4) (kg/day)	Future accu. Catchment BOD load: PC (kg/day)	Percent PC/PB (%)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Struma River Basin																	
	0			0	0					0		0	0		0	0	
ST1	102	1.14	0.68	27	24	4	4	II	3	176	9.91	18	20	74%	44	27	100%
ST2	791	2.05	1.79	3,622	2,365	7	10	II	3	464	0.46	1,014	1,126	31%	2,534	2,833	78%
ST3	1,394	2.47	2.03	3,953	2,586	6	9	II	3	526	0.41	1,293	1,437	36%	3,233	3,164	80%
ST4	2,202	7.55	3.35	4,170	2,733	5	7	II	3	869	0.53	1,640	1,822	44%	4,099	3,381	81%
ST5	3,649	20.32	8.52	5,664	3,722	6	8	II	3	2,209	1.15	1,923	2,136	38%	4,807	4,875	86%
ST6	5,106	31.58	14.58	8,877	5,854	6	8	II	3	3,779	1.26	2,988	3,320	37%	7,471	7,440	84%
ST7	6,195	40.45	17.81	10,884	6,823	5	6	II	3	4,616	0.87	5,283	5,870	54%	13,209	8,801	81%
ST8	6,390	42.76	18.91	10,912	6,844	4	5	II	3	4,901	0.74	6,620	7,356	67%	16,550	8,829	81%
ST9	7,216	51.53	21.35	11,834	7,254	4	5	II	3	5,534	0.80	6,927	7,697	65%	17,318	9,534	81%
ST10	8,667	71.35	30.05	21,576	12,638	4	5	II	3	7,789	0.71	10,965	12,183	56%	27,413	14,155	66%
STD1	770	4.28	2.67	2,701	1,818	8	11	II	3	691	1.01	682	758	28%	1,705	2,053	76%
2. Mesta River Basin																	
	0			0	0					0		0	0		0	0	
ME1	262	2.61	1.89	223	143	2	3	II	3	490	2.29	214	238	107%	535	223	100%
ME2	550	5.40	3.32	1,061	537	3	5	II	3	862	1.61	537	596	56%	1,341	628	59%
ME3	1,523	18.11	9.78	3,217	1,626	3	4	II	3	2,536	1.25	2,025	2,251	70%	5,064	1,817	56%
ME4	1,810	20.82	8.57	4,099	2,053	4	6	II	3	2,221	1.21	1,839	2,044	50%	4,598	2,503	61%
ME5	2,300	24.67	11.11	6,890	3,392	5	8	II	3	2,880	1.27	2,275	2,528	37%	5,688	3,608	52%
ME6	2,785	27.69	11.72	7,668	3,820	5	8	II	3	3,037	1.20	2,532	2,813	37%	6,329	4,386	57%
MEI1	449	7.06	4.15	1,584	783	4	5	II	3	1,075	1.21	887	986	62%	2,218	786	50%
3. Dospat River Basin																	
DO1	237	5.87	2.78	388	209	7	12	II	3	721	8.07	89	99	26%	223	388	100%
DO2	376	2.41	1.53	779	400	20	36	II	3	396	6.60	60	67	9%	150	605	78%

Table E.6.6 Required Accumulated Catchment BOD Loads and Proposed Future BOD Loads with the High and Medium Priority Towns for WWTPs in WABD

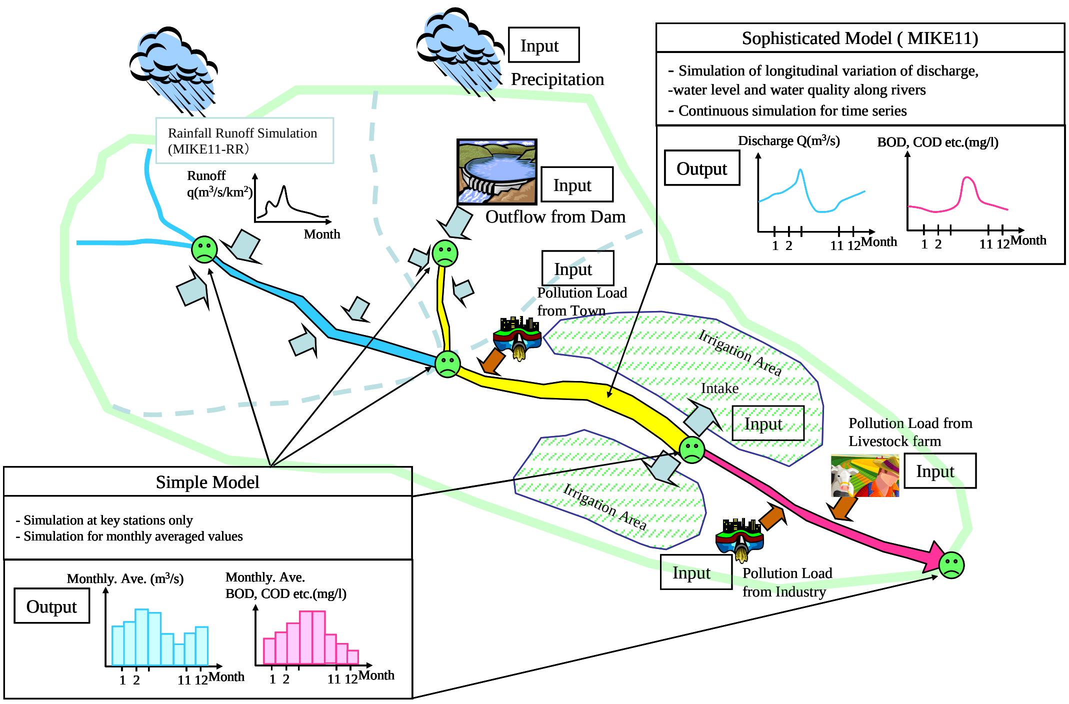
Supporting Report E

Figures



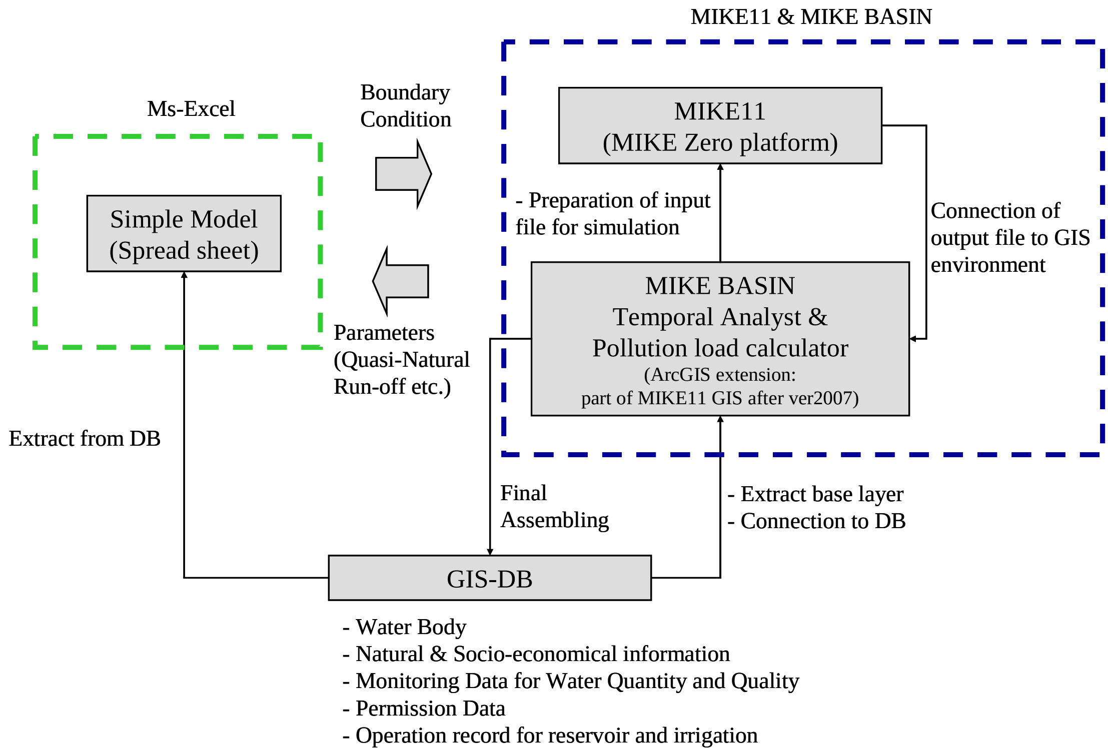
Source: JICA Study Team

Figure E.2.1 Work Contents and Data in the Study



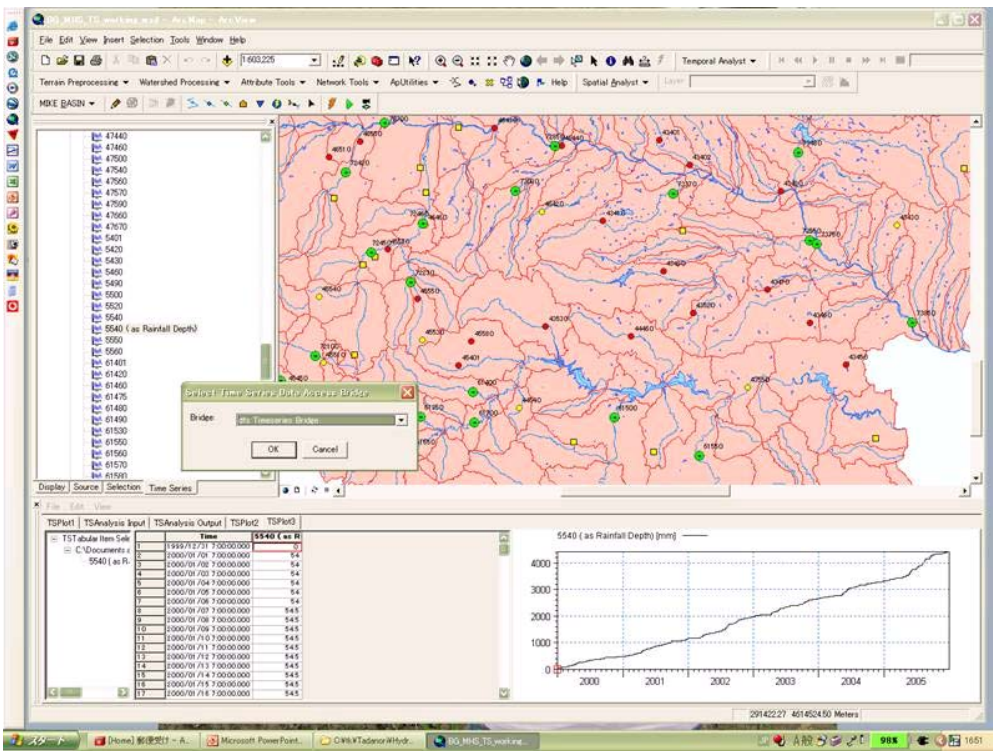
Source: JICA Study Team

Figure E.2.2 Relationship between Simple Model and MIKE11 Model



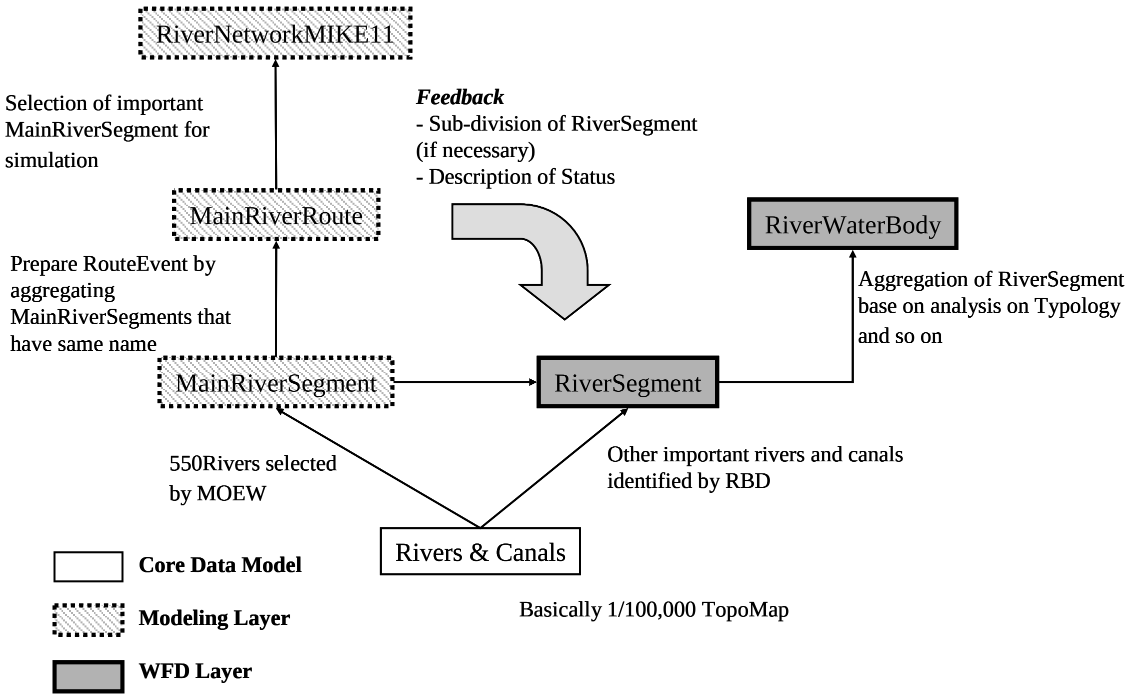
Source: JICA Study Team

Figure E.2.3 Structure of Modeling Environment



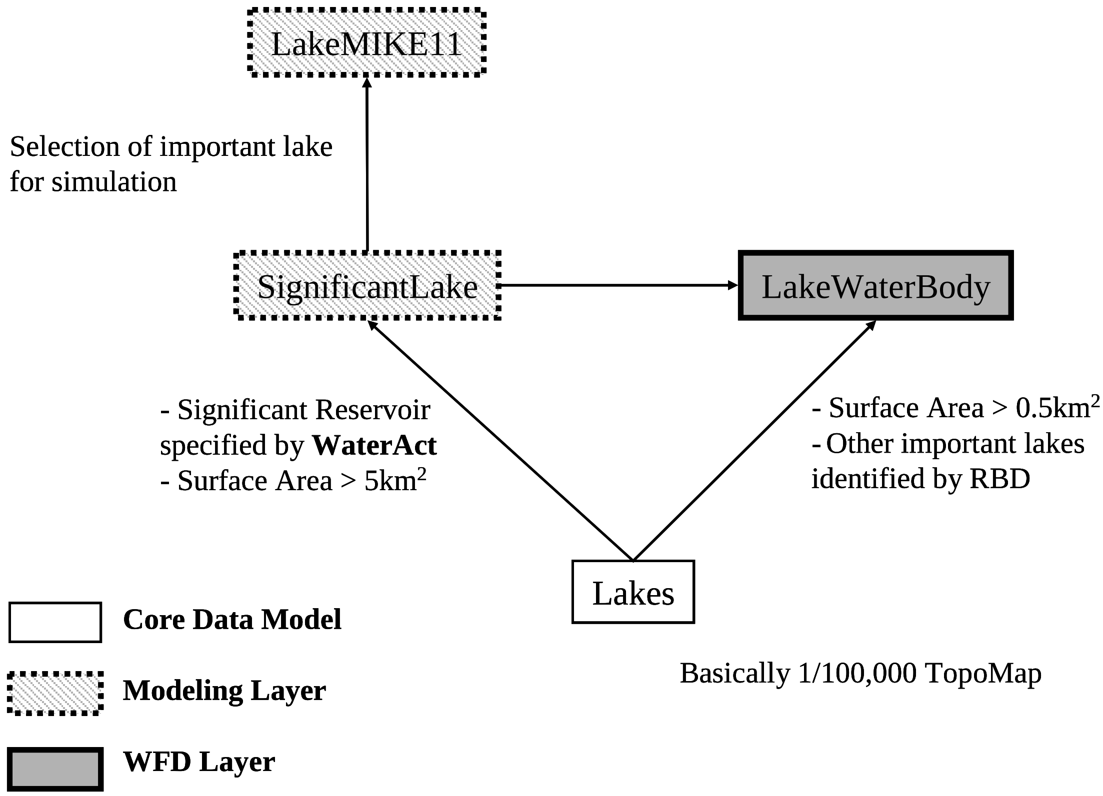
Source:JICA Study Team

Figure E.2.4 Image of Temporal Analyst



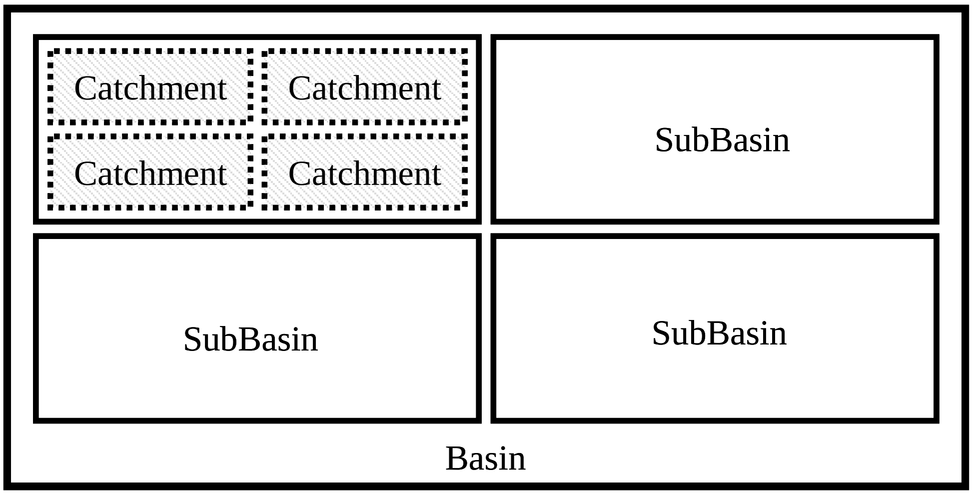
Source: JICA Study Team

Figure E.2.5 Relationship among Core Data Model, Analysis Layer and WFD Layer on River



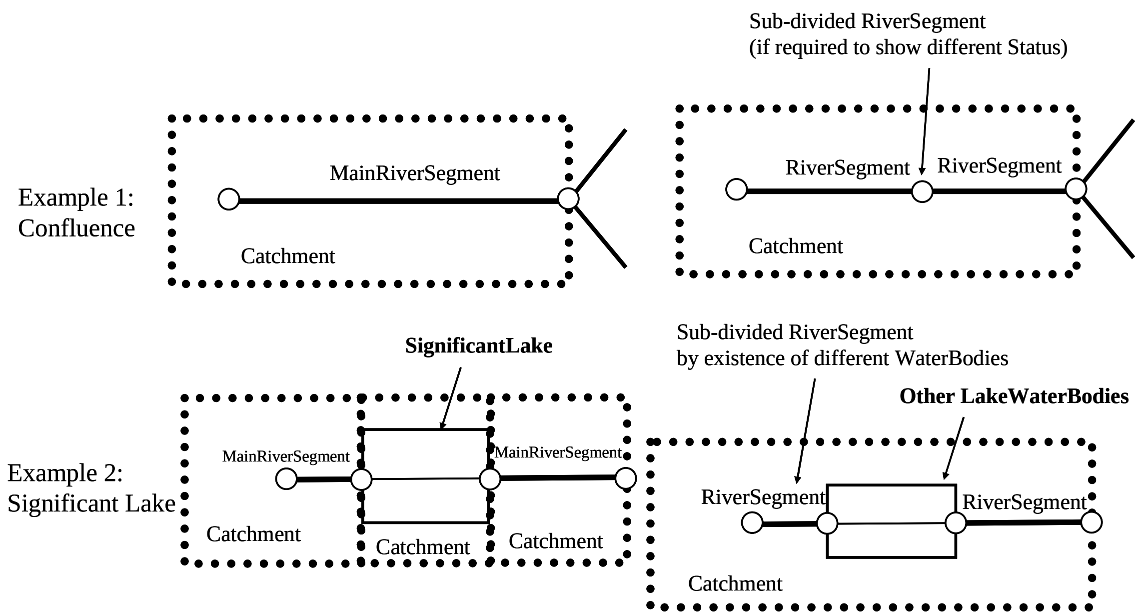
Source: JICA Study Team

Figure E.2.6 Relationship among Core Data Model Analysis Layer and WFD Layer on Lake



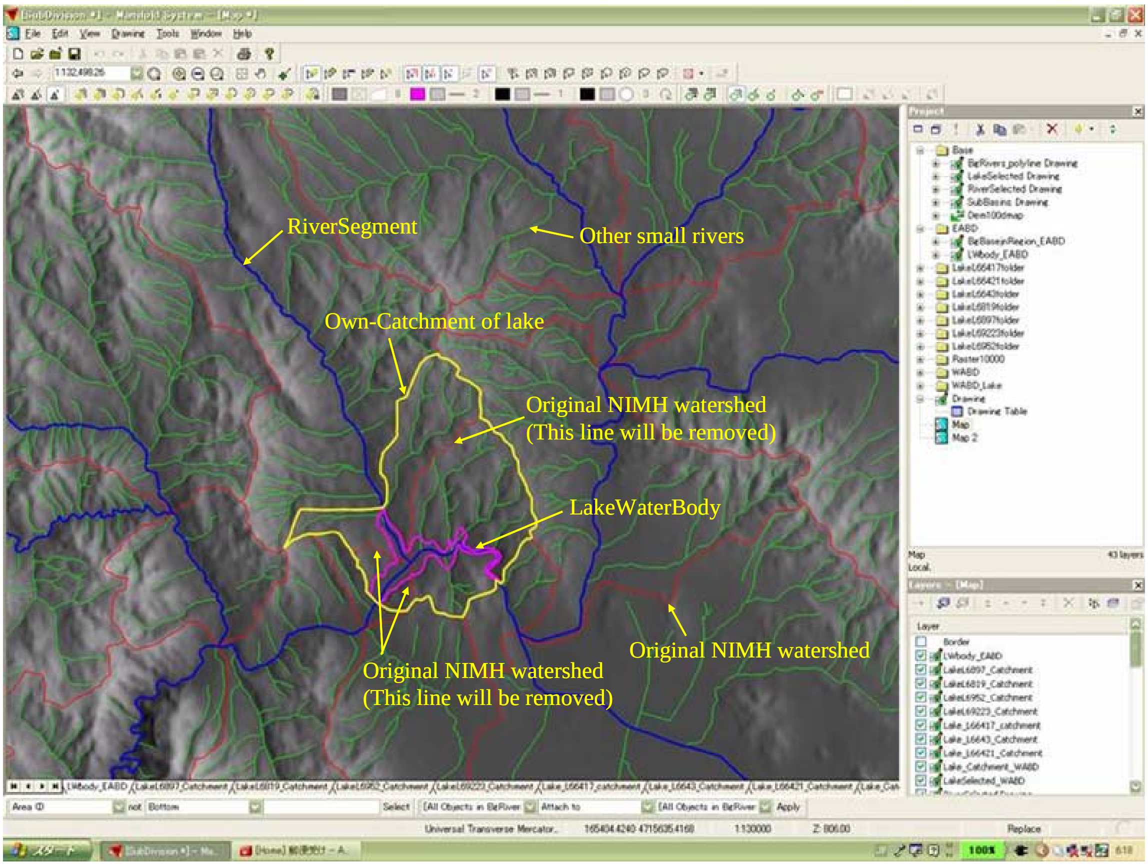
Source: JICA Study Team

Figure E.2.7 Relationship among Catchment, SubBasin and Basin



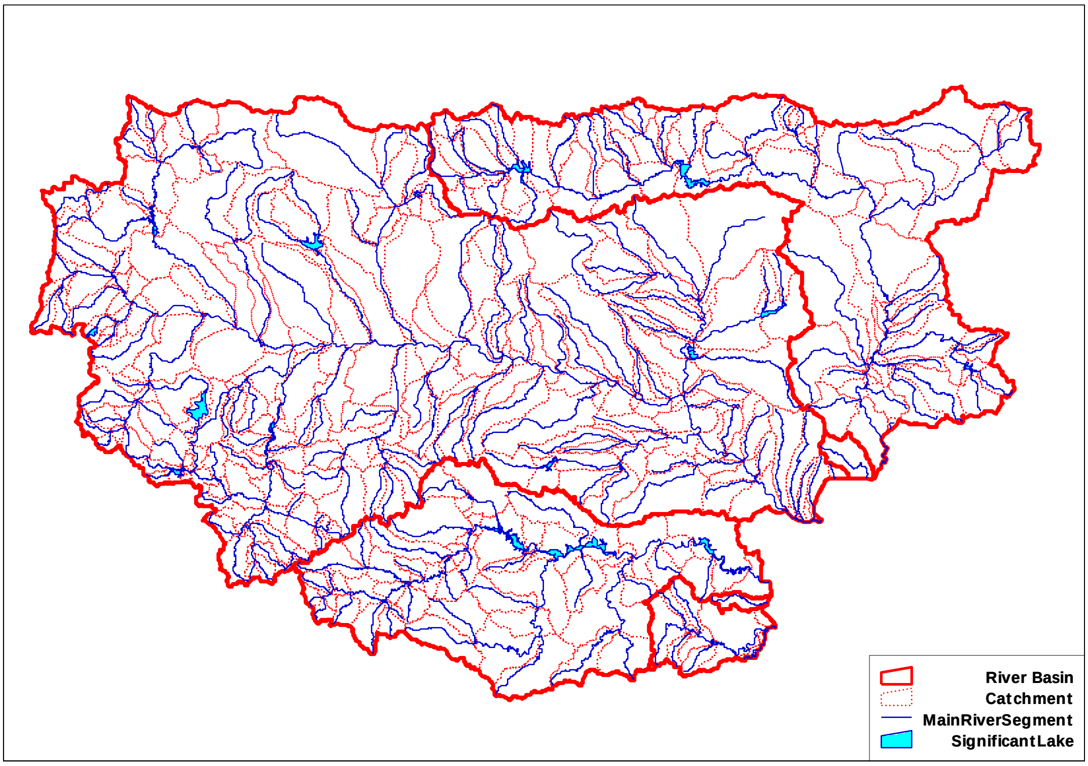
Source: JICA Study Team

Figure E.2.8 Examples of Delineation of Catchment



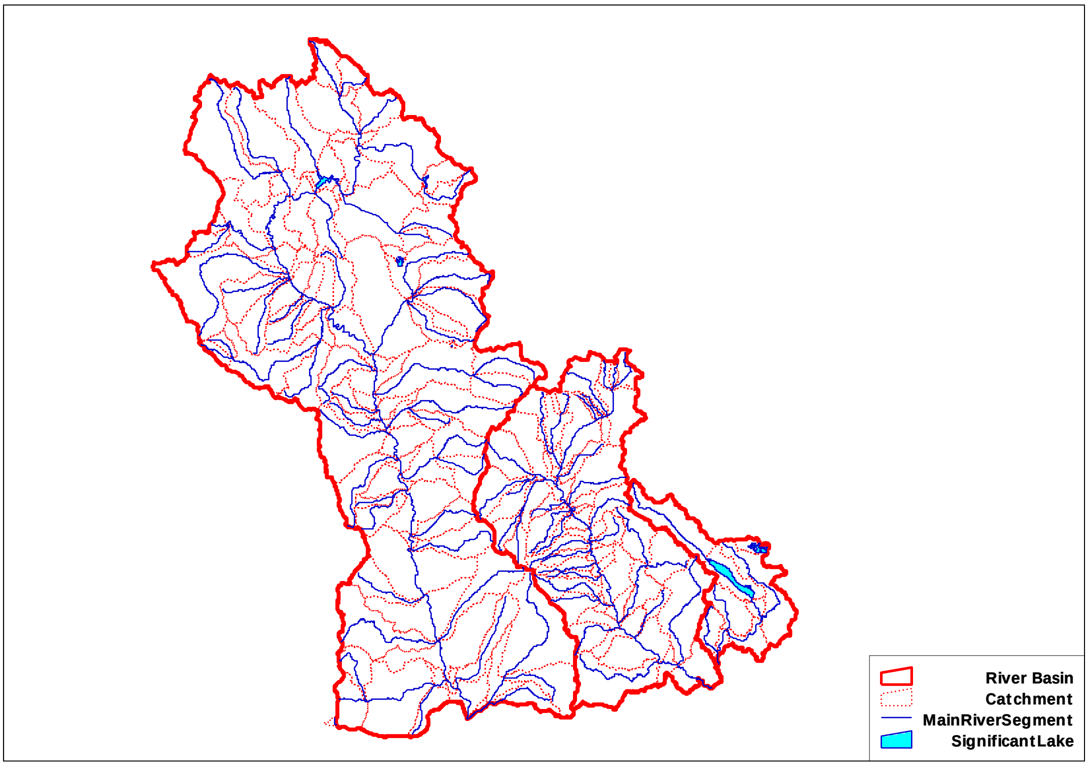
Source: JICA Study Team

Figure E.2.9 Example of Modification of Catchment around SignificantLake



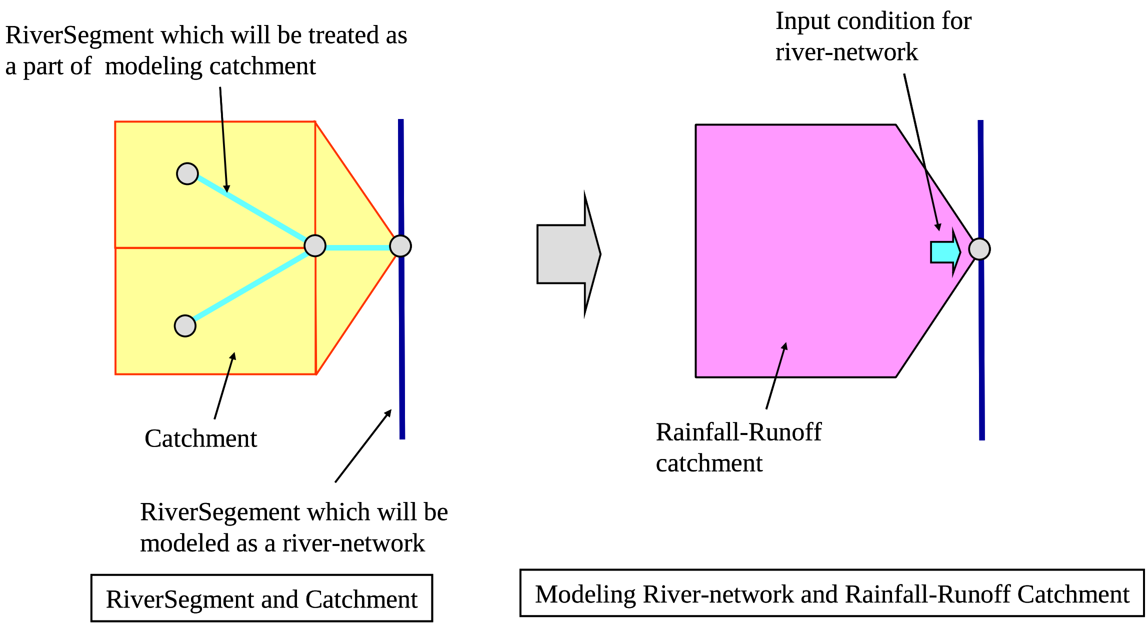
Source: JICA Study Team

Figure E.2.10 Delineated Catchment in EABD



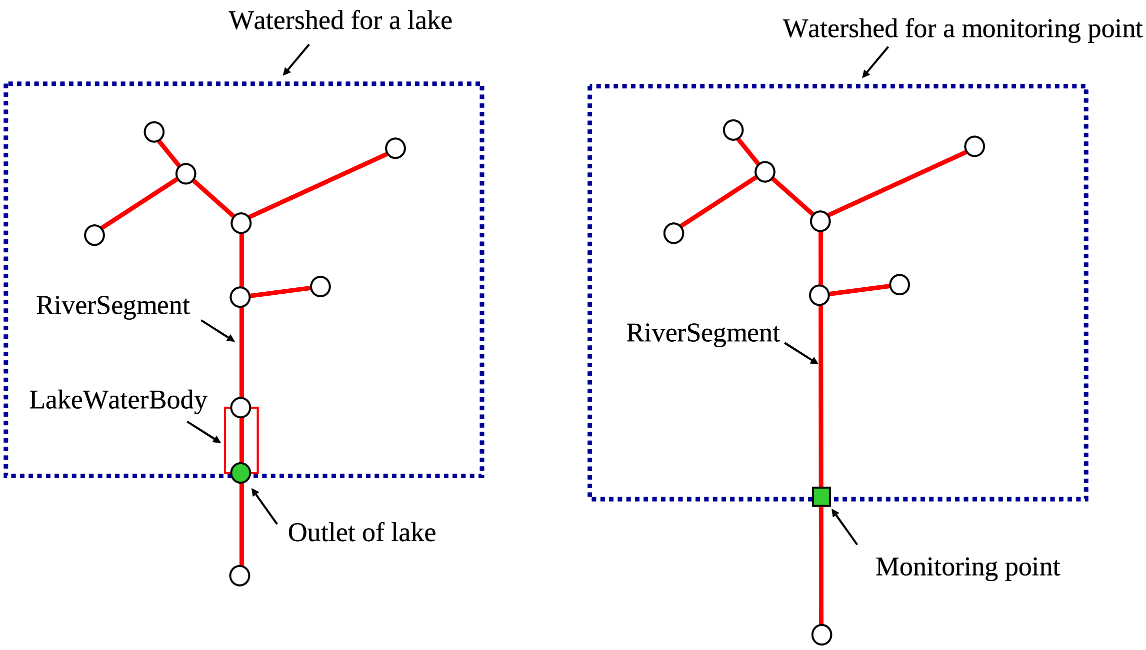
Source: JICA Study Team

Figure E.2.11 Delineated Catchment in WABD



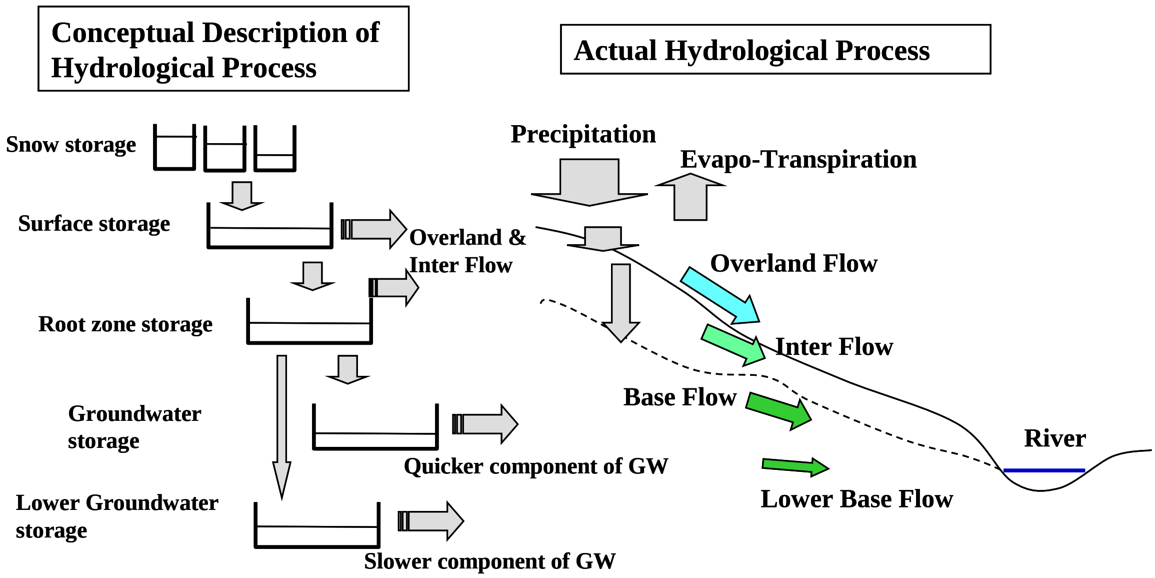
Source: JICA Study Team

Figure E.2.12 Aggregation of Catchment to prepare Rainfall-Runoff Catchment



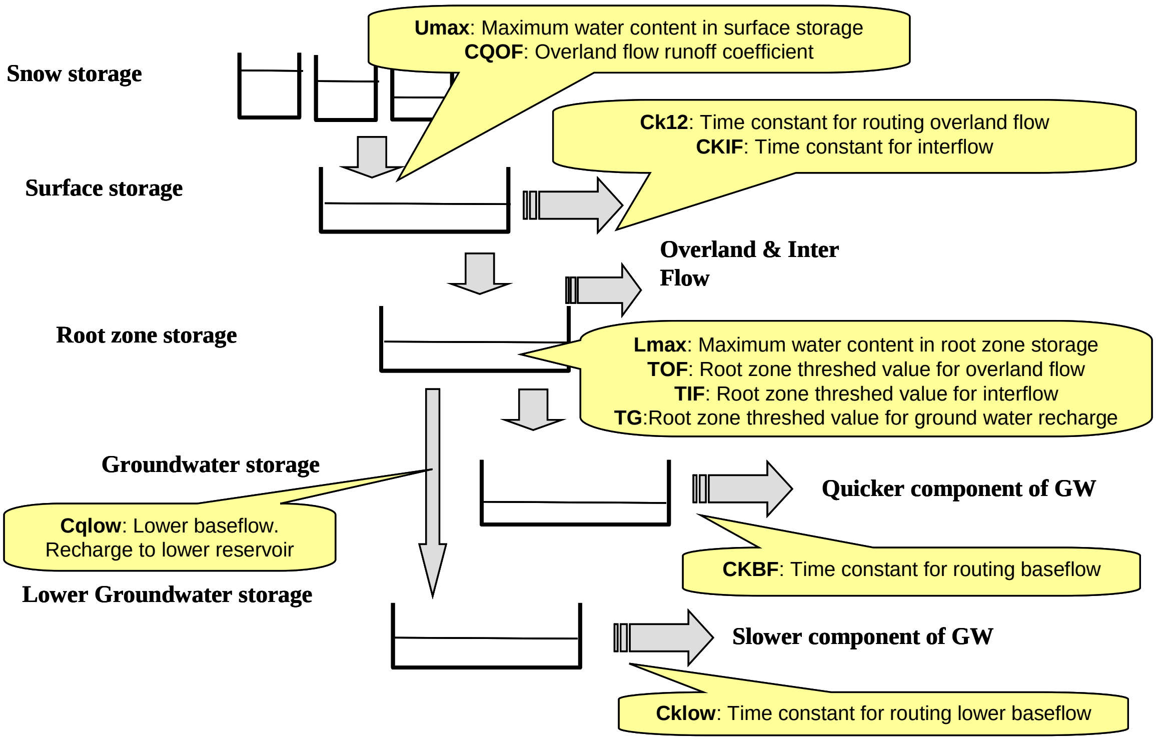
Source: JICA Study Team

Figure E.2.13 Watershed for Specific Point



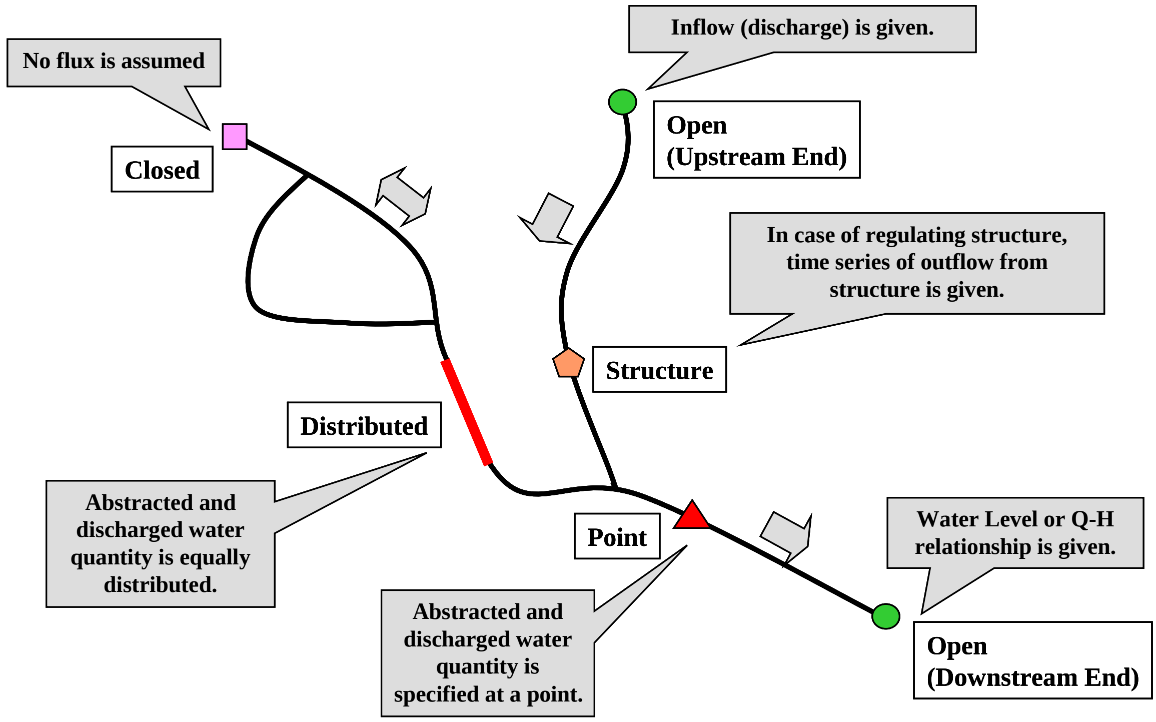
Source: JICA Study Team

Figure E.4.1 NAM Model for Rainfall-Runoff Process



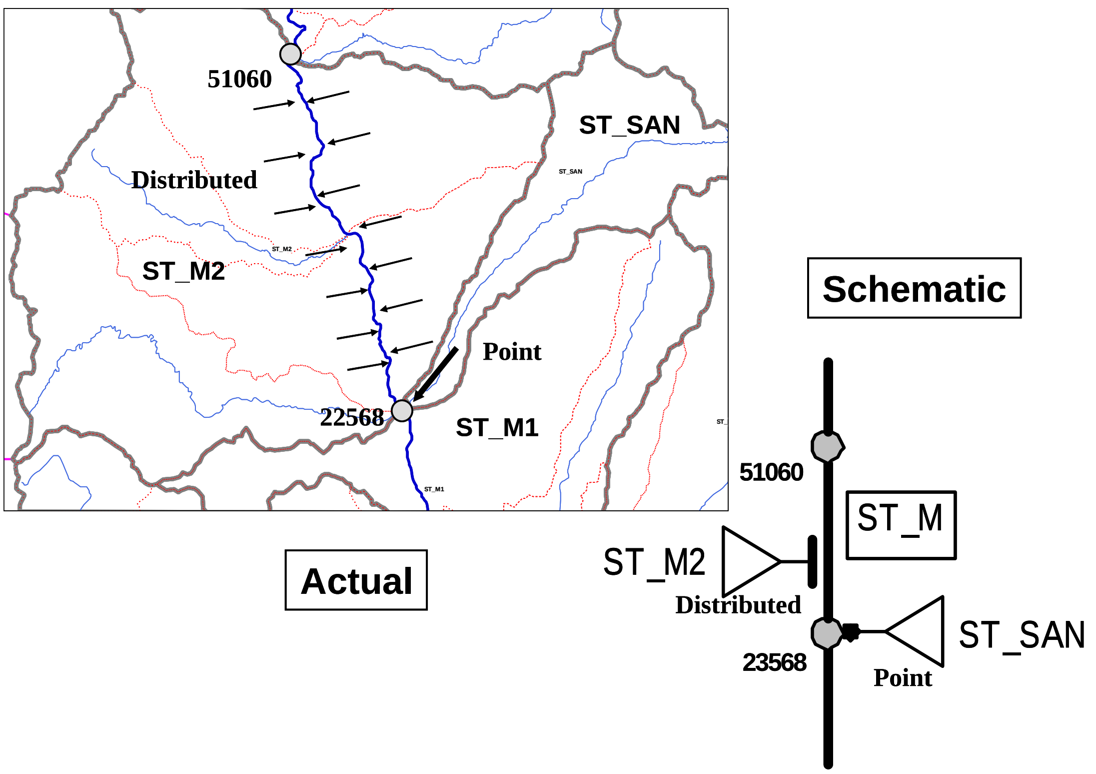
Source: JICA Study Team

Figure E.4.2 Primary Model Parameters in NAM Model



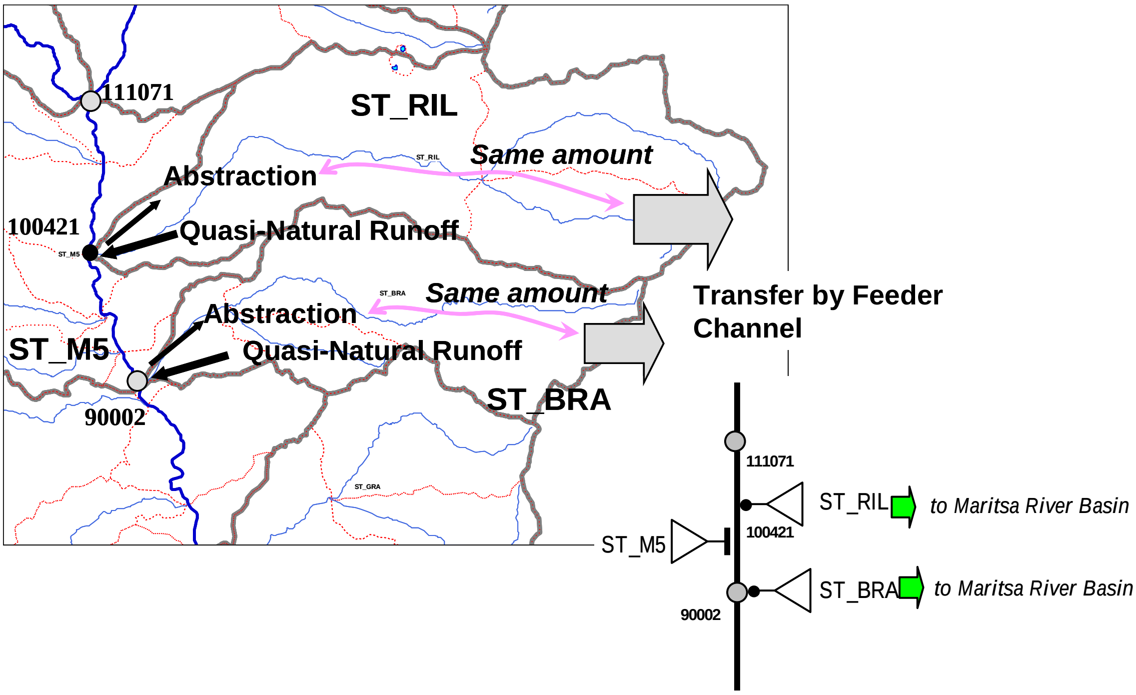
Source: JICA Study Team

Figure E.4.3 Primary Model Parameters in NAM Model



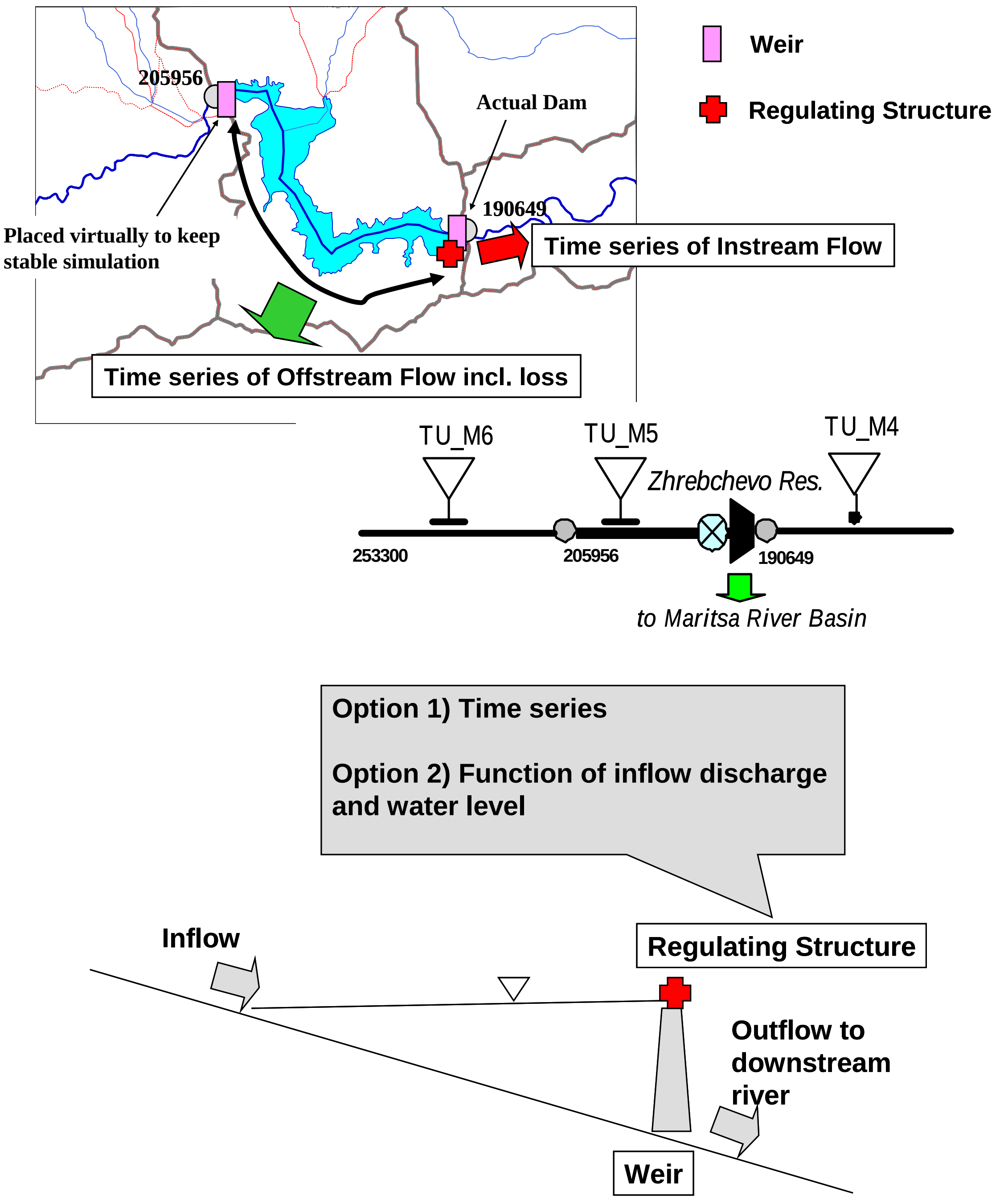
Source: JICA Study Team

Figure E.4.4 Example of RR-HD link



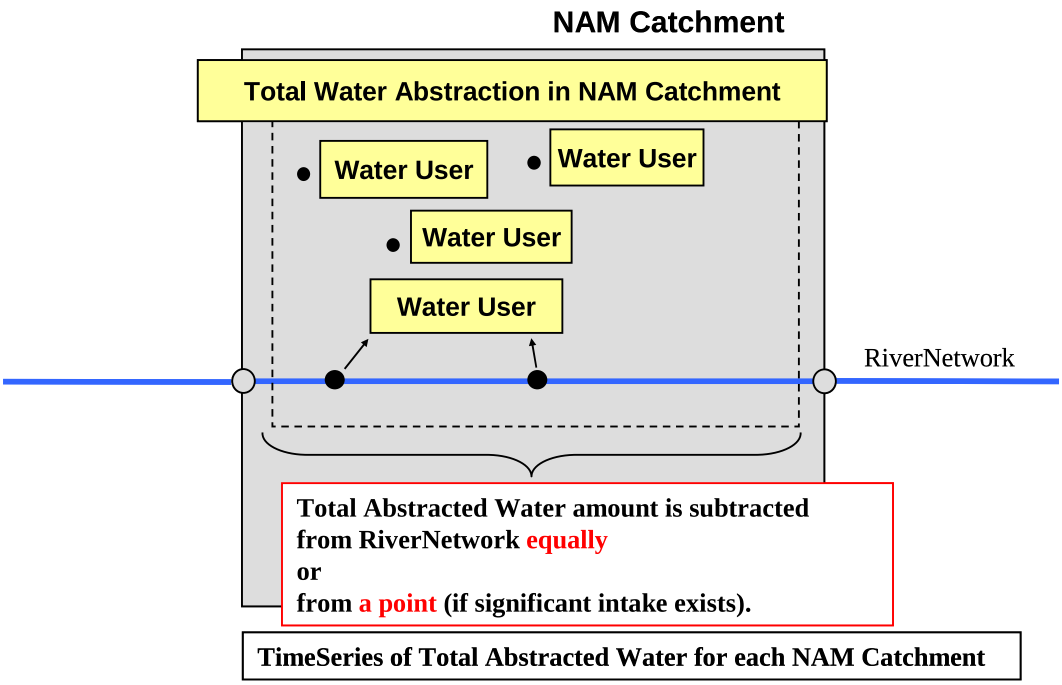
Source: JICA Study Team

Figure E.4.5 Example of Model for Transfer by Feeder Channels



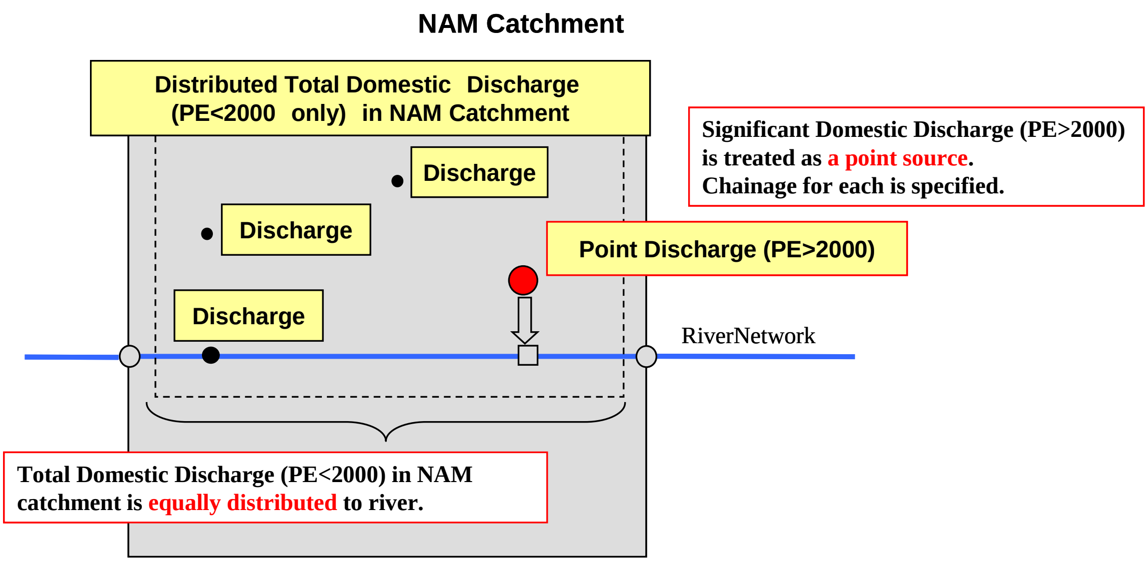
Source: JICA Study Team

Figure E.4.6 Example of Model for Reservoir



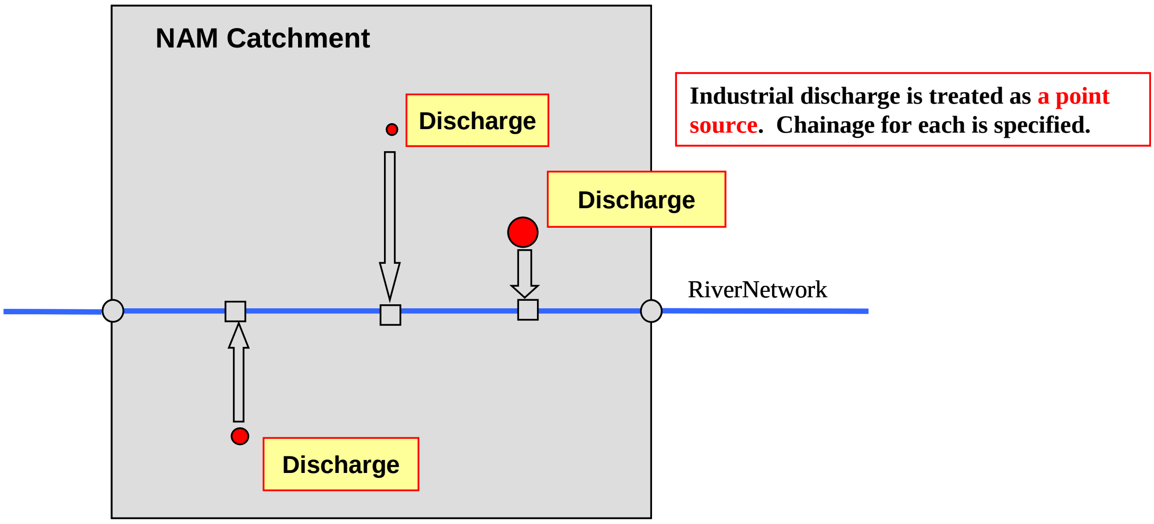
Source: JICA Study Team

Figure E.4.7 Water Abstraction from Rivers and Catchments



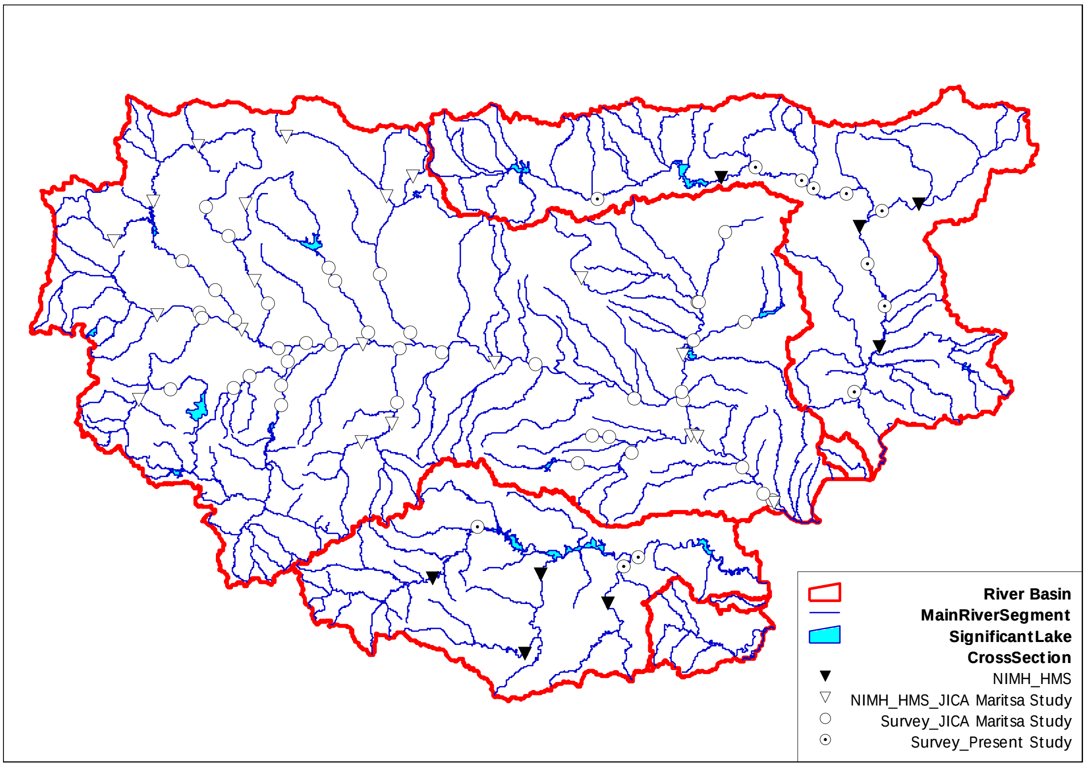
Source: JICA Study Team

Figure E.4.8 Domestic Discharge



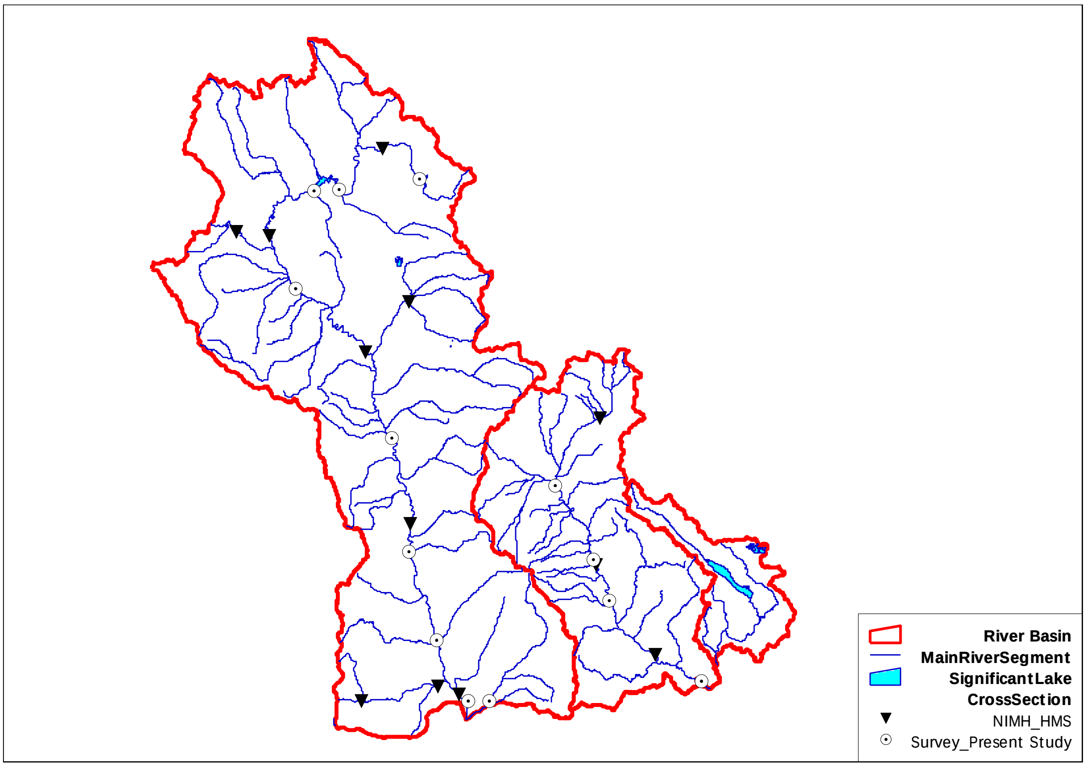
Source: JICA Study Team

Figure E.4.9 Industrial Discharge



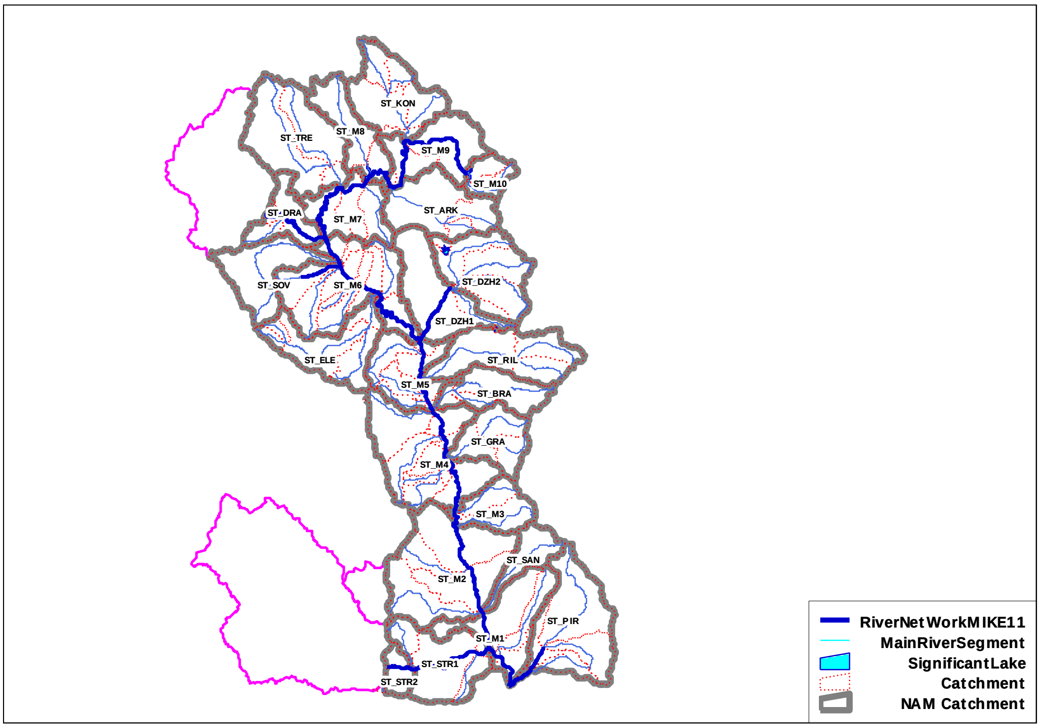
Source: JICA Study Team

Figure E.4.10 Location of Available Cross-Section Data in EABD



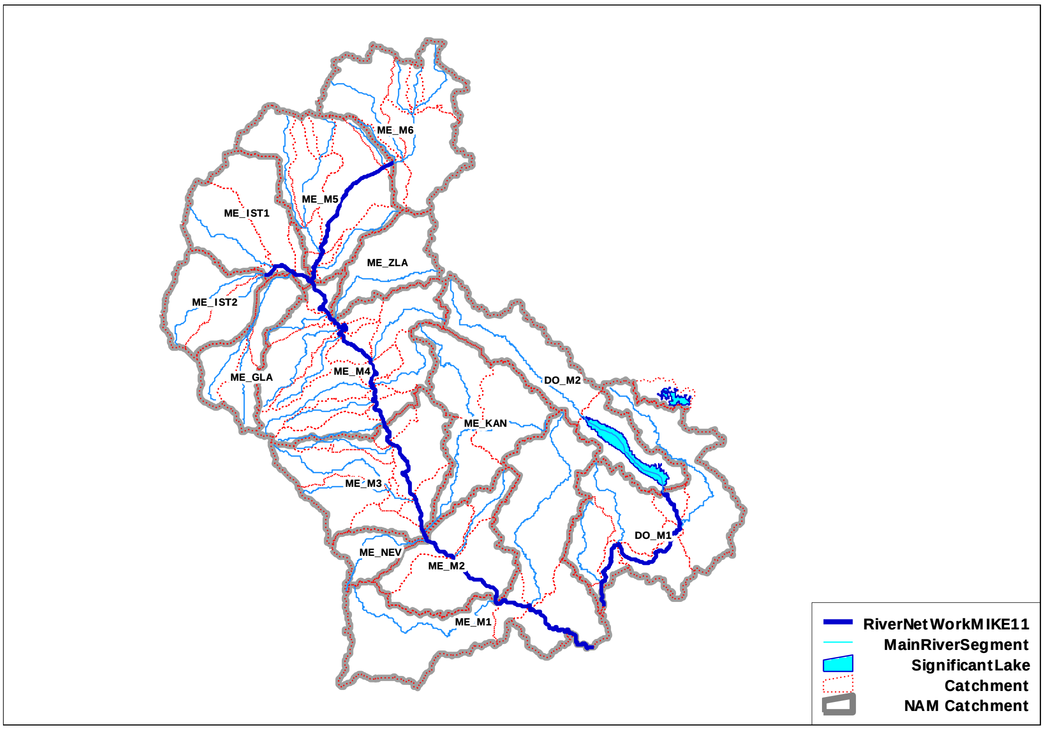
Source: JICA Study Team

Figure E.4.11 Location of Available Cross-Section Data in WABD



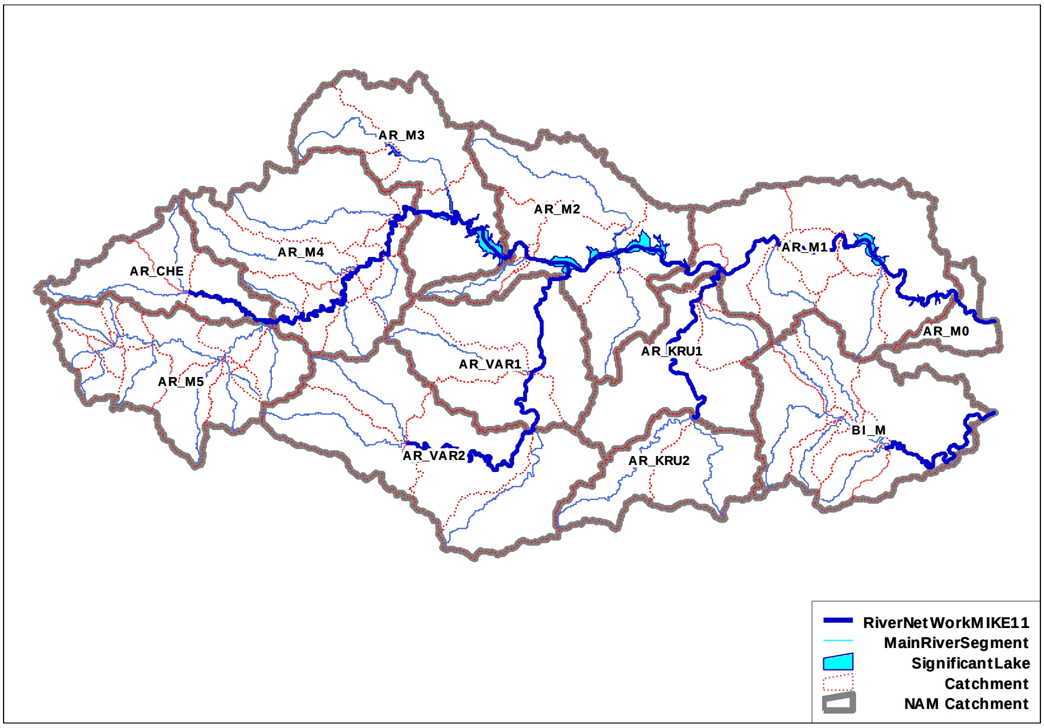
Source: JICA Study Team

Figure E.4.12 MIKE11 River Network and Rainfall-Runoff (NAM) Catchment in the Struma River Basin



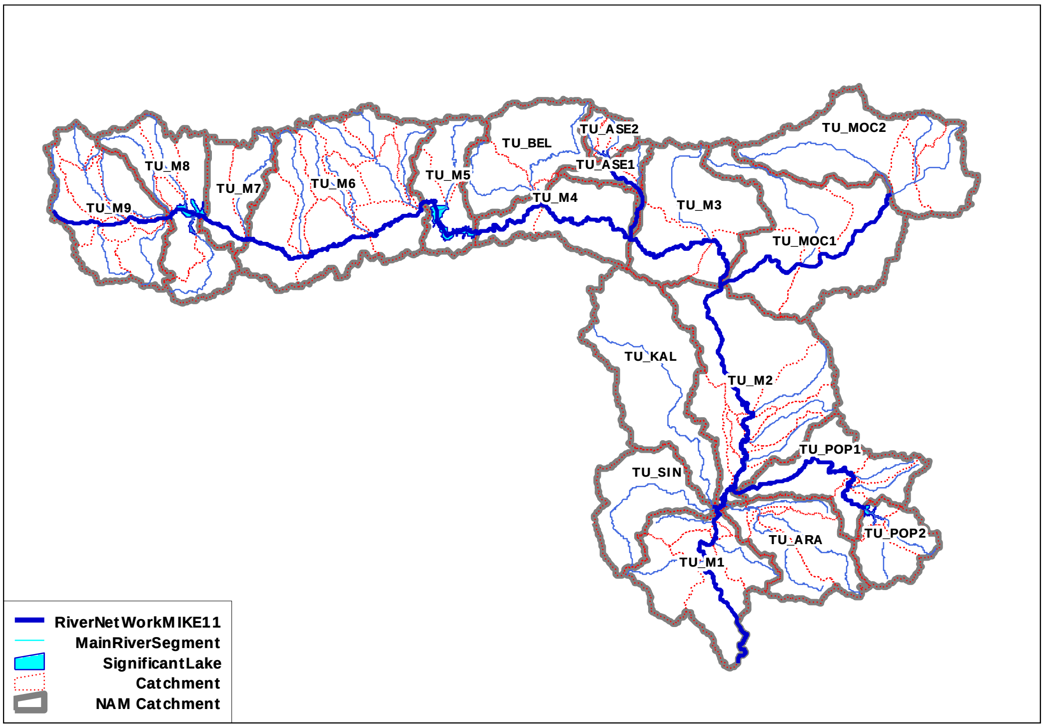
Source: JICA Study Team

Figure E.4.13 MIKE11 River Network and Rainfall-Runoff (NAM) Catchment in the Mesta and Dospat River Basins



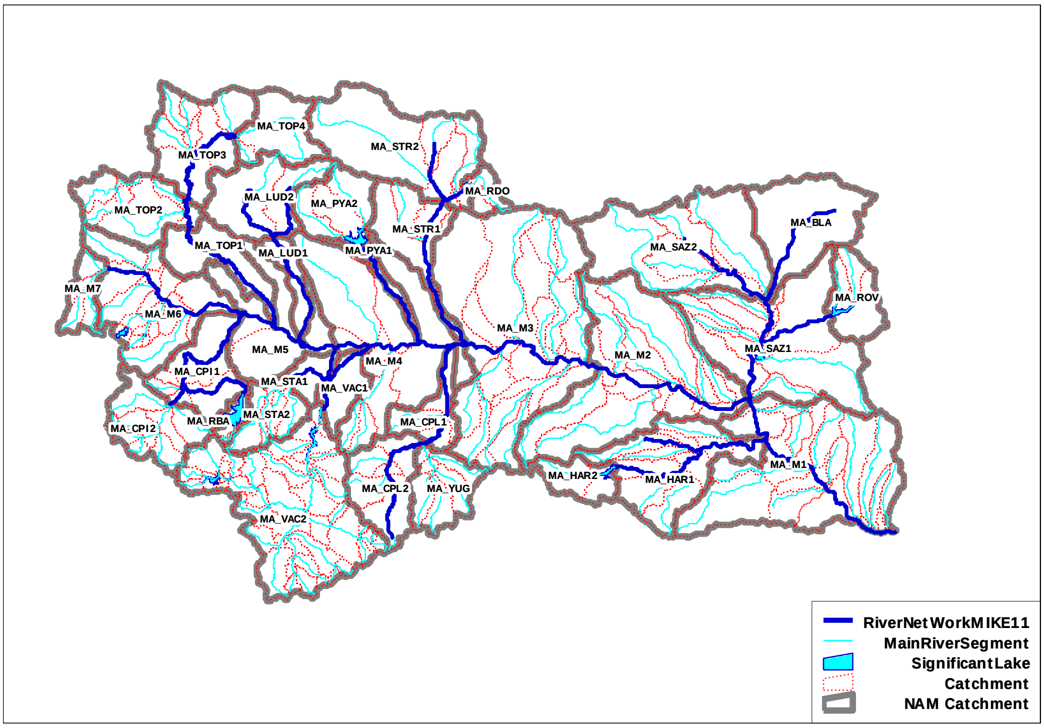
Source: JICA Study Team

Figure E.4.14 MIKE11 River Network and Rainfall-Runoff (NAM) Catchment in the Arda and Biala River Basins



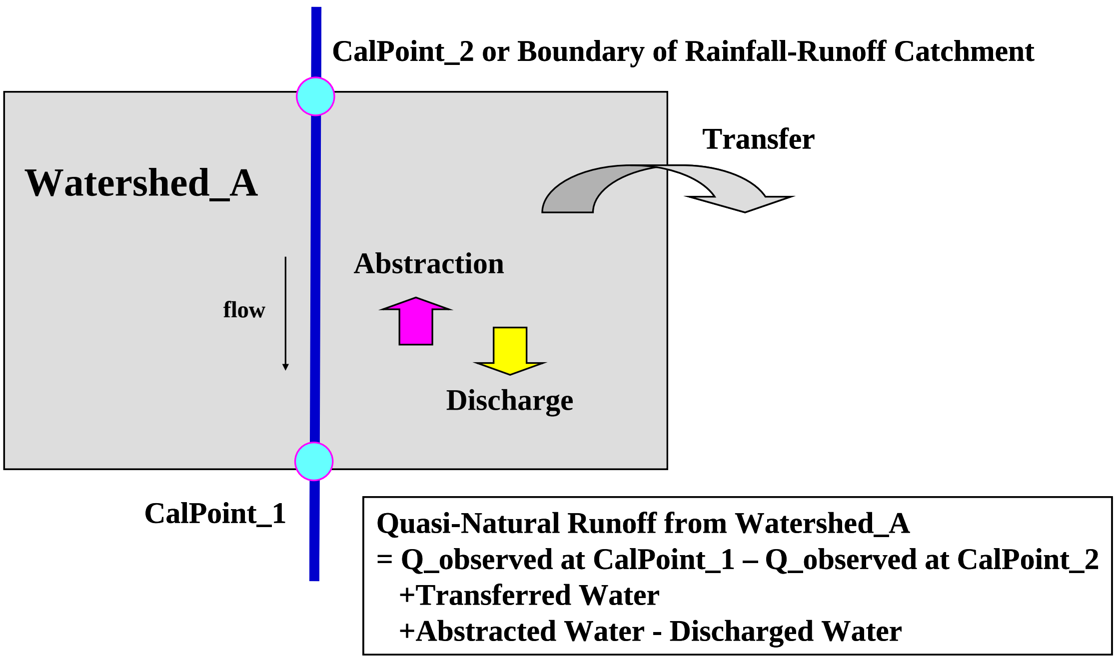
Source: JICA Study Team

Figure E.4.15 MIKE11 River Network and Rainfall-Runoff (NAM) Catchment in the Tundzha River Basin



Source: JICA Study Team

Figure E.4.16 MIKE11 River Network and Rainfall-Runoff (NAM) Catchment in the Maritsa River Basin

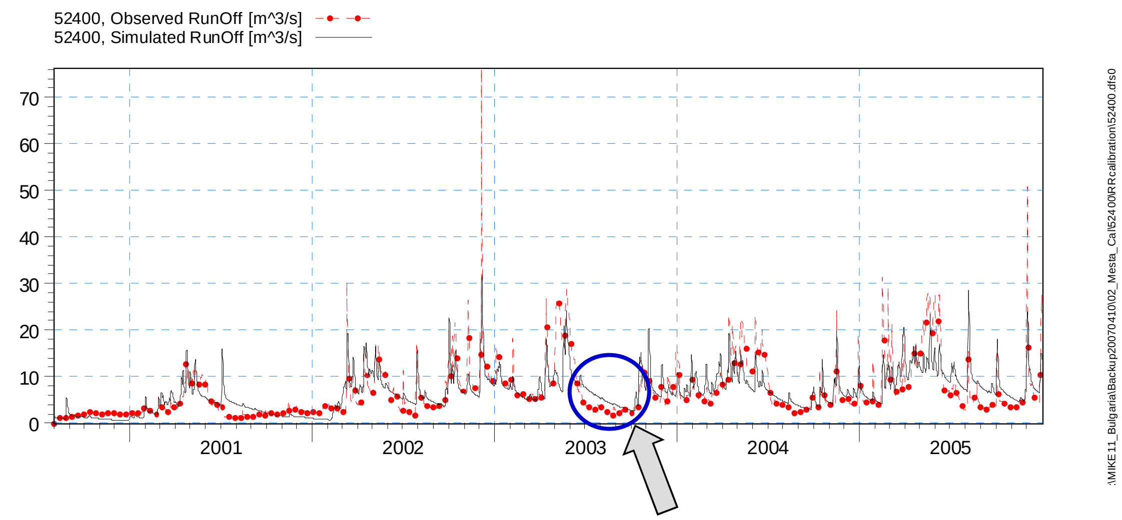


Note: 1) Q_observed at CalPoint_2 can be estimated Q at Boundary of Rainfall-Runoff Catchment
2) Effect of local reservoir is not taken into account.

Source: JICA Study Team

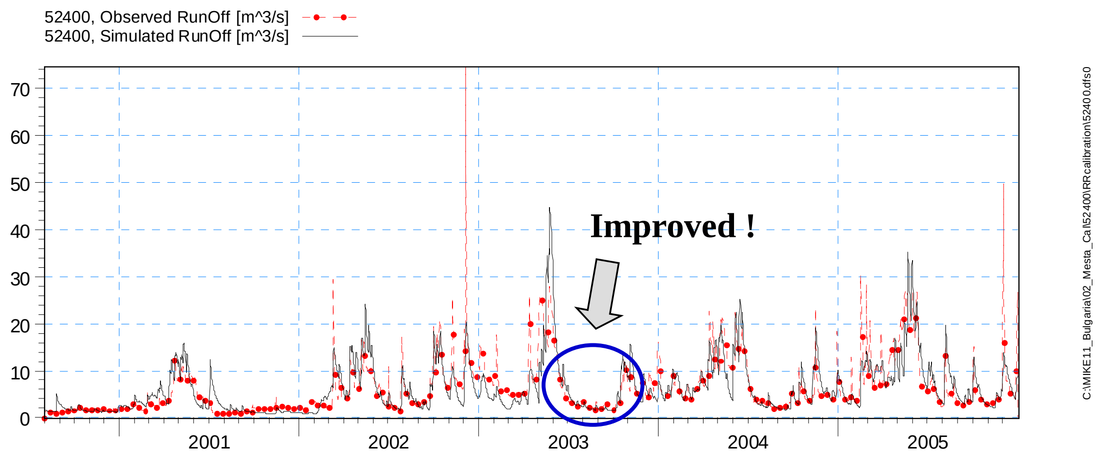
Figure E.4.17 Estimation of Quasi-Natural Runoff

Without Lower GW storage



Very difficult to model recession process

With Lower GW storage

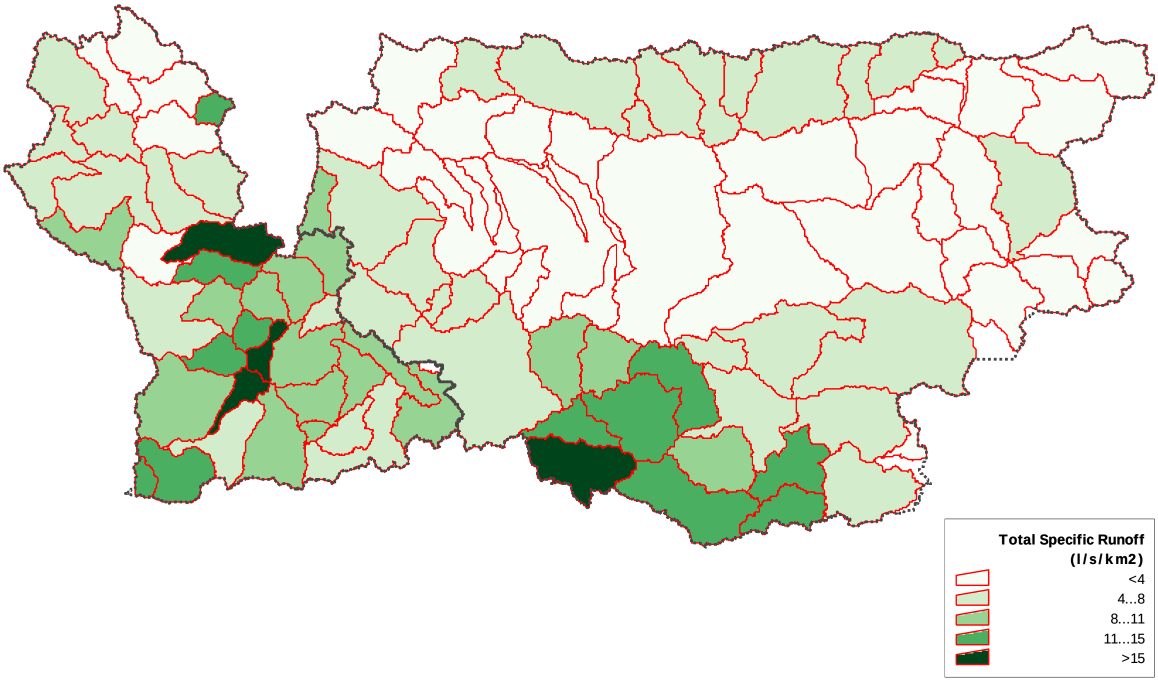


Time scale :

- **Base flow component in the model**
  ⇒ 200 – 500 hours ⇦ ***Very Quick***
  Similar behavior to Interflow
- **Lower base flow component in the model**
  ⇒ 10,000 hours

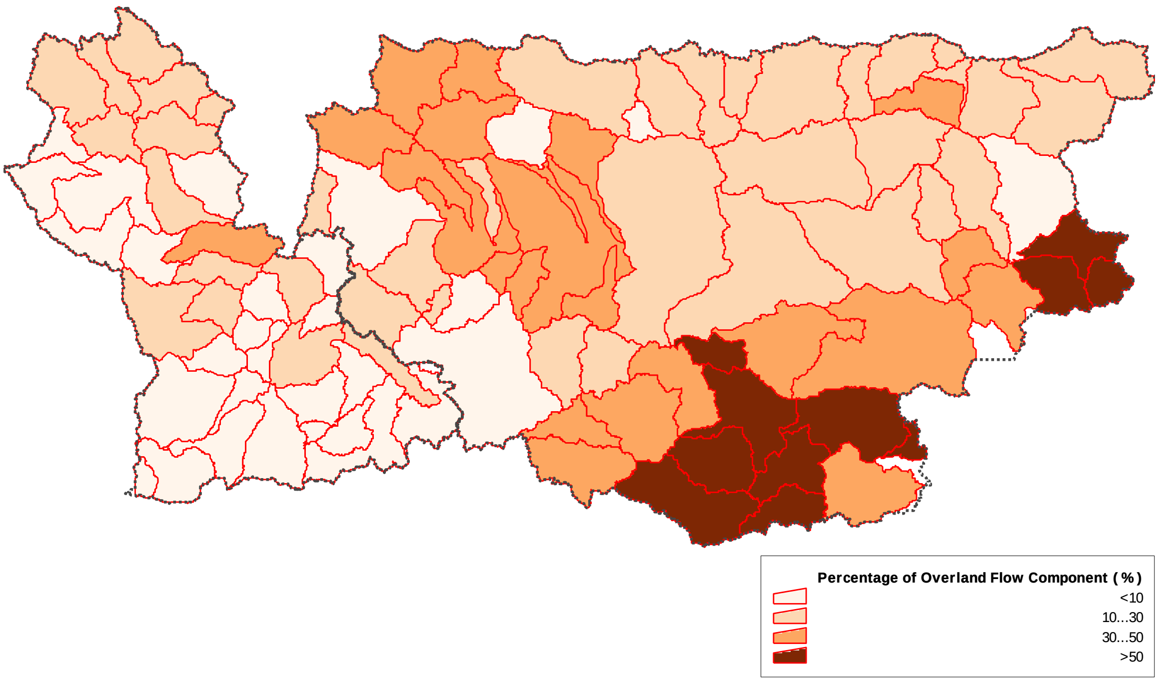
Source: JICA Study Team

Figure E.4.18 Example of Calibration



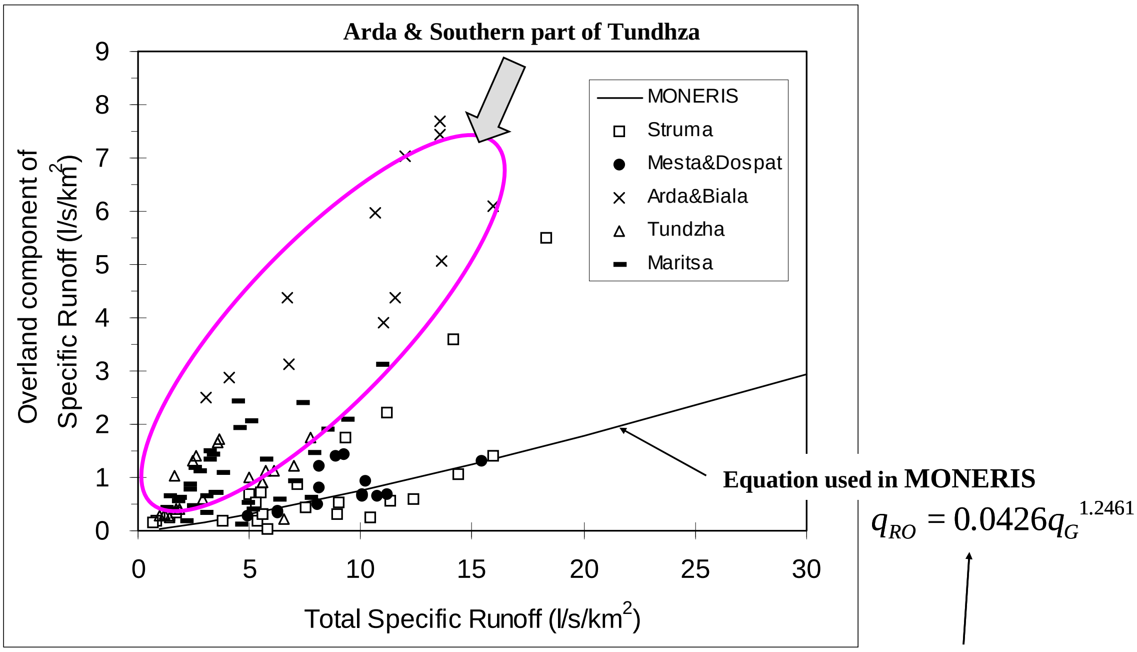
Source: JICA Study Team

Figure E.4.19 Total Specific Runoff for Quasi-Natural Condition (2001-2005)



Source: JICA Study Team

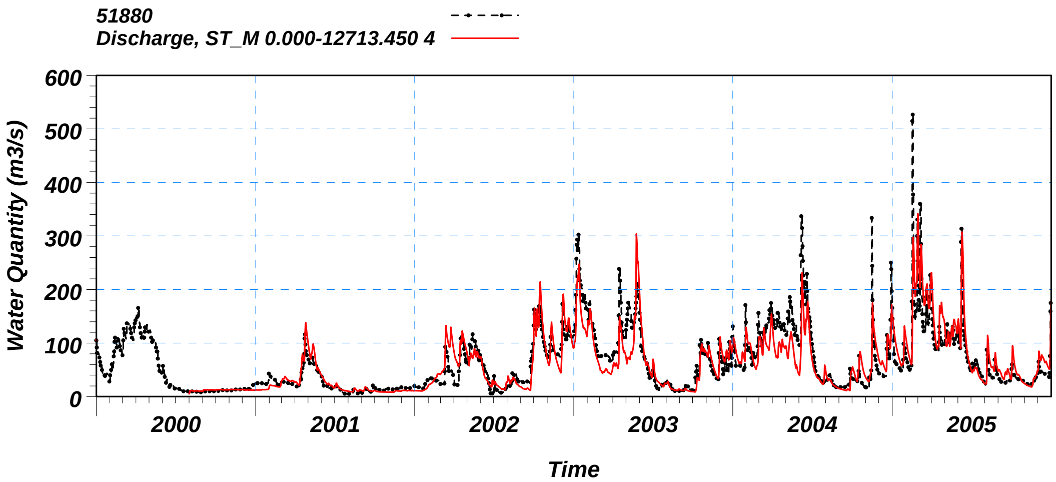
Figure E.4.20 Percentage of Overland Flow Component of Runoff (2001-2005)



qRO = specific surface (overland flow) runoff (l/s/km2)
qG = average yearly specific runoff (l/s/km2)
(from PPT material by Prof. Jordan Kosturkov of IWP)

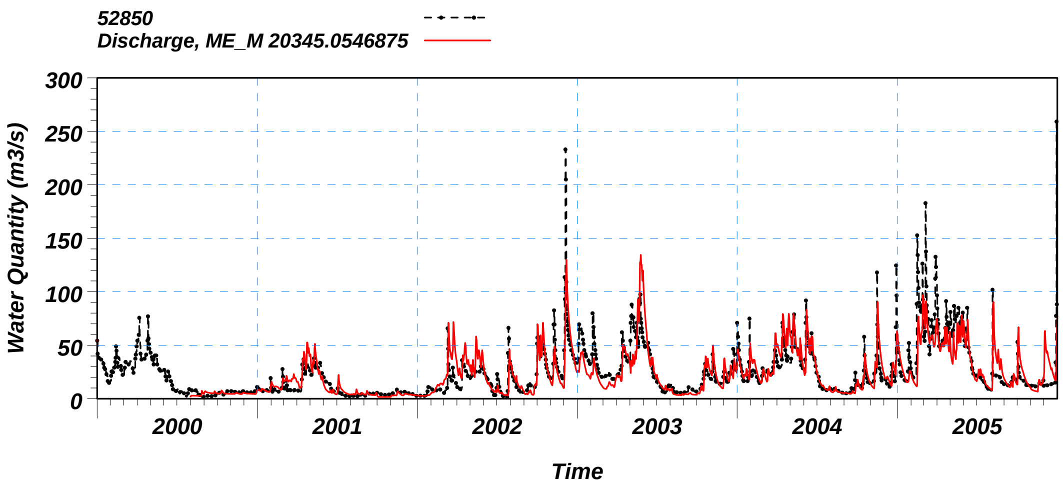
Source: JICA Study Team

Figure E.4.21 Relationship between total unit runoff and overland flow runoff component



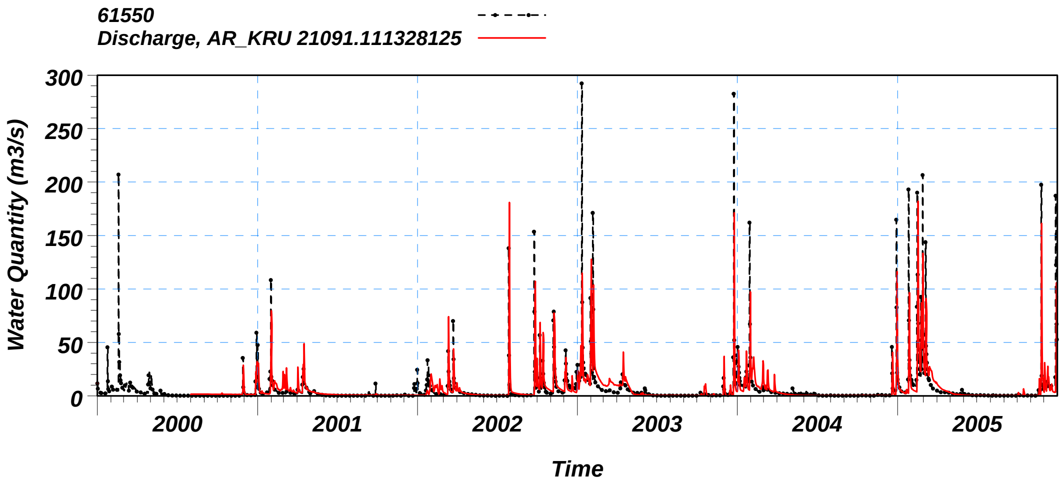
Source: JICA Study Team

Figure E.4.22 Comparison between Observed and Simulated Hydrograph (The Struma River: HMS51880)



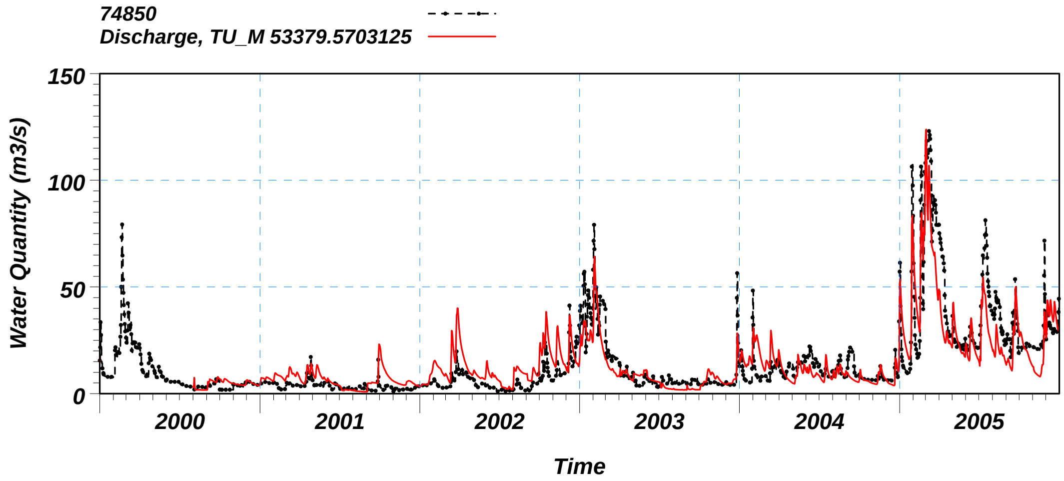
Source: JICA Study Team

Figure E.4.23 Comparison between Observed and Simulated Hydrograph (The Mesta River: HMS52850)



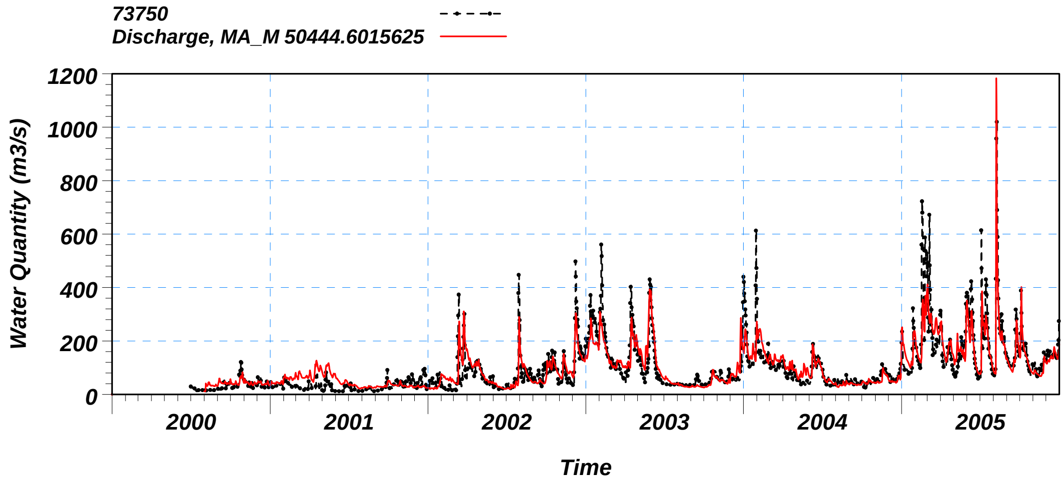
Source: JICA Study Team

Figure E.4.24 Comparison between Observed and Simulated Hydrograph (The Arda River: HMS61550)



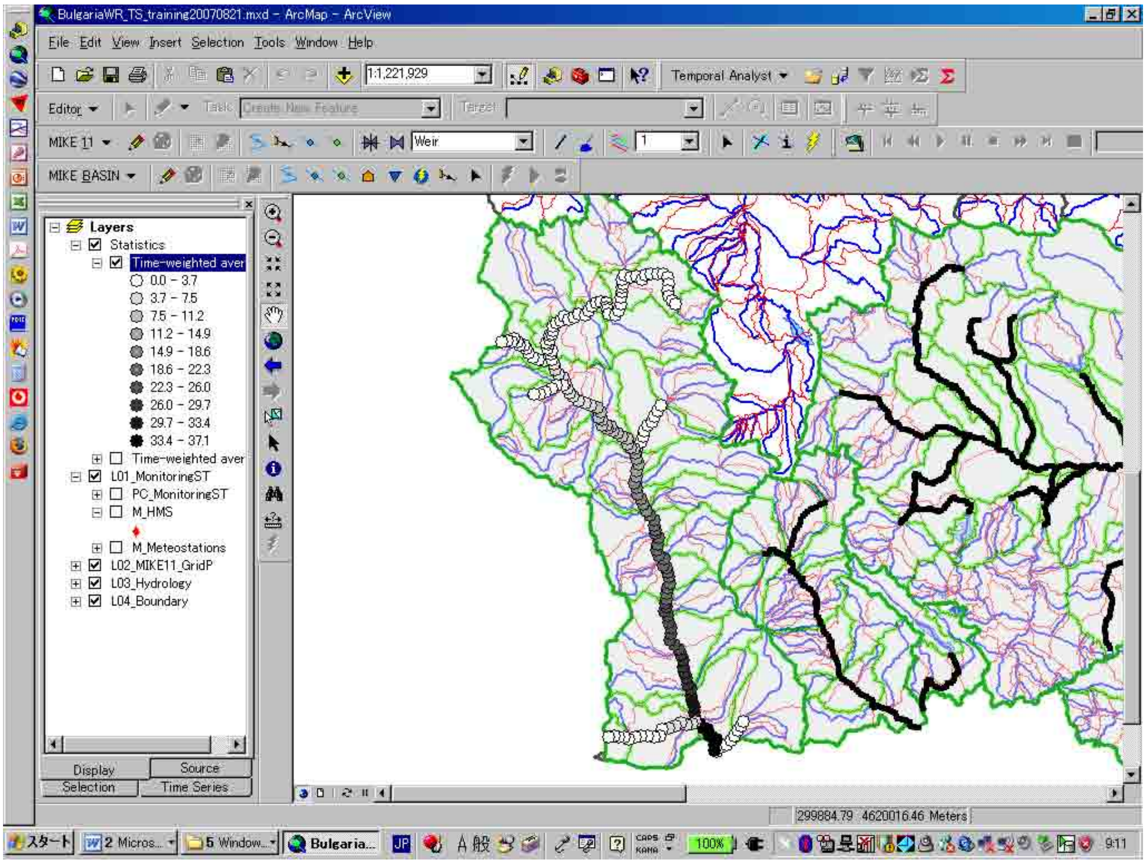
Source: JICA Study Team

Figure E.4.25 Comparison between Observed and Simulated Hydrograph (The Tundzha River: HMS74850)



Source: JICA Study Team

Figure E.4.26 Comparison between Observed and Simulated Hydrograph (The Maritsa River: HMS73750)



Source: JICA Study Team

Figure E.4.27 Example of Presentation of Results of MIKE11 Model Using Temporal Analyst

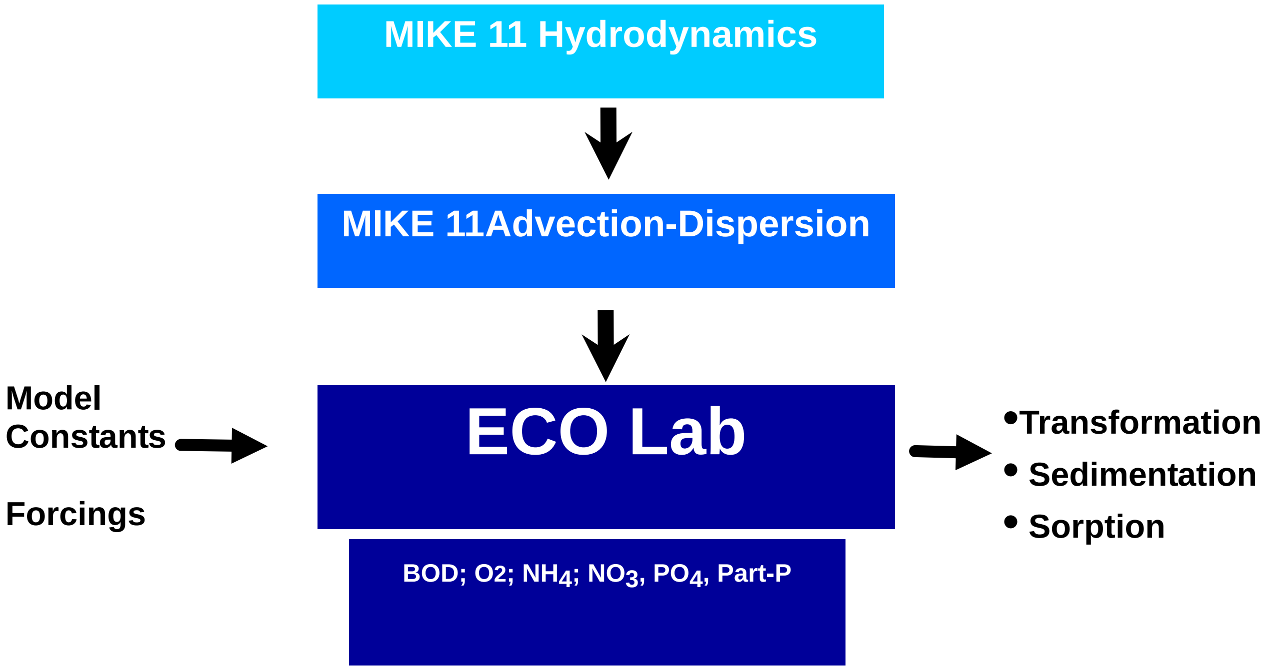


Figure E.5.1 Structure of the MIKE 11 Model Modules

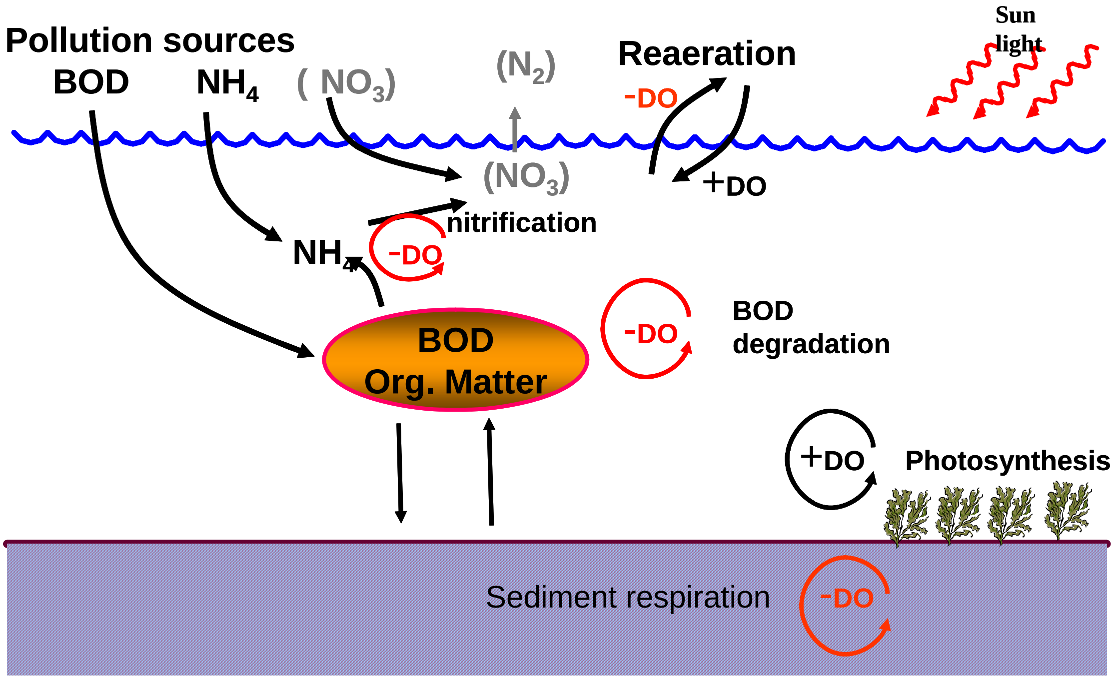


Figure E.5.2 Basic Processes with Respect to BOD, N-Component and Oxygen (DO) Included in the MIKE 11 WQ Model Used under This Study

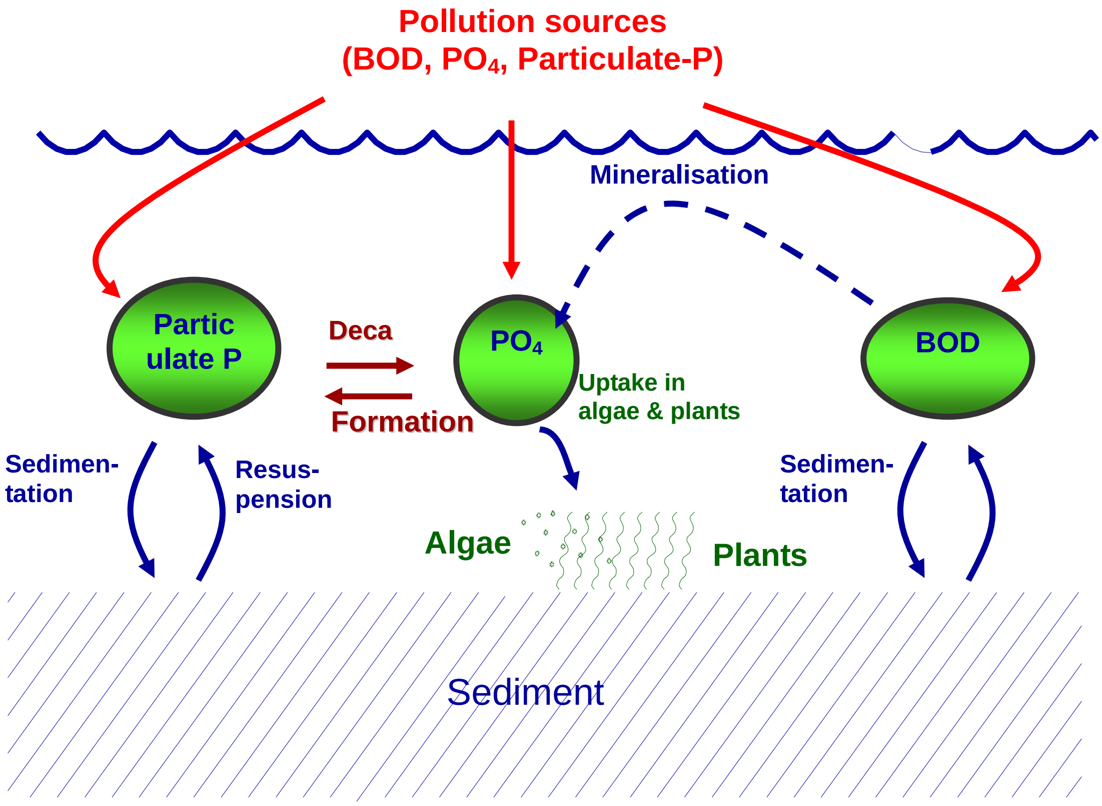
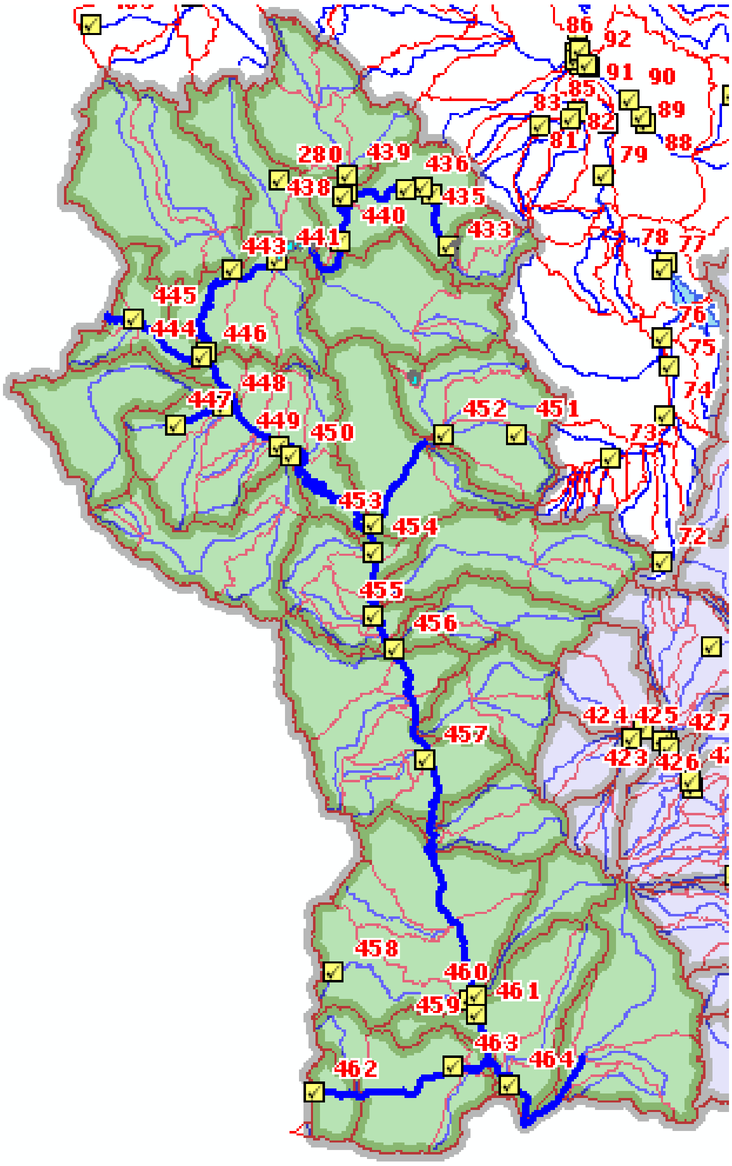


Figure E.5.3 Basic Processes with Respect to Phosphorus Included in the MIKE11 WQ Model Used under This Study



Note: Water quality is not monitored at all monitoring stations.

Station in the Struma River selected for presentation of calibration results

Monitoring station	MIKE 11 Branch	MIKE 11 chainage
464	ST_M	8,406
457	ST_M	69.250
455	ST_M	95,104
453	ST_DHZ	915
449	ST_M	140,806
443	ST_M	182,689
437	ST_M	220,684

Figure E.5.4 The Struma River Basin (green) with MIKE 11 River Branches (thick blue) and Monitoring Stations (yellow squares)

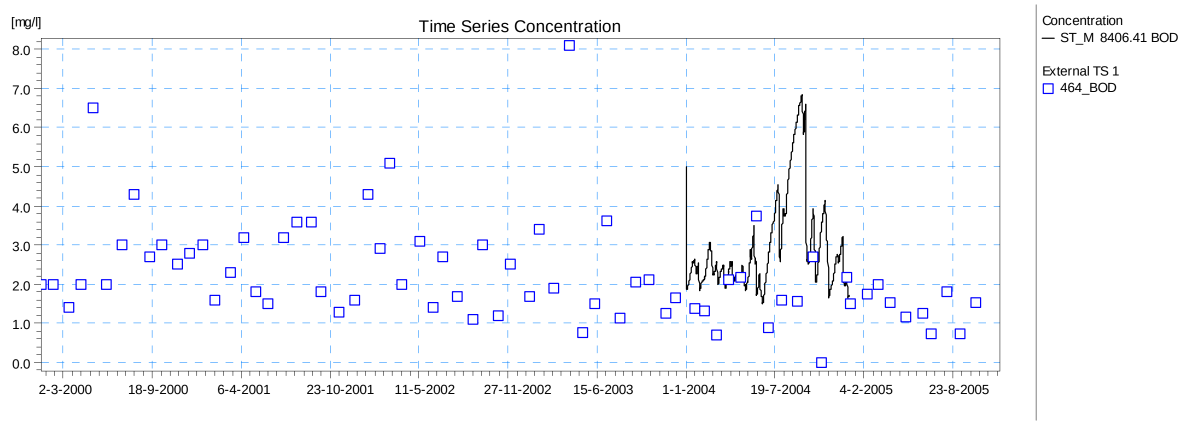


Figure E.5.5 Simulated and Monitored BOD Concentration at Station 464, The Struma River

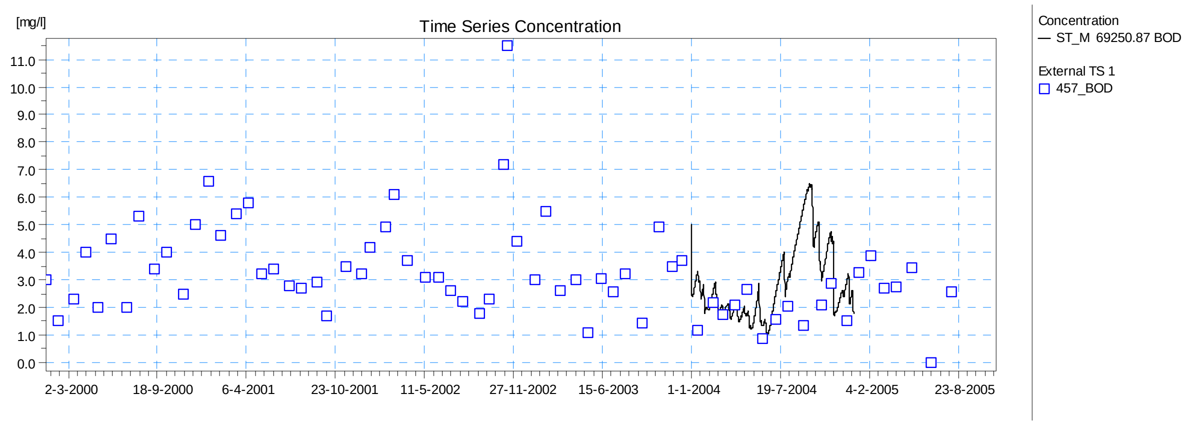


Figure E.5.6 Simulated and Monitored BOD Concentration at Station 457, The Struma River

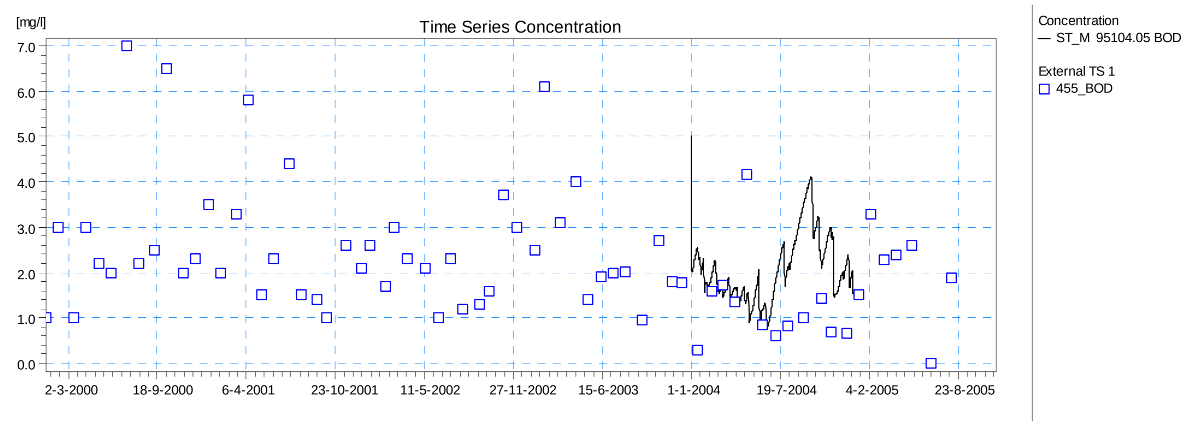


Figure E.5.7 Simulated and Monitored BOD Concentration at Station 455, The Struma River

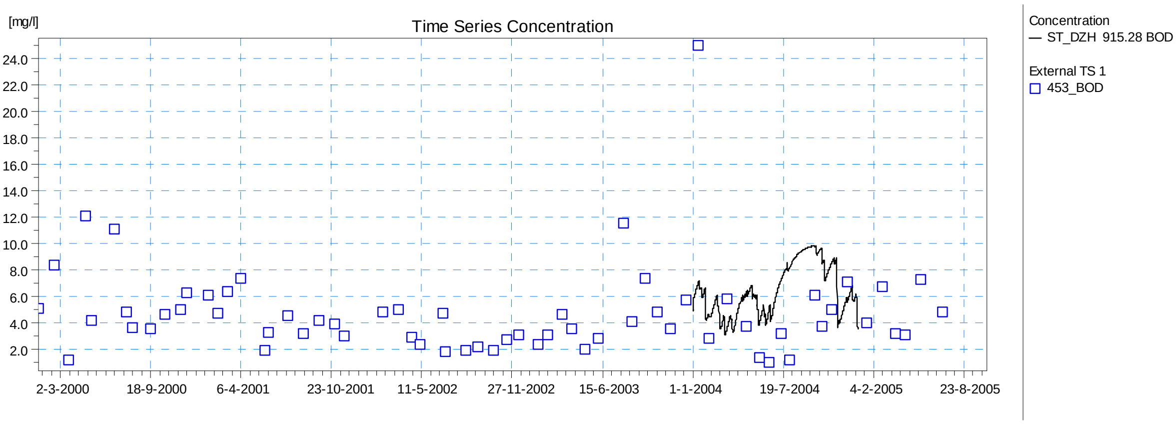


Figure E.5.8 Simulated and Monitored BOD Concentration at Station 453, The Struma River

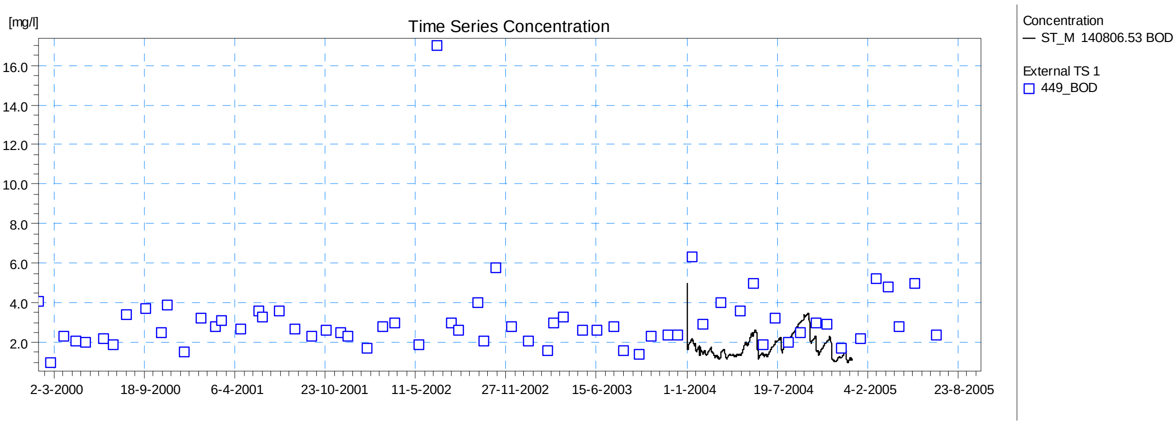


Figure E.5.9 Simulated and Monitored BOD Concentration at Station 449, The Struma River

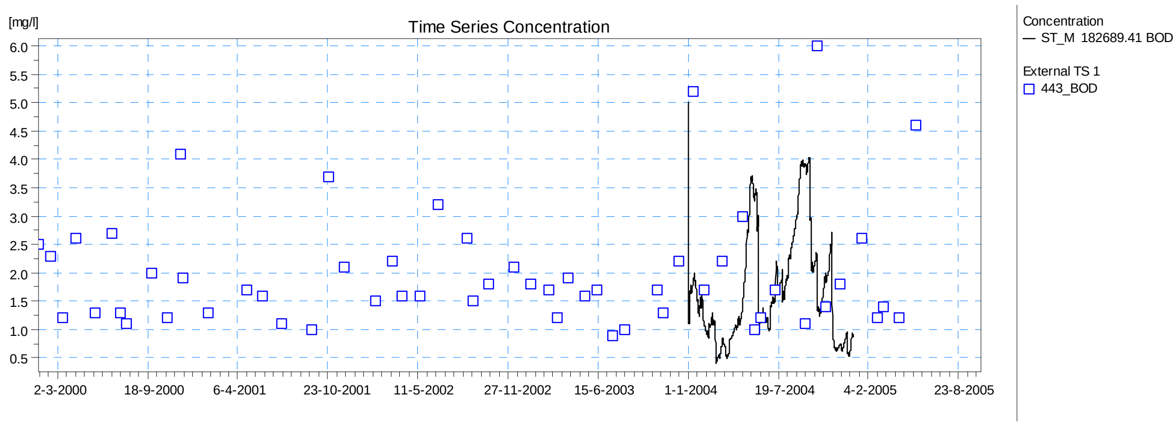


Figure E.5.10 Simulated and Monitored BOD Concentration at Station 443, The Struma River

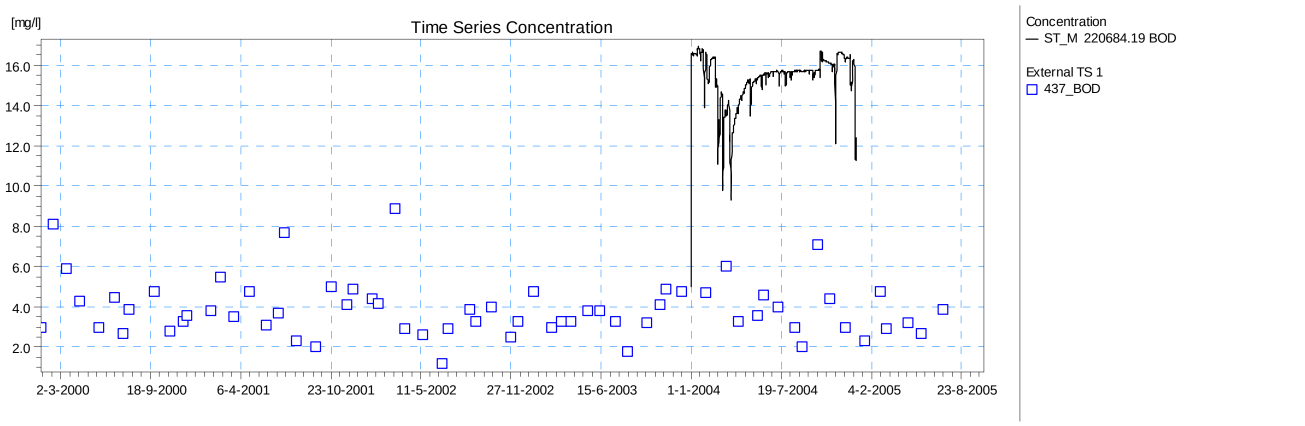


Figure E.5.11 Simulated and Monitored BOD Concentration at Station 437, The Struma River

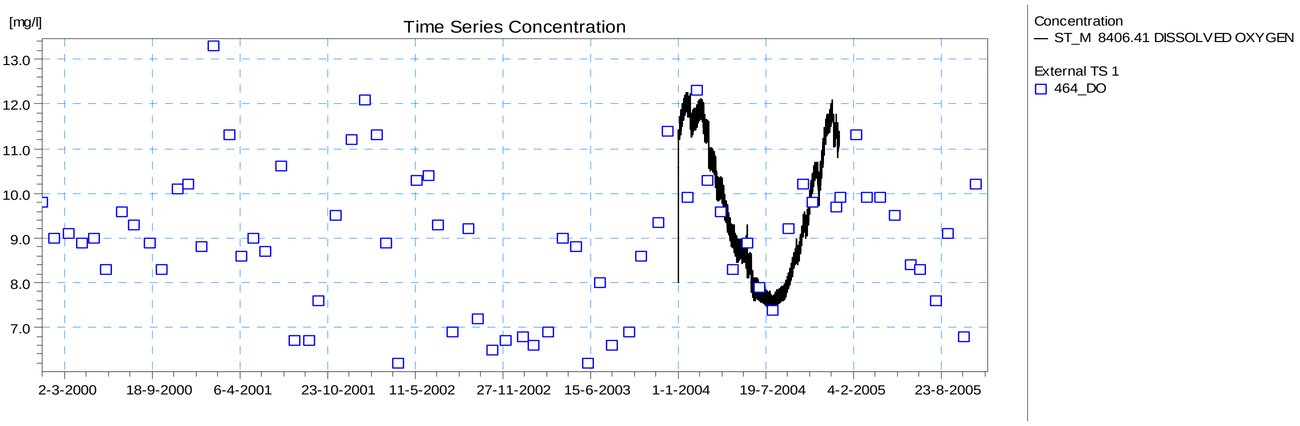


Figure E.5.12 Simulated and Monitored Oxygen (DO) Concentration at St. 464, The Struma River

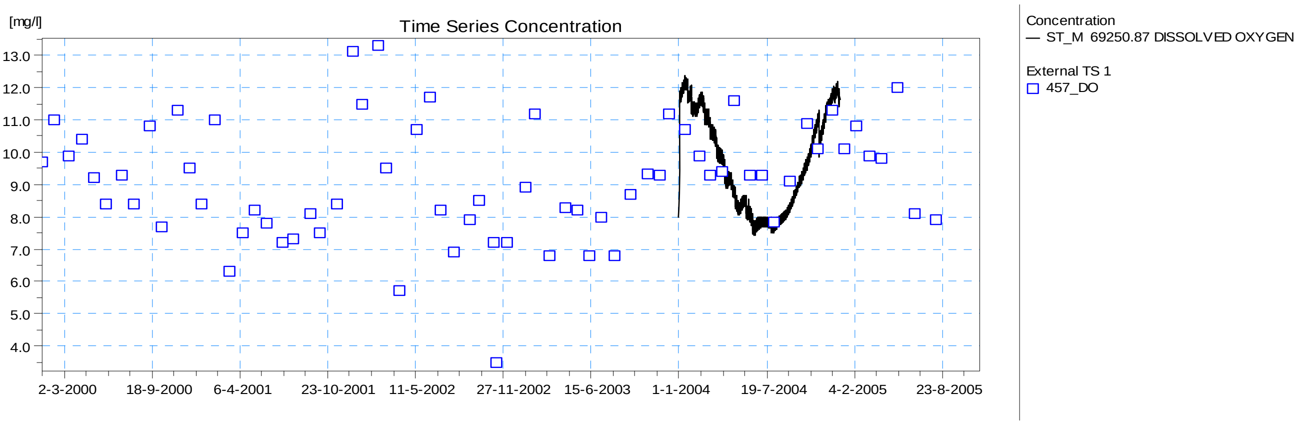


Figure E.5.13 Simulated and Monitored Oxygen (DO) Concentration at St. 457, The Struma River

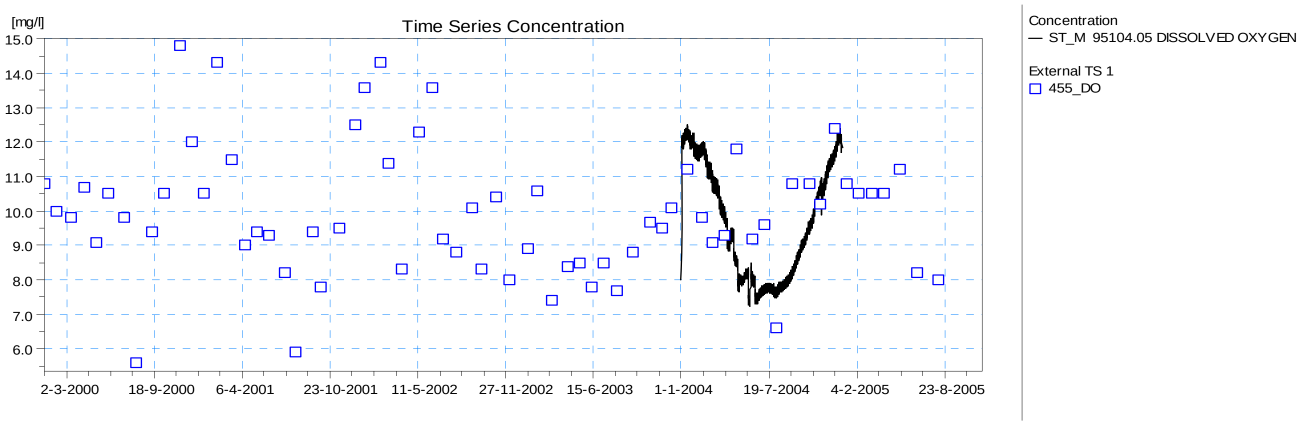


Figure E.5.14 Simulated and Monitored Oxygen (DO) Concentration at St. 455, The Struma River

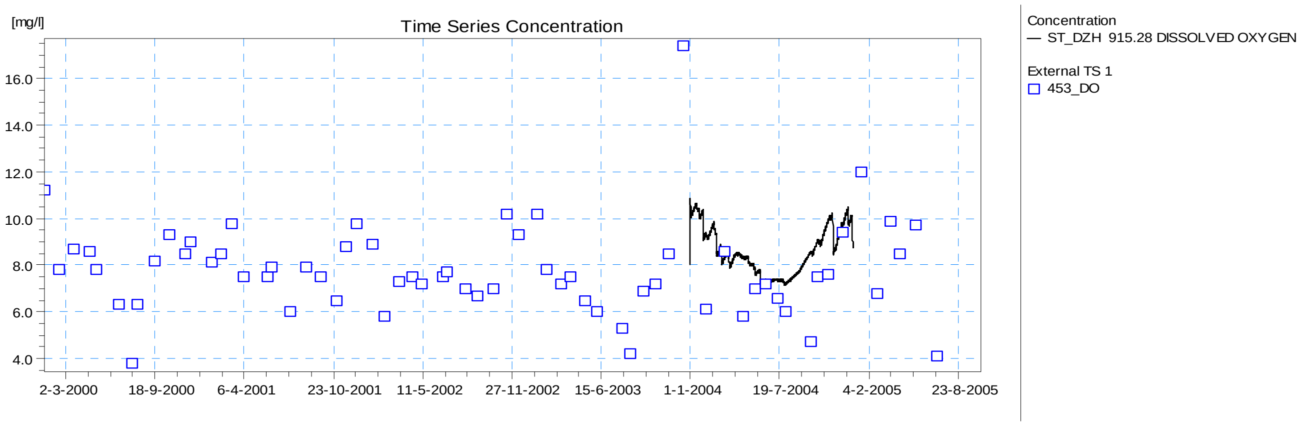


Figure E.5.15 Simulated and Monitored Oxygen (DO) Concentration at St. 453, The Struma River

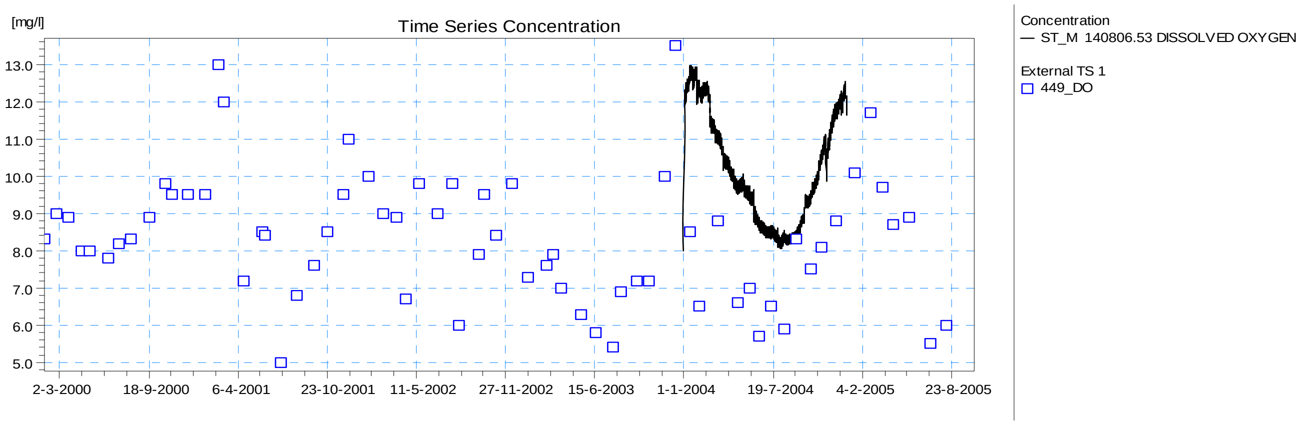


Figure E.5.16 Simulated and Monitored Oxygen (DO) Concentration at St. 449, The Struma River

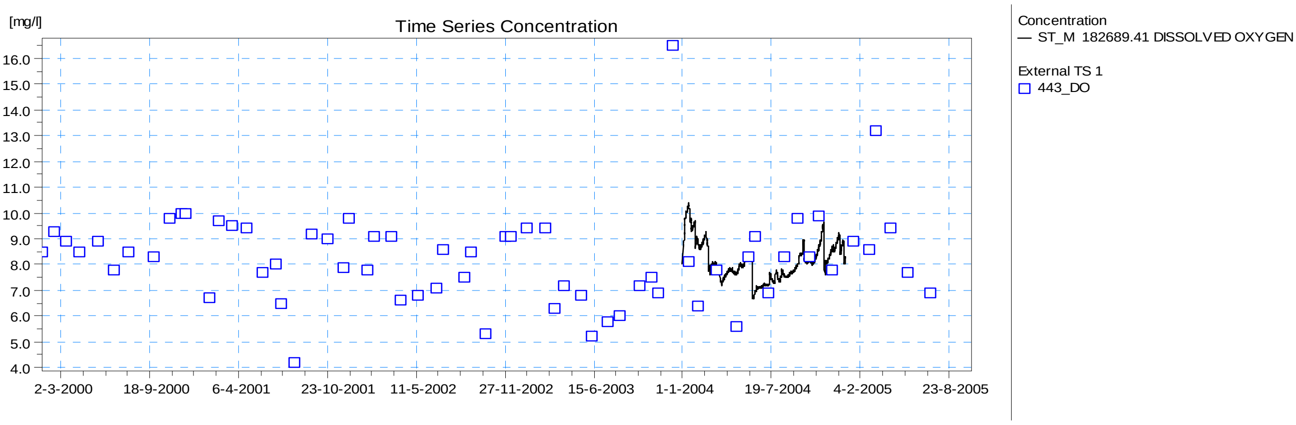


Figure E.5.17 Simulated and Monitored Oxygen (DO) Concentration at St. 443, The Struma River

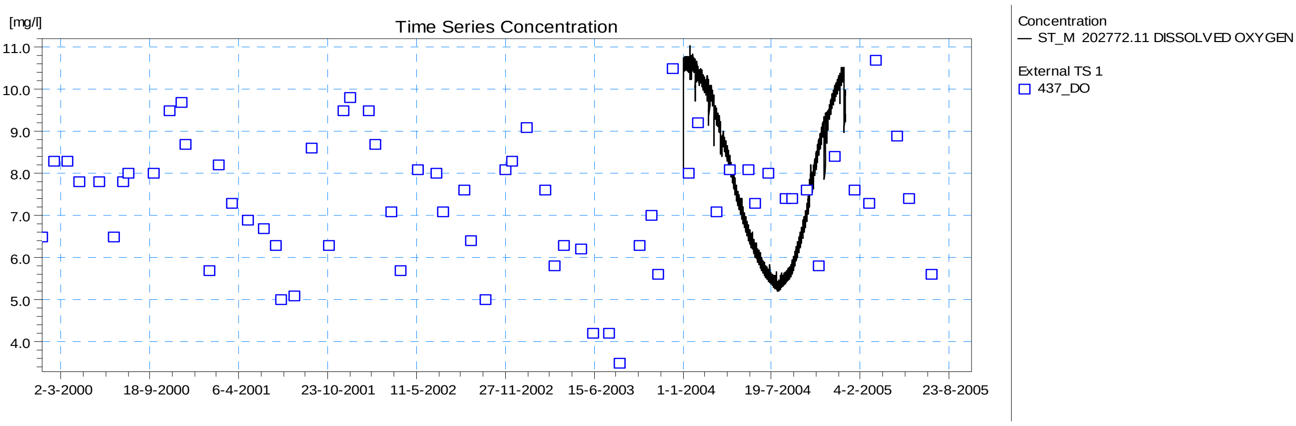


Figure E.5.18 Simulated and Monitored Oxygen (DO) Concentration at St. 437, The Struma River

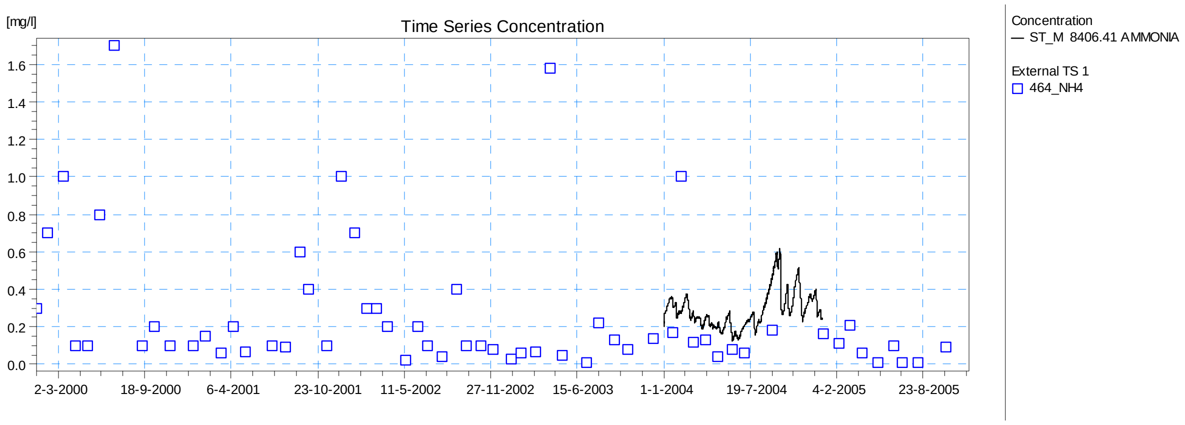


Figure E.5.19 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 464, The Struma River

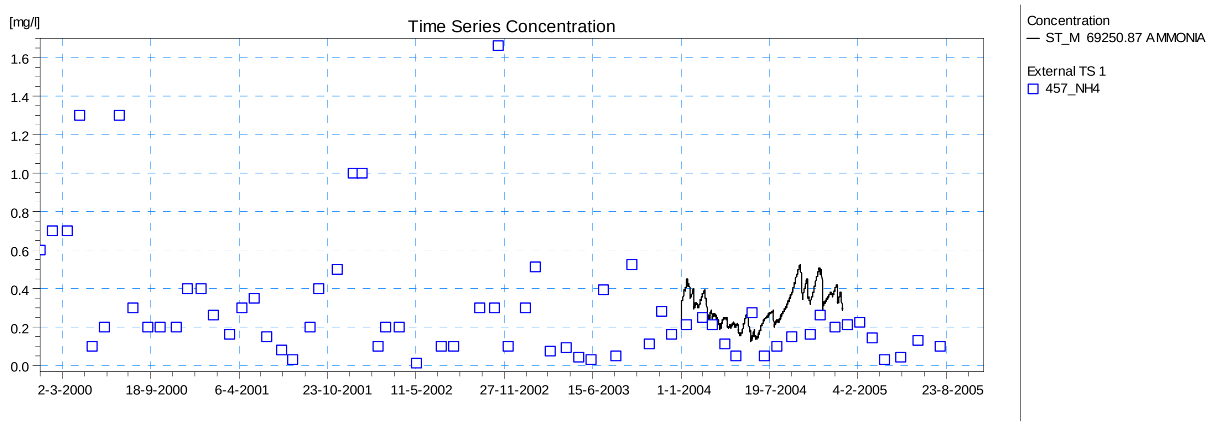


Figure E.5.20 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 457, The Struma River

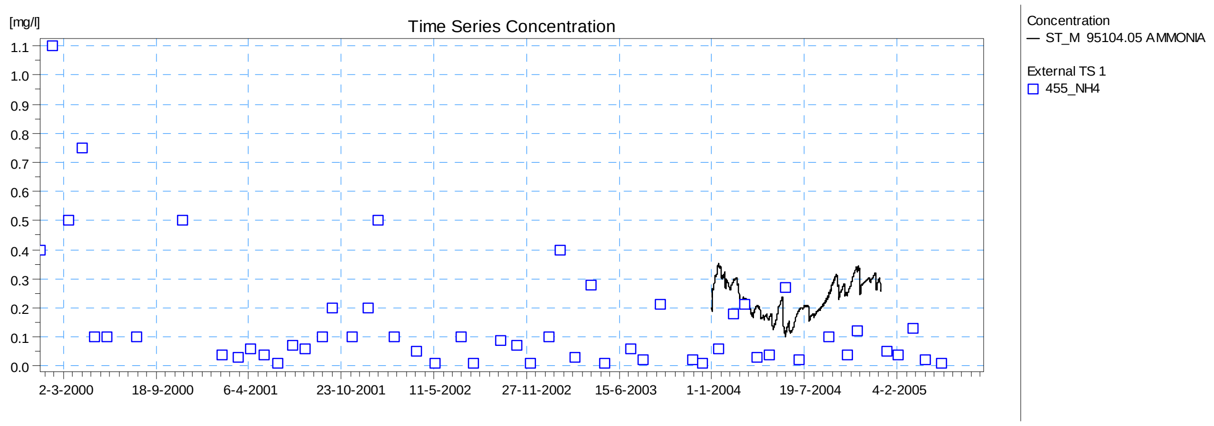


Figure E.5.21 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 455, The Struma River

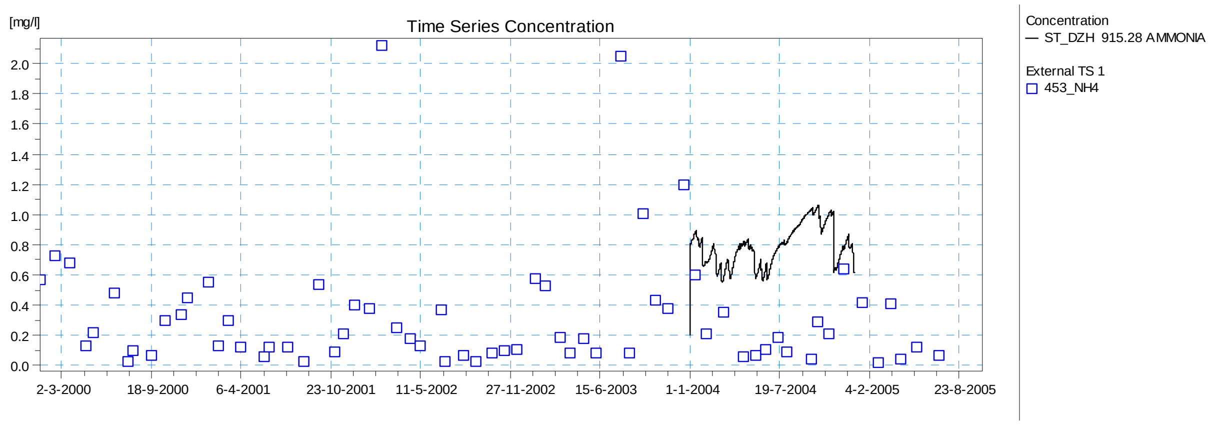


Figure E.5.22 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 453, The Struma River

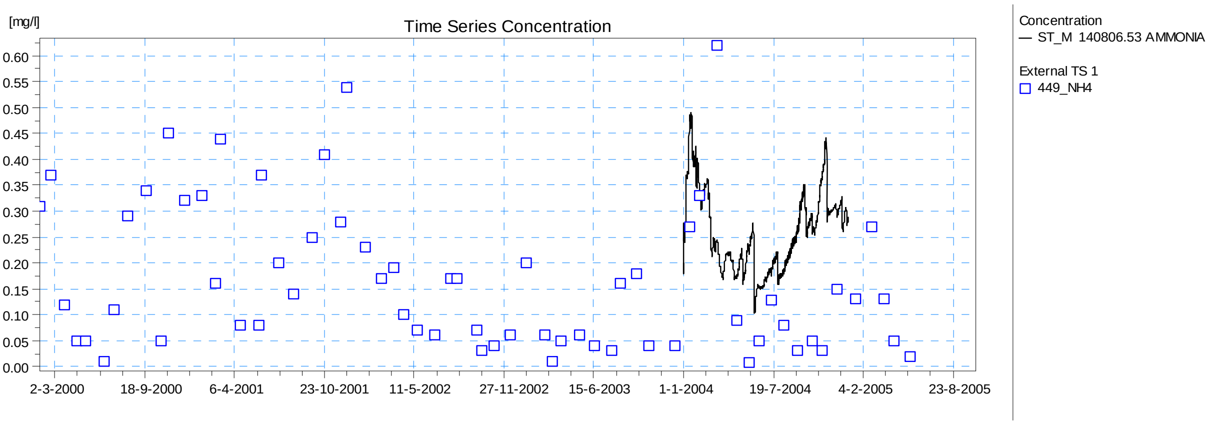


Figure E.5.23 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 449, The Struma River

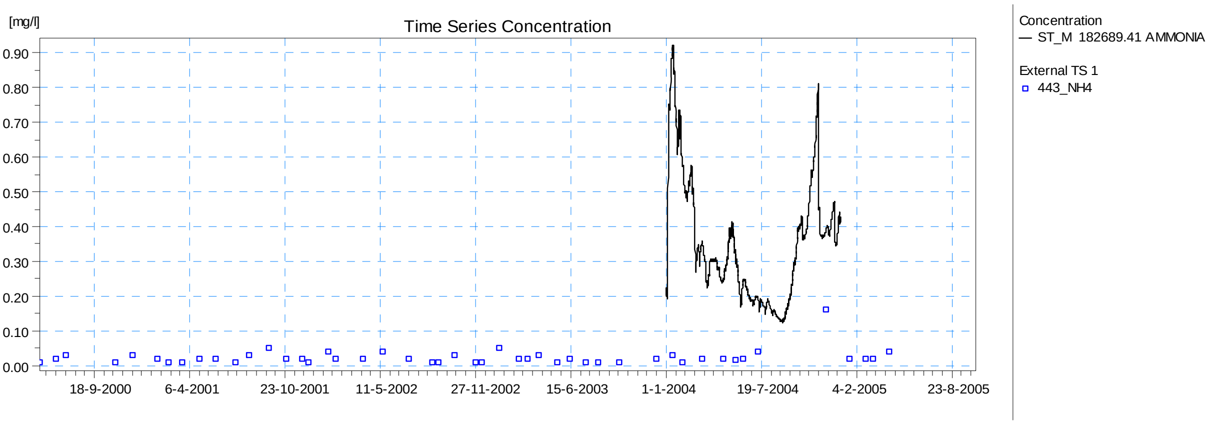


Figure E.5.24 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 443, The Struma River

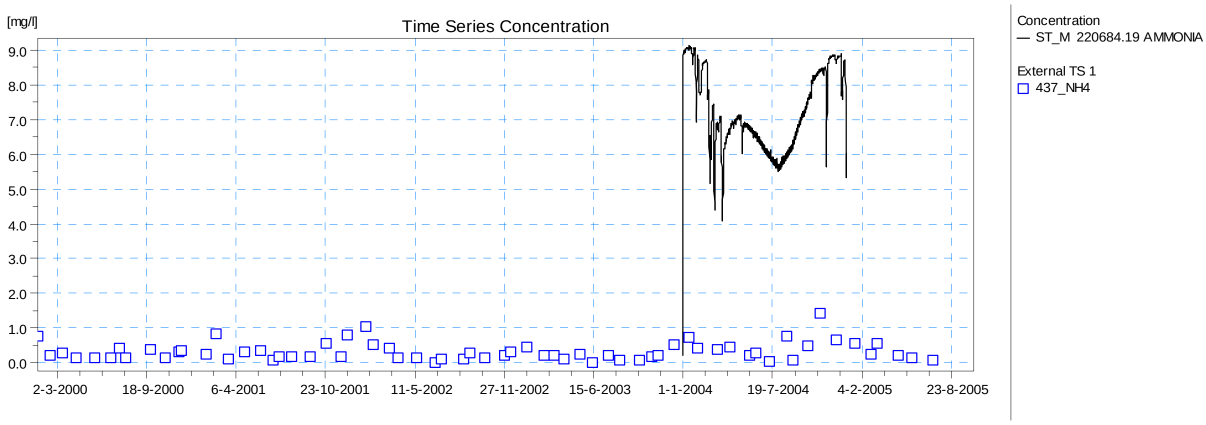


Figure E.5.25 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 437, The Struma River

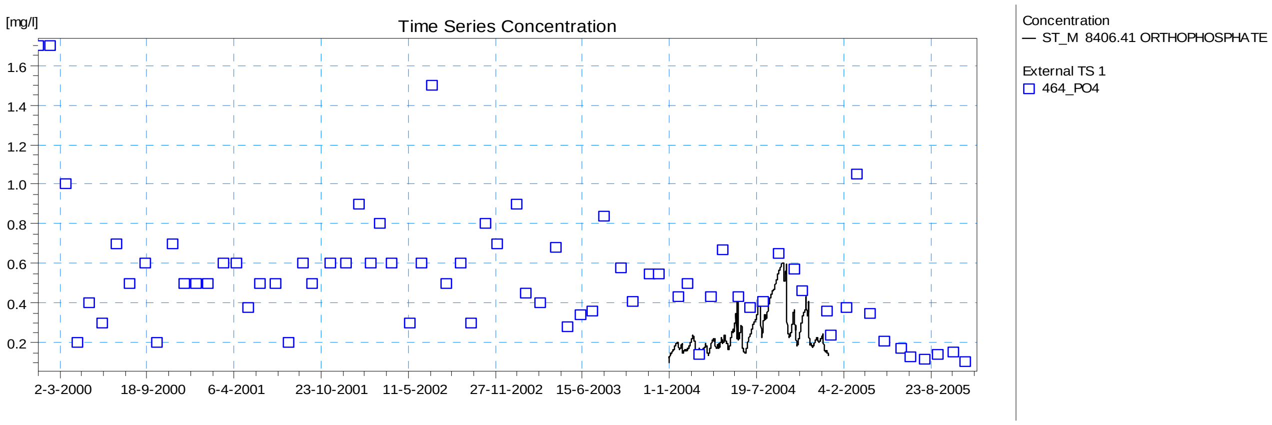


Figure E.5.26 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 464, The Struma River

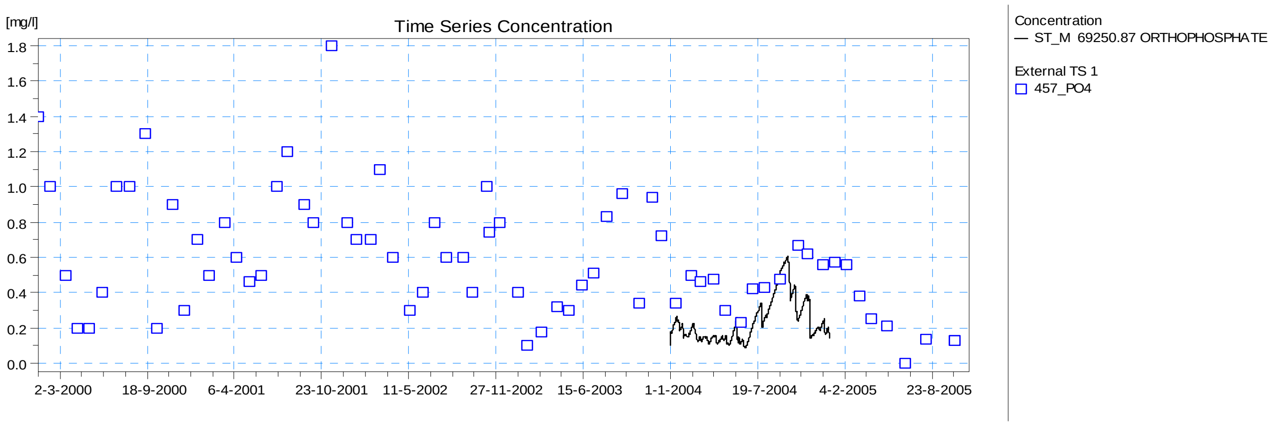


Figure E.5.27 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 457, The Struma River

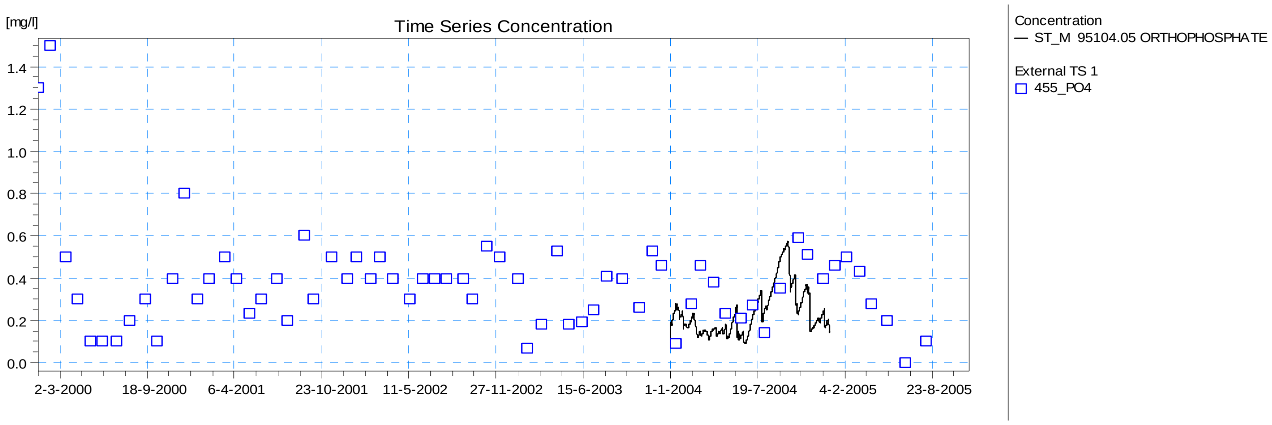


Figure E.5.28 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 455, The Struma River

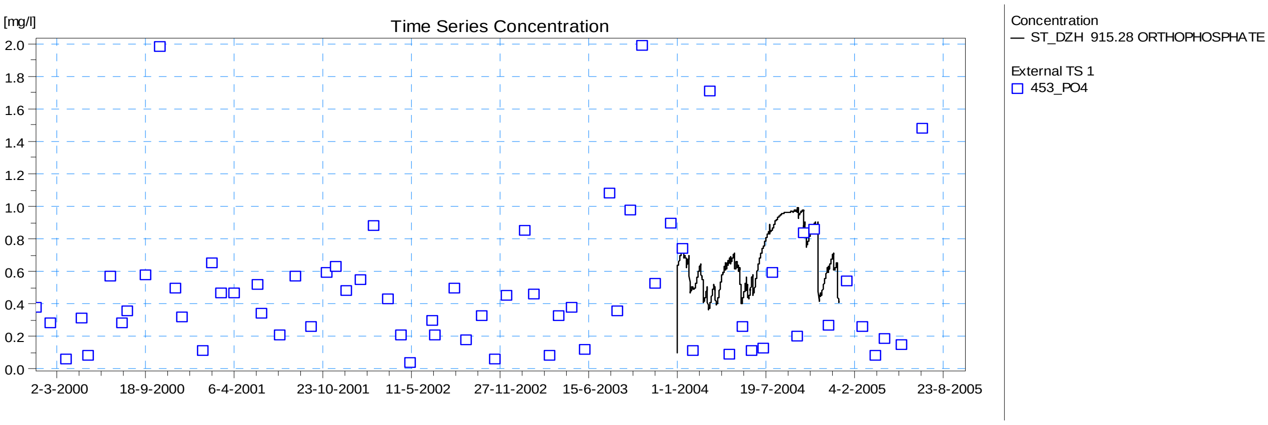


Figure E.5.29 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 453, The Struma River

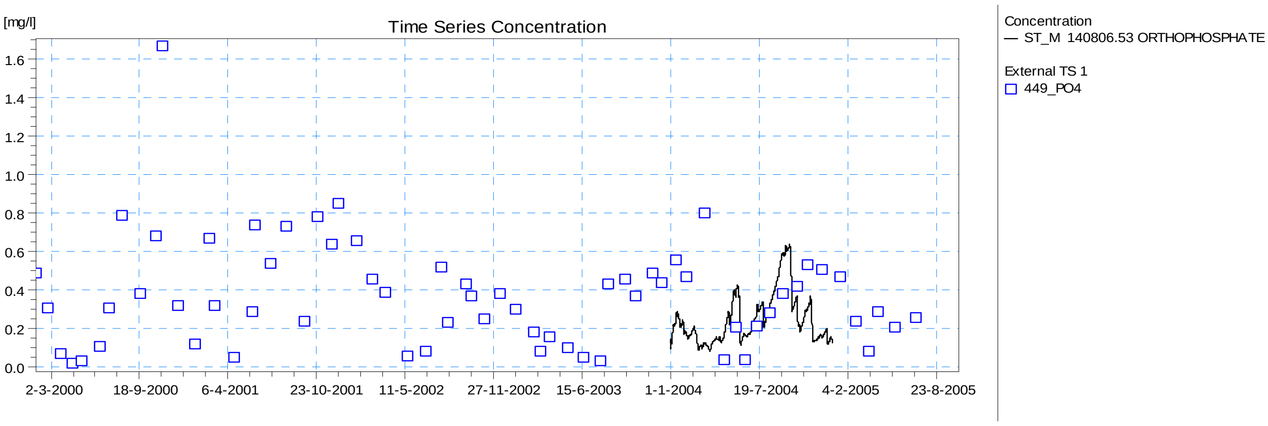


Figure E.5.30 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 449, The Struma River

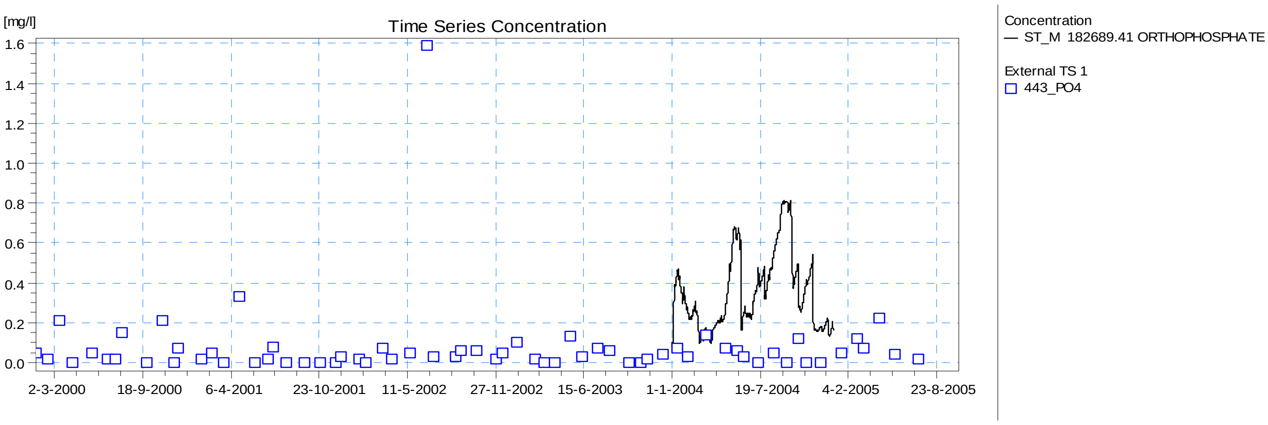


Figure E.5.31 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 443, The Struma River

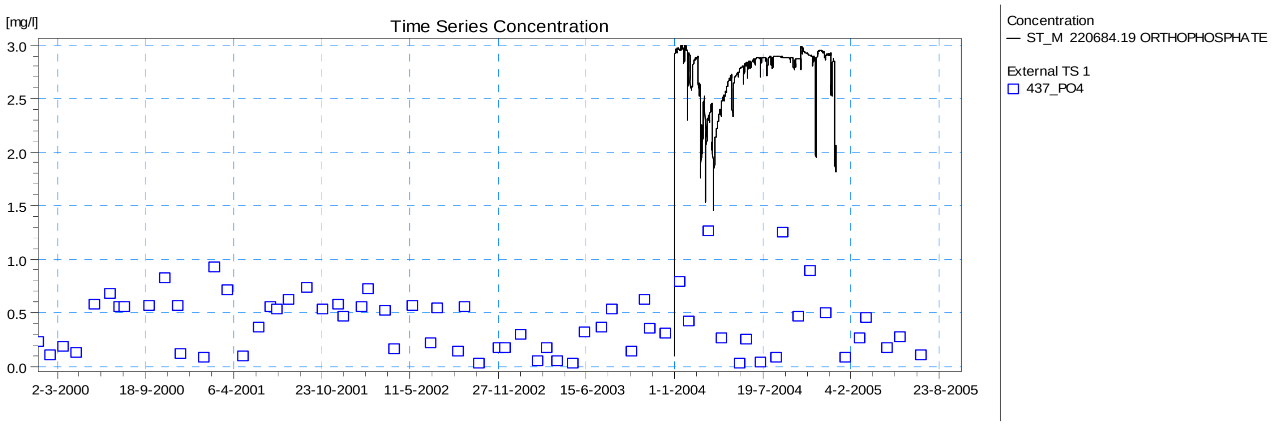
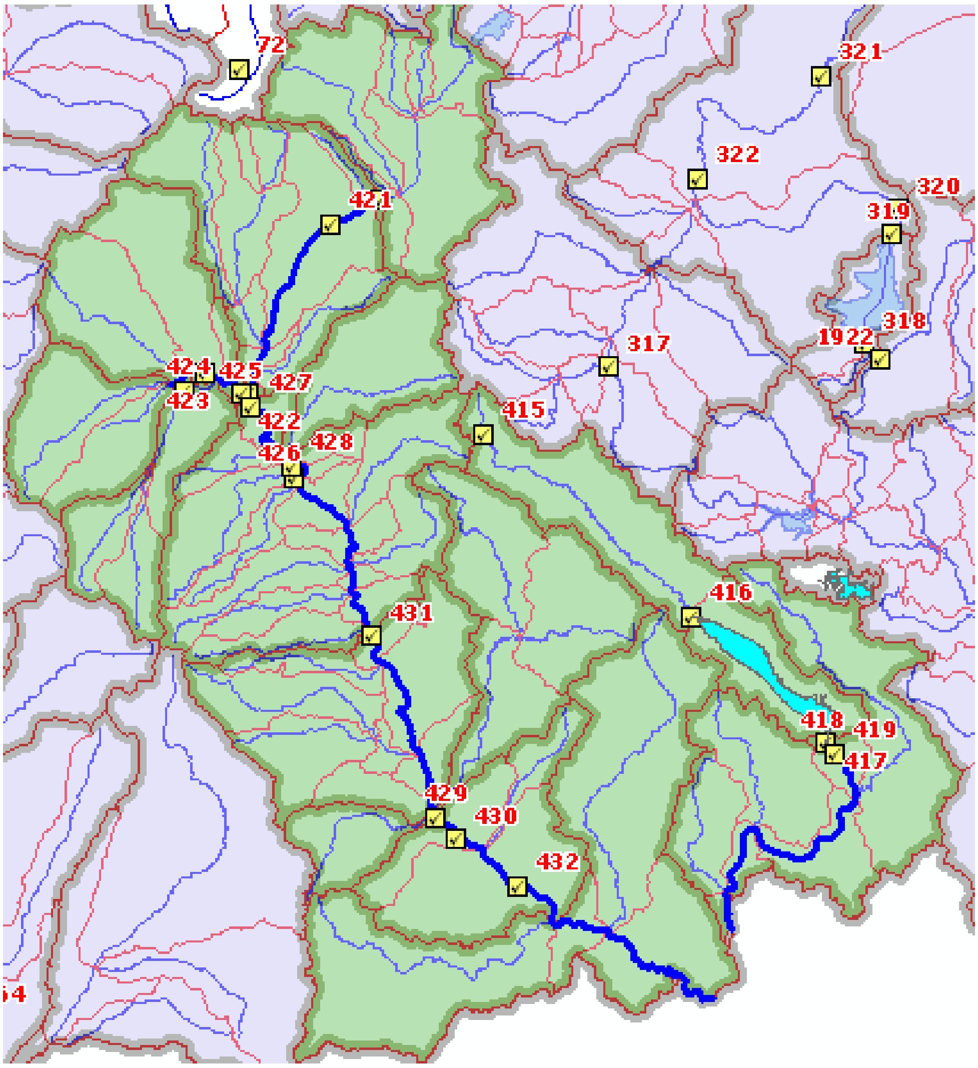


Figure E.5.32 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 437, The Struma River



Note: Water quality is not monitored at all monitoring stations.

Stations in the Mesta/Dospat Rivers selected for presentation of calibration results

Monitoring station	MIKE 11 Branch	MIKE 11 chainage
432	Me_M	21,250
431	Me_M	47,429
422	Me_M	83,879
419	Do_M	24,661

Figure E.5.33 The Mesta River Basin (green) with MIKE 11 River Branches (thick blue) and Monitoring Stations (yellow squares)

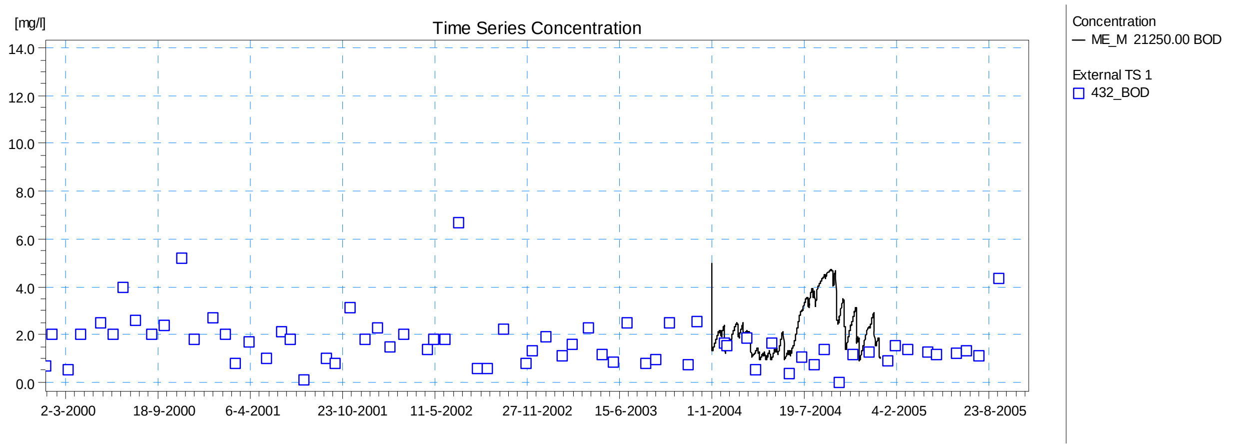


Figure E.5.34 Simulated and Monitored BOD Concentration, St. 432, The Mesta River

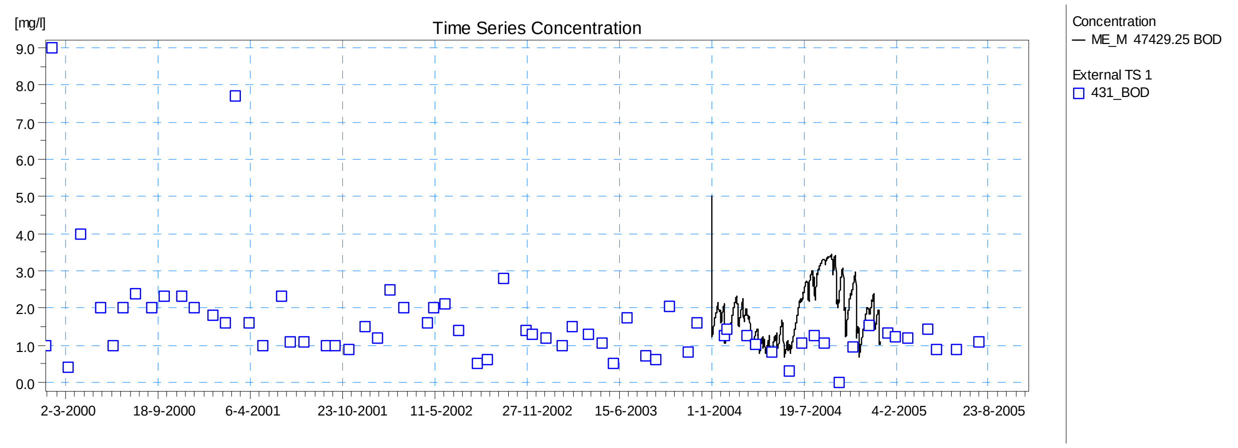


Figure E.5.35 Simulated and Monitored BOD Concentration, St. 431, The Mesta River

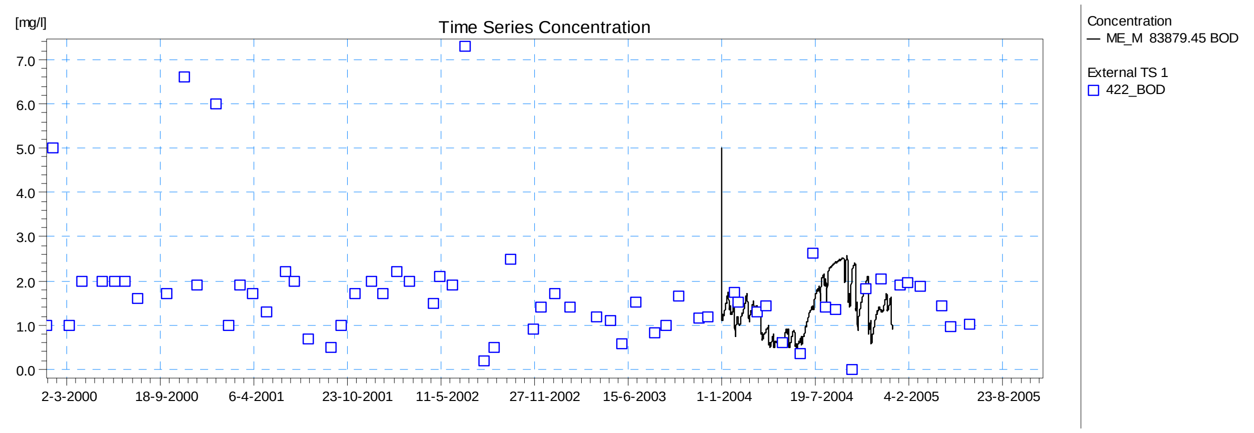


Figure E.5.36 Simulated and Monitored BOD Concentration, St. 422, The Mesta River

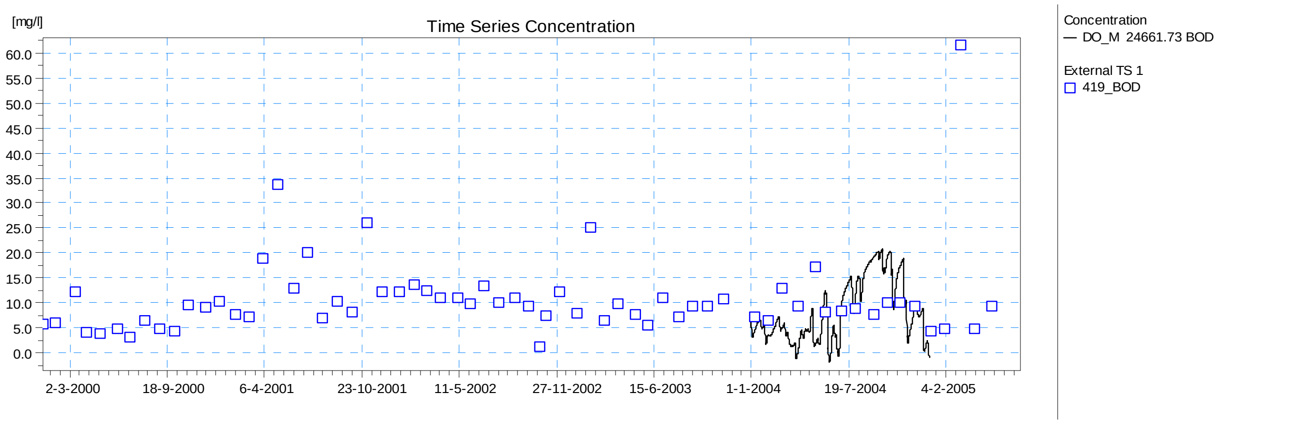


Figure E.5.37 Simulated and Monitored BOD Concentration, St. 419, The Dospat River

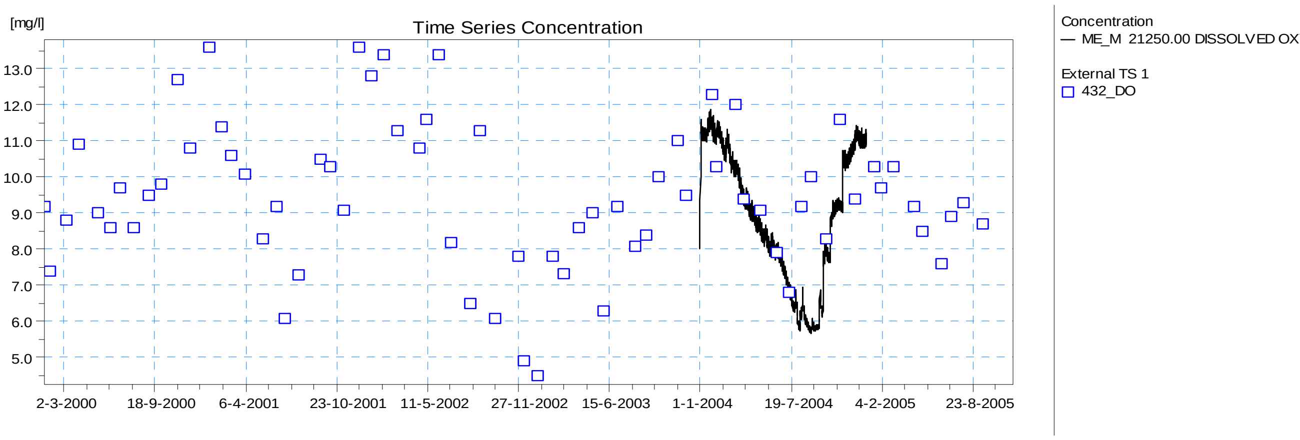


Figure E.5.38 Simulated and Monitored Oxygen (DO) Concentration at St. 432, The Mesta River

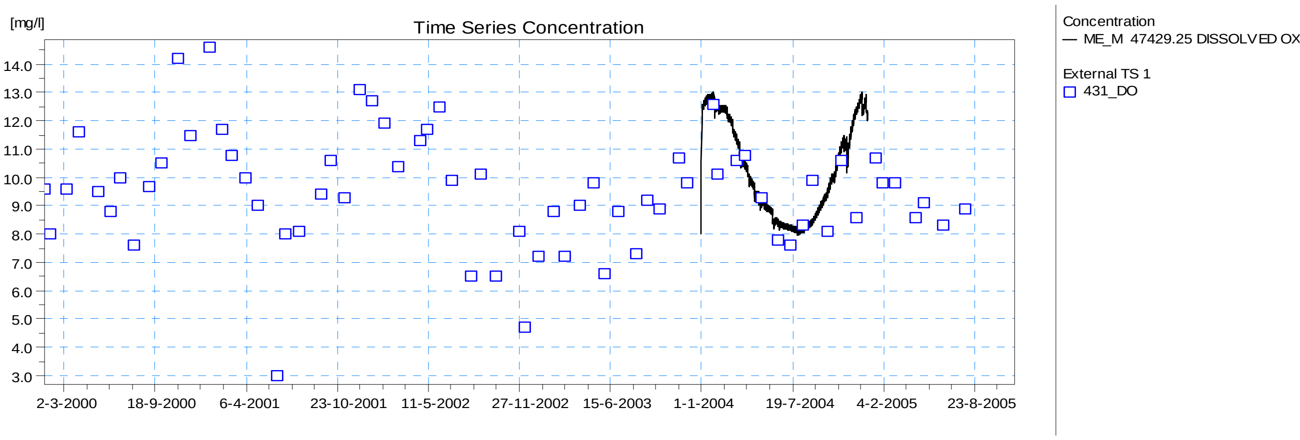


Figure E.5.39 Simulated and Monitored Oxygen (DO) Concentration at St. 431 in The Mesta River

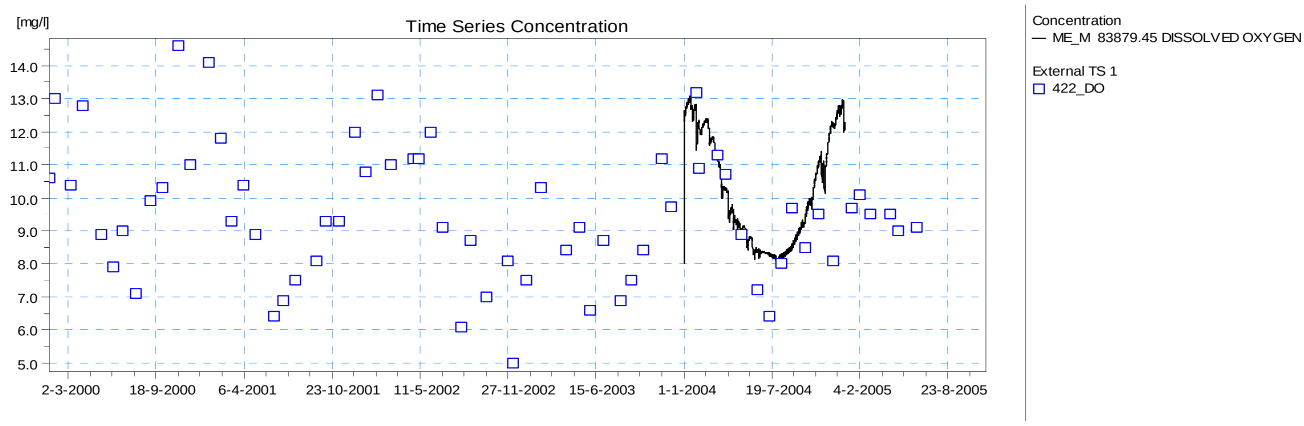


Figure E.5.40 Simulated and Monitored Oxygen (DO) Concentration at St. 422, The Mesta River

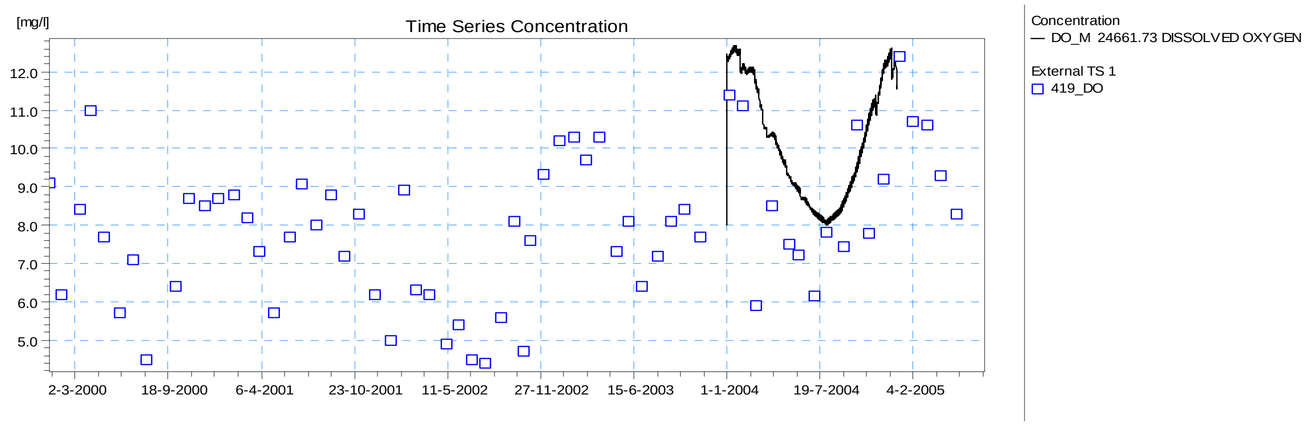


Figure E.5.41 Simulated and Monitored Oxygen (DO) Concentration at St. 419, The Dospat River

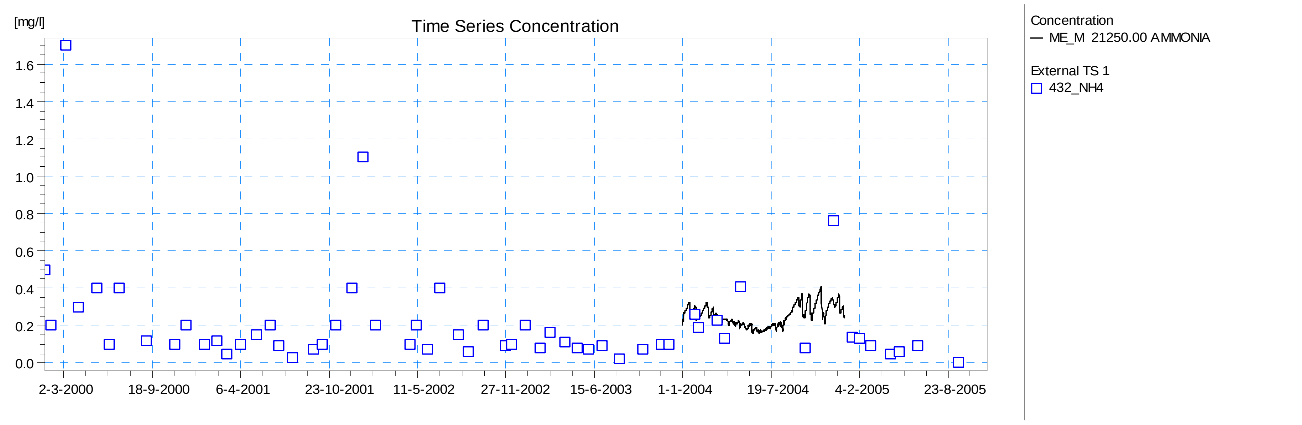


Figure E.5.42 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 432, The Mesta River

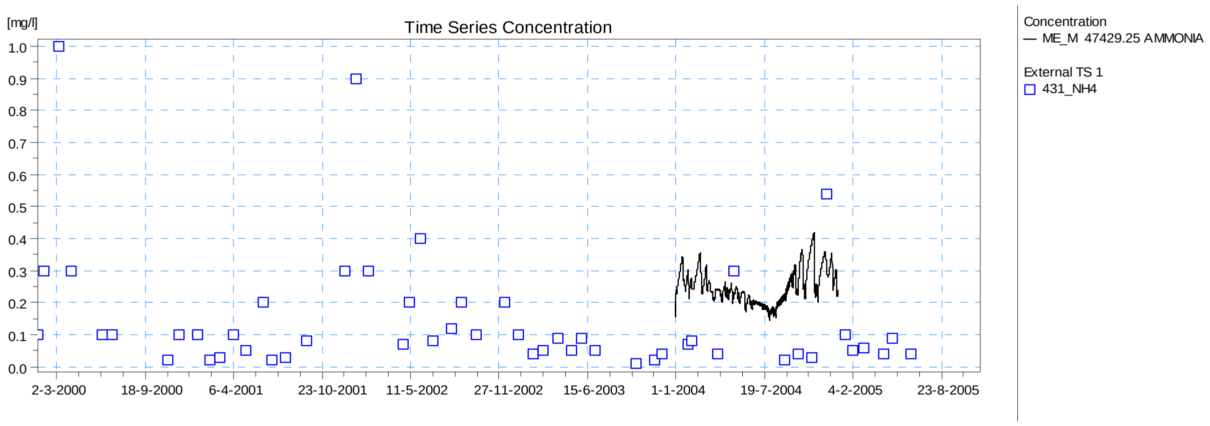


Figure E.5.43 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 431, The Mesta River

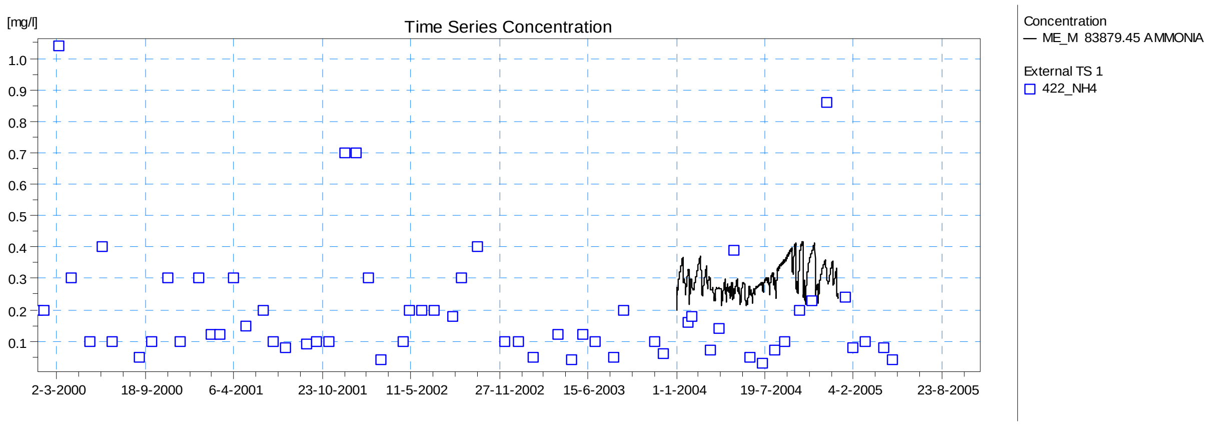


Figure E.5.44 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 422, The Mesta River

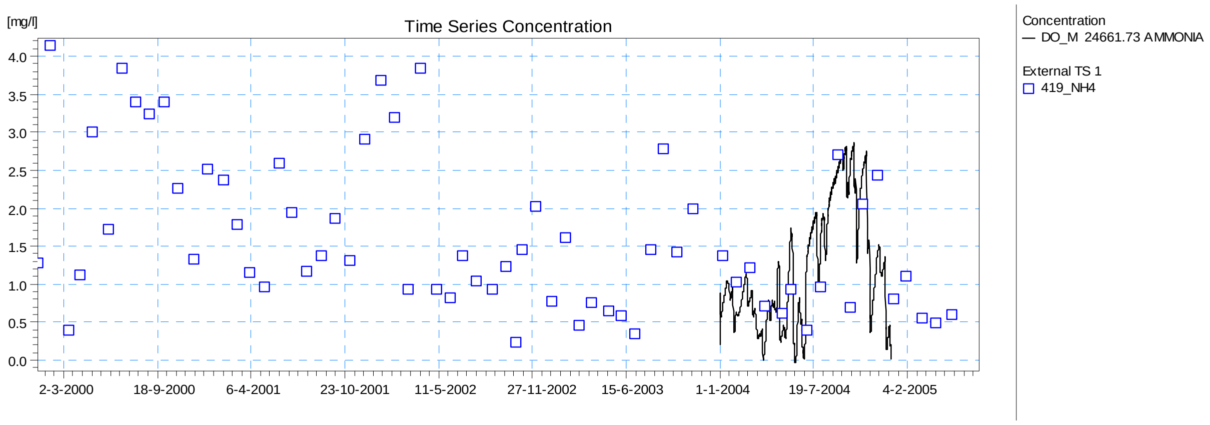


Figure E.5.45 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 419, The Dospat River

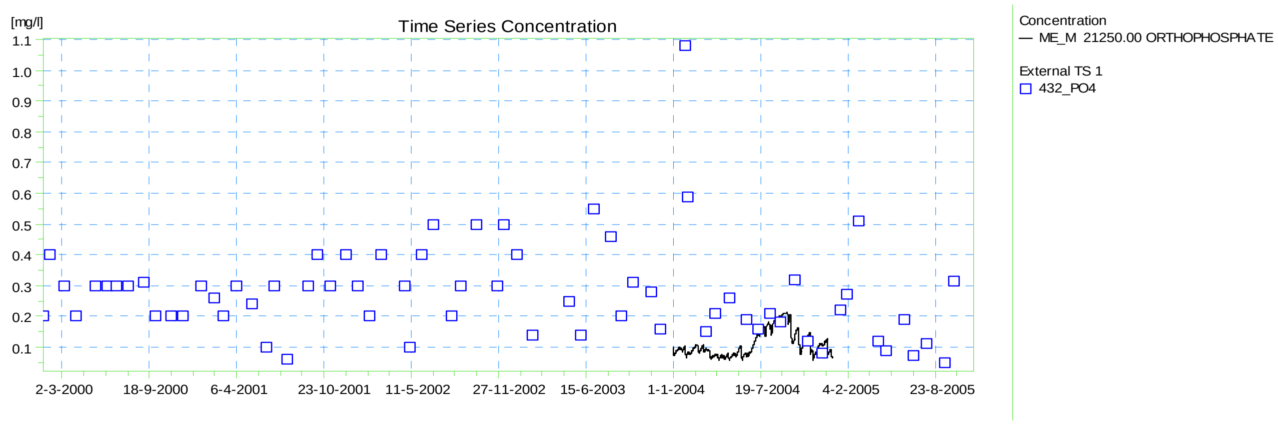


Figure E.5.46 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 432, The Mesta River

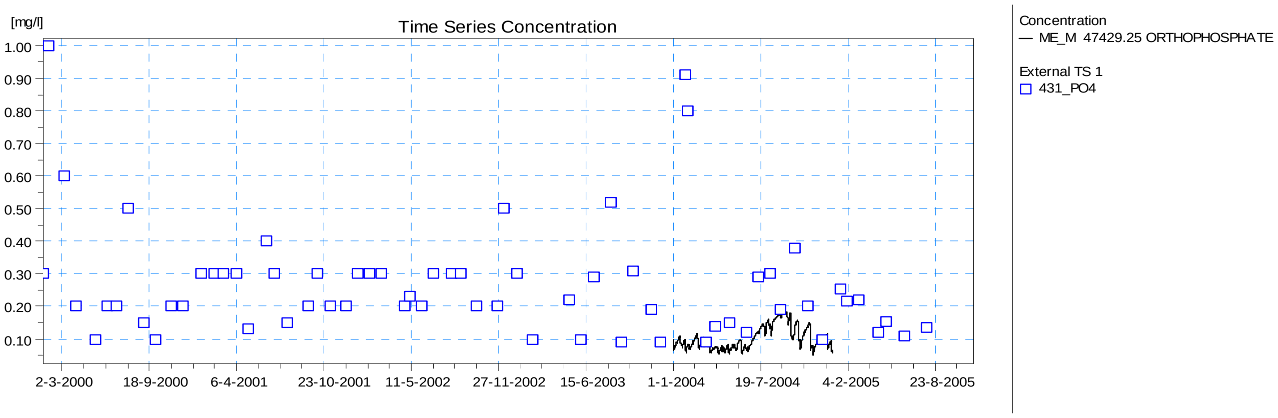


Figure E.5.47 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 431, The Mesta River

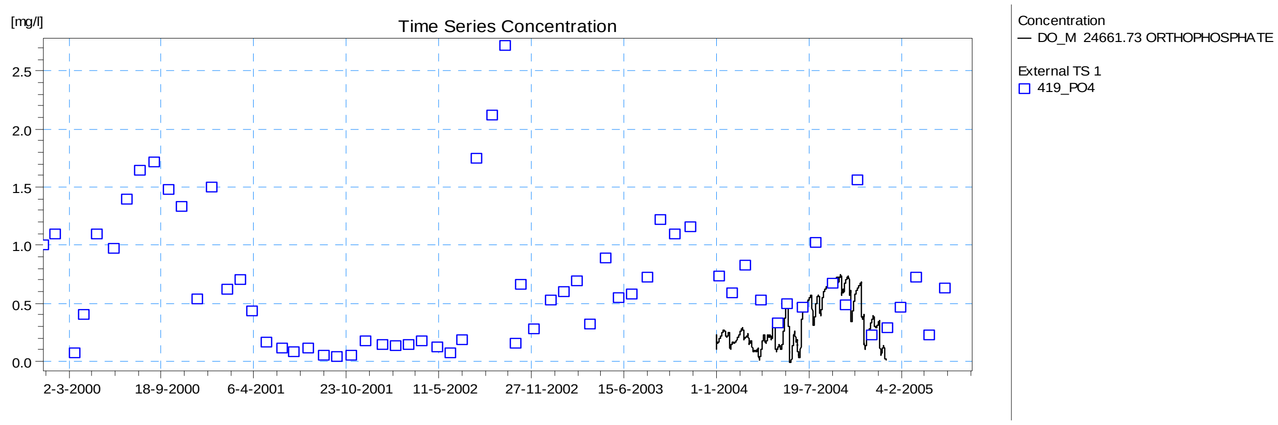
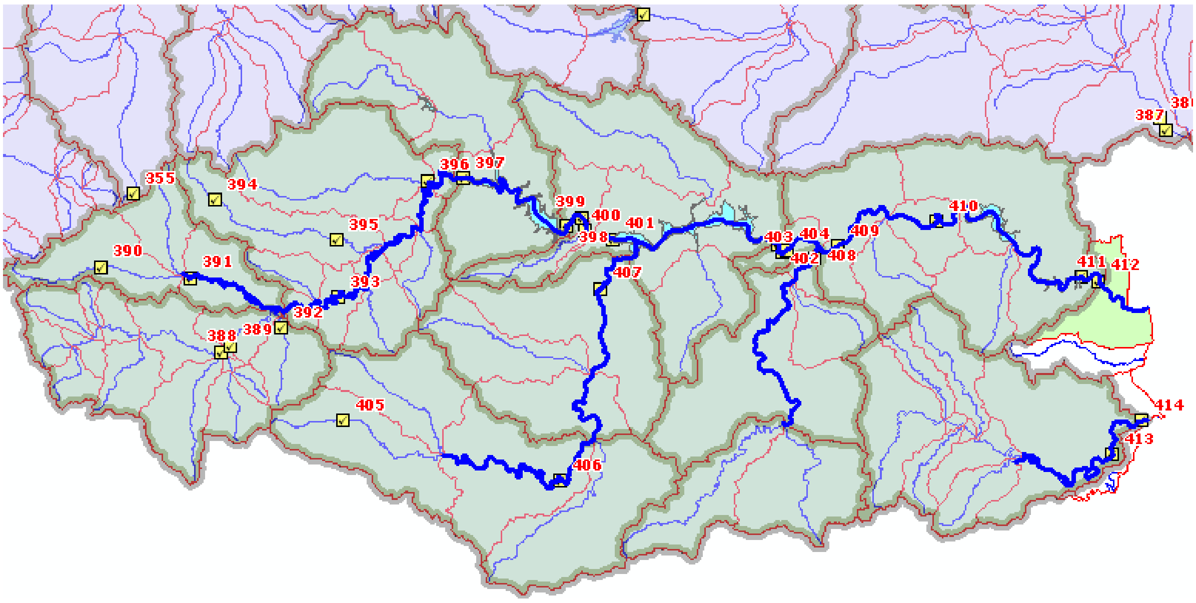


Figure E.5.48 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 419, The Dospat River



Station in the Arda River selected for presentation of calibration results

Monitoring station	MIKE 11 Branch	MIKE 11 chainage
412	AR_M	13,198
410	AR_M	42,737
402	AR_M	70,219
400	AR_M	97,960
399	AR_M	99,960
397	AR_M	127.068

Figure E.5.49 The Arda River Basin (green) with MIKE 11 River Branches (thick blue) and Monitoring Stations (yellow squares)

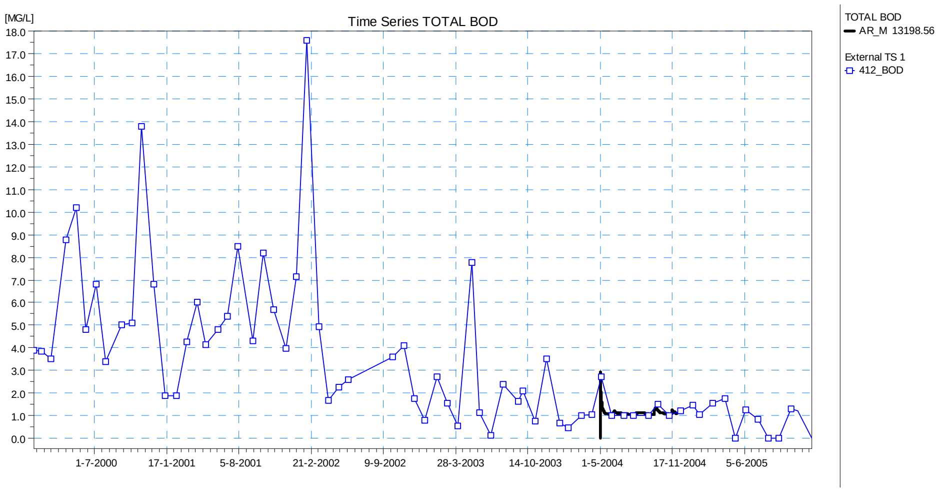


Figure E.5.50 Simulated and Monitored BOD Concentration, St. 412, The Arda River

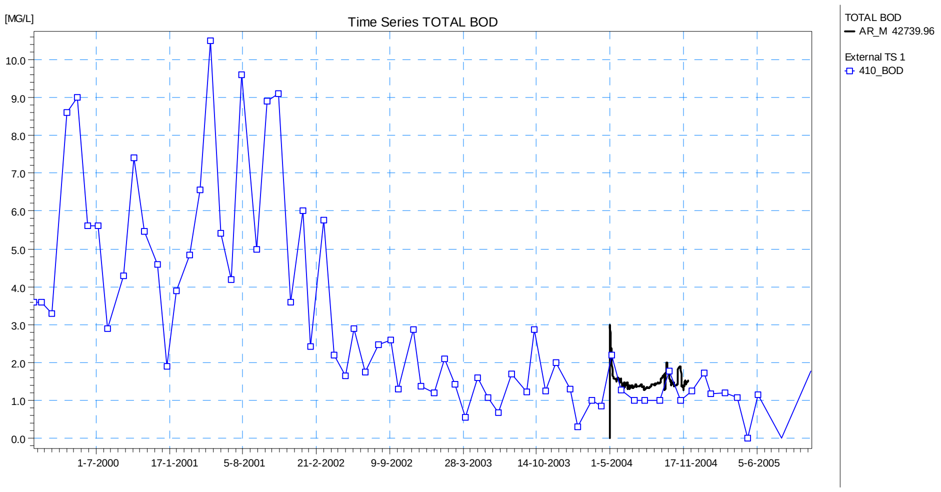


Figure E.5.51 Simulated and Monitored BOD Concentration, St. 410, The Arda River

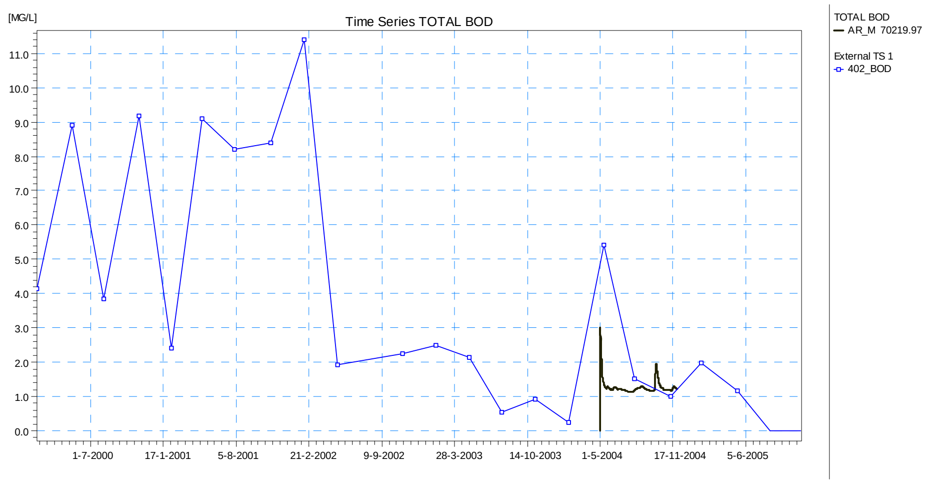


Figure E.5.52 Simulated and Monitored BOD Concentration, St. 402, The Arda River

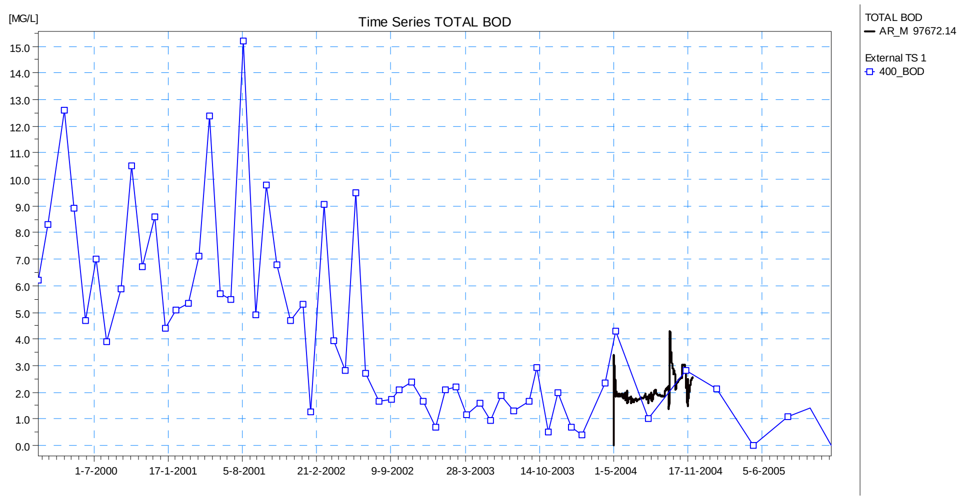


Figure E.5.53 Simulated and Monitored BOD Concentration, St. 400, The Arda River

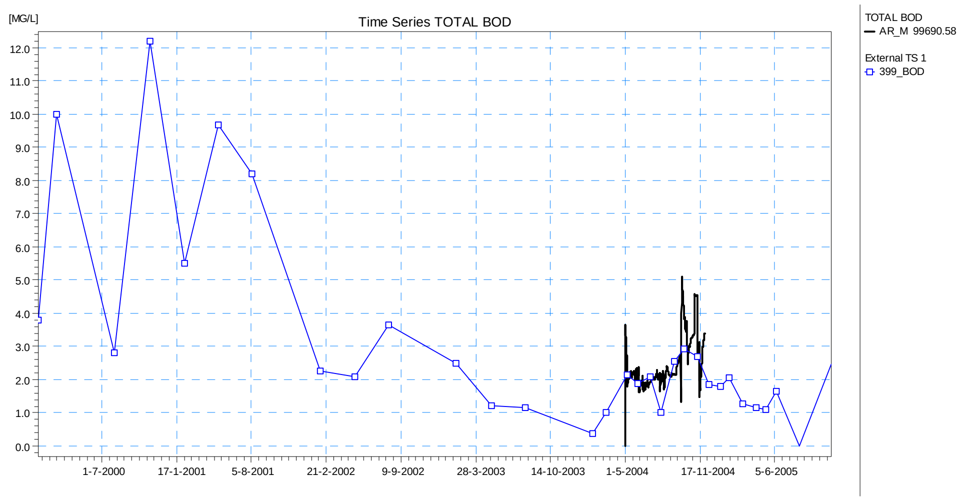


Figure E.5.54 Simulated and Monitored BOD Concentration, St. 399, The Arda River

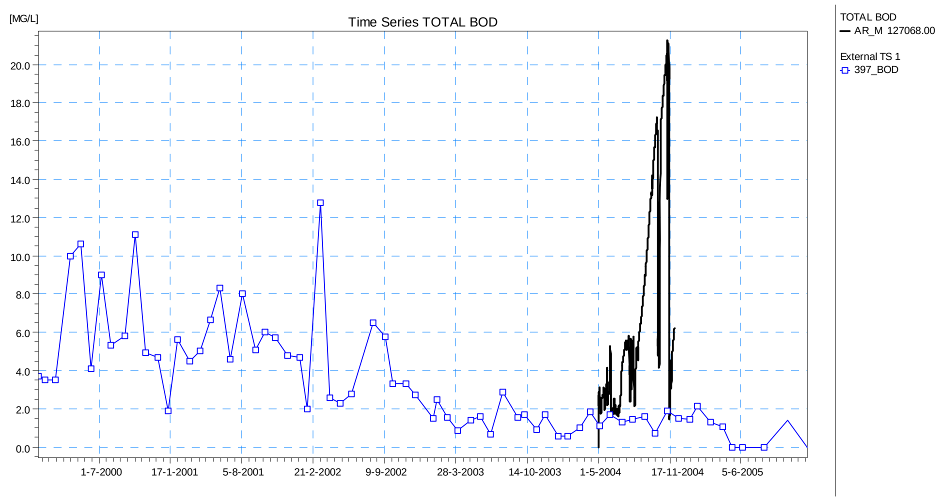


Figure E.5.55 Simulated and Monitored BOD Concentration, St. 397, The Arda River

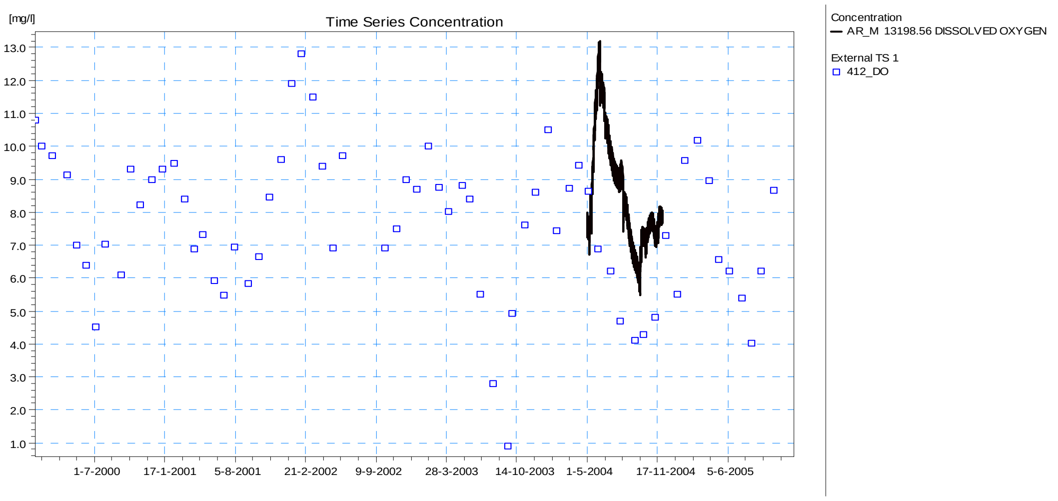


Figure E.5.56 Simulated and Monitored Oxygen (DO) Concentration, St. 412, The Arda River

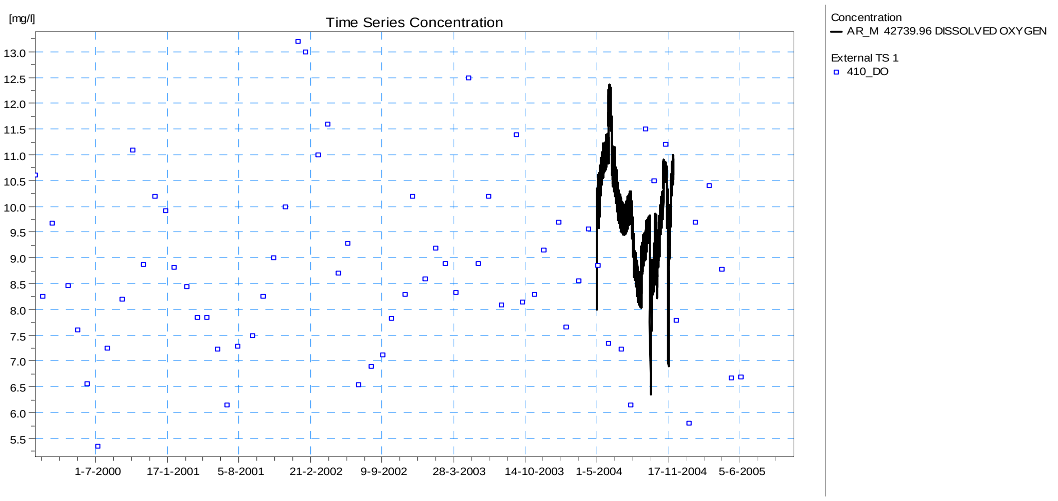


Figure E.5.57 Simulated and Monitored Oxygen (DO) Concentration, St. 410, The Arda River

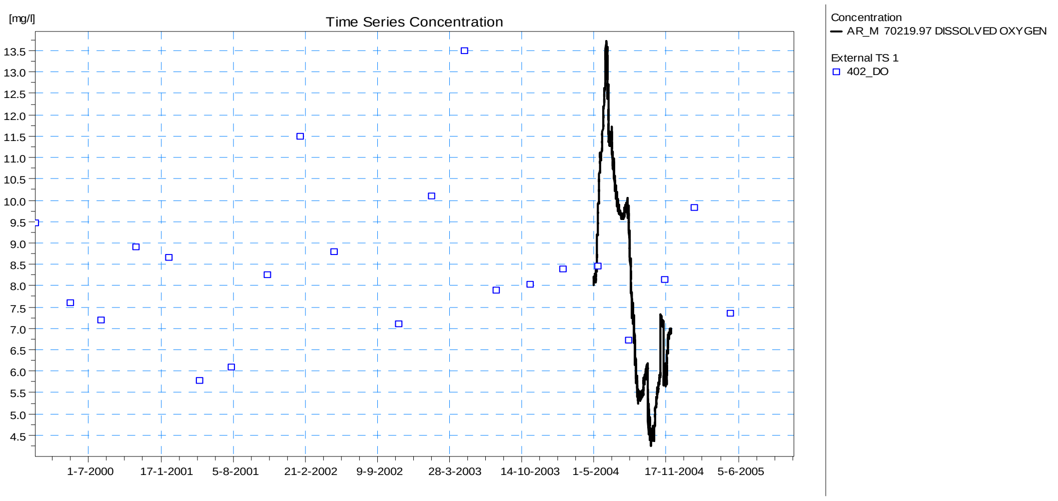


Figure E.5.58 Simulated and Monitored Oxygen (DO) Concentration, St. 402, The Arda River

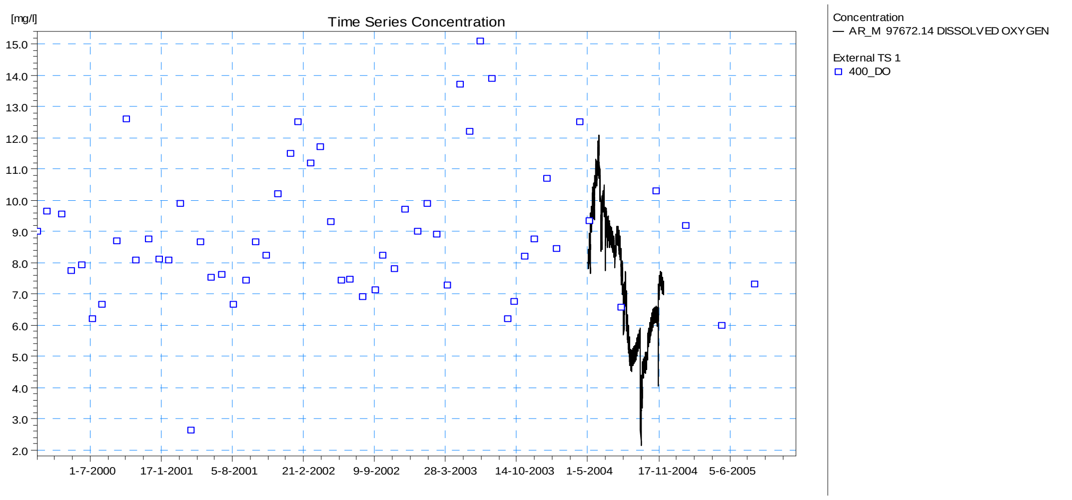


Figure E.5.59 Simulated and Monitored Oxygen (DO) Concentration, St. 400, The Arda River

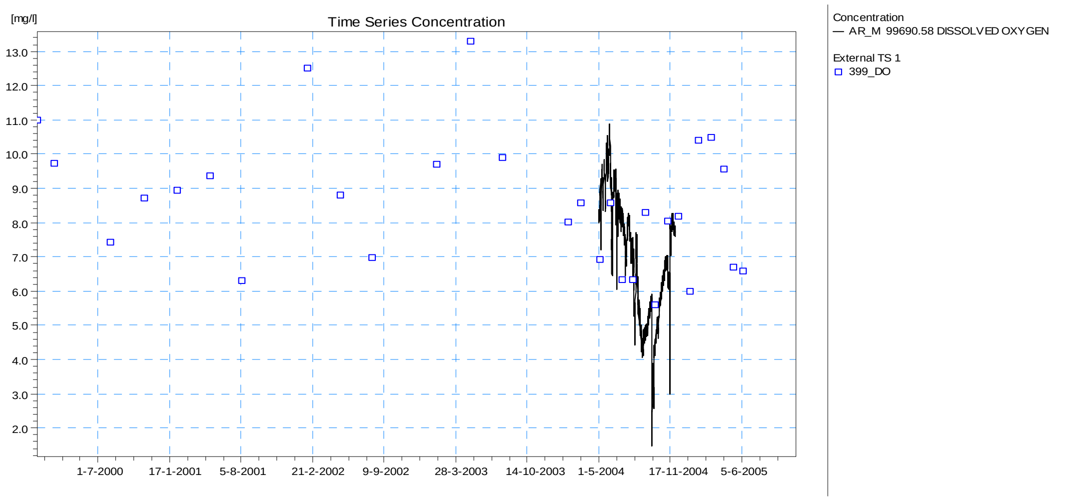


Figure E.5.60 S Simulated and Monitored Oxygen (DO) Concentration, St. 399, The Arda River

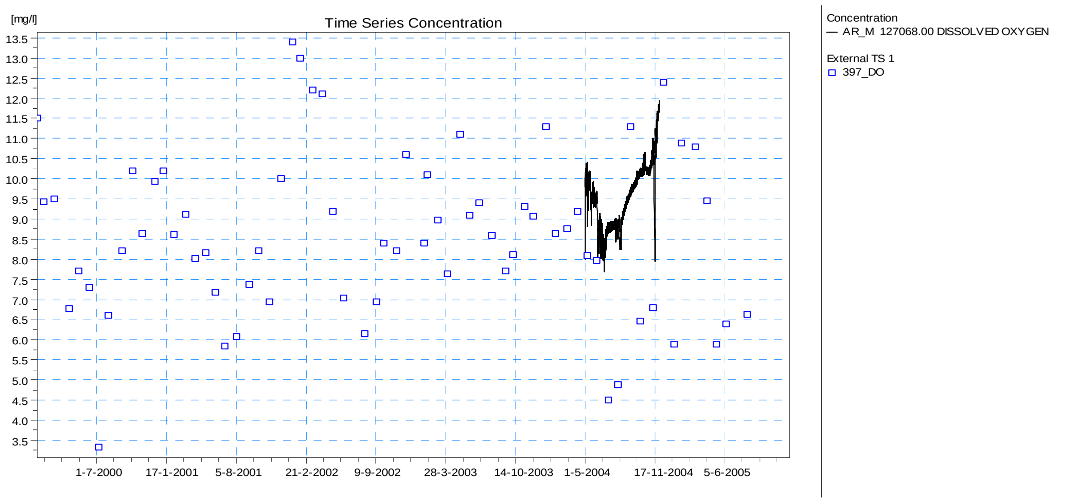


Figure E.5.61 Simulated and Monitored Oxygen (DO) Concentration, St. 397, The Arda River

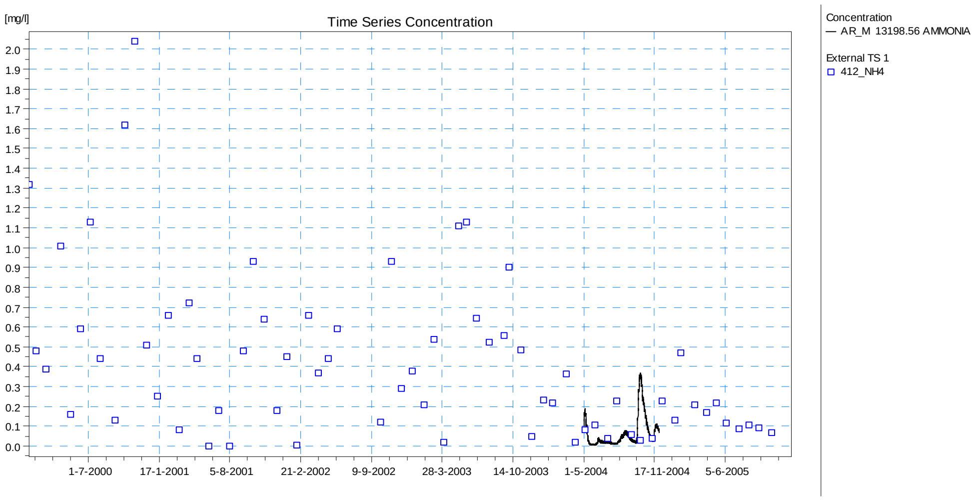


Figure E.5.62 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 412, The Arda River

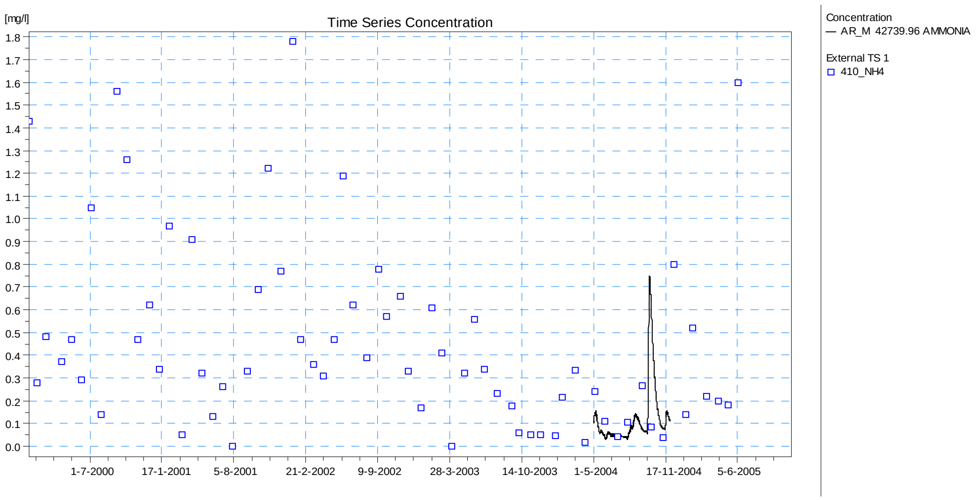


Figure E.5.63 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 410, The Arda River

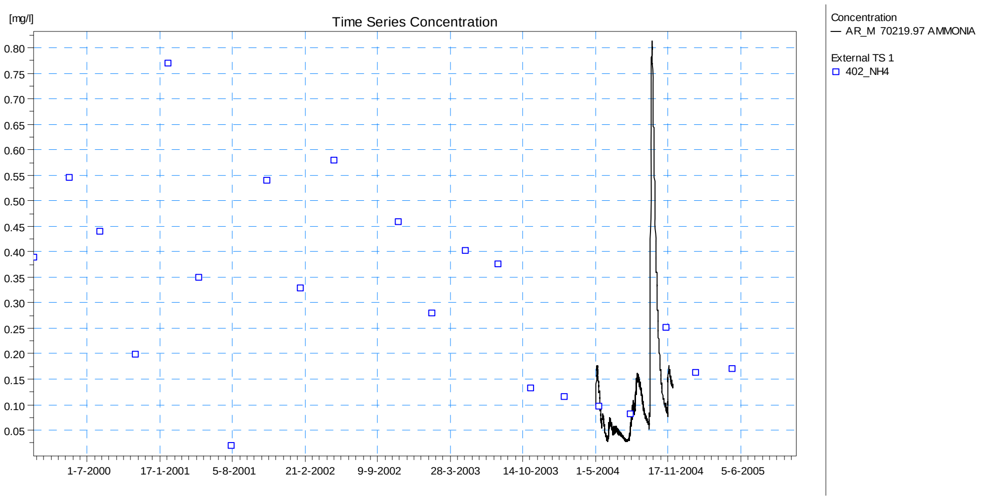


Figure E.5.64 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 402, The Arda River

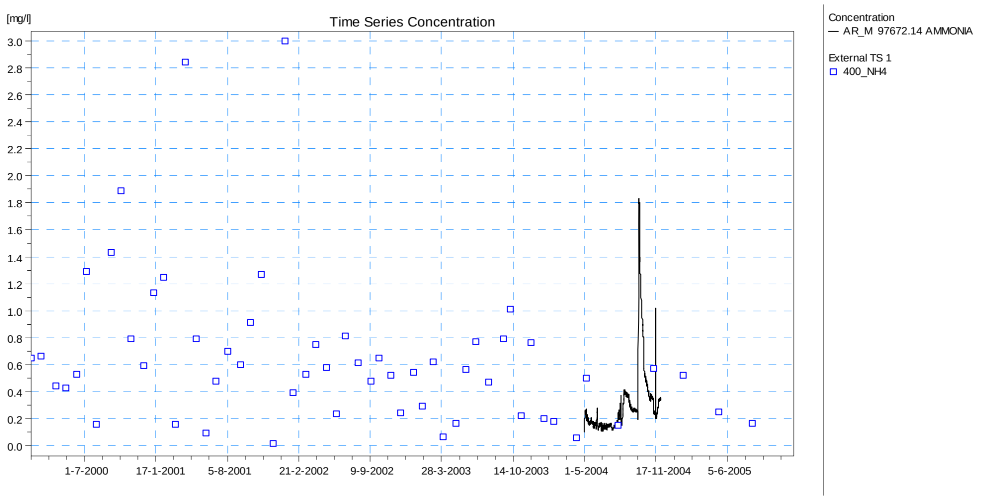


Figure E.5.65 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 400, The Arda River

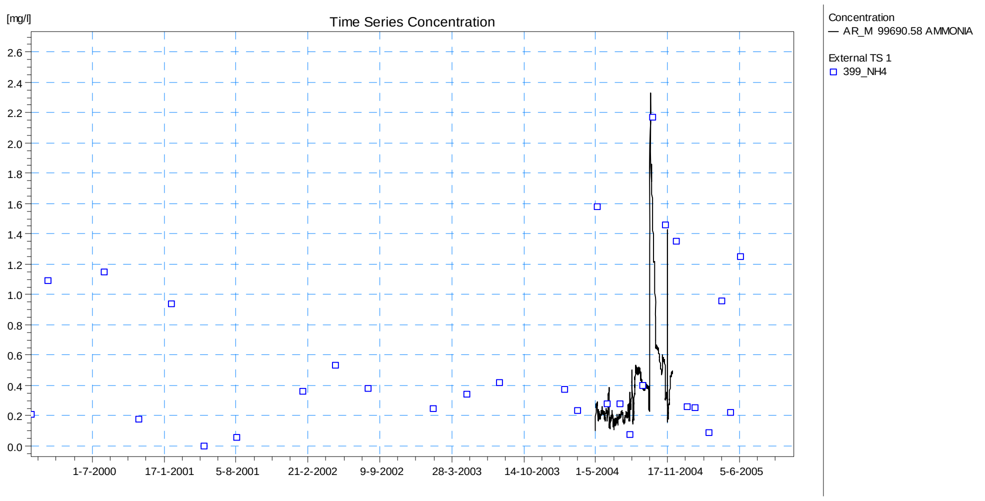


Figure E.5.66 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 399, The Arda River

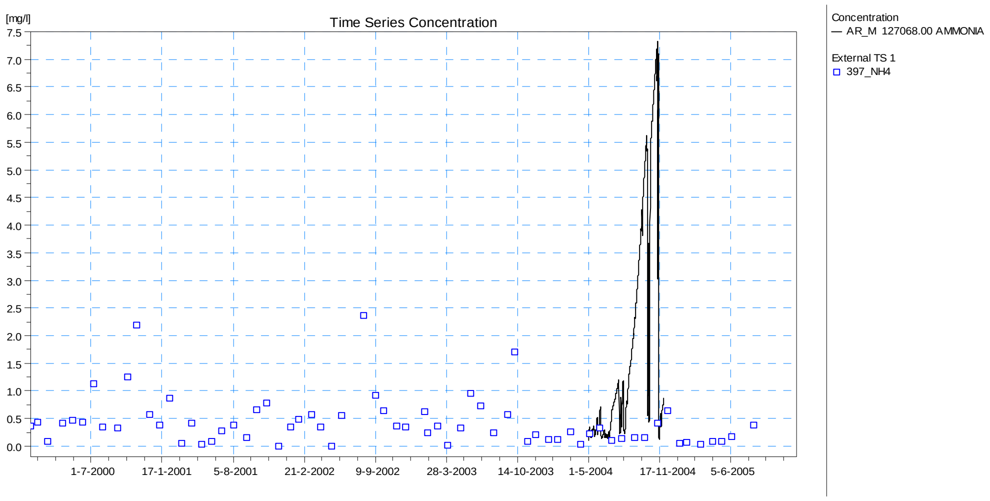


Figure E.5.67 Simulated and Monitored Ammonia (NH_4-N) Concentration, St. 397, The Arda River

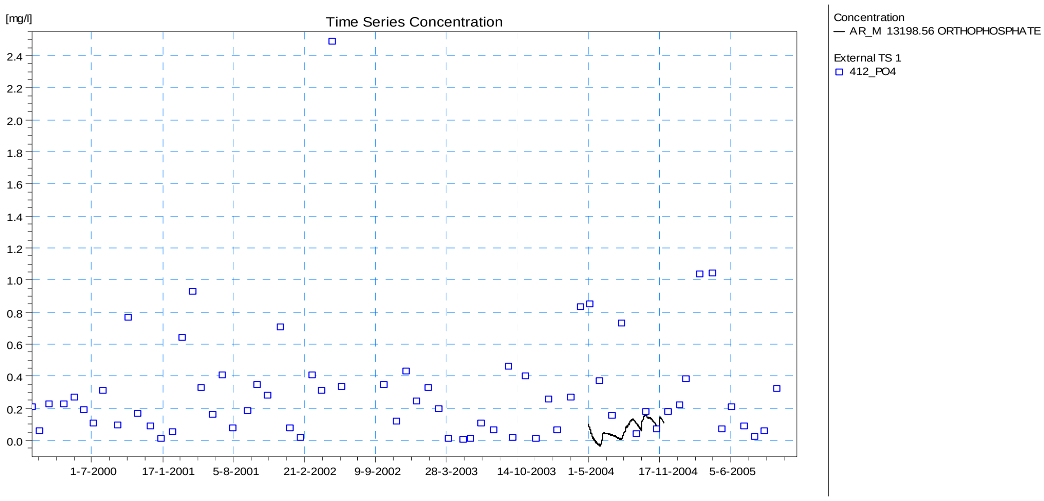


Figure E.5.68 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 412, The Arda River

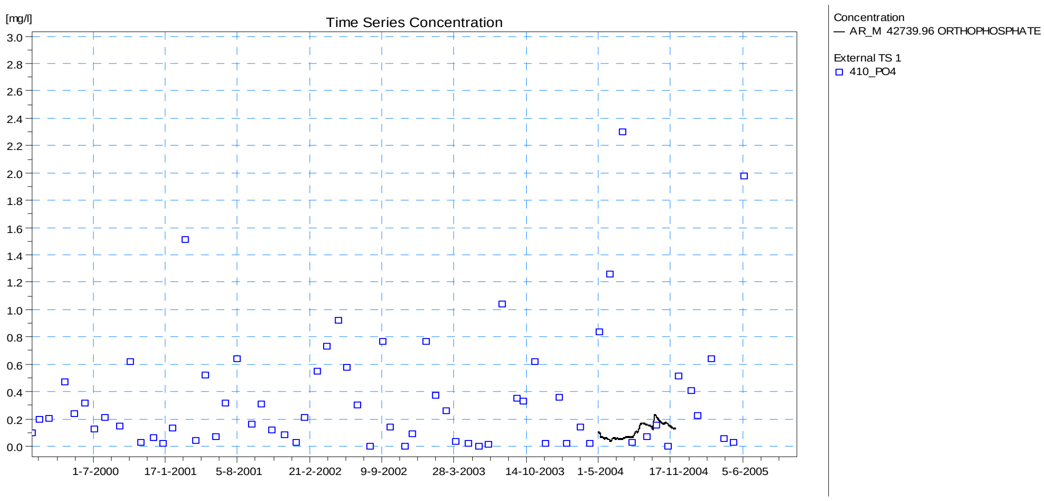


Figure E.5.69 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 410, The Arda River

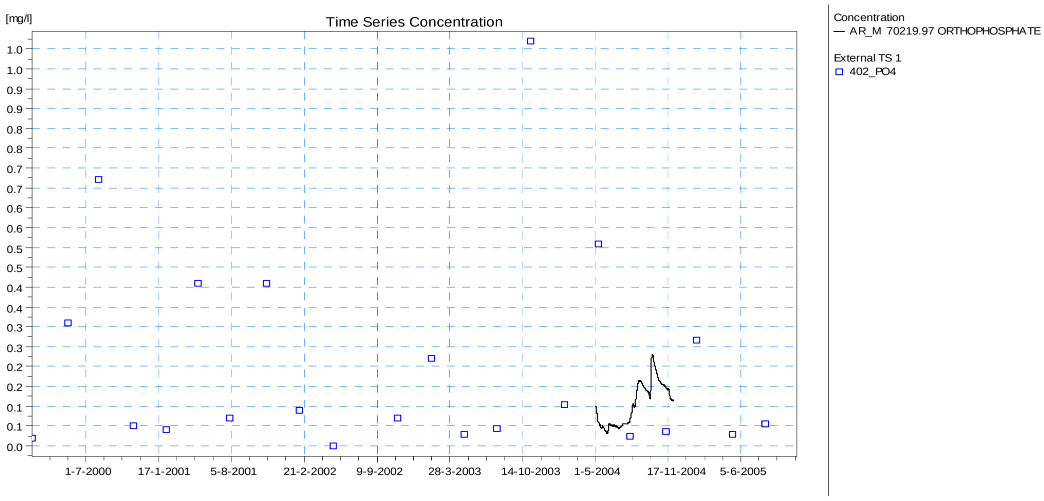


Figure E.5.70 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 402, The Arda River

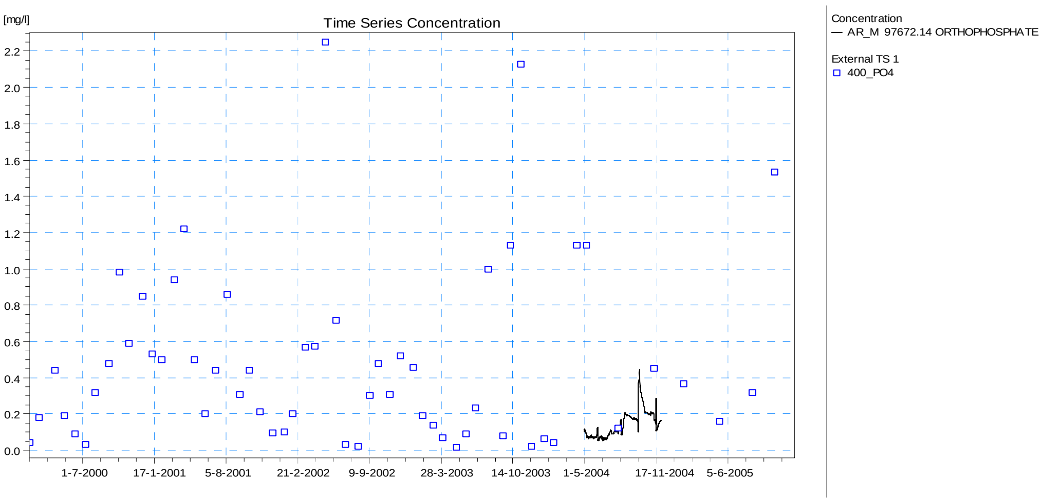


Figure E.5.71 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 400, The Arda River

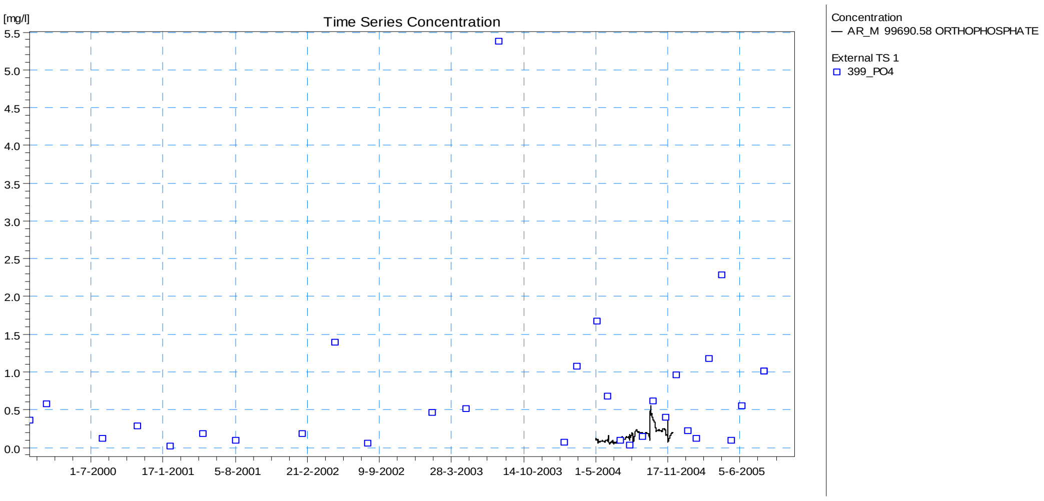


Figure E.5.72 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 399, The Arda River

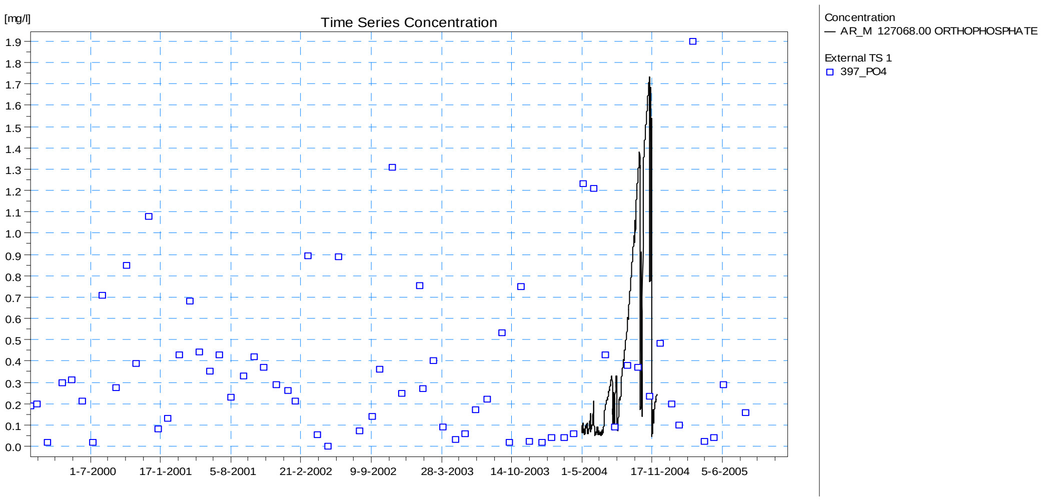
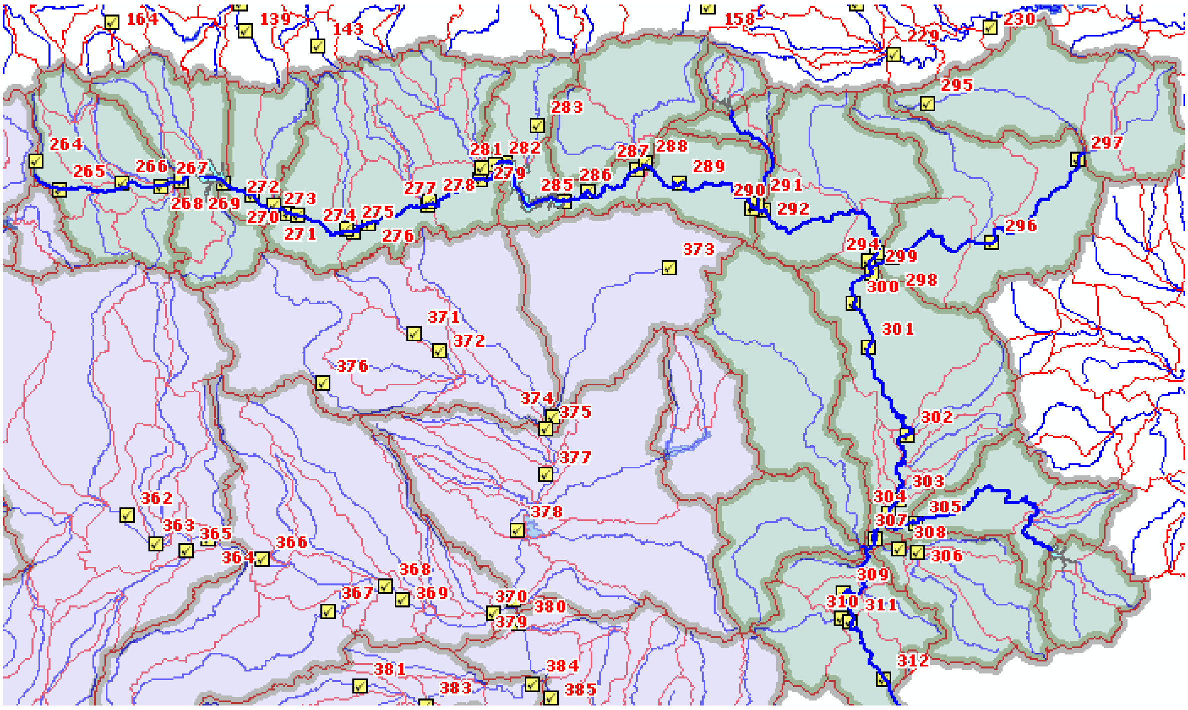


Figure E.5.73 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 397, The Arda River



Station in the Tundzha River selected for presentation of calibration results

Monitoring station	MIKE 11 Branch	MIKE 11 chainage
309	TU_M	31,004
304	TU_M	54,191
301	TU_M	97,315
286	TU_M	184,753
284	TU_M	205,148
276	TU_M	235,339
270	TU_M	256.999

Figure E.5.74 The Tundhza River Basin (green) with MIKE 11 River Branches (thick blue) and Monitoring Stations (yellow squares)

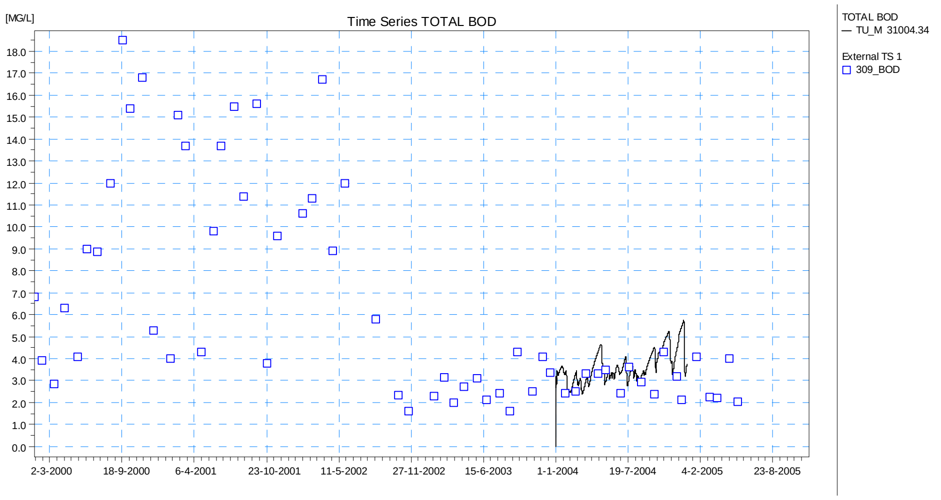


Figure E.5.75 Simulated and Monitored BOD Concentration, St. 309, The Tundzha River

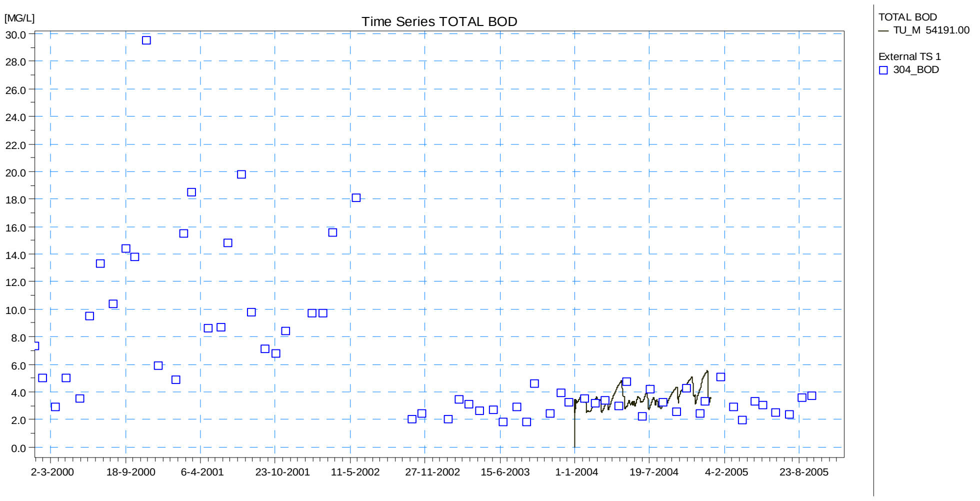


Figure E.5.76 Simulated and Monitored BOD Concentration, St. 304, The Tundzha River

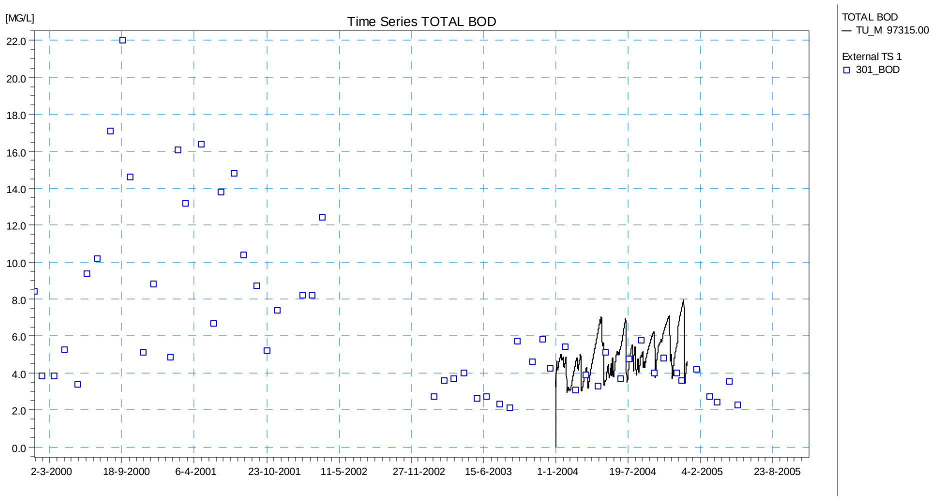


Figure E.5.77 Simulated and Monitored BOD Concentration, St. 301, The Tundzha River

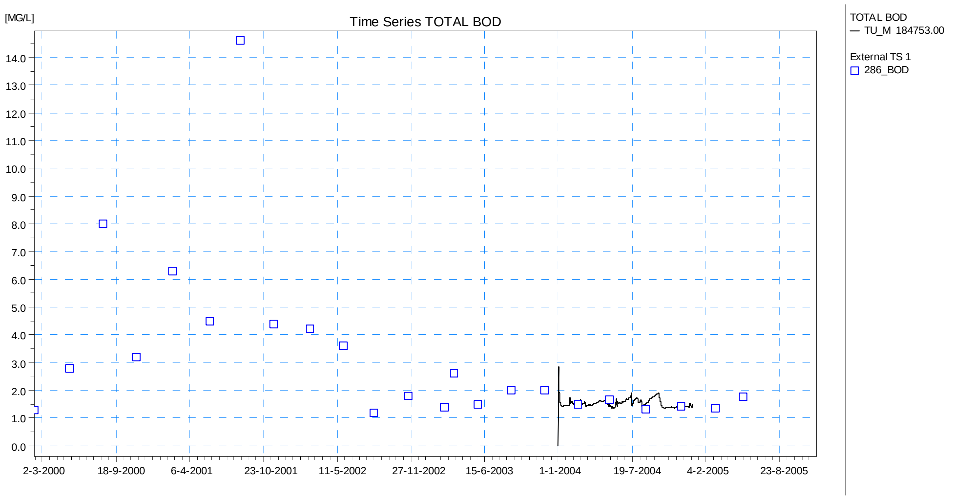


Figure E.5.78 Simulated and Monitored BOD Concentration, St. 295, The Tundzha River

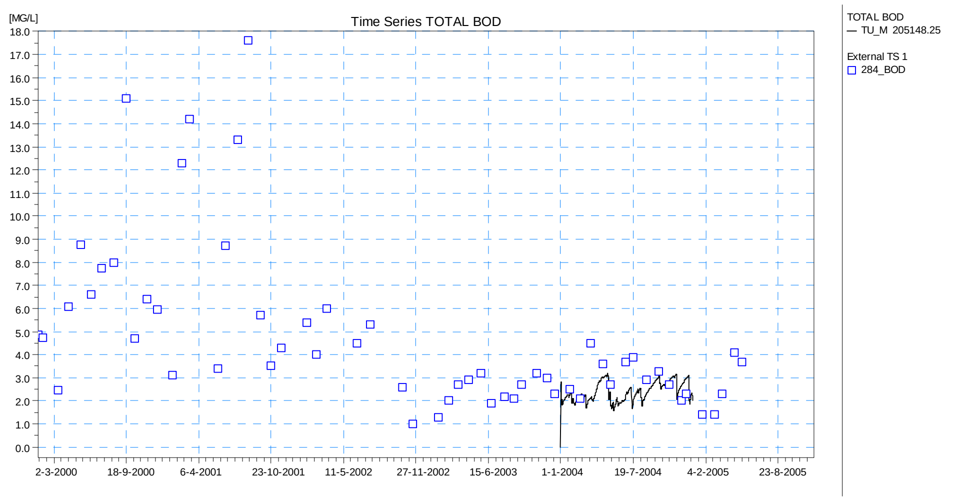


Figure E.5.79 Simulated and Monitored BOD Concentration, St. 284, The Tundzha River

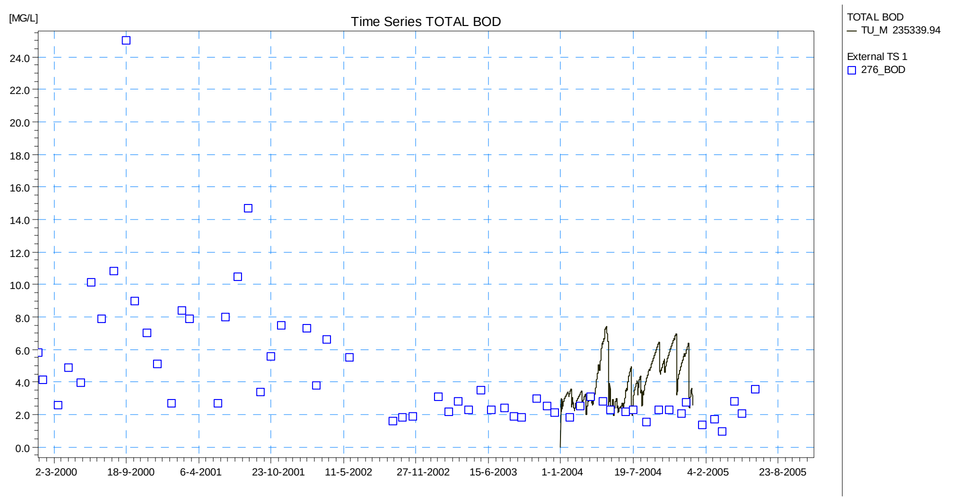


Figure E.5.80 Simulated and Monitored BOD Concentration, St. 276, The Tundzha River

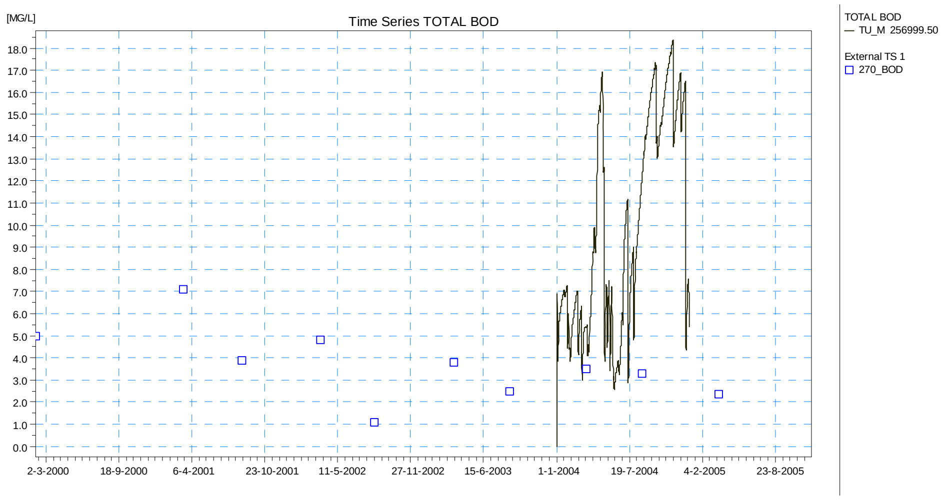


Figure E.5.81 Simulated and Monitored BOD Concentration, St. 270, The Tundzha River

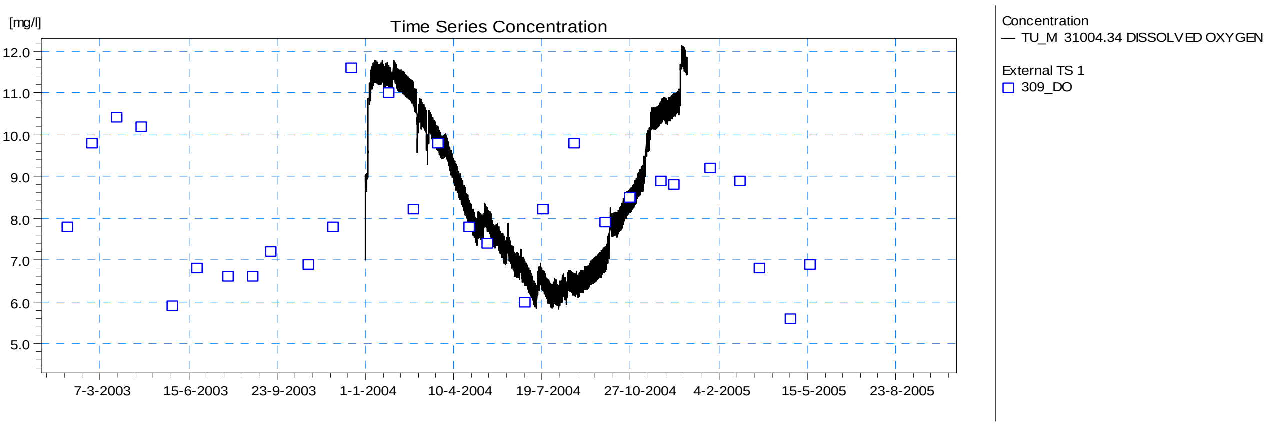


Figure E.5.82 Simulated and Monitored DO Concentration, St. 309, The Tundzha River

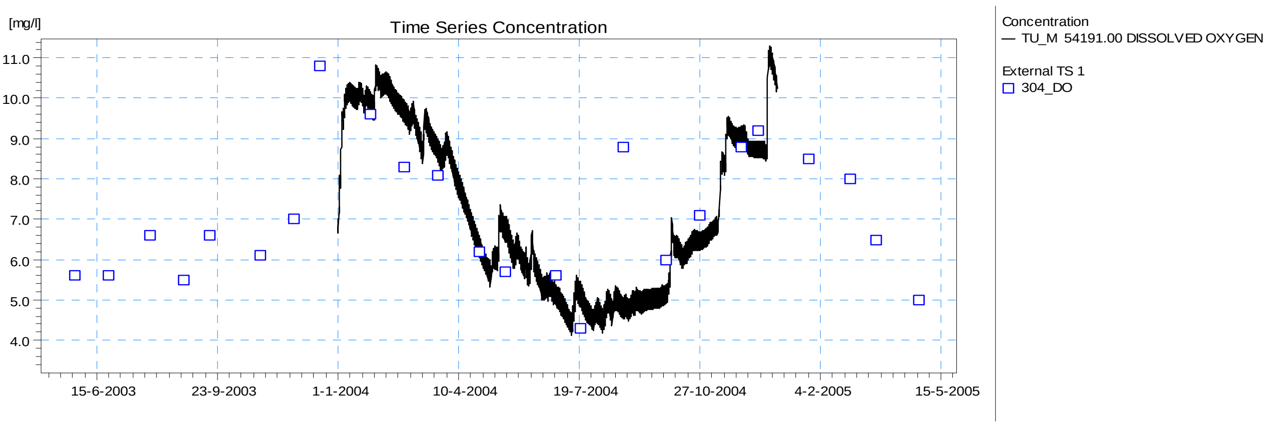


Figure E.5.83 Simulated and Monitored DO Concentration, St. 304, The Tundzha River

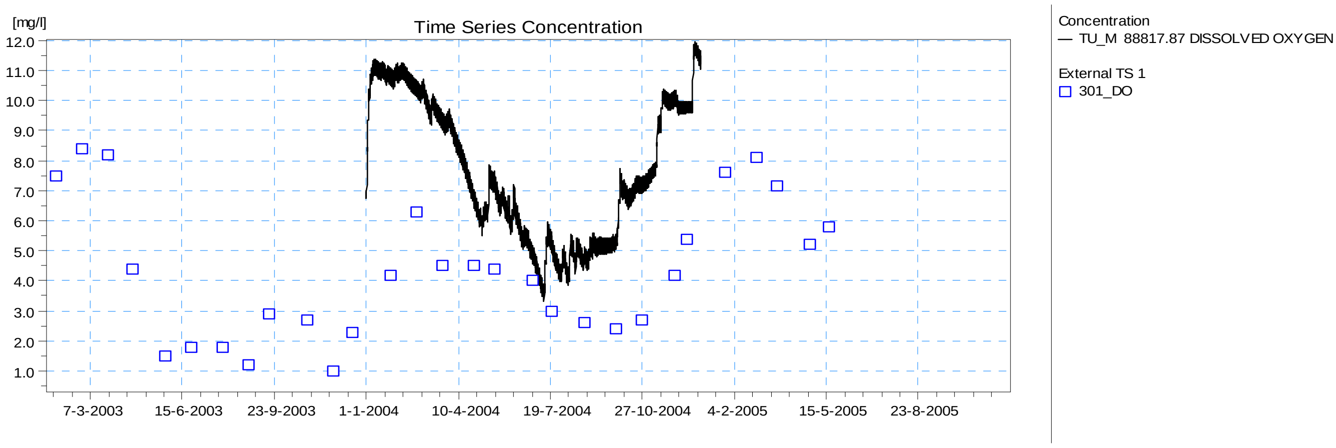


Figure E.5.84 Simulated and Monitored DO Concentration, St. 301, The Tundzha River

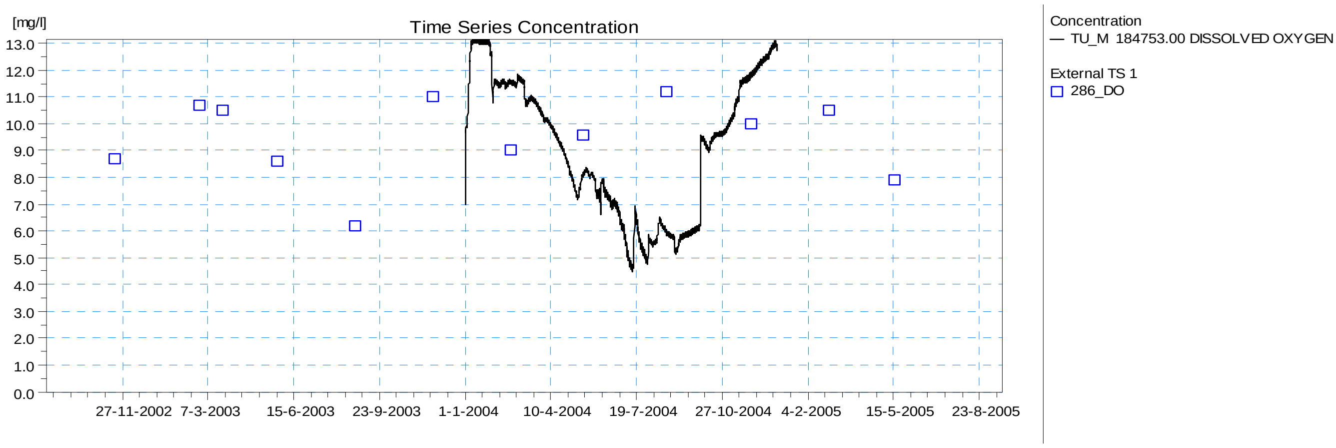


Figure E.5.85 Simulated and Monitored DO Concentration, St. 296, The Tundzha River

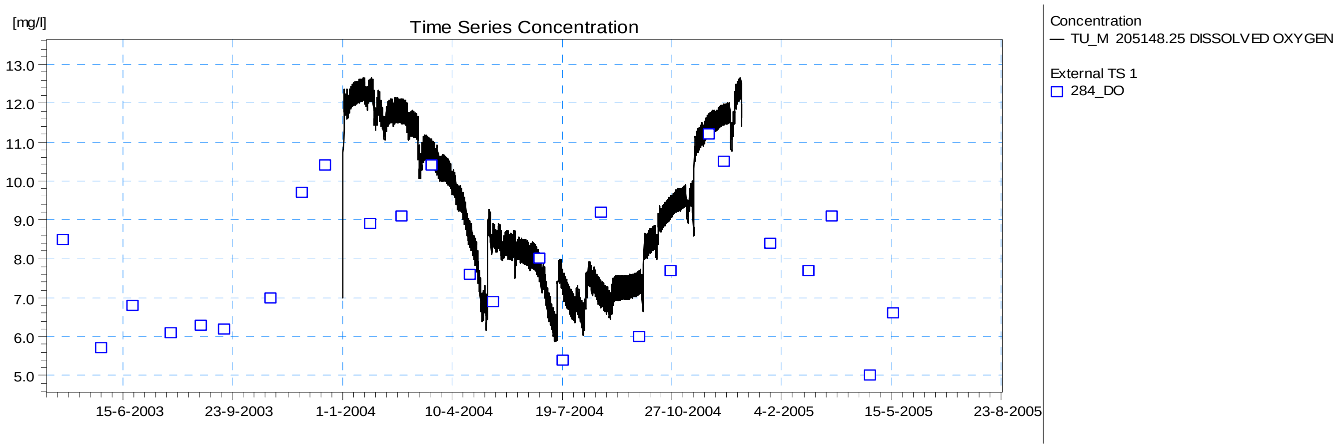


Figure E.5.86 Simulated and Monitored DO Concentration, St. 284, The Tundzha River

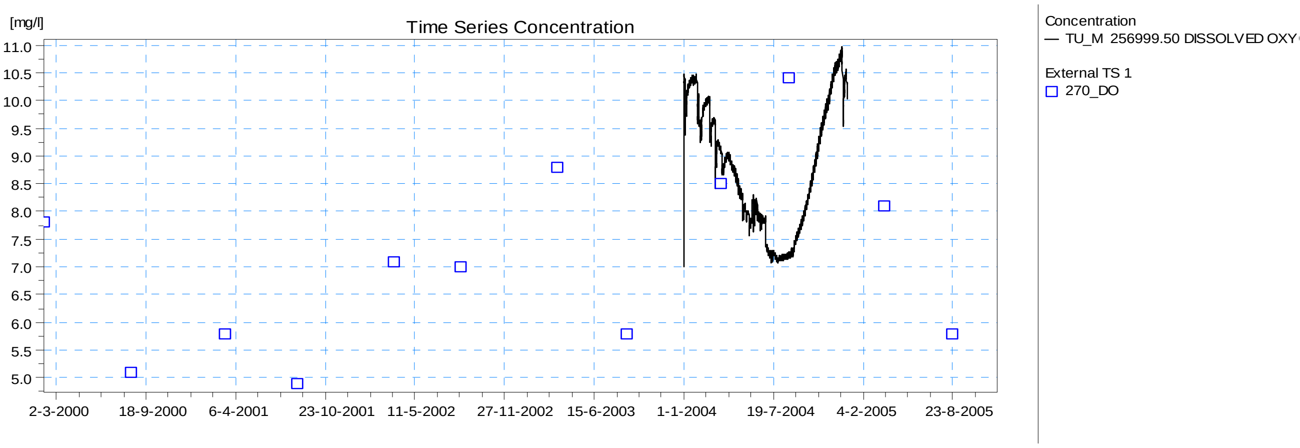


Figure E.5.87 Simulated and Monitored DO Concentration, St. 270, The Tundzha River

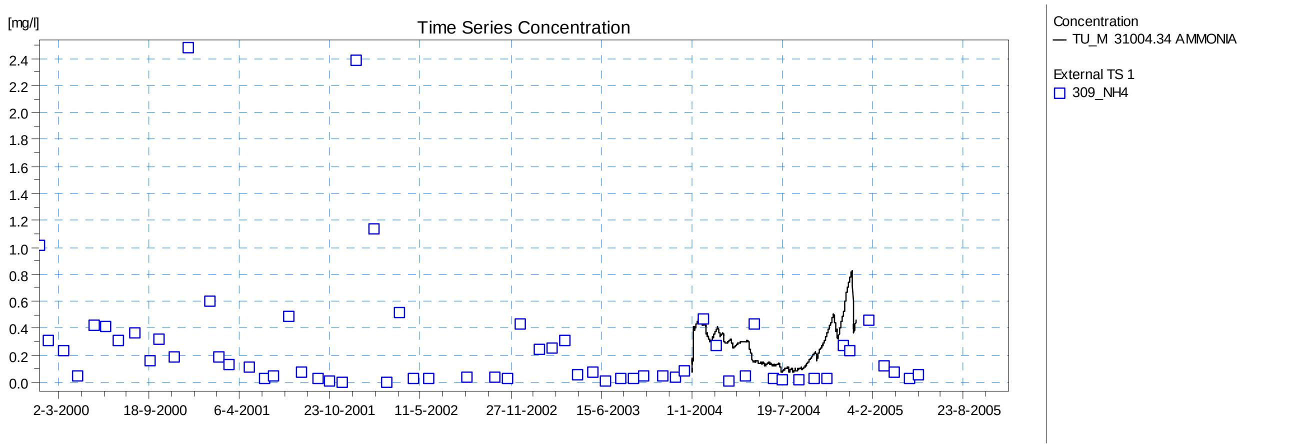


Figure E.5.88 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 309, The Tundzha River

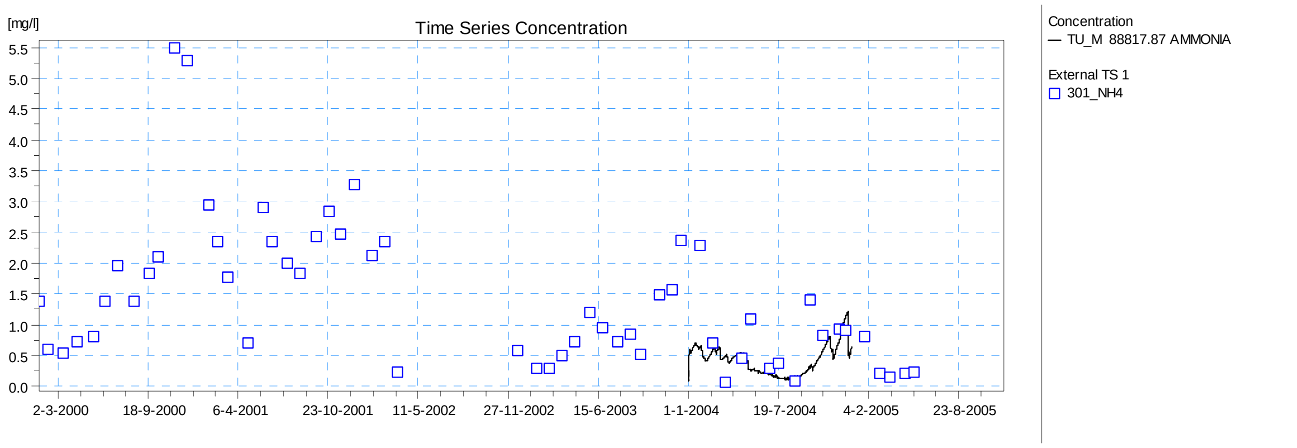


Figure E.5.89 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 301, The Tundzha River

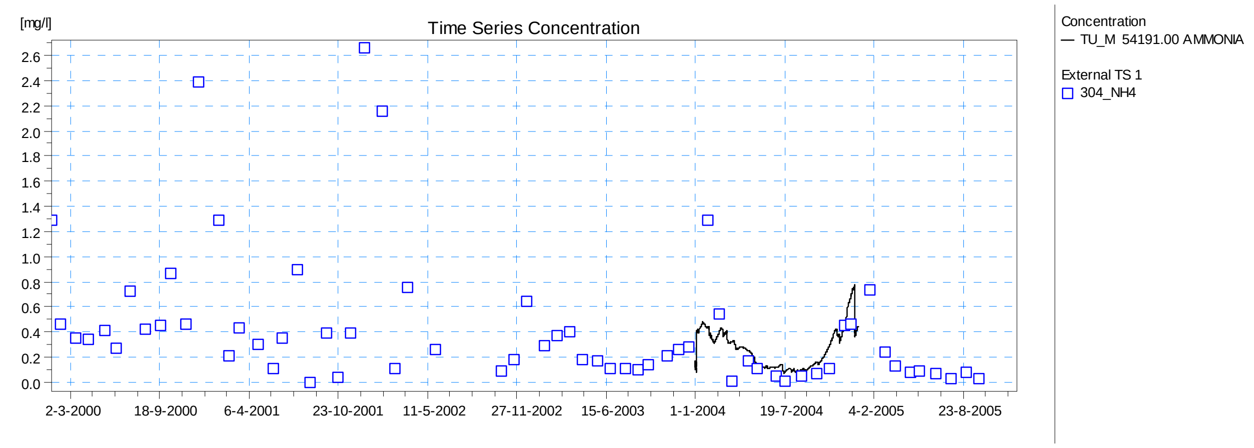


Figure E.5.90 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 304, The Tundzha River

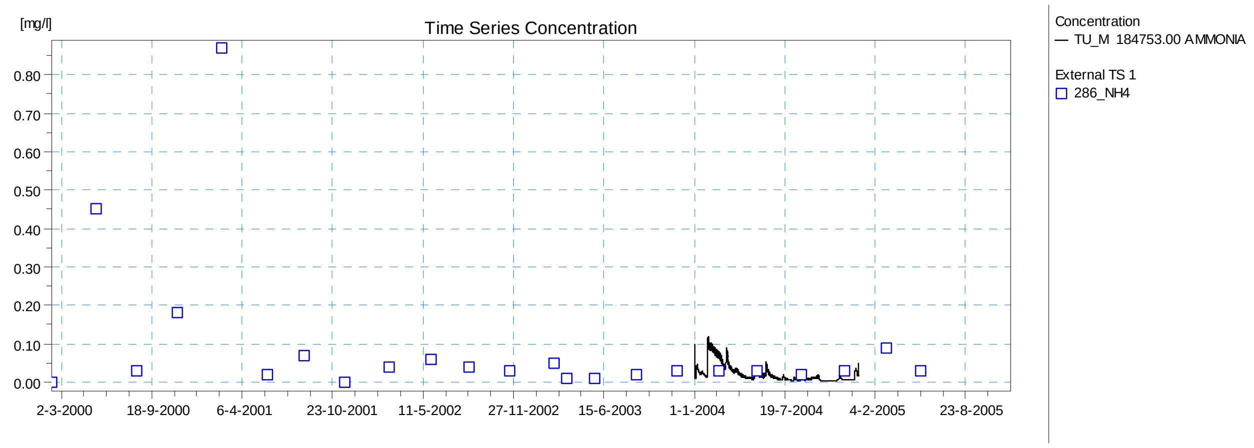


Figure E.5.91 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 296, The Tundzha River

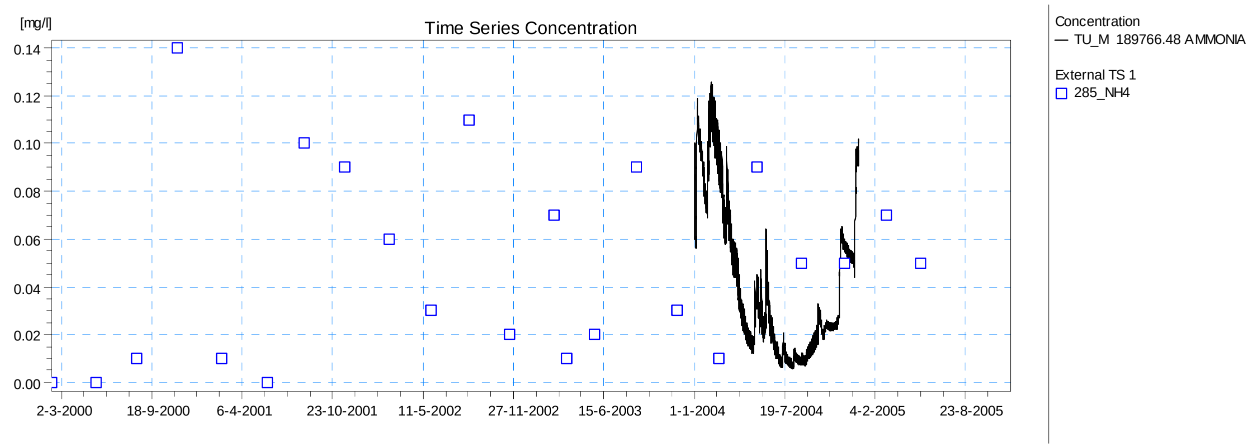


Figure E.5.92 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 285, The Tundzha River

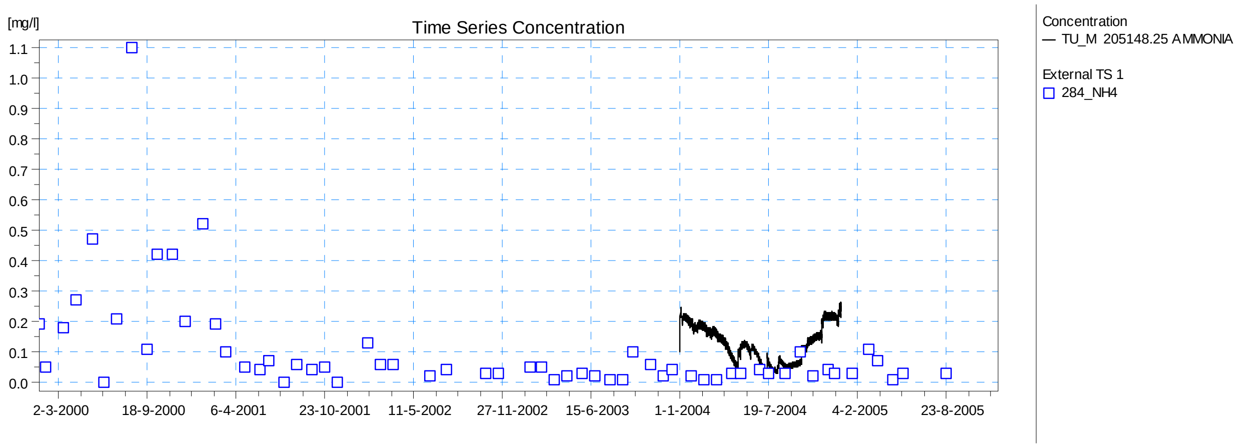


Figure E.5.93 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 284, The Tundzha River

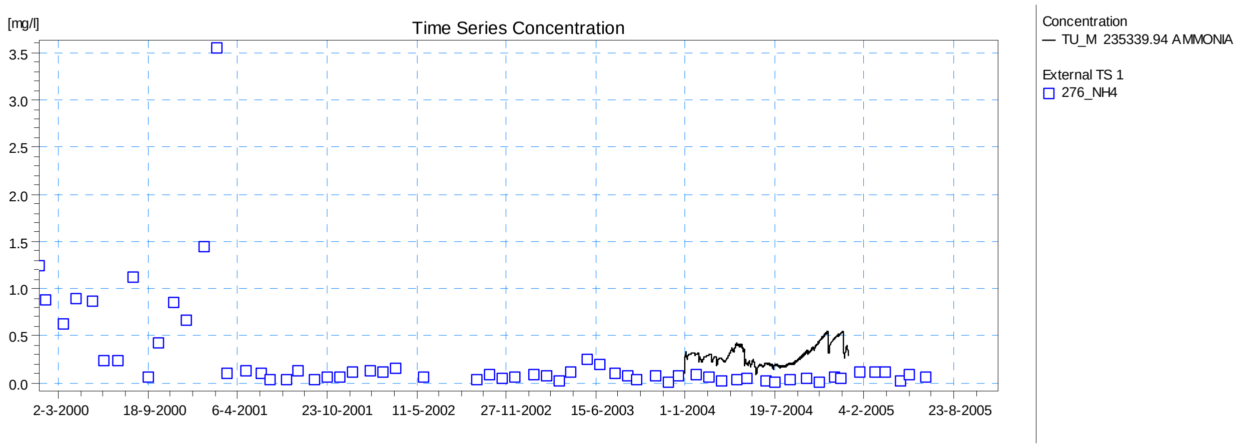


Figure E.5.94 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 276, The Tundzha River

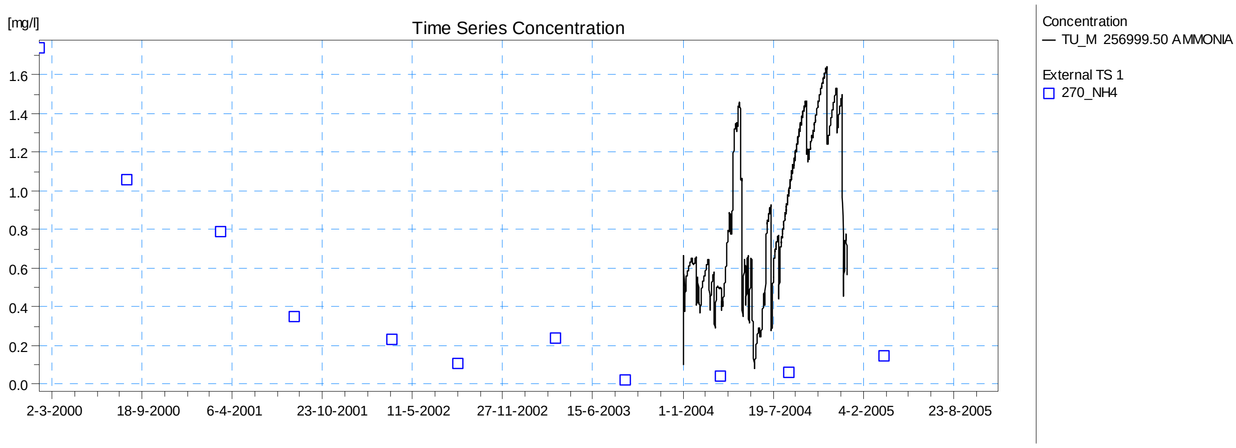


Figure E.5.95 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 270, The Tundzha River

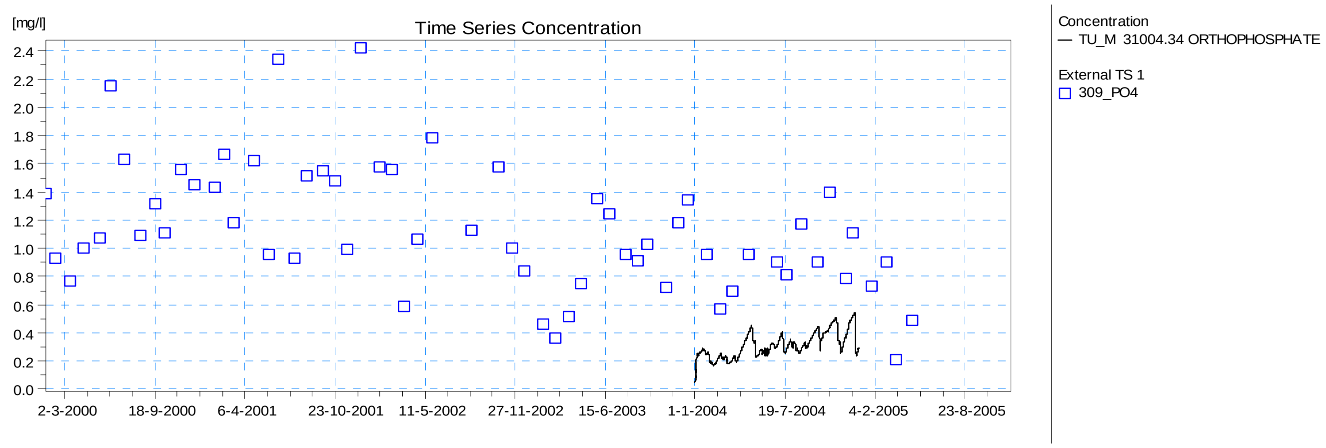


Figure E.5.96 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 309, The Tundzha River

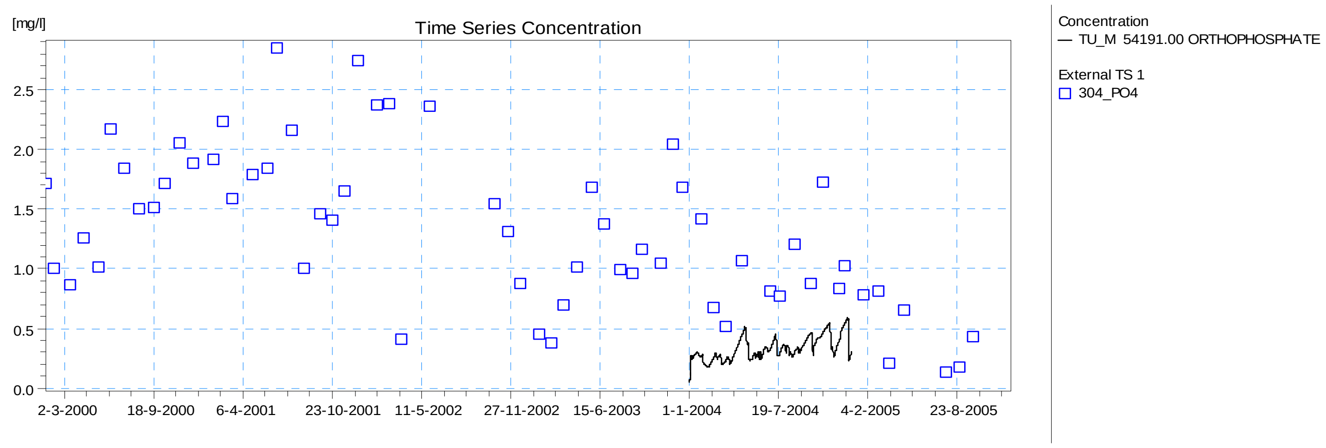


Figure E.5.97 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 304, The Tundzha River

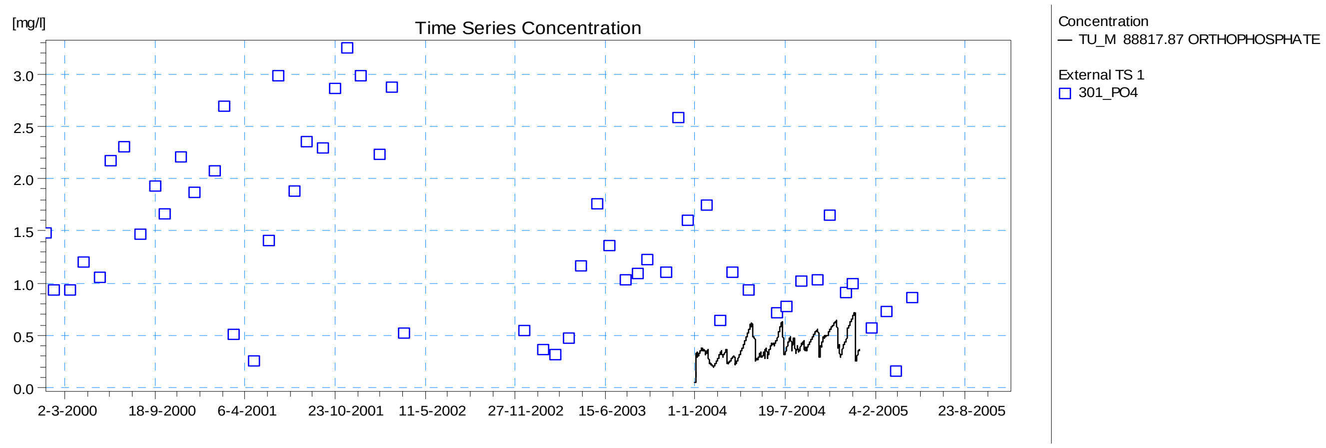


Figure E.5.98 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 301, The Tundzha River

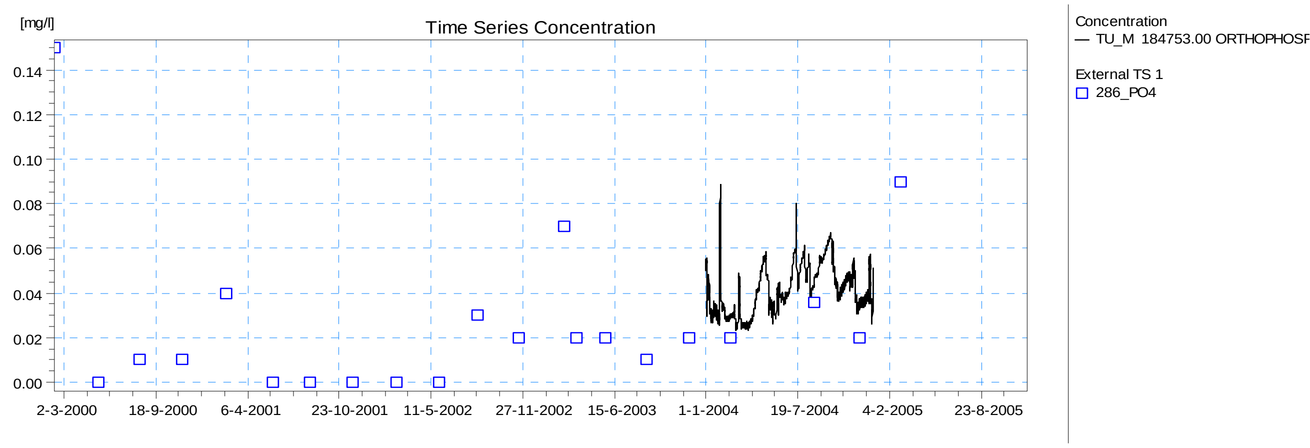


Figure E.5.99 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 296, The Tundzha River

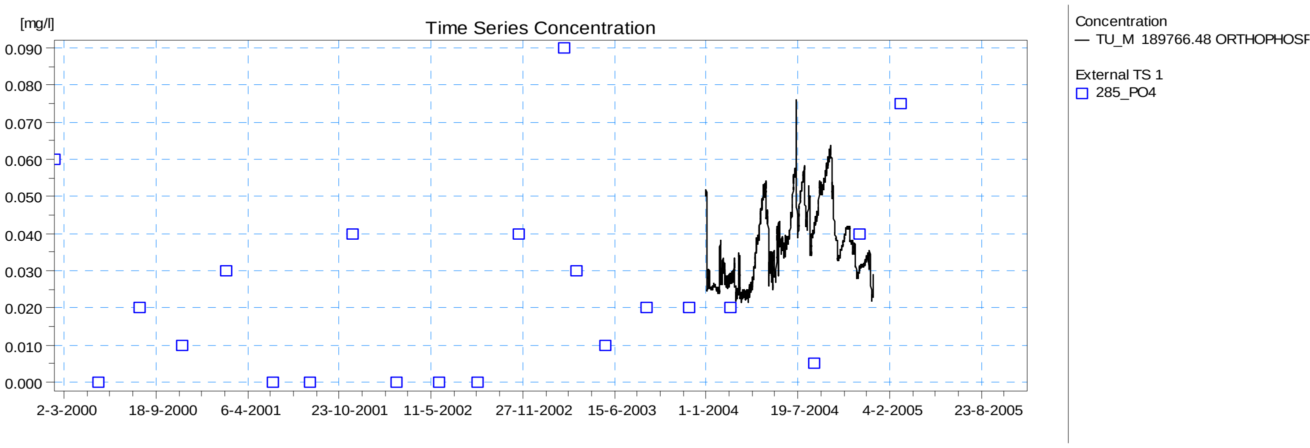


Figure E.5.100 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 285, The Tundzha River

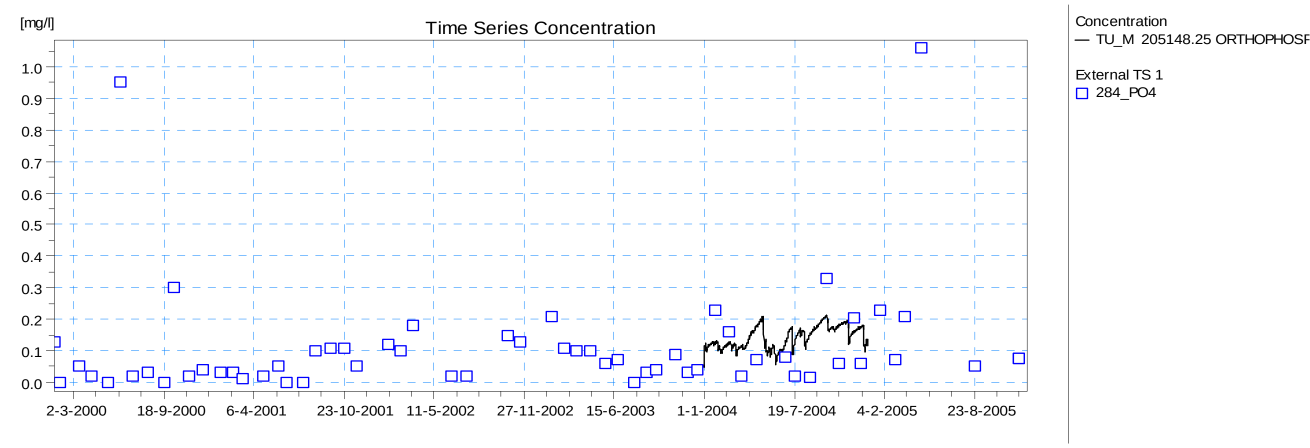


Figure E.5.101 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 285, The Tundzha River

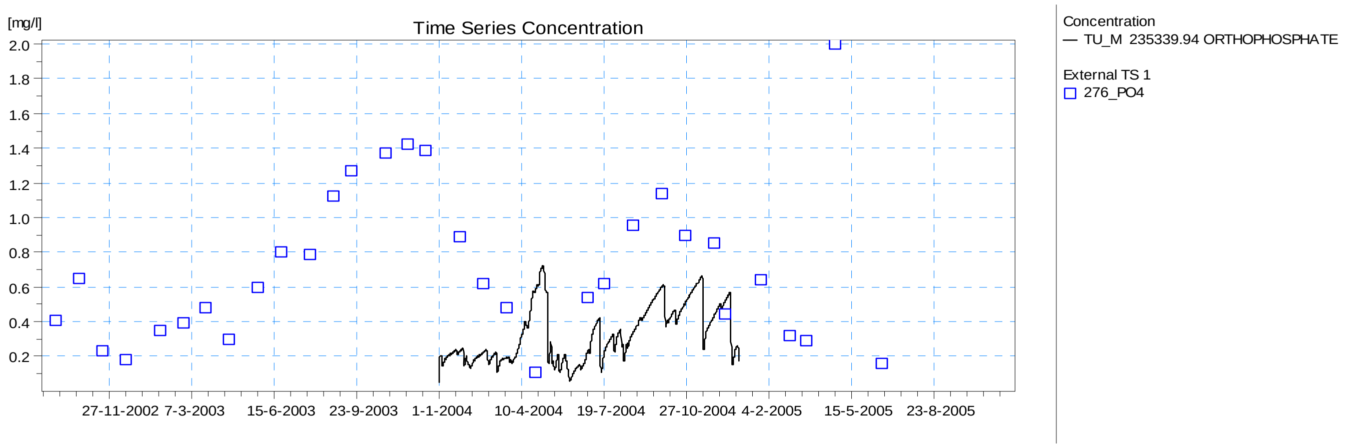


Figure E.5.102 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 276, The Tundzha River

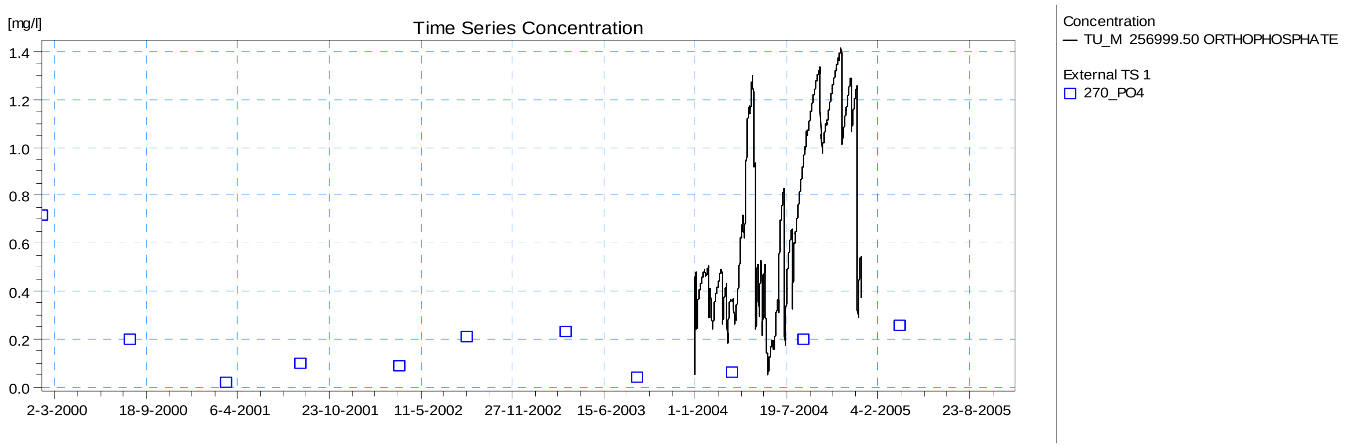
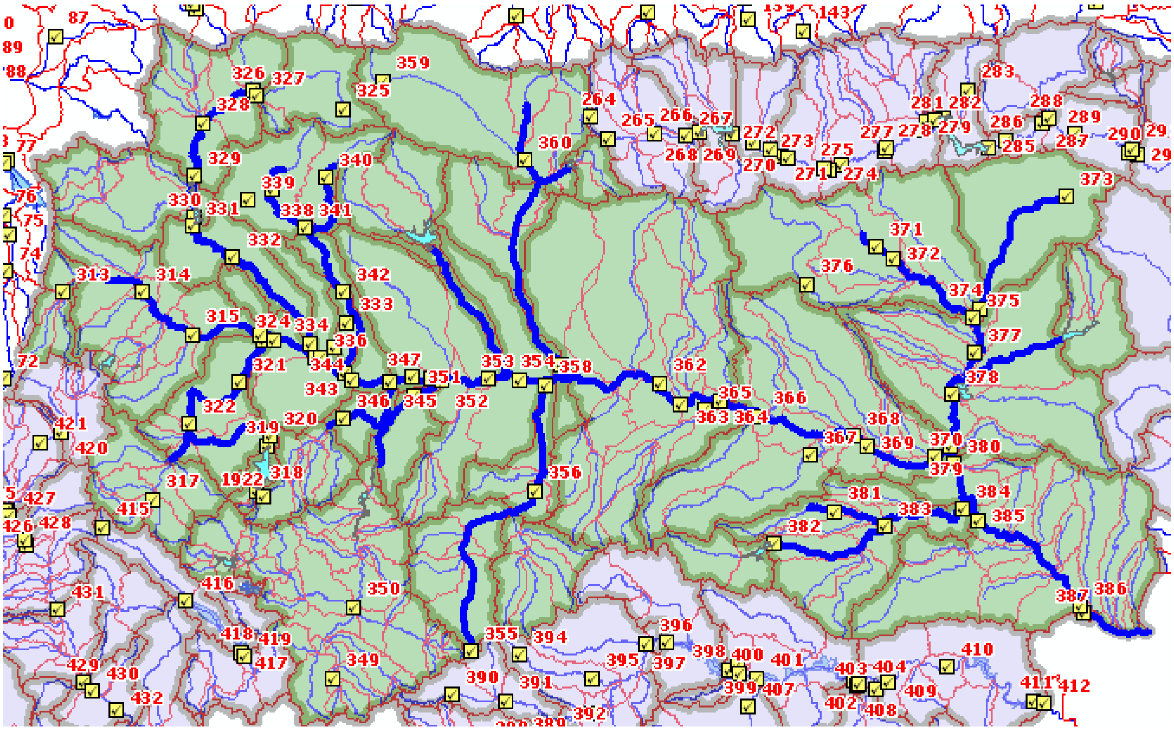


Figure E.5.103 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 270, The Tundzha River



Station in the Maritsa River selected for presentation of calibration results

Monitoring station	MIKE 11 Branch	MIKE 11 chainage
387	MA_M	3,640
385	MA_M	49,472
369	MA_M	86,236
361	MA_STR	5,028
353	MA_M	178,622
347	MA_M	196,419
336	MA_M	219,373
315	MA_M	249,741

Figure E.5.104 The Maritsa River Basin (green) with MIKE 11 River Branches (thick blue) and Monitoring Stations (yellow squares)

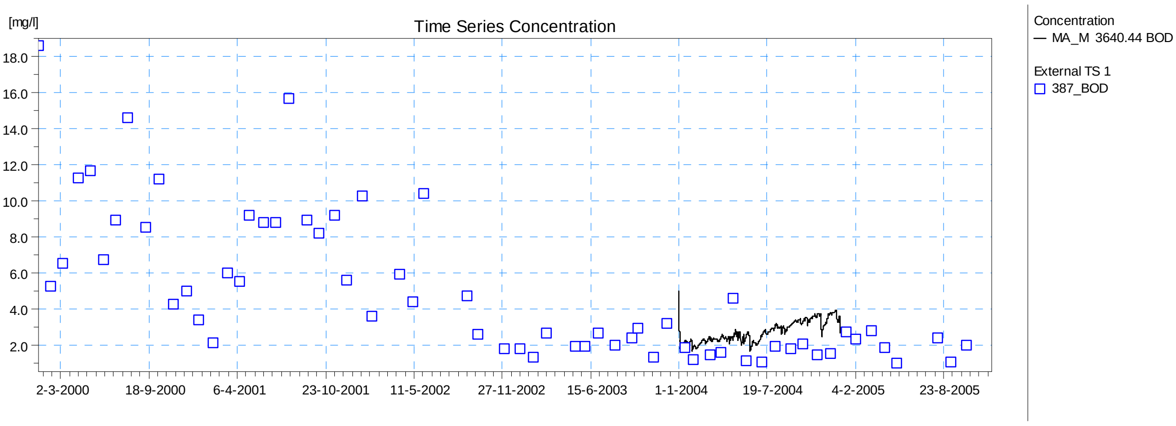


Figure E.5.105 Simulated and Monitored BOD Concentration, St. 387, The Maritsa River

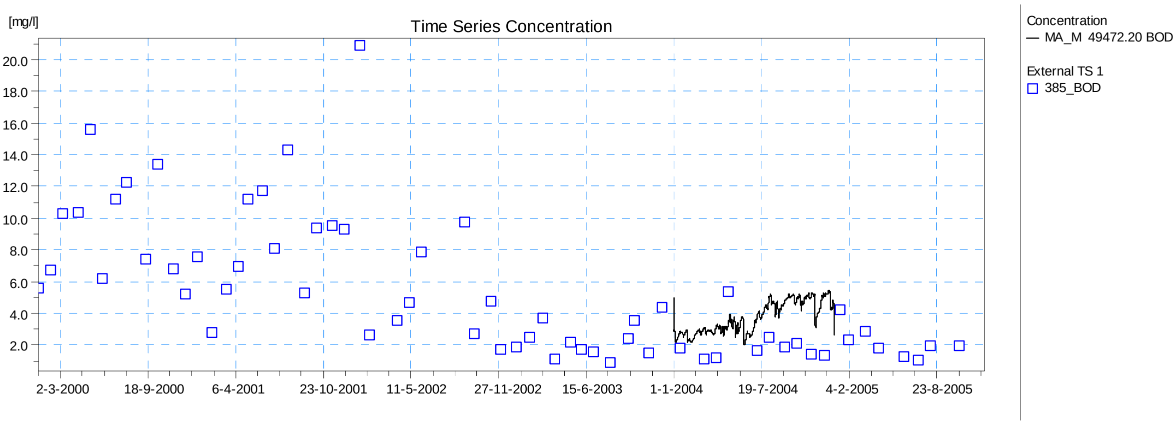


Figure E.5.106 Simulated and Monitored BOD Concentration, St. 385, The Maritsa Rive

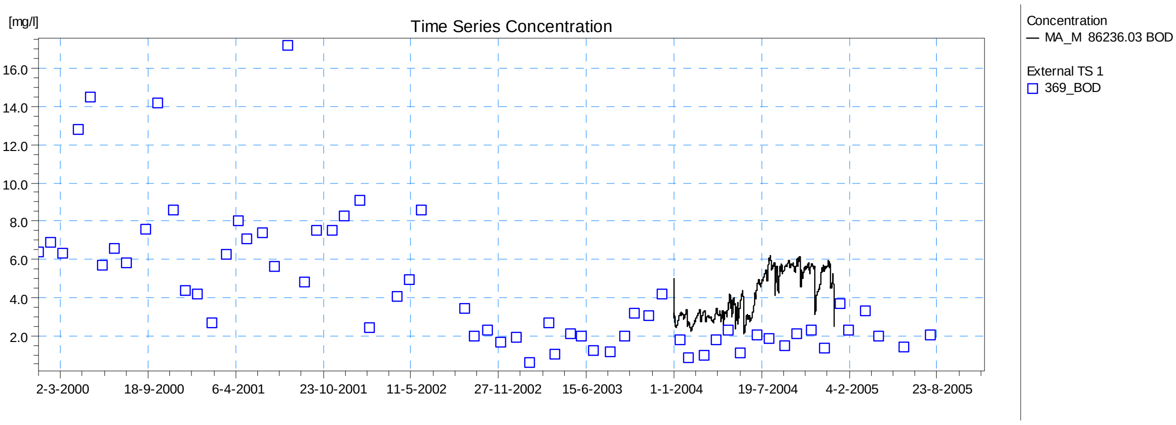


Figure E.5.107 Simulated and Monitored BOD Concentration, St. 369, The Maritsa River

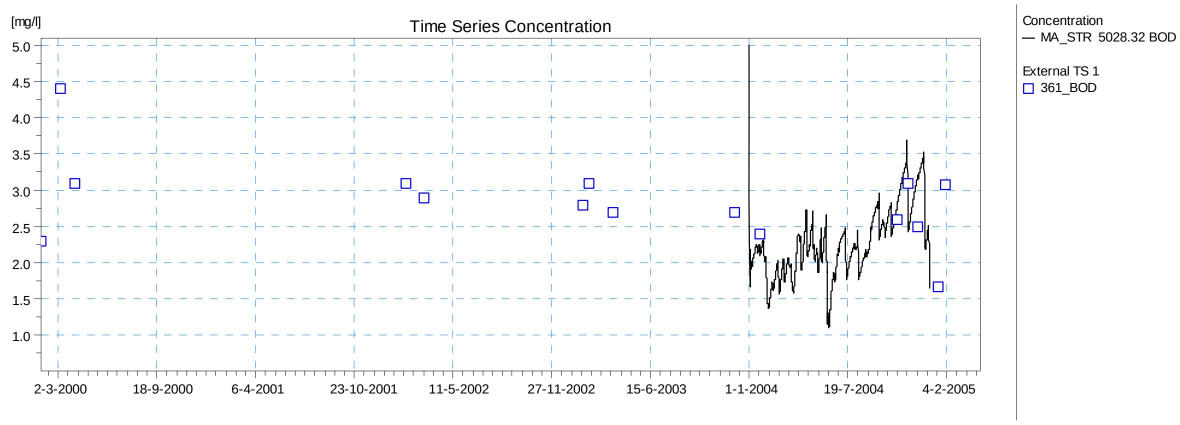


Figure E.5.108 Simulated and Monitored BOD Concentration, St. 361, The Maritsa River

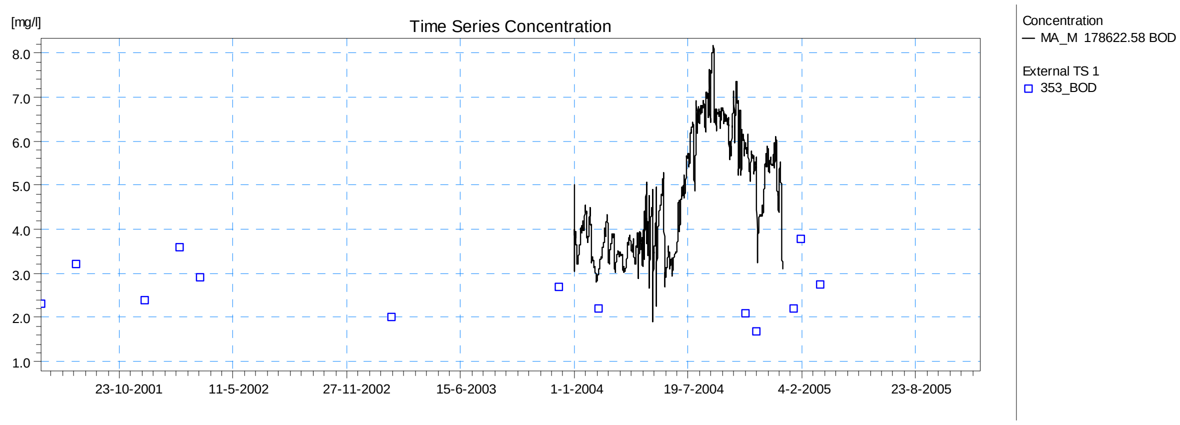


Figure E.5.109 Simulated and Monitored BOD Concentration, St. 353, The Maritsa River

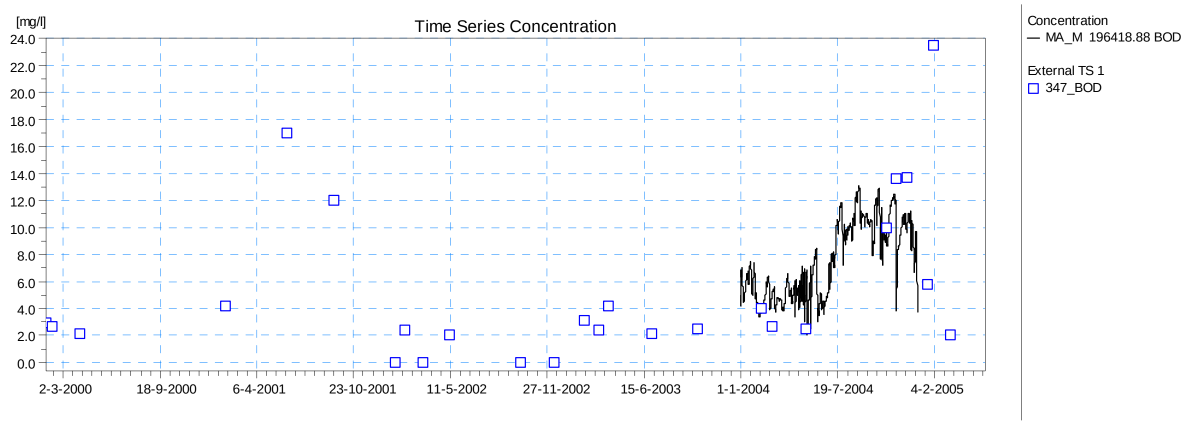


Figure E.5.110 Simulated and Monitored BOD Concentration, St. 347, The Maritsa River

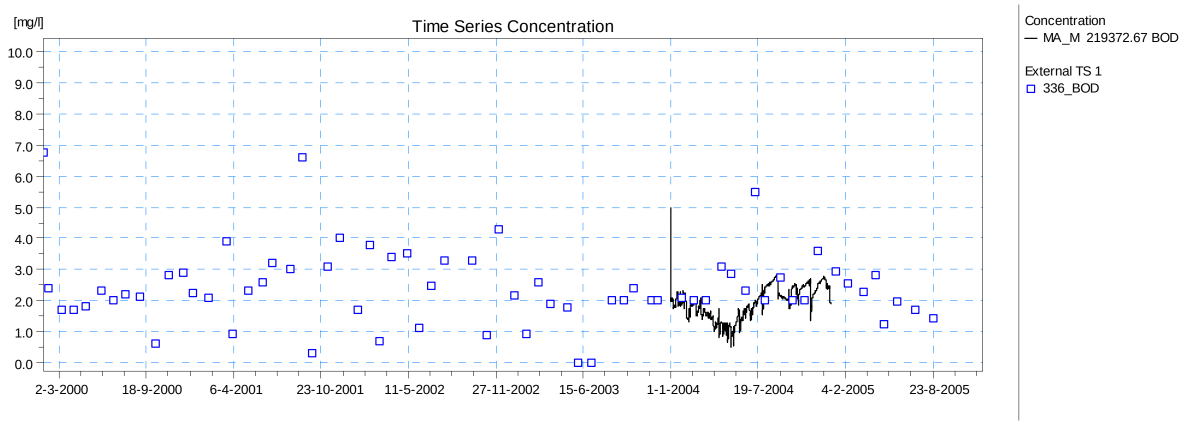


Figure E.5.111 Simulated and Monitored BOD Concentration, St. 336, The Maritsa River

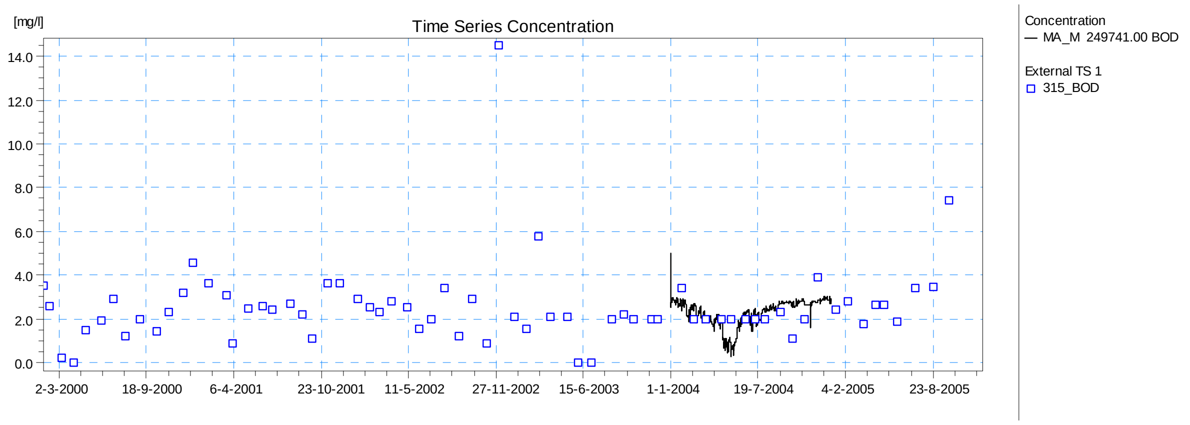


Figure E.5.112 Simulated and Monitored BOD Concentration, St. 315, The Maritsa River

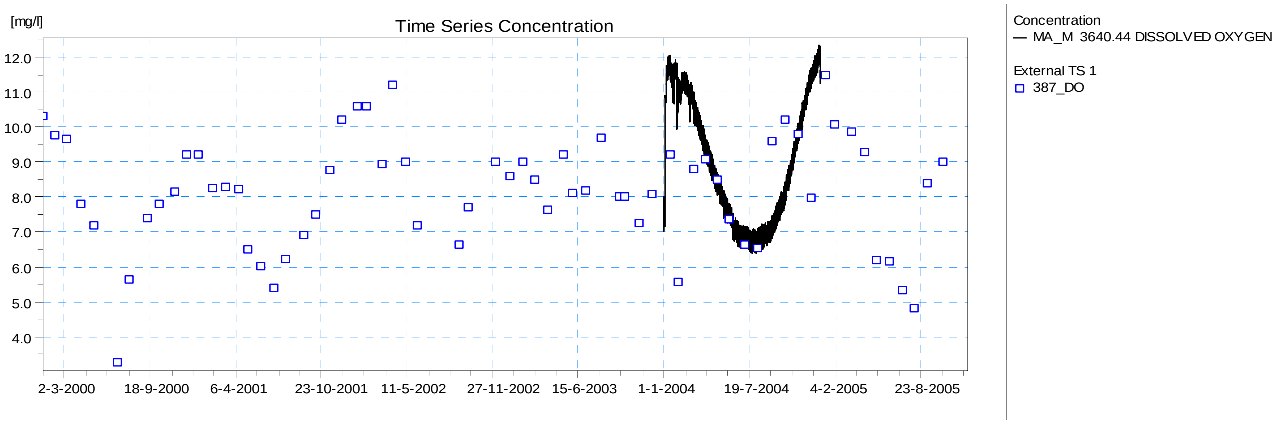


Figure E.5.113 Simulated and Monitored Oxygen (DO) Concentration, St. 387, The Maritsa River

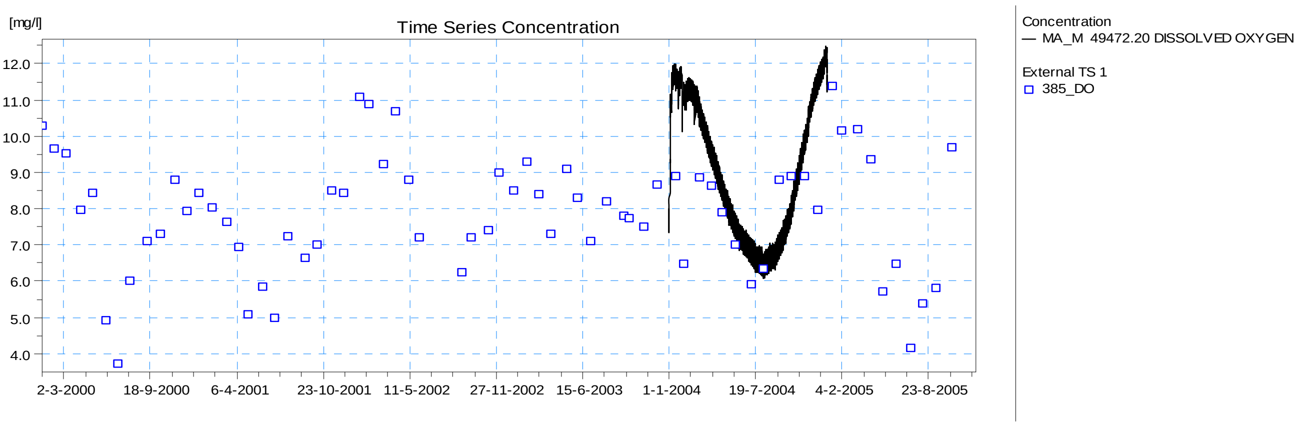


Figure E.5.114 Simulated and Monitored Oxygen (DO) Concentration, St. 385, The Maritsa River

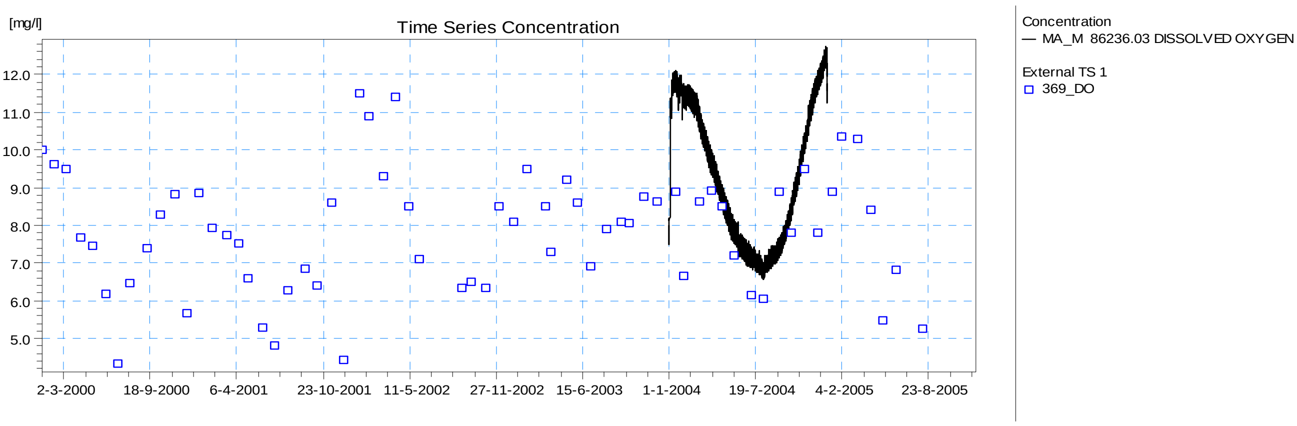


Figure E.5.115 Simulated and Monitored Oxygen (DO) Concentration, St. 369, The Maritsa River

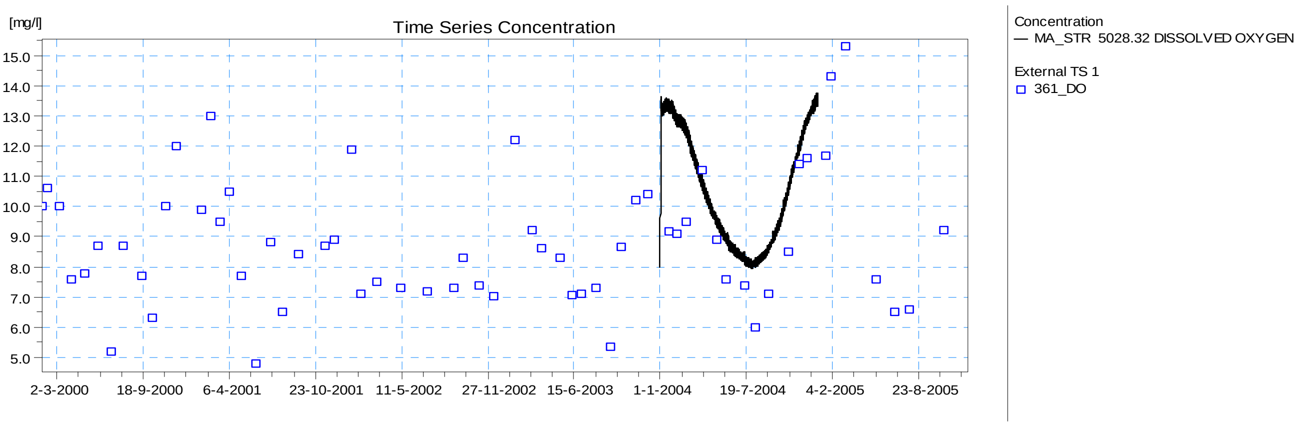


Figure E.5.116 Simulated and Monitored Oxygen (DO) Concentration, St. 361, The Maritsa River

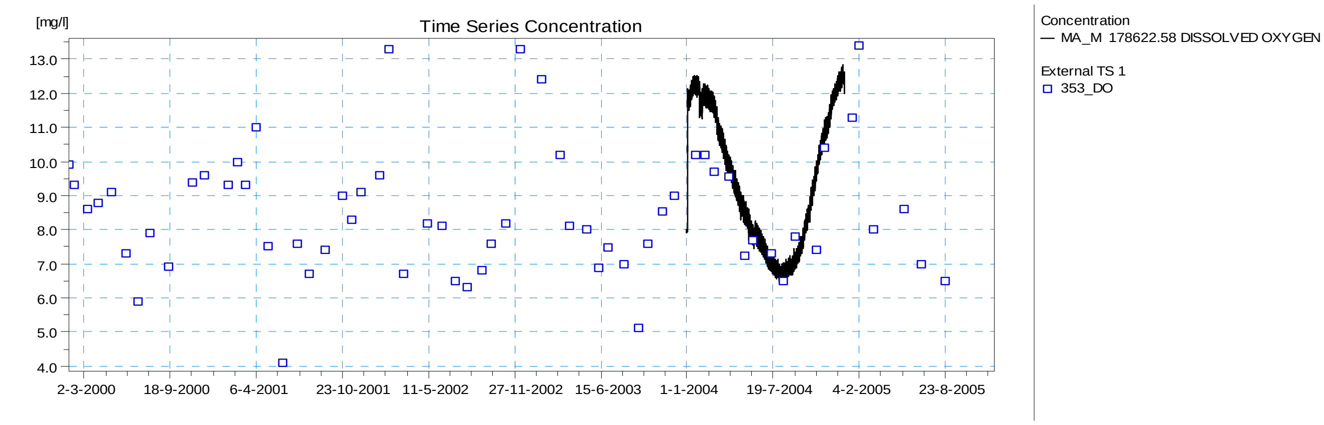


Figure E.5.117 Simulated and Monitored Oxygen (DO) Concentration, St. 353, The Maritsa River

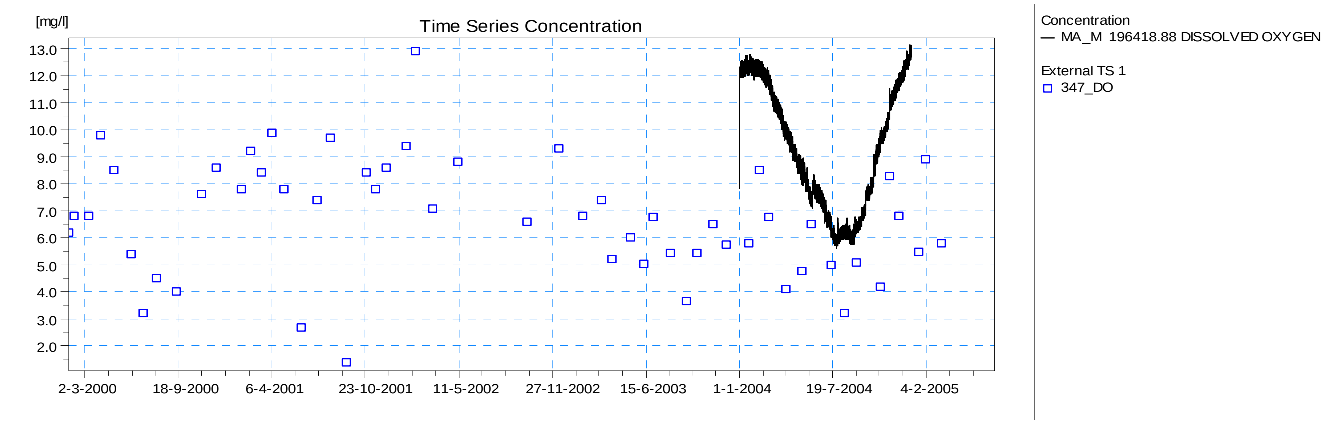


Figure E.5.118 Simulated and Monitored Oxygen (DO) Concentration, St. 347, The Maritsa River

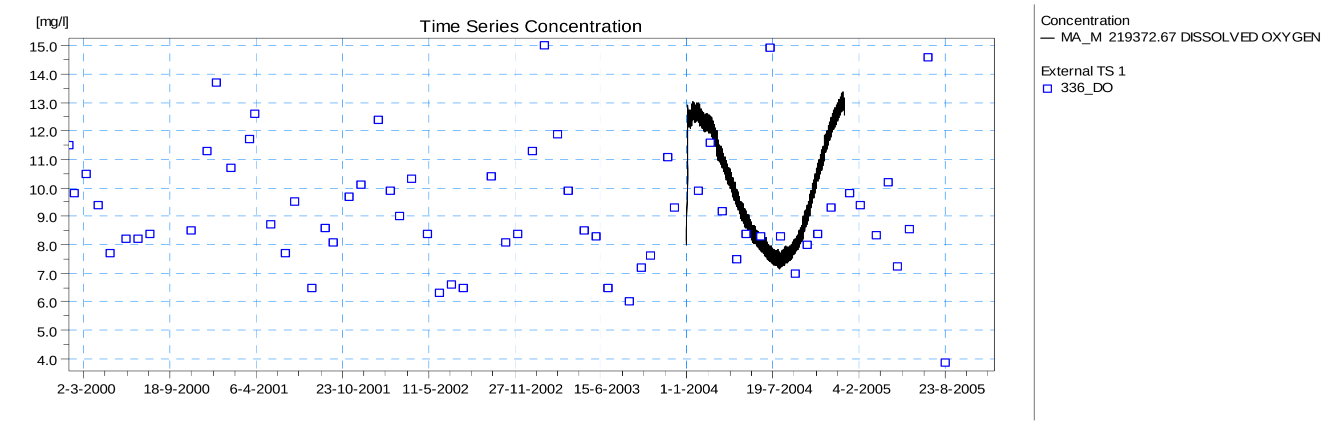


Figure E.5.119 Simulated and Monitored Oxygen (DO) Concentration, St. 336, The Maritsa River

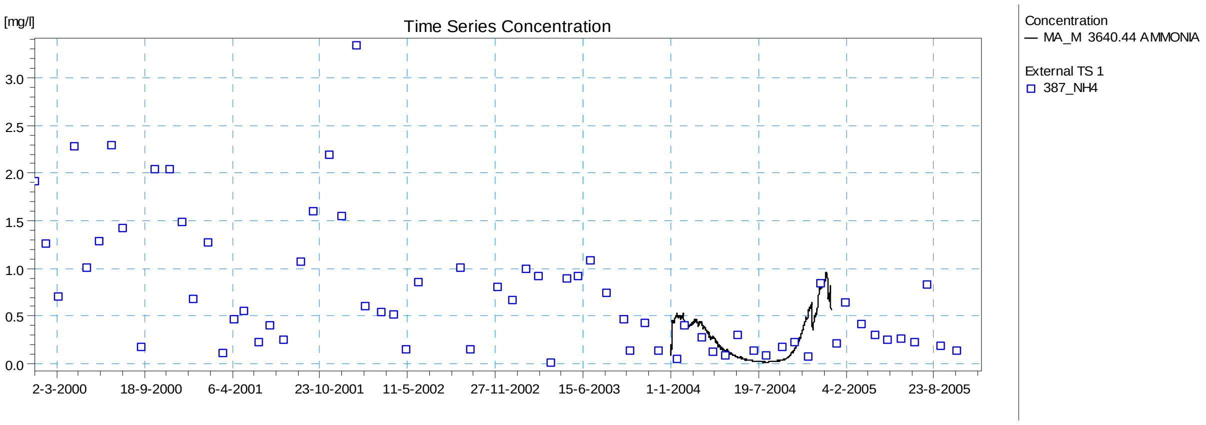


Figure E.5.120 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 387, The Maritsa River

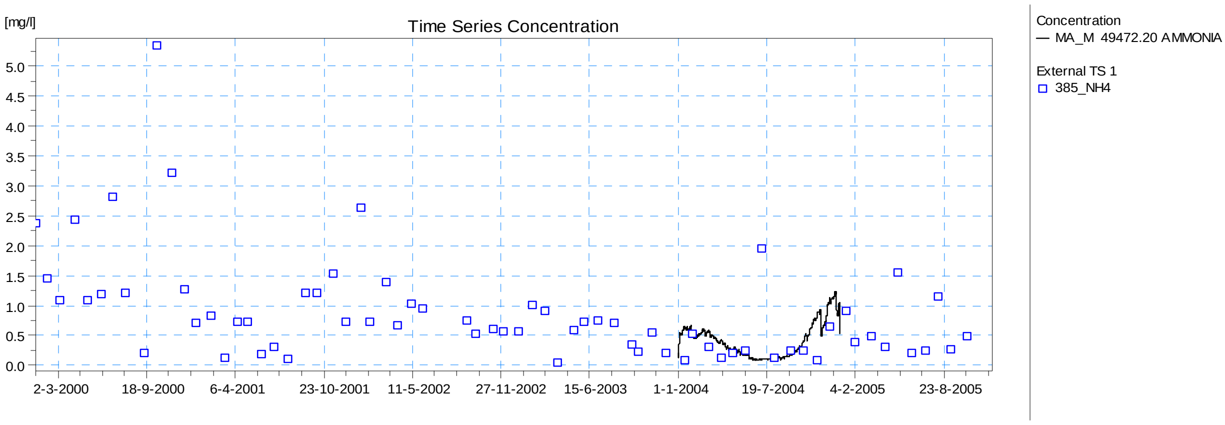


Figure E.5.121 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 385, The Maritsa River

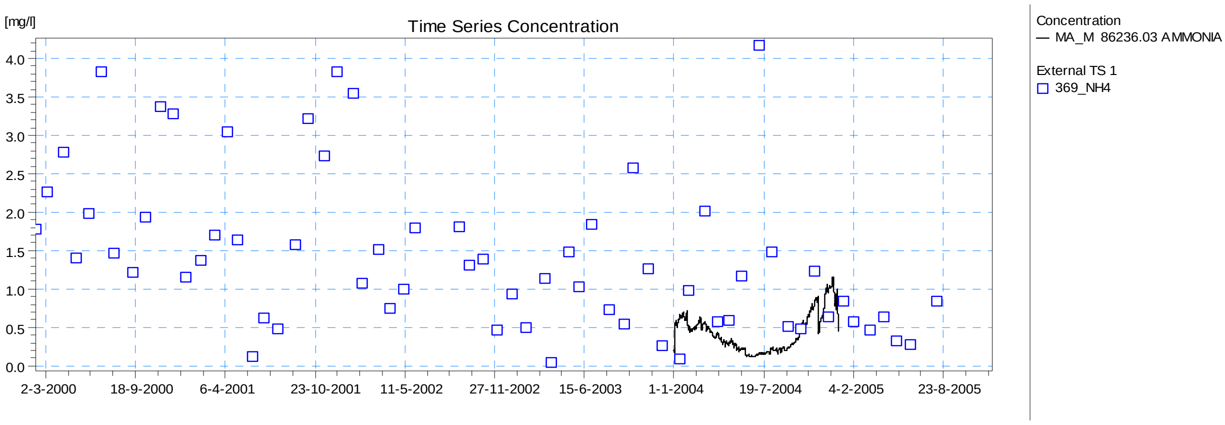


Figure E.5.122 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 369, The Maritsa River

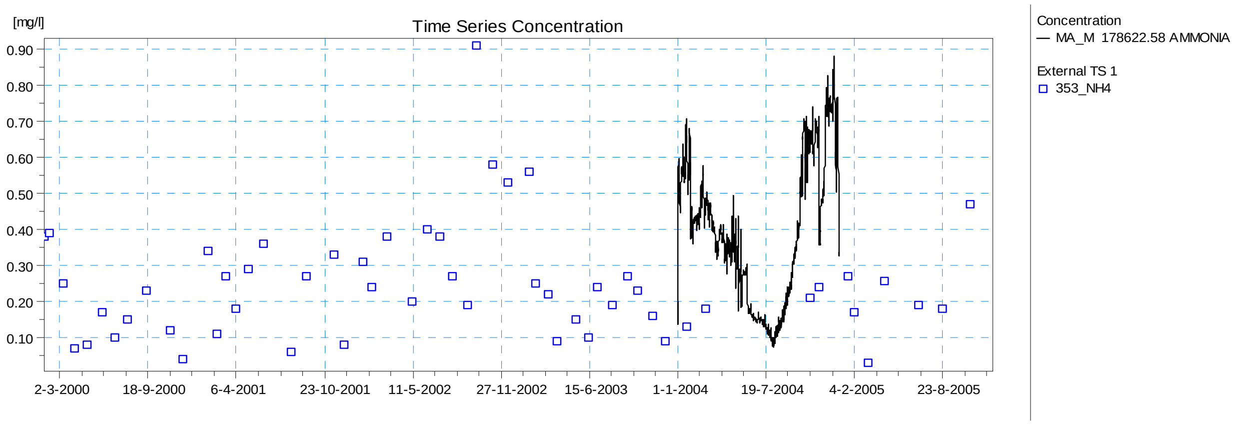


Figure E.5.123 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 353, The Maritsa River

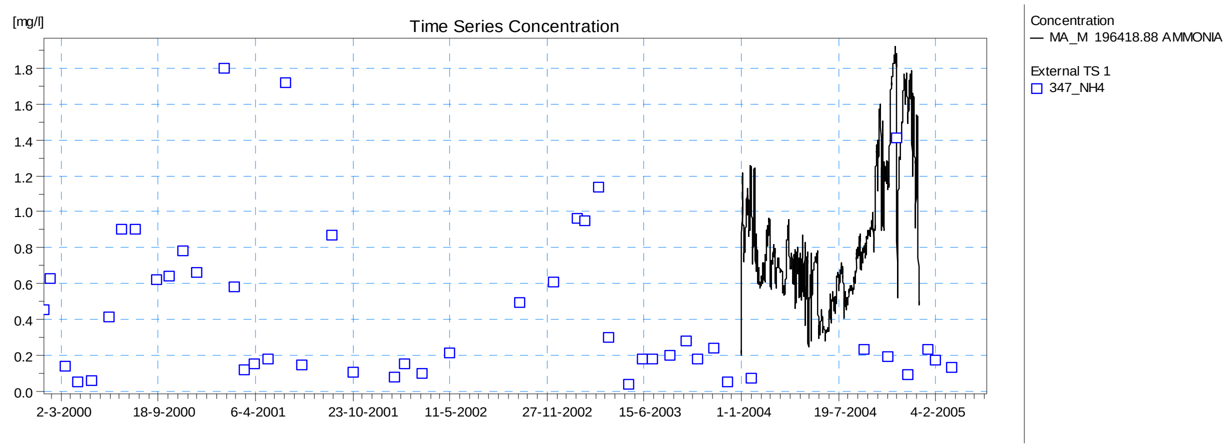


Figure E.5.124 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 347, The Maritsa River

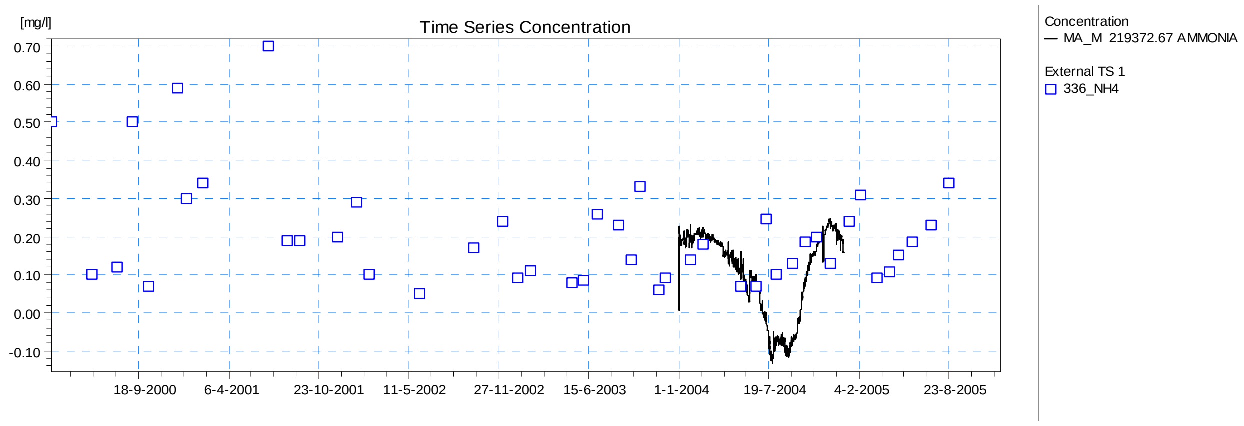


Figure E.5.125 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 336, The Maritsa River

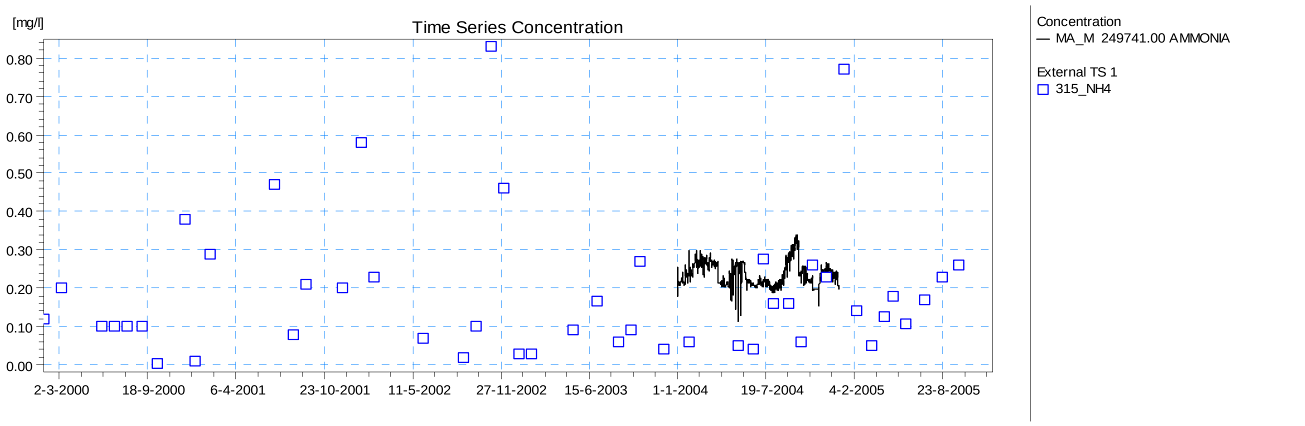


Figure E.5.126 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 315, The Maritsa River

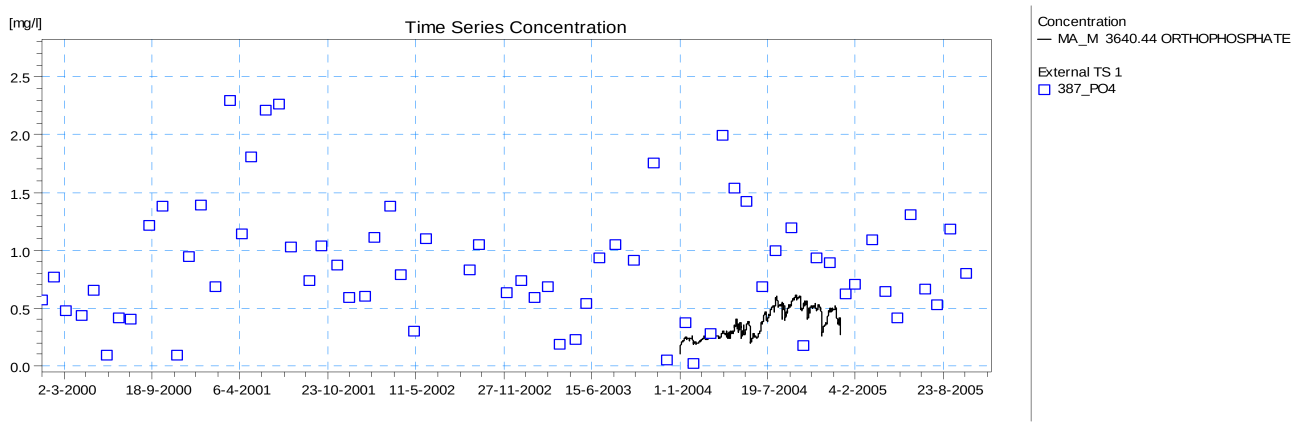


Figure E.5.127 Simulated and Monitored Ammonium (NH_4-N) Concentration, St. 387, The Maritsa River

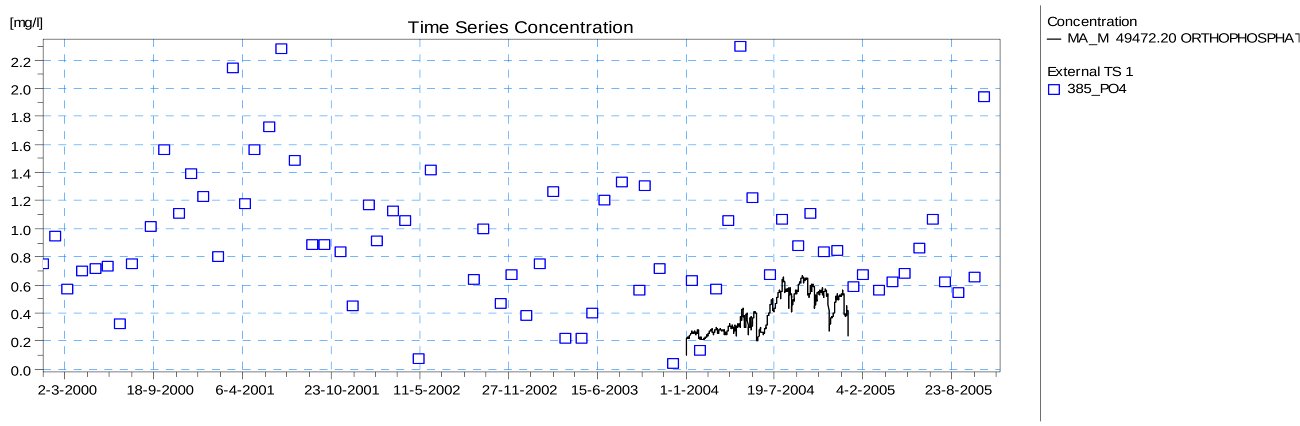


Figure E.5.128 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 387, The Maritsa River

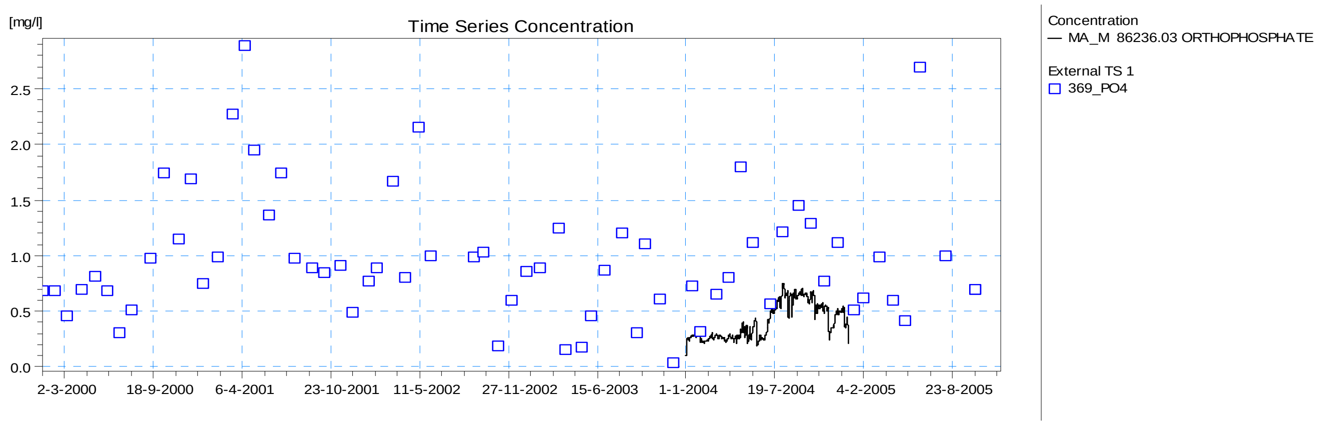


Figure E.5.129 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 369, The Maritsa River

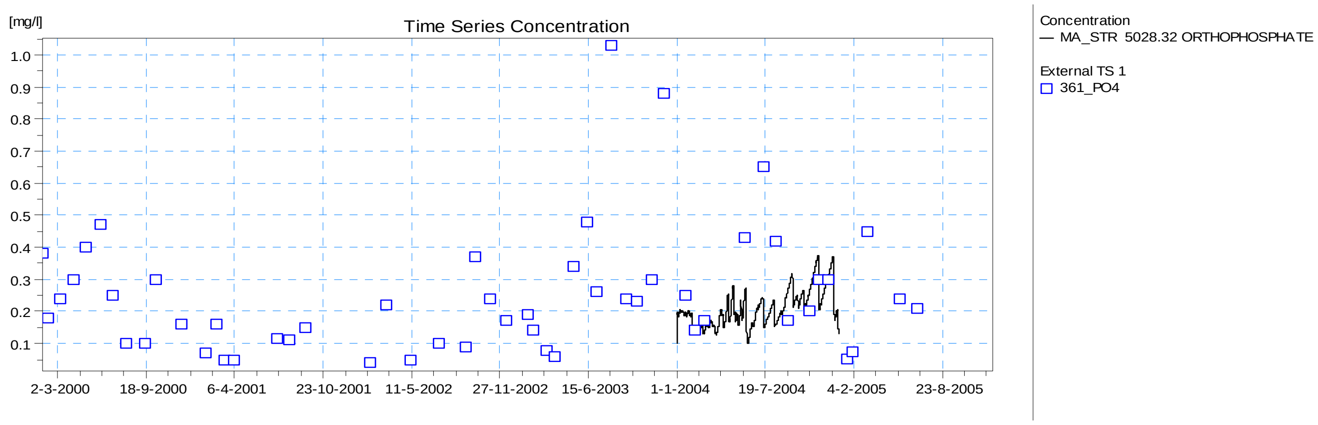


Figure E.5.130 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 361, The Maritsa River

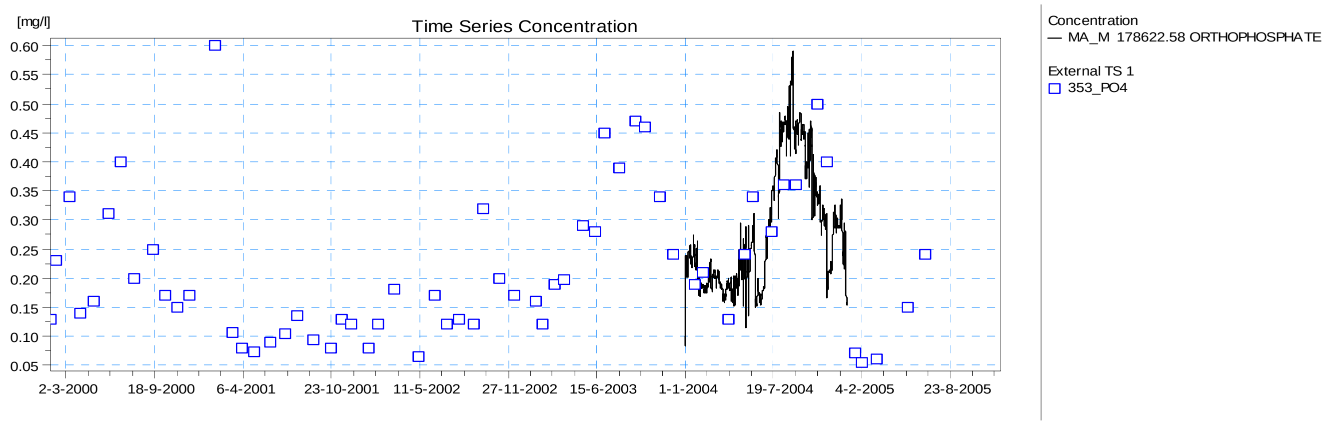


Figure E.5.131 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 353, The Maritsa River

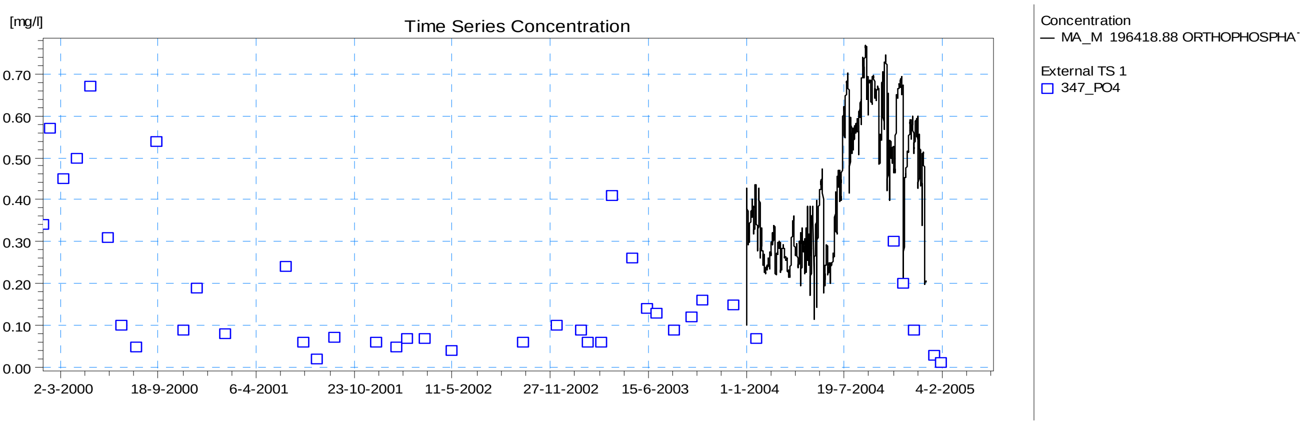


Figure E.5.132 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 347, The Maritsa River

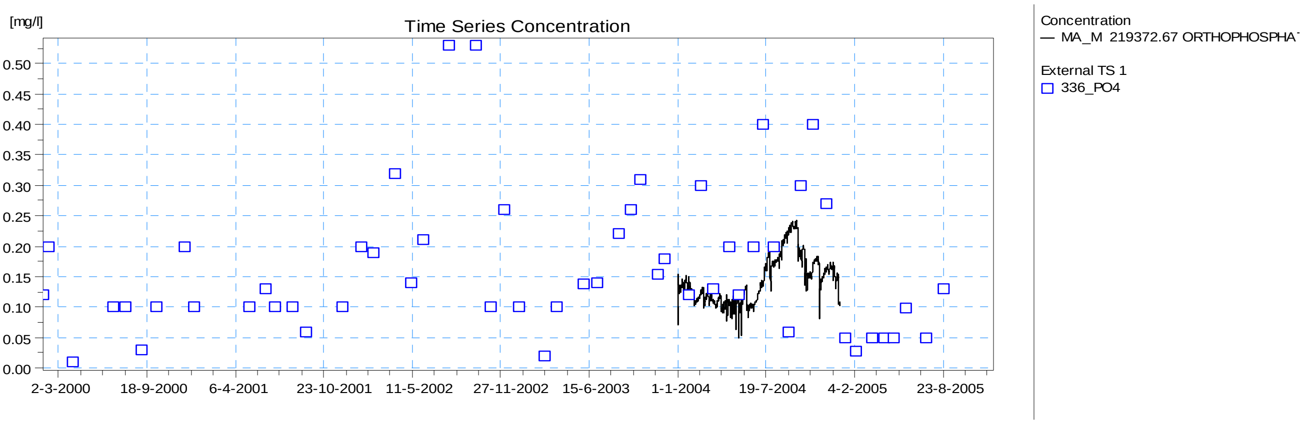


Figure E.5.133 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 336, The Maritsa River

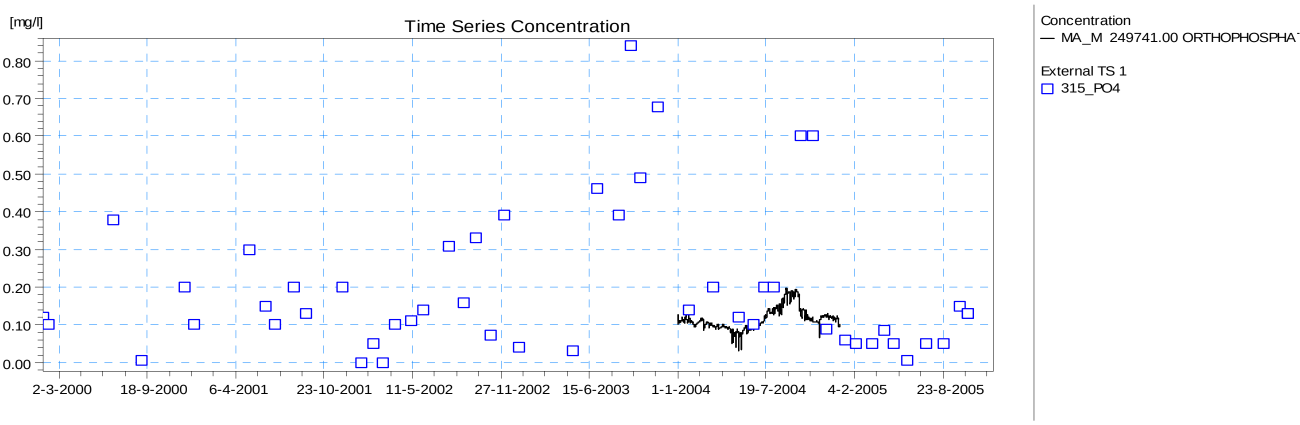


Figure E.5.134 Simulated and Monitored Phosphate (PO_4-P) Concentration, St. 315, The Maritsa River

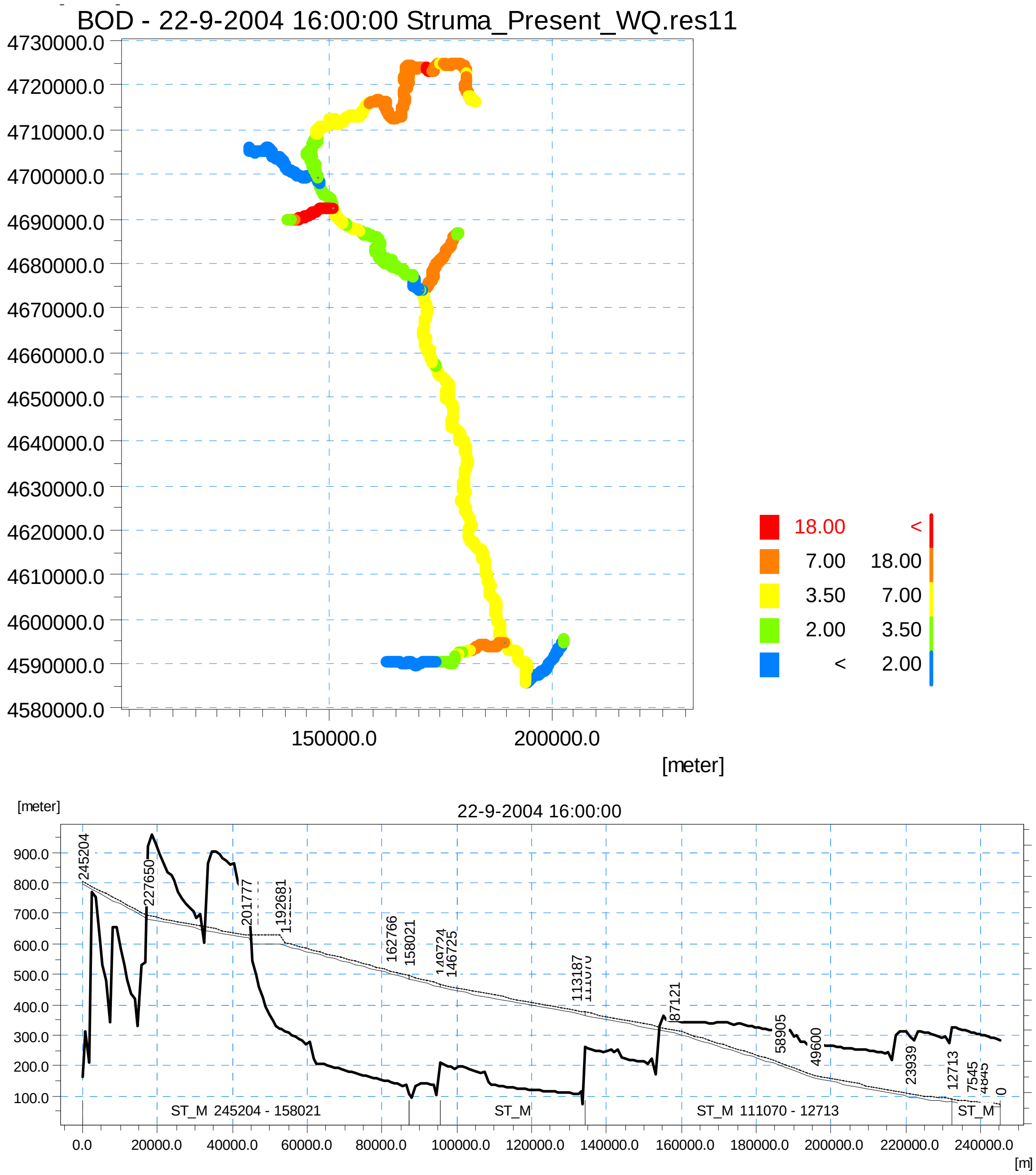


Figure E.5.135 Simulated BOD concentration (mg/l) in the Struma River. Scenario: Present condition.

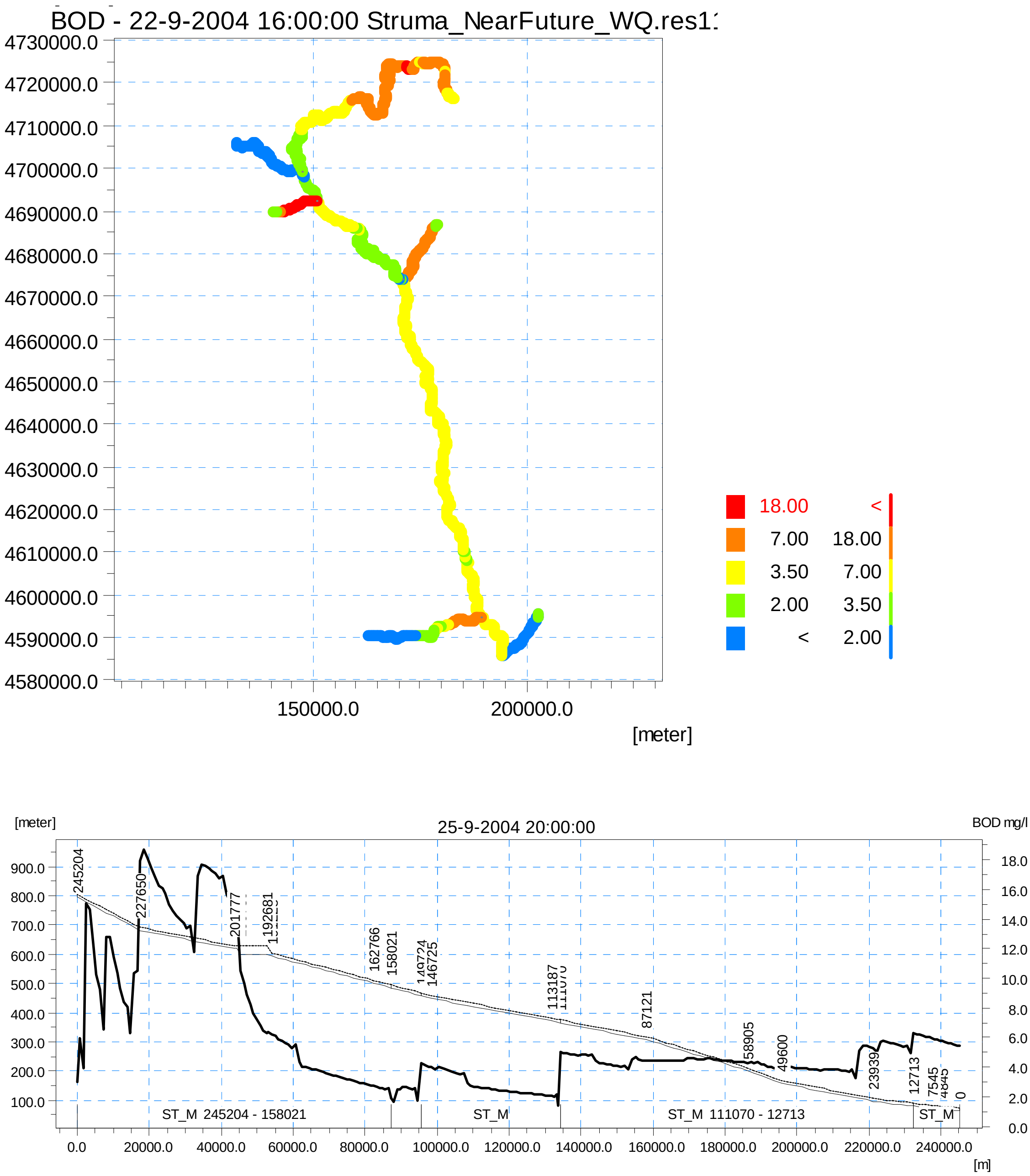
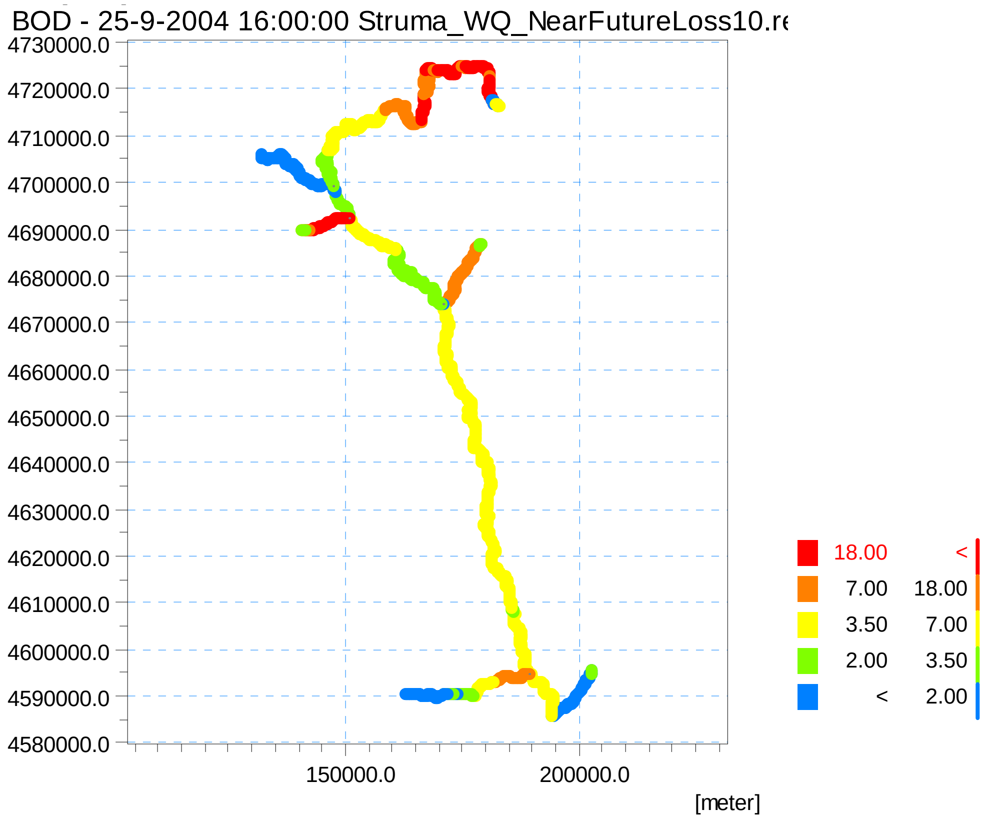


Figure E.5.136 Simulated BOD concentration in the Struma River. Scenario: Near Future.



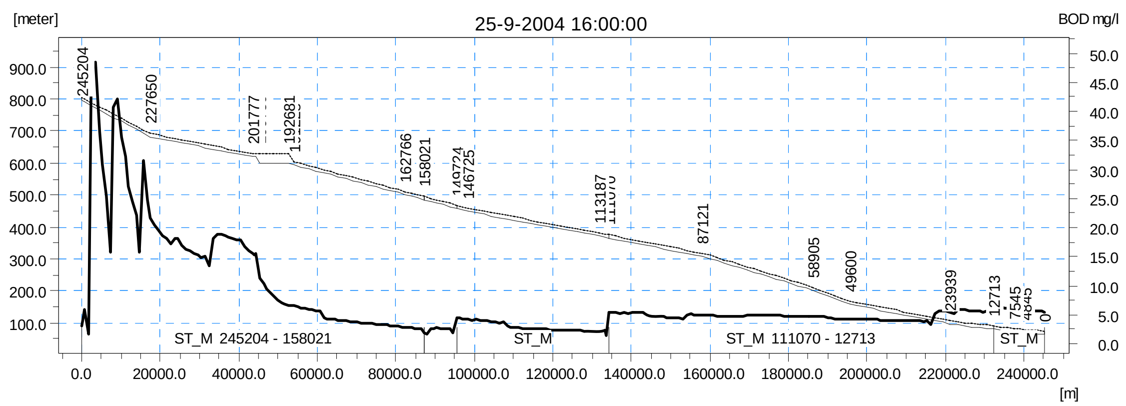
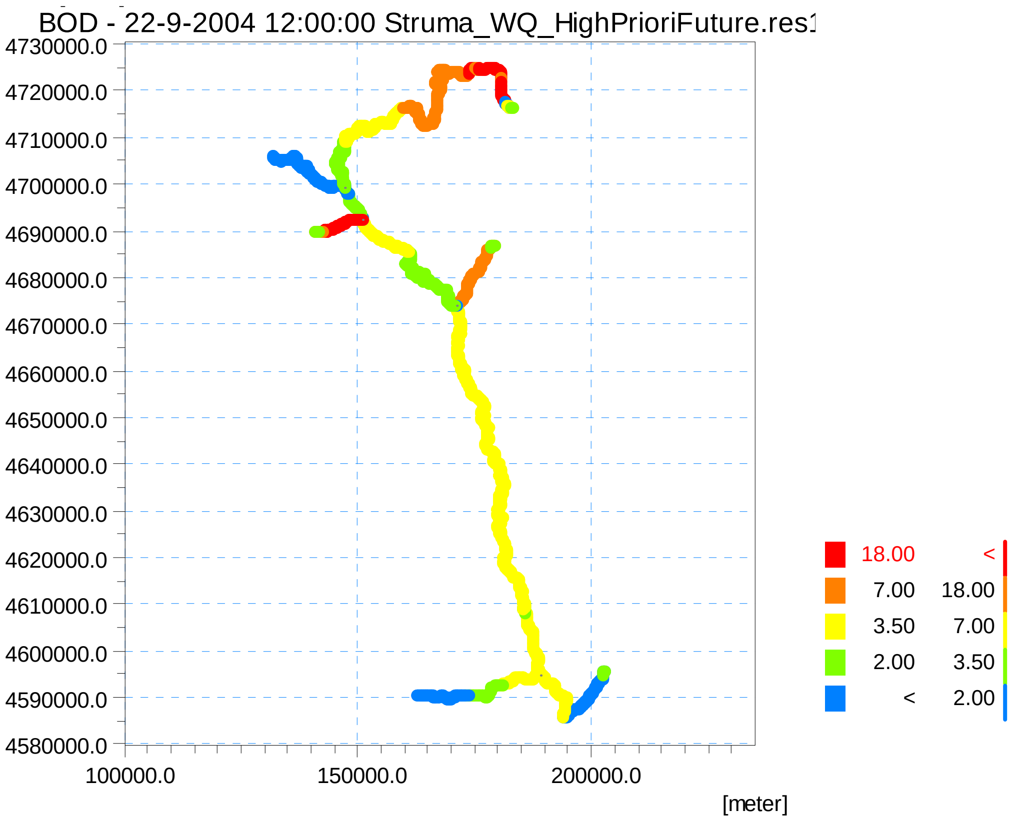


Figure E.5.137 Simulated BOD concentration in the Struma River. Scenario: Near Future 10 % loss.



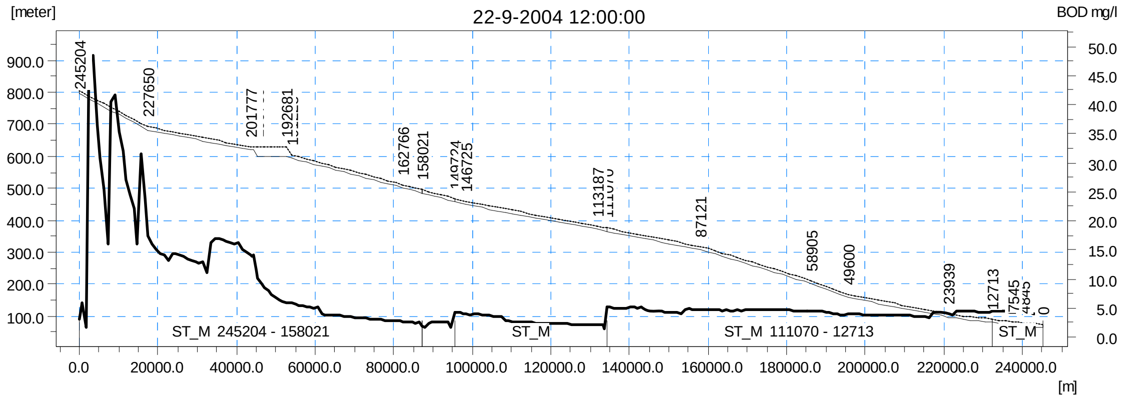
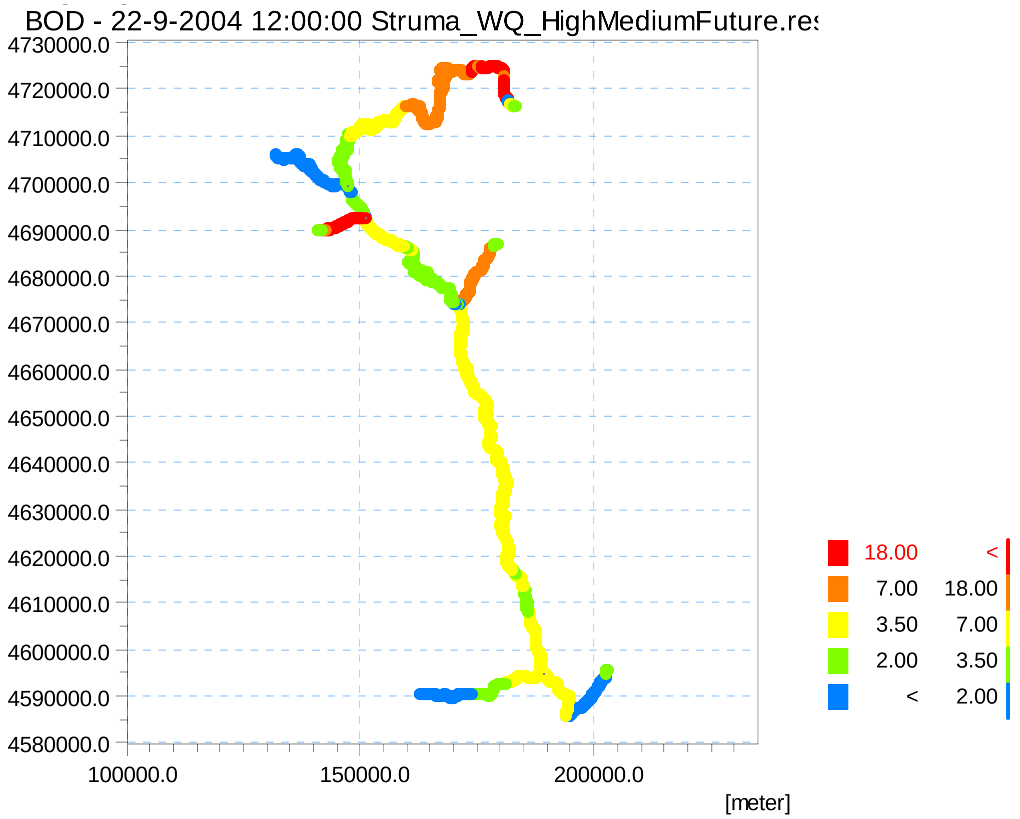


Figure E.5.138 Simulated BOD concentration in the Struma River. Scenario: High Priority Future.



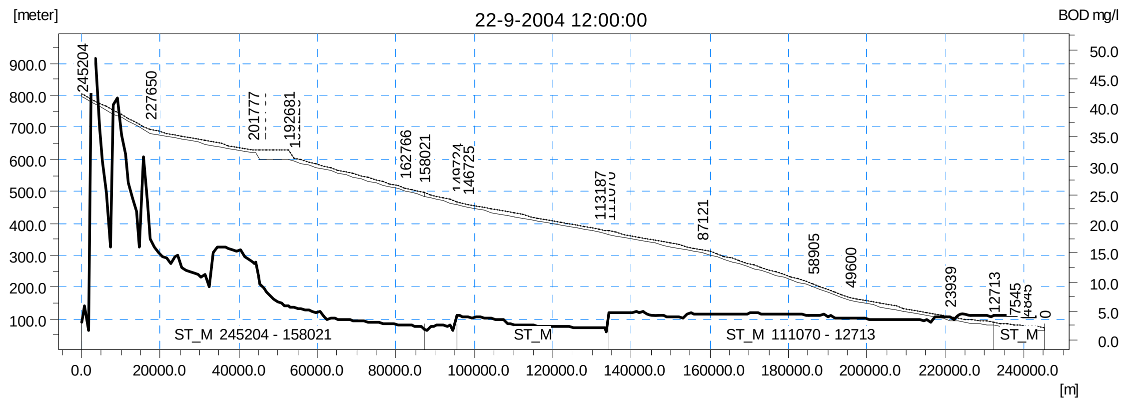


Figure E.5.139 Simulated BOD concentration in the Struma River. Scenario: High Medium Priority Future.

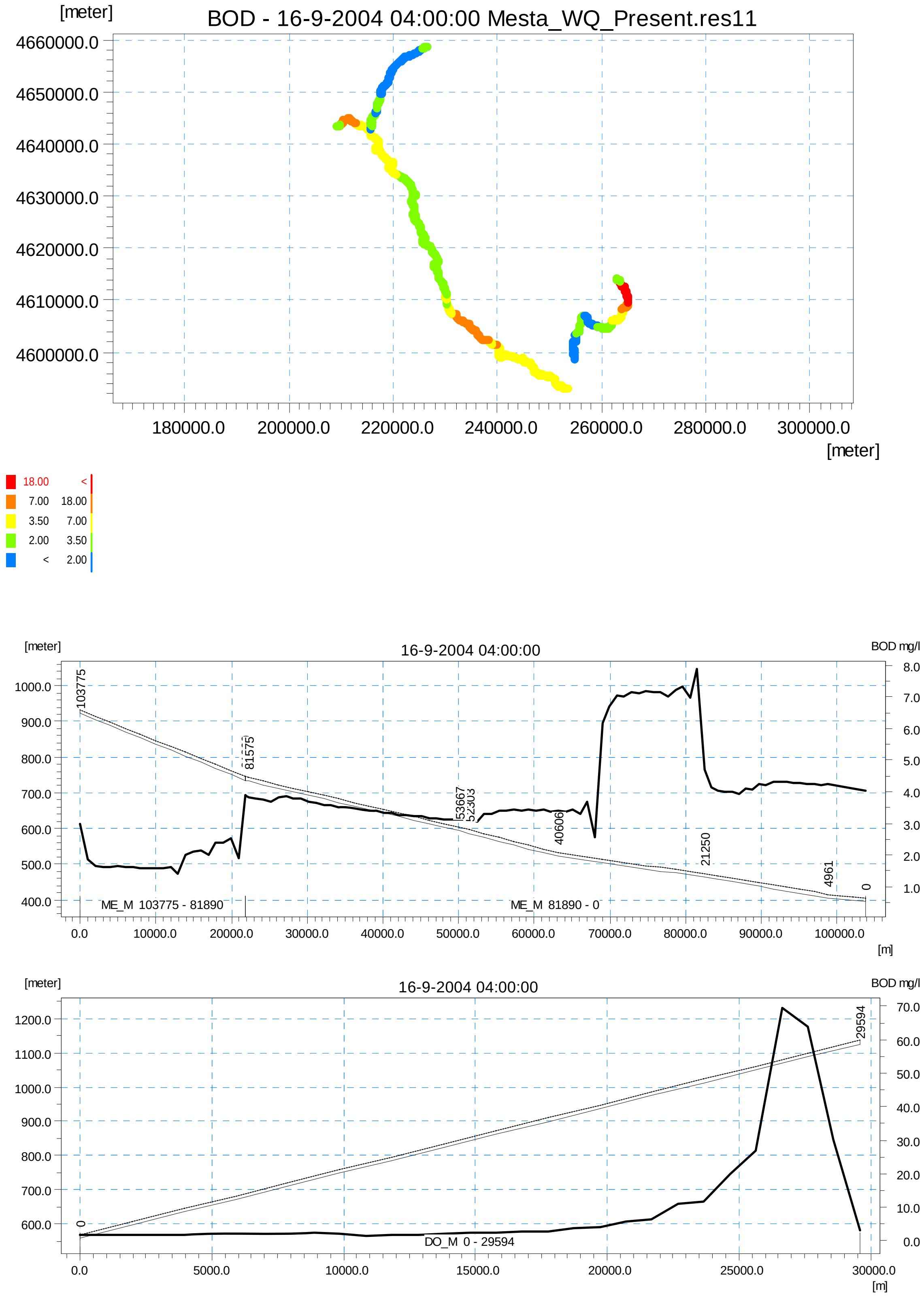


Figure E.5.140 Simulated BOD concentration in the Mesta River. Scenario: Present condition.

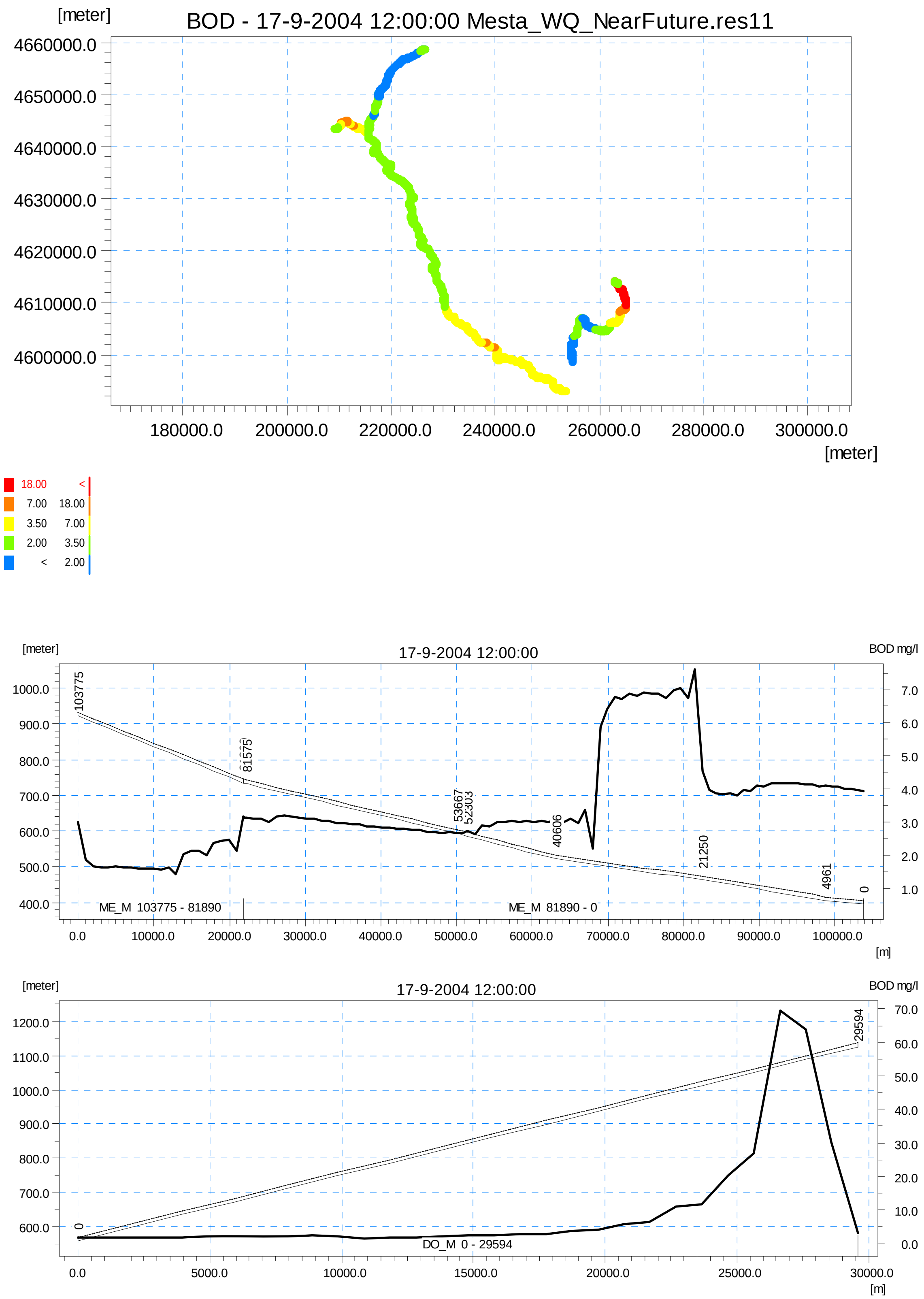


Figure E.5.141 Simulated BOD concentration in the Mesta River. Scenario: Near Future.

Figure E.5.142 Simulated BOD concentration in the Mesta River. Scenario: Near Future 10 % loss.

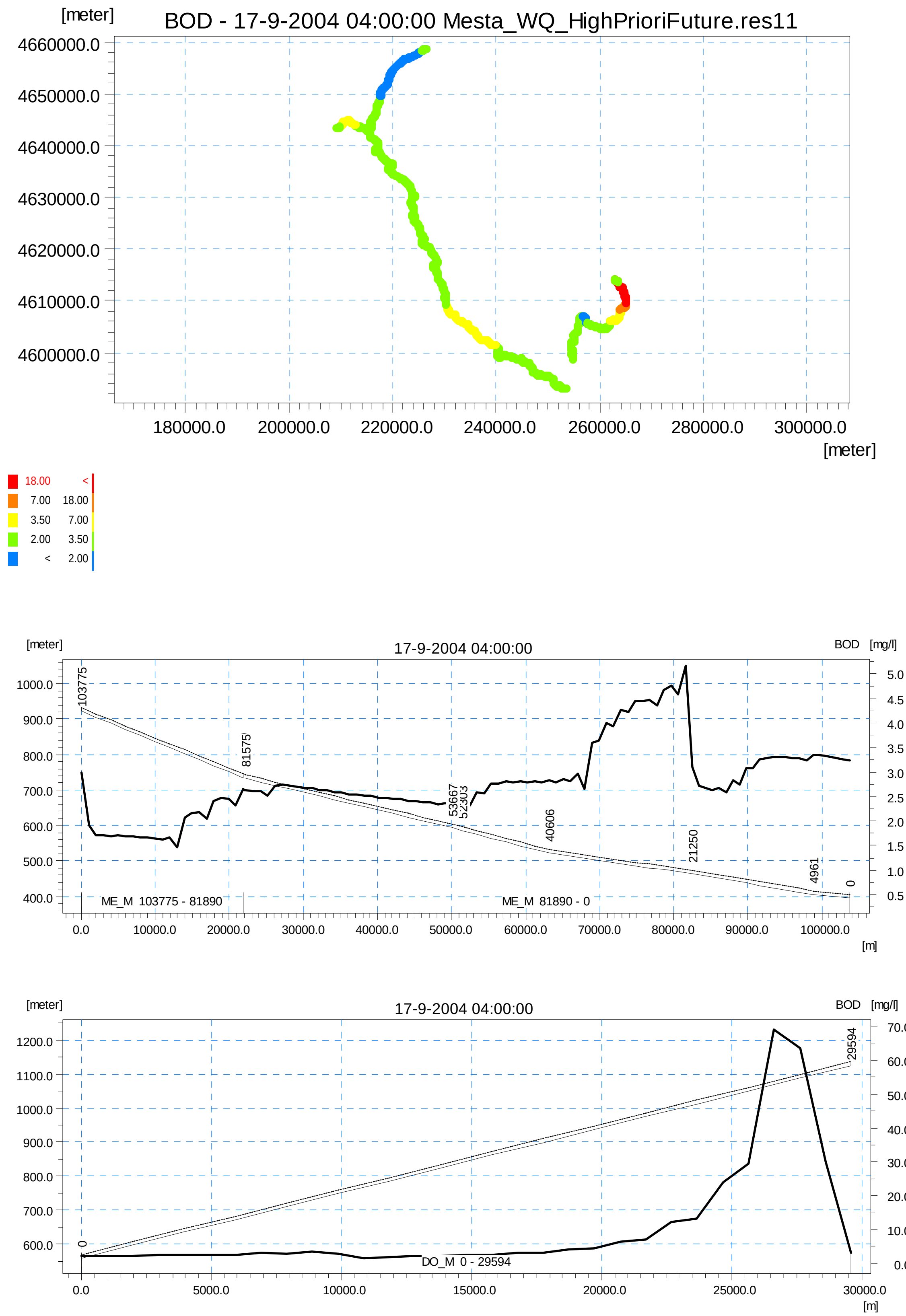
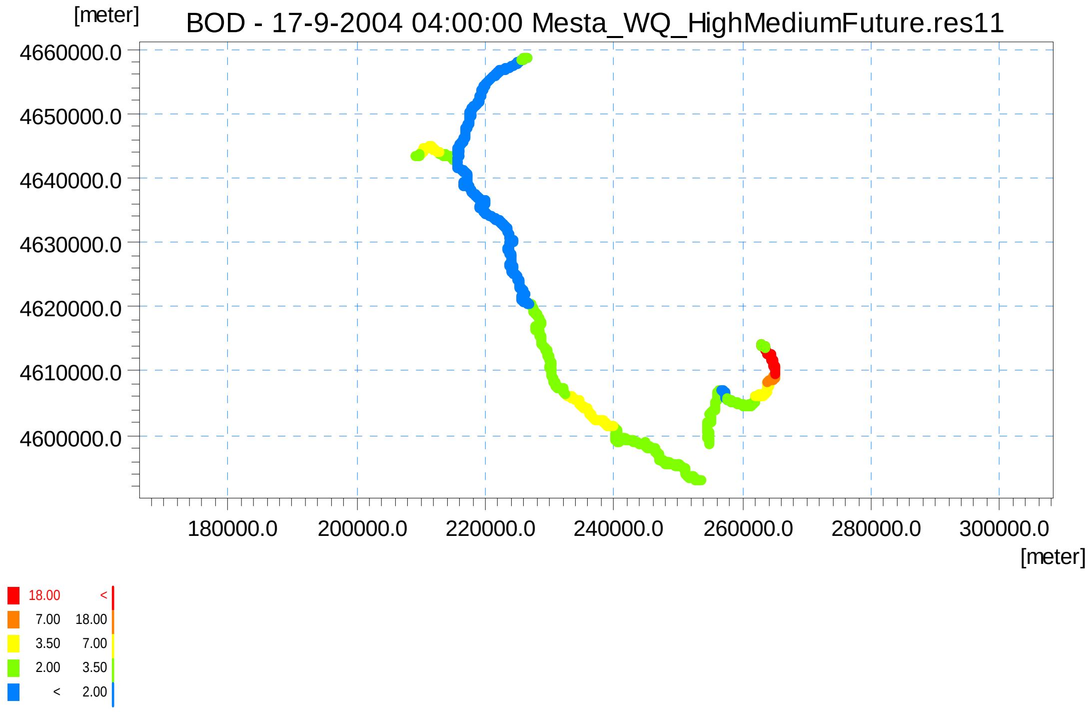
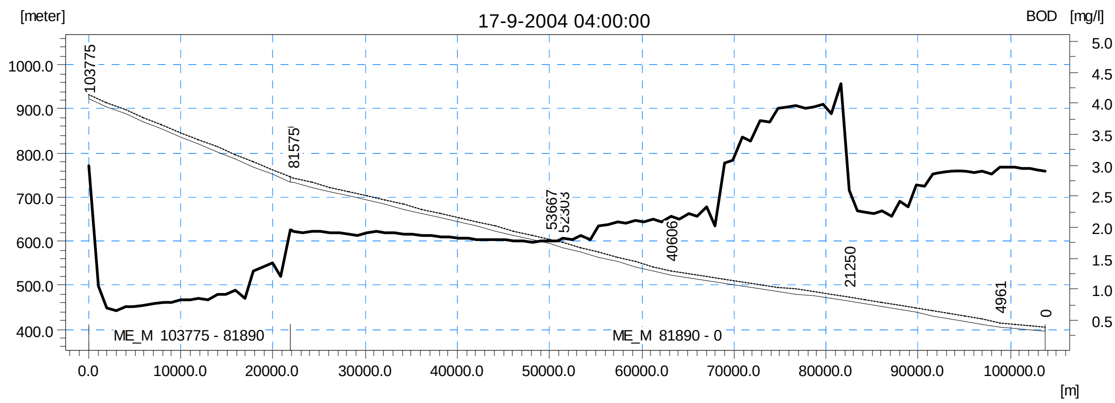


Figure E.5.143 Simulated BOD concentration in the Mesta River. Scenario: High Priority Future.





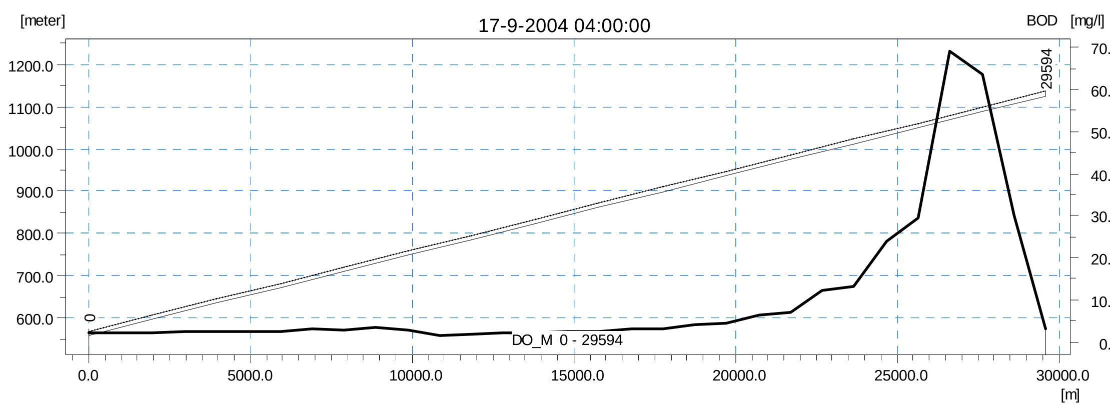


Figure E.5.144 Simulated BOD concentration in the Mesta River. Scenario: High Medium Priority Future.

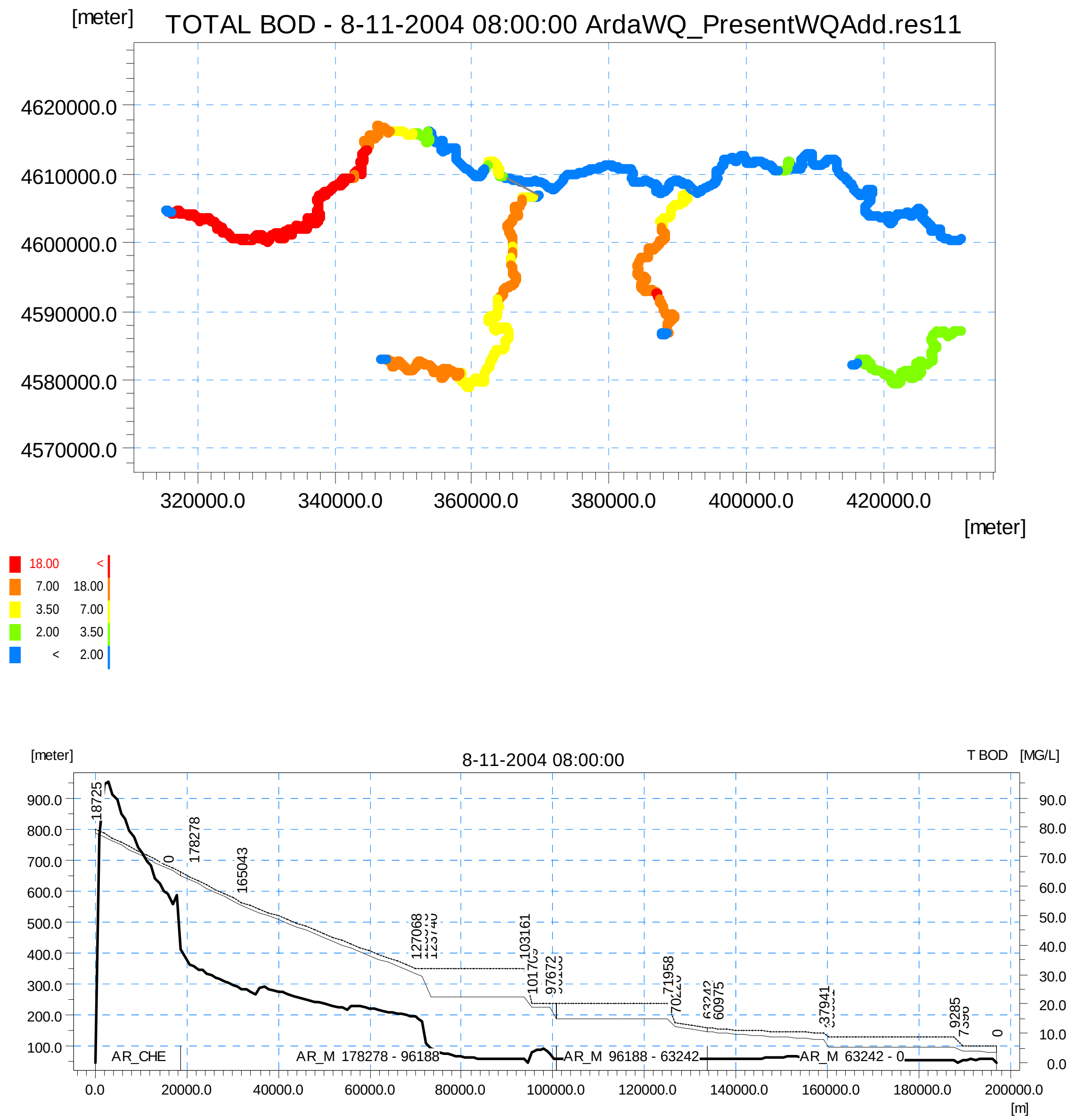


Figure E.5.145 Simulated BOD concentration in the Arda River. Scenario: Present condition.

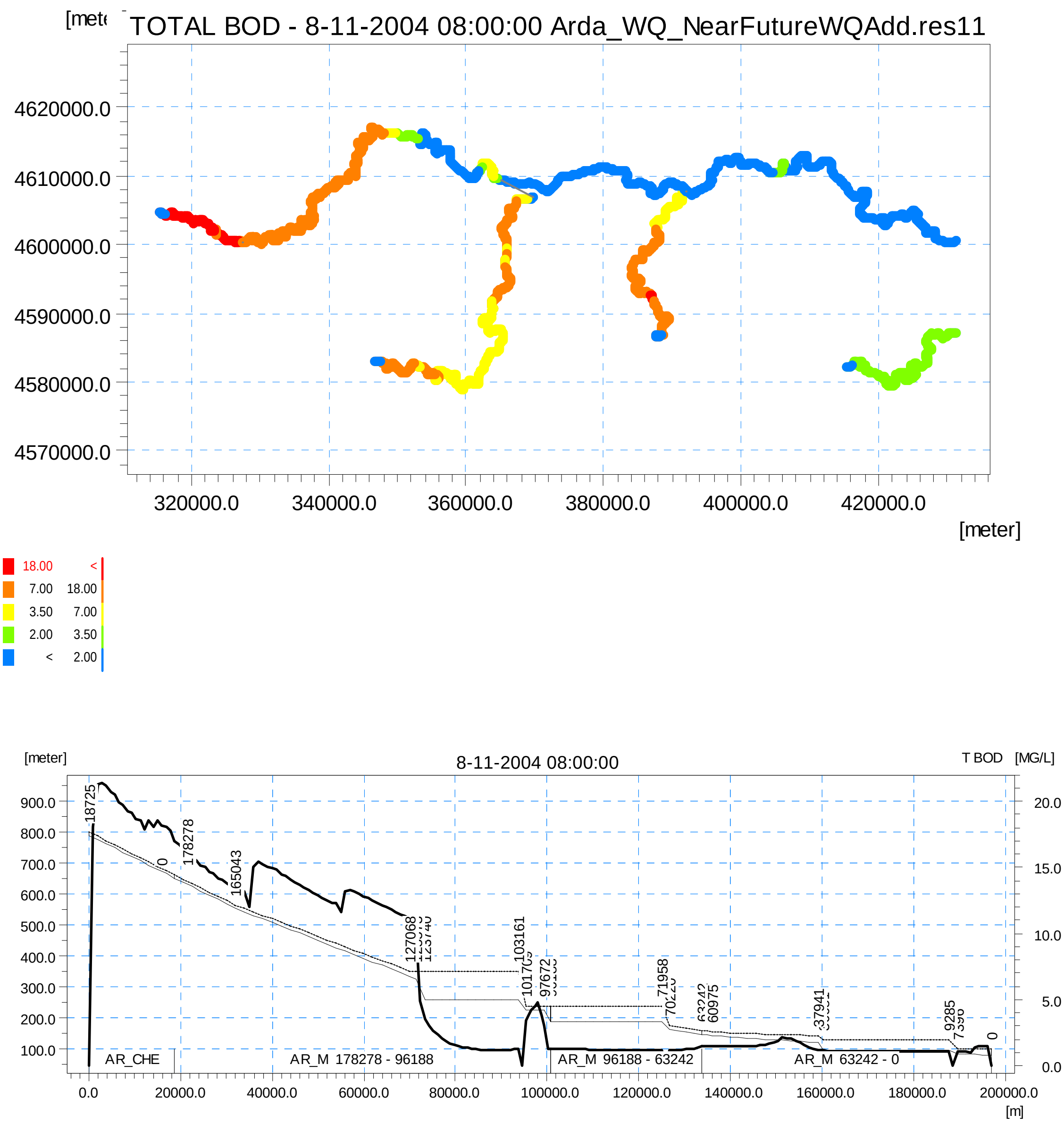
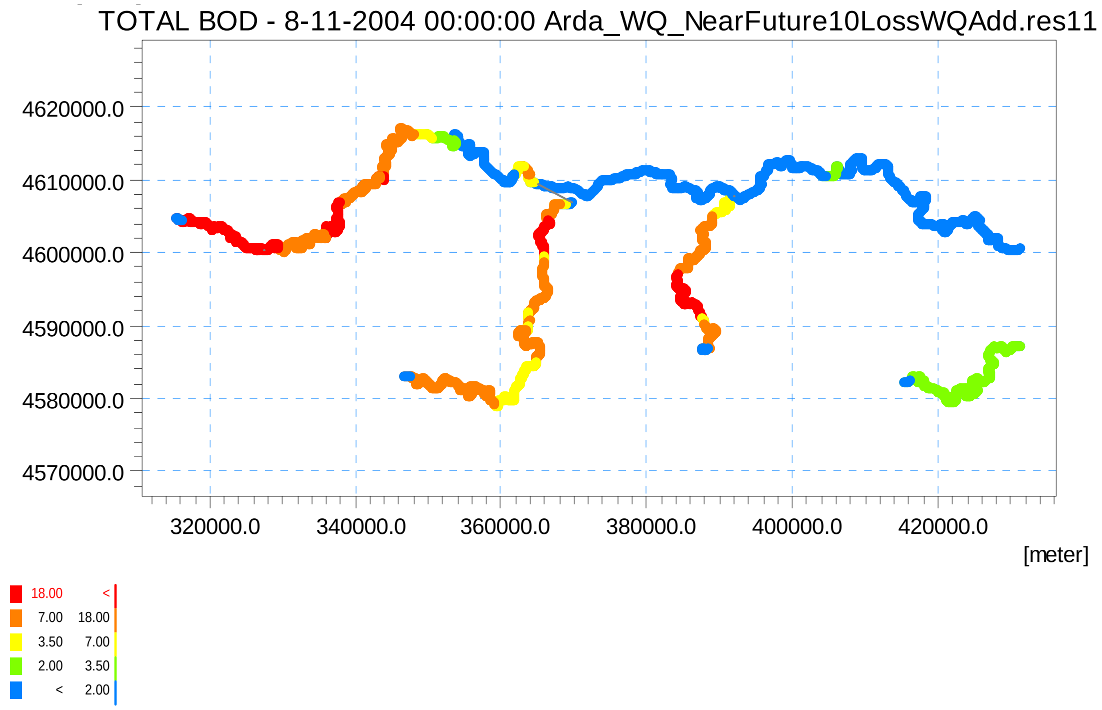


Figure E.5.146 Simulated BOD concentration in the Arda River. Scenario: Near Future.



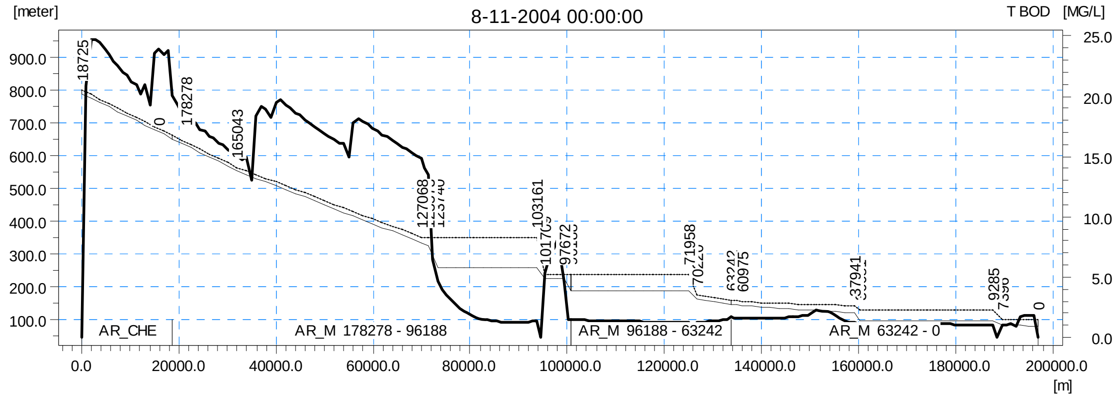
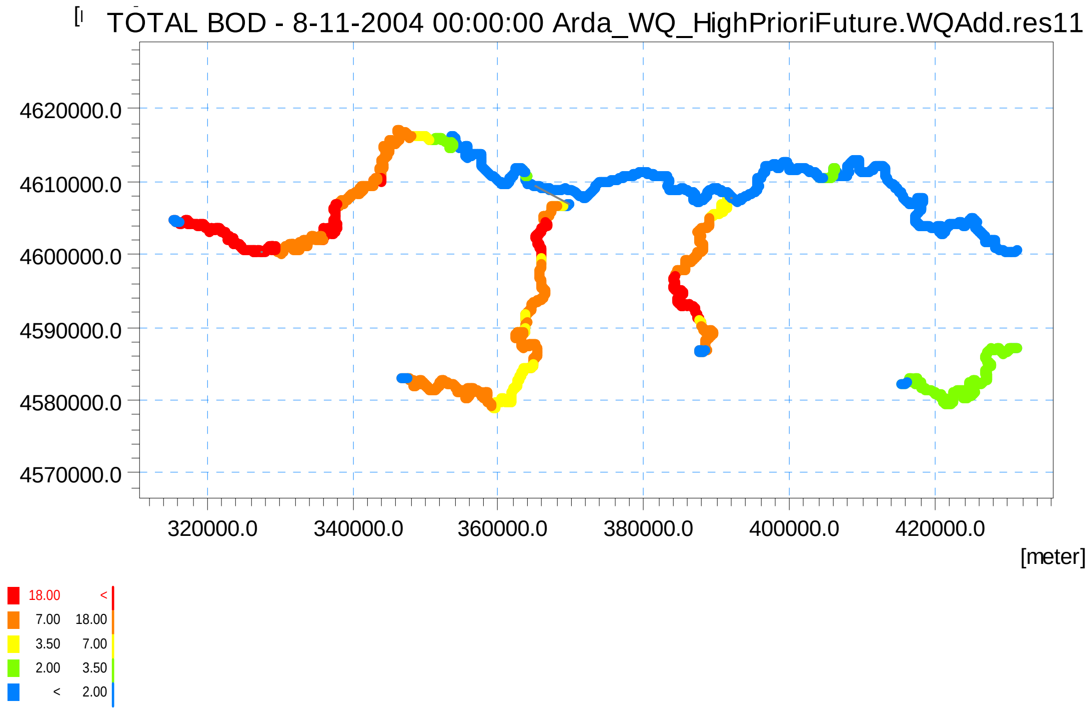


Figure E.5.147 Simulated BOD concentration in the Arda River. Scenario: Near Future 10 % loss.



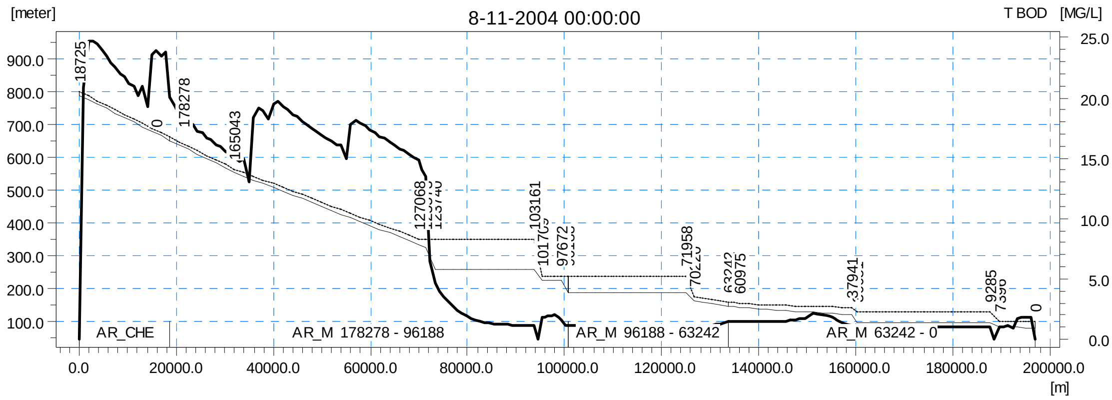
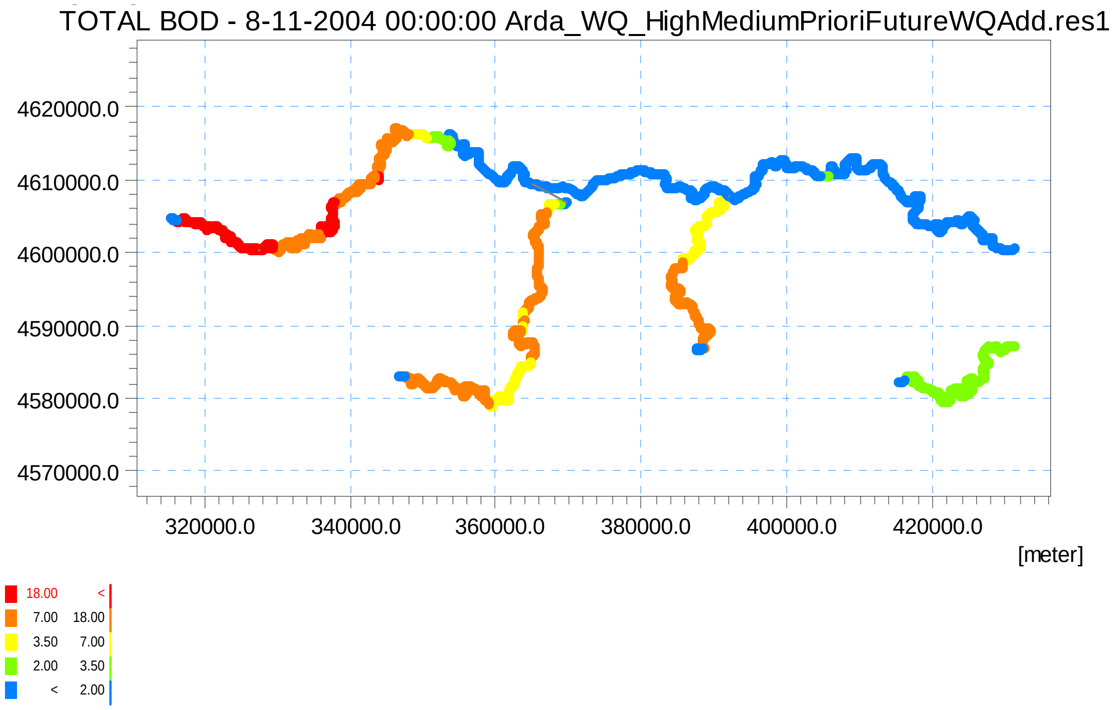


Figure E.5.148 Simulated BOD concentration in the Arda River. Scenario: High Priority Future.



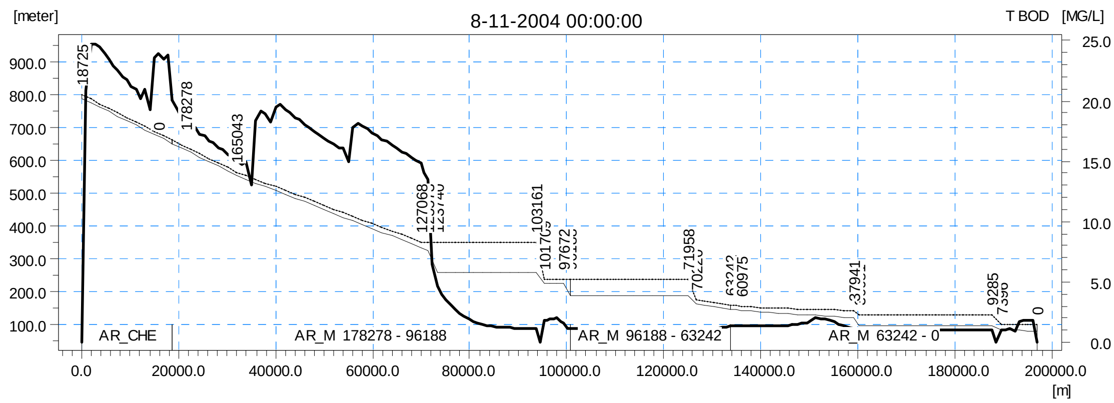


Figure E.5.149 Simulated BOD concentration in the Arda River. Scenario: High Medium Priority Future.

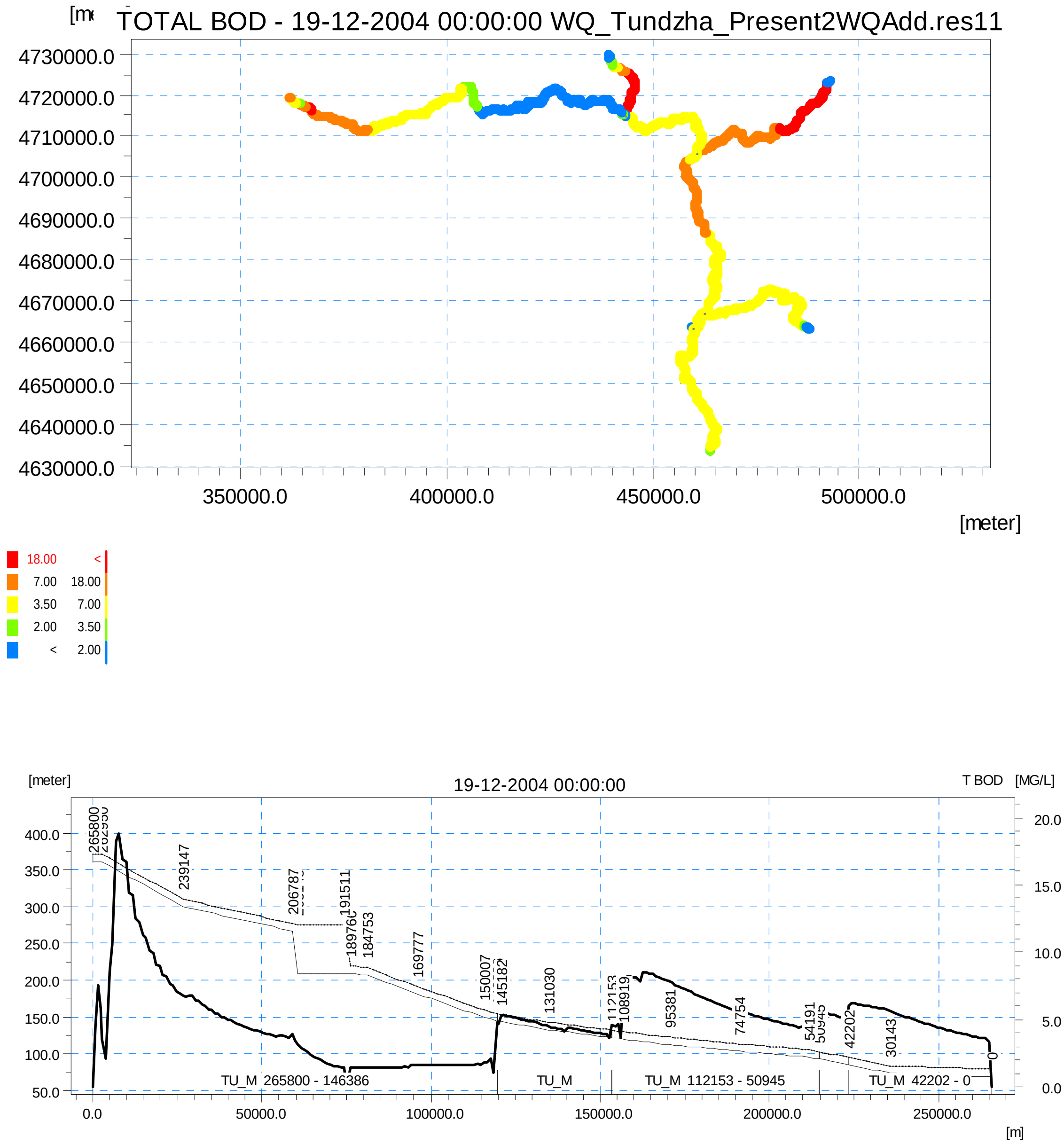
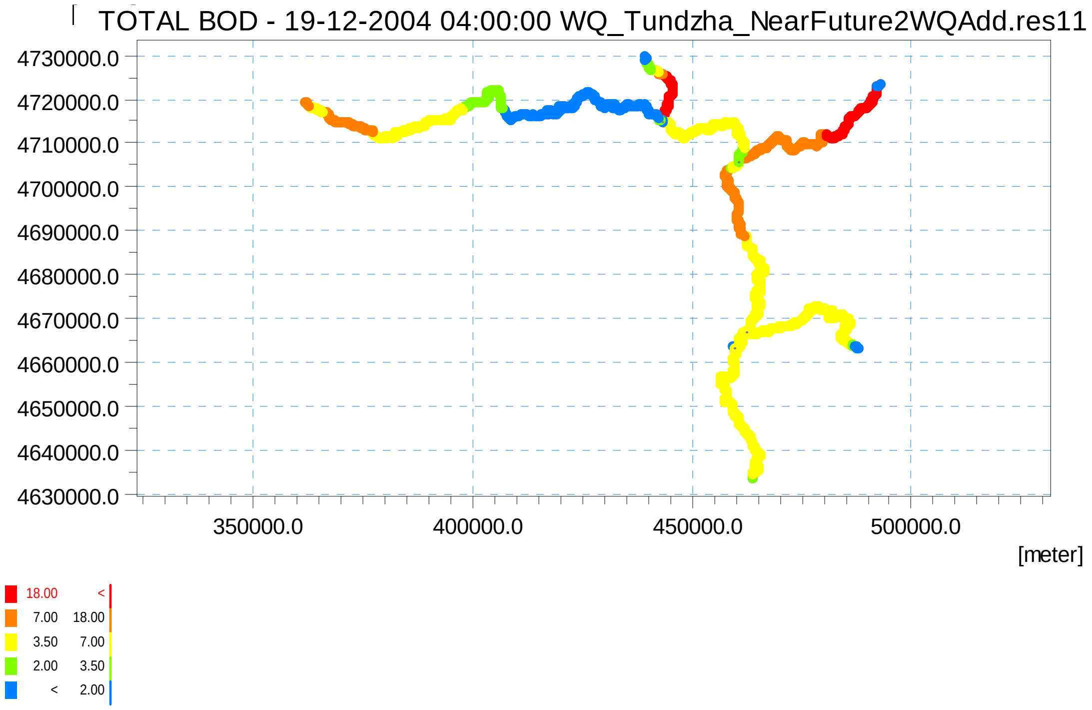


Figure E.5.150 Simulated BOD concentration in the Tundzha River. Scenario: Present condition.



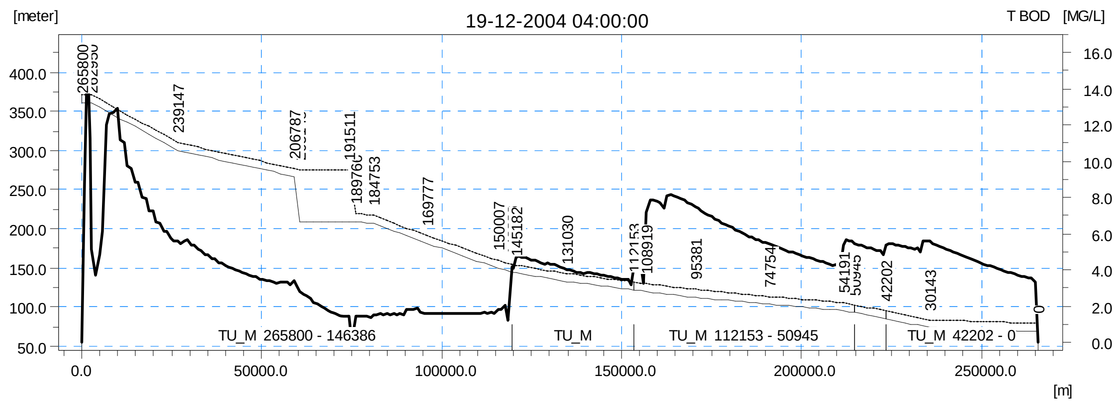


Figure E.5.151 Simulated BOD concentration in the Tundzha River. Scenario: Near Future.

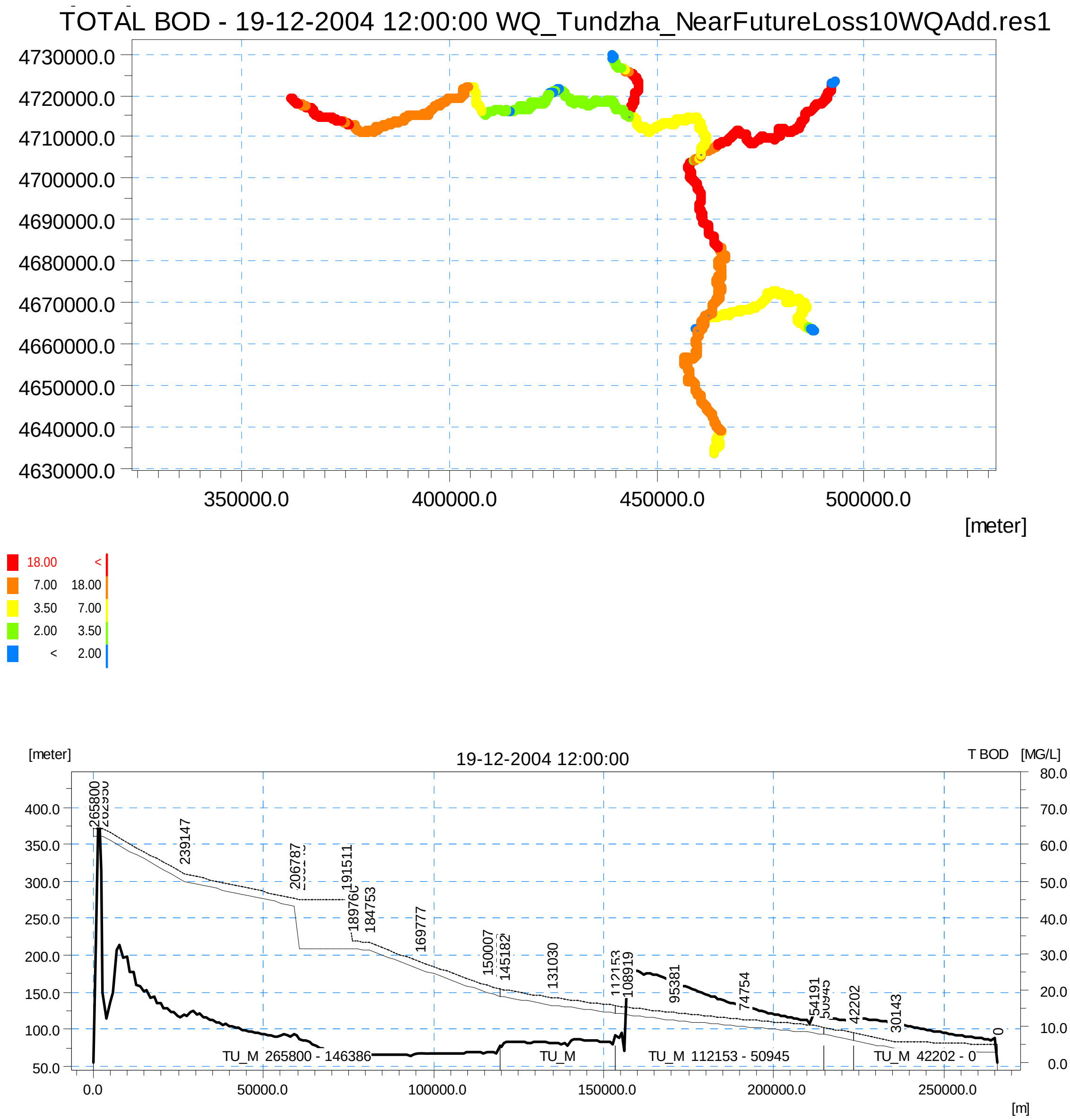
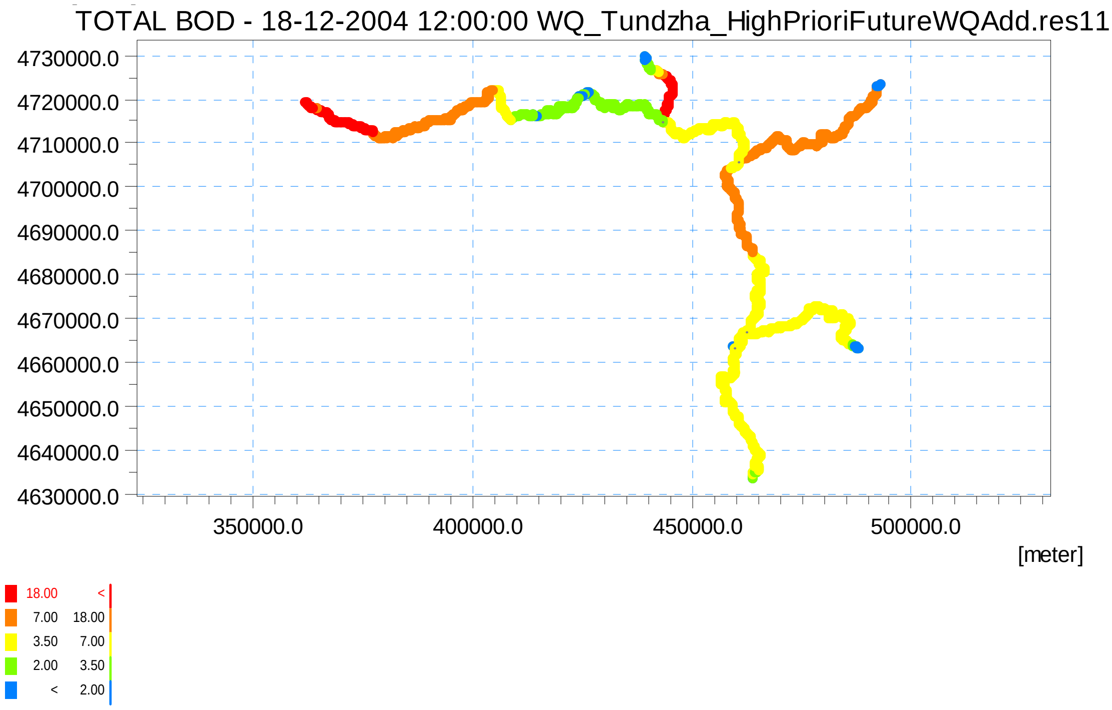


Figure E.5.152 Simulated BOD concentration in the Tundzha River. Scenario: Near Future 10 % loss.



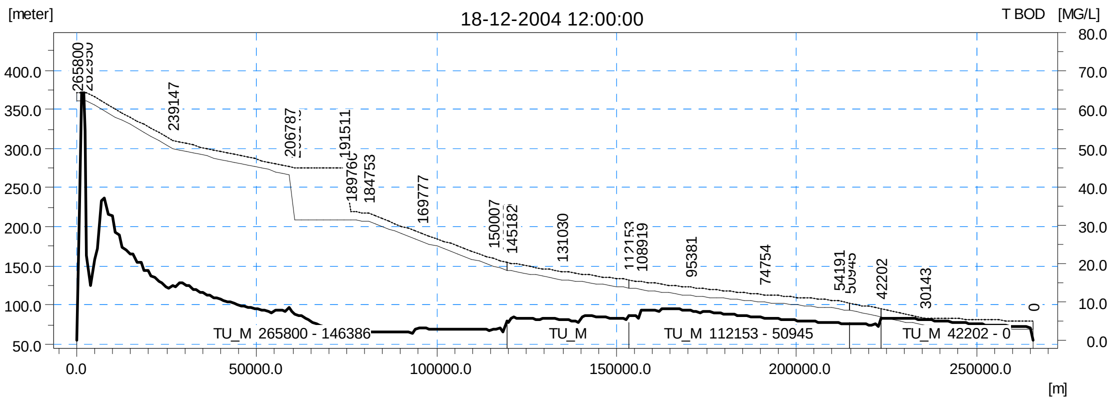
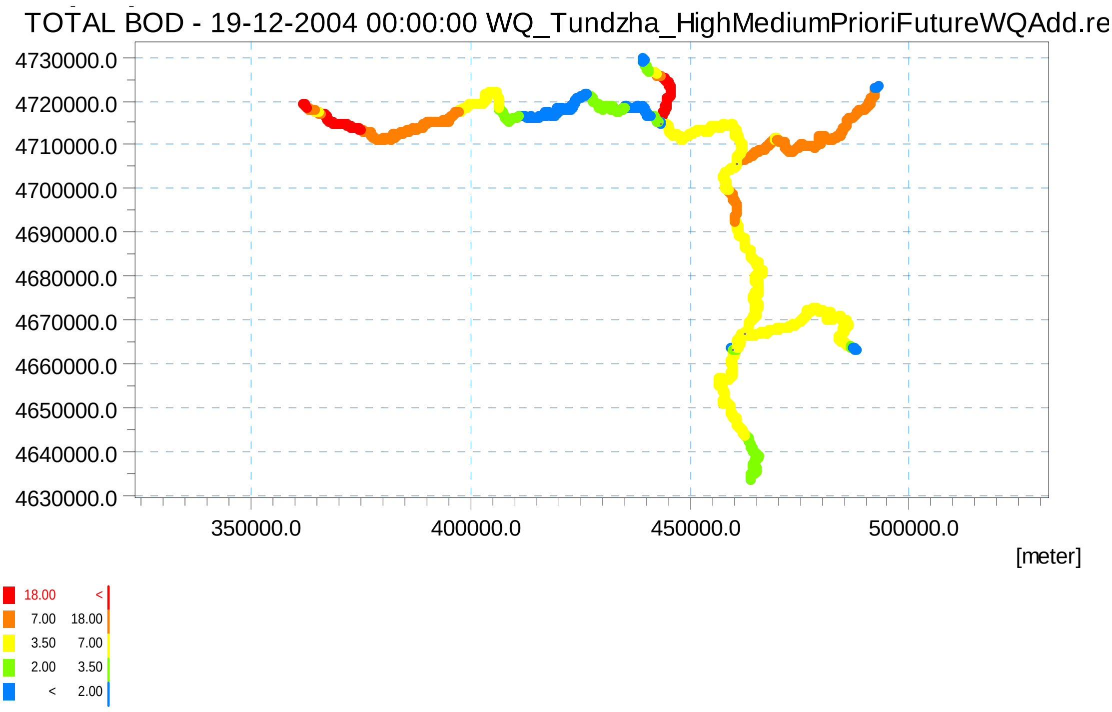


Figure E.5.153 Simulated BOD concentration in the Tundzha River. Scenario: High Priority Future.



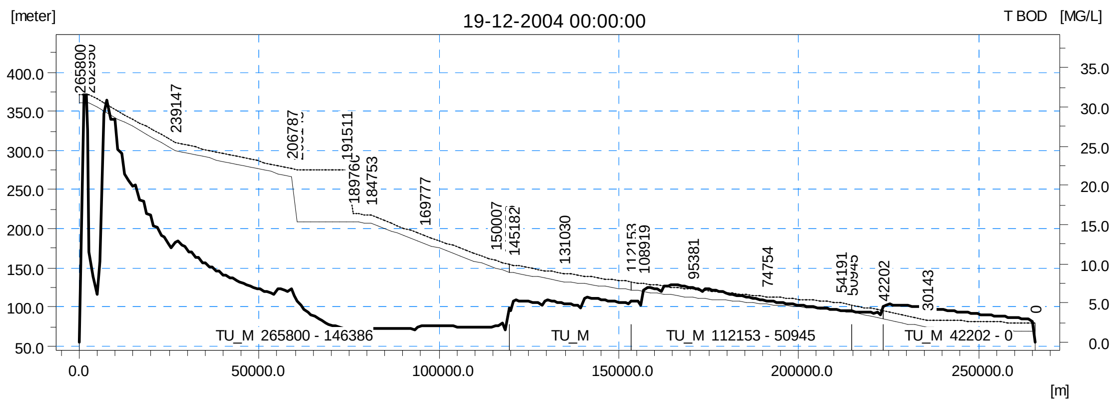


Figure E.5.154 Simulated BOD concentration in the Tundzha River. Scenario: High Medium Priority Future.

Figure E.5.155 Simulated BOD concentration in the Maritsa River. Scenario: Present condition.

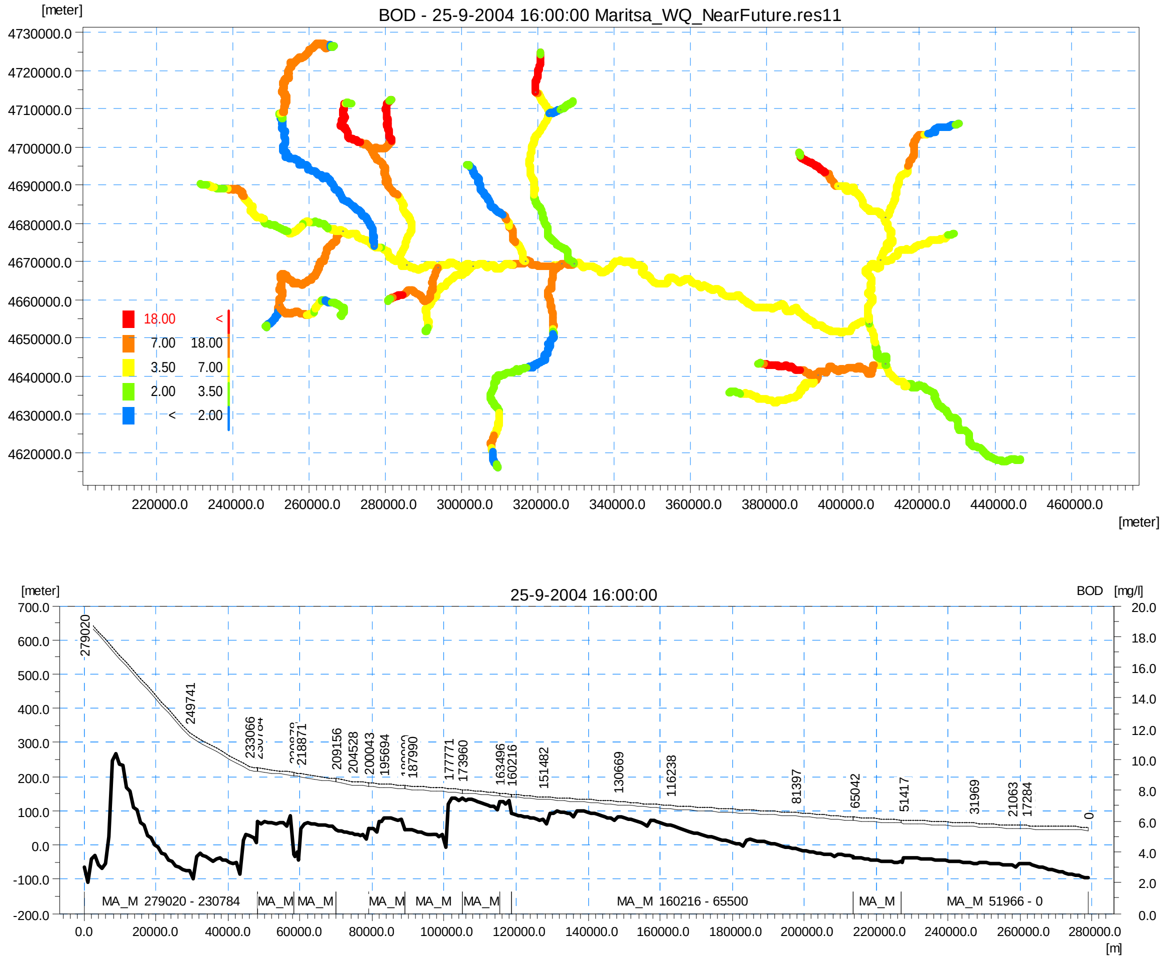
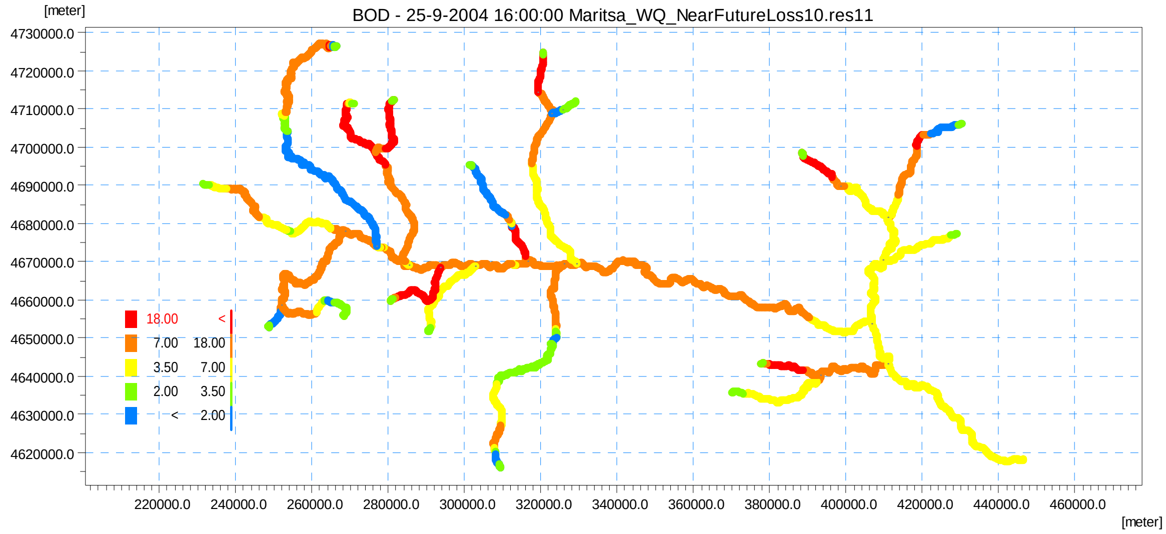


Figure E.5.156 Simulated BOD concentration in the Maritsa River. Scenario: Near Future.



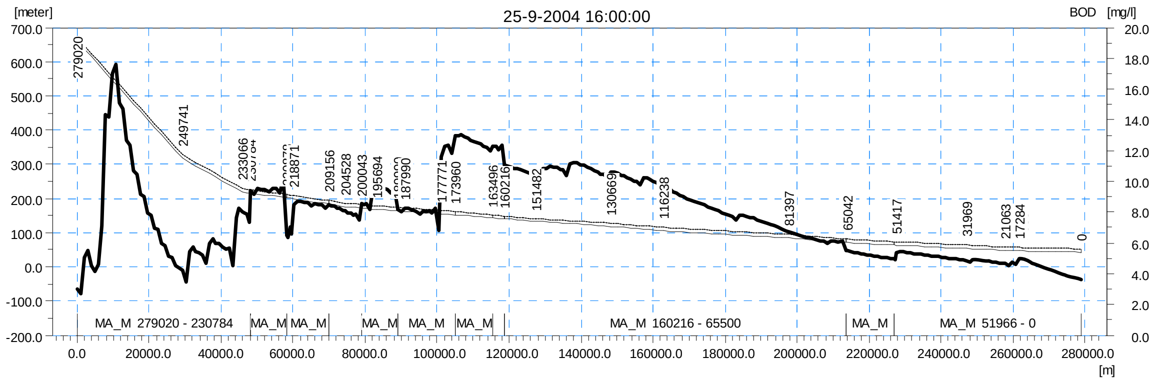
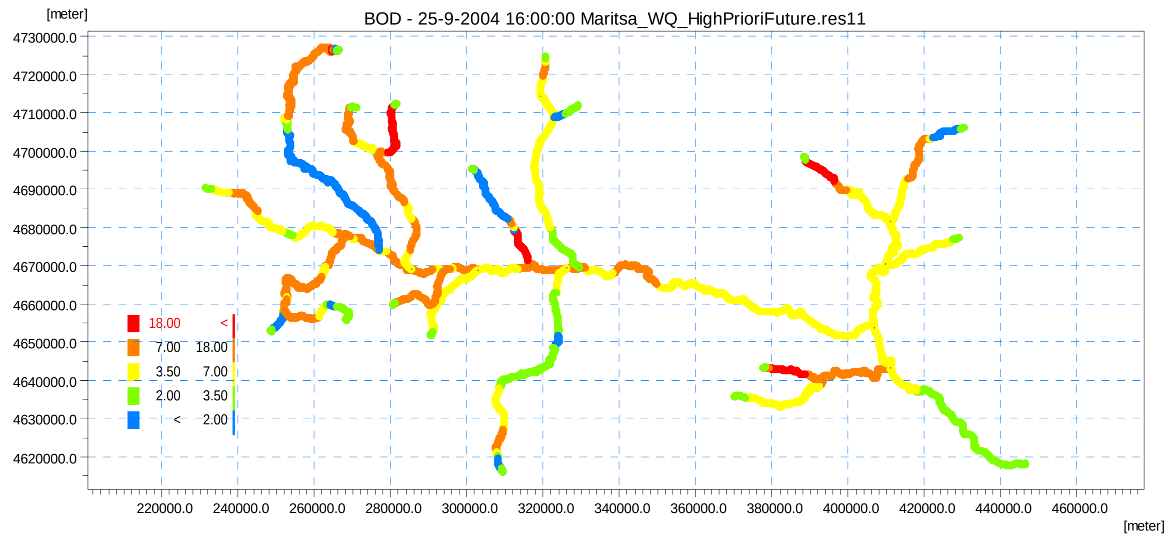


Figure E.5.157 Simulated BOD concentration in the Maritsa River. Scenario: Near Future 10 % loss.



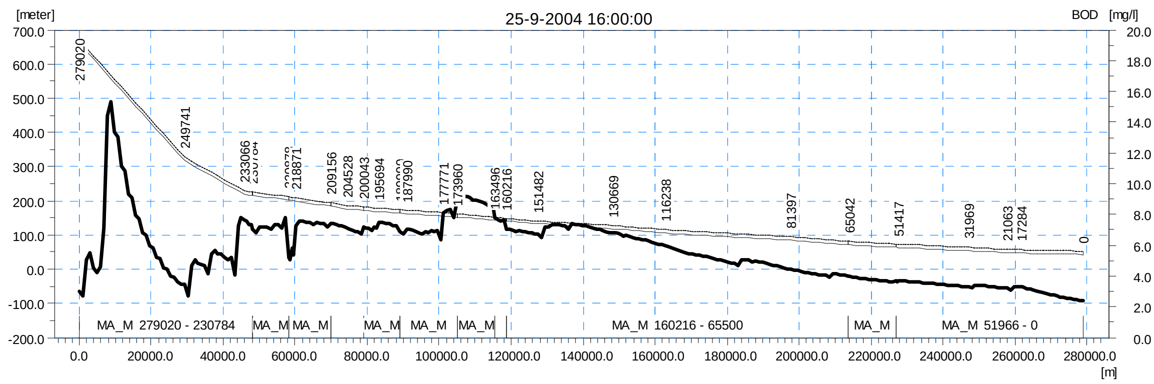
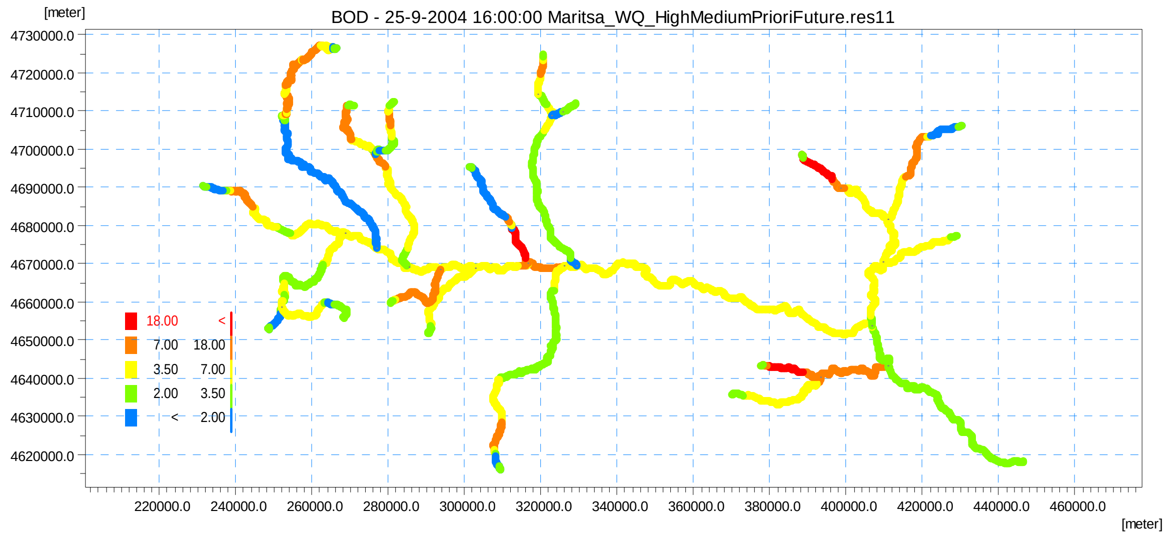


Figure E.5.158 Simulated BOD concentration in the Maritsa River. Scenario: High Priority Future.



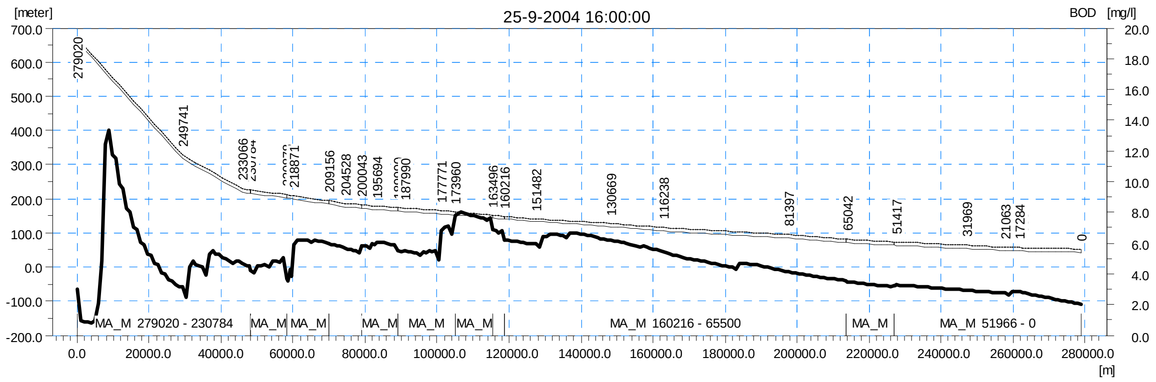
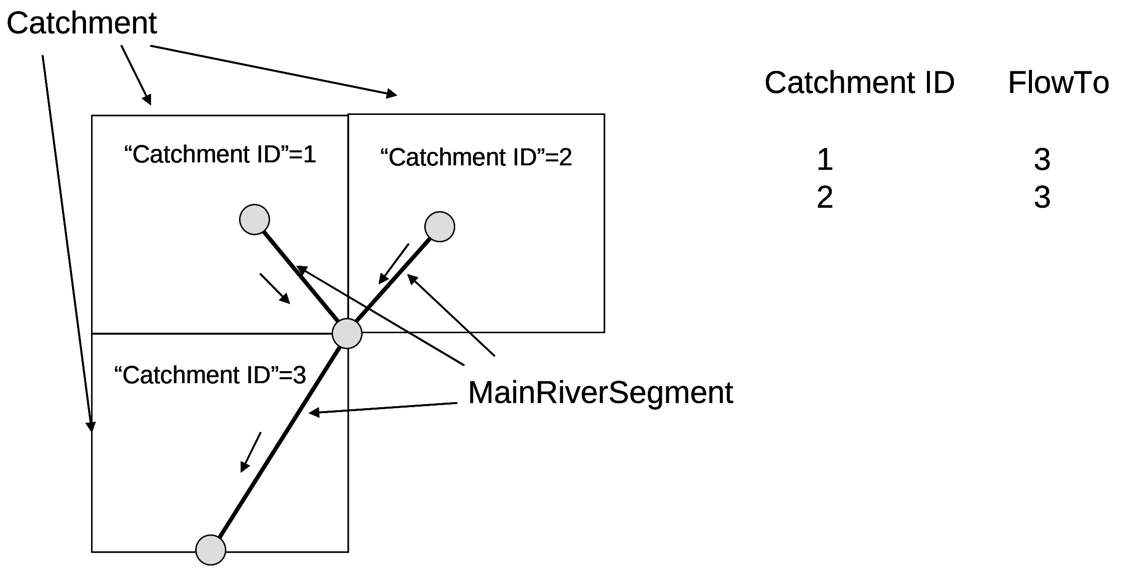
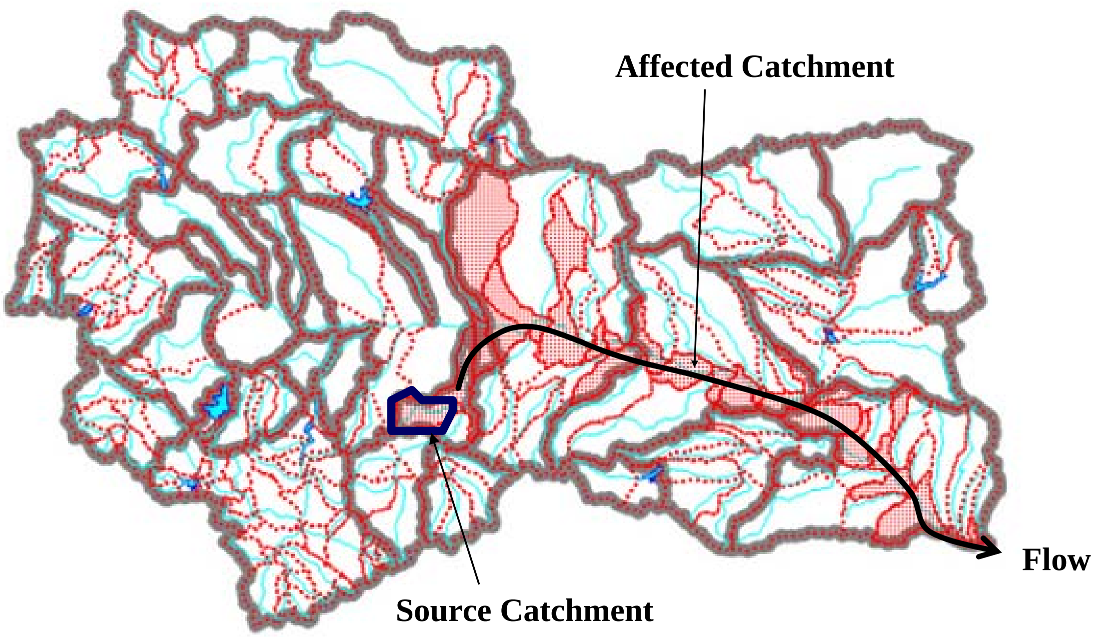


Figure E.5.159 Simulated BOD concentration in the Maritsa River. Scenario: High Medium Priority Future.



Source: JICA Study Team

Figure E.6.1 Catchment Connectivity



Source: JICA Study Team

Figure E.6.2 Example of Affected Catchments by a Source Catchment

JICA_ID	ST_ARK 342	ST_ARK 547	ST_ARK 560	ST_BRA 397	ST_BRA 414	ST_BRA 419	ST_DRA 331	ST_DRA 338
342	1	0	1	0	0	0	0	0
547	0	1	1	0	0	0	0	0
560	0	0	1	0	0	0	0	0
397	0	0	0	1	1	0	0	0
414	0	0	0	0	1	0	0	0
419	0	0	0	0	1	1	0	0
331	0	0	0	0	0	0	1	0
338	0	0	0	0	0	0	1	1
341	0	0	0	0	0	0	1	0
369	0	0	0	0	0	0	0	0
556	0	0	0	0	0	0	0	0
597	0	0	0	0	0	0	0	0
343	0	0	0	0	0	0	0	0
349	0	0	0	0	0	0	0	0
362	0	0	0	0	0	0	0	0
364	0	0	0	0	0	0	0	0

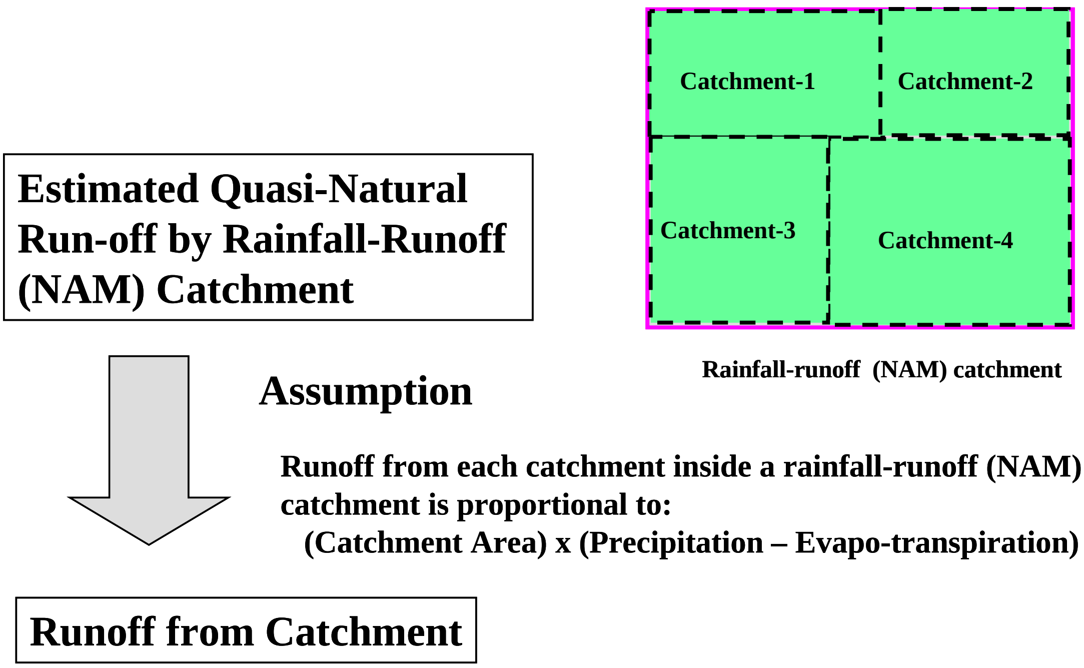
Source from "397" contributes "397" and "414".

Summation

Total accumulated amount

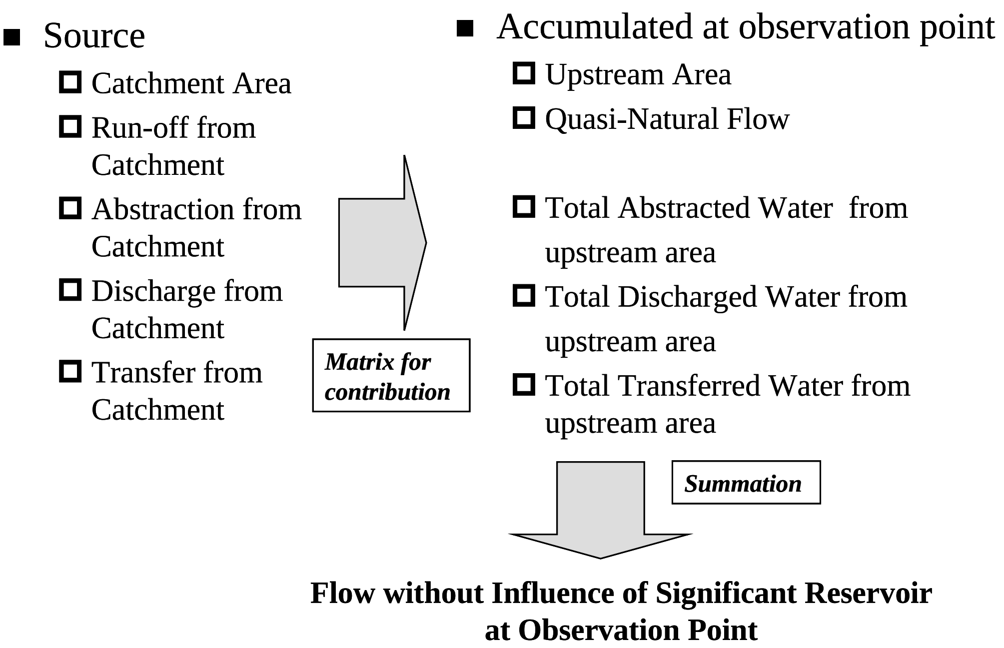
Source: JICA Study Team

Figure E.6.3 Example of Matrix for Contribution



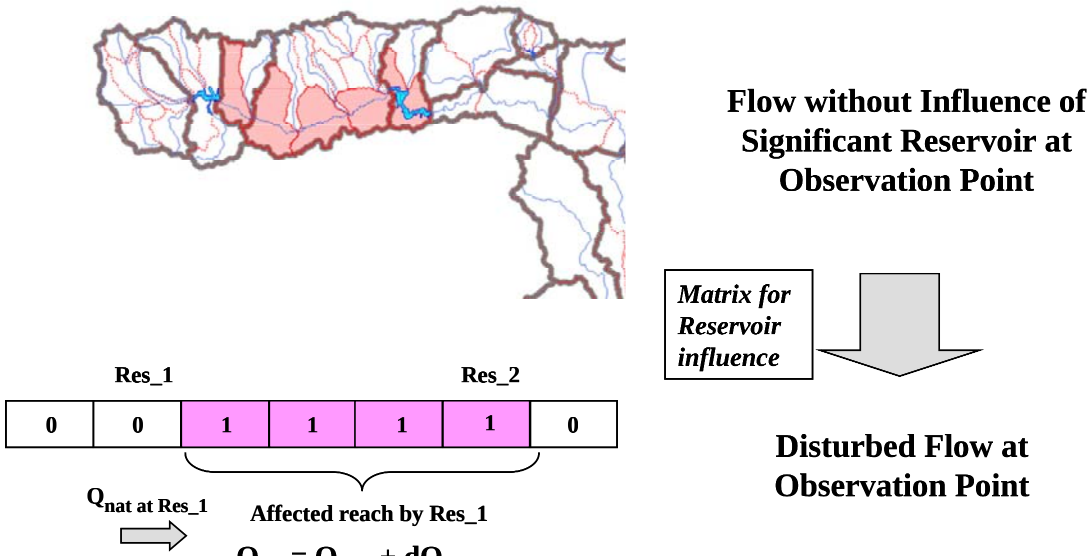
Source: JICA Study Team

Figure E.6.4 Estimation of Quasi-Natural Runoff from Catchment



Source: JICA Study Team

Figure E.6.5 Calculation of Accumulated Values at Observation Points

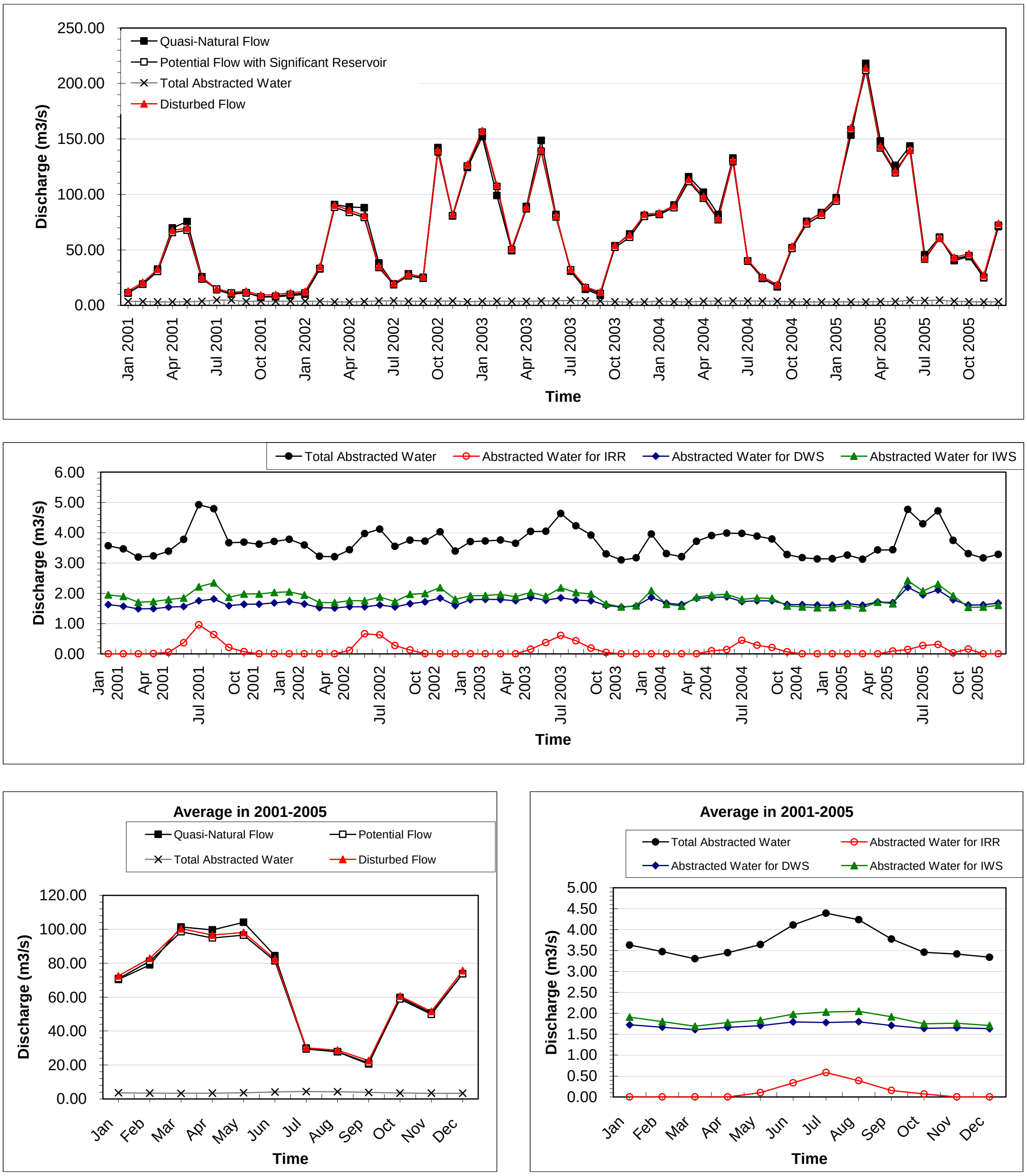


$$Q_{dis} = Q_{nat} + dQ$$
$$dQ = -Q_{nat} \text{ at Res\_1} + Q_{dis} \text{ at Res\_1}$$

Source: JICA Study Team

Figure E.6.6 Modification of Water Quantity considering Operation of Significant Reservoir

Point 1: RefPoint 2: Segment	No. of RefPoint (for 1)	Catchment JICA_ID (For 2)	
2	ST4	538	Re-plot TimeSeries



Source: JICA Study Team

Figure E.6.7 Example of Presentation of Simple Model_ver_Existing

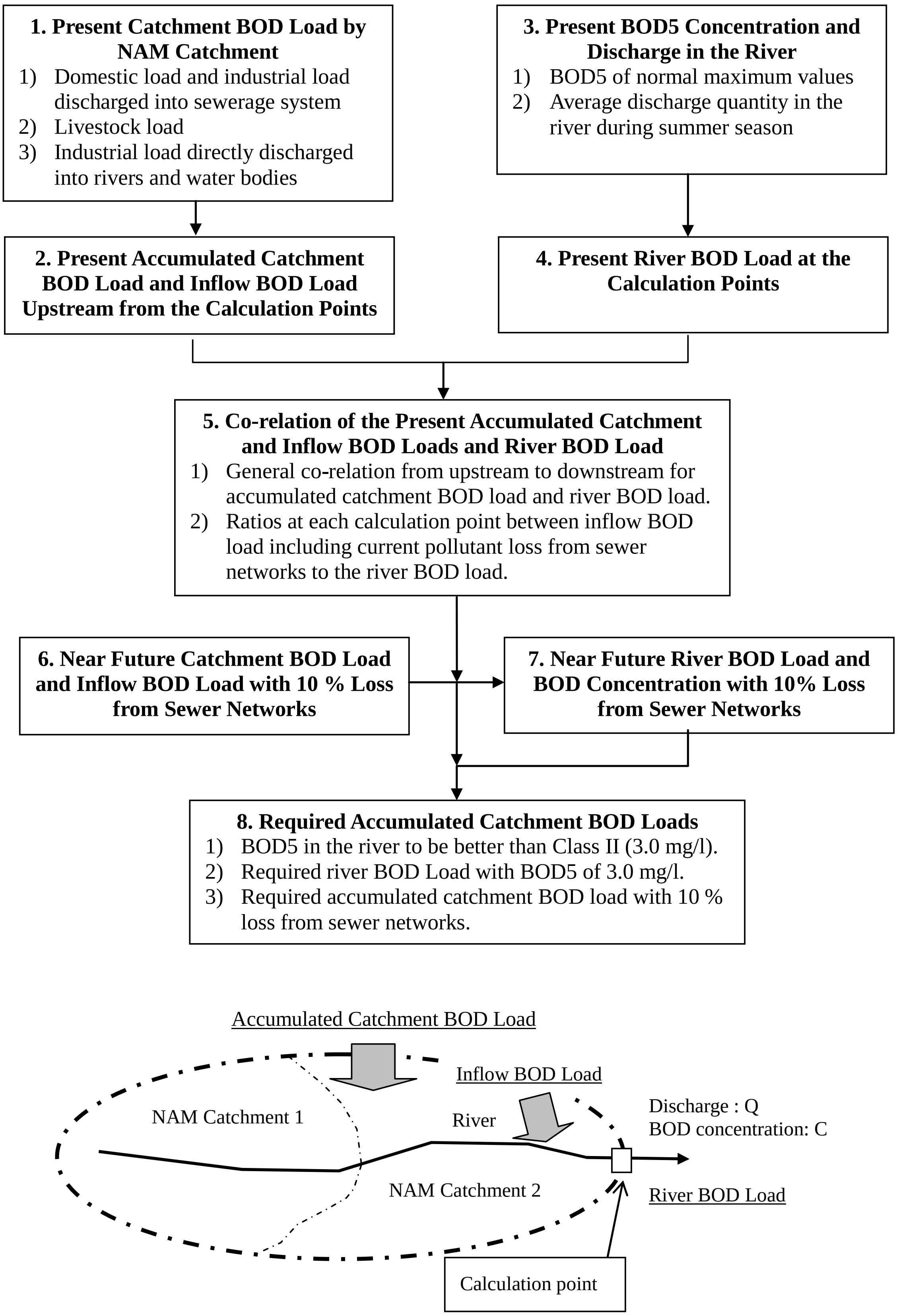


Figure E.6.8 Procedure of Developing the Simple Model for Water Quality

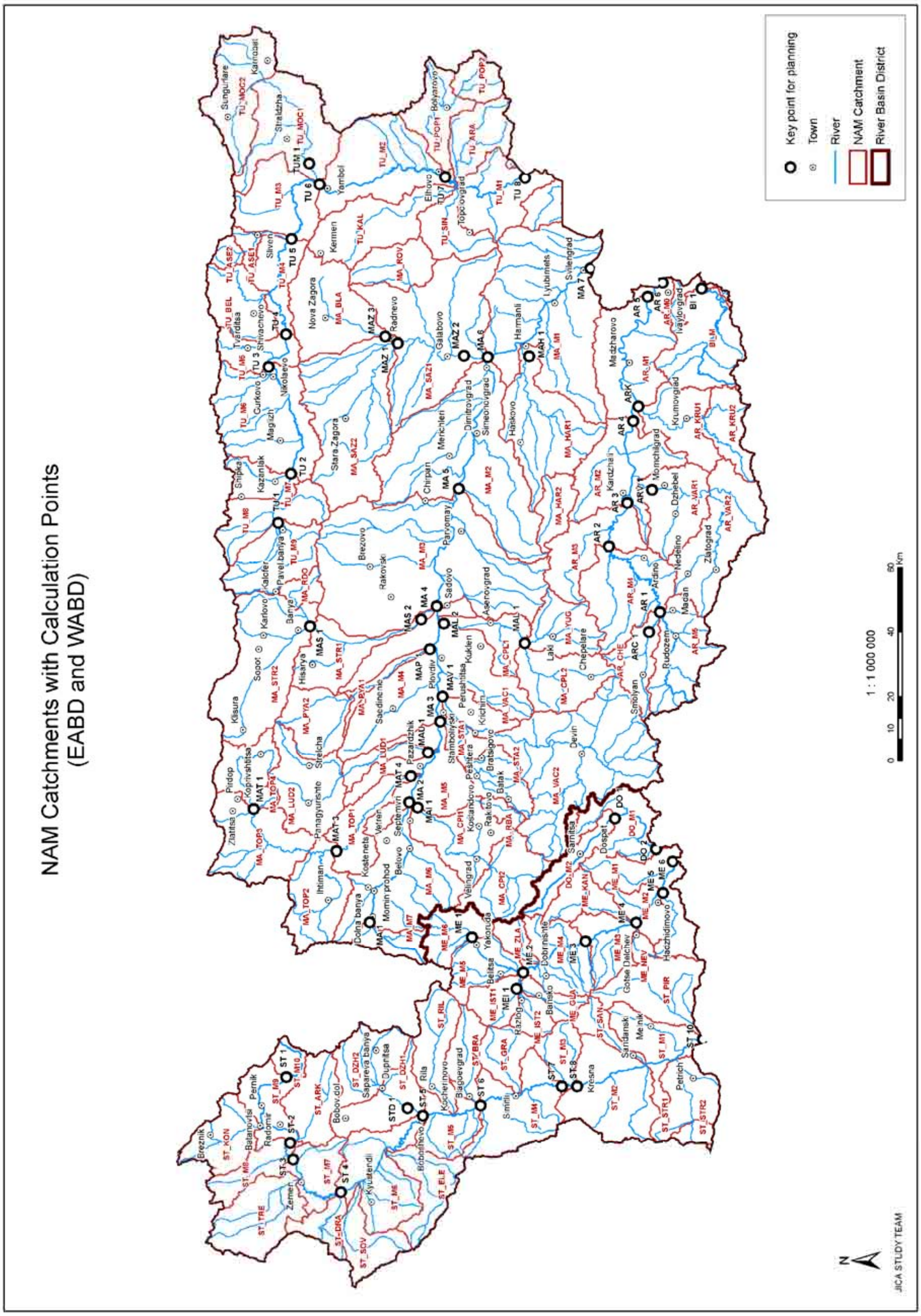


Figure E.6.9 Calculation Points for EABD and WABD with NAM catchments

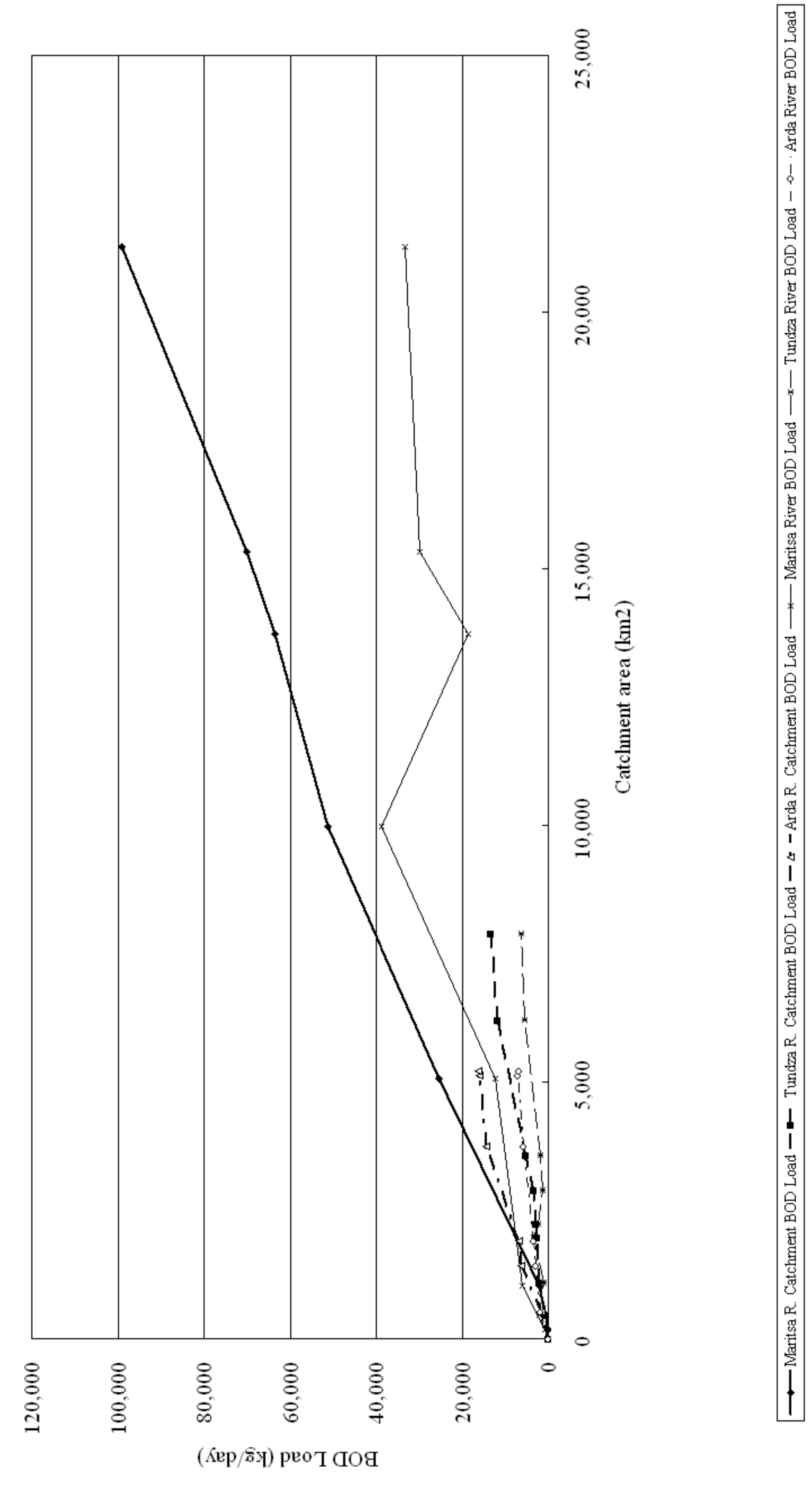


Figure E.6.10 Present Accumulated Catchment BOD Loads and River BOD Loads in EABD

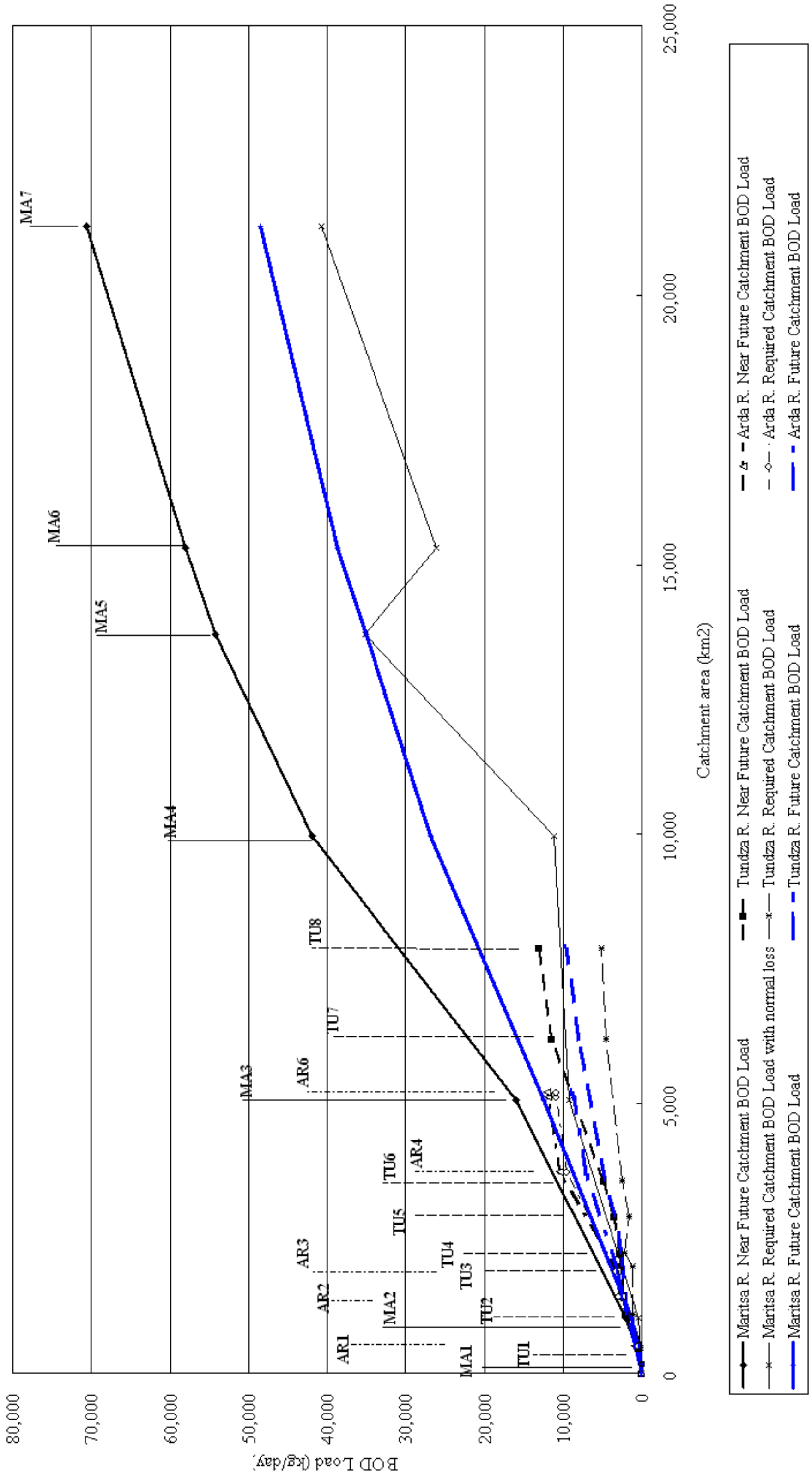


Figure E.6.11 Required Accumulated Catchment BOD Loads and River BOD Loads in EABD with High Priority Towns for WWTPs

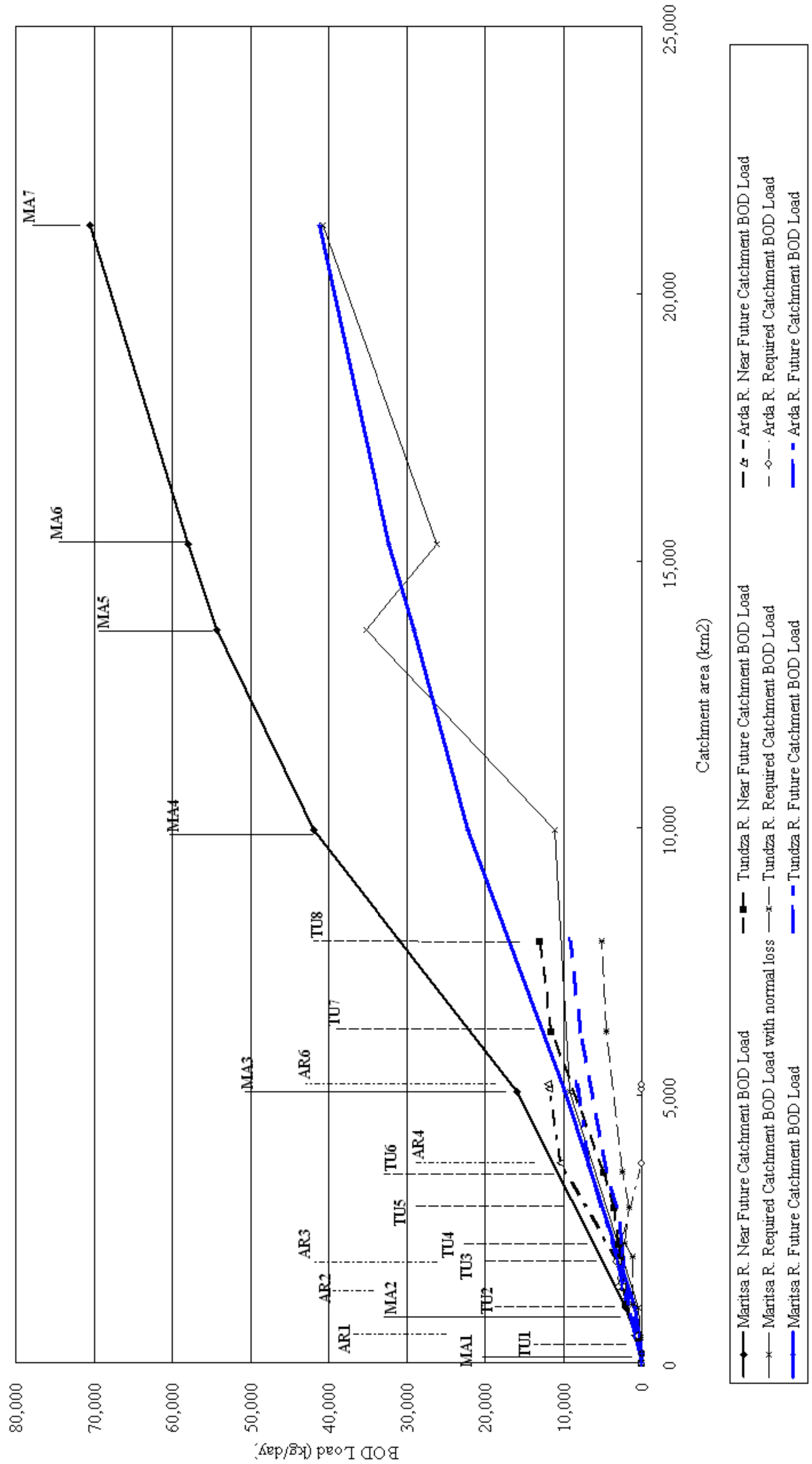


Figure E.6.12 Required Accumulated Catchment BOD Loads and River BOD Loads in EABD with High and Medium Priority Towns for WWTPs

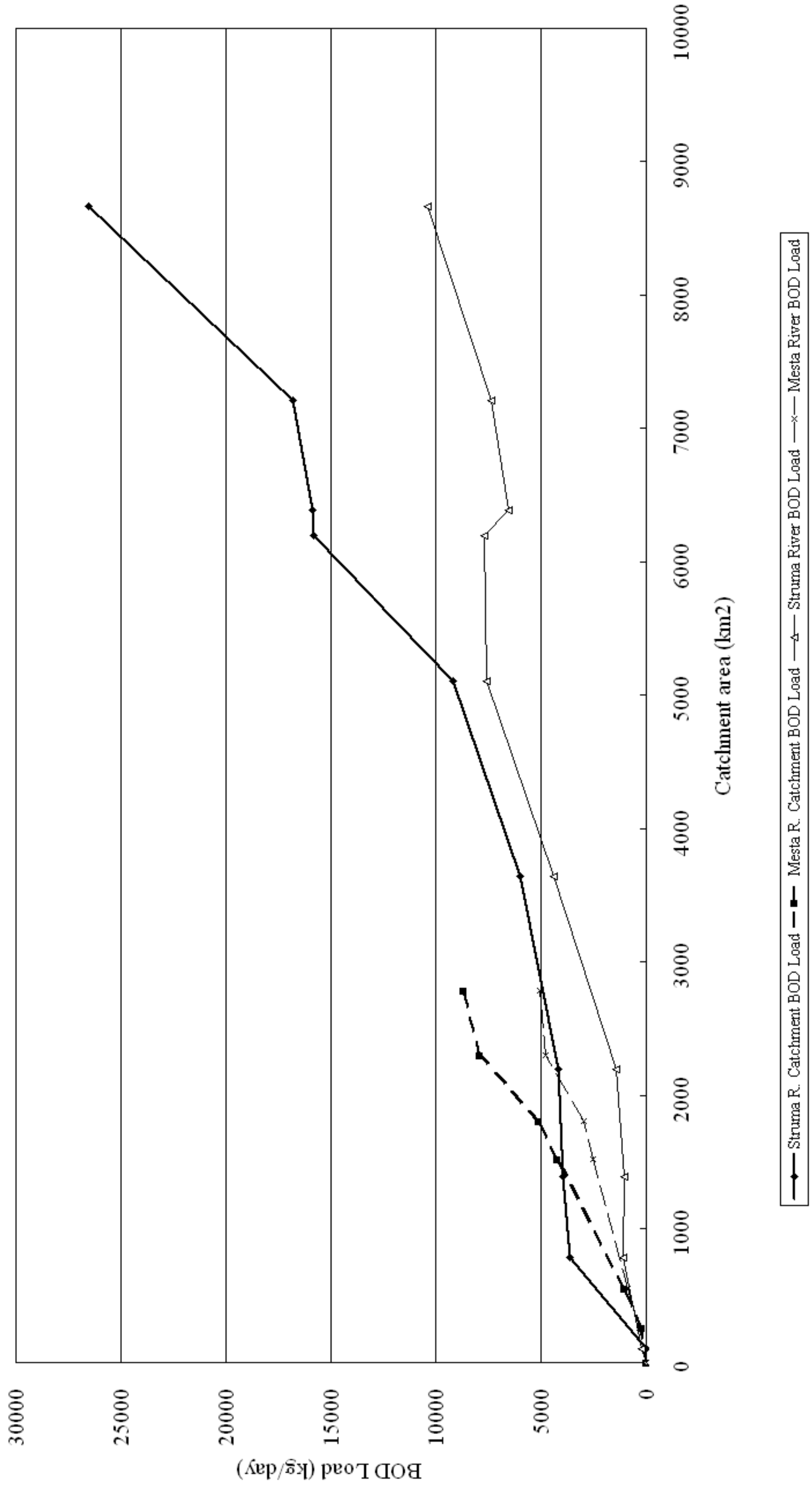


Figure E.6.13 Present Accumulated Catchment BOD Loads and River BOD Loads in WABD

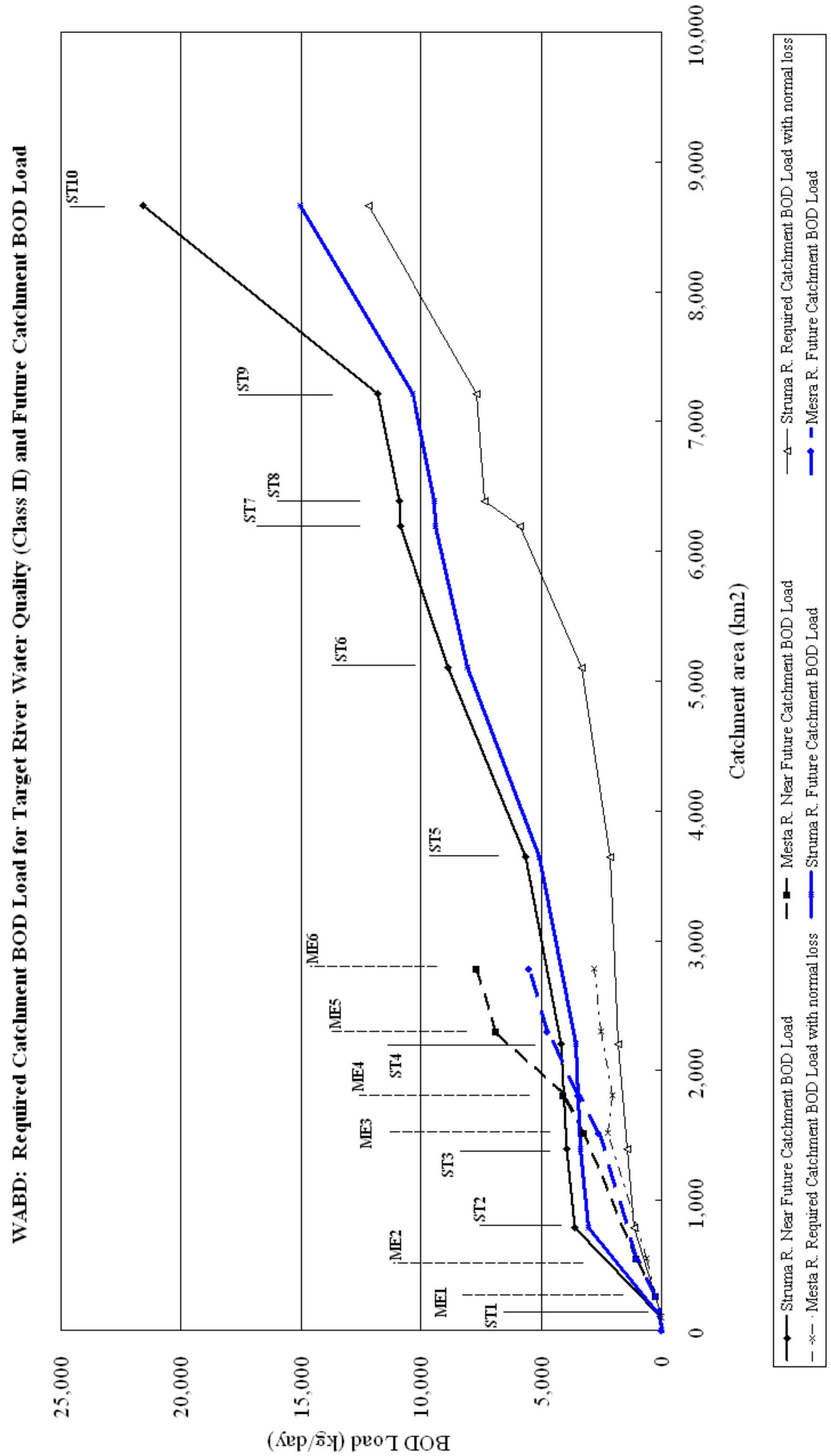


Figure E.6.14 Required Accumulated Catchment BOD Loads and River BOD Loads in WABD with High Priority Towns for WWTPs

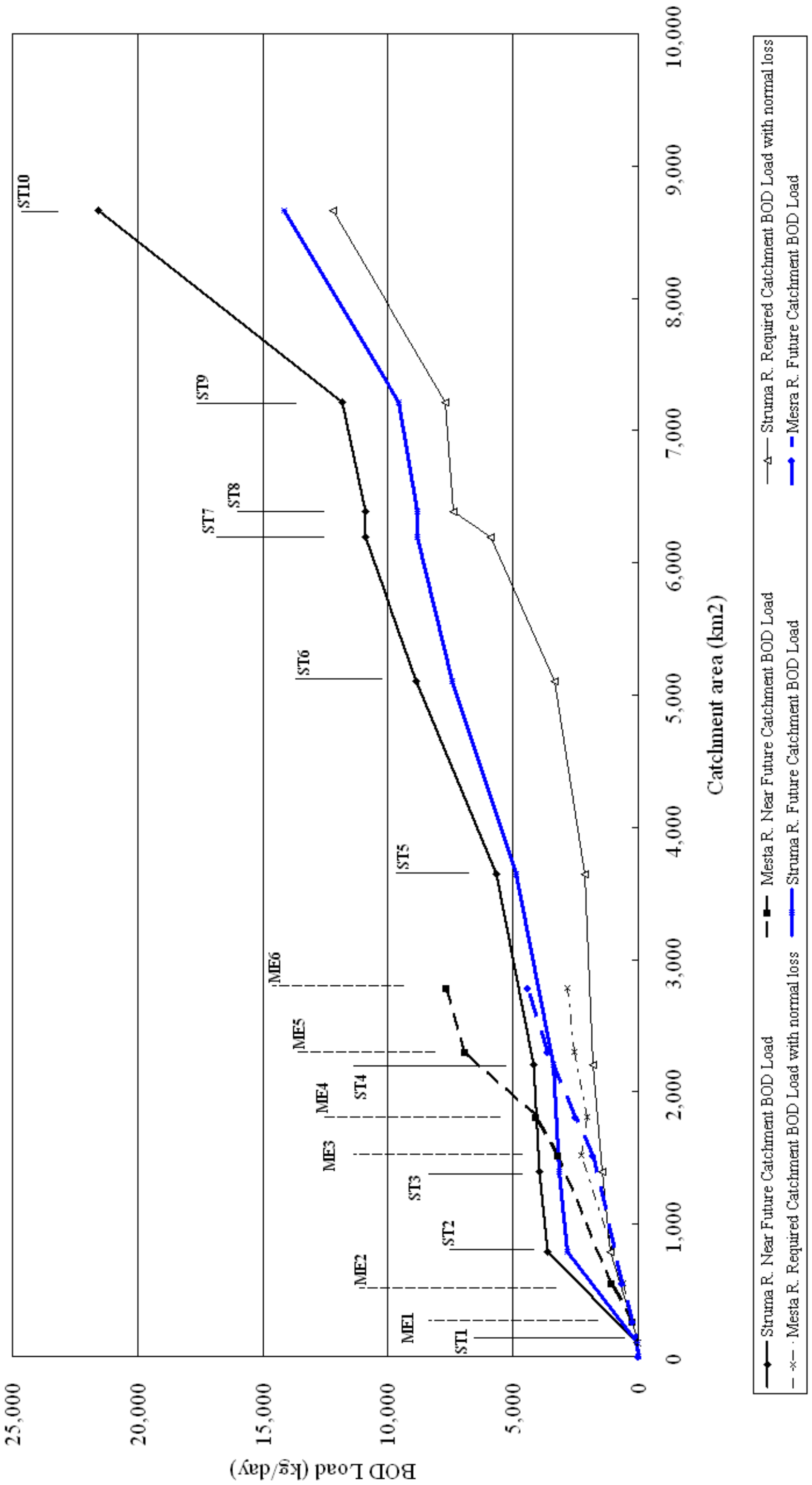


Figure E.6.15 Required Accumulated Catchment BOD Loads and River BOD Loads in WABD with High and Medium Priority Towns for WWTPs