Transport model application in River Vuoksi

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Abstract:

We describe our recent experiences in dynamic river modelling. An example is given of a trans boundary river, where short term water level regulation is practiced due to hydropower production. Plans to lead purified municipal waste waters to the river have been discussed among the authorities in the both countries.

1. Introduction

Changes in municipal and industrial sites and their water uses as well as needs to lead purified waste waters in the water courses call new methods in water quality assessments locally [1]. Climate change causes new regional challenges for river management like frazil ice development in southern rivers as the winter time ice cover is weakened and even disappearing in future and waters also in southern river rapids will face occasional super cooling, frazil ice formation and sudden ice jamming. New tools are needed for assessment, too [2].

In the following we have summarized our experiences from a trans boundary river Vuoksi flowing from the Lake Saimaa in Finnish side to the Lake Ladoga on the Russian side. Short term water level regulation is practiced by two hydropower plants in Finnish territory. New plans to lead purified municipal waste waters from the Finnish City of Lappeenranta have raised discussion among the authorities in the both countries, because the City of Svetogorsk situated along the river uses the river water for municipal and industrial purposes.

For providing material for decision making, a dynamic river model, called SOBEK, was used and different scenario runs for water outlet location options and also accidental major waste water release were performed. The model application is reported in detail by Ropponen et al. in 2014 [1]. Here we summarize the major results as an example about using a modelling tool for solving aquatic problems.

2. SOBEK-river model on River Vuoksi

SOBEK 1D/2D model [3] is all-in-one software suite for modelling river hydrodynamics and water quality. The SOBEK model has been used in a wide range of aquatic applications all over the world. The core of the system is the solution of well-known shallow water equations with different approximations. In River Vuoksi application modelled variables were water level, discharge, water velocity, total nitrogen and phosphorus concentrations and fecal enterococci bacteria.

A special work was done at SYKE by programming a Matlab/Octave application to transform 3D point cloud bathymetry data into river transects which could be used by the SOBEK river modelling software (Fig 1). The developed application is semiautomatic and can be configured to extract transects at desired resolution and intervals along the river. Detailed bathymetry data from Tainionkoski to the border was provided by Fortum Ltd as 3D point cloud files. The data was measured by echo sounding of the river bottom and laser scanning of the river banks by Kemijoki Aquatic Technology Ltd (KAT). The point data was converted into cross-sections at 100 m intervals. A much sparser cross-section data with 1-2 km intervals was applied from the Finnish border to Rouhiala/Lesogorsk. The data originated from the VIVATVUOKSIA EU-project.

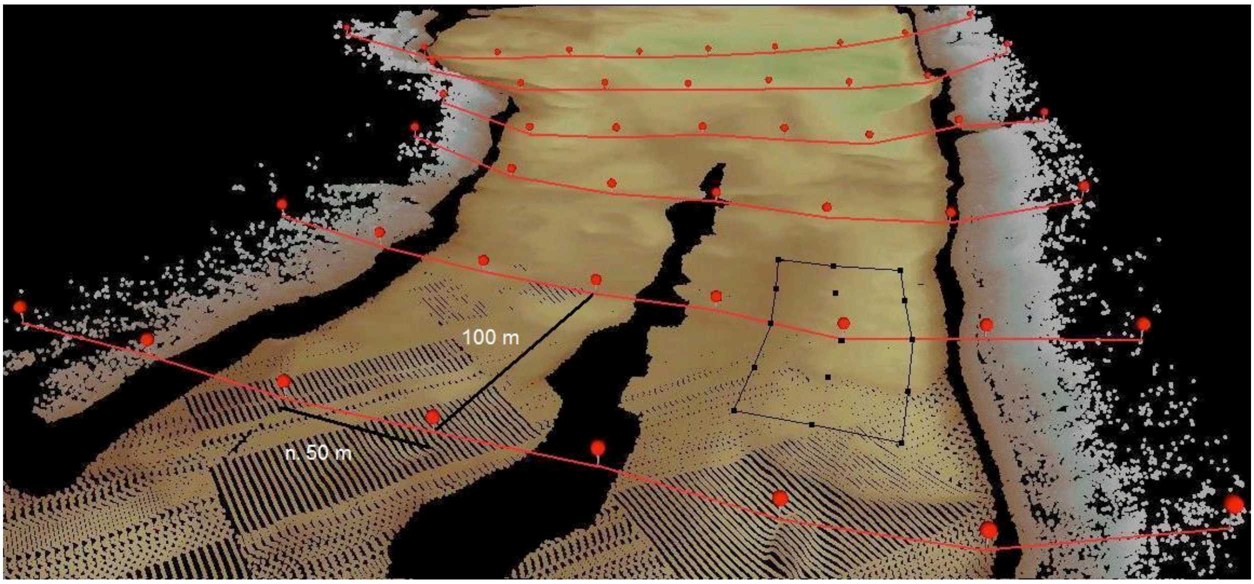


Figure 1. Detailed 3D point cloud data of River Vuoksi bathymetry obtained by echo sounding of the bottom and laser scanning of the river banks and transects (red lines/dots) for use in the SOBEK river modelling software.

The model was built on a base map obtained from a GIS (ArcMap) on the Finnish territory and

Google Maps on the Russian territory. A 50 m modelling resolution was selected. Water elevation was used as forcing data at boundaries (Lake Saimaa +75.75 m, Rouhiala +26.60 m) (Fig 2).

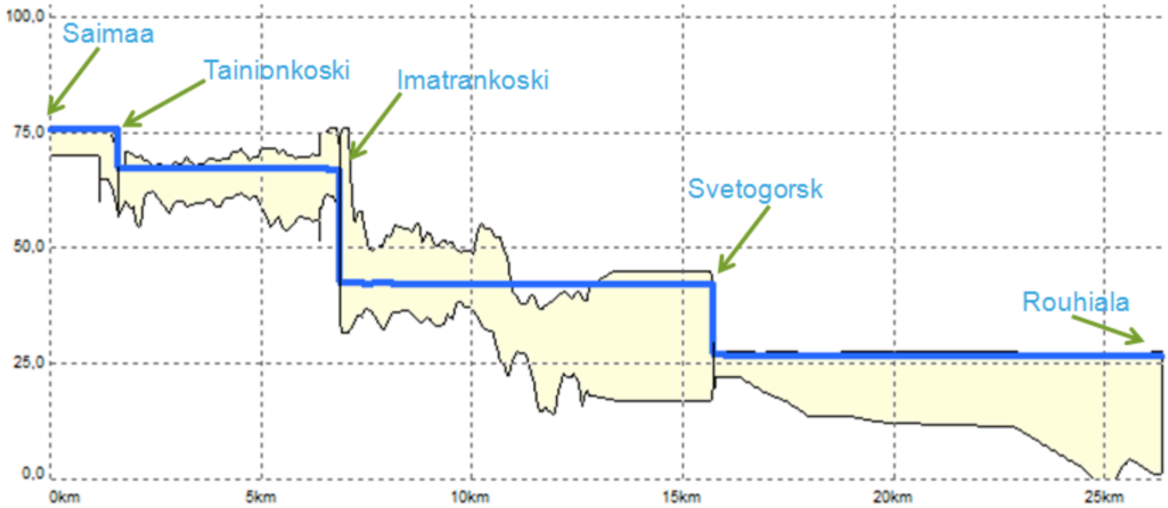
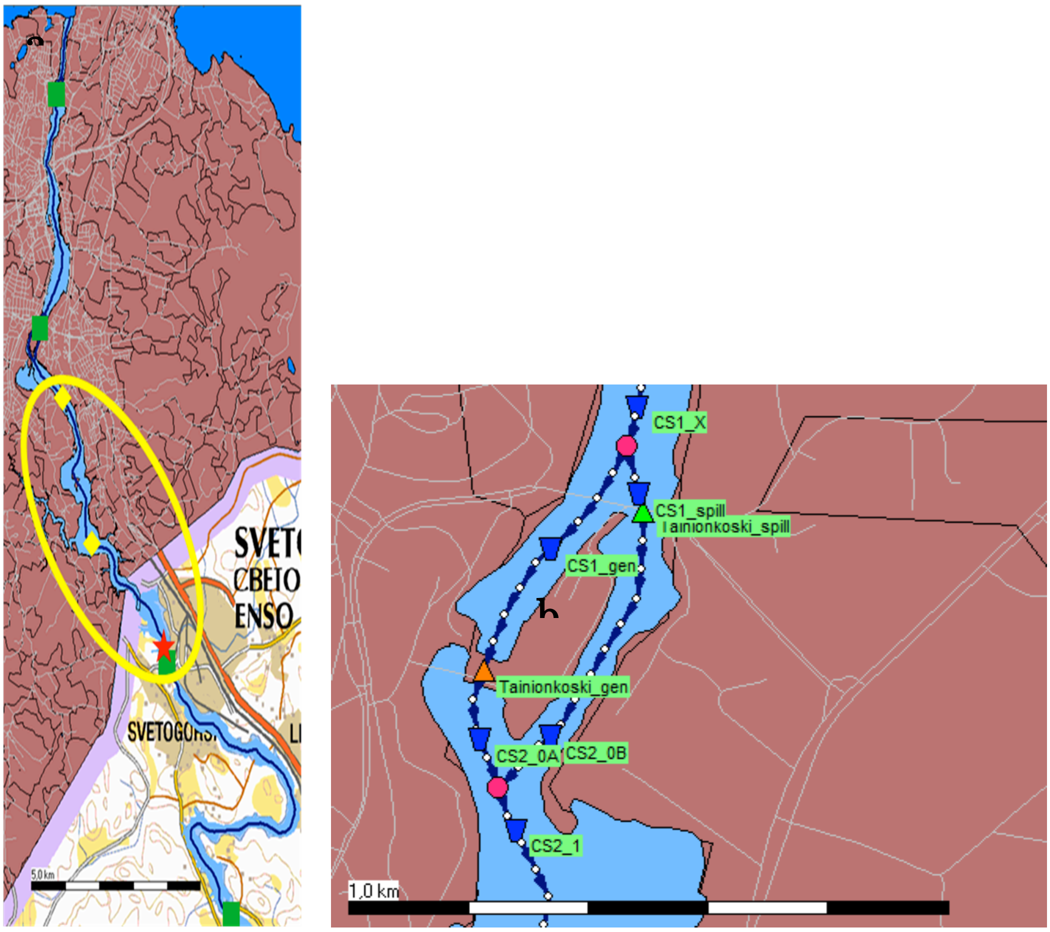


Figure 2. A representation of the simulated water level in meters (blue) along the River Vuoksi from Lake Saimaa to Rouhiala (Lesogorsk) hydroelectric plant. The figure also shows the bathymetry (lower line) used in the simulation as well as the river bank data (top line) where it was available.



Figures 3. In a (left), the whole modelling area is shown with the blue line, and the most interesting area from Meltola to Svetogorsk is within the yellow ellipse. Hydroelectric power plants in the River Vuoksi are marked with green squares and the possible wastewater discharge sites with yellow diamonds. The Svetogorsk water intake is marked with a red star. In b (right) a close-up of the model setup in the Tainionkoski hydroelectric plant region is shown. The river is divided into 50 m sections (white circles) and transect data applied is marked with blue trapezoids. The dam and generator is marked with an orange triangle.

Concentrations of nutrients were simulated as passive tracers without interactions. Fecal enterococci were simulated with a submodel in SOBEK for fecal coliforms with the mortality parameters modified for fecal enterococci.

The average daily discharges were obtained from Tainionkoski power plant and a synthetic hourly variation was applied to the data to emulate typical operation of the hydropower plants (low nightly discharge) while maintaining the daily average value.

Discharge and water temperature information from Lauritsala (R. Vuoksi) for the years 2010 and 2011 were collected from the hydrological database of SYKE. Weather data was obtained from the Finnish Meteorological Institute's (FMI) weather stations located in the City of Lappeenranta and Parikkala. Additionally, Fortum Ltd. provided some detailed water level and discharge data of the River Vuoksi. Water quality data from seven sites in years 2010 and 2011 was collected from SYKE's HERTTA water quality database. Data from three sites located in the Lake Saimaa (1-3), near the outflowr and four sites from the River Vuoksi (4-7) were used (Fig. 4).

Figure 4. Water quality monitoring sites (Original figure from Hertta database).

Nutrient loading data at 1-4 week intervals from the wastewater treatment plants from Toikansuo (the City of Lappeenranta) and Meltola (the City of Imatra) for the years 2010 and 2011 were obtained from SYKE's VAHTI database.

The physical part of the river model was calibrated by adjusting the bottom friction coefficient and comparing simulation results to measured river water level data. A *Manning's n* value of

0.032 produced the most realistic flow conditions.

There are large observed changes in elevation after Imatrankoski, because the hydropower plant at Svetogorsk does not operate entirely in synchronisation with the plants upstream. Furthermore, due to maintenance work at Svetogorsk in the recent years, all the turbines havn't been in operation simultaneously. Therefore thee operator of the plant has been forced to let the elevation in the River Vuoksi to drop during the night and rise during the day with a difference up to 1.5-2 m. In the simulation these effects were ignored and the discharges through all the hydroelectric plants were synchronized to reproduce a more realistic future scenario.

The simulated substances included total P, total N and fecal enterococci. Mortality of fecal enterococci was set to zero in the model.

The river modelling was conducted for the four location options plus present state using the hydrological and water quality data from 2011. Correspondingly, the data of the year 2010 were used in the calibration of the river model.

3. **Results**

As an example results from a scenario where the treated wastewater of the City of Lappeenranta is discharged into Vortorninlahti (Vortor) are shown in Fig. 5. In this wastewater scenario the total N concentration increases slightly compared to the current state (Fig. 5). However, the change is quite minimal and the total N concentration varies between 400-520 µg L^{-1}. Total P concentration stays nearly the same as in the current state (6-16 µg L^{-1}).

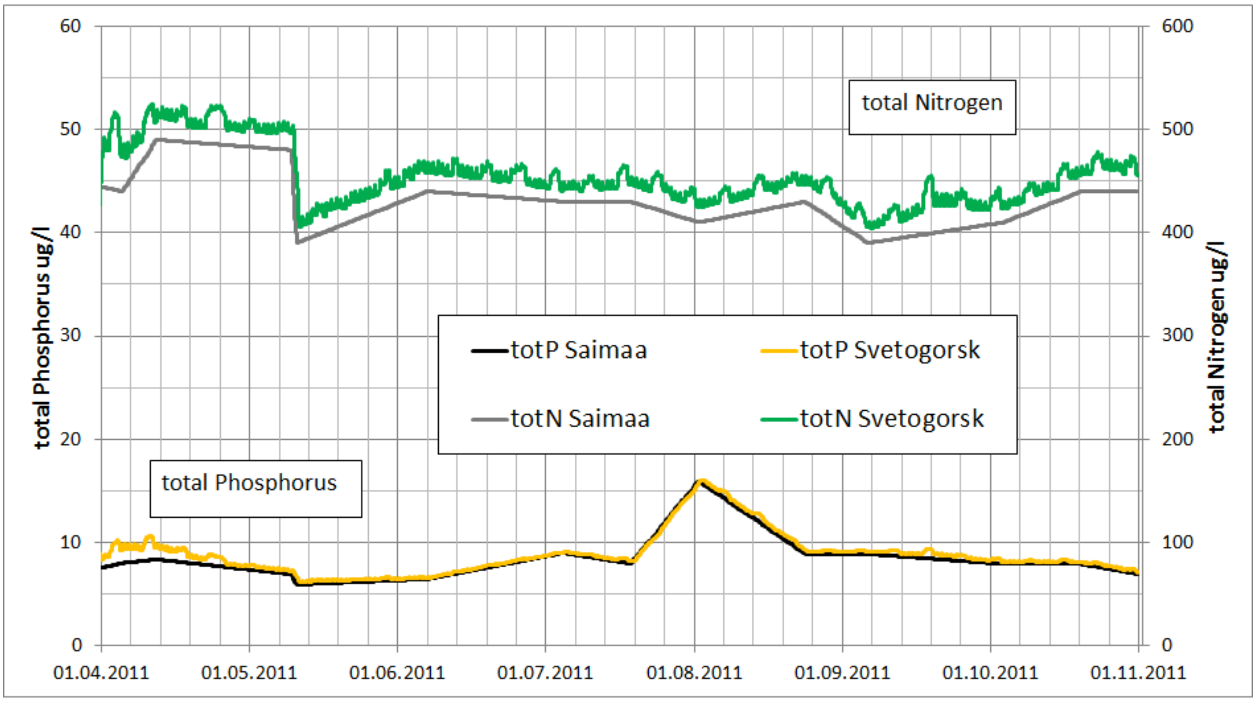


Figure 5. Total N and P concentrations of River Vuoksi in Vortor-scenario Results are shown from the inlet of River Vuoksi and at Svetogorsk, Russia.

In the Vortor-scenario, the treated wastewater from Lappeenranta can occasionally increase the amount of bacteria in the River Vuoksi (Fig 6). However, the water quality mostly stays in excellent condition according to the Finnish water quality standards for swimming. Effects of the discharge of the waste waters on water quality at Svetogorsk can be observed during spring and during summer weekends with low river flow . During low flow conditions the concentration can be higher compared to high flow situations but also the water velocity is then low. Hence it takes longer for the bacteria to drift downstream making it likely that a smaller fraction of the bacteria will survive. It should be reminded that the mortality rate of the bacteria was set to zero in the simulations. So the calculations are likely to be underestimations.

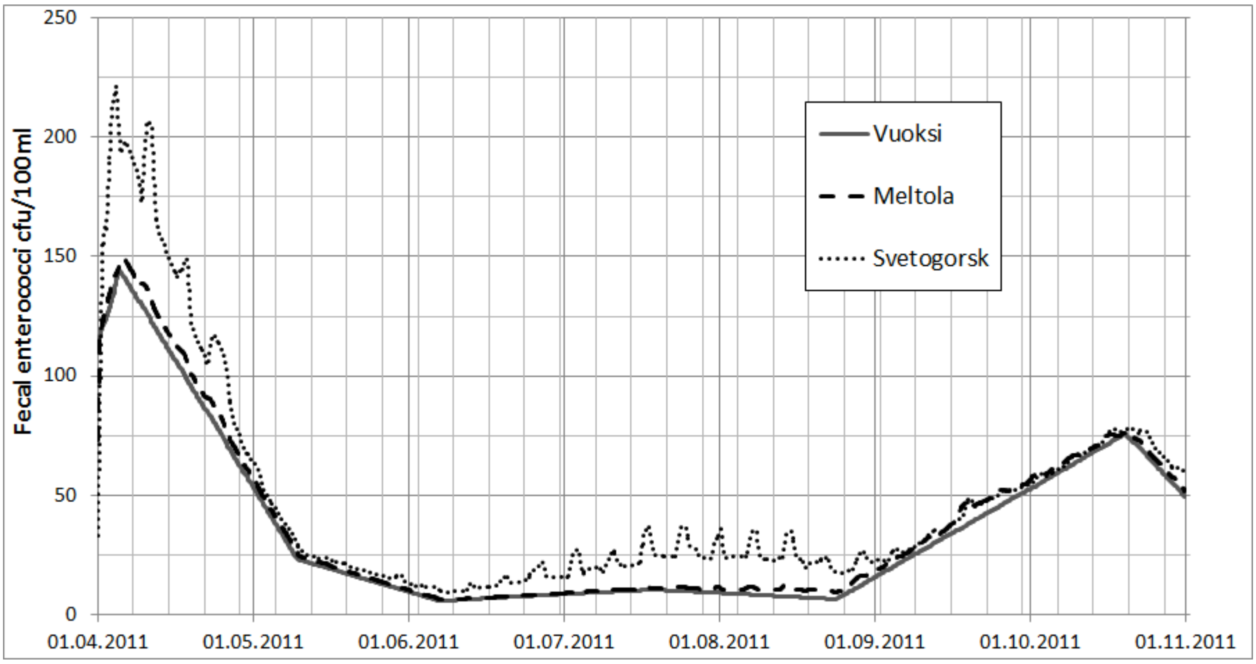


Figure 6. Amount of fecal enterococci in the River Vuoksi in waste water scenario Vortor (calculated with zero mortality of the bacteria).

If wastewater from both cities is treated in a new treatment plant and discharged to Vortorninlahti (waste water new treatment scenario Vortor2), the effect of the treated wastewater to the total N concentration of the River Vuoksi at Svetogorsk is something between the current state and waste water Vortor scenario, varying between 400-520 µg L^{-1}. Total P stays nearly the same as in the current state (6-16 µg L^{-1}).

Two additional scenarios (*worst case* and *realistic worst case*) were simulated. A typical low discharge summer week was chosen for the scenarios. In the *worst case scenario* the assumptions were that untreated wastewater from the new combined treatment plant would be discharged into Vortorninlahti and the discharge of the River Vuoksi 200 m^3 s^{-1}. In that case, the total N concentration at Svetogorsk might rise compared to the current state. Especially the total P concentration would be higher than in the previous scenarios (Fig. 7). In the *realistic worst case scenario* the discharge of the River Vuoksi was considered to be normal. In that scenario, total N and P concentrations fluctuate more than in the worst case scenario and they also drop occasionally (Fig 20). The total P concentration seems to double at worst and total N would rise approximately 100 µg L^{-1} compared to the current state.

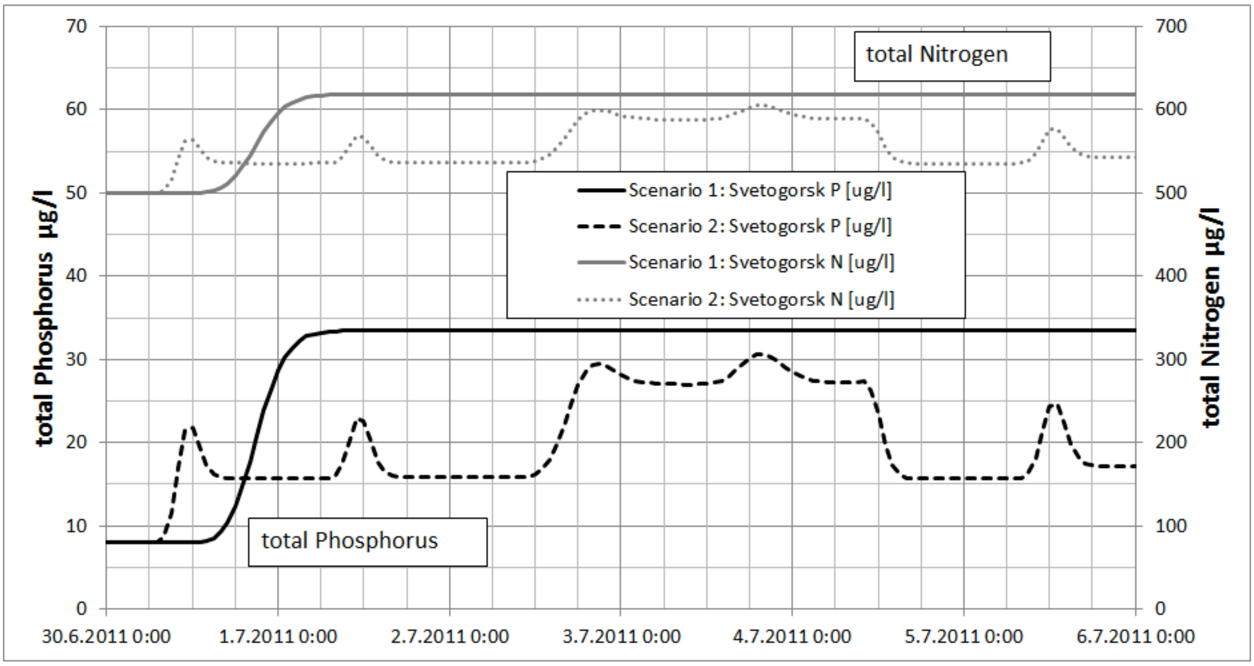


Figure 7. Total N and P concentrations of the River Vuoksi in the worst case scenarios at Svetogorsk water intake. The solid and dashed lines represent the worst case scenario and realistic worst case scenario, respectively.

For fecal enterococci, in *the worst case scenario* it was assumed that the bacterial concentration of the untreated wastewater is extremely high (4000000 cfu 100 ml^{-1}) with zero mortality. In the worst case the effect of the accidental discharge would be seen immediately at Vortorninlahti and at Svetogorsk the bacterial amount would likely start to rise within 12-18 hours (Fig. 8). The rise in the amount of fecal enterococci would seem to be substantial compared to the current state. In *the realistic worst case scenario* the concentration of fecal enterococci was assumed to be 1000000 cfu 100 ml^{-1} and the mortality rate was set to 0.5 1/d. Since the discharge of the River Vuoksi was assumed to be normal, the transport seems to be somewhat faster (8 hours) than in the worst case scenario and the amount of fecal enterococci might be lower and fluctuate more than in the worst case (Fig. 8). In the realistic worst case scenario the dramatic drop in bacterial concentration is explained with the lower initial bacterial concentration, realistic mortality rate and more realistic discharge conditions compared to the worst case scenario.

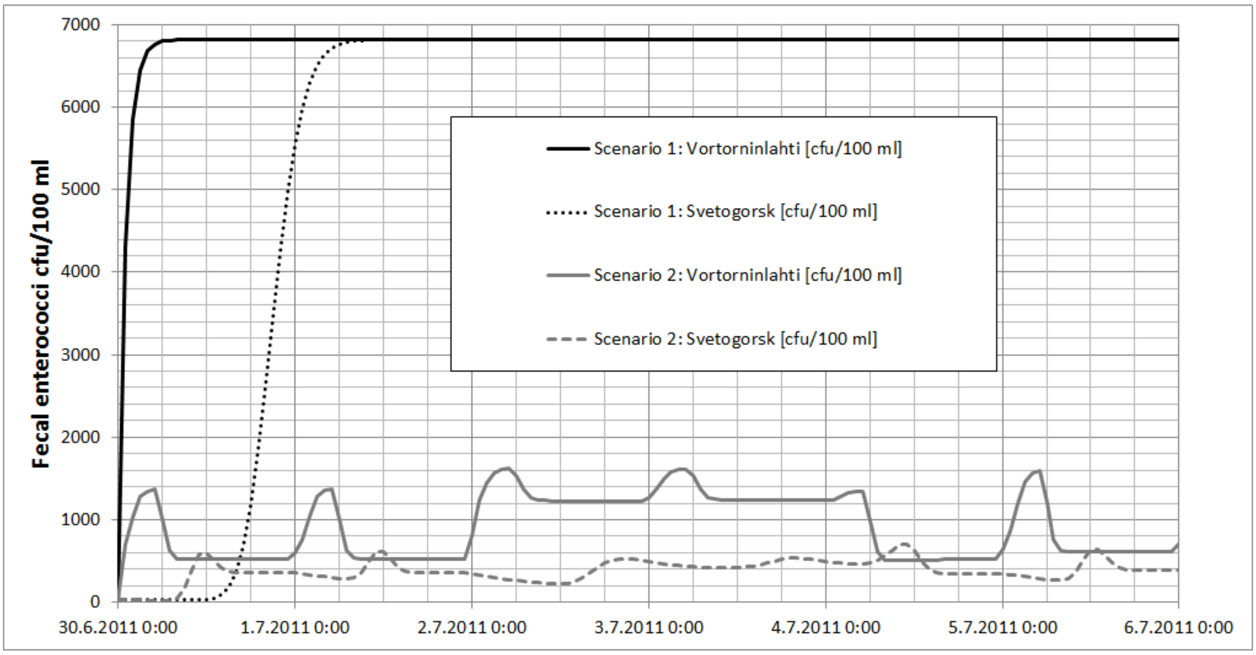


Figure 8. Fecal enterococci amounts of the River Vuoksi in the worst case scenarios at Vortorninlahti and Svetogorsk water intake. The black and grey lines represent the worst case scenario and realistic worst case scenario, respectively.

4. Conclusions

According to the modelling results, the treated wastewater effluent of the City of Imatra discharged into the River Vuoksi from Meltola (current situation) has minimal effect on the total N, total P and fecal enterococci concentrations in the River Vuoksi. Compared to the current state, discharging treated wastewater from Lappeenranta to the River Vuoksi would not significantly affect the total N and P concentrations but the bacterial concentration might be observed to increase occasionally. However, according to the modelling results the amount of fecal enterococci would in practise remain at a reasonably low level. In the scenario where a new treatment plant is built and sewage from both cities treated there, the possible hygienisation of the wastewater might even reduce the amount of fecal bacteria in the River Vuoksi compared to the current situation. In the modelled worst case scenarios the water quality would deteriorate compared to the current situation during the event, because the initial concentrations in the discharged effluent would be significantly higher than in other scenarios.

Selection of the discharge site has an influence on the mixing of the discharged water with the river water before reaching the Svetogorsk intake. According to estimations of the dispersion, the treated wastewater might have less influence on the water quality at Svetogorsk if the discharge site will be located at Meltola. This is because the treated wastewater would have more time to mix with the waters of the River Vuoksi.

The application of the SOBEK model in a strongly regulated water course was very successful and the work in model set up was quite straightforward. The excellent bathymetric data made it possible to have very good hydronamic results. In the water quality model application and especially in the microbiological application the data collection and model calibration was much more challenging. Still the model system functioned well in Finnish conditions. The lack of ice module limits seasonal applications in Nordic conditions.

References

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