PROBLEMS ON APPLICATION OF SCREENING MODELS AT STREAM WATER QUALITY ASSESSMENT

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Many a time, the professional estimate, dealing with the assessment of the stream water quality change as a result of anticipated improvements of pollution sources, issues from the results of the so called “screening modelling”. Such kind of modelling is usually stressed by the lack of time, data and money. The results obtained are still frequently a basis for the decision about national and/or foreign financial funding and support of extensive investments. Many a time, the modelling focuses on the impact on stream transboundary profiles. This paper aims to show some stream water quality screening-modelling techniques, to point out related problems and to suggest their solution. The main goal is to achieve relevant and sufficiently accurate results and to present them representatively at the limited time, data and money conditions.

Introduction

The quality of water directly affects the quality of our lives. Polluted water endangers health of family, pets and livestock. Clean surface water - streams, rivers, ponds and lakes - can also increase the value of our property. Population distribution, land use, industrial activity, agricultural practices, and pollution-control strategies have all changed significantly since 1990. The effects of these changes on water quality and the consequences on human and ecological health and the use of water resources are of major economic and social importance. Thus, the early 2000's are an appropriate time to examine water-quality conditions and trends in larger catchments. Such an assessment is more significant and important in the case of boundary streams between countries. The river Dyje is one of the biggest boundary streams in the Czech Republic. It is located at the southern part of Moravia, several times it is crossing state boundary between Austria and Czech Republic and it creates the state boundary of the total length about 50 km. This paper shows modelling techniques used for the assessment of the stream water quality as a result of anticipated improvements of pollution sources management at the river Dyje basin.

The goal of the modelling

The main purpose of the modelling is to evaluate the effect of anticipated improvements of pollution sources management at the river Dyje basin. The improvements are reconstruction, upgrading, refurbishment and construction of selected existing waste treatment plants (WWTP), reconstruction of existing sewerage systems and/or their completion and connection to the WWTP. The improvements are focused on the municipalities with a population equivalent greater than 2000.

The present water quality at river Dyje was assessed using data from monitoring during the period 1998 - 1999 and historical data dealing with period 1993 - 1997 taken from older stream water quality studies (e.g. [5] and [8]). The assessment deals with selected water quality parameters only, namely BOD, COD, ammonia Nitrogen and total Phosphorus.

The screening model aims to evaluate the effect of improvements mentioned on the stream water quality at main streams at the river Dyje basin with special respect to the river Dyje transboundary profile - downstream of the city of Břeclav. The evaluation was performed using the simplified numerical model based on the solution of the mass balance equation along selected streams at the river Dyje river network. The model was based on observed water quality data sampled by River board agency - Povodí Moravy and Czech Hydrometeorological Institute in the period 1998 - 1999. The anticipated improvements of pollution sources management were evaluated separately for 8 subcatchments of the river Dyje basin (see Fig. 1):


The solution was carried out in 11 scenarios of the extent of pollution sources improvement. Final improvement is expressed in the form of concentration, mass flow and percentage of improvement at the downstream (junction) river cross sections and water quality maps.
Description of the stream water quality model

Mathematical model

The mathematical model of the stream water quality is based on the solution of the mass balance equation expressed for particular pollution parameter along selected streams at the river Dyje river network [2], [3], [8]. The effect of larger reservoirs was expressed by regression equations obtained from the simplified evaluation of the long-term monitoring performed upstream and downstream of the reservoirs.

Following assumptions were made when deriving the general stream mass-balance equation:

- the flow and pollution transport are one dimensional - in the direction of the stream longitudinal axis;
- the suspended solids do not affect water-pollution mixture density, water is incompressible;
- the concentration of the solid through the river cross section is constant, the suspension is well mixed.

The basic equation is as follows:

$$\frac{\partial (Ac)}{\partial t} = - \frac{\partial (Avc)}{\partial x} + \frac{\partial (AD_{t} \frac{dc}{dx})}{\partial x} + S + AR. \quad (1)$$

Initial and boundary conditions

Initial condition expresses the state of the pollution at the beginning of the solution ($t_{0}=0$) at the entire river network solved.

$$c(x,0) = c_{0}(x) \at \text{time} \ t = t_{0} = 0. \quad (2)$$

Boundary conditions

Two types of boundary condition can be applied:

1. type - known concentration at boundary nodes of the river network:
   $$c(0,t) = c_{0}(t) \text{ input nodes (x=0)};$$
   $$c(L,t) = c_{L}(t) \text{ end node (x=L)}; \quad (3)$$

2. type - at the end node of the river system (x=L) the zero concentration gradient can be applied:
   $$\frac{dc(L,t)}{dx} = 0. \quad (4)$$

The following additional simplifications were assumed:
flow and pollution conditions are steady, the average discharges, pollution sources, concentrations, mass flow and other variables are assumed;
- at the steady state conditions, the dispersion coefficient can be neglected (see [9]);
- the Streeter-Phelps first order kinetics decay formula \( R = -k \cdot c \) is used [3], [7].

The equation (1) then reduces into:

\[
\frac{d(A \cdot v \cdot c)}{dx} - S + A \cdot k \cdot c = 0
\]  
(5)

with boundary condition \( c(0,t) = c_0(t) \) at input nodes \((x=0)\), the concentration at the node \( x=L \) is calculated during the solution.

**Numerical solution**

The numerical solution was carried out using the simple numerical scheme based on finite difference method. Assuming mass flow \( L_j, L_k \) in nodes \( j, k \), expressing it as \( L = A \cdot k \cdot c \) and the sum of pollution sources along the given river reach \( L_S = S \cdot \Delta x \), the equation (5) can be written in the following form (see Fig. 2):

\[
L_k - L_j - L_S + A \cdot k \cdot c \cdot \Delta x = 0
\]  
(6)

Expressing mass decay in (6) as

\[
A \cdot k \cdot c \cdot \Delta x = k \cdot t \cdot L_j
\]  
(7)

final expression for mass flow in the river node (cross section) \( k \) is as follows:

\[
L_k = L_j + L_S - L_j \cdot k \cdot t = 0
\]  
(8)

At the stream junction, the mixing equation is applied.

The river network topology was “programmed” using the Excell spreadsheet tool, where the graphs – longitudinal mass flow charts – can be efficiently based on calculation results.

![Fig. 2: Schematization of the river reach.](image)

**River network topology**

The river network consists of the main stream - river Dyje and two principal tributaries - Svratka and Jihlava. The subject of the modelling were also two smaller streams Bobrava and Litava (tributaries of the Svratka river) and the Oslava river (tributary of the Jihlava river). Due to the position of improved pollution sources, several additional streams has to be added to the model. Total length of modelled streams was 1093 km.

**Model philosophy**

As the majority of pollution sources (municipal, industrial, agricultural, diffusion, etc.) were not identified, analysed and therefore known, the model was based on observed water quality data (see above). The sampling data were obtained in the form of concentration of selected water quality parameters in 66 sampling points in the river Dyje catchment.

The mentioned stream pollution data were also basis for the estimate and verification of real pollution sources, which were mostly „unknown“, especially in terms of the real handling with pollution in the source (liquidation, treatment) and its time distribution. Therefore, the model was based on averaged pollution data in terms of concentration and discharge Annual average mass flow (mass load) estimate was carried out using the average annual discharge and average concentration.

**Simulation of selected scenarios**

The simulations of selected pollution sources improvement scenarios were carried out by successive “switching on” and “switching off” the individual pollution sources corresponding to the particular improvement variants. Calculations mentioned were performed for all selected pollution parameters. The results of the solution were summarized in tables.
Results of the solution

The improvements as reconstruction, upgrading, refurbishment and construction of selected existing WWTPs, reconstruction of existing sewerage systems and/or their completion and connection to the WWTP will be done in Dyje- Moravská Dyje, Jihlava - lower part, Jihlava - upper part, Oslava, Bobrava, Svatka - lower part, Svatka - upper part and Litava catchments.

Evaluation of the impact of anticipated investments was carried out for 11 variants – particular sucatchments:

- Dyje- Moravská Dyje;
- Jihlava - lower part;
- Jihlava - upper part;
- Oslava;
- Bobrava;
- Svatka - lower part;
- Svatka - upper part;
- Litava;
- Dyje- Moravská Dyje, Jihlava-lower part, Jihlava-upper part, Oslava, Bobrava;
- Svatka - lower part, Svatka - upper part, Litava;
- River Dyje basin (catchment 1 - 8).

Final evaluation of impact of anticipated investments is summarized in terms of mass flow, concentration and percentage of original mass flow values at the boundary cross section of river Dyje. Following tables (1, 2 and 3) and figure Fig.3 show final results of modelling for individual variants. Finally the impact of improvements for variant 11 was evaluated against limits according to ČSN 75 7221 [1] by water quality maps.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Present</th>
<th>Var.1</th>
<th>Var.2</th>
<th>Var.3</th>
<th>Var.4</th>
<th>Var.5</th>
<th>Var.6</th>
<th>Var.7</th>
<th>Var.8</th>
<th>Var.9</th>
<th>Var.10</th>
<th>Var.11</th>
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<tr>
<td>BOD</td>
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<td>7244</td>
<td>7151</td>
<td>7029</td>
<td>7280</td>
<td>7318</td>
<td>7264</td>
<td>7275</td>
<td>7300</td>
<td>6627</td>
<td>7157</td>
<td>6444</td>
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<tr>
<td>COD</td>
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<td>42023</td>
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<td>43060</td>
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<td>41188</td>
<td>42643</td>
<td>40730</td>
</tr>
<tr>
<td>N-NH₄</td>
<td>471</td>
<td>458</td>
<td>466</td>
<td>470</td>
<td>467</td>
<td>466</td>
<td>466</td>
<td>469</td>
<td>446</td>
<td>432</td>
<td>446</td>
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<td>P</td>
<td>593</td>
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<td>560</td>
<td>567</td>
<td>534</td>
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Tab. 1.: Mass flow in [t/year] at the boundary cross section of river Dyje.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Present</th>
<th>Var.1</th>
<th>Var.2</th>
<th>Var.3</th>
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<th>Var.5</th>
<th>Var.6</th>
<th>Var.7</th>
<th>Var.8</th>
<th>Var.9</th>
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<tr>
<td>BOD</td>
<td>5.45</td>
<td>5.38</td>
<td>5.31</td>
<td>5.22</td>
<td>5.41</td>
<td>5.43</td>
<td>5.39</td>
<td>5.40</td>
<td>5.42</td>
<td>4.92</td>
<td>5.31</td>
<td>4.78</td>
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<tr>
<td>COD</td>
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<td>31.76</td>
<td>31.20</td>
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<td>31.91</td>
<td>31.91</td>
<td>31.94</td>
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<td>N-NH₄</td>
<td>0.35</td>
<td>0.34</td>
<td>0.35</td>
<td>0.35</td>
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<td>0.35</td>
<td>0.35</td>
<td>0.32</td>
<td>0.33</td>
<td>0.31</td>
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<tr>
<td>P</td>
<td>0.44</td>
<td>0.43</td>
<td>0.43</td>
<td>0.44</td>
<td>0.44</td>
<td>0.43</td>
<td>0.43</td>
<td>0.43</td>
<td>0.44</td>
<td>0.42</td>
<td>0.42</td>
<td>0.40</td>
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Tab. 2.: Concentration in [mg/l] at the boundary cross section of river Dyje.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Var.1</th>
<th>Var.2</th>
<th>Var.3</th>
<th>Var.4</th>
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<th>Var.7</th>
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<th>Var.9</th>
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<tbody>
<tr>
<td>BOD</td>
<td>1.32</td>
<td>2.59</td>
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<td>0.83</td>
<td>0.31</td>
<td>1.05</td>
<td>0.90</td>
<td>0.55</td>
<td>9.72</td>
<td>2.50</td>
<td>12.22</td>
</tr>
<tr>
<td>COD</td>
<td>0.75</td>
<td>2.50</td>
<td>2.09</td>
<td>2.88</td>
<td>0.09</td>
<td>0.28</td>
<td>0.28</td>
<td>0.19</td>
<td>4.44</td>
<td>1.06</td>
<td>5.50</td>
</tr>
<tr>
<td>N-NH₄</td>
<td>4.86</td>
<td>1.14</td>
<td>0.29</td>
<td>0.86</td>
<td>1.14</td>
<td>0.57</td>
<td>0.57</td>
<td>8.29</td>
<td>5.43</td>
<td>10.29</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>1.82</td>
<td>2.27</td>
<td>0.68</td>
<td>0.23</td>
<td>0.23</td>
<td>2.27</td>
<td>1.36</td>
<td>0.45</td>
<td>5.45</td>
<td>4.32</td>
<td>9.77</td>
</tr>
</tbody>
</table>

Tab. 3: Percentage [%] of improvement at the boundary cross section of river Dyje.

Conclusions

The main purpose of the study is to evaluate the effect of anticipated improvements of pollution sources management at the river Dyje basin. The solution was carried out in 11 variants. For the evaluation of improvement effects, the simple pollution balance model was used. Concerning the model level, so called „screening model“ was used (see [4]). The analysis evaluates predominantly the relative impacts of anticipated measures, the accuracy of quantitative results is influenced mostly by the fact, that the discharge and pollution data were professionally estimated and derived from sampling data.

Finally it must be emphasised, that the model used has a role of preliminary estimate. The more precise tool should succeed after the collecting of all necessary data, i.e. especially more accurate pollution data, corresponding real discharge data at the time of sampling, more accurate flow hydrodynamics calculation etc [5], [6], [8]. Activities mentioned are quite time and money consuming, nevertheless necessary, when the improvement impacts on the stream receiver has to be more precisely assessed and quantified.
Acknowledgement
This research was supported by the Grant Agency of The Czech Republic, Grant project No. 103/99/0456

BASIC data sources and references
[1] ČSN 75 7221 Surface water quality classification (Czech national standard)

List of variables

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A(x,t)$</td>
<td>cross-sectional area,</td>
</tr>
<tr>
<td>$c(x,t)$</td>
<td>concentration of observed solid,</td>
</tr>
<tr>
<td>$c_0$</td>
<td>given concentration at headwater nodes of river network,</td>
</tr>
<tr>
<td>$c_L$</td>
<td>given concentration at the downstream node of river network,</td>
</tr>
<tr>
<td>$D(x,t)$</td>
<td>coefficient of longitudinal hydrodynamic dispersion,</td>
</tr>
<tr>
<td>$k$</td>
<td>rate constant,</td>
</tr>
<tr>
<td>$L$</td>
<td>the length between the downstream and headwater node.</td>
</tr>
<tr>
<td>$Q(x,t)$</td>
<td>discharge,</td>
</tr>
<tr>
<td>$R(x,t)$</td>
<td>constituent changes (growth, decay),</td>
</tr>
<tr>
<td>$s(x,t)$</td>
<td>external pollution sources,</td>
</tr>
<tr>
<td>$v(x,t)$</td>
<td>mean velocity,</td>
</tr>
<tr>
<td>$x$</td>
<td>co-ordinate measured along the stream axis,</td>
</tr>
<tr>
<td>$t$</td>
<td>time</td>
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