Effective catchment management of soil erosion for long-term improvement of surface water bodies quality

Matjaž Glavan¹, Polona Ojsteršek Zorčič², Marina Pintar¹

1 University of Ljubljana, Biotechnical Faculty, Slovenia
2 Savaprojekt Ltd.

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INTRODUCTION

Problems of accumulation lakes

- Inflow of suspended sediments:
  - Building of pollutants
  - Less useful volume capacity
  - Changed hydro-morphology
Ecoremediation - use of ecological engineering, i.e. physiology and morphology of plants, including soil cultivation and other interventions in the area of reconstruction and protection (i.e. remediation) of the environment.

ERM measures – Constructional and non-constructional
Efficiency depends on topography, soil characteristics, climatic conditions, land use and production practices.
Aim

Develop a set of proven effective measures and determine the extent and location of their placement in the river catchment area in order to improve and preserve the ecological potential of the accumulation lakes.

Objective

Develop a tool to support decision-making in the selection and placement of ERM measures into the space of the river-catchment area to reduce the load on the accumulations.
Accumulation Ledava Lake

- W-part of Landscape Park Goričko, in NE of Slovenia
- Catchment area of 105.25 km$^2$
  (33.7 km$^2$ in Austria)
- Useful capacity of accumulation:
  $2.42 \times 10^6$ m$^3$ (at level 220.9 m.a.s.l.).

- Environmental Agency (ARSO): Accumulation does not reach good ecological state (WFD)

<table>
<thead>
<tr>
<th>Land use</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arable</td>
<td>37.8 %</td>
</tr>
<tr>
<td>Forest</td>
<td>36.7 %</td>
</tr>
<tr>
<td>Grassland</td>
<td>12.1 %</td>
</tr>
</tbody>
</table>

Avg. annual rainfall: 800 mm
Avg. annual temperature.: 11.2°C
Tool for optimal Selection and Allocation of the ERM measures (TSA)

- Support for decision-making in selection and placement
- A systematic approach that is divided into two phases:
  1. professional basis
  2. plan for placement and setting up
MATERIALS & METHODS

TSA Phasa 1

1. REGULATION LITERATURE
2. LITERATURE and MEASURES of AGRICULTURAL and WATER POLICY
3. Monitoring
4. Stat. in Cartogr. DATA & SWAT MODELING

- PROBLEM IDENTIFIED
  - ANALYSE WATER BODY
  - ANALYSE CATCHMENT AREA AND STREAMS
- DEFINE CRITICAL SOURCE AREAS
- DEFINE OBJECTIVES AND CRITERIA
- DESIGN A SET OF POSSIBLE MEASURES
- CHOOSE MEASURES AND DESIGN SCENARIOS
- MEASURES EVALUATION
- ARE THEY EFFECTIVE?
  - YES
  - NO
## RESULTS

### Analyze water body - Monitoring

#### Analysis of Ledava lake and Ledava River

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Total N [TN mg/l]</th>
<th>Nitrates [NO₃ mg/l]</th>
<th>Total P [TP mg/l]</th>
<th>Orto-P [PO₄ mg/l]</th>
<th>DO [O₂ mg/l]</th>
<th>Susp. S. [TSS mg/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>June</td>
<td>1.09</td>
<td>1.32</td>
<td>0.05</td>
<td>0.000</td>
<td>10.45</td>
<td>84.12</td>
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<tr>
<td></td>
<td>July</td>
<td>1.25</td>
<td>0.00</td>
<td>0.05</td>
<td>0.000</td>
<td>5.98</td>
<td>134.11</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>1.17</td>
<td>0.00</td>
<td>0.09</td>
<td>0.015</td>
<td>4.95</td>
<td>87.00</td>
</tr>
<tr>
<td></td>
<td>Septemb.</td>
<td>1.68</td>
<td>0.15</td>
<td>0.07</td>
<td>0.039</td>
<td>4.48</td>
<td>68.00</td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>2.66</td>
<td>1.48</td>
<td>0.18</td>
<td>0.028</td>
<td>10.25</td>
<td>104.63</td>
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<tr>
<td></td>
<td>Novemb.</td>
<td>2.21</td>
<td>5.07</td>
<td>0.25</td>
<td>0.017</td>
<td>8.10</td>
<td>85.67</td>
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<td>Decemb.</td>
<td>2.90</td>
<td>7.84</td>
<td>0.18</td>
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<td>10.80</td>
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<td>January</td>
<td>2.01</td>
<td>5.82</td>
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<td>0.010</td>
<td>10.84</td>
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<td></td>
<td>February</td>
<td>1.31</td>
<td>9.57</td>
<td>0.57</td>
<td>0.009</td>
<td>10.39</td>
<td>129.13</td>
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<td>March</td>
<td>1.29</td>
<td>6.72</td>
<td>0.18</td>
<td>0.011</td>
<td>11.76</td>
<td>74.27</td>
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<td>April</td>
<td>1.27</td>
<td>1.83</td>
<td>0.19</td>
<td>0.000</td>
<td>10.97</td>
<td>90.28</td>
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<tr>
<td></td>
<td>May</td>
<td>1.17</td>
<td>2.94</td>
<td>0.15</td>
<td>0.000</td>
<td>9.37</td>
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<td>Average</td>
<td>1.67</td>
<td>3.56</td>
<td>0.17</td>
<td>0.01</td>
<td>8.92</td>
<td>98.32</td>
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<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Total N [TN mg/l]</th>
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<th>DO [O₂ mg/l]</th>
<th>Susp. S. [TSS mg/l]</th>
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<tr>
<td>2013</td>
<td>June</td>
<td>2.14</td>
<td>7.35</td>
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<td>91.17</td>
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<tr>
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<td>July</td>
<td>1.58</td>
<td>3.69</td>
<td>0.12</td>
<td>0.000</td>
<td>43.33</td>
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<td>August</td>
<td>0.99</td>
<td>1.17</td>
<td>0.07</td>
<td>0.039</td>
<td>48.75</td>
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<td>Septemb.</td>
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<td>0.07</td>
<td>0.068</td>
<td>46.75</td>
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<td>October</td>
<td>2.05</td>
<td>6.48</td>
<td>0.18</td>
<td>0.026</td>
<td>50.56</td>
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<tr>
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<td>Novemb.</td>
<td>3.27</td>
<td>11.79</td>
<td>0.37</td>
<td>0.024</td>
<td>62.63</td>
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<td>Decemb.</td>
<td>2.88</td>
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<td>January</td>
<td>2.76</td>
<td>9.11</td>
<td>0.16</td>
<td>0.013</td>
<td>53.66</td>
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<td>February</td>
<td>4.50</td>
<td>15.33</td>
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<td>0.038</td>
<td>67.75</td>
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<td>0.064</td>
<td>44.21</td>
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<tr>
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<td>April</td>
<td>2.77</td>
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<td>0.26</td>
<td>0.000</td>
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<td>May</td>
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<td>13.12</td>
<td>0.79</td>
<td>0.000</td>
<td>55.50</td>
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</tbody>
</table>

- Exceeded recommended value for total suspended solids (25 mg TSS/l)
- Exceeded recommended value for TP for cyprinid fish waters (0.2 mg TP/l)
- After OECD criteria for TP is accumulation hypereutrophic (> 0.1 mg TP/l)

### Average:

- 1.67 [Total N]
- 3.56 [Nitrates]
- 0.17 [Total P]
- 0.01 [Orto-P]
- 8.92 [DO]
- 98.32 [Susp. S.]

### 1.7.1987

- 9.6.1996

### 10.7.2011
Calibration and Validation of the SWAT model

<table>
<thead>
<tr>
<th>Objective function</th>
<th>CALIBRATION - FLOW</th>
<th>VALIDATION - Flow</th>
<th>CALIBRATION SUSPEND. SOLIDS load</th>
<th>Acceptable values (Moriasi; van Liew)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>year</td>
<td>month</td>
<td>day</td>
<td>day</td>
</tr>
<tr>
<td>E(_\text{NS})</td>
<td>0.996</td>
<td>0.493</td>
<td>0.571</td>
<td>0.5</td>
</tr>
<tr>
<td>PBIAS</td>
<td>-5.29</td>
<td>-5.19</td>
<td>-5.29</td>
<td>14.08</td>
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<tr>
<td>R(^2)</td>
<td>0.701</td>
<td>0.618</td>
<td>0.571</td>
<td>0.525</td>
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</tbody>
</table>

0 = optim.. ± 25% for flow ± 50 % za TSS

0.5; 1 ali -1 = optim.

### RESULTS

#### CALIBRATION suspe. solids load monthly (2013-2014)

#### CALIBRATION flow (2006-2010)

#### VALIDATION flow (2011-2013)

#### CALIBRATION suspe. solids load daily (2013-2014)
Critical source areas (CSA)

<table>
<thead>
<tr>
<th>Transport Class (t/ha/year)</th>
<th>Area (ha)</th>
<th>Percent of total area (%)</th>
<th>Transport of Suspended Solids (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.01 - 4.10</td>
<td>355.06</td>
<td>3.37</td>
<td>1.72</td>
</tr>
<tr>
<td>0.51 - 1.00</td>
<td>905.32</td>
<td>8.60</td>
<td>0.69</td>
</tr>
<tr>
<td>0.11 - 0.50</td>
<td>2245.50</td>
<td>21.33</td>
<td>0.23</td>
</tr>
<tr>
<td>0.06 - 0.10</td>
<td>855.62</td>
<td>8.13</td>
<td>0.08</td>
</tr>
<tr>
<td>0.00 - 0.05</td>
<td>6163.80</td>
<td>58.56</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>10525.31</strong></td>
<td><strong>100.00</strong></td>
<td><strong>0.28</strong></td>
</tr>
</tbody>
</table>

CSAs account for 31.1% of all arable fields, or 12.1% of all land use.

The most erodible are:

- gley and pseudogley soils;
- the slope between 11 and 24%
- fields and fields with drainage ditches
OBJECTIVES:
• improve ecological potential and to maintain a useful value (WFD for HMWB)
• Reduce soil loss and thus:
  ➢ reduce the inflow of suspended solids or to maintain a useful volume
  ➢ to preserve fertile soil

CRITERIA:
• to reduce the concentration of suspended solids below 25 mg TSS/l*
• Reduce the loss of soil where it exceeds 0.5 t/ha/year**

* Decree on the quality of waters for the life of freshwater fish species (Ul. RS, št. 46/2002)

** On the basis of literature, the area is strongly subjected to the action of external forces, due to badly fished sediments there are frequent avalanches and landslides. The European Center for Soil Research estimates 1 t/ha/year as natural erosion. (http://eussoils.jrc.ec.europa.eu)
ERM measures to mitigate the transport of suspended solids from agricultural land and in the watercourses:

- USDA* lists 164 measures for different types of load, of which approx. 22 for erosion;
- Agri-Envi-Climate measures (CAP RDP) – 10 requirements to reduce erosion and improve the soil structure;
- 3 RBMP measures to reduce erosion and improve the hydromorphology of watercourses

13 ERM measures based on 92 published results from 43 sources of literature

* U.S. Department of Agriculture
RESULTS

The set of 13 measures

CRITERIA:
- characteristics of CSA
- existing measures CAP RDP (in implementation 3)
- high efficiency against load
- adaptation to actual use, technology of cultivation....
- capacity of the numerical model

1. S1: Vegetation buffer on a slope of 0-11%
2. S2: Vegetation buffers on slope of 11-24%
3. S3: Vegetation buffer on slope of 0-11% and from 11 to 24%
4. S4: Conservation tillage
5. S5: Contour farming on slope between 11 and 24%
6. S6: Terraces on slopes between 11 and 24%
7. S7: Crop rotation without winter catch crop
8. S8: Crop rotation with winter catch crop
### Evaluation of measures

#### RESULTS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Area (ha)</th>
<th>% from agri. land area</th>
<th>% from total area</th>
<th>Efficiency (%)</th>
<th>Load of susp. solids at inflow to lake</th>
<th>Transport susp. solids from HRU</th>
<th>Concentration susp. solids in the river Ledava</th>
<th>Half life period of accumulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 - veg. strip 0-11%</td>
<td>32.8</td>
<td>0.6</td>
<td>0.3</td>
<td></td>
<td>13.3</td>
<td>12.8</td>
<td>4.2</td>
<td>15.1</td>
</tr>
<tr>
<td>S2 - veg. strip 11-24%</td>
<td>36.4</td>
<td>0.7</td>
<td>0.4</td>
<td></td>
<td>6.8</td>
<td>43.4</td>
<td>11.7</td>
<td>7.5</td>
</tr>
<tr>
<td>S3 - veg. strip 0-11-24%</td>
<td>69.2</td>
<td>1.2</td>
<td>0.7</td>
<td></td>
<td>8.5</td>
<td>56.1</td>
<td>13.1</td>
<td>9.7</td>
</tr>
<tr>
<td>S4 – conservation tillage to 24%</td>
<td>3422.9</td>
<td>60.8</td>
<td>32.5</td>
<td></td>
<td>7.9</td>
<td>20.3</td>
<td>3.3</td>
<td>8.6</td>
</tr>
<tr>
<td>S5 – contour farming 11-24%</td>
<td>1453.8</td>
<td>25.8</td>
<td>13.8</td>
<td></td>
<td>8.2</td>
<td>18.9</td>
<td>2.8</td>
<td>8.6</td>
</tr>
<tr>
<td>S6 - terraces11-24%</td>
<td>1453.8</td>
<td>25.8</td>
<td>13.8</td>
<td></td>
<td>30.5</td>
<td>42.4</td>
<td>5.8</td>
<td>44.1</td>
</tr>
<tr>
<td>S7 – no winter catch crop</td>
<td>3422.9</td>
<td>60.8</td>
<td>32.5</td>
<td>-24.7</td>
<td>-11.5</td>
<td>-1.3</td>
<td>-19.4</td>
<td></td>
</tr>
<tr>
<td>S8 – with winter catch crop</td>
<td>3422.9</td>
<td>60.8</td>
<td>32.5</td>
<td>7.7</td>
<td>11.9</td>
<td>1.0</td>
<td>8.6</td>
<td></td>
</tr>
</tbody>
</table>

Spatial view of the influence of scenarios on the transport of susp. solids (t/ha/year) at the HRU level.

$r = \left( \frac{y_1 - y_2}{y_1} \right) \times 100$

$r$ ... efficiency (%)

$y_1$ ... base scenario

$y_2$ ... test scenario
The most effective measures and critical source areas (CSAs) are the basis for the TSA Phase 2 allocation plan.

Future challenges:

- More precisely to define the limit values of the quality parameters for water accumulations and soil loss criteria;
- Design a set of measures for different types of loads;
- Define CSA on aggregate agricultural land use;
- Using evolutionary algorithms to a greater number of combinations of measures;
- Upgrade SWAT or other programmes to assess measures to protect river banks;
- TSA tool design into a software tool for easy use.

**RESULTS**

Exceeding TSS concentration, nutrients do not exceed limit values

Sediment CSA cover 12% of total area. Erosion is high on gley and p-gley soils and fields on slope (11-24%)

Reduce TSS conc. Erosion processes and TSS inflow in to accumulation

After review selected 13 efficient measures for TSS reduction

5 measures selected, designed into 8 scenarios

Best impact with scenarios S2, S3, S6

Check combination of measures and correctness of limit values
We have **developed the TSA tool**, which makes it possible to **optimize the selection and allocation of ERM measures** in the river catchment area for the restoration and protection of accumulations.

Based on the results of **previous research**, it is possible to **collect data on the effectiveness of ERM measures** according to the type of load and the characteristics of the area of concern.

**Criteria for ERM measures allocation into the space can be determined** in order to achieve their optimum efficiency and distribution. **On the basis of critical source areas (CSA) we were able to set criteria and place measures where they are most needed** and effective.

With the integration of the SWAT numerical model in the TSA tool, **we evaluated the impact of measures on reducing the inflow of suspended solids** into the Ledava Lake accumulation, the maintenance of useful volume, the concentration of suspended solids and the soil loss.
Thank you for your attention!