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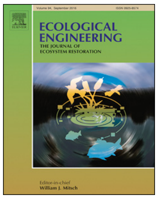

A tool for the selection and implementation of eco-remediation mitigation measures

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ABSTRACT

Erosion processes in the watershed and sediment transport cause hydro-morphological changes, eutrophication, and the loss of storage capacity in reservoirs. This study examines the tool for the optimal selection and implementation (TSI) of eco-remediation measures (ERM) in the river basin area to improve water quality and to reduce storage loss in the reservoir in question. The main purpose of this tool is to support decisions and measures taken to correct defined problems and to improve water quality and storage capacity in the watershed while minimising sediment transport. This tool enables the effective and necessary implementation of these measures to the most critical source areas (CSAs). In order to verify its operability, we selected the Ledava reservoir with a transboundary area of 105.25 km^2 in NE Slovenia and SE Austria. With the use of the Soil and Water Assessment Tool (SWAT), critical source areas were determined and the effects of eight different scenarios on sediment yield and load transport were simulated. The results showed that CSAs occupy 12% of the watershed and that sediment inflow into the Ledavsko jezero reservoir could be reduced by up to 30%. After determining the CSAs and which measures would be most effective, the implementation plan could be defined. Within this framework, the TSI enabled the selection of effective measures and contributed to the long-term improvement of the ecological status of surface waters required by Water Framework Directive (2000/60/EC), improving the quality of water bodies of all types to safeguard water ecosystems from harmful consequences.

1. Introduction

Reservoirs are artificial lakes, some of which are created by damming streams and rivers and others by filling excavated pits that were used for extracting ore, gravel or rock. Their purpose is to provide a water supply for drinking and irrigation, contribute to flood control by adjusting the flow regime, and generate electricity (ICOLD, 2017). In Europe, lakes and reservoirs (excluding the Caspian Sea) comprise 300,000 km^2, or 3% of Europe's surface, of which more than one third are reservoirs. There are approximately 7000 large reservoirs with a height of over 15 m (EEA, 2012). Most of them are multipurpose reservoirs intended for irrigation (49%), generating electricity (20%), drinking water supply (13%) and flood protection (9%) (ICOLD, 2017).

Due to the multi-purpose use of reservoirs, their operators are often faced with issues of water quality, capacity, security, and cost of facility maintenance (Naughton et al., 2017). The two main interrelated problems in reservoirs are: (i) loss of useful volume and hydro-morphological changes resulting from the inflow and deposition of sediment as a result of soil and riverbank erosion; and (ii) the loss of water quality due to the inflow of nutrients as a result of natural processes and human activities in the basin area (Urbanič et al., 2003; Pope and Odhiambo, 2014). The annual loss of volume in all reservoirs in the world is estimated to be > 0.5%, which is equal to 45 km^3 of water (Wisser et al., 2013). Deposition of sediments causes the degradation of fish habitats in rivers and reservoirs, which, in the United States, has led to a 31% decrease in reservoir populations (Miranda et al., 2010).

Most European lakes and reservoirs have been impacted by increased nutrient intake, which has led to the excessive production of organic matter. The rate and speed of eutrophication also depends on factors such as the size and depth of the reservoirs, flow rate or retention time, and the patterns of stratification and circulation of water in the water body, which changes over time through the accumulation of sediment (Straškraba, 2007; Wetzel and Academic, 2015).

With the expansion and intensification of agricultural land, urbanisation, and deforestation, the erosion processes in river basin areas and consequently, the inflow of sediment into reservoirs, has greatly increased, which has led to higher maintenance costs (Morris and Fan, 2010). Eco-remediation measures (ERMs) are considered relatively

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economical and effective preventive measures. They are designated as methods for the protection and restoration of the environment using ecological engineering (Vrhovšek et al., 2008), which includes the processes of constructing and restoring ecosystems (Mitsch et al., 2014) consisting of plants, water, soil, and microorganisms in the root system (McCutcheon and Schnoor, 2003; Crawford, 2005).

With carefully thought-out placements of selected ERM measures in the river basin, the inflow of sediment can be significantly reduced (Ghebremichael et al., 2013; Ahmadi et al., 2015; Bouraoui and Grizzetti, 2014). The effectiveness of the selected measure depends on hydrological and climatic factors, soil type, land use, topography, the extent of the implementation, and the location of the placement. Given the many possible combinations, optimal solutions are sought to prevent the causes of erosion in an efficient, sustainable, and affordable way (Wetzel and Academic, 2015; Mekonnen et al., 2015).

The studies on processes in the basin area and on the optimisation of the selection and positioning of measures have shown that numerical models can define the areas of diffuse pollution and erosion more accurately at the basin and agricultural level (Zhang et al., 2010; Kaini et al., 2012 Panagopoulos et al., 2011; Ahmadi et al., 2014; Ghebremichael et al., 2013). Due to the mathematical abstraction of systems, numerical models have multiple shortcomings, especially when it comes to integrating factors that cannot be quantitatively assessed and included in numerical modelling (e.g. socio-political, natural, and geographical space restrictions). In order to bridge spatial gaps and compensate for insufficient data, it is necessary to integrate decision-supporting tools at the river basin level, which would combine numerical models for assessing the impact of the measures to be implemented, setting the space for placement and optimising benefits and costs (Xie and Lian, 2013).

Due to the complex processes between the basin area and individual water bodies, a systematic but simple approach is needed in the form of a tool for selecting and positioning measures that improve transparency in the decision-making process. This approach should determine the problem, outline possible measures or solutions, define goals and criteria, evaluate and select the appropriate measures, and create plans for implementing the decisions made. Such a systematic approach to problem-solving is used in personal, business, and professional decision-making (Bohanec, 2012).

The aim of the study is to develop a tool to support decision-making in the selection and implementation of eco-remediation measures into the river basin area in order to reduce the inflow and transport of sediment into the river and reservoir. The tool has been tested with a set of proven and effective ERM measures for the improvement and conservation of good chemical and ecological levels in reservoirs, by determining the their extent and location in the Ledava River basin area.

2. Materials and methods

2.1. Study areas

The Ledava River and the Ledavsko jezero reservoir are located in the northeast of Slovenia (Fig. 1). The transboundary basin covers an area of 105.25 km^2, of which 33.7 km^2 are located in Austria. From the source, originating 430 m above sea level, to the reservoir inflow, the river is 17.4 km long. The first eight km flow through Austria. For the most part, the Ledava River is a typical lowland river with low gradients and slow flow. In the summer months, the water level becomes very low and has a specific outflow of 5.8 $l/s/km^2$ and a drainage factor of 21.6% (gauging station Čentiba). During the period between 2003 and 2014, the Nuskova gauging station showed the greatest measured flow discharge at 17.8 m^3/s (4 August 2009) and the lowest at 0.002 m^3/s (22 August 2003).

Over a third of the watershed is covered with agricultural land (37.8%), followed by forests (36.7%) and meadow (12.1%). Permanent crops, urban areas, and water cover the remaining area. The landscape is steeper in the upper part of the Ledava basin due to the solid geological composition of volcanic origin. The poor adhesive tertiary and quaternary sediment, topographical properties, and exchange of light to heavy soils increase the possibility of sliding and erosion. Due to the rapid hydrological response in the basin, the Ledava River floods regularly. The Ledavsko jezero reservoir (5.6 million m^3) was built in 1977 in order to protect the regional capital of Murska Sobota and the cultivated land (10,000 ha) along the Ledava River.

The Ledavsko jezero reservoir is classified as a heavily modified water body that deviates from the natural hydrological and morphological characteristics of the area. It has problems achieving a good ecological status. The situation is critical and requires the implementation of thorough and extensive remedial measures that will ensure the planned volume for the intended purposes: flood protection, irrigation, fishing, and recreation (Triglav, 2012). Despite a certain level of improvement, the reservoir is overloaded with nutrients and plant-protection products. It has low transparency (Secchi depth < 1 m), regular algae flowering, and widespread macrophyte growth (Remec-Rakar, 2014). Its poor ecological status is attributed to agricultural activities in the hinterland areas of the basin (Mazej et al., 2013).

2.2. Database

Topographical maps, land use, and soil from Slovenia and Austria were used to represent and model the area (Table 1). The stream's network was defined based on data obtained from the Environment Agency of the Republic of Slovenia (ARSO). Basic weather data between 2003 and 2014 were obtained from the ARSO and Zentralanstalt für Meteorologie und Geodynamik (ZAMG) in Austria. Data for typical management practices such as crop rotation, crop type, fertiliser application, and tillage operations for different land use were gathered from the Agricultural Advisory Service of the Chamber of Agriculture and Forestry of Slovenia-Murska Sobota Unit.

Daily discharge data was supplied by ARSO from the Nuskova gauging station (46°48′38.14″N, 16°1′39.02″E) for the period between 2003 and 2014 (Fig. 1). Established in 2007, the active sampling points (ARSO) for the monthly monitoring of water quality were at Sveti Jurij (46°47′49.99″N, 16°1′55.55″E) and at Ledavsko jezero reservoir (46°44′49.95″N, 16°2′24″E).

Due to the limited data on water quality provided by ARSO, additional bi-weekly water quality monitoring was carried out. Concentrations of total suspended solids (mg TSS/l) were measured bi-weekly (June 2013-May 2014). Ninety-four samples were taken at the sampling point of Pertoča (46°46′26, 52″N, 16°2′24, 64″E), located on the Ledava River about 1.5 km upstream of the Ledavsko jezero reservoir (Fig. 1) and at the outflow of the Ledavsko jezero reservoir (46°44′49, 95″ N 16°2′24″ E).

2.3. Tool for optimal selection and implementation of eco-remediation measures

The tool for optimal selection and implementation of measures (TSI) enables the development of a systematic approach giving the user improved clarity in the decision-making process (Fig. 2). The tool is divided into: (1) the first phase by defining critical areas and selecting cost and environmentally effective measures, and (2) the second phase for optimising the implementation of these effective measures. This paper focuses on the first phase, which seeks the balance among cost, public requirements, development opportunities, and environment protection, which is one of the cornerstones of the integrated river basin management according to the European Union's Water Framework Directive (WFD). Detailed descriptions of the first phase (Fig. 2) are as follows:

(1) To identify the underlying problem, water-quality monitoring and

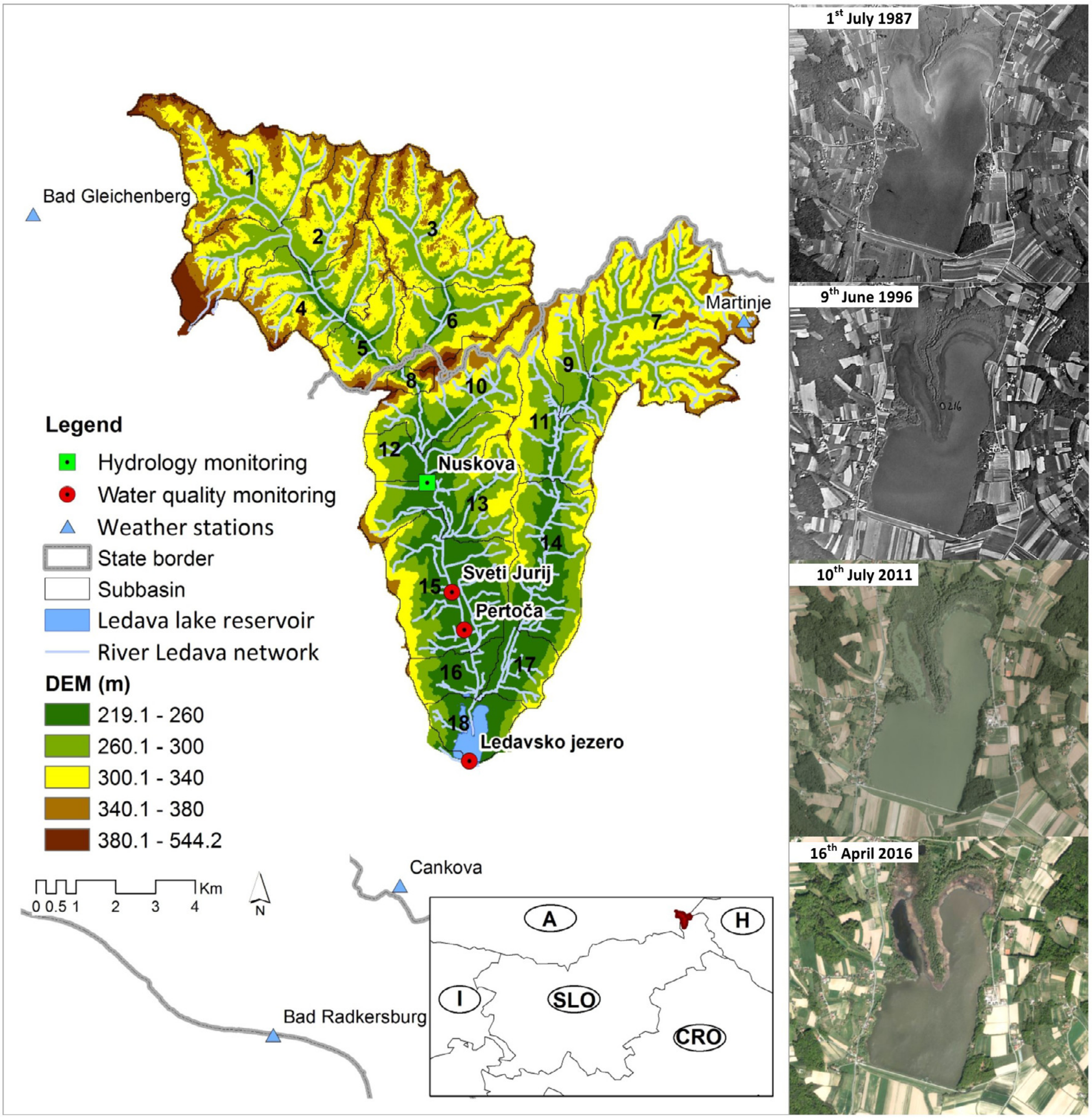


Fig. 1. Aerial image of the basin of the Ledava River and Ledavsko jezero reservoir between 1987 and 2016, where an increase of delta and decrease of bay area in the NW section of the reservoir is visible (The Surveying and Mapping Authority of the Republic of Slovenia, Archives of Aerial Photos).

water body analysis should be carried out to assess the chemical and ecological status of the water body in accordance with the legislative criteria and environmental quality standards.

(2) To define hydrologically active critical source areas (CSA) of the water body with increased potential for the transport of sediment and nutrients. With CSA defined, we can reduce the amount of agricultural land needed for the implementation of measures, which, consequently, will reduce the associated costs. The CSA can be defined by analysing natural, geographical, and hydro-meteorological data, data from water-quality sampling, data on the effectiveness of measures that have already been implemented, and the locations of the pollution sources (point, diffuse). GIS tools are proposed for this type of analysis.

(3) To define the criteria needed for selecting measures to reduce pressure on the water body. Such criteria in the EU are mostly based on the WFD (2000/60/EC) and are determined by the following objectives: to improve water quality, and to choose acceptable and effective measures (Article 11 of Annex III of the WFD), which are two cornerstones in the decision-making process and in the design of River Basin Management Plans (RBMP). Based on the objectives, criteria need to be formulated (e.g. legislative target and/or recommended values) to support the selection and evaluation of measures.

(4) To prepare a set of measures to achieve the goal of reducing the pressure of diffuse pollution with regard to (i) the type of pressure (e.g. sediment, nutrients, plant protection products); (ii) the effectiveness of the measure taken to achieve the objective; and (iii) land use (urban, fields, meadows, forests). Active measures that are to be implemented or that are foreseen as being necessary in the context of the agri-environment and/or water policy should be taken into consideration. The set of measures can be limited by evaluating the cost of their establishment and maintenance, as well as their acceptance by the stakeholders.

(5) To design scenarios from selected measures to model CSA. The selection should account for: (i) the suitability of the land for implementing the measures (reducing the usable area, costs); (ii) the interaction between measures (synergy or discord); (iii) transferability of technology (climate, soil, land size, mechanisation); (iv) adaptation to production and processing management; (v) adaptation to natural conditions and landscape typology; (vi) selection of

Table 1
Database of the ledava river basin.

Data type	Scale	Source	Data description
Topography	Slovenia DEM: 25 m Austria DEM: 1 m	The Surveying and Mapping Authority of the Republic of Slovenia, GIS Steiermark and GIS Burgenland	Elevation, overland and channel slopes, lengths
Soils	Slovenia: 1:25000 Austria: 1 km raster	Ministry of Agriculture, Forestry and Food of the Republic of Slovenia; Biotechnical Faculty (University of Ljubljana) Austrian Research Centre for Forests	Spatial soil variability, soil types and properties
Land Use	Slovenia: 1 m Raster (Graphical Units of Agricultural Land) Austria: 1:5000	Slovenia: Ministry of Agriculture, Forestry and Food of the Republic of Slovenia Austria: GIS Steiermark, GIS Burgenland and Municipalities (At. Anna am Aigen, Kapfenstein, Nauhaus am Klausenbach)	Land use, land cover classification, and spatial representation
Land Management	/	Chamber of Agriculture and Forestry of Slovenia – Murska Sobota Unit	Crop rotations (harvesting, planting, management), fertiliser application (rates and time)
Weather	Slovenia: 3 stations Austria: 2 stations	Environmental Agency of the Republic of Slovenia (ARSO), Zentralanstalt für Meteorologie und Geodynamik (ZAMG), Austria	Daily precipitation, Temperature (max., min.), relative humidity, wind, solar radiation (2003–2014)
Waste Water Treatment Plant	Slovenia: 3 Austria: 2	Environmental Agency of the Republic of Slovenia; Land Steiermark – Amt der Steiermärkischen Landesregierung	Average daily discharge of organic P, sediment and organic N
River Flow	1 point (Nuskova)	Environment Agency of the Republic of Slovenia	Daily flow data (m^3/s) (2003–2014)
Water Quality	2 monitoring stations (Pertoča and Ledavsko jezero);	Own biweekly monitoring	TSS, NO_3^-, NO_2^-, PO_4^{2-}, TP, TN, temperature, dissolved O_2 (2013–2014)
	2 monitoring stations (Sveti Jurij and Ledavsko jezero	Environment Agency of the Republic of Slovenia (monthly monitoring)	TN, NO_3^-, TP, PO_4^{2-}, TSS (2007–2014)

the model to simulate the effectiveness of the measures (i.e. SWAT model).

(6) To assess the modelling results of the measures' effectiveness by taking into account the objectives and criteria. The effectiveness of mitigation measures must be assessed on a spatial level and in terms of the impact of combining measures. A measure may be suitable on an agricultural level, but less effective at the basin level. Environmental effectiveness of the measures can reduce the harvested yield of the farm. If measures fail to achieve the set objectives, the following should be verified: (i) that the problem and the related objectives and criteria are correctly set, (ii) whether there are other measures to be consider, and (iii) whether an error was made in the process of modelling or selecting a model. After choosing the most effective measures, the plan for installation and implementation can be designed.

(7) To create a proposal for implementing mitigation measures that (i) ensures maximum efficiency; (ii) accounts for spatial limitations (water bodies, natural heritage, landscapes, public infrastructure, and facilities) and guidelines in legislation (local, regional, state, cross-border, EU); (iii) stabilises or improves the economic position of agriculture; and (iv) estimates optimal costs of installation and maintenance. The objectives are achieved when the installation plan is adopted and when measures are implemented. At this stage, a monitoring programme should be established to verify the effectiveness of the measures and to make adjustments in terms of natural and social changes in the basin.

2.4. The SWAT model setup

The soil and water assessment tool (SWAT) model is a process-based, semi-distributed, time-continuous hydrological model that operates at the level of river basins (Arnold et al., 1998; Arnold et al., 2012; Gassman and Wang, 2015). It is intended to predict the long-term effects of agricultural and soil management, meaning the transfer of nutrients and other pollutants into the water bodies. The main components of the model are data on climate, hydrology, inclination, soil, plants, nutrients and plant protection products management, soil management, and spatial planning.

The simulation of hydrological processes is divided into two phases: (i) a land-based process that controls the input of water, sediments (suspended matter), nutrients, and pesticides into the main reach of each sub-basin, and (ii) a transfer-based process that controls the pollutant pathways in a generated river network to the point of outflow from the basin. Given that the hydrology is climate-dependent, SWAT needs data on daily precipitation, temperature, solar radiation, relative air humidity, and wind speed. Based on this data, the model simulates hydrological processes: storage of water in crops, surface runoff, infiltration, evapotranspiration, lateral flow, drainage, distribution of water in the soil profiles, return flow, water abstraction, and groundwater recharge. For the simulation of transport and transformation of various forms of phosphorus and nitrogen plant-protection products and sediments, data on land management and operations (fertilisers, plant- protection products, crop rotation, harvest, etc.) are required within each hydrologic response unit HRU.

In the framework of this research, we used the SWAT 2012 model, ArcGIS 10.3 software, and the ArcSWAT interface. The data from Table 1 were used to prepare the model. The model was divided into 18 sub-basins and 3.196 HRU. The flow was calibrated (2005–2010) and validated (2011–2013) on a daily basis at the gauging station, Nuskova. Due to limited data, sediment was only calibrated for the period between June 2013 and May 2014 on a monthly and daily basis at the monitoring station, Pertoča. The results of the effectiveness of the model scenario are prepared as average monthly or annual values for the modelling period of 2006–2013. See Glavan et al. (2016) for further details.

2.5. Defining scenarios of ERM measures

Based on the observations and modelling results carried out in this research, it was found that the main pressure on the Ledavsko jezero reservoir and the Ledava River was sediment. We selected measures to mitigate the erosion process and sediment transfer to the water body.

After reviewing 92 published results from 43 sources, a set of 13 effective mitigation measures was developed (Fig. 3). See Ojsteršek Zorčič (2015) for more details. Due to the different characteristics of the studied basins, climatic conditions, ways of implementing the measures, and the different methods of measurements and modelling techniques mentioned in the literature, this set of measures is only one of the possibilities. In the selection of measures for scenario development, we considered: (i) land use; (ii) production technology and machinery; (iii) properties of the area (soil type, inclination, land parcel size); (iv) EU Rural Development Programme (RDP) measures which are included in the river basin management plans (RBMP) programme that protect soil from erosion; and (iv) modelling requirements and

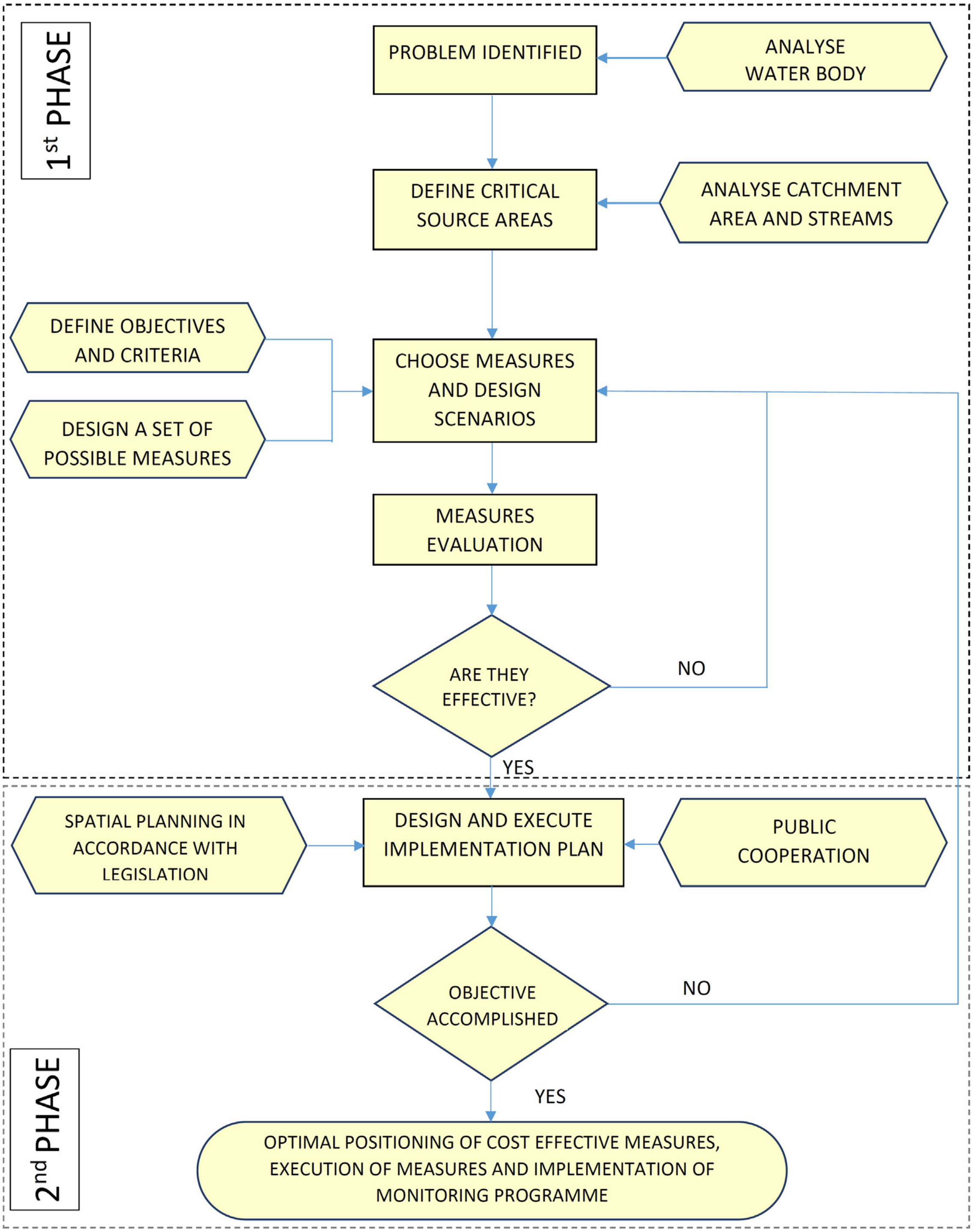


Fig. 2. Conceptual decision flowchart for selecting and implementing mitigation measures in the basin.

availability of data.

Out of 13 measures, we excluded those whose efficiency would increase with their spatial extent such as grassed waterways and sedimentation basins. Such measures are inadequate for the area in question due to fragmented ownership and the spatial structure of the land. Because of the large spatial extent of agricultural land on slopes > 11%, we selected terraces despite the fact that they are rare in the area. During the selection process, we included three EU RDP measures for improving fertility and reducing soil erosion (greening, wide rotation, and conservation tillage), vegetative filter strips, and contour farming, which are among the most commonly used mitigation measures. The simulation of these measures was carried out only on arable land, as such land is the most critical source area in terms of soil erosion. All of the arable land on slopes (> 24%) was transformed into permanent grassland (5.5% of the basin and 14.5% of all arable land), as this procedure follows the World Code of Good Agricultural Practice (Verbič et al., 2006). "The code considers the cultivation of arable land on slopes to be inappropriate due to water erosion and the consequently higher production costs it would entail.

From the set of mitigation measures, we prepared eight scenarios:

- Vegetative filter strips between 0 and 11% slopes – S1 (32.8 ha),

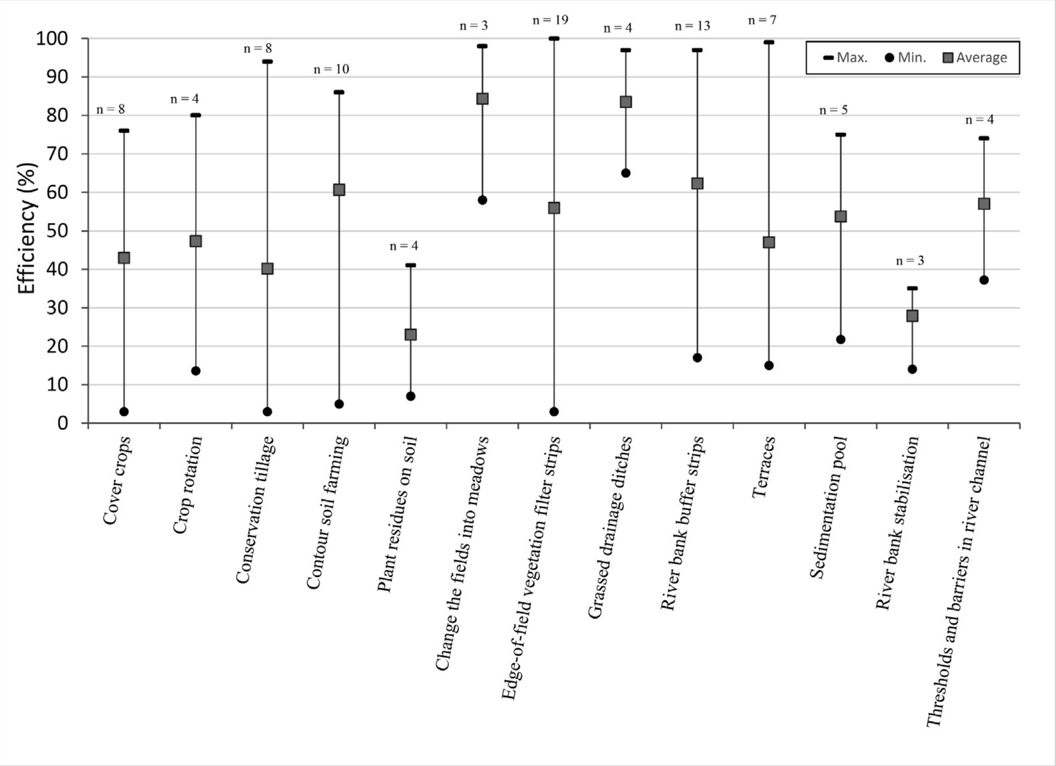


Fig. 3. Efficiency of measures after review of the 43 sources of literature (n – number of references) (See Ojsteršek Zorčič, 2015 for more details).

- Vegetative filter strips between 11 and 24% slopes – S2 (36.4 ha),
- Vegetative filter strips between 0 and 24% slopes – S3 (69.2 ha),
- Conservation tillage – S4 (3422.9 ha)
- Contour farming between 11 and 24% slopes – S5 (1453.8 ha),
- Terraces on land with slopes between 11 and 24% – S6 (1453.8 ha),
- Without cover crops – S7 (3422.9 ha),
- With cover crops – S8 (3422.9 ha).

3. Results and discussion

3.1. Identifying the problem

Data from the Environmental Agency of the Republic of Slovenia (EARS) showed that due to the average annual values of individual parameters (nitrates, phosphorus, dissolved oxygen, suspended solids, and sediments), the Ledavsko jezero reservoir is classified as a eutrophic to hyper-eutrophic lake type according to the OECD criteria. The latest report states that, in accordance with the national criteria in the decree on surface water status (2009), the reservoir did not achieve good ecological potential in 2013 (Remec-Rakar, 2014).

This was confirmed by our own simultaneous bi-weekly monitoring of the Ledava River and the Ledavsko jezero reservoir in 2013 and 2014 (Fig. 4). Results revealed that the average annual concentration of total suspended solids (sediment) in both water bodies (river and reservoir) exceeded the target value of 25 mg/l defined by the policy makers (Fig. 4).

The high sediment values were measured during high flows (January, February, May, June, October, and November) as well as during base flows. The higher sediment values during base flows were expected in warmer waters (Vondracek et al., 2003), which is characteristic of the Ledava River basin.

These results confirm the records of the water surface area indicating that morphological changes are happening in the lake due to the consequences of depositing sediment (Triglav, 2012). Of the 164 ha purchased for the construction of the reservoir, of which 122 ha were intended for the lake, today's actual water surface area is 76 ha. Changes are most noticeable in the outflow of the Ledava River into the reservoir (Fig. 1). The reduced area means less volume is required for the primary purpose (flood protection). The calculations showed 80% sediment-trapping efficiency in the reservoir at a working capacity of 2.42 million m^3 and at a mean outflow of 1.26 m^3/s, and 89% at the minimum, guaranteed outflow of 0.5 m^3/s.

3.2. Critical source areas (SCA)

3.2.1. Calibration and validation of base model

Calibration and validation results of measured and simulated daily and monthly flows and sediments were rated as acceptable (Table 2, Fig. 5) for the ENS, R2, PBIAS objective functions (van Liew et al., 2003; Moriasi et al., 2007). The SWAT simulated the stream-flow trends in the calibration period very well, as simulated stream-flow values did not exceed the measured stream-flow data by > 15% (Moriasi et al., 2007). Results show that on daily and yearly time steps, the model simulations for stream flow are between good and very good in terms of correlating with measured values. Validation of the stream flow is in line with the calibration results. The sediment load was calculated as the product of the measured concentrations of sediment (mg/l) and the average daily and monthly flows (m^3/s). Due to the limited amount of data for sediment calibration, with only one year of measurements, validation was not carried out. The R2 indicates a moderate to strong positive agreement for daily and monthly time steps. Objective functions for a daily and monthly time step sediment calibration show that statistics significantly improve (monthly ENS > 0.5) when only one outlier value (17.2.2014 with 260 t/day) is excluded from the calculation. PBIAS describes the 20% deviation of the results for a daily time step, which is in the range of very good model performance (Moriasi et al., 2007). The performance for R2 and ENS improved from an unsatisfactory to a satisfactory level for daily time steps after the removal of only one measured maximal outlier value (Fig. 5). However, this is because the efficiency coefficient is sensitive to extreme values, which shows sub-

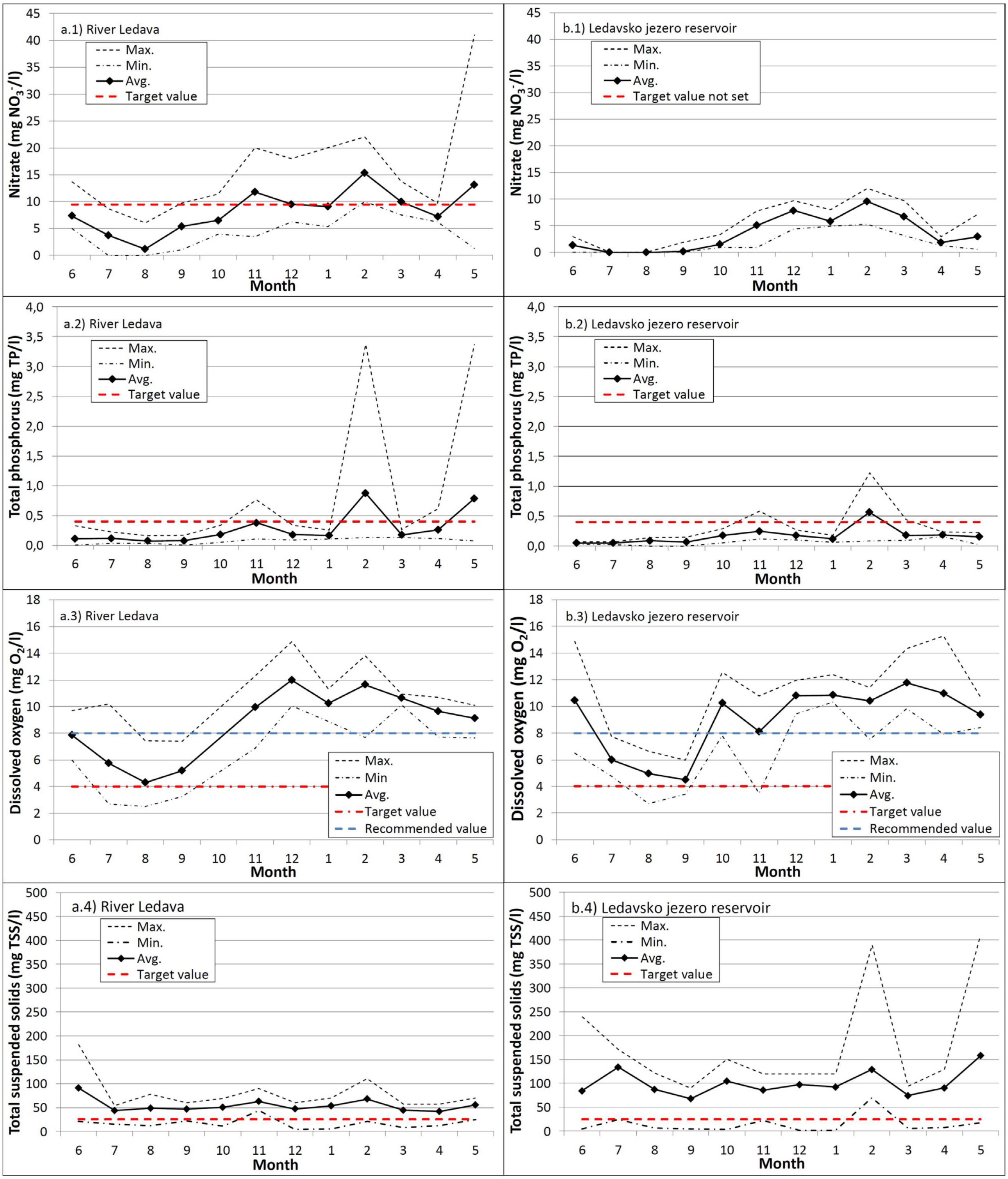


Fig. 4. Average monthly concentrations (mg/l) for nitrate (NO_3^-), total phosphorous (TP), dissolved oxygen and total suspended solids in the (a) Ledava River and (b) Ledavsko jezero reservoir observed between June 2013 and May 2014.

optimal results when the data set contains outliers (Moriasi et al., 2007). As the results for stream flow and sediment will be presented as yearly averages, we can confirm that our model is calibrated sufficiently to be used for further simulations. After the base model calibration was completed, the parameters remained fixed for further use in scenario modelling. For further details on the calibration and validation process, see Glavan et al. (2016).

3.2.2. CSA identification and target definition

The simulated annual quantity of sediment yield from average HRU (base scenario) is on the sub-basin level transported from sub-basins 1, 2, 4 (0.36–0.44 t/ha/year) and 5 (0.28 t/ha/year) (Fig. 6). Standard deviations indicate that the values can fluctuate by ± 0.3 t/ha/year. The fluctuations are the result of spatial and temporal distribution of precipitation and heterogeneity in land use, soil type, cultivation technologies, and slope. The sub-basins 1, 2, and 4 present 28% of

Table 2
Objective functions for the annual, monthly, and daily time step calibration (2005–2010) and validation (2011–2013) for stream flow of the Ledava River (2006–2010) at the Nuskova observation station, and for daily and monthly calibration of sediment load (t/day) in the Ledava River at the Pertoča observation station (June 2013–May 2014).

Stream flow (m^3/s)

Objective function	Calibration (2005–2010)			Validation (2011–2013)	Objective functions optimal range
	Year	Month	Day	Day	
E_{NS}	0.99	0.49	0.57	0.50	0–1
PBIAS	−5.29	−5.20	−5.30	14.08	± 25
R^2	0.70	0.62	0.57	0.53	> 0.5

Sediment load (t/day)

Objective function	Calibration (06/2013–05/2014)				
	Month		Day		
	All values	No outlier value*	All values	No outlier value	
E_{NS}	0.29	0.96	0.10	0.38	0–1
PBIAS	36.91	−4.39	48.10	20.01	± 50
R^2	0.36	0.60	0.20	0.32	> 0.5

* No outlier value – excluded only one value from February 17, 2014.

arable land with drainage systems, 30% of all soils with a high proportion of silt and clay (gley, pseudo-gley), and 53% of all land with > 50% slopes and 23% of land with 11–24% slopes. Among the sub-basins with gentle slopes, a relatively high average sediment transport of sub-basin 15 stands out (0.22 t/ha/year), with 69% of all fields with drainage systems, 91% of grassland with drainage systems, 64% of land on 0–11% slopes, and 85% of eutric brown soils.

Areas that go beyond natural processes for characteristic erosion are called critical source areas (CSA). "The most important CSA were those in which the annual loss of soil exceeded > 0.5 t/ha/year, thus defining the target soil erosion value that should be achieved with the implementation of ERM measures (Fig. 6). Although the generally valid limit value of sustainable geological soil erosion is set at 1 t/ha/year, we chose a lower limit value because this area is heavily susceptible to human activity and weather conditions (Komac and Zorn, 2009). It is recognised that average rate of natural soil formation from the parent material under agricultural conditions ranges from 0.5 to 1 t/ha/year (Pimentel and Burgess, 2013).

In the period between 2006 and 2013, the average annual simulated sediment load (base scenario) transported from the HRUs to the Ledava River, was 0.17 t/ha; while on certain northern and central HRUs it could reach up to 4.10 t/ha (Table 3, Fig. 6). In wet periods of high rainfall, in 2009 for example, the maximum simulated values from the particular HRU reached up to 18 t/ha/year. Average results are in line with the latest assessment of soil loss by water erosion in Europe (Panagos et al., 2015b).

Areas with average annual simulated sediment transport between 1.01 and 4.10 t/ha, comprise only 3.4% (355 ha) of the Ledava River basin but contribute 30% of sediment yield (Table 3, Fig. 6). The entire CSA area, with > 0.5 t/ha/year of transported sediment, is limited to 301 HRUs covering 12% (1.285 ha) of the basin and contributes 65% of the total sediment yield transported into the reach (Table 3). The largest sources of sediment are areas with slopes between 11 and 24% and > 50%. Arable fields dominate among the CSAs, with 98% of the CSA area representing 31% of total arable land in the river basin and 11.8% of the total basin area. Arable land with drainage systems represents only 3.2% of the basin area, but is also the largest source of sediment (0.598 t/ha/year), since drained arable fields, particularly in the Austrian part of the basin (sub-basins 1–6, 7), are placed on steeper slopes. In terms of other land uses, the annual sediment transport is 0.396 t/ha for normal fields, 0.396 t/ha for vineyards, 0.045 t/ha for meadows, and 0.004 t/ha for forests. Arable land comprises 35%,

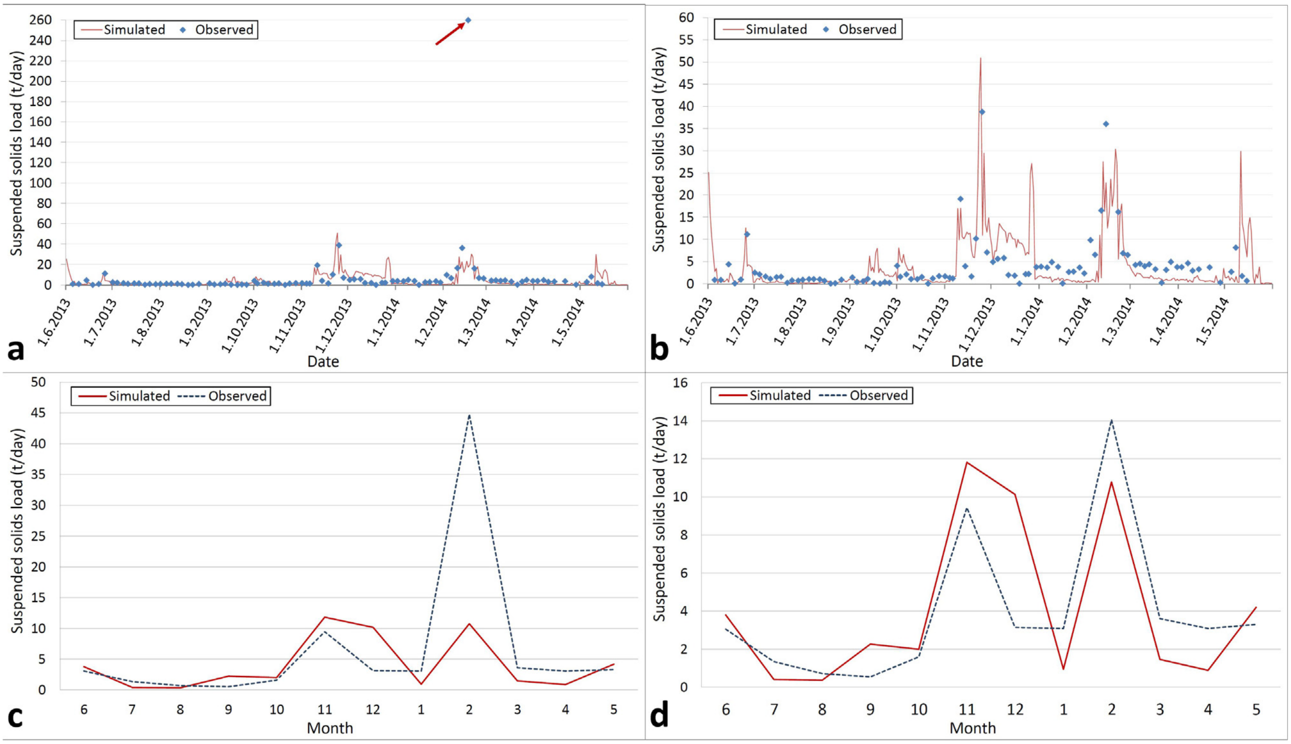
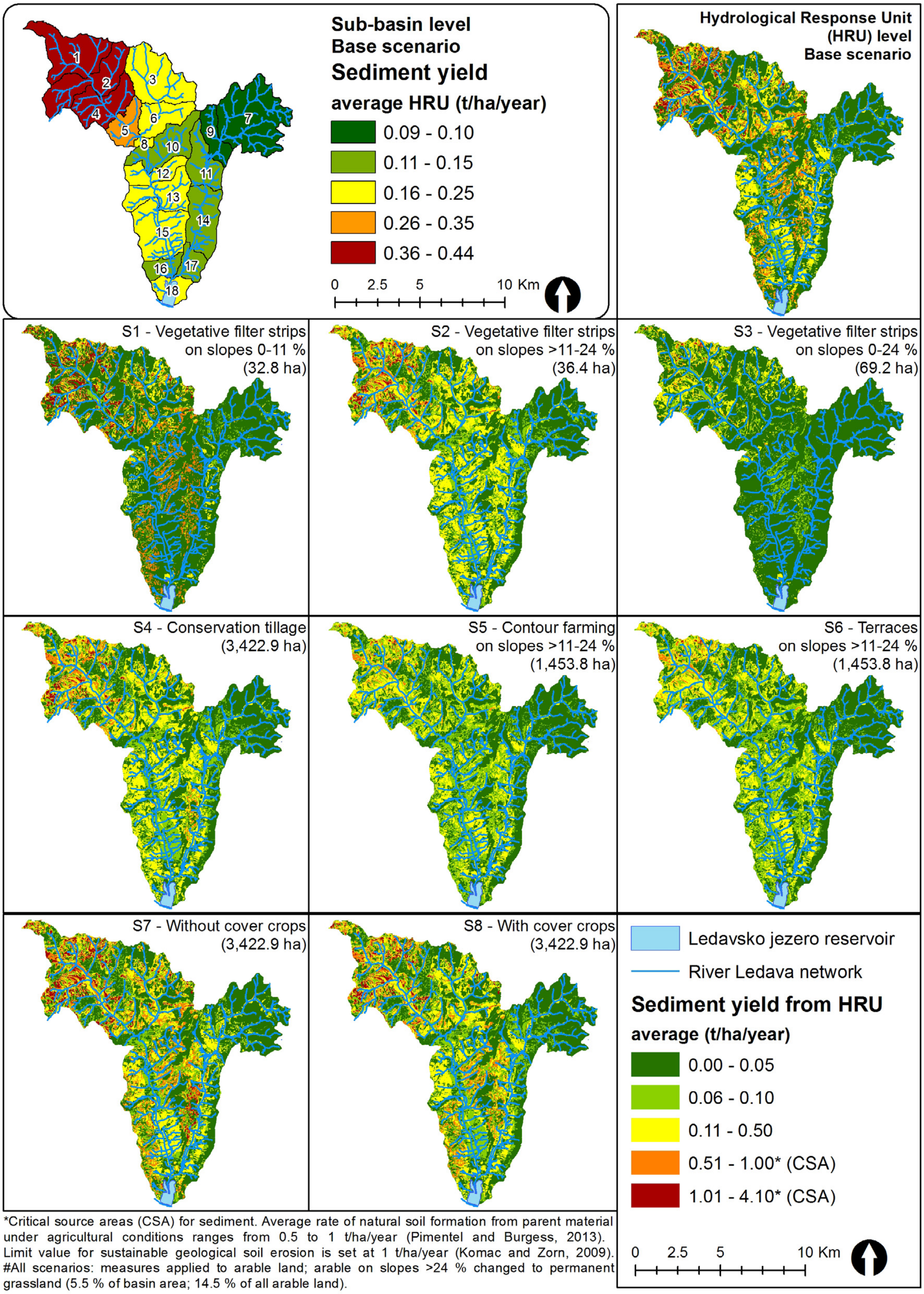


Fig. 5. Simulated vs. observed sediment load (t/day) and monthly level in Ledava River at the Pertoča sampling station with (a, c) and without (b, d) extreme outlier value from February 27, 2018 (red arrow).



Sub-basin level
Base scenario

Hydrological Response Unit (HRU) level
Base scenario

S1 - Vegetative filter strips on slopes 0-11 % (32.8 ha)

S2 - Vegetative filter strips on slopes >11-24 % (36.4 ha)

S3 - Vegetative filter strips on slopes 0-24 % (69.2 ha)

S4 - Conservation tillage (3,422.9 ha)

S5 - Contour farming on slopes >11-24 % (1,453.8 ha)

S6 - Terraces on slopes >11-24 % (1,453.8 ha)

S7 - Without cover crops (3,422.9 ha)

S8 - With cover crops (3,422.9 ha)

*Critical source areas (CSA) for sediment. Average rate of natural soil formation from parent material under agricultural conditions ranges from 0.5 to 1 t/ha/year (Pimentel and Burgess, 2013). Limit value for sustainable geological soil erosion is set at 1 t/ha/year (Komac and Zorn, 2009). #All scenarios: measures applied to arable land; arable on slopes >24 % changed to permanent grassland (5.5 % of basin area; 14.5 % of all arable land).

Fig. 6. Average annual sediment yields values (t/ha/year) on the level of (a) hydrological response units (HRU) and (b) sub-basins (SUBB) for base scenario.

grassland 12%, forests 39%, and vineyards 1% of the basin area. Among the most erodible soil types are gley and pseudo-gley soils with 0.39 t/ha/year (11% of the area), followed by gley and pseudo-gley brown soils with 0.22 t/ha/year (33% of the area), and district and eutric brown soils with 0.18 t/ha/year (56% of the area). The described types of soil, slopes, and land use form the fundamental database for the optimal determination of critical areas for the implementation of the ERM measures in the Ledava River basin. Based on the modelled results, selected measures were in the alternative scenarios designed only to reduce erosion that originated from arable land (sub-chapter 2.5).

Table 3
Classified average annual simulated values of sediment yield (t/ha) from average HRU to the Ledava River basin (2006–2013) for base scenario.

Yield class (t/ha)	HRU count	Area (ha)	Percent of total area (%)	Average sediment yield (t/ha)	Total sediment yield (t/year)
> 1.00–4.10*	97	355.06	3.37	1.72	582.87
> 0.50–1.00*	204	929.75	8.83	0.69	659.75
> 0.10–0.50	791	2371.19	22.53	0.23	572.88
> 0.05–0.10	410	780.81	7.42	0.07	60.35
> 0.00–0.05	1486	4888.94	46.45	0.01	44.48
0.00	208	1199.56	11.40	0.00	0.00
Total/average	3196	10,525.31	100	0.17	1920.34

* Critical source areas (CSA) for sediment. Average rate of natural soil formation from the parent material under agricultural conditions ranges from 0.5 to 1 t/ha/year (Pimentel and Burgess, 2013). Limit value of sustainable geological soil erosion is set at 1 t/ha/year (Komac and Zorn, 2009).

3.3. Impacts of measures on river flow

The impact of the scenarios on the mean annual flow in the Ledava River is minimal and ranges from 0 to 1.6% (Fig. 7). The reason lies in the model settings, since the modelling goal was not focused on water cycles and water pathways. Other studies (Bracmort et al., 2006, Cho et al., 2010) have confirmed that measures for reducing soil erosion have minimal effects on river flow. While scenarios S1–S7 increase the average annual stream flow, scenario S8 reduces the flow in the Ledava River. After reviewing the average monthly values, it is evident that scenarios S1–S6 reduce the flow in the river between May and September, which is influenced by increased evapotranspiration and the interception of precipitation with vegetation cover. Scenarios S8 (with cover crops) and S7 (without cover crops) show that cover crops increase water retention (S8) in the soil and plant biomass, and also in non-growing winter season. At the same time, cover crops improve soil structure, organic matter content, soil stability, and infiltration capacity (Norris, 2008; Panagos et al., 2015a).

3.4. Impacts of measures on sediment yield from HRUs

The sediment yield (t/ha/year) at the HRU level was most reduced by vegetative filter strips (S2, S3) and terraces (S6), followed by conservation tillage (S4), contour tillage (S5), and cover crops (S8) (Table 4, Fig. 6). A combination of vegetative filter strips (S3) on slopes up to 24% has proven to be much more effective than any other measure. This scenario reduced sediment yield by 56% and CSA area from 12.21% (301 HRUs) to only 1.28% (142 HRUs). A very similar impact on sediment yield reduction at HRU level was observed between scenarios S2 – Vegetative filter strips (by 43%) and S6 – Terraces (by 42%) placed on the same slopes (11–24%). "Tools like filter strips are a low-cost alternative to the construction of terraces. All scenarios were most effective in the sub-basins dominated by arable land and with slopes of

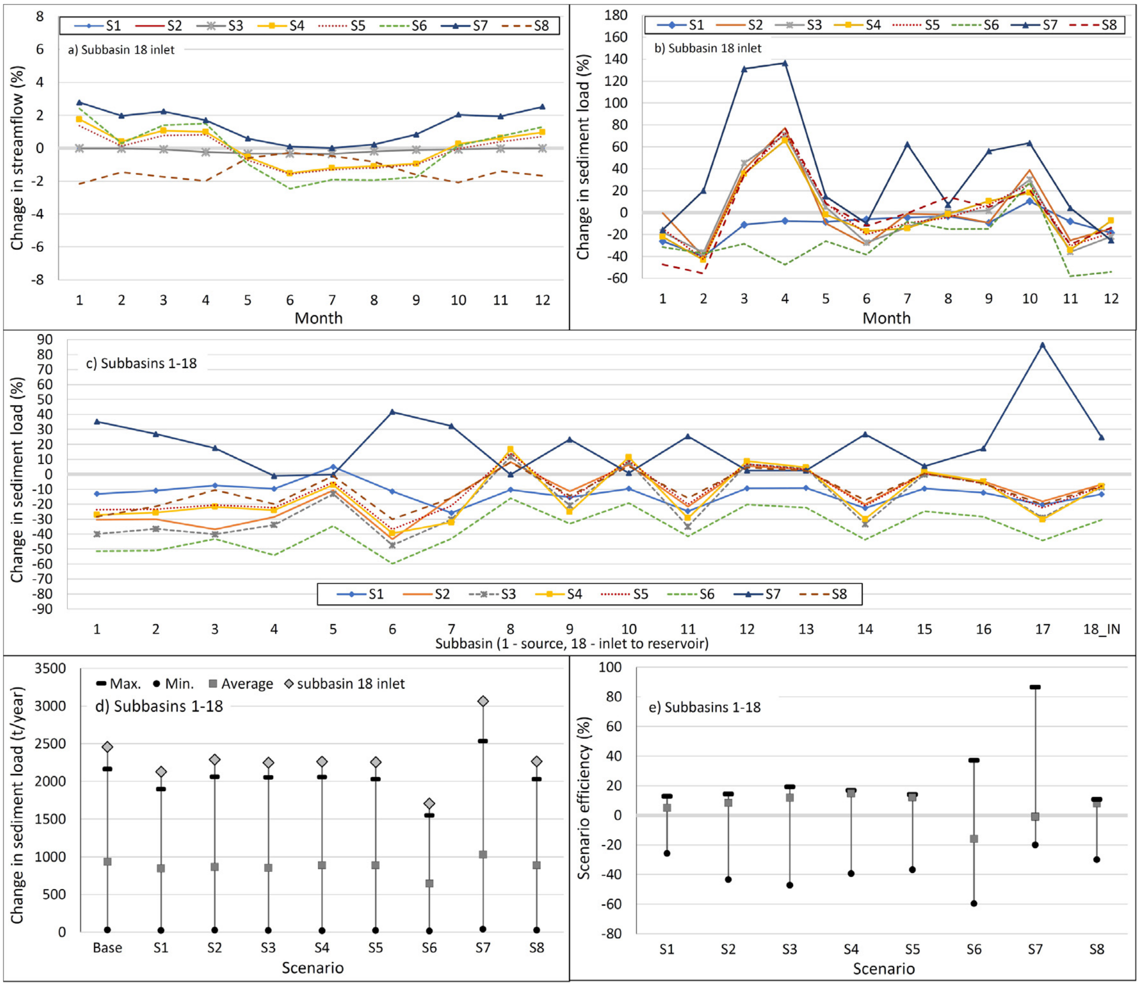


Fig. 7. The impact of scenarios on changes on (a) average monthly stream flow values and (b–e) on sediment load (%, t/year) in the Ledava River sub-basins and (d) separately for sub-basin 18 inlet (18_IN) between the base and ERM measures scenarios shown as a percentage (%) of the monthly averages. Positive values (+) mean increase and negative (−) reduction in sediments.

Table 4
The impact of the scenarios on the annual average annual sediment yield (t/ha) at the sub-basin level of the Ledava River basin expressed as a percentage (%) change to the baseline scenario (2006–2013).

Sub-basin	BASE (t/ha)	Scenario impact on average annual sediment yield at HRU level (change in %)							
		S1	S2	S3	S4	S5	S6	S7	S8
1	0.42	−8.64	−32.35	−40.90	−14.65	−14.07	−32.15	+8.59	−8.98
2	0.44	−12.84	−41.75	−54.59	−19.56	−18.09	−41.34	+11.15	−11.62
3	0.18	−9.25	−32.35	−41.60	−16.42	−15.09	−31.66	+8.23	−8.16
4	0.37	−9.86	−43.79	−53.65	−19.37	−18.72	−43.01	+10.49	−11.67
5	0.28	−15.24	−48.29	−63.52	−21.31	−20.44	−46.67	+12.58	−13.69
6	0.20	−16.40	−50.93	−67.34	−24.81	−22.77	−49.24	+14.11	−13.75
7	0.09	−10.55	−41.09	−51.64	−22.97	−19.26	−39.44	+22.26	−10.15
8	0.16	−14.92	−40.27	−55.18	−19.41	−16.75	−37.85	+18.13	−13.13
9	0.10	−28.65	−53.43	−82.09	−29.67	−23.74	−50.34	+19.47	−18.61
10	0.14	−17.14	−54.47	−71.61	−27.64	−24.57	−52.44	+17.07	−14.15
11	0.12	−23.37	−55.92	−79.30	−30.80	−25.33	−53.81	+21.20	−16.69
12	0.15	−21.60	−54.82	−76.42	−30.22	−24.92	−53.07	+19.11	−15.10
13	0.16	−20.16	−54.16	−74.32	−30.10	−24.51	−52.28	+16.83	−16.87
14	0.13	−20.11	−57.10	−77.21	−28.83	−25.78	−54.65	+24.15	−15.37
15	0.22	−20.06	−64.42	−84.48	−31.55	−28.62	−61.95	+13.09	−16.46
16	0.14	−21.42	−52.92	−74.34	−26.95	−24.64	−51.72	+9.42	−16.08
17	0.11	−25.49	−59.91	−85.40	−31.44	−27.98	−57.17	+12.89	−18.75
18	0.15	−20.80	−57.13	−77.93	−28.44	−26.55	−54.99	+11.18	−14.80
Average:	**0.28**	**−12.78**	**−43.36**	**−56.13**	**−20.33**	**−18.94**	**−42.41**	**+11.53**	**−11.91**
CSA HRUs (count)	301	282	161	142	221	225	160	335	258
CSA area (%)	12.21	11.00	2.49	1.28	6.22	6.18	2.47	14.24	9.92

[*] Positive values (+) mean increase and negative (−) reduction in sediment yield CSA – Critical source areas of sediment (soil erosion).

up to 24%.

In sub-basins 1, 2 and 4, where the erosion processes are most pronounced, the terraces (S6) on the 11–24% slopes decreased sediment transport to the river by 32%, 41%, and 43% respectively (Table 4, Fig. 6), and in the river by 51–54% (Table 5). Terraces have the greatest impact on the reduction of sediment yield in the sub-basin 15 (62%), where average annual sediment transport from HRUs to the river at 0.76 t/ha is still above the target value set for the CSAs. Although the scenario 6 average simulates sediment transport from sub-basins 1, 2, and 4 as being relatively small with 0.11–0.13 t/ha/year, it is mostly eroded from the 11–24% slopes with 0.40–0.49 t/ha/year of sediment yield, which is just below target value for the CSAs.

High impact of the vegetative filter strips scenario (S3) was also demonstrated by a reducing the sediment yield in sub-basins 1, 2, and 4 by 41–55% (Table 4), and the sediment load in the river at the outflow by 34–40% (Table 5).

Results also show the importance of cover crops (S7, S8) in current crop rotation. Modelling rotations without cover crops (S7) resulted in negative spatial impact and increased CSA by 2.03% (14.24%) of total river basin area (from 301 HRUs to 335 HRUs). Inclusion of cover crops as part of all rotations resulted in positive spatial impact and decreased CSA by 2.29% (9.92%) of total river basin area (from 301 HRUs to 258 HRUs).

3.5. Impacts of measures on sediment load in the river

The scenarios had less of an impact on the average annual sediment load (t/year) in the river compared to the effect on the sediment yield at the HRUs level. As is evident in Fig. 7, the efficiency of the scenarios fluctuates both spatially and temporally. In most scenarios, efficiency

Table 5
The impact of the scenarios on the annual average amount of sediment load (t/year) at the outlets from sub-basin and at the inflow into sub-basin 18, expressed as a percentage (%) change from the baseline scenario (2006–2013).

Sub-basin	BASE (t/year)	Scenario impact on average annual sediment load at outlet (change in %)							
		S1	S2	S3	S4	S5	S6	S7	S8
1	569	−13.06	−30.36	−39.92	−27.07	−23.69	−51.40	+35.18	−28.28
2	1,013	−10.88	−30.00	−36.45	−25.63	−23.32	−50.97	+26.86	−21.39
3	192	−7.51	−36.73	−40.13	−21.74	−20.64	−43.28	+17.48	−10.55
4	1,452	−9.68	−28.44	−33.82	−24.01	−22.29	−54.14	−1.10	−19.91
5	1,260	+5.00	−10.73	−13.09	−7.17	−5.30	−34.56	−0.19	−1.03
6	386	−11.43	−43.39	−47.39	−39.40	−36.79	−59.75	+41.70	−30.03
7	29	−25.77	−15.54	−30.29	−32.15	−21.09	−43.06	+32.27	−15.92
8	1,270	−10.30	+8.19	+11.79	+16.76	+13.90	−16.07	−0.13	+8.03
9	61	−15.39	−11.40	−20.75	−25.19	−16.47	−33.04	+23.26	−14.43
10	1,482	−9.60	+6.31	+8.13	+11.47	+8.91	−19.19	+0.83	+5.26
11	127	−24.66	−21.52	−34.91	−29.34	−19.99	−41.40	+25.39	−15.86
12	1,629	−9.40	+5.46	+6.69	+8.79	+6.77	−20.26	+2.53	+4.49
13	1,771	−9.14	+3.35	+3.93	+4.62	+3.26	−22.28	+2.55	+2.45
14	222	−22.58	−20.04	−33.23	−29.94	−21.06	−43.80	+26.77	−17.37
15	1,969	−9.53	+0.71	−0.00	+1.87	+0.53	−24.72	+5.41	+0.49
16	2,161	−12.36	−4.70	−5.03	−4.87	−6.13	−28.41	+17.14	−6.09
17	270	−20.33	−18.10	−29.06	−30.25	−22.48	−44.17	+86.39	−20.23
18 - Inlet to reservoir	2597	−13.30	−6.79	−8.47	−7.93	−8.17	−30.47	+24.68	−7.73

[*] Positive values (+) mean increase and negative (−) reduction in sediment load.

increases between May and September. Most of the scenarios show higher sediment loads in late winter and spring time which coincident with major soil tillage actions.

The most significant effects on the sediment load reduction were achieved by measures that required a major financial investment for construction (S6 – Terraces) or space for placement (S1–S3 – Vegetative filter strips) (Table 5, Fig. 7). The most efficient in reducing sediments was scenario S6, followed by S1 and S3. Although the cover crops (S8) do not achieve as high of an overall efficiency as S3 or S6, it is evident that without them (S7), the sediment load at the inflow into the reservoir increases by > 25% (Table 5, Fig. 7).

The sediment is characterised by the fact that particles float in the water stream for a long time (Rusjan and Mikoš, 2006) and only settle when the stream settles down. Simulation indicates that vegetative filter strips (S1–S3) are supposed to be most effective on slopes up to 11%, as the inclination increases volume and surface flow velocity (Leeds et al., 2013). We demonstrated that, by placing strips on the CSAs, we can achieve major changes. The same was also confirmed by other studies (Bosch, 2008; Lam et al., 2011; Kaini et al., 2012; Strauch et al., 2013).

3.6. The TSI tool evaluation

Because of its simple schematic structure, the TSI tool is transferable to all surface water bodies. In the future, it could be supported by software tools for multi-parameter decision-making, especially when there are is pressure or management requirements in the basin area. When optimising the tool, it is necessary to take the simultaneous occurrence of several different load sources, different types of critical areas, and different combinations of measures into account. In doing so, the use of space (land) should be minimised, costs should remain low, and effectiveness of the measures high. This can be achieved in combination with different river basin models and by using genetic algorithms (GA) (Arabi et al., 2006; Maringanti et al., 2009). For this purpose, the multi-criteria decision analysis (MCDA) models are used (Ahmadi et al., 2014).

However, in order to use such sophisticated algorithms, water managers must possess advanced computer knowledge and additional training for setting parameters such as: (1) criteria for all the steps in the tool (e.g. limit values for water quality parameters); (2) an acceptable range of costs for implementing measures; (3) the ability to refine the set of measures according to the type of pressure (sediment, nitrogen, phosphorus, plant-protection products, heavy metals, pathogens, etc.); and (4) the ability to determine the location of measure implementation (urban, agricultural, and forest). The set of parameters would be represented in a database with ranges of the measures' effectiveness and the cost of establishing a measure according to the selected spatial unit (ha or HRU). However, for the complete functioning of such a system, a very detailed database would be required (Panagopoulos et al., 2012). This could be followed by the transformation of the schematic TSI tool into a software tool that would be more useful and supportive to key stakeholders.

3.7. Uncertainties and proposed improvements with regard to the process

For a detailed description of the problem, long-term continuous (dense time interval) measurements of water quality are required. This would enable one to capture various weather conditions and year-round human activities. Current national monitoring at monthly intervals with a limited number of sampling points is insufficient for serious analysis. Well-planned monitoring could support investigation on how much of the sediment in water bodies actually originates from CSA and the amount of soil particles that is temporarily or permanently deposited along the way to the reach due to the morphology of the surface. SWAT is not yet capable of spatial interconnection with different HRUs, which would enable a calculation of the path of eroded soil particles from the top of the slope to the bottom of the valley, as this process is a demanding operation. The SWAT's daughter model, SWIM, proved to be a good example for the simulation of these processes (Krysanova and White, 2015).

CSAs can be determined according to the various types of pressure (sediment, phosphorus, nitrogen, etc.) whose transport factors may be different but not exclusive. While CSAs for phosphorus and sediment often overlap, CSAs for nitrogen control can be defined elsewhere (Niraula et al., 2013). This can lead to the CSAs total area increase and spatial location diversification. The precision of defining the CSAs depends on the model used and the accuracy and extent of the data.

Before final measures are selected, a set of proven effective measures from literature must be carried out, which depend on the problem identified and reservoir intended for use. When analysing the effectiveness of the measures, we must pay attention to various factors: the geographical location, size and characteristics of the area under consideration, the accompanying hydrological factors, the model type, parameters used in the simulation, the quality of the input data, and whether the effectiveness of the measures was checked by observations in the test fields, or by using models for large scale basin areas. 'The efficiency of the measure is expected to be better at the test-field level, as the number of transmission pathways and the factors influencing erosion processes increase as the basin size increases. (Verstraeten et al., 2006). Therefore, the results of research are not interpreted as being directly applicable to the area in question, but rather they serve as a reference in the selection of measures and further planning.

When selecting the measures, a focused objective is essential, e.g. reducing pressure for achieving a good ecological state of the water body. Selection also depends on the basin properties and type of pressure, which is identified through the CSA analysis. With solid knowledge of the processes in the basin, it is possible to eliminate the essential pressure factors. Selection of the measures to avert the cause, or measures to mitigate the consequences, is unique to each river basin (Rickson, 2014; Wetzel and Academic, 2015).

Scenarios of reducing riverbank erosion or repositioning of the sediment in the reach were not simulated, although it is estimated that riverbank erosion contributes 35% of the total sediment (Narasimhan et al., 2010). The impact of the riverbank consolidation in the SWAT is simulated by the parameters of the river channel's roughness (Manning's coefficient and the overgrowth of the riverbanks). Considering this, a greater number of measurements along the river's watercourse would be required (Waidler et al., 2011; Bouraoui and Grizzetti, 2014).

3.8. Assessment of the effectiveness of the measures

The main aim of the selected measures, in the case of Ledavsko jezero reservoir, was to reduce the inflow of sediment from the basin areas to the reservoir and to prolong the half-life of the reservoir. From the set of measures, we selected those that did not limit the yield or require major adjustments in the existing farming management. In addition, we focused selection on ERM measures that are adapted to existing elements in the landscape, and contribute to biodiversity and long-term effectiveness. Although it has been established that agri-environmental policy measures are unacceptable from a socio-economic point of view, in order to achieve the objectives of the Water Framework Directive (Volk et al., 2009), they were reasonably used to preserve soil fertility and production.

Comparing SWAT modelling results from literature and the effectiveness of the scenarios in this study show similar efficiencies (Table 6). A comparison of the observed results in the test fields shows better efficiency than the modelled results. In any case, a complete direct comparison cannot be made due to differences in the properties and the extent of the areas under consideration.

Although the implementation of terraces and vegetative filter strips is one of the more expensive measures, their impact is much greater than the other measures. In the future, detailed analysis of the costs and

Table 6
A comparison of the measures in reduction of sediment yield between the results of literature review in chapter 2.6 and the results of the Ledava River basin SWAT model simulation (inflow to reservoir).

Eco-remediation measure (ERM)	Efficiency of measures (%) Reduction of sediment transport		
	Literature		This study
	Observations	SWAT simulations	SWAT simulations
Vegetative filter strips (S1–S3)	65.4	39.2	12.78–56.13
Conservation tillage (S4)	69.6	8.9	20.33
Contour farming (S5)	77.4	45.0	18.94
Terraces (S6)	57.5	29.8	42.41
With cover crops (S8)	59.8	15.5	11.91

benefits of the individual measures or their combinations should be carried out, while ensuring that the reduction of costs does not exceed its effectiveness. When taking into account the benefits of effective measures, the following should be considered: (i) reducing soil erosion and preserving soil fertility with sustainable land management; (ii) meeting and preserving good ecological status of the water bodies; and (iii) maintaining reservoir water storage capacity.

The extent to which the proposed measures will influence the reduction of sediment transport will depend on the designed plan and its implementation carried out in the second phase of the TSI tool. Thus, with the monitoring of the inflow into the reservoir, it becomes certain that its half-life time be prolonged. It should be considered that certain ERM measures (e.g. vegetative filter strips) need time to reach their full potential. Climate changes can also impact the effectiveness of the measures by influencing transport processes, which, in the future, will require an adaptation strategy to cope with extreme weather events.

Even if excessive erosion is reduced to a natural rate typical for a particular area, a certain amount of soil particles will be eroded, transported, and deposited as sediment on the way to water bodies. For long-term assurance of water quality and volume of the reservoir, technologies should be used to capture and divert transported sediment to the side or through the reservoir, or to remove sediment from the reservoir (Kondolf et al., 2014). The sedimentation can be mitigated by changing the reservoir operational regime during and after a period of high flows.

4. Conclusions

The complexity of the processes between the basin area and the water body requires a systematic but simple approach, such as the proposed TSI tool. A clear structure of the tool enables a programme of measures to be designed as suggested by the Water Framework Directive for any type of water body.

The TSI tool enables proper planning, implementation, and positioning of ERM measures for the protection and restoration of reservoirs in the river basin where they are most needed and effective. Based on continuous measurements of water quality, we can define the problematic pressure in detail and improve the understanding of processes in the river basin. By defining properties of the CSAs, criteria were set for the selection of measures, which would have the greatest impact. These can reduce the size of the area needed for the positioning of the measures and, consequently, the costs of planning and implementing them. The integration of numerical models in the tool enables a comprehensive analysis of the river basin, determination of the CSAs and assessment of the measures' effectiveness. In this study, the Soil and Water Assessment Tool (SWAT) model proved to be very effective and useful.

The study confirmed that direct transmission of the ERM measures, effectiveness in other basins is not possible due to the differences in natural geographical characteristics, the size of the basin areas, and the accompanying hydrological and metrological factors of the research areas. By limiting the erosion processes at field scale, the sediment loads in the Ledava River and in the reservoir are reduced. By doing so, we can preserve the fertile soil, which is an important factor in the assessment of the measures.

The average effectiveness of the measures at the HRU level was much greater than at the sub-basin level or at the inflow into the reservoir. This is due to a number of factors that influence the transport processes of the pressure substances in the basin. This study shows that combining several measures increases the overall effectiveness and that such measures are necessary, since the absence of cover crops in the rotation increases the sediment load in the Ledava River.

In the future, software solutions for multi-parameter decision-making should support the TSI tool, especially when the basin area or water body has several problems or management requirements. This would enable the TSI tool to be widely used and to reach key decision-making stakeholders. The TSI tool could be applied inside the framework of the Triple Bottom Line (TBL) approach where environmental, social, and economic interests are investigated and, when aligned, some of the greatest returns are achieved for business, society, and nature. Quantification and valuation of social or economic benefits improves performance and adds additional meaning to the results. In the future, more will have to be done by monitoring the actual effects of scenarios implemented in the field and even in laboratories.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoleng.2019.01.022.

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