ACTION PLAN FOR **THE PILOT CATCHMENT AIST** (D.T3.5.9)

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CONTENT

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1. Introduction to the Action Plan - Purpose and summary of the document

In the frame of the FramWat project on Natural Small Water Retention Measures (NSWRM) six pilot catchments in Central Europe were chosen to test the NSWRM approach and the FramWat project tools. The final pilot study reports that are presenting the main outcomes for the pilot catchments are called “Action Plans”.

The existing Action Plan for the Austrian pilot catchment Aist provides a compilation of the catchment modeling results and presents the effectiveness of a selected set of NSWRM in the Aist catchment. The overall aim of the Action Plan is to support a sustainable sediment management in the Aist catchment.

Rivers in the Aist catchment (and also neighboring catchments in the Mühlviertel region) suffer from sediment accumulation in the river bed. This in-stream sediment accumulation in the size of coarse sand to fine gravel (diameter 1-10 mm) can negatively affect the morphological, physicochemical, and biological status of water bodies (Wohl et al., 2005).

NSWRM have the potential to improve the sediment balance of a catchment. Recently introduced in European policy, NSWRM include a broad set of in-stream, off-stream, structural, and management practices with the aim to mitigate negative impacts of human activities on freshwater ecosystems (Collentine and Futter, 2018; Knott et al., 2019). Similarly to agricultural and forestry best management practices, alteration of hydrological, nutrient and sediment cycles can be targeted (Liu et al., 2017). However, the purpose of NSWRM is to exploit natural processes and cycles to restore and rehabilitate degraded aquatic ecosystems (Keesstra et al., 2018; Nesshöver et al., 2017).

Dynamic hydrological, hydraulic, and sediment models can effectively support the planning of NSWRM at different scales (catchment scale, reach scale, habitat scale). In the frame of the FRAMWAT project, the assessment of the effectiveness of NSWRM was – for the first time – performed with an interlinked modeling cascade to bridge the different scales. The models of this ecohydrological modeling cascade were used to assess the effectiveness of a set of NSWRM that are of special interest for nature protection and water management authorities. The effectiveness in mitigating the sand accumulation issue was evaluated both at the catchment scale and for some selected (diagnostics) reaches, where improvements in the ecological status are desired. The presented outcomes can serve as guidance and support nature protection and water management authorities in decision-making in the future.

The Action Plan is not meant to be used as a direct planning tool for an implementation of the selected set of NSWRM in the Aist catchment. It points out modeling possibilites and gives insights into NSWRM effectiveness assessment with the help of models. The selected set of NSWRM represents one possibility of how to combine NSWRM in the catchment in order to improve the main catchment problem of sand accumulation. As highlighted by the modeling results, the effectiveness of NSWRM strongly depends on local conditions. Therefore, NSWRM always need detailed planning and analyses at the local scale before implementation.

The Action Plan is supposed to generally support the goal of an enhanced NSWRM planning and to facilitate the implementation of NSWRM in catchment management. At the moment, NWRM implementation is often hampered by a lack of specific and targeted funding schemes and legislation documents. But NSWRM have mulitple benefits and can help to achieve the legal obligations of different policy objectives. Several EU and national funding programs can be used to finance NSWRM. Therefore, the Action Plan also sums up opportunities and limitations given by European and national legislation for NSWRM implementation and gives an overview on existing funding possibilites.

Finally, the existing Action Plan gives examples of how NSWRM can be monitored. Monitoring of NSWRM can give valuable information on the measures effectiveness and can support future planning with analysis and interpretation of field data collected for specific local situations. Field data are essential to support and to validate model results and assumptions. In the Aist catchment and in the neighbouring Maltsch catchment, some NSWRM have been built recently. Monitoring investigations have been carried out and the results can support further NSWRM planning.

Given the topics highlighted above, the goals of this document are to:

1. **Present the FRAMWAT pilot catchment Aist - the catchment characteristics and the main environmental problems (Chapter 2);**
2. **Present the potential of NSWRM to address the problem of sediment accumulation by showing the results of an effectiveness assessment of a set of selected NSWRM with the use of a cascade of dynamic models (Chapter 3);**
3. **Present an overview on policies and funding schemes to support NSWRM implementation (Chapter 4);**
4. **Present an example of a monitoring program suitable to assess the effectiveness of single NSWRM in the Aist catchment and in the neighboring Maltsch catchment that is sharing the same problem of siltation (Chapter 5).**

2. Introduction to the Pilot Catchment

The Aist Basin was chosen as a pilot catchment in Austria because the existing topographical characteristics as well as the prevailing problems, pressures and water management measures make it an appropriate case study region for a NSWRM approach. It is a representative catchment for the Austrian part of the ecoregion Central Uplands (low mountain ranges with plateaus and gorges), a region that geologically belongs to the Bohemian Massif (Variscan orogeny, 370-290 million years) with the prevailing bedrocks granite and gneiss.

Within this region all river catchments share one common problem: coarse sand to fine gravel accumulations in the river bed (modal diameter 1 - 10 mm) from granite weathering and erosion, causing ecological problems in rivers (habitat degradation) as well as problems for water and flood management (riverbed rising). Further issues in the Aist catchment are: (a) hydromorphological deficits due to river regulations and flood protection measures, and (b) poor ecological status in several river stretches (assessment for WFD, Austrian Water Management Plan). NSWRM can help mitigate the existing problems in the catchment and at the same time improve conditions related to the aspects of water quality, sediment balance, nutrient cycling and habitat diversity.

2.1 Description of the catchment

The Aist catchment (650 km^2) is located in the northeastern part of the state of Upper Austria (Fig. 1A, 1B), with an elevation ranging between 240 and 1100 meters and a mean slope of 18 % (DORIS, 2017). The bedrock is granite and gneiss (GBA, 2019) and Haplic Cambisols (SoilGrids, 2019) are the prevalent soil type. The land use is dominated by forests (47%) and agriculture (49%), with limited area occupied by settlements (4 %; Büttner, 2014). The climate is temperate, with an average yearly temperature of 7.1 ºC and an average yearly precipitation of 835 mm (HDLO, 2017). The Aist River flows north to south and forms after the confluence of two main tributaries, the Feldaist and the Waldaist (Fig 1C). The Feldaist drains an agriculture/pasture dominated landscape and the Waldaist drains a pasture/forest dominated landscape. The average multiannual flow at the confluence of the Aist with the Danube is 6.4 $m^3\ s^{-1}$ (HDLO, 2017). Rivers in the Aist catchment are classified as “plane bed” with cobbles and sands as dominating substrates (Leitner et al., 2015; Montgomery and Buffington, 1997), while steep sections are classified as “cascade type” with a boulder substrate (Hauer, 2015).

The Aist catchment hosted population of the highly endangered Freshwater Pearl Mussel (Margaritifera margaritifera) with more than 20,000 specimens occupying 30 km of river length in the early 1990s (Ofenböck et al., 2001). Less than 3,000 individuals are left in the eastern tributary, the Waldaist. Nevertheless, the remnant population is still relevant for regional genetic diversity (Geist, 2010). The Waldaist River is part of the Natura 2000 site “Waldaist and Naarn” (AT3120000).

Activities to reduce the sand accumulation in the catchment are already included in various strategic national planning documents, based on the Water Framework Directive, e.g. action plans within the National Water Management Plan (NGP, 1st 2009, 2nd 2015) and the National Flood Risk Management Plan (HRMP 2015).

In the Waldaist area forestry and extensive pastures are dominating, the Feldaist area is characterized by intensive agricultural practices. Summarizing there is a north to south and an east to west gradient regarding land use intensity and population density.

Table 1 – Characteristics of the Aist catchment. * From multiannual statistic 1984-2016; ** From multiannual statistic 1981-2010; *** From CORINE LandCover 2012

Characteristic	Unit	Value
Character of catchment		Central Uplands
Catchment size:	km^2	647
Average flow low/avg/high*	m^3/s	5.1/6.4/7.8
Extreme flow low/high*	m^3/s	0.44/336.6
Annual precipitation low/avg/high**	mm	726/835/993
Annual air temperature min/avg/max**	°C	5.4/7.1/9.5
Agriculture area***	%	48.9
Urban area***	%	3.9
Forest area***	%	46.8
Open Water area***	%	0.01
Flooded area (1/100 years)	km^2	1.9
Artificial drainage area	km^2	0

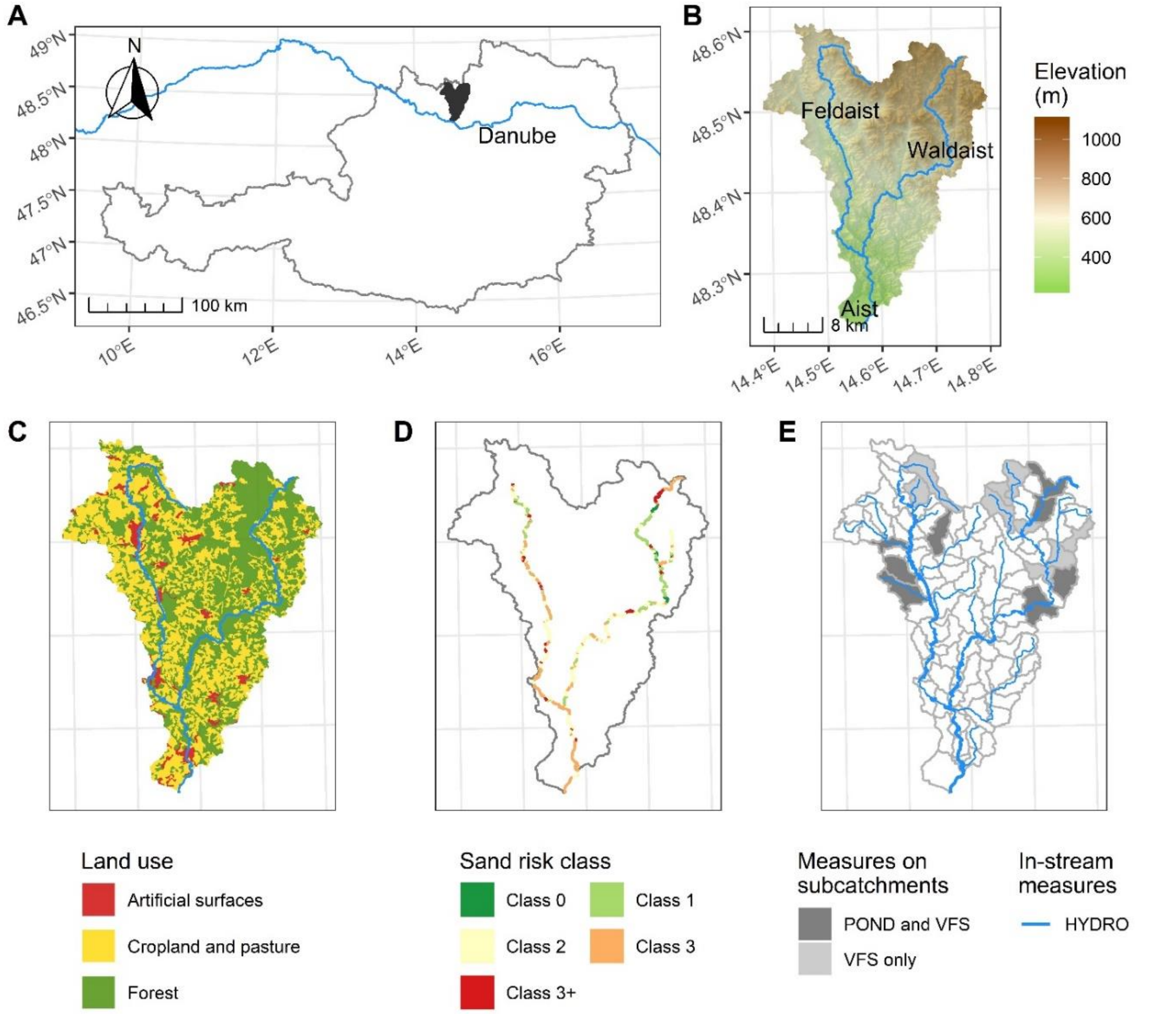

Figure 1: Aist catchment overview and implemented measures. A) position of the Aist catchment in Austria; B) Terrain elevation and position of the main channels in the Aist catchment; C) Land use; D) Mapped sand accumulation risk in the main channels: class 0 = No alteration of the natural substrate; class 1 = Little disturbance due to sand accumulation; class 2 = Some habitat changes but main morphological features are kept; class 3 = Mesohabitat is fully covered by sand accumulations; class 3+ = Mesohabitat is fully covered by sand accumulations, that are mobile during low flow conditions; E) Geographic position of implemented measures: sediment ponds (POND), vegetated filter strips (VFS), and hydromorphological improvements (HYDRO). Polygons represent SWAT subcatchments and the river network represents the Hec-RAS modeled reaches.

2.2 Land use, infrastructure and protected areas

Land use (see figure 1C) within the Aist catchment is dominated by agriculture (48,9%) and forestry (46,8%), urban areas are very limited (3,9%).

Regarding agricultural practices the catchment can be divided into three main areas - the southernmost part belonging to the Danube valley, the central midlands, and the northern highlands - following a gradient from intensive to extensive agriculture: In the southern part the amount of arable land is very high (77%, mainly winter wheat, barley and corn), whereas pastureland is limited (23 %). In the central midlands this ration gets more balanced, and it turns for the northern highlands where pastureland predominates (70%, arable land: 30%, mainly winter titricale).

Regarding forestry a differentiaion must be made between planted forests (mainly spruce monocultures) and natural forest (mixed conifer and broadleaf forest) as these thwo types have very different effects on the water and sediment balance in the catchment. A GIS estimation shows that that planted forests (mostly spruce monoculture) occupy 80% of the forested area, with the remaining 20% left to semi-natural, broad-leaves forest.

The biggest towns in the catchment are Freistadt in the northern part (ca. 8.000 inhabitants), Pregarten in the central part (ca. 5.500 inhabitants), and Schwertberg in the sourthern part (ca. 5.000 inhabitants). The population in total amounts to 56.000 inhabitants in the catchment, the population density varies between 31 (in the less populated north-eastern highlands) and 89 inhabitants (in the denser populated southern part) per km².

The most relevant protected area within the Aist catchment is the **Natura 2000 site "Waldaist, Naarn"** (protected area of the European network of nature protection areas based on the Habitats Directive, see figure 2). This FFH area is dominated by the valleys of the rivers Waldaist and Naarn, which are largely preserved in a natural condition, but locally also affected by small power plant constructions. In addition to man-initiated spruce cultures there are also numerous natural mixed forest types e.g. alluvial forests with alder and ash in the valley floors. In the widening sections, small-scale cultivated landscapes with extensive meadows have been preserved.

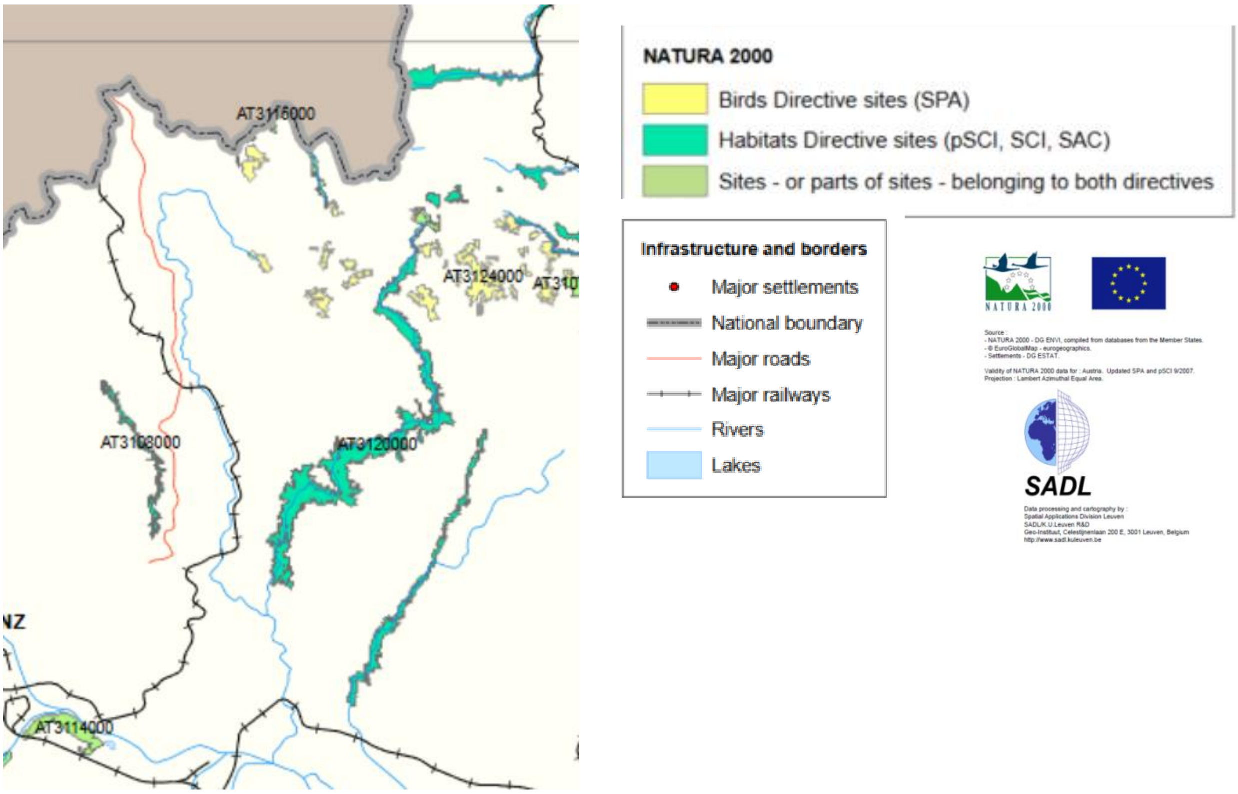

Figure 2:Natura 2000 sites in the pilot catchment: "Waldaist, Naarn", site ID: AT3120000; area: 3838,14 ha and „Meadows in the forest" (Wiesen im Freiwald) site ID: AT3124000, area: 2410 ha

2.3 Catchment problems

Due to the catchment geographical, climatic, morphological and anthropogenic characteristics, the Aist catchment shows the following main problems:

- Area with peculiar geological background – high erosion rates of granite/gneiss and their weathering products;
- Accumulation of fine sediments (granite weathering products) in river beds in the form of coarse sand to fine gravel accumulations;
- Hydromorphological conditions of most of the river sections are "moderate" (according to WFD assessment status 2015, fig.3);
- Conditions of riverbed habitats are deteriorated due to fine sediment accumulation - degradation and disappearance of suitable habitat, target species: freshwater pearl mussel (WFD status 2015, fig. 4);
- There are no recent problems with the chemical status (very good according to WFD status 2015).

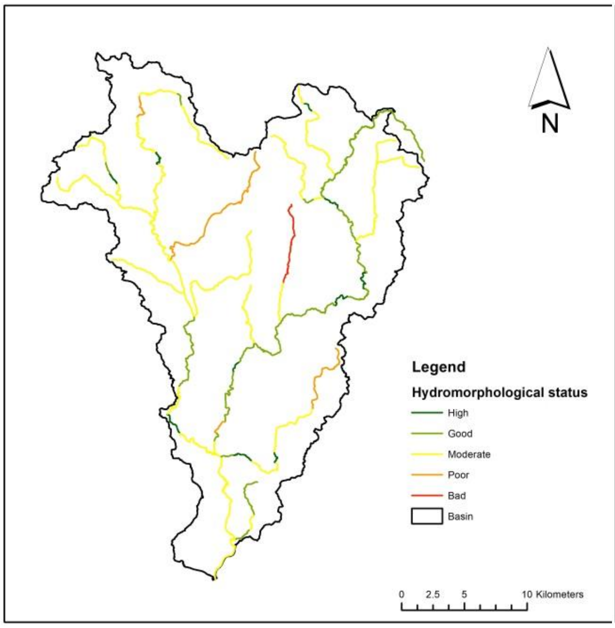

Figure 3 - Hydromorphological status for the Aist catchment (WFD assessment 2015)

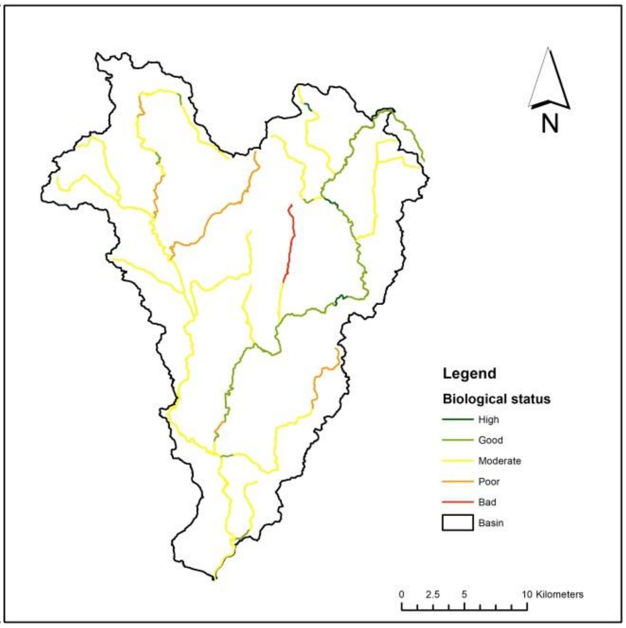

Figure 4 - Biological status for the Aist catchment

During several field trips (with and without regional stakeholder involvement) the catchment was specifically visited and investigated. Sand accumulation is quite strong in the Waldaist sub-catchment despite generally being the 'more natural/forested' part of the Aist catchment. High erosion rates at banks of forest roads and banks of small brooks could be identified. The manifold reasons include the existing forestry practices, such as the prevalence of planted spruce monocultures and a high density of forest roads. The consequence is high accumulation rates of fine sediments in rivers, especially in reaches with low slope.

The siltation risk has been assessed by Hauer et al., 2015, and is reported in Fig. 1D. The extent of siltation at the mesohabitat scale was mapped in 2013 – 2014 with field surveys and is expressed in siltation classes ranging from class 0 (no fine sediment accumulation) to class 3+ (the fine sediment accumulations are completally clogging the mesohabitat). As expected, Feldaist and Aist have higher abundance of silted sites because of the higher extent of anthropogenic activities. However, also in the Waldaist the siltation risk is present, even in the headwaters in the northern part, where the anthropogenic disturbance is supposed to be small.

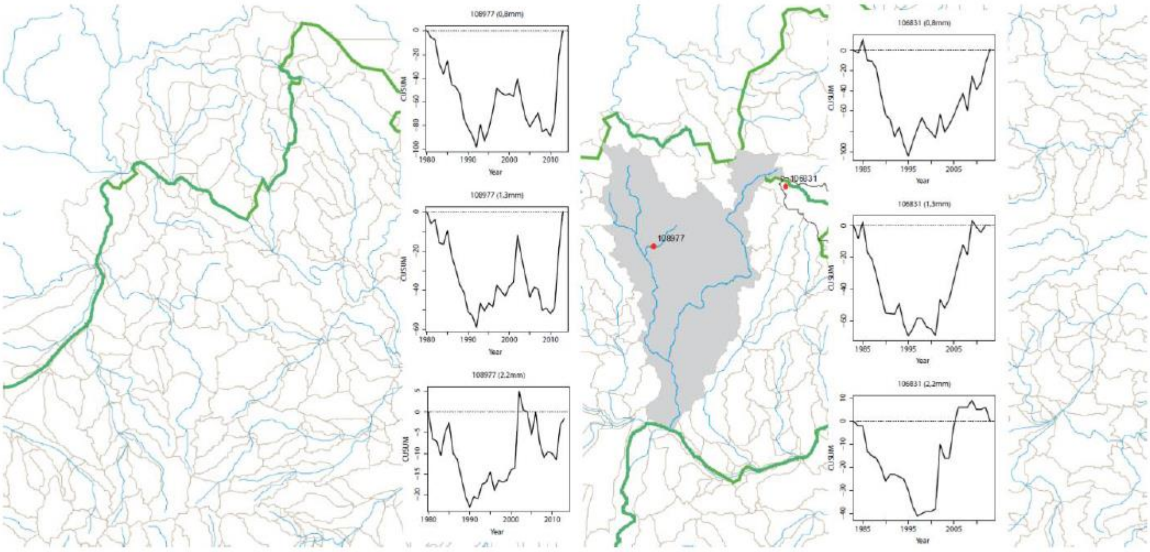

Figure 5 - Changes in the precipitation patterns in the region

Previous projects running in the area have identified also climate change as one of the drivers of the fine sediment accumulation (Fig. 5; Hauer et al., 2015). In fact, changes in precipitation patterns (i.e. heavy rainfall events) have supposedly modified the energy that rainfall can develop to detach and mobilize fine sediments.

3. Selection of NSWRM for the catchment

The strategy for testing the effects of Natural Small Water Retention Measures in the Aist catchment follows three main steps:

1. Implement, calibrate, and validate a sequence of interlinked models describing hydrology, hydraulics, and sand accumulations.
2. Implement NSWRM in the hydrological model.
3. Propagate the effects on the hydraulics and sand accumulation models.

Detailed information on step 1 is described in:

- the dynamic modeling report for the Aist catchment (Deliverable D2.4);
- the peer-reviewed paper Baldan et al., 2020;
- the attached technical background document.

In the following sub-chapters, the main results are presented for steps 2 and 3. Further detailed information can be found in the attached technical background document.

3.1 Models implemented in the Aist Catchment

An eco-hydrological modeling cascade (EMC, Fig. 6) was established for the Aist catchment. The EMC is composed of a sequence of models structured in a way that the outputs from the coarser spatial scale can be used as inputs to finer scale models (Kiesel et al., 2013). A complete description of the EMC and the models implemented can be found in Baldan et al. (2020). Briefly, models used were:

(i) the eco-hydrological Soil and Water Assessment Tool 2012 (SWAT) for discharge and sediment generation and transport at the catchment scale (Arnold et al., 2012);

(ii) (the hydrodynamic numerical 1D-model hydraulic Engineering Centre – River Analysis System (HEC-RAS) for reach scale hydraulics (Brunner, 2002);

(iii) Random Forests ensemble (RFs, R package 'caret') for sand and fine gravel accumulation at the reach scale (Kuhn, 2008);

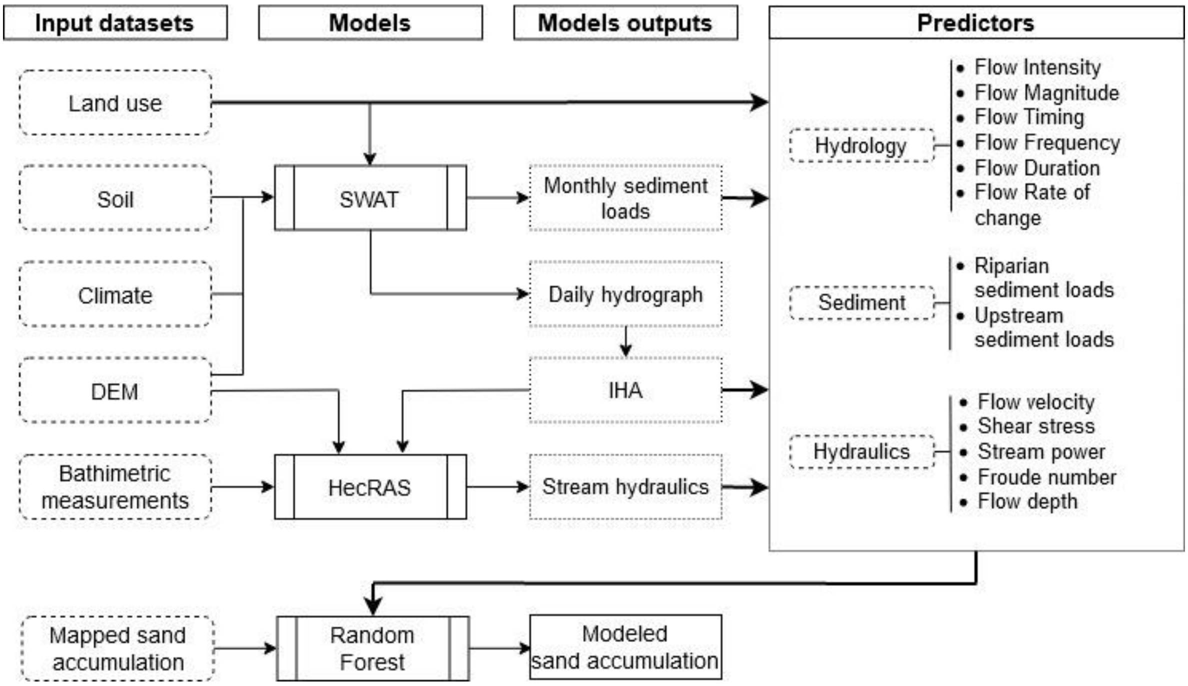

Figure 6 - Ecohydrological modeling cascade for the Aist catchment (Baldan et al., 2020)

3.2 Strategy for implementing measures in the model SWAT

Three different types of measures have been identified to be relevant in the Aist catchment, and have therefore been tested with the dynamic models (the code refers to the official EU Catalogue of NSWRM, www.NSWRM.eu):

- **<u>BPRC</u> - Natural channels and best practices of river channels maintenance/ improvements,** e.g. riverbed material re-naturalization, stream bed re-naturalization, natural bank stabilization. Those measures will be referred in this report as Hydromorphological improvements (abbreviation: HYDRO). Hydromorphological improvements (HYDRO scenario) are structural modifications of the river morphology aiming at increasing habitat heterogeneity (Bisson et al., 1992; Haase et al., 2013; Jähnig et al., 2010)
- **<u>BPDA</u> - Best practices on drained areas: small sediment retention ponds** (located in-stream and off-stream). Those measures will be referred in this report as Sediment/water ponds. Two different typologies were implemented: ponds with the primary aim to trap sediments (abbreviation: P50), and ponds with the primary aim to store excess runoff water (abbreviation: P300). Sediment ponds are implemented in agricultural and forested area to store excess runoff water and increase sedimentation (Mekonnen et al., 2015; Verstraeten and Poesen, 2001)
- **<u>A02</u> - buffer strips and hedges**: mainly between (or across) fields, also along water courses, or **<u>F01</u> – Forest riparian buffers**: tree covered areas alongside streams. Those measures will be referred in this report as Vegetated Filter Strips (abbreviation: VFS). Vegetated filter strips are buffers of dense vegetation located at the edge of agricultural fields with the purpose of trapping sediments (Magette et al., 1989).

NSWRM were implemented in SWAT by modifying parameters in the input files and scenarios were developed by running SWAT for 2002 - 2013.

3.3 Measures siting

For each measure type, two implementation variants were computed:

- a catchment-scale, uniform distribution of the selected set of NSWRM: the "maximum" potential variant
- a realistic implementation strategy of the selected set of NSWRM: the "local" variant (Fig. 7),

As the overall aim is to maximize the effect on the catchment sediment budget, hotspots of sediment generation were targeted in the local variant by vegetated filter strips and sediment ponds (Giri et al., 2012). Thus, 8 out of 103 sub-catchments responsible for 58 % of the catchment sediment yield were selected for the implementation of sediment ponds, and 17 sub-catchments responsible for 88 % of the catchment sediment yield were selected for VFS. Refer to the technical background document for more information on the process of selection of sub-catchments, and Table 2 for a synthesis. Subcatchments were selected also taking into account the reaches that are supposed to be improved, described in the next sub-section.

Only the main Feldaist, Waldaist and Aist reaches were selected for hydromorphological improvements based on the reaches that are in a moderate-to-bad hydromorphological status according to WFD 2015 assessment. These are reaches that are supposed to be improved in the future.

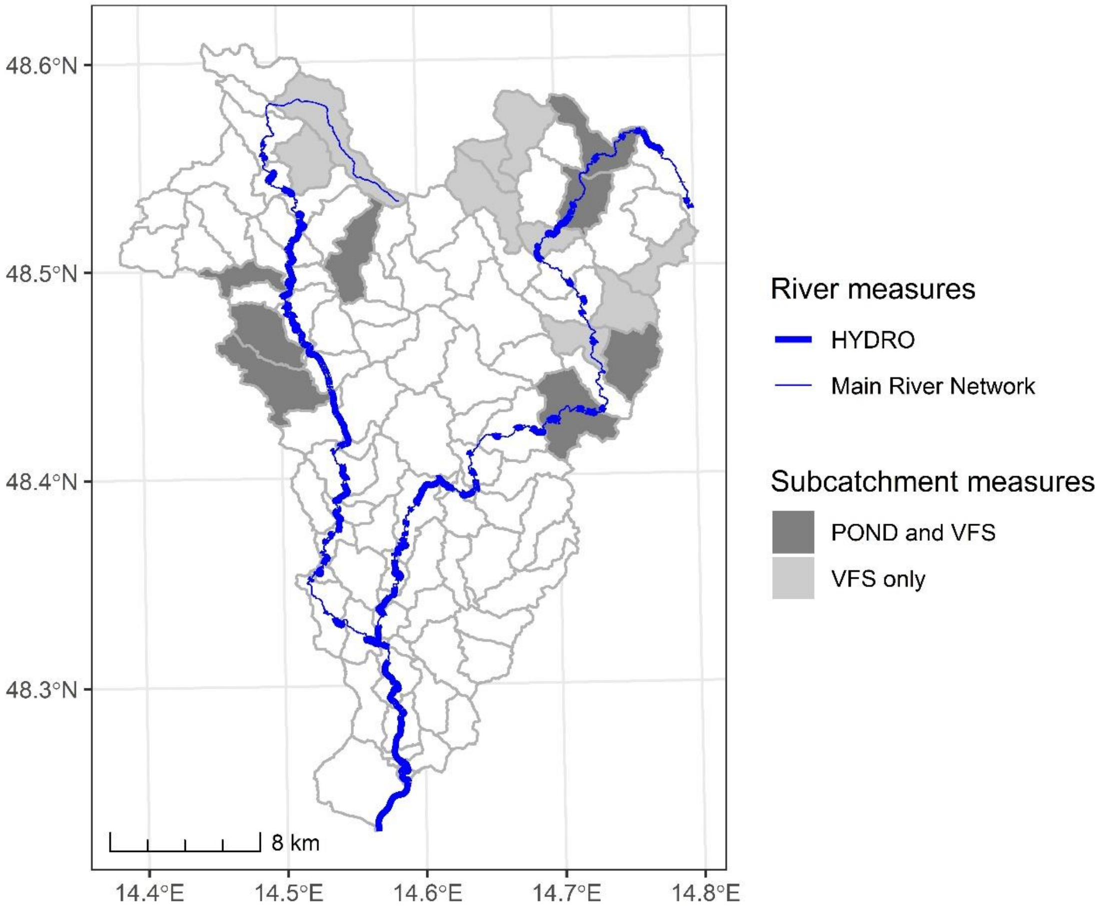

Figure 7 – Local implementation strategy

Table 2 – Fraction of the sediment yield upstream of the diagnostic reaches that is targeted by the measures implementation for the local variant. Refer to Fig. 8 for the position of the diagnostic reaches were improvements are desired.

Reach	Measures	Rationale for the choice
Reach A	Sediment ponds (BPDA)	Responsible for 50% of sediment generation upstream of site A
	Vegetated filter strips (A02)	Responsible for 100% of sediment generation upstream of site A
	Hydromorphological improvements (BPRC)	Main channel, where WFD assessment is available
Reach B	Sediment ponds (BPDA)	Responsible for 50% of sediment generation upstream of site B
	Vegetated filter strips (A02)	Responsible for 90% of sediment generation upstream of site B
	Hydromorphological improvements (BPRC)	Main channel, where WFD assessment is available
Reach C	Sediment ponds (BPDA)	Responsible for 32% of sediment generation upstream of site C
	Vegetated filter strips (A02)	Responsible for 50% of sediment generation upstream of site C
	Hydromorphological improvements (BPRC)	Main channel, where WFD assessment is available
Reach D	Sediment ponds (BPDA)	Responsible for 35% of sediment generation upstream of site D
	Vegetated filter strips (A02)	Responsible for 50% of sediment generation upstream of site D
	Hydromorphological improvements (BPRC)	Main channel, where WFD assessment is available
Reach E	Sediment ponds (BPDA)	Responsible for 40% of sediment generation upstream of site E
	Vegetated filter strips (A02)	Responsible for 45% of sediment generation upstream of site E
	Hydromorphological improvements (BPRC)	Main channel, where WFD assessment is available

3.4 Diagnostics for effects of NSWRM

Five diagnostic reaches were selected, to test the effects of measures on specific reaches in the catchment, three in the Waldaist and two in the Feldaist, with different hydrological and hydraulics conditions (Fig. 8). Measures effects were diagnosed:

- for the <u>local</u> variant and for the uniform <u>maximum</u> implementation variant (see chapter 3.4 above);
- both <u>at the catchment scale</u> (all the light blue reaches in Fig. 8) and for <u>specific diagnostic reaches</u> (dark blue reaches marked with alphabetic letters in Fig. 8).

The position of the diagnostic reaches in the Waldaist was chosen by the Upper Austrian Nature Protection Agency. These reaches correspond to sections of the Waldaist with high ecological value due to the presence of the Freshwater Pearl Mussel. The diagnostic reaches in the Feldaist were selected to be representative for an upstream section and a downstream section.

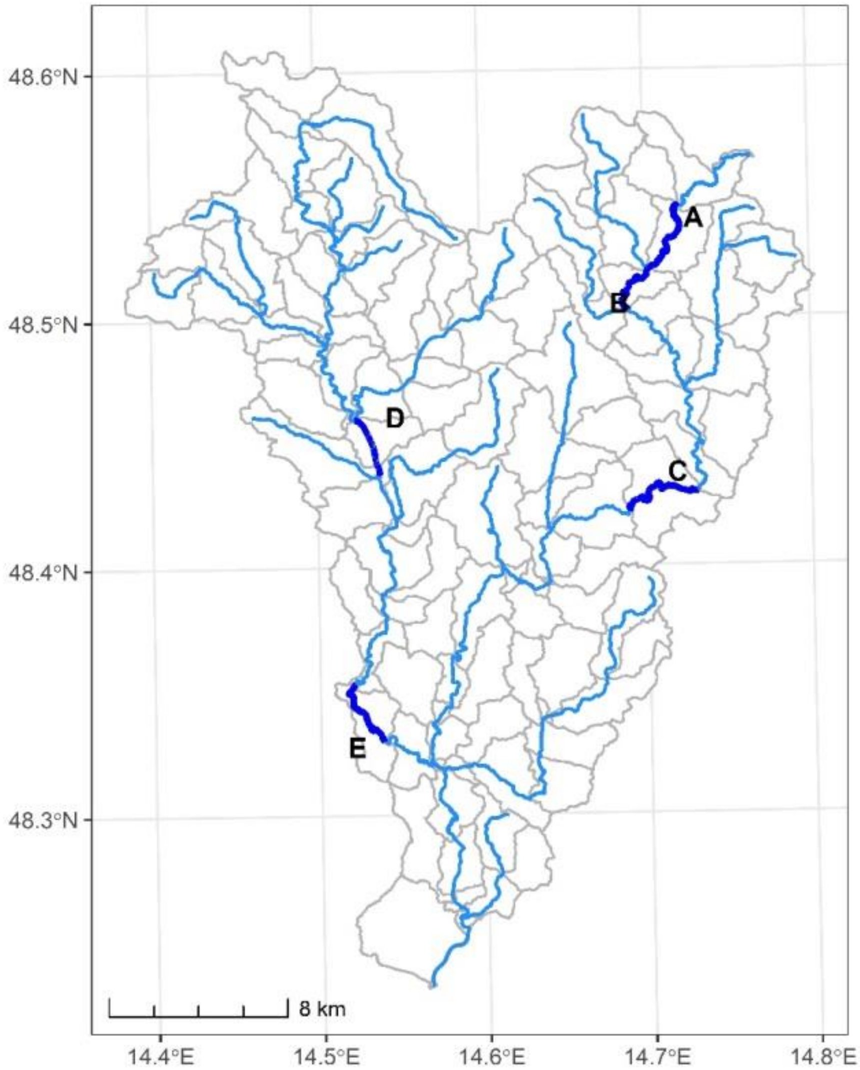

Figure 8 – Position of diagnostic reaches. As reported in the technical annex, such reaches correspond to SWAT sub-catchments number 13, 20, 51, 54, and 85 respectively.

3.5 Effectiveness of NSWRM at the catchment scale

Effects of measures on sediment accumulation at the catchment scale are diverse, and depend on the implementation strategy (“maximum” and “local” variants defined above).

The results are presented as boxplots, where the mean response, the standard deviation, and the 90th percentiles of the uncertainty are reported. The uncertainty is obtained through different repetition of the random forest (RF) to predict sand accumulation (the individual models in the ensemble). Each boxplot in Fig. 9 represents the relative percent change of the spatial extent that is covered by a specific sand accumulation class after the implementation of a specific set of measure. The assessment of the uncertainty is done with the “direction of change” index (DC) – detailed information can be found in the technical background document.

Figure 9 shows that measures that are most effective (mean relative percent change, mRC%) in reducing the spatial extent of class 3+ are hydromorphological improvements (-10.3 %) and water ponds (-18.5 %). However, ponds are not effective when located strategically on sediments hotspots (local strategy). On the contrary, both water and sediment ponds are effective at reducing the extent of class 3 for both catchment (-28.9 % and -18.1 % respectively) and local strategy (-5.8 % and -8.3 % respectively). Water and sediment ponds are also effective at reducing the extent of class 2 (-59.1 % and -56.4 % respectively) and increasing the extent of class 1 (+97.4 % and +78.6 % respectively) for the catchment implementation strategy, but VFS are more effective when located strategically (-13.5 % for class 2 and +15.5 % for class 1). Targeted VFS are also more effective in increasing the extent of class 0 (+4.7 %).

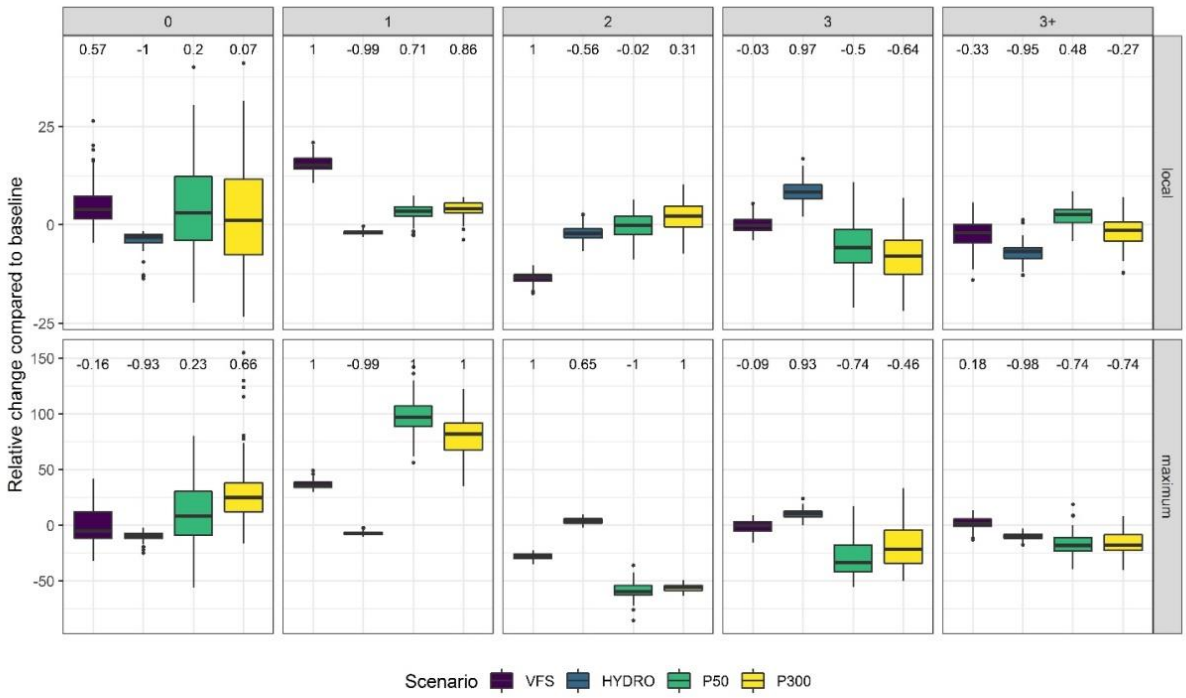

Figure 9 - Effect of measures on sand accumulation risk class (0 to 3+) for the maximum implementation and the local variant. The boxplot variation represents the relative changes of the Random Forest ensemble (999 individual random forests) The numeric annotations above the boxplots represent the direction of change index(DC). The DC index ranges from 0 to 1 where 0 is highly uncertain change and 1 is high certain change. The DC index is calculated base on the multiple runs of the model.. Refer to the text for the meaning of measures acronyms.

3.6 Effectiveness of NSWRM for sub-catchment (reach) diagnostic points

When different diagnostic points are considered, both the effectiveness and the related uncertainty, expressed with the direction of change index (DC), are affected (Fig. 10). Effectiveness was measured as the mean absolute change in the length of the diagnostic reach that is occupied by a specific sand class (mAC index). Here, only the mean response is presented; refer to the technical background document for the boxplots for the whole distribution.

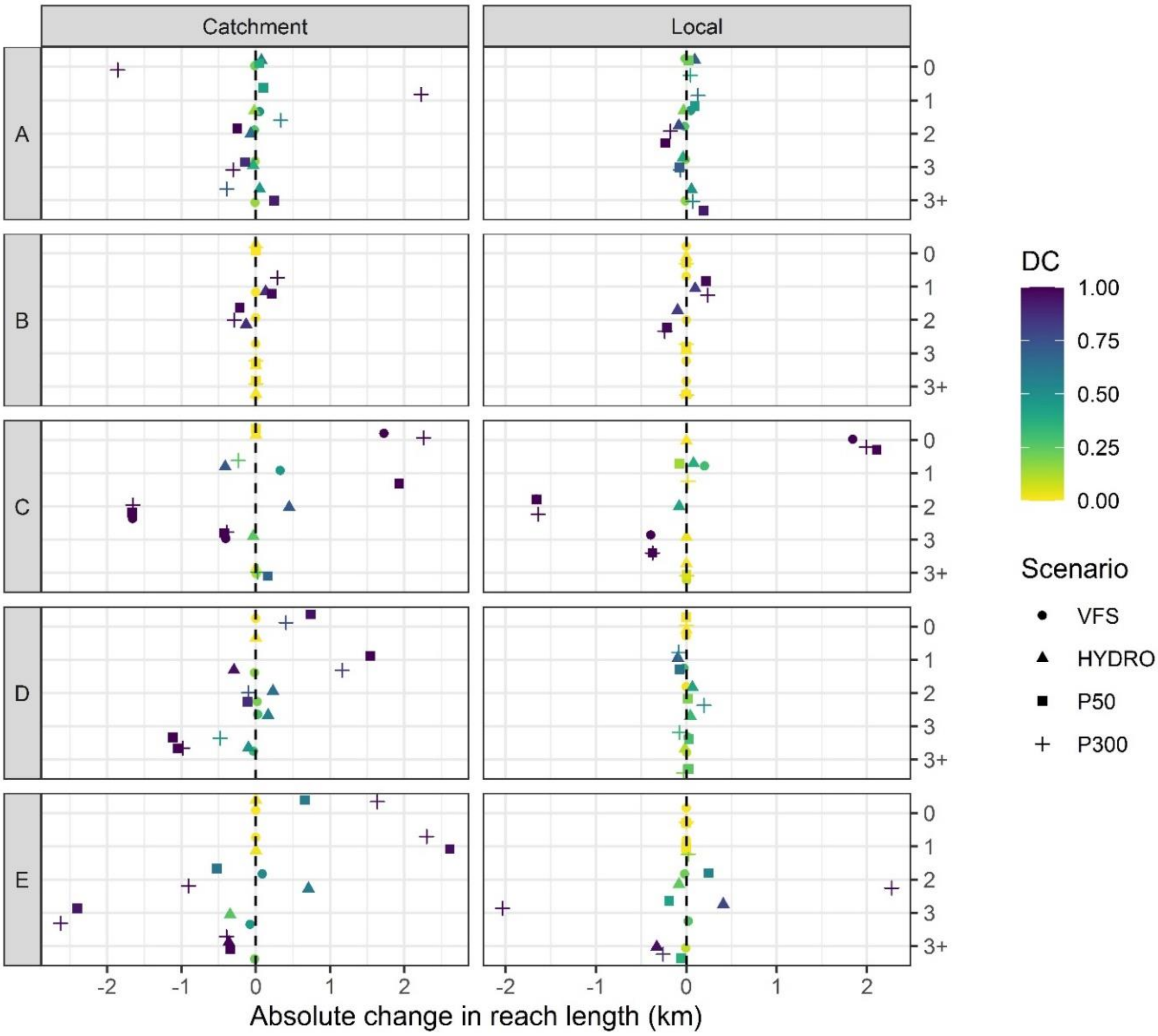

Figure 10 - Effect of tested measures are represented as changes in river length (x axis) occupied by each sand risk class (0 to 3+, y axis), for the diagnosed subcatchment (A-E, grouping factor). Sets of measures are represented with symbols shape; "local" and "maximum" implementation strategies are marked with different colors. The shading of the symbols represents the absolute value of the direction of change (DC) index. The DC index ranges from 0 to 1 where 0 is highly uncertain change and 1 is high certain change. The DC index is calculated based on the multiple runs of the model. Refer to the text for the meaning of measures acronyms.

In reach A, water ponds are reducing the extent of class 0 and 3+ (mAC = -2 and +2.2 km respectively) for the catchment strategy, while the local strategy shows no clear preference ranking for measures types and an overall low effectiveness (mAC always < 0.2 km). Reach B has a low sensitivity to the implementation of measures (mAC < 0.2 km), with hydromorphological improvements and ponds being able to reduce the extent of class 2 and increase the extent of class 1 both for local and catchment strategy. In reach C, both ponds and VFS can reduce the extent of class 3 (mAC = -0.5 km) and increase the extent of class 1 (mAC up to +2.1 km), with local and catchment strategies show similar effectiveness. In reach D, ponds are effective in reducing the extent of classes 3+ and 3 and increasing the extent of class 0 and 1. Low effectiveness is observed for the local strategy (mAC always < 0.2 km), when compared to the catchment strategy (mAC up to 1.5 km).In reach D, water and sediment ponds are more effective in reducing classes 3 and 3+ (mAC = -0.4 km and -2.5 km respectively), while in the local strategy only water ponds are highly effective in reducing class 3 (mAC = -2 km).

3.7 Main take-home messages from measures assessment with the dynamic models

The main conclusions that can be gained from the dynamic models implementation are:

1. Effects of NSWRM on the sand accumulation issue can be succesfully projected with a modeling cascade. The modeling cascade allows to propagate the effects of measures at the catchment scale and at local scales.

2. Effects of NSWRM greatly depend on local conditions. Therefore, both catchment scale and local scales have to be considered with the models when planning measures. The dynamic models presented in this Action Plan can support the assessment of NSWRM effectiveness for both catchmentand local scales.

3. A selection of measures can be made based on the targeted class:
    - Vegetated filter strips stopping overland sediment fluxes can support creating sites that are free from accumulations (increasing the spatial extent of class 0 and 1)
    - Sediment and water ponds, targeting water and sediment fluxes, can reduce the spatial extent covered by class 3 sites
    - Hydromorphological improvements can reduce the spatial extent occupied by class 3+ sites by increasing the transport capacity of the reach.

It must be stressed that the effectiveness results presented here are referring to two different implementation strategies and are derived for one catchment. Caution must be used before extending the results to other catchments in the same region.

4. NSWRM Legislation and Financing

4.1 Policy Background

The multiple benefits of NSWRM can contribute to different policy objectives, including policies on surface water, groundwater and coastal management, agriculture, forestry, energy, disaster risk management, green growth, climate change mitigation and adaptation and even nature conservation.

EU legislation addressing NSWRM in the field of water management comprises the Water Framework Directive (WFD), the Floods Directive (FD) and the Habitats and Birds Directive. NSWRM can contribute to both WFD and FD goals, can enhance synergies between the implementation of both directives, and can support the coordination between the River Basin Management Plans (RMBPs) and Flood Risk Management Plans (FRMPs). NSWRM are a potential solution to improve or preserve hydro-morphological conditions as well as water quantity and quality issues.

NSWRM can help to achieve the legal obligations of the Birds and Habitats Directives and the connected Natura 2000 management plans by improving the status of species and habitats towards a favorable conservation status. They can also contribute to the different targets of the EU 2020 Biodiversity Strategy (especially Target 2: “ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems by 2020”).

Considering the multifunctional aspects of NSWRM, they are addressed also in different policy fields and policy documents. Table 2 gives an overview on national Austrian policy documents that are directly or indirectly addressing the application of NSWRM.

Table 2: Overview on selected national policy documents connected to NSWRM application

Field	Name and type of the document	Year when the document was prepared and adopted	Main points related to NSWRM
Water Manage-ment	Wasserrechtsgesetz WRG: Austrian National Water Rights Act LAW	1959; 1990: negative ecological effects have to be minimized, ecological functioning has to be ensured; 2003: adaption to WFD objectives; 2011: adaption to FD requirements; 2014: update in water usage rights; 2017: reducing bureaucratization	Any measure which might have a significant effect on water quality/ecology needs authorization -> protection <u>against</u> water (flooding) and protection <u>of</u> waters (water bodies, water supply)
Water Manage-ment	Wasserbautenförderungs-gesetz, WBFG: Act on Funding of Water Management Measures LAW	1985; latest update 2014	Defining all measures that may be financed by national funds, covering also measures falling under the term NSWRM
Water Manage-ment	Technical Guidelines for Flood Protection (RIWA-T) - strategies for sustainable flood management	Update 2016 issued based on WBFG	Passive flood protection has priority over active flood protection; measures in the catchment have priority over measures in the main channel; retention measures have priority over linear structures; (near) natural methods of constructing

			have priority over purely technical measures
Water Manage-ment + Nature protection;	Umweltförderungsgesetz, UFG: Austrian Environmental State Funding Act LAW	1993, latest update 2017	Defines requirements of funding for various kinds of environmental protection (mainly environmental remediation)
Water Manage-ment	Gefahrenzonenplanungsverordnung: Regulation on risk zone mapping	2014 issued based on WRG	Defining mapping of flooded areas; assessment of retention volumes and flood peak mitigation
Water Manage-ment	Richtlinie für Kosten-Nutzen-Untersuchungen im Schutzwasserbau (KNU) 2009: guidelines for cost-effectiveness analyses in flood protection	1980, update 2009; issued based on WBFG	cost-effectiveness analyses for flood protection measures only
Water Manage-ment	National Water Management Plan (NGP) STRATEGY/ACTION PLAN Incl. plan of measures to restore good ecological & chemical status (good ecological potential for HMWB)	1st 2009, 2nd 2015, 6 years cycle	Based on WFD; NSWRM are mentioned mainly in the context of nutrients - as strategies against diffuse sources emissions, and also in the context of hydro- morphological alterations
Water Manage-ment	Quality Objective Ordinance - Ecological Status of Surface Waters	BGBl. II Nr. 99/2010 Federal Law Gazette	Based on WFD; giving type-specific target values for biological, hydro-morphological and chemical-physical parameters for the five ecological status categories
Water Manage-ment	Quality Objective Ordinance - Chemical Status of Surface Waters	BGBl. II Nr. 96/2006, Federal Law Gazette Update 2016	Based on WFD; giving target values for chemical parameters for the five chemical status categories
Water Manage-ment	National Flood Risk Management Plan (Hochwasserrisikomanagementplan, HRMP 2015)	2015 based on FD 2007/60/EG;	NSWRM are mentioned in connection with climate change adaptation strategies; reference to AAR14
Water Manage-ment	Action plans for each APSFR (area of potential significant flood risk)	2015; based upon National Flood Risk Management Plan	22 Types of measures in 5 fields of action, each APSFR choses certain types; Various measure types fall under term NSWRM (e.g. M07: Restoration of flood plains and sedimentation areas)
Agriculture	ÖPUL funding programme = Austrian agri-environmental funding programme	Latest: ÖPUL 2015 (covering 2015-2020)	Funding for farmers if they apply certain measures in forestry and agriculture to enhance the protection of soil and water (ÖPUL2015: 23 types of measures, e.g.: buffer strips along rivers for reduced nutrient input…)
Agriculture	Nitrates Directive and Austrian Implementation of Nitrates Directive: Nitrat-Aktionsprogramm-Verordnung (Nitrate Action Plan Directive)	91/676/EWG Update 2018	to protect water quality across Europe/Austria by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices
Agriculture	Austrian Directive for Fertilizer Usage (Richtlinie für eine sachgerechte Düngung)	Latest update 2017	Instructions for soil investigations and proper fertilizer usage -> to protect soil and waters
Land Use Planning	Spatial Planning laws &regulations (regional)		Restrictions and exemptions for areas with a certain flood hazard and a certain protection status
Nature	Natura2000 - Habitats Directive	92/43/EWG	Protecting and enhancing biodiversity;

protection	->Special Areas of Conservation (SACs)	Dec. 2017: 204 Natura2000 protected areas in Austria	various measures in the Natura2000 areas also fall under the term NSWRM, e.g. floodplain reconnections, river renaturations…
Nature protection	Austrian Nature Protection Laws	9 different laws: one for each of Austria's 9 provinces	Protection of habitats and species
Nature protection	Austrian National Park Laws	8 different laws, one for each province, except Vorarlberg	Legal framework for national park set-up, management and funding
Climate Change	Austrian Assessment Report on Climate Change AAR14 (Österreichischer Sachstandsberichts zur Anpassung an den Klimawandel 2014)	2014	NSWRM are mentioned in the context of climate change adaptation strategies: „…a successful adaptation of Austrian water management to climate change can be reached through an interdisciplinary & integrative approach, e.g. NSWRM…"
Climate Change	Austrian Strategy on Climate Change Adaptation (Die Österreichische Strategie zur Anpassung an den Klimawandel) including an Action Plan	Update 2017	Offering guidance, promoting water retention
Climate Change	Analyses of climate change impacts on water mangement issues in Upper Austria (report, 2013)	2013	Implications for floods, low flow, water quality, water temperature, ground & drinking water -> further investigations needs on low flow mitigation and flood mitigation

Catchment scale spatial planning is essential for identifying the most appropriate locations for NSWRM in combination with other measures so they can contribute to multiple policy objectives. For a successful and sustainable catchment management a cross-sectoral cooperation of affected sectors (water management, nature protection, spatial planning, agriculture, forestry, tourism…) is urgently needed. A harmonization between directives and policies in different sectors can support a better integration of NSWRM in catchment planning processes.

Further information on NSWRM and policy can be found at the European online platform for NSWRM (http://NSWRM.eu/), especially in Synthesis document no. 10 which is dedicated to Policy coordination linked to NSWRM (http://NSWRM.eu/sites/default/files/sd10_final_version.pdf) and in the FramWat project reports "National Overview of the existing policy documents: Austria" (June 2018) and "Regional Overview of the existing Policy Document (joint report D.T3.1.2, September 2018).

4.2 NSWRM Financing

There are no dedicated funds for the implementation of NSWRM in Austria. So far, NSWRM in Austria have mostly been financed by public budgets, either national or EU funds or a combination of both.

Many bigger river restoration and floodplain re-connection projects get funded out of EU LIFE funds. National funds have mainly been used for smaller river restoration and flood management projects. Often, measures are co-funded by institutions at different levels (national, regional, local). Various ecological measures/improvements are implemented in the course of the implementation of flood protection measures, as according to the WFD no deterioration of the ecological status is allowed. Various agro-environmental measures are funded by the ÖPUL programme (= incentive for farmers to manage land in a more sustainable way) that is financed by EU (50%) and national funds (50%).

Opportunities to fund NSWRM also exist in various EU financing instruments:

- Common Agriculture Policy (CAP) and Rural Development Plans (RDP): e.g. agricultural measures implemented at the farm level (buffer strips, hedgerows…), river and wetland restoration, flood prevention;
- Life Programme: The LIFE Programme is the specific funding instrument supporting the Birds and Habitat Directive, and it is therefore specifically tailored to support environmental conservation and restoration in Europe (e.g. river and wetland restoration);
- Structural & Cohesion Funds: ERDF (European Regional Development Fund) is targeting ecosystem-based approaches and green infrastructures.

Emerging and innovative financing sources (e.g. Payments for Watershed Services (PWS) schemes, Water Funds, bio-carbon markets, product labelling and certification schemes, or biodiversity compensation funds) can act as complementary financing sources for implementing several types of NSWRM in the future.

Further information on funding can be found at the European online platform for NSWRM (http://NSWRM.eu/), especially in Synthesis document no. 11 which is dedicated to Financing NSWRM (http://NSWRM.eu/sites/default/files/sd11_final_version.pdf).

5. Monitoring

The effectiveness of NSWRM at the local scale is affected by multiple geographic, geologic, climatic, land use, and anthropogenic factors. Thus, monitoring the effectiveness of NSWRM at the local scale is important as insights into the local effectiveness can be gained. Field-collected data are necessary for upscaling the effectiveness to the catchment scale (Liu et al., 2017).

While the scientific and technical literature covers monitoring of sediment retention ponds (Fiener et al., 2005; Verstraeten and Poesen, 2002) and vegetated filter strips (Abu-Zreig et al., 2004; Magette et al., 1989), less literature is available on the monitoring of hydromorphological improvements and in-stream sediment ponds located in small tributaries.

In the following two sub-chapters we present possible monitoring strategies for hydromorphological improvements and for small in-stream sediment ponds. We discuss results from the monitoring carried out during the project duration in the FramWat pilot catchment Aist (in-stream pond) and in the neighboring Maltsch catchment (hydromorphological improvements via floodplain reconstructuon). The Maltsch river shares with the Aist catchment the problem of fine sediment accumulation in the river beds. Furthermore, plans exist to implement the same structural measure in degraded reaches in the Aist catchment. The focus of the monitoring program is on sediment quality (stocks) and reactivity (ecologically relevant processes).

5.1 Monitoring of hydromorphological improvements

The hydromorphological improvements in the Maltsch catchment are designed to allow the water to spread over a small constructed floodplain during floods. This leads to a reduction of shear stresses and to a stabilization of the substrate without reducing the cross-sectional transport capacity (Flödl and Hauer, 2019). Increased stability in the substrate can offer more stable conditions also for the biotic compartment.

The artificial floodplain located north of the settlement of Leopoldschlag (Fig. 11) is a perfect case study for monitoring hydromorphological improvements, as it is located near to channelized sections and to river sections that are not regulated and are naturally meandering.

For monitoring the floodplain effectiveness, sediment samples along a continuum that includes smaller headwater reaches, natural floodplains, channelized sections, and an artificial floodplain were collected under different hydrological conditions: post-flood (floodplains flooded, 10-07-2018), post-bankfull (floodplains not flooded, 5-06-2018) and baseflow (4-09-2018). Additionally, we collected soil samples from natural and artificial floodplain sites. Due to heterogeneities in soil and sediment composition, five replicates per sampling point were collected for lab analysis.

Samples were analyzed for structural parameters (grain size distributions), organic matter and nutrients (Nitrogen, Phosphorous) stocks, and ecologically relevant processes (benthic respiration rate and Phosphorous adsorption capacity). Sediments respiration rate is a measure of the biofilm integrity, and directly measures the biotic response to the disturbance related to high shear stress during bankfull and flood conditions (Atkinson et al., 2008). Phosphorous adsorption capacity (EPC0) measures the capacity of benthic sediments to buffer P dissolved in the water column. EPC0 is also affected by hydrologic conditions, where high flows can disturb the sediment and cause the release of P (Stutter and Lumsdon, 2008).

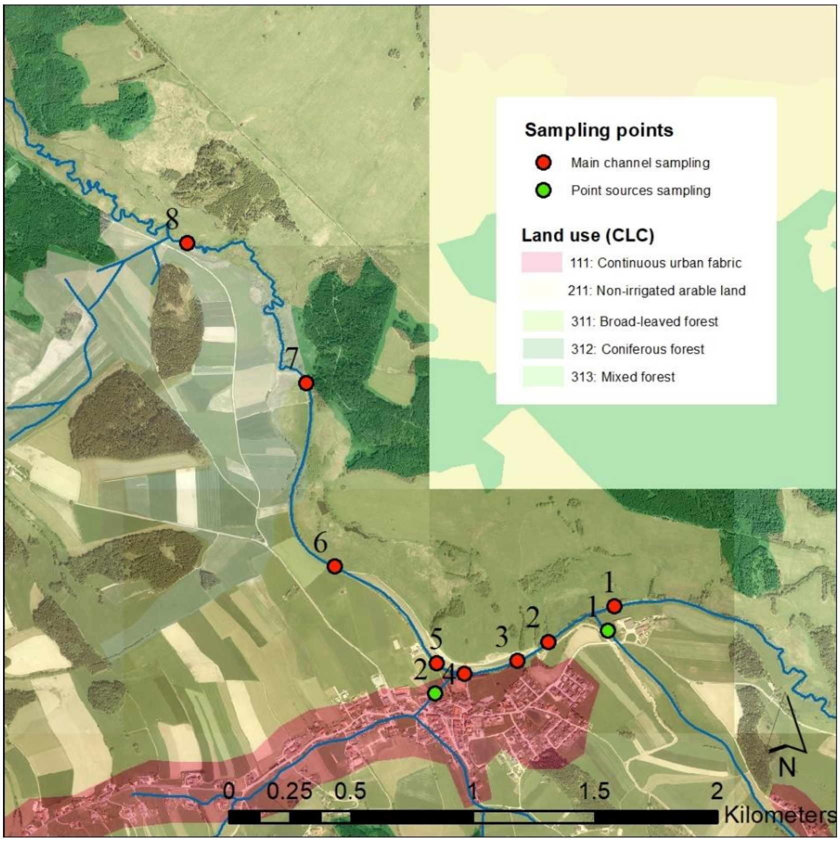

Figure 11 – Maltsch sampling design. Numbered red dots indicates the position of the sampling points: 1,2: sampling points located upstream the artificial floodplain; 3,4,5: sampling points located in the channel near to the artificial floodplain; 6: sampling point located in the channel downstream of the artificial floodplain; 7,8: sampling points located in the natural floodplain area.

The analyses of the physical structure of the sediments, the organics content, and the nutrient stocks with a PERMANOVA algorithm ('vegan' package in R computing environment; 999 permutations) indicate that the local morphology can predict alone 27 % of the dissimilarity between sites ($p<0.001$), while the hydrologic conditions account for 10% of the dissimilarity between the sites ($p<0.001$). The interaction between hydrology and site was found to be non significant ($p> 0.05$).

The response of EPC0 and benthic respiration rate to local factors, local morphology and flow event were assessed with an analysis of covariance (ANCOVA, 'lm' function in 'stats' package in R). The analysis was repeated for random choice of predictors and predictors interactions and the predictors importance was assessed by counting the frequency they appear in the best models within the final set of ANCOVA models ('MuMIn' package in R). The most important factors to explain EPC0 were the specific surface, the hydrological event and the morphological conditions. The most important factors to explain the respiration rate were the fine organic matter, the nitrogen content, and the morphological conditions.

Thus, site-specific responses in terms of phosphorous adsorption capacity and respiration rate depend on the interplay between the local morphology and the hydrological conditions. As visually diagnosed in Fig. 12, samples collected next to the natural and artificial floodplains show no effect of the hydrology –i.e. EPC0 and benthic respiration rate are not different between baseflow, bankfull, and flood conditions, while in both the channelized sections upstream and downstream, an effect of the hydrological condition is visible.

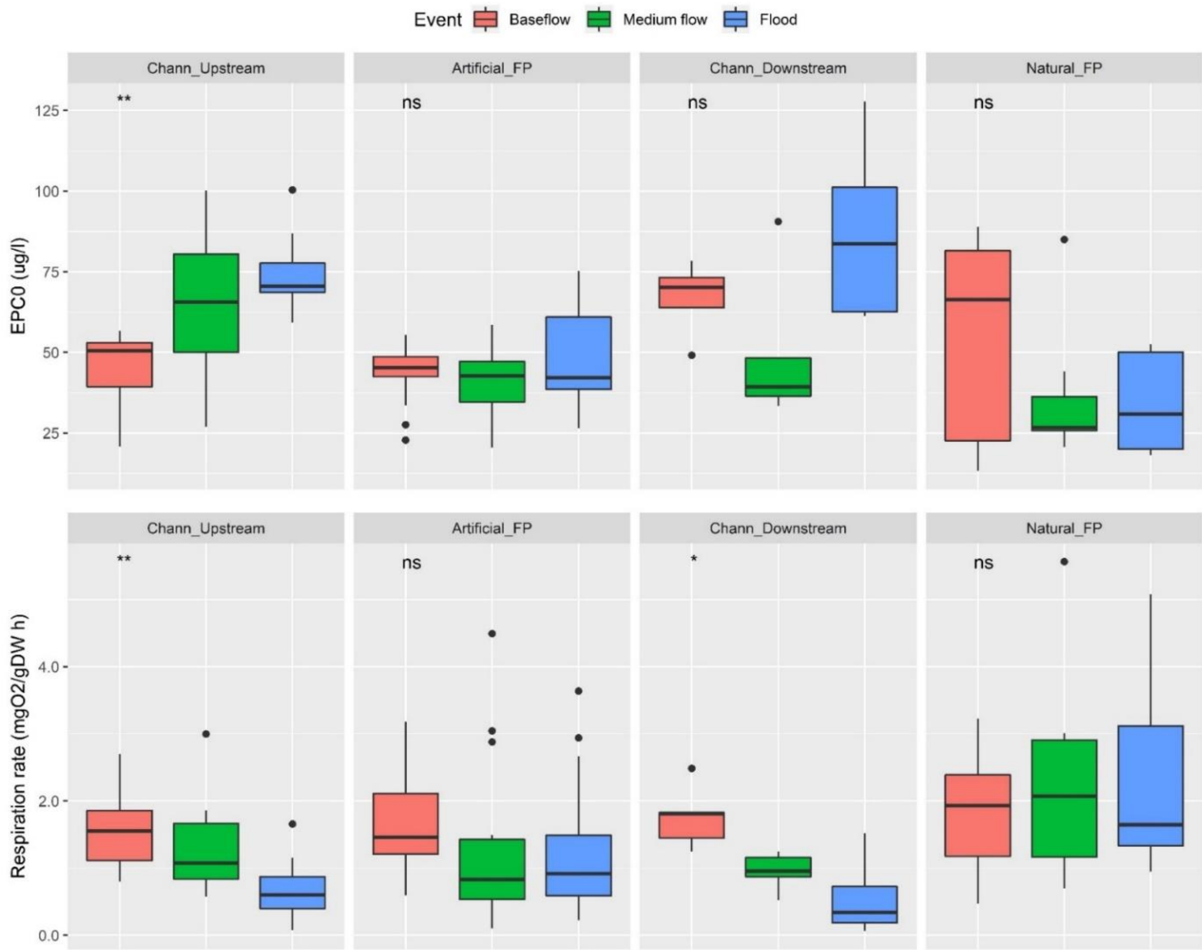

*Figure 12 – Monitoring of the artificial floodplain in the Maltsch River (Leopoldschlag) along an hydrological gradient. Chann_Upstream: channelized section of the Maltsch upstream of the artificial floodplain; Artificial_FP: artificial floodplain sites, Chann_Downstream: channelized seciton of the Maltsch downstream of the artificial floosplain; Natural_FP: natural floodplain section. Asterisks show statistical differences between groups (Kruskal-Wallis test; ns: not signofocant; * p<0.05; ** p<0.01; *** p<0.001)*

5.2 Monitoring of in-stream sediment deposition ponds

A sediment pond is monitored in the Aist catchment on a small northern tributary (Schwarze Aist). The suggested monitoring strategy is the BACI (before after control impact) design, so that sediments are analyzed before and after the pond construction, upstream and downstream (Fig. 13). The analyzed parameters are the same as described in the previous chapter.

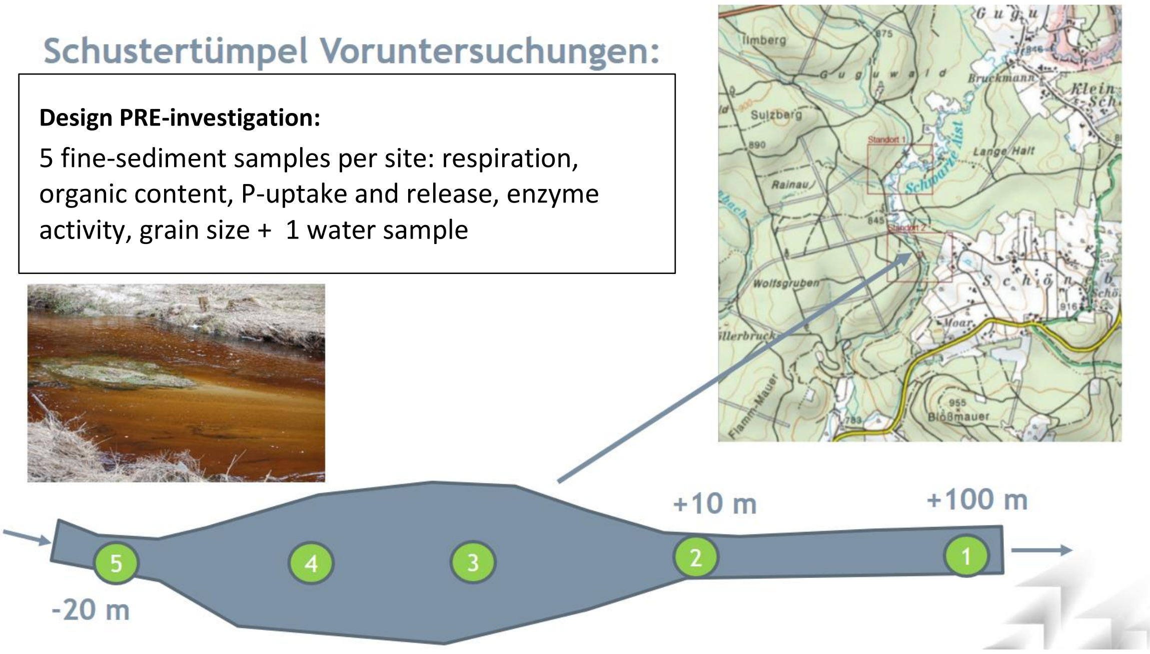

Figure 13 – Location of the pond and analyzed parameters

6. Technical Background Document

For further details on the measures implementation and the modeling cascade, refer to the attached *“Technical background document to the ACTION PLAN for the Aist catchment: information on measures siting and effectiveness assessment with the modeling cascade”.*

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