EU LIFE Programme integrated project
"Implementation of River Basin Management Plans of Latvia towards good surface water status"

REPORT ON HABITAT MODELLING RESULTS FOR PILOT BASINS

Prepared within the LIFE GoodWater IP Action C3 "Assessment of natural flow regime in the waterbodies at risk affected by small hydropower plants (HPPs)"

Riga, 2023

Report on habitat modelling results for pilot basins

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Recommended citation: LEGMC. 2023. Report on habitat modelling results for pilot basins, LIFE GoodWater IP, Riga, 51 pp.

Document prepared in the frame of the integrated project “Implementation of River Basin Managament Plans of Latvia towards good surface water status” (LIFE GOODWATER IP, LIFE18 IPE/LV/000014), project has received funding from the LIFE Programme of the European Union and the State Regional Development Agency.

Document versioning sheet	
Document version number	v 1.0
Document planned elaboration date	06.2023
Document elaboration date	06.2023
Document actual version elaboration date	06.2023
Project activity/sub-activity number	C3.3.

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Abbreviation

E-Flow	Ecological Flow
EU	European Union
HPP	Hydropower Plant
HMU	Hydromorphic unit (riffle, glide…)
H-Q	Water level – water discharge relation
LAS	Latvian Elevation System
LEGMC	Latvian Environment, Geology and Meteorology Centre
MS	Monitoring station
Q_{30_min}	Low flow period minimum water discharge
Q_{30_avg}	Low flow period average water discharge
Q_{30_max}	Low flow period maximum water discharge
Q_{an_avg}	Annual flow
$Q_{\mathbf{optimum}}$	River flow value, at which the area of available habitat reaches its maximum
RB	River Basin
RBD	River Basin District
WFD	Water Framework Directive

I. INTRODUCTION

In the frame of the LIFE GOODWATER IP, suitable river habitat modelling was carried out in the project pilot rivers within four Latvian River Basin Districts (RBD).
River habitat modelling has been done to calculate the habitat suitability for selected fish species in different hydrological conditions. Modelling results analysis leads to the ecological flow (E-flow) value estimation in rivers regulated by operating hydropower plant (HPP) in the Daugava, Gauja, Lielupe and Venta river basins.
General E-flow calculation principles and approaches are defined by the EU Water Framework Directive (WFD) and CIS Guidance document Nr.31 “Ecological flows in the implementation of the Water Framework Directive” [1].

The River habitat modelling have been carried out for the following case-study sites:

- Aģe River (Gauja RBD) - below Aģe HPP, G264DA water body is at risk due to water regulations by HPP and land drainage;
- Mergupe River (Daugava RBD) - below Krīgaļi and Brūni HPPs, D408DA and D409 water body is at risk due to water regulations by HPPs;
- Auce River (Lielupe RBD) - below Bēne and Kroņauce HPPs, L117SP and L118 water bodies are at risk due to water regulations by HPPs and land drainage;
- Zaņa River (Venta RBD) - below Pampāļi and Zaņa HPPs, V060 water body is at risk due to water regulations by HPPs.

The Conditional Fish Model created by the Interreg V-A Latvia – Lithuania Programme 2014-2020 TRANSWAT Project (2021-2022) was validated and used for habitat modelling also in this project.

Gathered data will allow to validate the E-flow estimation method developed in the previous Interreg V-A Latvia – Lithuania Programme 2014-2020 ECOFLOW Project (2017-2018).

II. MESO-SCALE HABITAT SIMULATION MODEL (MesoHABSIM)

2.1. Model concept and application

Meso-scale habitat models (MesoHABSIM) describes the relationship between channel hydro-morphology and river biota. The approach can be used to evaluate the impact of both hydrological and morphological alterations.

Quantifying (physical) HABITAT resources for biota links:

1. hydrology (hydraulic conditions, flow regime),
2. morphology (channel geometry, shelters, reproduction area),
3. biology (aquatic and communities).

This habitat metric, based on physical parameters (water depth, flow velocity, channel geometry, substrate and cover), the spatio-temporal variation of which physical represents HABITAT resources that are needed to maintain local populations.

MesoHABSIM consists of three separate sub-models:

1) Fish conditional model: fish habitat model which describes relationships between abundance of selected fish species and abiotic environment of river (depth, flow velocity, substrate composition, presence of boulders, woody debris or in-stream vegetation, etc.).
2) Hydrological data: flow time series in reference (natural) and altered (impacted by HPP) conditions.
3) Hydromorphic unit (HMU) data: HMU as polygons and hydromorphological data as points based on field measurements, including river depth, channel substrate and stream velocity.

Due to the scale of resolution increasing from micro- to meso-scales, the MesoHABSIM takes into account the variations in stream morphology along the river and is applicable to large-scale issues. Habitat and fish measurements at large spatial units are practical and relevant to river management.

The results of MesoHABSIM can be used as for ecosystem analysis and selection of adequate mitigation measures, such as construction of fish bypass channels or changes in HPP operations. It creates a basis for balance between water resources use and ecological quality – evaluation of ecological flow.

2.2. Sim-Stream Model

Within the LIFE GOODWATER IP the SimStrem-WEB platform has been developed in order to achieve wide applicability and the ease-of-use of obtained results from this project. The software is available at https://mesohabsim.isprambiente.it/ .

Sim-Stream software combines all three parts of MesoHABSIM (fish model, hydrological data series and HMU) and simulates physical habitat suitability at different flow conditions.
Sim-Stream model is a tool that supports the MesoHABSIM Simulation approach; describes river features that are relevant for aquatic species; calculates habitat suitability; and report on the actual and projected status of investigated river.

The software integrates field collected hydro-morphological data with biologic data (fish). This physical habitat simulation model describes the utility of instream habitat conditions for aquatic fauna, allowing to simulate change in habitat quality and quantity in response to alterations of flows or river morphology.
Since the distribution of hydro-morphologocal units (HMUs) changes as a function of flow, the meso-habitats are mapped under multiple flow (at least four) conditions at representative (natural river bed, no artificial obstacles) stretches of the river. The independent biological data (fish) is collected in representative meso-habitats. In Sim-Stream model the relationship between fish abundance and suitable habitat distribution is calculated with multivariate statistics.

III. MODEL INPUT DATA

3.1. Hydromorphic unit maps and Field Survey

Hydro-morphological units mapping and field works were done in ice-free period of May 2020 – December 2022. Hydromorphological type-specific, meso-scale river stretches were selected downstream of each studied HPP. Depending on river size, these river stretches were 90-290 m long. Only natural sites without channelization were selected in order to assess the ecological impact of water level alterations below HPP. Each river stretch was divided into hydromorphological units (HMU), which were mapped at multiple flow conditions. HMU can be described as lotic meso-habitats (riffles, rapids, glides, pools). HMU were mapped as polygons which allows to assess changes in habitat area under different water levels. Flow velocity, water depth and channel substrate were measured at least in seven points within each HMU. For modelling the spatial information about HMU location and size as well as data of water depth, flow velocity and river bed substrate within HMU have been used.

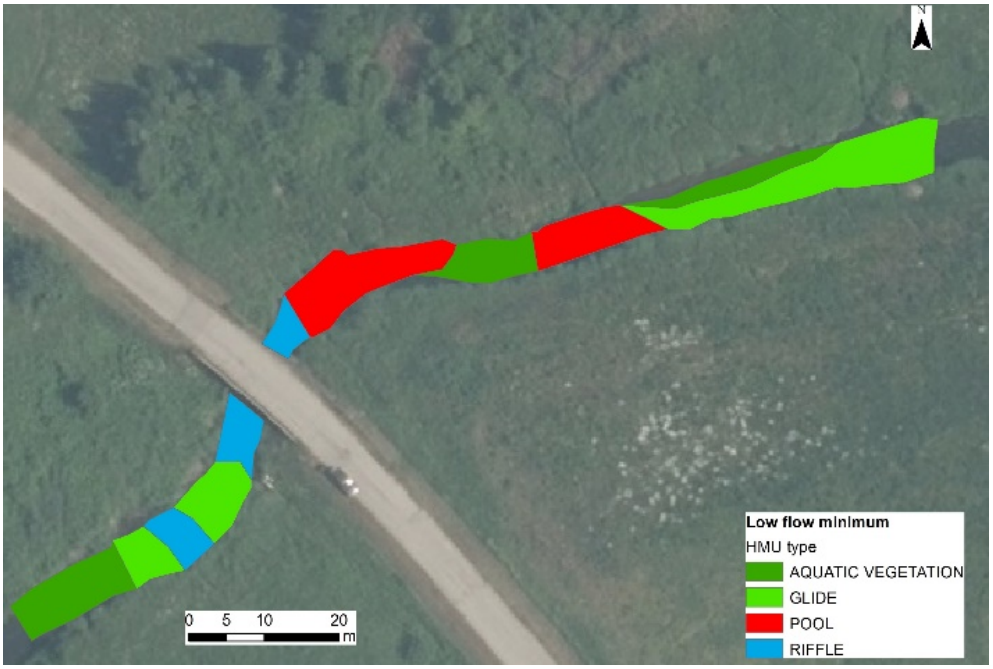


Figure 3.1.1. Example of hydromorphic unit map of the Auce River below Kroņauce HPP (Q = 0.038 m^3/s)

3.2. Hydrological data

For each case study site two hydrological data series were used: daily water flow data in reference (upstream the HPP) and altered conditions (downstream of HPP). Data series have been created for one year (normal hydrological conditions) in order to describe the habitat suitability in typical hydrological conditions. Figure 3.2.1 shows example of the hydrographs used for habitat modelling.

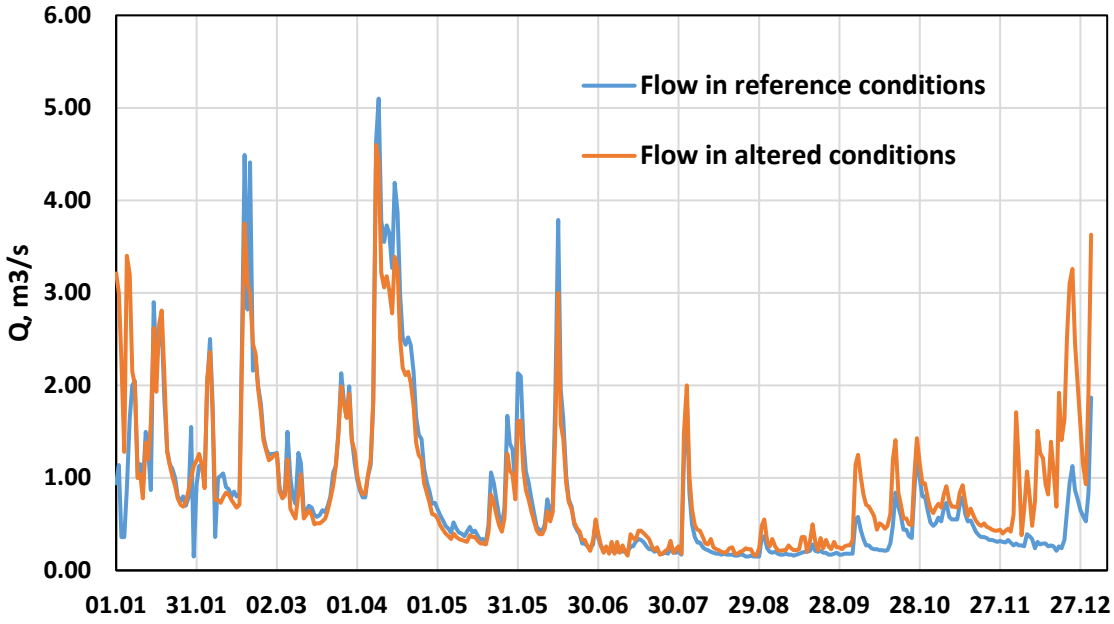


Figure 3.2.1. Example of Mergupe River daily water flow at reference and altered conditions

During this project special water level sensors were installed below and above all sites, water discharge measurements were carried out for the creating of H-Q rating curve and providing higher quality hydrological calculations. Figure 3.2.2 illustrate changes of the water level regime due to HPP operation.

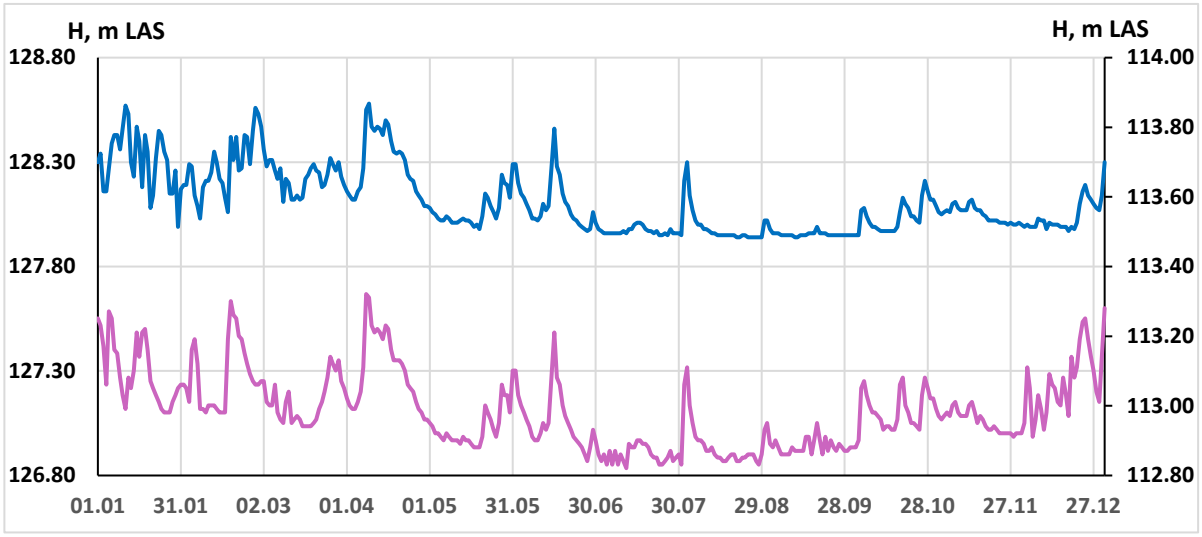


Figure 3.2.2. Daily water level of Mergupe River upstream (blue line) and downstream (violet line) Krīgaļu HPP.

3.3. Fish conditional model and fish data

The Fish conditional model is a MesoHABSIM sub-model that includes data of water depth, flow velocity, substrate of river bed and fish cover/shelter (e.g. woody debris, undercut banks, boulders, emergent & submerged vegetation), and evaluate how listed parameters influence the frequency of selected fish species in different geomorphic units (HMU). The fish conditional models are created for particular fish species of two different age groups (adults and juveniles) and they are adjusted to evaluate presence and abundance of specific fish species. The example of conditional models of *Salmo trutta* (Brown trout) is shown in Table 3.3.1.

Table 3.3.1. Conditional models for prediction of presence and abundance of Salmo trutta (juveniles) in studied rivers

Salmo trutta (Brown trout) JUVENILES Presence	**Salmo trutta (Brown trout) JUVENILES High abundance**
IF [D_15+D15_30+D30_45+D45_60+D60_75]>0.3 AND [CV15_30+CV30_45+CV45_60+CV60_75+CV75_90]>0.3 AND [MESOLITHAL+MICROLITHAL +AKAL]>0.3 AND [WOODY_DEBR=1 OR BOULDERS=1]	IF [D_15+D15_30+D30_45+D45_60]>0.3 AND [CV30_45+CV45_60+CV60_75]>0.4 AND [MESOLITHAL+MICROLITHAL +AKAL]>0.7 AND [WOODY_DEBR=1 OR BOULDERS=1]

Fish data have been collected within the activity A5.1 of LIFE GoodWater IP project. During the survey the hydromorphological features, fish fauna and ecological status of rivers of interest was evaluated. Hydromorphological features was evaluated by using of standard River Habitat Survey or RHS method developed in UK. In addition, suitability for reproduction of sea trout and brown trout was evaluated by using of modified Trout Habitat Score or THS. Electrofishing was used for fish fauna survey and ecological quality of surveyed rivers was evaluated by calculation of Latvian Fish index. The standard SE 300 electrofishing device powered by 2 kW generator was used.
For habitat modelling a List of specific species of interest has been created for each river within the project area (Table 3.3.2).

Table 3.3.2. List of specific species for E-Flow calculation

River	**HPP**	**Fish species included in modelling**
Aģe	Aģe HPP	salmon, brown trout, stone loach
Mergupe	Brūnu HPP	bullhead, spirlin, stone loach
Mergupe	Kīigaļu HPP	brown trout, bullhead, spirlin
Auce	Kroņauce HPP	chub, minnow, spined loach
Auce	Bēne HPP	chub, minnow, spined loach
Zaņa	Pampāļi HPP	chub, minnow
Zaņa	Zaņa HPP	chub, minnow, brown trout

IV. HABITAT SUITABILITY MODELLING RESULTS

4.1. Aģe River – Aģe HPP

This stretch of Aģe River is included into List of priority fish waters and belongs to salmonid fish waters. Aģe HPP is the only HPP on Aģe River, in the stream there is no other major obstacles that disturbs longitudinal continuity. According to Water use permits, the guaranteed water discharge is determined as 0.015 m^3/s and ecological flow is 0.09 m^3/s.
Aģe River List of species of interest:

- Juvenile salmon (*Salmo salar*),
- Juvenile brown trout (*Salmo trutta*),
- Adult stone loach (*Barbatulus barbatulus*).

Habitat curves for selected fish species depending on flow rate are shown in Figure 4.1.1. These curves have been modelled for each fish species of interest (salmon, brown trout, stone loach) that were pre-selected by fish expert especially for Aģe River. It is evident that relationship between water discharge and in-stream habitat availability is very similar for most of studied fish species.

The very special value can be defined in these curves, with ecological meaning – the optimum flow as an instream flow that produces a maximum value of potential habitat. Obviously, it is the reference flow for ecological enhancement.

Habitat sharply increases from the minimum to the average flow of the low flow period and then it increases slightly to the mean annual flow, where reaches the maximum value. It is clear that annual water discharge is the optimum flow for the Aģe River.

Habitat for the minimum flow of the low flow period (Q_{min} = 0.18 m^3/s) is almost unsuitable for salmon and brown trout. However, the ecological flow specified in the Water use permit of the Aģe HPP (E-flow = 0.09 m^3/s) is lower than this value.

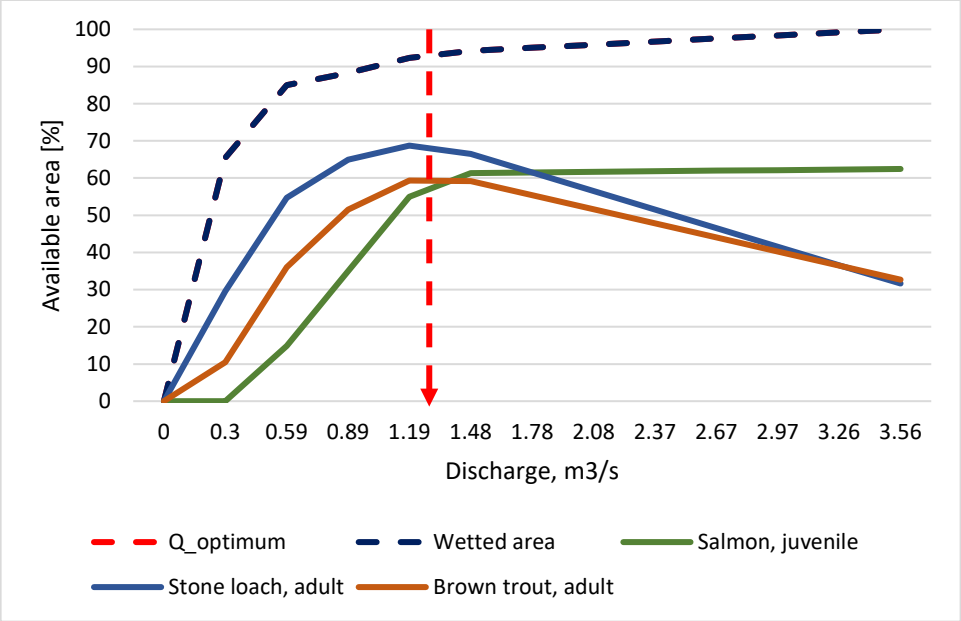


Figure 4.1.1. Habitat-Flow rating curve of Aģe River downstream Aģe HPP

Figures 4.1.2., 4.1.3. and 4.1.4. show habitat suitability maps for brown trout, salmon and stone loach, which are species of high priority for Aģe River.

It is evident that available habitat (optimal and suitable habitats) for adult **brown trout** rapidly increases from the average to the maximum flow of the low flow period, where reaches its maximum value (Figure 4.1.2.). When discharge is larger than the maximum flow of the low flow period, habitat availability starts to decrease, mostly because of too high stream velocity.

Figure 4.1.2. Habitat suitability maps for juvenile brown trout in four different flow conditions

Slightly different habitat suitability trend is observed for **juvenile salmon**. The minimum flow of the low flow period is not suitable for salmon. Habitat rapidly increases from the average to the maximum flow of the low flow period, where reaches its maximum value (Figure 4.1.2).
Habitat does not change if water flow is larger than the maximum flow of the low flow period. According to the Fish conditional model salmon is used to live in more turbulent in-stream conditions than other fish species.

Figure 4.1.3. Habitat suitability maps for juvenile salmon in four different flow conditions

Habitat suitability is different for adult **stone loach**. In low flow conditions almost whole studied river stretch is available for stone loach (41% optimal). Optimal habitat continuously increases until discharge reaches the maximum flow of the low flow period (1.28 m^3/s) and then habitat

suitability slowly decreases. When flow is larger than the maximum flow of the low flow period, only 28% of studied site' habitat is optimal for adult stone loach (Figure 4.1.4.).

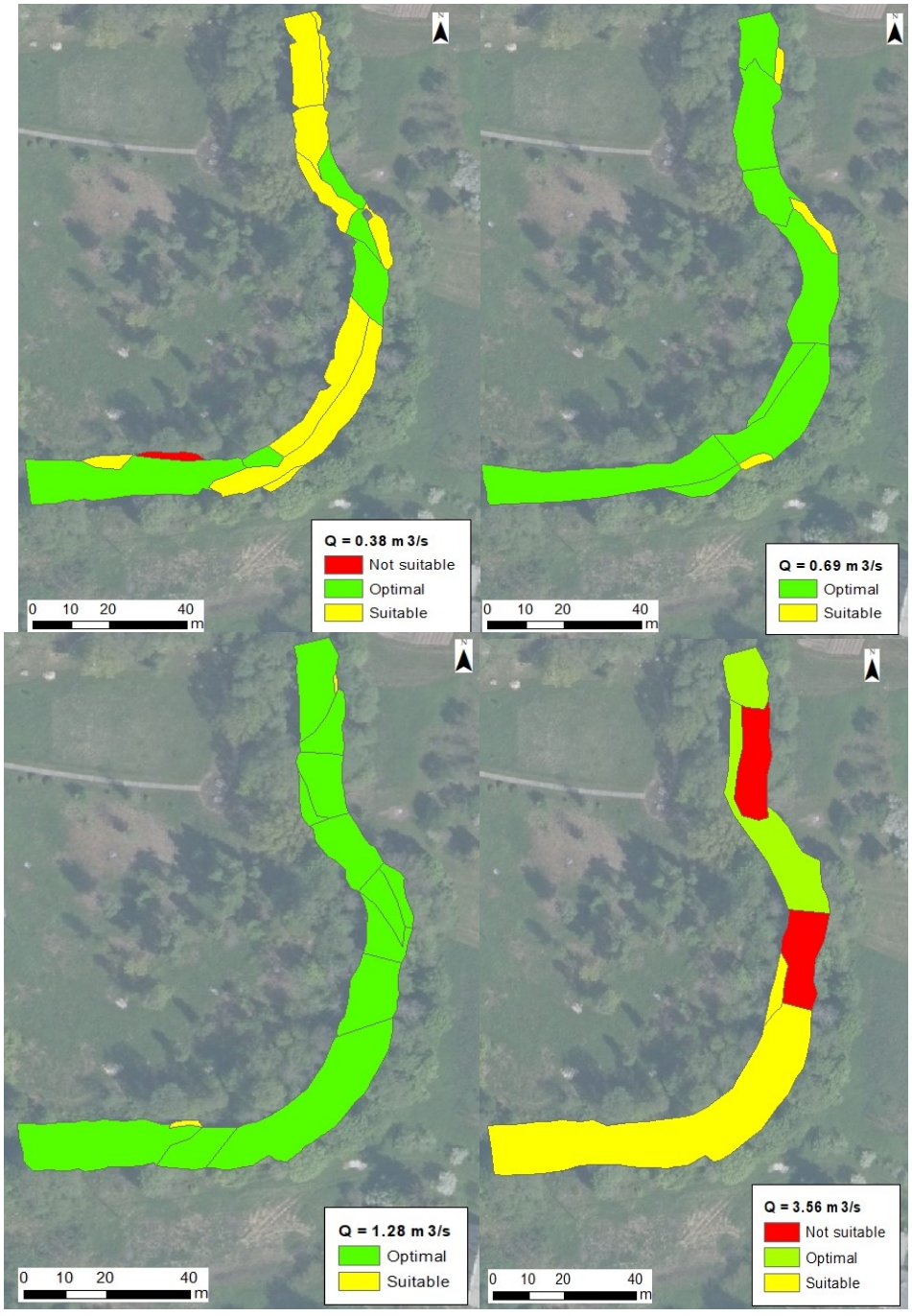


Figure 4.1.4. Habitat suitability maps for adult stone loach in four different flow conditions

Figures 4.1.5 and 4.1.6 show the habitat distribution in time. The red line on pictures is a threshold corresponding of habitat area with 97% of probability, and the blue line is an average habitat area.

Results show that all modelled fish species are under hydromorphological pressure due to habitat loss.

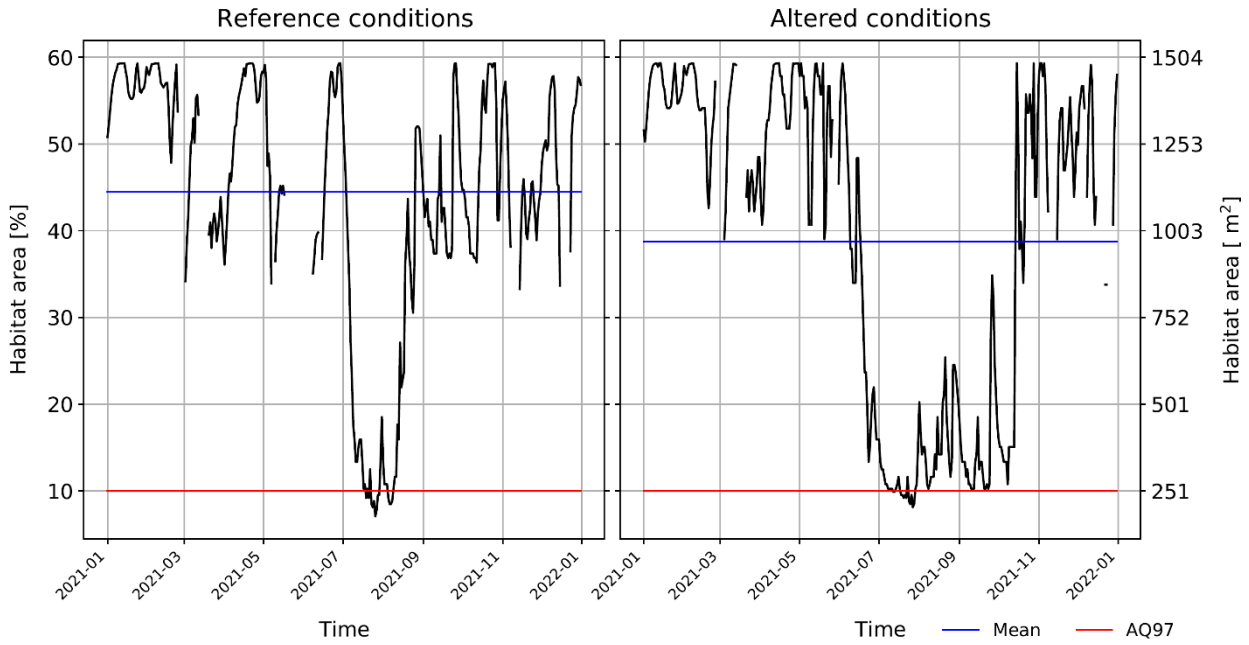


Figure 4.1.5. Habitat time series of the juvenile brown trout in reference and altered conditions

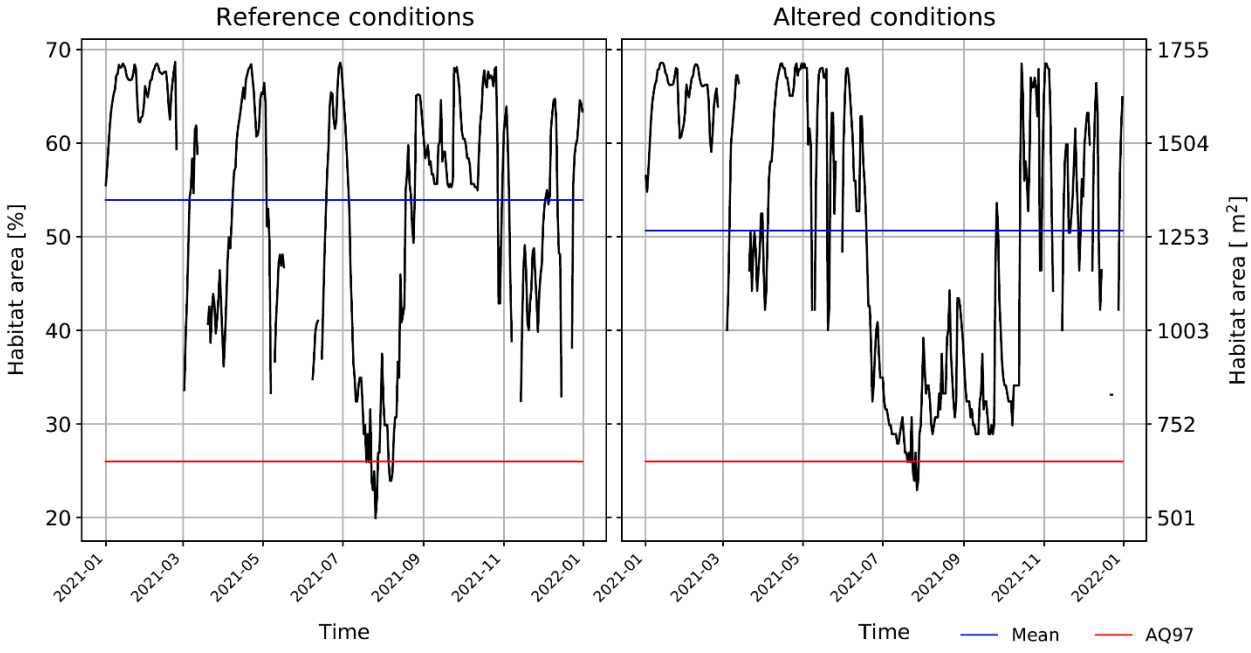


Figure 4.1.6. Habitat time series of the adult stone loach in reference and altered conditions

4.2. Auce River – Bēne HPP

This stretch of the Auce River is not included into List of priority fish waters. There are two HPPs on Auce River and Bēne HPP is the closest one to the river source. According to the Water use permits, the guaranteed water discharge is determined as 0.007 m^3/s and ecological flow is 0.15 m^3/s.

Auce River List of species of interest:

- Adult Eurasian minnow (*Phoxinus phoxinus*),
- Adult stone loach (*Barbatulus barbatulus*),
- Adult chub (*Squalius cephalus*),
- Adult gudgeon (*Gobio gobio*).

Habitat curves for selected fish species depending on flow rate are shown in Figure 4.2.1. These curves were modelled for each fish species of interest (minnow, stone loach, chub and gudgeon) that was pre-selected by fish expert for both Auce River sites. It should be mentioned that this river stretch is naturally unsuitable for chub and gudgeon (river has small catchment area and river bed is relatively shallow even without impact of HPP). It is evident that relationships between water discharge and in-stream habitat availability are very different for studied fish species. In total, available habitat increases with increasing of water discharge and reaches its maximum at the maximum flow of the low flow period (minnow and stone loach) or at the mean annual flow (chub and gudgeon). Optimum flow was defined as the maximum flow of the low flow period taking into account hydromorphological conditions of this river stretch.

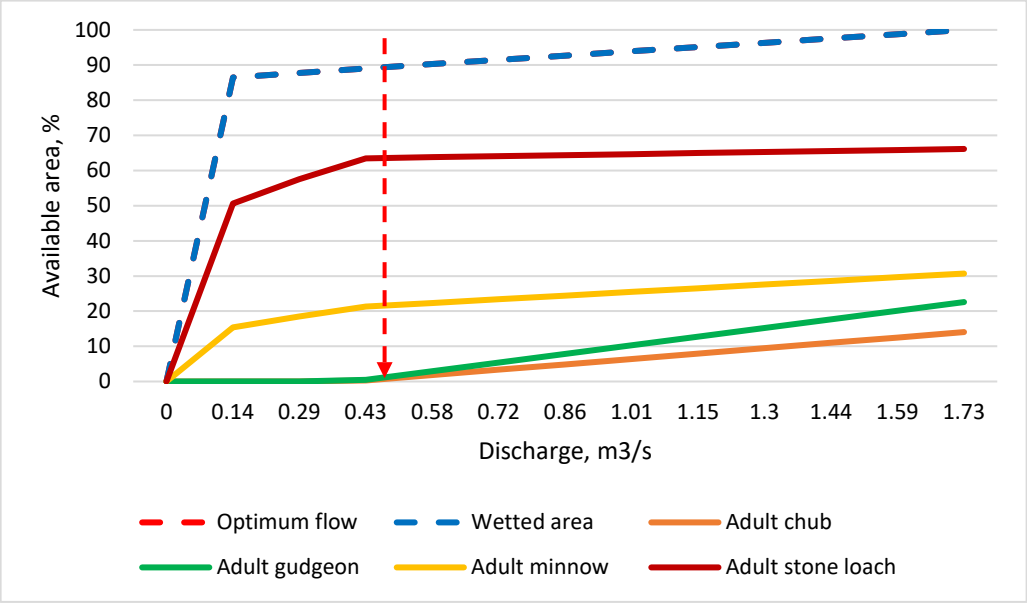


Figure 4.2.1. Habitat-Flow rating curve of Auce River below Bēne HPP

Figures 4.2.2 show habitat suitability maps for the **minnow**. As the water flow increases, so does the suitable habitat area for minnow. It varies from 41% for the minimum flow of the low flow period to 62% for the mean annual flow. Especially rapidly habitat increases in flow conditions between the minimum flow (0.027 m^3/s) and the average flow of the low flow period (0.14 m^3/s).

Figure 4.2.2. Habitat suitability maps for adult Eurasian minnow in four different flow conditions

Different trend can be observed for the adult **stone loach** (Figure 4.2.3). Availability of habitat is relatively high even at the minimum flow of the low flow period (~21% of assessed habitat is optimal and 79% suitable for stone loach). Habitat gradually increases until the maximum flow of the low flow period, where it reaches its maximum value (optimal habit is about 95%).

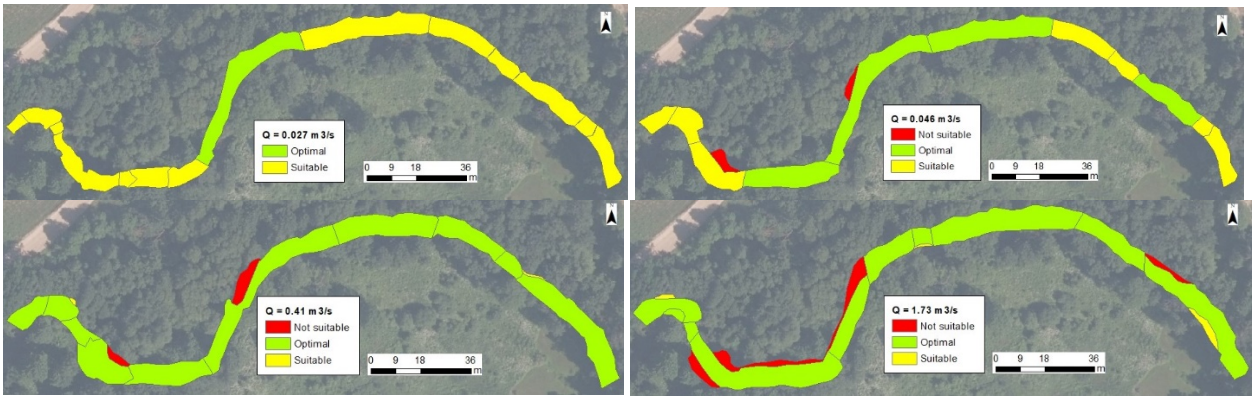


Figure 4.2.3. Habitat suitability maps for adult stone loach in four different flow conditions

Also, habitat' availability for the adult **chub** differs from the other analysed fish species in Auce River (Figure 4.2.4). During low flow period no habitat is available for chub and insignificant habitat increase is observed only at the maximum flow of the low flow period (<1% of studied river reach is suitable). Habitat gradually increases till the mean annual flow, where its suitability reaches 55% of river stretch. It must be taken into account that even at the mean annual flow there is no optimal habitat in this river stretch. Chub is relatively large fish but Auce River at this site is small and shallow, and river naturally is not suitable for such a big fish.

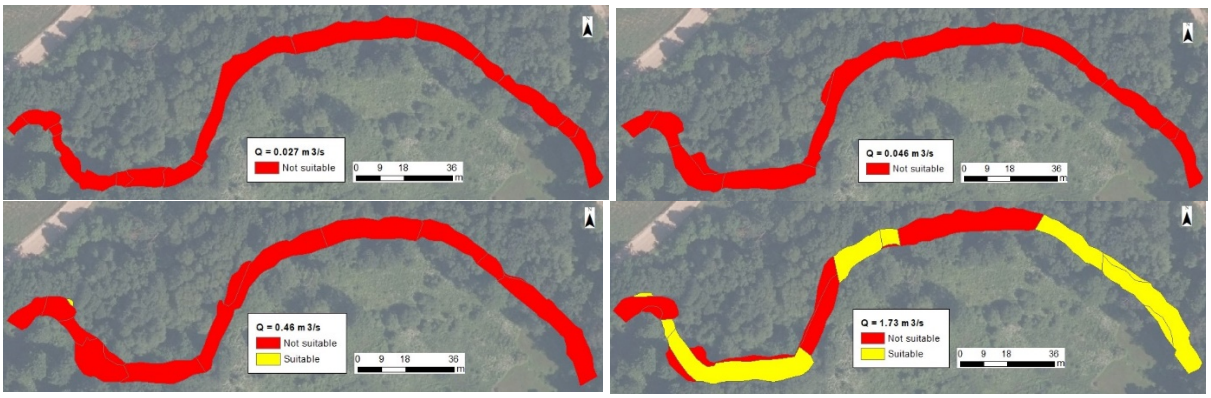


Figure 4.2.4. Habitat suitability maps for adult chub in four different flow conditions

Figures 4.2.5 and 4.2.6 show the habitat distribution in time. The red line on pictures is a threshold corresponding of habitat area with 97% of probability, and the blue line is an average habitat area. Although only two fish species are shown in the example, similar trends can be observed for all modelled indicatorspecies for the Auce River. It is clear that all modelled fish species are under strong hydromorphological pressure due to operating HPP. Even in reference or unaffected conditions during summer- autumn low water period habitats in Auce River are unsuitable for any fish. Obviously in altered conditions (hydrological regime affected by HPP) low water period extends and the habitat loss significantly increases.

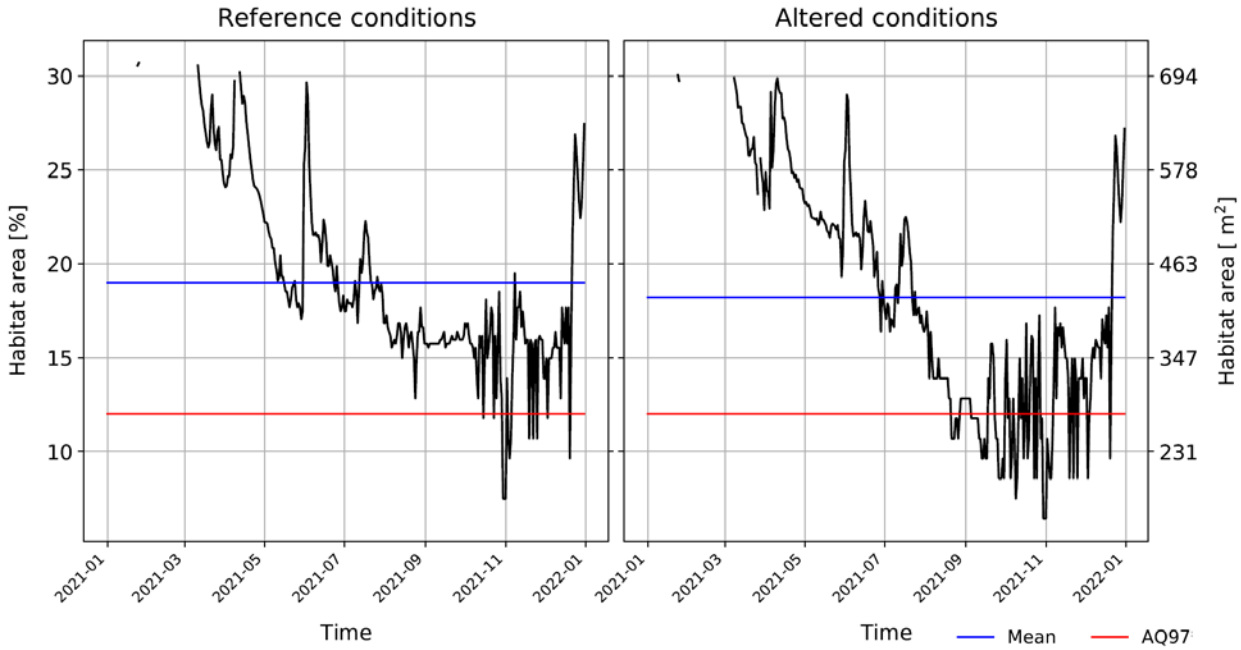


Figure 4.2.5. Habitat time series of the adult minnow in reference and altered conditions

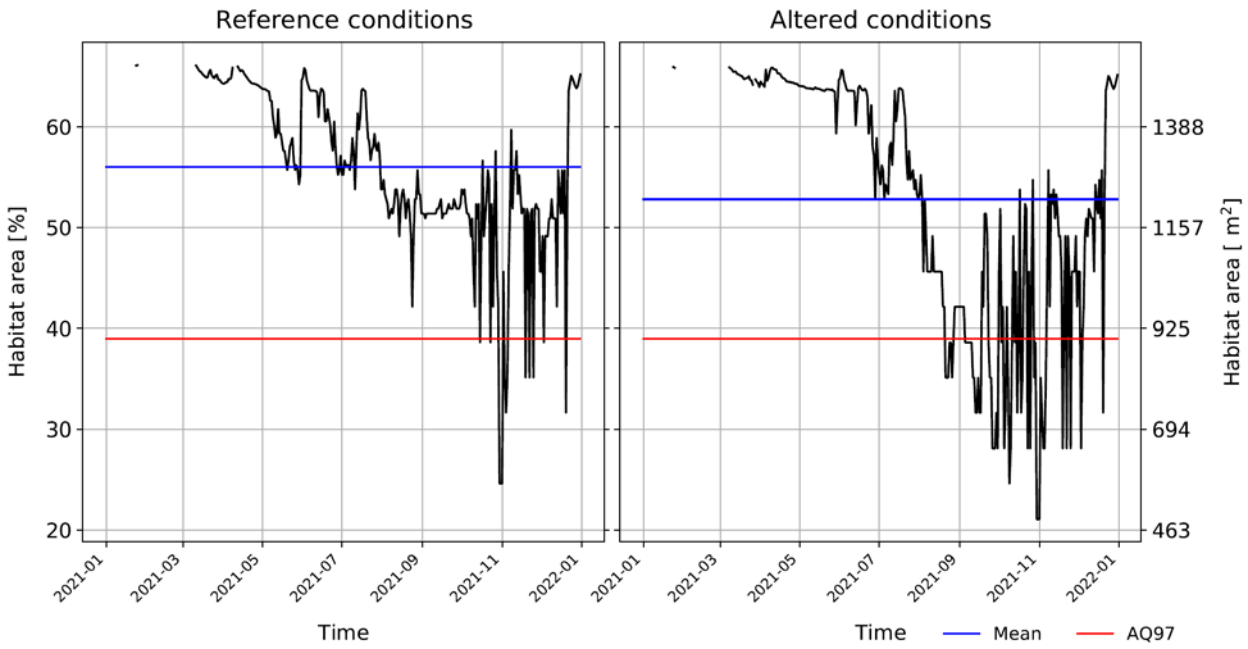


Figure 4.2.6. Habitat time series of the adult stone loach in reference and altered conditions

4.3. Auce River – Kroņauce HPP

This stretch of Auce River is included into List of priority fish waters and belongs to cyprinid fish waters. There are two HPPs on Auce River and Kroņauce HPP is the closest one to the river mouth. According to Water use permits, the guaranteed water discharge is determined as 0.003 m^3/s and ecological flow is equal to the guaranteed water discharge.

Auce River below Kroņauce HPP List of species of interest:

- Adult Eurasian minnow (*Phoxinus phoxinus*),
- Adult stone loach (*Barbatulus barbatulus*),
- Adult chub (*Squalius cephalus*),
- Adult gudgeon (*Gobio gobio*).

Habitat curves for selected fish species depending on flow rate are shown in Figure 4.3.1. These curves have been modelled for each fish species of interest (chub, minnow, stone loach and gudgeon) that was pre-selected by fish expert especially for this Auce River stretch. It is evident that relationships between water discharge and in-stream habitat availability are very similar for all studied fish species. In total, available habitat increases with increasing water discharge and reaches its maximum, when water discharge is close to the maximum flow of the low flow period. This maximum flow value of the low flow period is defined as the optimum flow for this river stretch.

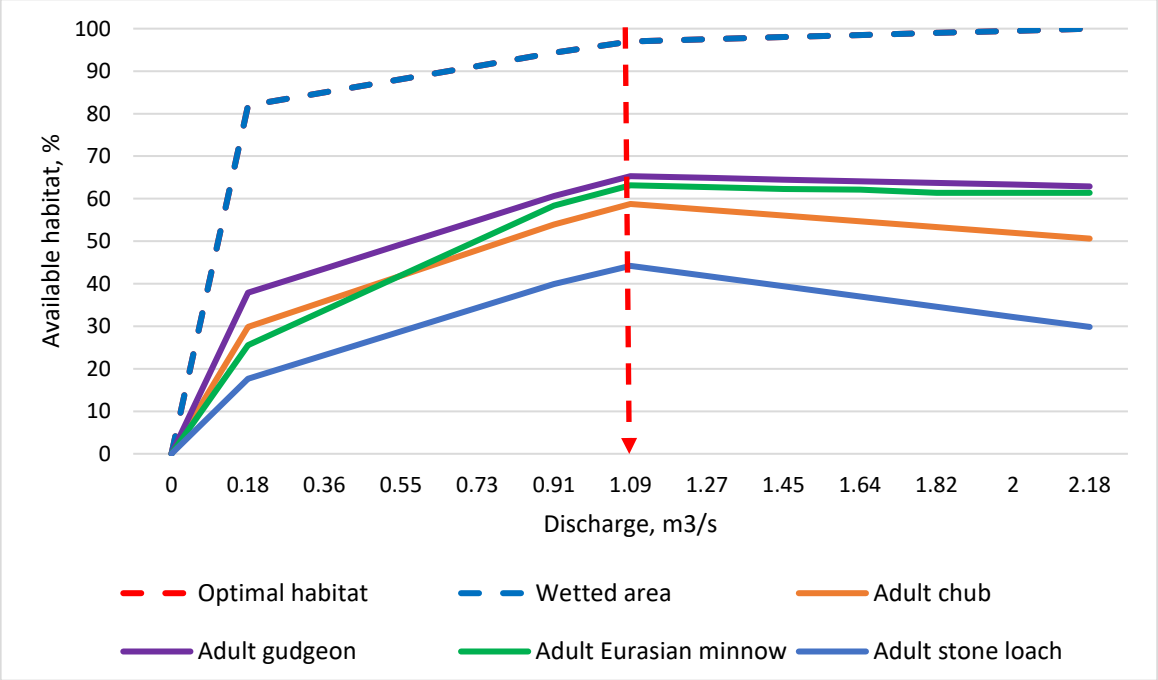
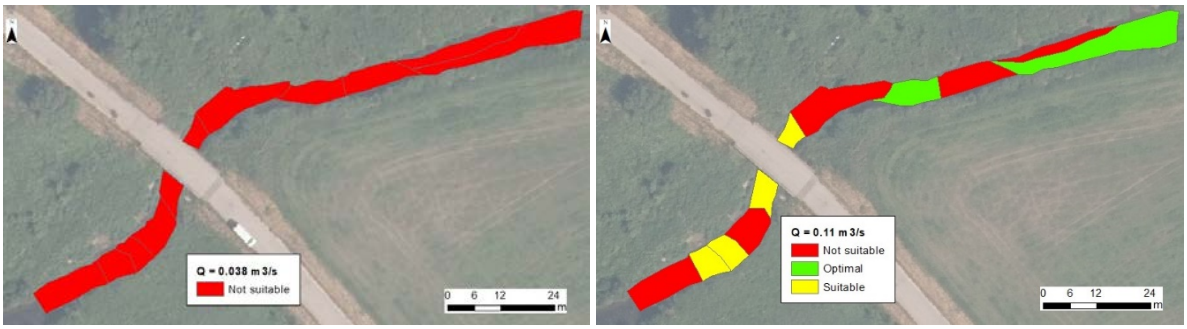


Figure 4.3.1. Habitat-Flow rating curve of Auce River below Kroņauce HPP

Figures 4.3.2 show habitat suitability maps for **minnow**. As the water flow increases, so does the available habitat area for minnow. At the minimum flow of the low flow period no habitat is available for minnow. Available habitat significantly increases from the average flow of the low flow period (~ 49% of river is available for minnow) to the maximum flow of the low flow period (~ 96% of river is available for minnow), where reaches its maximum.



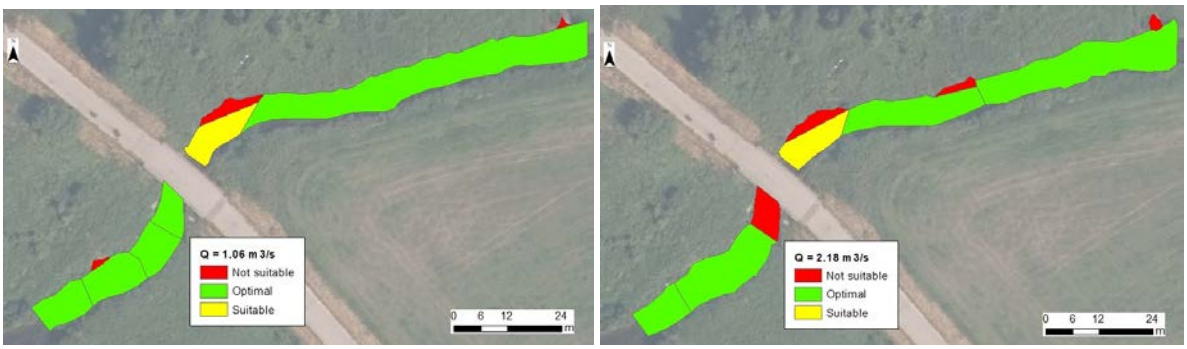


Figure 4.3.2. Habitat suitability maps for adult Eurasian minnow in four different flow conditions

Another trend can be observed for adult **gudgeon** (Figure 4.3.3). At the minimum flow of the low flow period habitat availability is the lowest but ~ 49% river is potentially used for gudgeon. Habitat sharply increases from the minimum to the average flow of the low flow period (73% availability) and then it increases slightly to the maximum flow of the low flow period, where reaches the maximum value (96% of river site is available for gudgeon). When discharge is larger than the maximum flow of the low flow period, habitat availability starts to decrease, mostly because of too high stream velocity. When water discharge is about mean annual flow, habitat for gudgeon slowly decreases, mainly because of too large water depth.

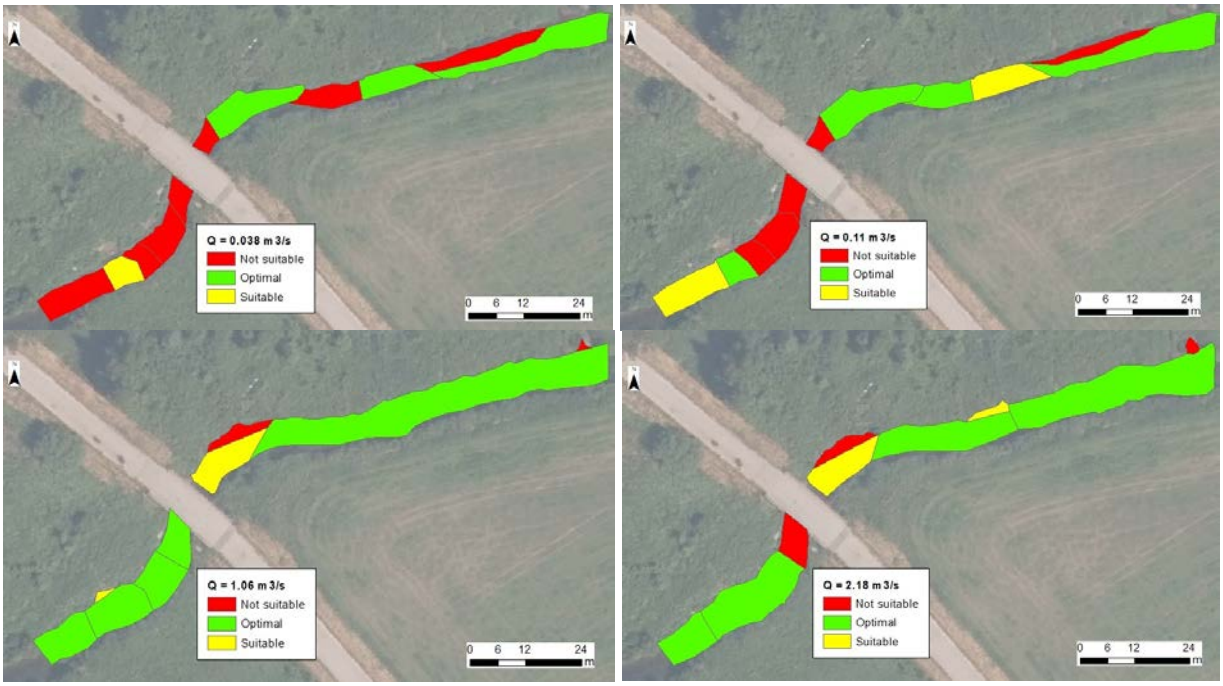


Figure 4.3.3. Habitat suitability maps for adult gudgeon in four different flow conditions

The availability of habitats for the adult **chub** is similar to other selected fish species (Figure 4.3.4). At the minimum flow of the low flow period only about 60% of Auce River is suitable for chub. When water discharge increases, increases also habitat availability and at the maximum flow of the low flow period reaches its maximum. At this time almost whole river stretch is available for

chub (18 % suitable and 81% optimal habitat). If water flow is larger than the maximum flow of the low flow period, habitat availability slowly decreases (40 % suitable and 54% optimal habitat).

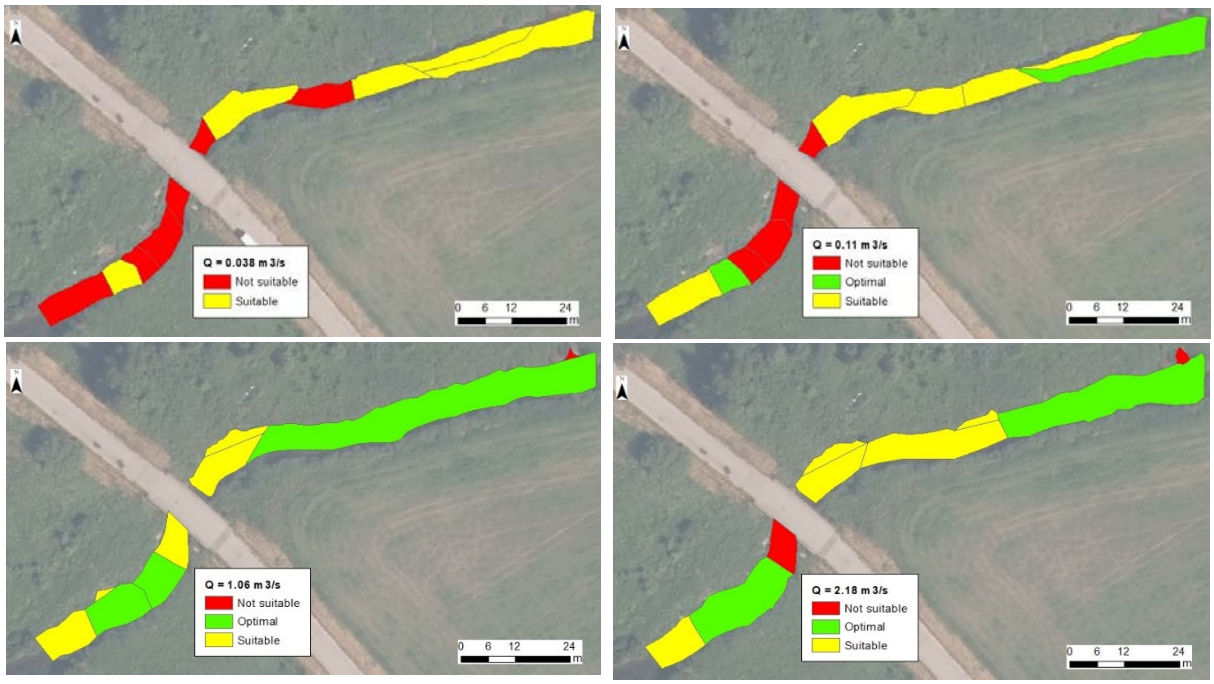


Figure 4.3.4. Habitat suitability maps for adult chub in four different flow conditions

Figures 4.3.5 and 4.3.6 show the habitat distribution in time. The red line on pictures is a threshold corresponding of habitat area with 97% of probability, and the blue line is an average habitat area. Although only two fish species are shown in the example, similar trends are observed for all modelled indicator species in the Auce River. It is clear that in reference conditions (no impact of operating HPP) during summer low flow period there are only some habitat loss events. In altered conditions (hydrological regime affected by HPP) habitat strongly decreases for all fish species but low flow events become longer.

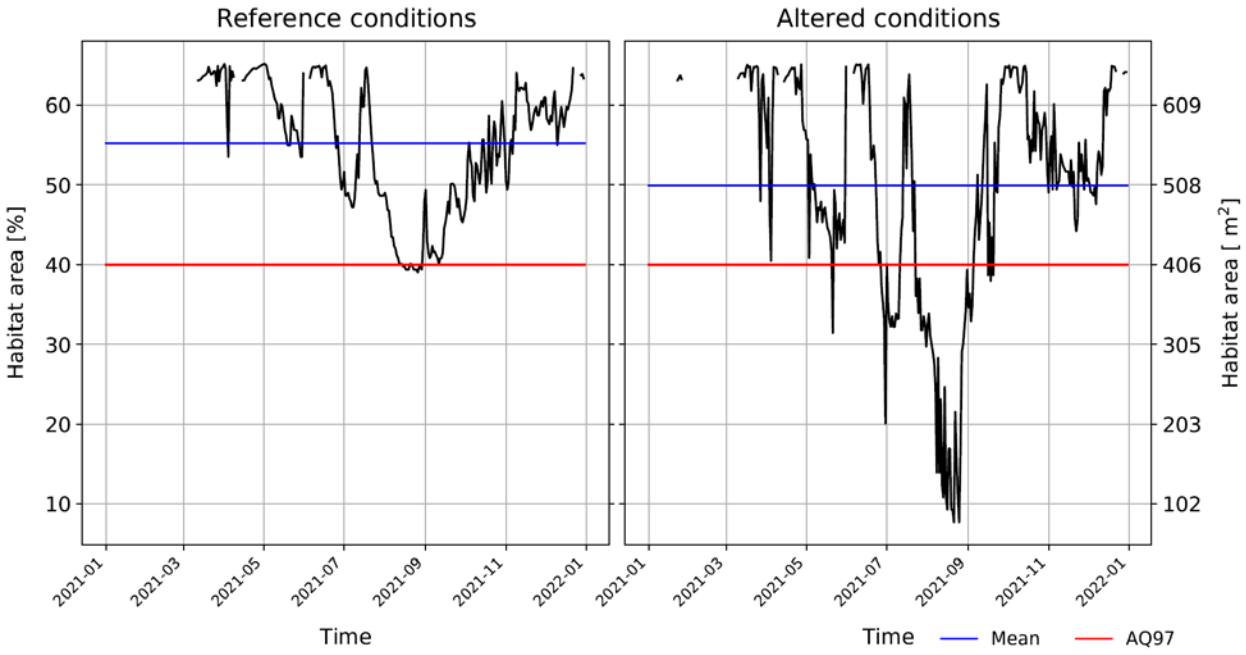


Figure 4.3.5. Habitat time series of the adult gudgeon in reference and altered conditions

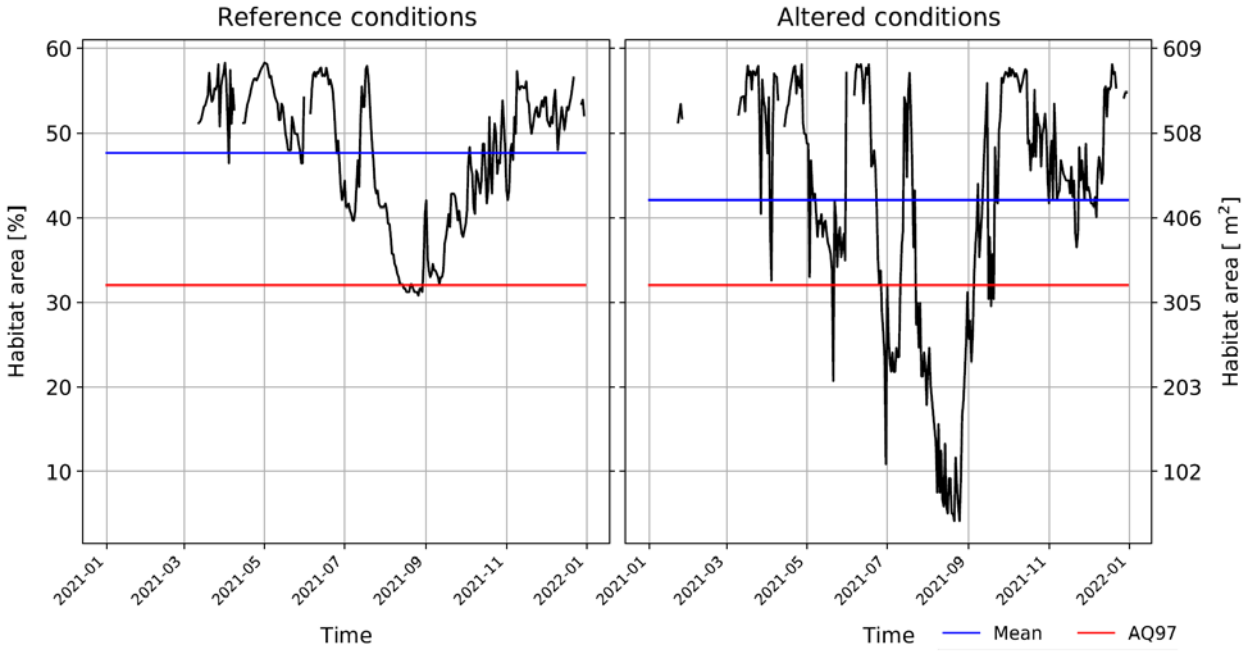


Figure 4.3.6. Habitat time series of the adult chub in reference and altered conditions

4.4. Mergupe River – Brūni HPP

This stretch of Mergupe River is included into the List of priority fish waters and belongs to salmonid fish waters. There are two HPPs on Mergupe River and Brūni HPP is the closest one to

the river mouth. According to Water use permits, the guaranteed water discharge is determined as 0.124 m^3/s, the ecological flow is 0.50 m^3/s.

Mergupe River, below Brūni HPP List of species of interest:

- Adult bullhead (*Cottus gobio*),
- Juvenile brown trout (*Salmo trutta*),
- Adult stone loach (*Barbatulus barbatulus*),
- Adult spirlin (*Alburnoides bipunctatus*).

Habitat curves for selected fish species depending on flow rate are shown in Figure 4.4.1. These curves have been modelled for each fish species of interest (spirlin, brown trout, stone loach and bullhead) that was pre-selected by fish expert especially for this Mergupe River stretch. It is evident that relationships between water discharge and in-stream habitat availability are very similar for the most of studied fish species, except spirlin. In total, available habitat increases slightly with increasing water discharge to the mean annual flow, where reaches the maximum value for the most of selected fish species (bullhead, brown trout and stone loach). Different trend can be observed for spirlin. The graph shows that as the flow increases, habitat increases continuously but the optimal value isn't reached because of unsuitable flow conditions.

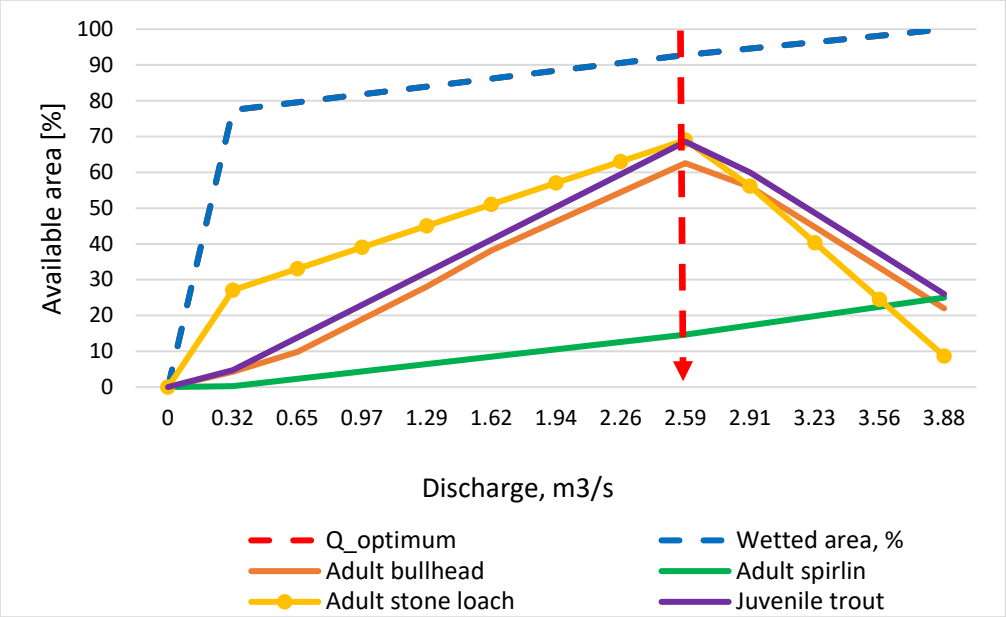


Figure 4.4.1. Habitat-Flow rating curve of Mergupe River downstream Brūni HPP

Figures 4.4.2., 4.4.3. and 4.4.4. show habitat suitability maps for brown trout, bullhead and spirlin, which are species of high priority for Mergupe River, below Brūni HPP.

In lowest flow conditions habitat availability for **juvenile trout** is very low (Figure 4.4.2.), mostly because of insufficient stream velocity. When water discharge is closed to the mean annual flow

(2.63 m^3/s) habitat reaches its maximum and the whole investigated stretch of Mergupe River is optimal for juvenile trout.

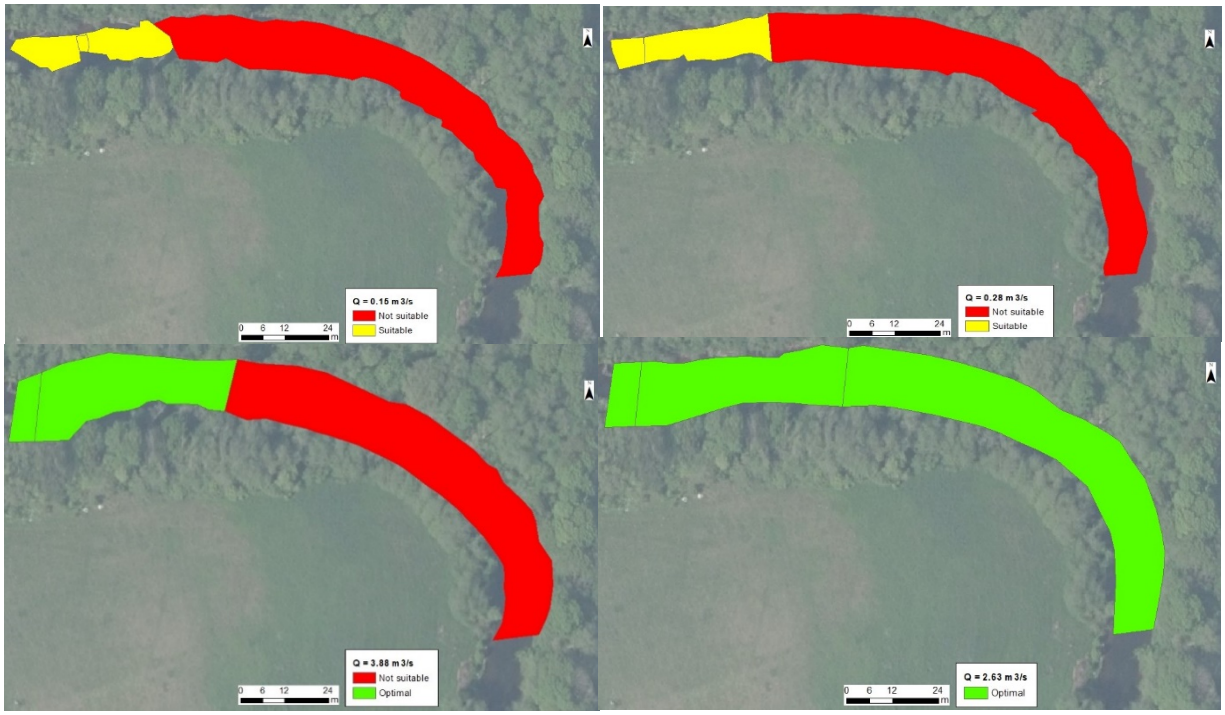
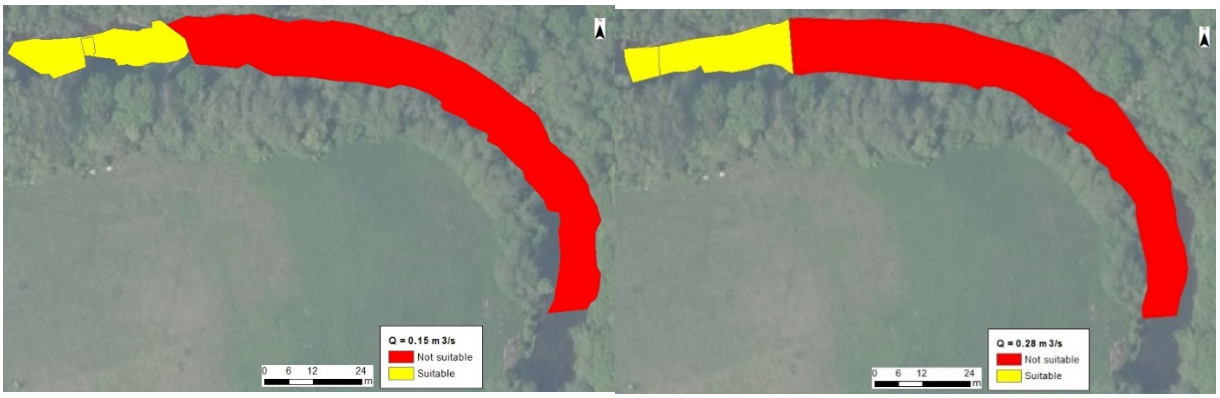


Figure 4.4.2. Habitat suitability maps for juvenile brown trout in four different flow conditions

Similar trend is observed for adult **bullhead** (Figure 4.4.3) with the highest habitat availability at the mean annual flow.



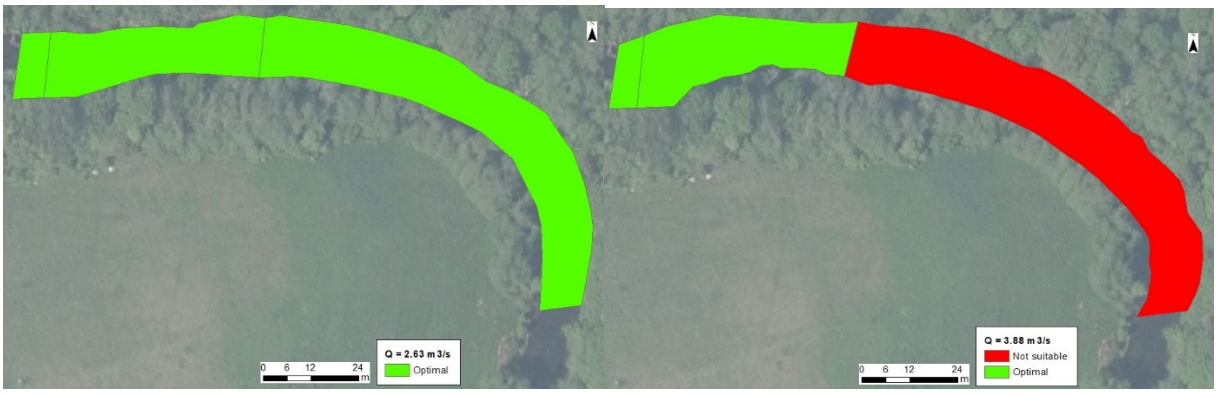


Figure 4.1.3. Habitat suitability maps for adult bullhead in four different flow conditions

Habitat suitability is very different for adult **spirlin**. In low flow conditions (discharges 0.15 m^3/s and 0.28 m^3/s) river is unsuitable for spirlin at all. Habitat gradually increases from the maximum flow of the low flow period to the mean annual flow (Figure 4.4.4.). According to fish conditional model, spirlin prefers deep rivers and high flow velocity that may be naturally too high threshold for this part of river.

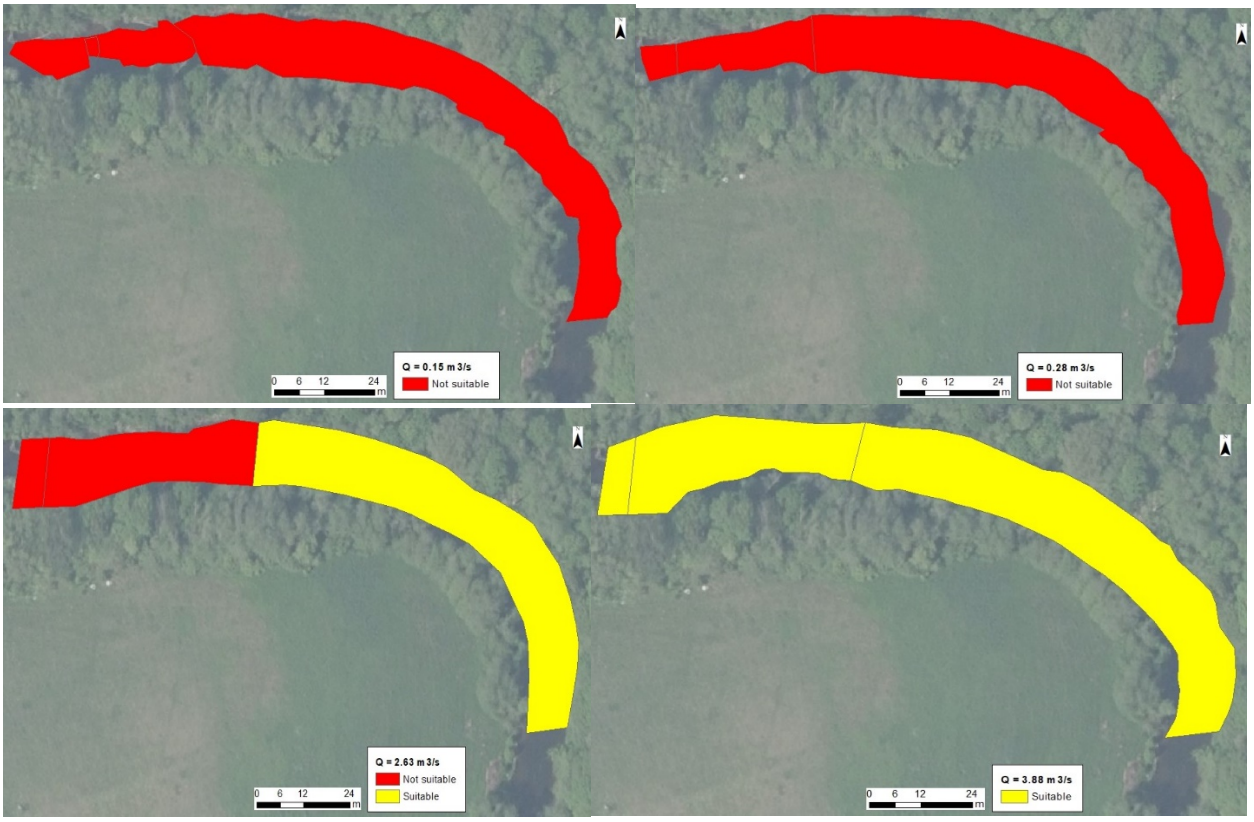


Figure 4.4.4. Habitat suitability maps for adult spirlin in four different flow conditions

Figures 4.4.5 and 4.4.6 show the habitat distribution in time. The red line on pictures is a threshold corresponding of habitat area with 97% of probability, and the blue line is an average habitat area.

Although only two fish species are shown in the example, similar trends can be observed for all modelled indicatorspecies. Results show that all modelled fish species are under hydromorphological pressure due to habitat loss.

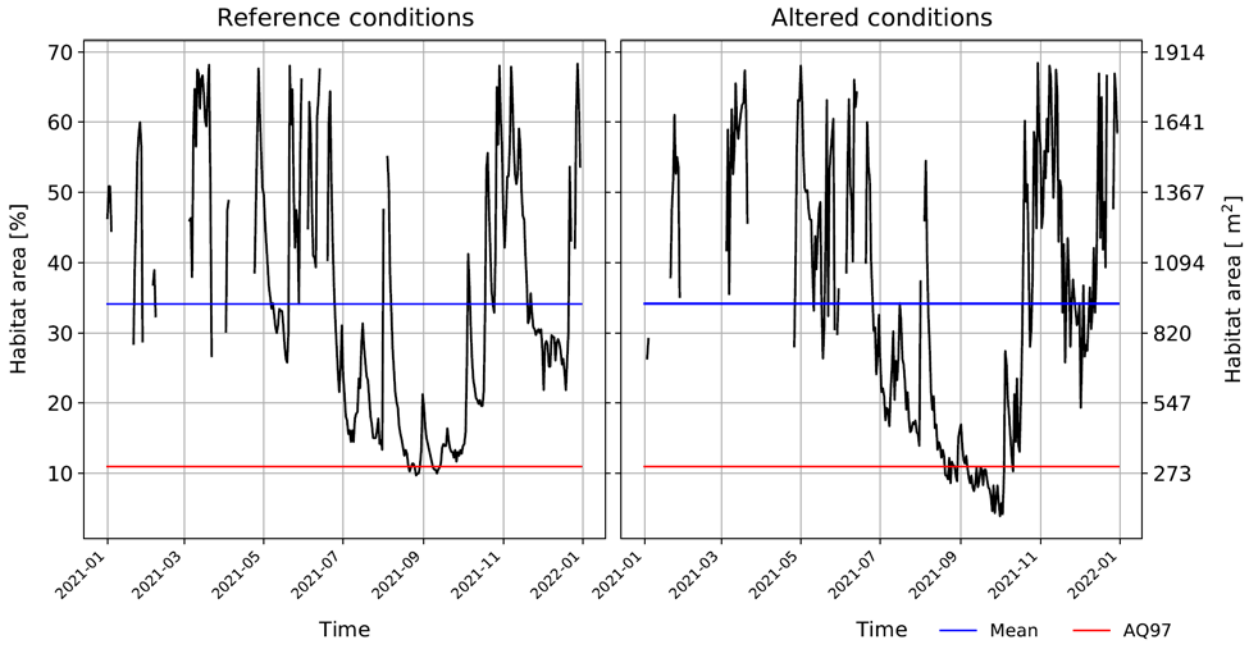


Figure 4.4.5. Habitat time series of the juvenile brown trout in reference and altered conditions

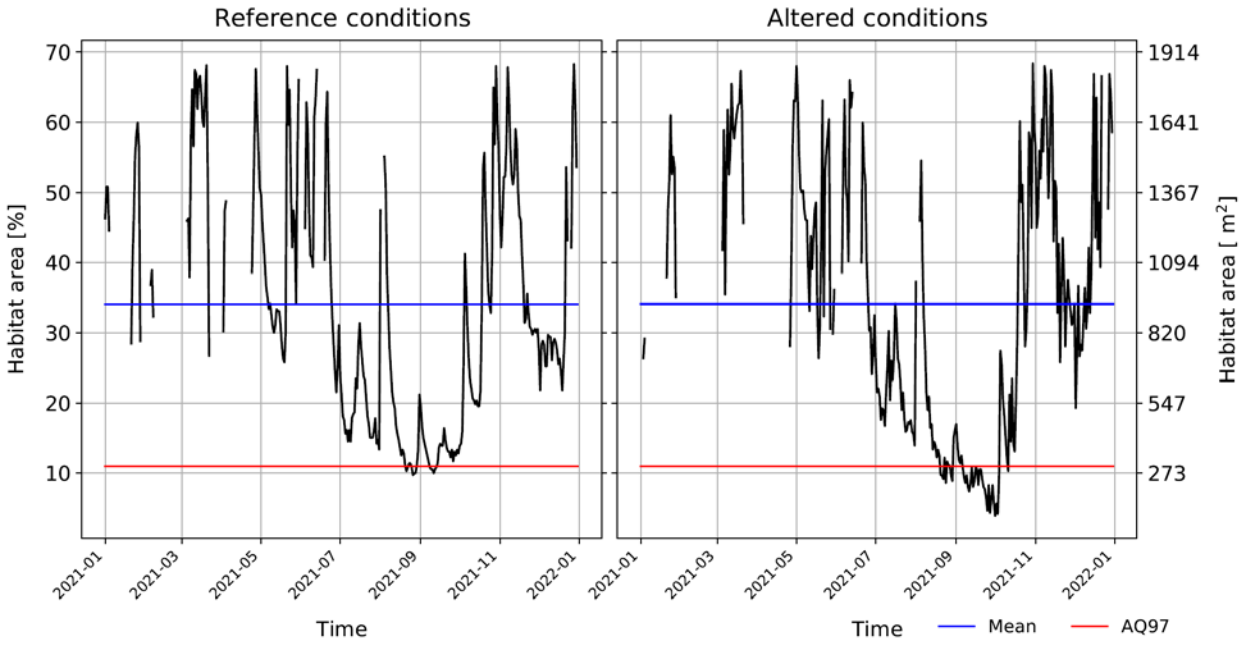


Figure 4.4.6. Habitat time series of the adult bullhead in reference and altered conditions

4.5. Mergupe River – Krīgaļi HPP

This stretch of Mergupe River is included into List of priority fish waters and belongs to salmonid fish waters. There are two HPPs on Mergupe River and Krīgaļi HPP is the closest one to the river source. According to Water use permits, the guaranteed water discharge is determined as 0.015 m^3/s and ecological flow is 0.12 m^3/s.

Mergupe River, below Krīgaļi HPP List of species of interest:

- Adult bullhead (*Cottus gobio*),
- Juvenile brown trout (*Salmo trutta*),
- Adult spirlin (*Alburnoides bipunctatus*).

Habitat curves for selected fish species depending on flow rate are shown in Figure 4.5.1. These curves were modelled for each fish species of interest (spirlin, brown trout, and bullhead) that was pre-selected by fish expert especially for this Mergupe River stretch. It is evident that relationships between water discharge and in-stream habitat availability are very similar for all of studied fish species. In total, available habitat increases with increasing water discharge and reaches its maximum at annual average flow (~0.79 m^3/s) that is defined as the optimum flow. In lowest flow conditions available habitat for selected fish species is about 10% of total assessed habitat area of the Mergupe River stretch below Krīgaļi HPP.

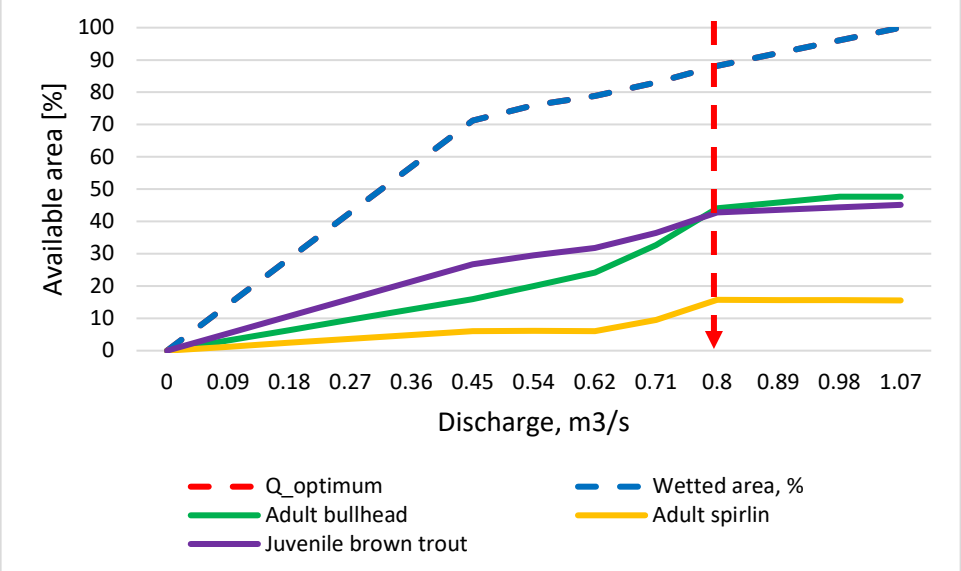


Figure 4.5.1. Habitat-Flow rating curve of Mergupe River below Krīgaļi HPP

Figures 4.5.2, 4.5.3 and 4.5.4 show habitat suitability maps for brown trout, bullhead and spirlin, which are species of high priority for Mergupe River, below Krīgaļi HPP.
At lowest discharges habitat availability for juvenile **brown trout** also is relatively low (Figure 4.5.2), mostly because of insufficient river depth. When water discharge is closed to the annual

average flow (~0.79 m^3/s) habitat availability reaches its maximum and the whole investigated river stretch is optimal or suitable for juvenile trout.

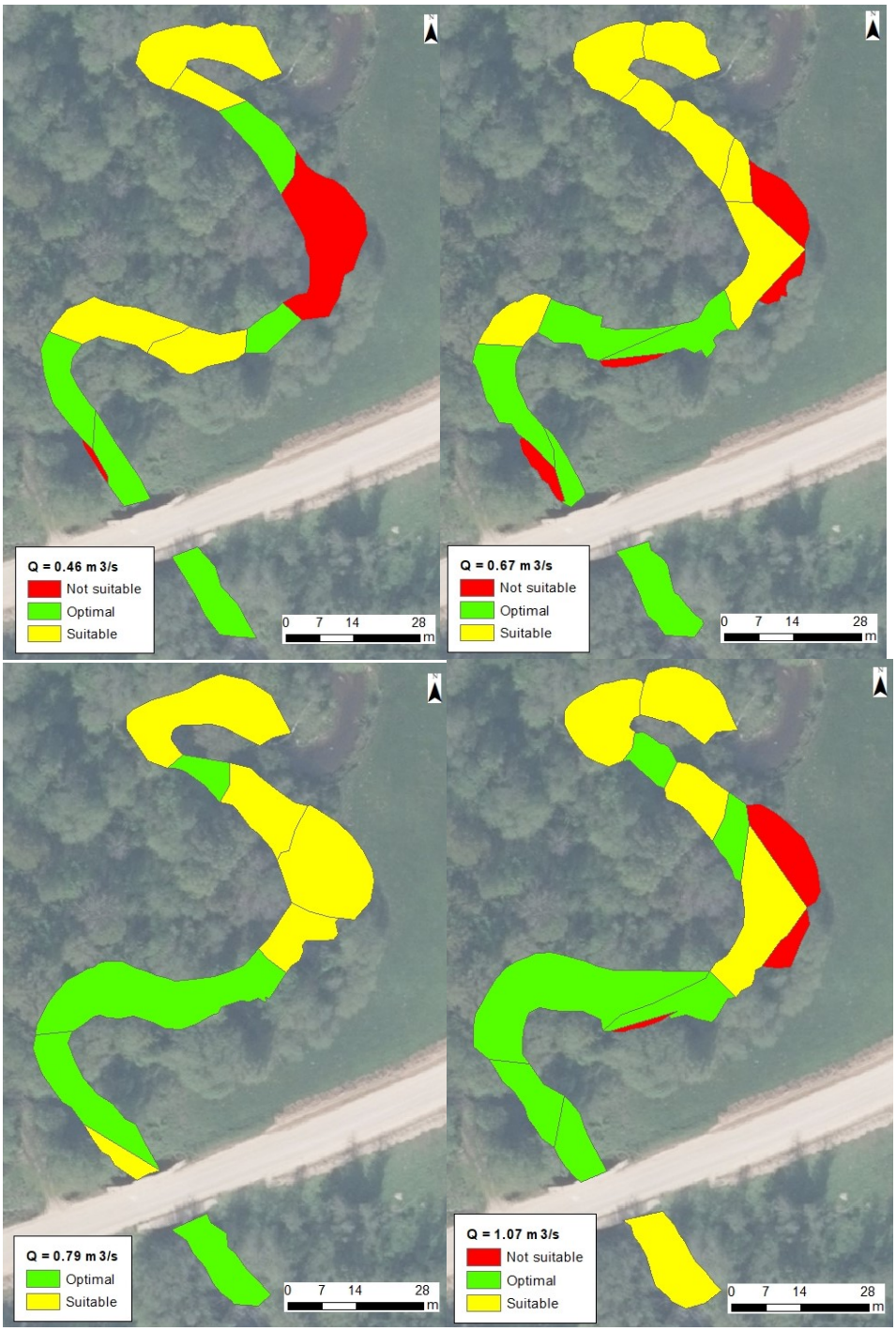


Figure 4.5.2. Habitat suitability maps for juvenile brown trout in four different flow conditions

Similar trend is observed for adult **bullhead** (Figure 4.5.3) with the highest habitat availability observed at mean annual flow.

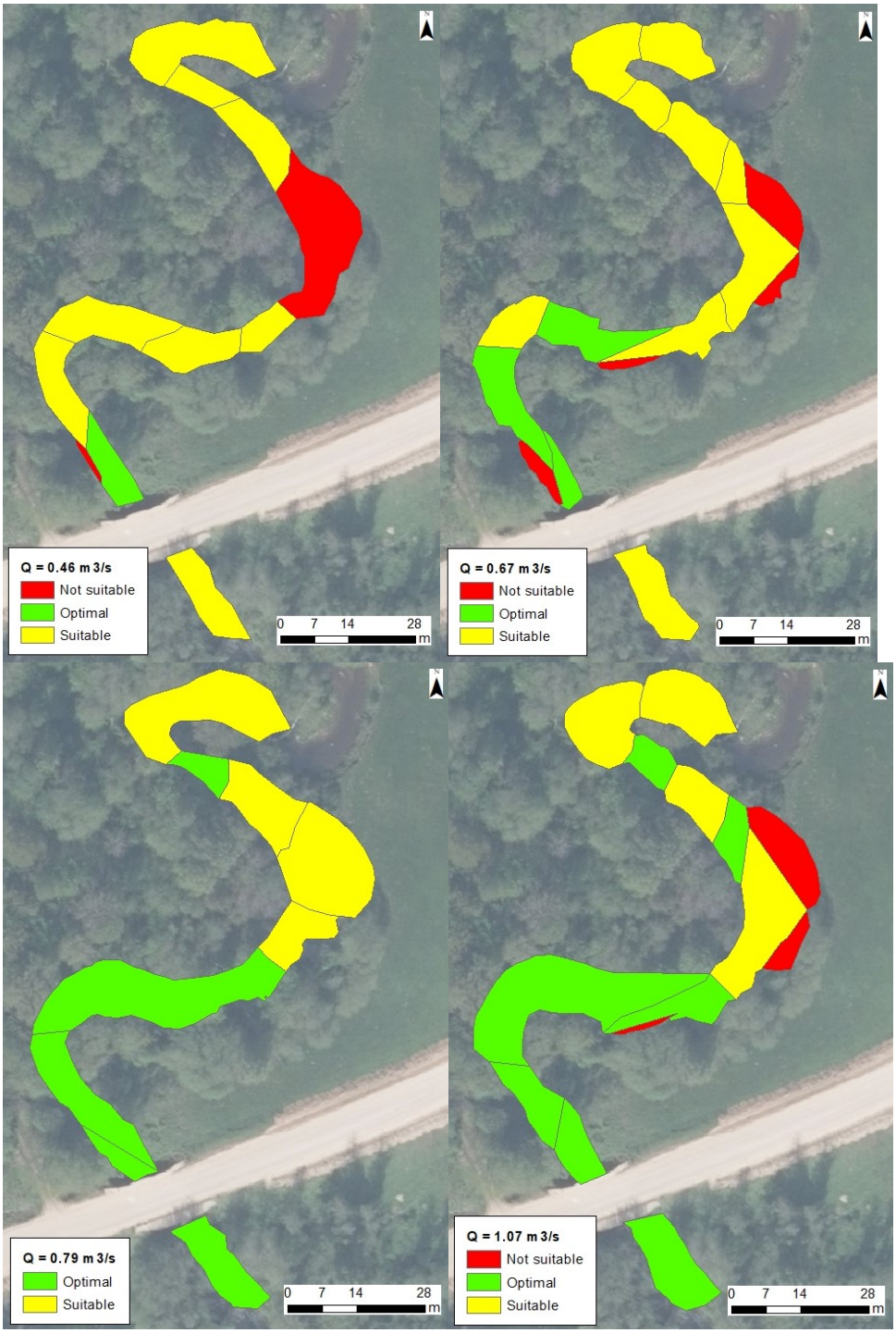


Figure 4.5.3. Habitat suitability maps for adult bullhead in four different flow conditions

Habitat suitability is different for adult **spirlin** (Figure 4.5.4). This fish prefers deep waters with relatively high flow velocity and hard substrate. Mergupe River downstream Krīgaļi HPP is naturally small and relatively shallow. The deep places can be found only in pools but the flow

velocity there is very low. Therefore, this section of the river is naturally not suitable for spirlin in general. Even at the annual average flow the suitable habitat reaches only 16% of assessed habitat area, but at the maximum flow of the low flow period its only 6%.

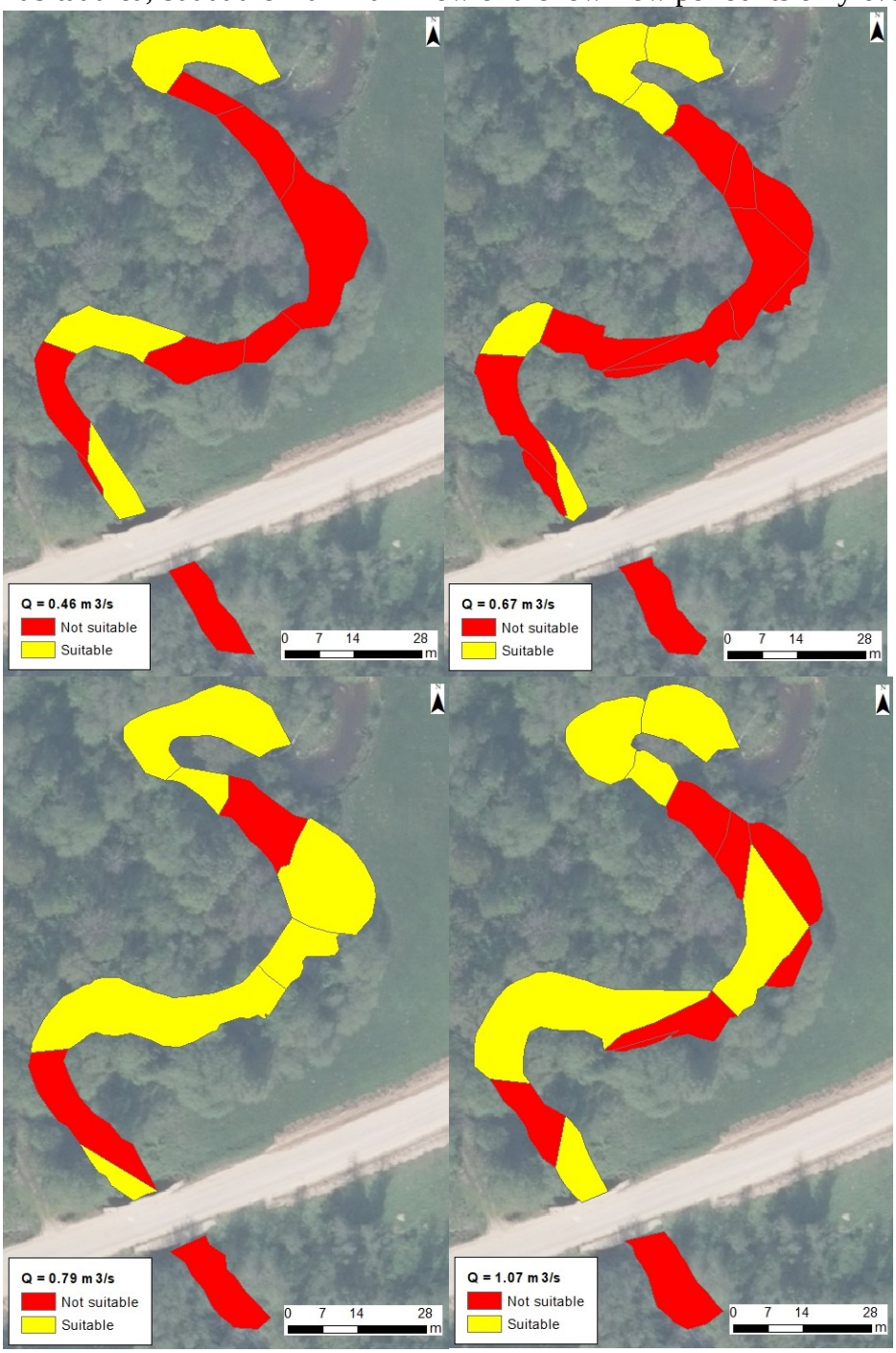


Figure 4.5.4. Habitat suitability maps for adult spirlin in four different flow conditions

Figures 4.5.5 and 4.5.6 show the habitat distribution in time. The red line on pictures is a threshold

corresponding of habitat area with 97% of probability, and the blue line is an average habitat area. Although only two fish species are shown in the example, similar trends can be observed for all modelled indicatorspecies. Results show that all modelled fish species are under strong hydromorphological pressure due to habitat loss. It is clear that the fluctuation of water flow caused by the HPP operating has the greater effect on the brown trout because of high sensitivity of this fish (Figure 4.5.5).

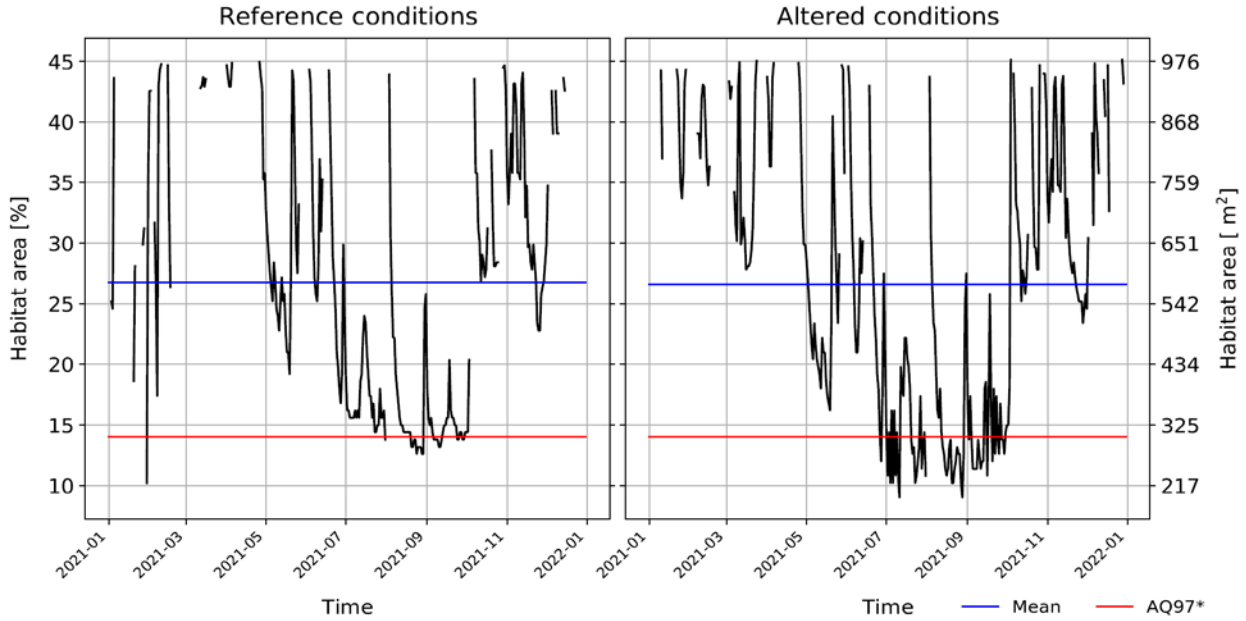


Figure 4.5.5. Habitat time series of the juvenile brown trout in reference and altered conditions

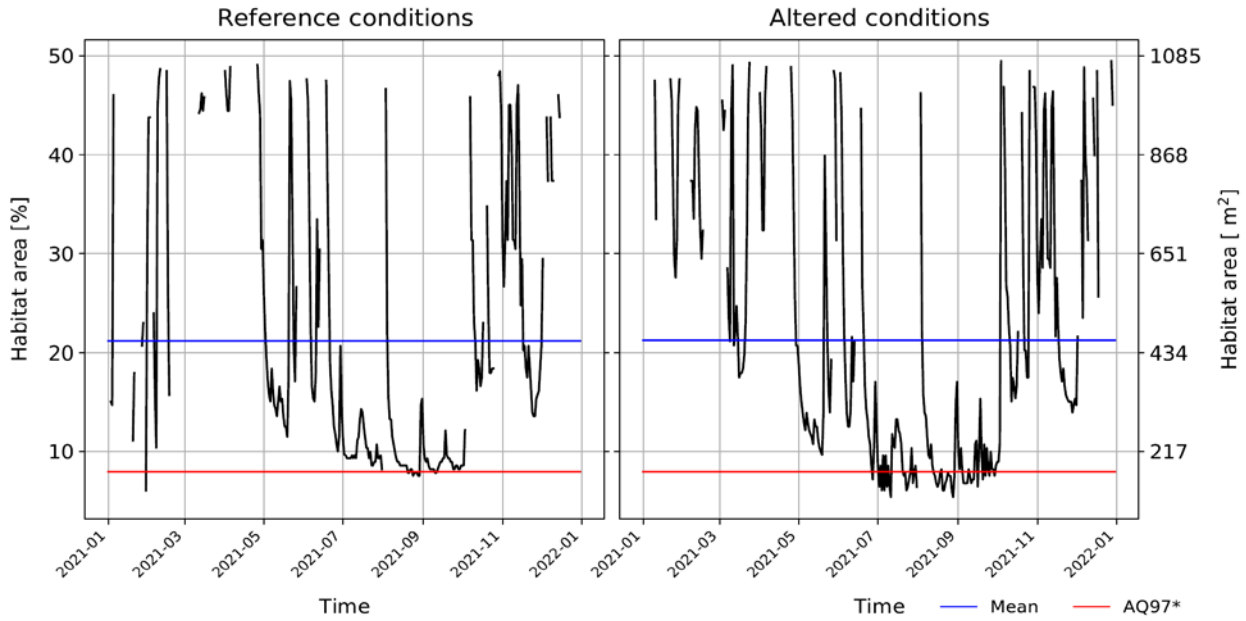


Figure 4.5.6. Habitat time series of the adult bullhead in reference and altered conditions

4.6. Zaņa River – Pampāļi HPP

This part of Zaņa River into List of priority fish waters and belongs to cyprinid fish waters. There are two HPPs on Zaņa River and Pampāļi HPP is the closest one to the river source. According to Water use permits, the guaranteed water discharge is determined as 0.039 m^3/s and ecological flow is 0.20 m^3/s.

Zaņa River below Pampāļi HPP List of species of interest:

- Adult chub (*Squalius cephalus*),
- Adult Eurasian minnow (*Phoxinus phoxinus*),
- Adult stone loach (*Barbatulus barbatulus*),
- Adult bullhead (*Cottus gobio*).

Habitat curves for selected fish species depending on flow rate are shown in Figure 4.6.1. These curves have been modelled for each fish species of interest (chub, minnow, stone loach and bullhead) that was pre-selected by fish expert especially for this river stretch. It is evident that relationships between water discharge and in-stream habitat availability are different for studied fish species.

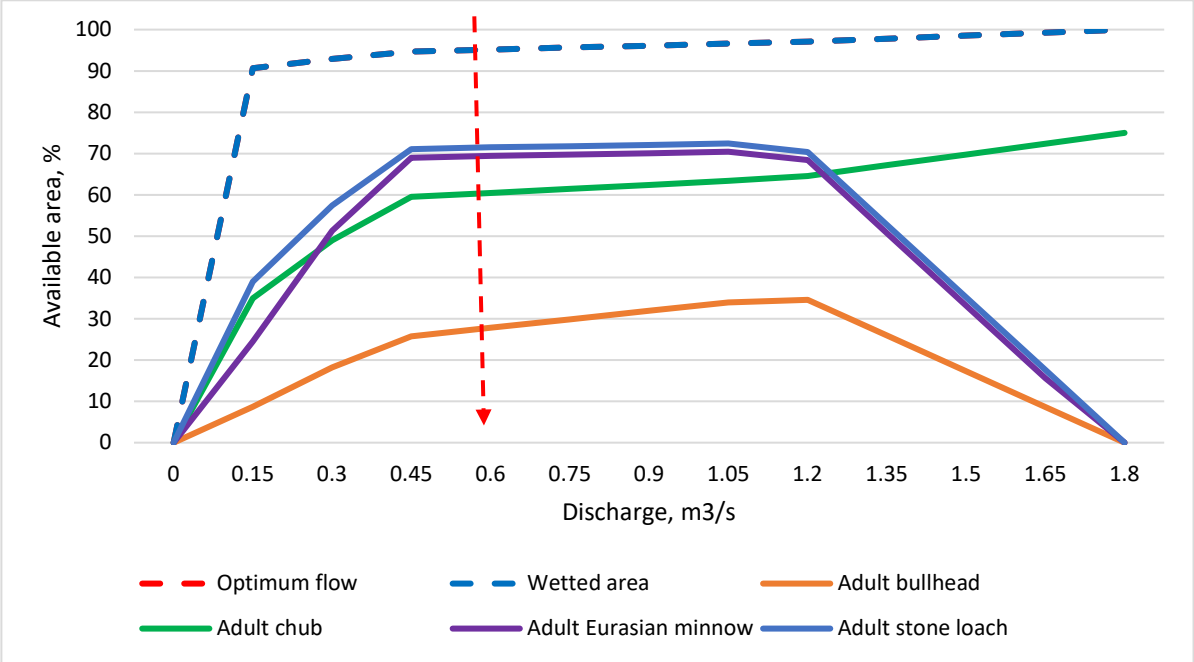


Figure 4.6.1. Habitat-Flow rating curve of Zaņa River below Pampāļi HPP

For stone loach and Eurasian minnow available habitat reaches its maximum at the average flow of the low flow period (0.41 m^3/s), and then it increases slightly to the mean annual flow. Habitat of bullhead reaches its maximum at the maximum flow of the low flow period. Habitat of chub continues to increase even at annual average flow, because this fish needs deep waters. Taking into

account all above mentioned conditions, the water discharge close to low flow maximum flow (0.60 m^3/s) is determined as the optimum flow for the Zaņa River at Pampāļi.

Figures 4.6.2, 4.6.3 and 4.6.4 show habitat suitability maps for bullhead, stone loach and chub. Habitat availability is very variable for different fish species in Zaņa River.

At the minimum flow of the low flow period no habitat is available for **bullhead** (Figure 4.6.2), mostly because of insufficient river depth and stream velocity. Habitat starts to increase at the average flow of the low flow period (all studied habitat is available for bullhead and 3% of it is optimal for this fish) and reaches its maximum at the maximum flow of the low flow period (24% of habitat is optimal). At the annual average flow no habitat is available for adult bullhead, mostly because of too high river depth.

Figure 4.6.2. Habitat suitability maps for adult bullhead in four different flow conditions

Different trend can be observed for **adult chub** (Figure 4.6.3). As the water discharge increases, the area of the optimal habitat also increases. At the minimum flow of the low flow period all assessed habitat is suitable for chub, but no optimal habitats can be found. At the average flow of the low flow period about 75% of habitat is optimal for chub, and it slightly increases with flow increasing. At the mean annual flow all assessed habitats are optimal for chub. According to the Fish conditional model, chub prefers deep waters with low flow velocity that is typical for Zaņa River.

Figure 4.6.3. Habitat suitability maps for adult chub in four different flow conditions

Habitat suitability for adult **stone loach** is shown in Figure 4.6.4. At the minimum flow of the low flow period all assessed habitats are suitable for stone loach. Habitat rapidly increases from the minimum flow to the average flow of the low flow period, where becomes optimal for stone loach. There is no habitat availability changes from the average and maximum flow of the low flow period. Rapid decrease of available habitat is observed between the maximum flow of the low flow period and the mean annual flow. At the mean annual flow no habitat is available for stone loach, because of depth increasing.

Figure 4.6.4. Habitat suitability maps for adult stone loach in four different flow conditions

Figures 4.6.5 and 4.6.6 show the habitat distribution in time. The red line on pictures is a threshold corresponding of habitat area with 97% of probability, and the blue line is an average habitat area. Although only two fish species are shown in the example, similar trends can be observed for all modelled indicatorspecies within Zaņa River. It is clear that under reference conditions (no impact

of operating HPP) there are some habitat loss events during summer low flow period. Under altered conditions (hydrological regime is affected by HPP) habitat loss strongly increases for all fish species – it is more substantial than in reference conditions.

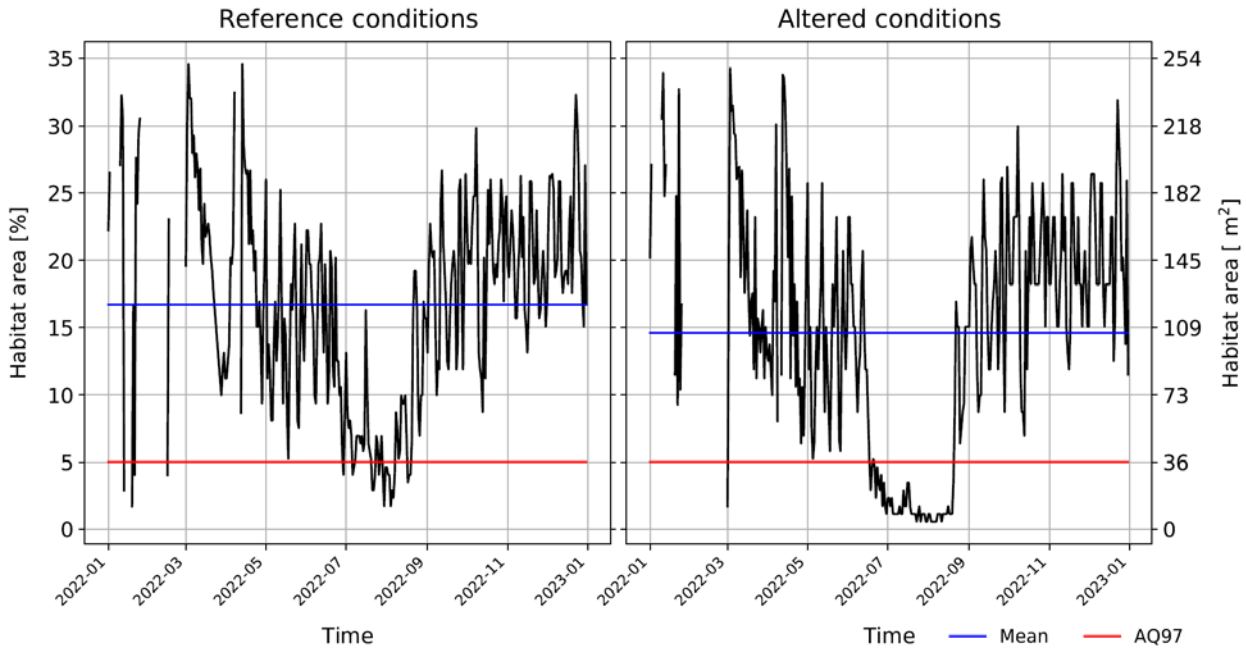


Figure 4.6.5. Habitat time series of the adult bullhead in reference and altered conditions

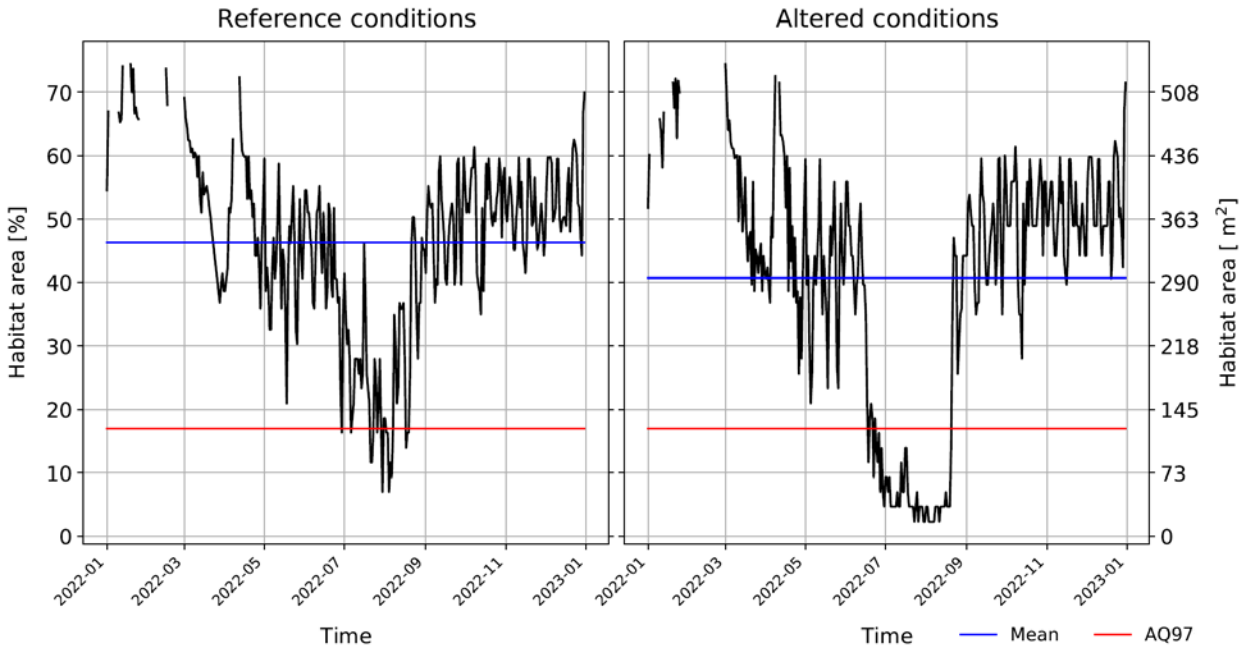


Figure 4.6.6. Habitat time series of the adult chub in reference and altered conditions

4.7. Zaņa River – Zaņa HPP

This part of Zaņa River is included into List of priority fish waters and belongs to cyprinid fish waters. There are two HPPs on Zaņa River and Zaņa HPP is the closest one to the river mouth. According to Water use permits, the guaranteed water discharge is determined as 0.069 m^3/s and ecological flow is 0.32 m^3/s.

Zaņa River, below Zaņa HPP List of species of interest:

- Adult chub (*Squalius cephalus*),
- Adult Eurasian minnow (*Phoxinus phoxinus*),
- Juvenile brown trout (*Salmo trutta*).

Habitat curves for selected fish species depending on flow rate are shown in Figure 4.7.1. These curves have been modelled for each fish species of interest (chub, minnow and brown trout) that was pre-selected by fish expert especially for this Zaņa River site. It is evident that relationships between water discharge and in-stream habitat availability are very similar for studied fish species. During low flow period habitat availability is low and doesn't exceed 14% of total assessed area. Habitat area gradually increases from the minimum flow to the maximum flow of the low flow period, where reaches the maximum value. As the discharge continues to increase to the mean annual, no increase in available habitat area is observed. The maximum flow of the low flow period is defined as optimum flow for Zaņa River below Zaņa HPP.

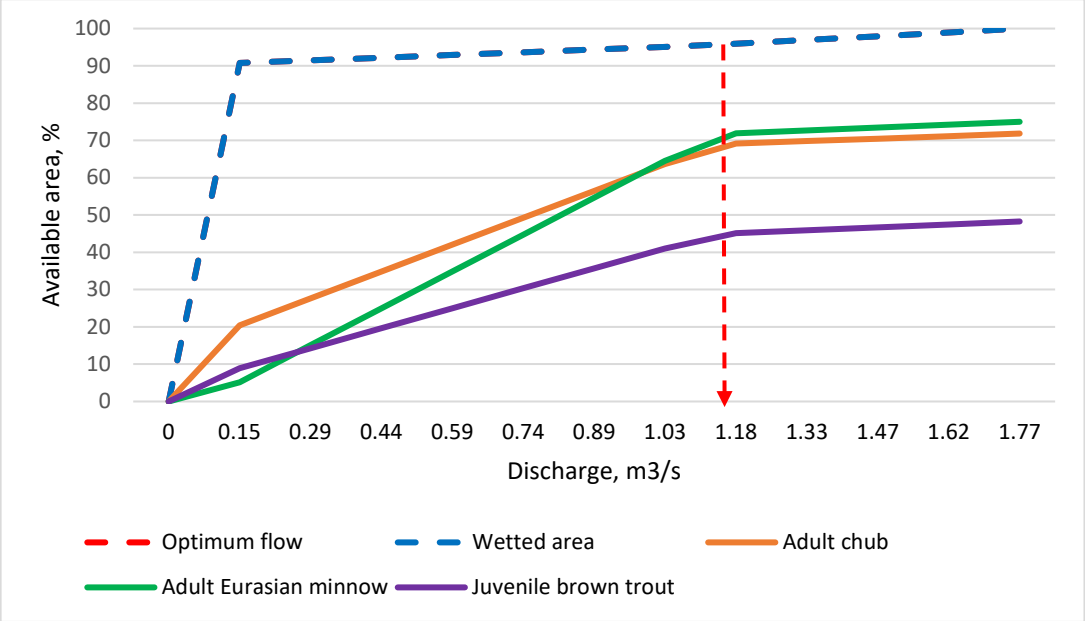


Figure 4.7.1. Habitat-Flow rating curve of Zaņa River below Zaņa HPP

Figures 4.7.2, 4.7.3 and 4.7.4 show habitat suitability maps for **minnow**, brown trout and chub. Habitat availability is very similar for different fish species in Zaņa River. At the minimum flow and the average flow of the low flow period no habitat is available for minnow, mostly because of insufficient stream velocity (Figure 4.7.2). Available habitat rapidly increases and reaches its maximum at the maximum flow of the low flow period (whole assed stretch is optimal for minnow). There is almost no habitat changes, when water flow exceeds the maximum flow of the low flow period.

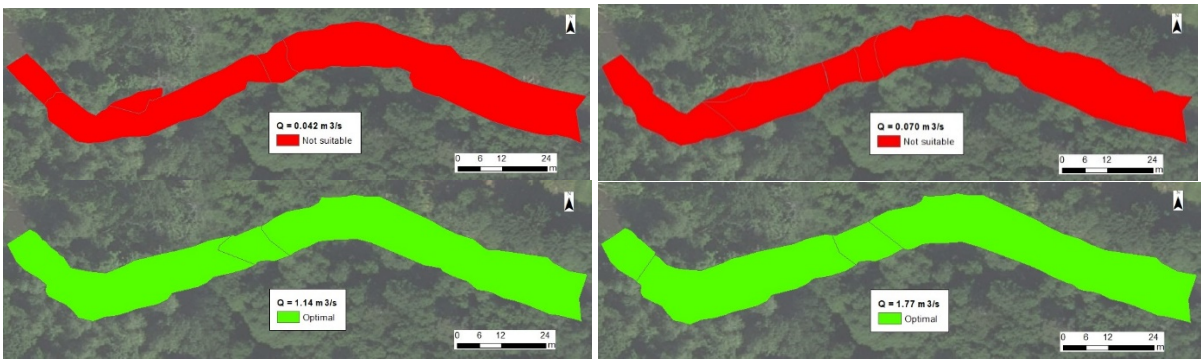


Figure 4.7.2. Habitat suitability maps for adult Eurasian minnow in four different flow conditions

Slightly different trend can be observed for adult **chub** (Figure 4.7.3). Habitat increases from the minimum flow of the low flow period (suitable area - 57%) to the maximum flow of the low flow period (94% of assessed area is optimal and 6% are suitable), where reaches its maximum value. There is no habitat changes, when water flow exceeds the maximum flow of the low flow period.

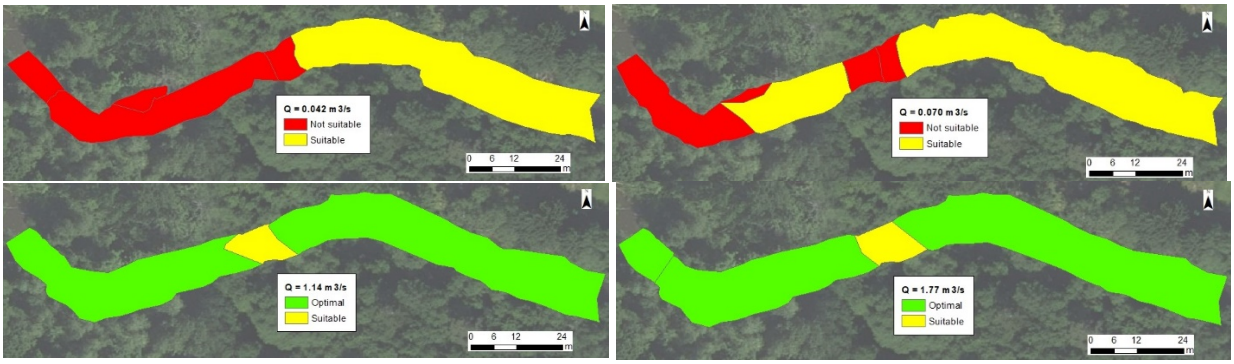


Figure 4.7.3. Habitat suitability maps for adult chub in four different flow conditions

Habitat suitability for juvenile **brown trout** is shown in Figure 4.7.4. Habitat increases from the minimum flow of the low flow period (suitable area - 10% %) to the maximum flow of the low flow period (54% of assessed area is optimal and 44% is suitable), where reaches its maximum value. Habitat slightly increases, when water flow exceeds the maximum flow of the low flow period.

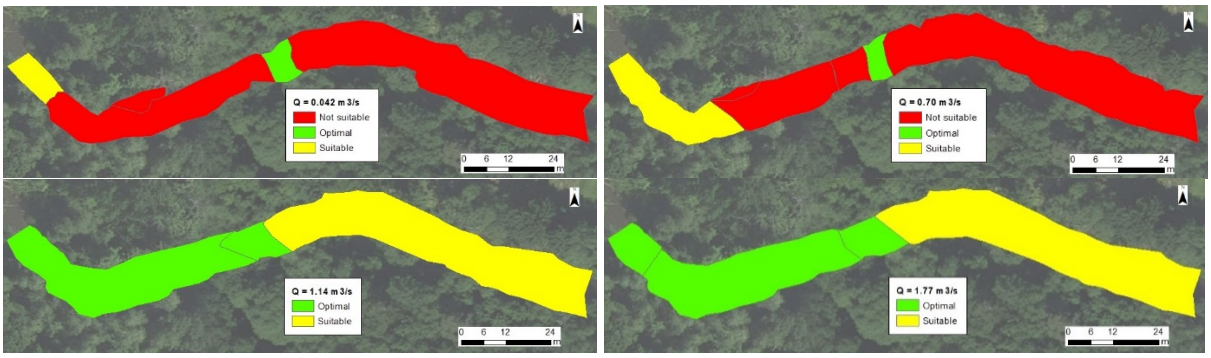


Figure 4.7.4. Habitat suitability maps for juvenile brown trout in four different flow conditions

Figures 4.7.5 and 4.7.6 show the habitat distribution in time. The red line on pictures is a threshold corresponding of habitat area with 97% of probability, and the blue line is an average habitat area. Although only two fish species are shown in the example, similar trends can be observed for all modelled indicatorspecies within Zaņa River. It is clear that in reference conditions (no impact of operating HPP) there are some small habitat loss events during summer low flow period. In altered conditions (hydrological regime affected by HPP) habitat loss increases for all fish species.

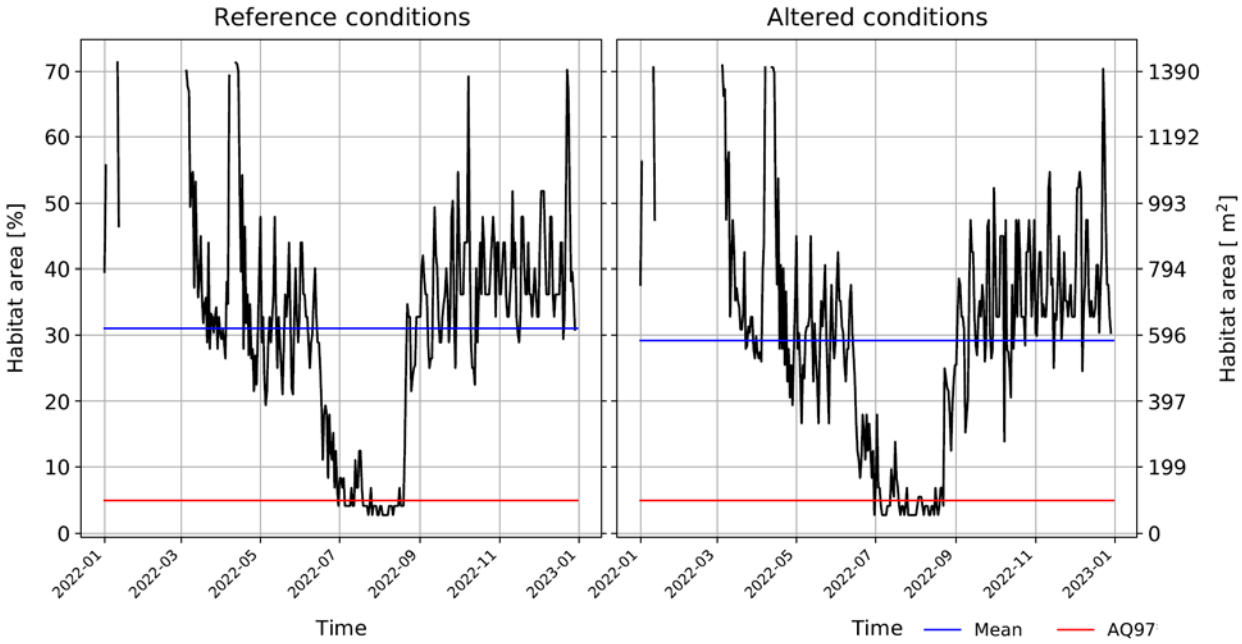


Figure 4.7.5. Habitat time series of the adult chub in reference and altered conditions

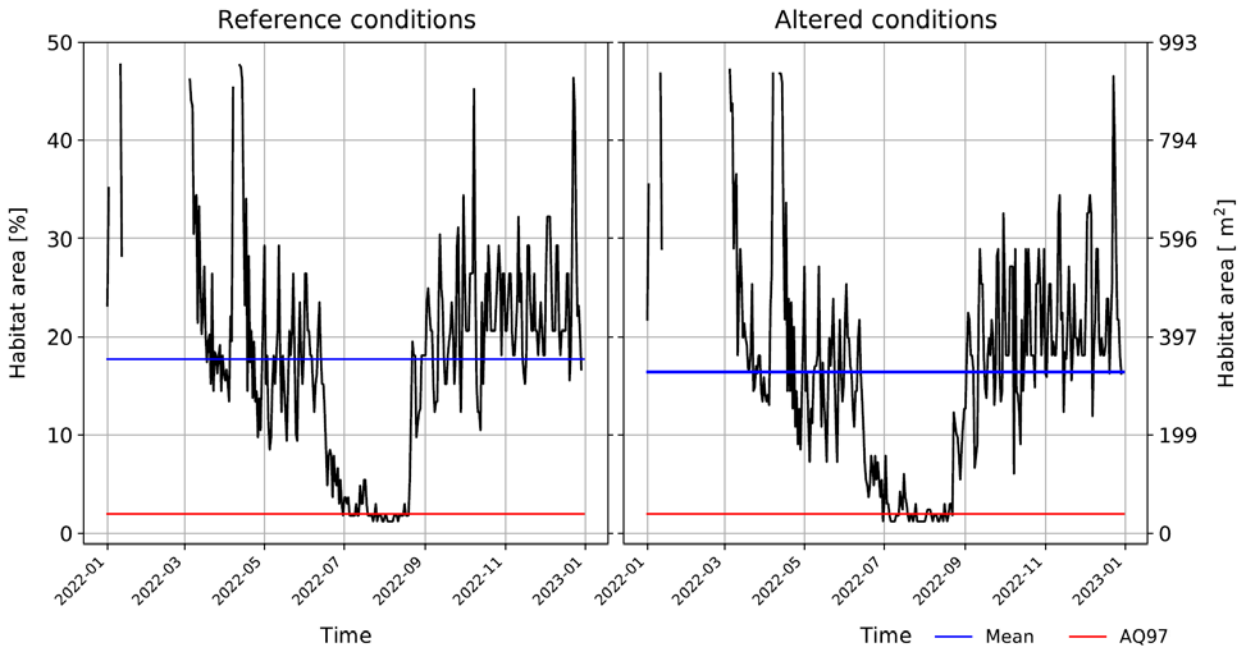


Figure 4.7.6. Habitat time series of the juvenile brown trout in reference and altered conditions

V. E-FLOW EVALUATION FOR PILOT RIVERS

Ecological flows (E-flow) were determined using methodology, developed in the Interreg V-A Latvia – Lithuania Programme 2014-2020 ECOFLOW Project and full methodical description can be found in the ECOFLOW project developed materials [3]. During period of 2017 – 2021 an E-flow was evaluated in 9 rivers regulated by HPP within Latvian territory and verified in the Lithuanian ECODAM project [2]. E-flow calculation in Latvian rivers were also described in the scientific article [4].

According to this methodology, E-flow can be calculated using optimum flow ($Q_{optimum}$) as a key hydrological value. Optimum flow is a river flow value, at which the area of available habitat reaches its maximum or insignificant habitat suitability increase can be observed.

To provide E-flow criteria representing the needs of different life stages, the year was divided into two bioperiods: rearing and growth (July – mid-October), and spawning (mid-October –June). Based on empirical research' results and WFD guidelines [1] it is assumed that 60% of the $Q_{optimum}$ is sufficient value for presence and development of aquatic fauna during spawning period. For the rearing and growth period 30% of the $Q_{optimum}$ is necessary to protect the aquatic fauna and flora during the dry season.

5.1. Aģe River – Aģe HPP

Using habitat-flow rating curve (Fig. 5.1.1) the $Q_{optimum}$ was defined as 1.20 m^3/s, which is equal to maximum value of a low flow period. According to the E-flow calculation methodology, the suggested ecological flow regime of the Aģe River below Aģe HPP is following:

1). water discharge not less than 0.36 m^3/s in the period from July to mid-October and

2). water discharge ≥0.72 m^3/s in the period from mid-October to June.

Proposed minimum E-flow is corresponding to the average flow of the low flow period (Q_{30_avg}).

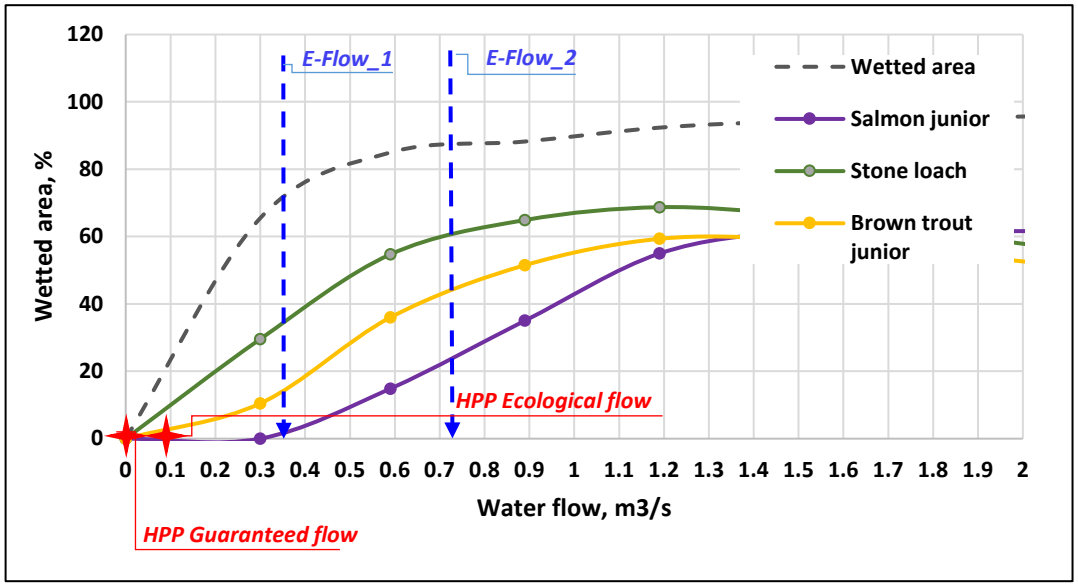


Figure 5.1.1. Habitat flow-rating curve for Aģe River below AģeHPP; blue arrow – E-Flow for summer (1) and winter (2), red stars –guaranteed and ecological flow in HPP permit

5.2. Auce River – Bēne HPP

Using habitat-flow rating curve (Fig. 5.2.1) the $Q_{optimum}$ was defined as 0.50 m^3/s, which is between low flow maximum flow and annual average flow. According to the E-flow calculation methodology, the suggested ecological flow regime of the Auce River below Bēne HPP is following:

1). water discharge not less than 0.15 m^3/s in the period from July to mid-October and

2). water discharge ≥0.30 m^3/s in the period from mid-October to June.

Proposed minimum E-flow is corresponding to the average flow of the low flow period (Q_{30_avg}).

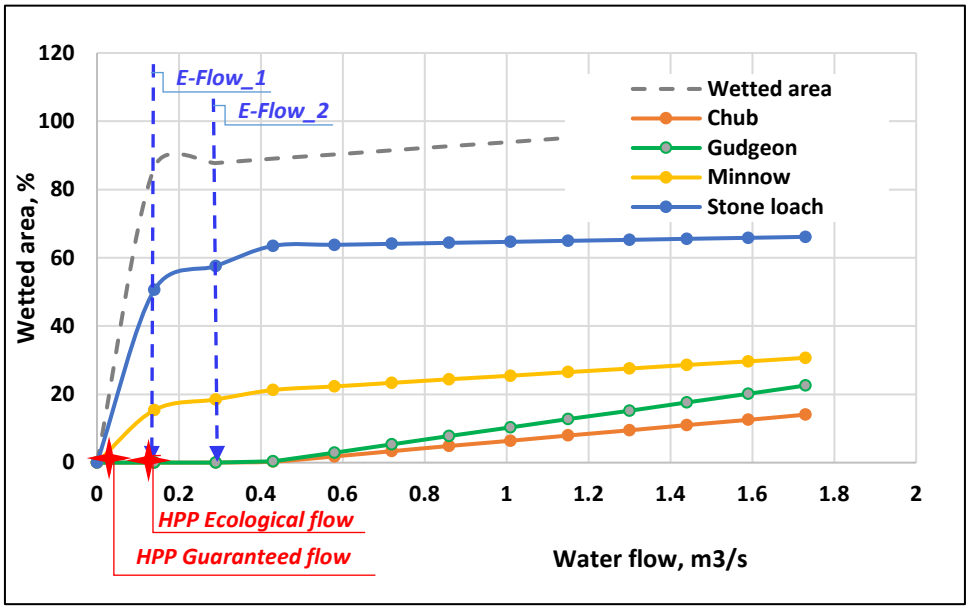


Figure 5.2.1. Habitat flow-rating curve for Auce River below Bēne HPP; blue arrow – E-Flow for summer (1) and winter (2), red stars – guaranteed and ecological flow in HPP permit

5.3. Auce River – Kroņauce HPP

Using habitat-flow rating curve (Fig. 5.3.1) the $Q_{optimum}$ was defined as 1.10 m^3/s, which is equal to the mean flow. According to the E-flow calculation methodology, the suggested ecological flow regime of the Auce River below Kroņauce HPP is following:

1). water discharge not less than 0.33 m^3/s in the period from July to mid-October and

2). water discharge ≥0.66 m3/s in the period from mid-October to June.

Proposed minimum E-flow is corresponding to the average of the low flow period (Q_{30_avg}).

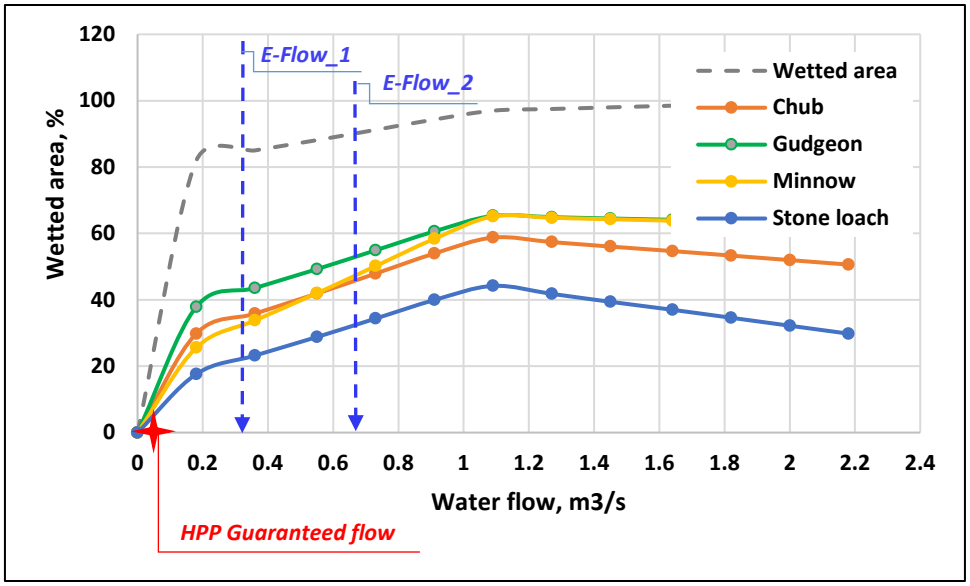


***Figure 5.3.1.** Habitat flow-rating curve for Auce River below Kroņauce HPP; blue arrow – E-Flow for summer (1) and winter (2), red star – guaranteed /ecological flow in HPP permit*

5.4. Mergupe River – Brūni HPP

Using habitat-flow rating curve (Fig. 5.4.1) the $Q_{optimum}$ was defined as 2.60 m^3/s, which is between the annual average and maximum flow of the low flow period. According to the E-flow calculation methodology, the suggested ecological flow regime of the Mergupe River below Brūnu HPP is following:

1). water discharge not less than 0.78 m^3/s in the period from July to mid-October and

2). water discharge ≥1.56 m^3/s in the period from mid-October to June.

Proposed minimum E-flow is corresponding to the average flow of the low flow period (Q_{30_avg}).

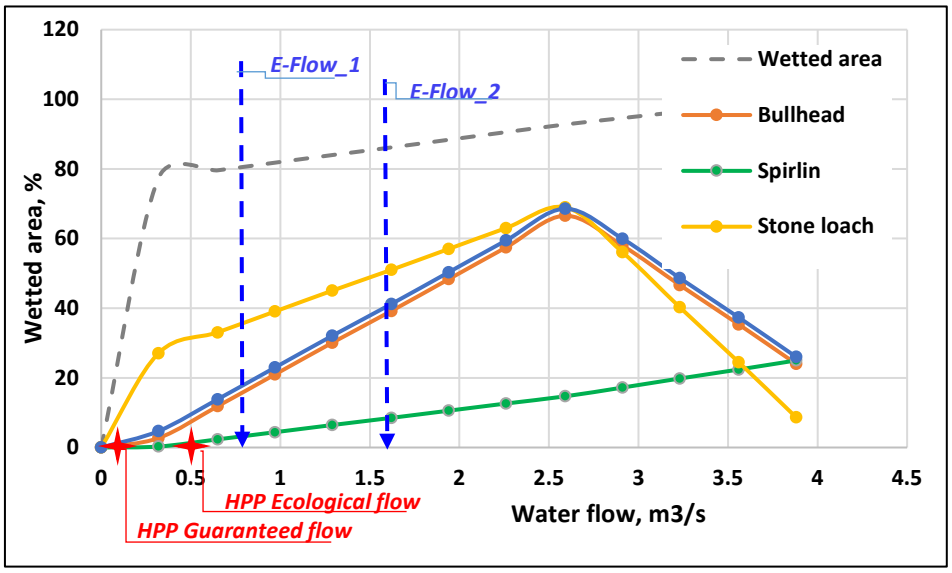


Figure 5.4.1. Habitat flow-rating curve for Mergupe River below Brūnu HPP; blue arrow – E-Flow for summer (1) and winter (2), red stars – guaranteed and ecological flow in HPP permit

5.5. Mergupe River – Krīgaļi HPP

Using habitat-flow rating curve (Fig. 5.5.1) the $Q_{optimum}$ was defined as 0.79 m^3/s, which is equal to the annual average water discharge. According to the E-flow calculation methodology, the suggested ecological flow regime of the Mergupe River below Krīgaļi HPP is following:
1). water discharge not less than 0.24 m^3/s in the period from July to mid-October and
2). water discharge ≥0.48 m^3/s in the period from mid-October to June.
Proposed minimum E-flow is corresponding to the average flow of the low flow period (Q_{30_avg}).

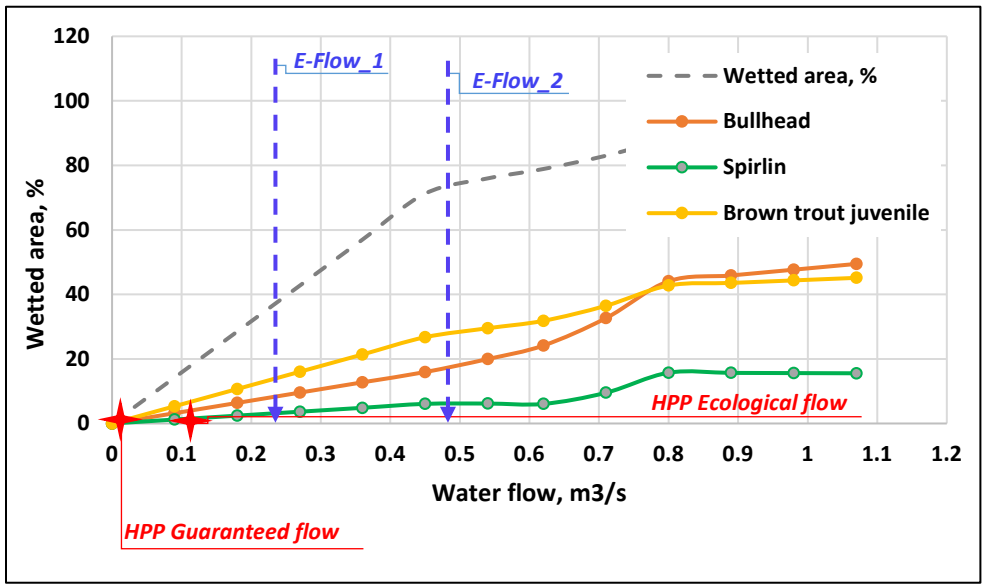


Figure 5.5.1. Habitat flow-rating curve for Mergupe River below Krīgaļi HPP; blue arrow – E-Flow for summer (1) and winter (2), red stars – guaranteed and ecological flow in HPP permit

5.6. Zaņa River – Pampāļi HPP

Using habitat-flow rating curve (Fig. 5.6.1) the $Q_{optimum}$ was defined as 0.60 m^3/s, which is close to low flow maximum flow. According to the E-flow calculation methodology, the suggested ecological flow regime of the Zaņa River below Pampāļi HPP is following:

1). water discharge not less than 0.18 m^3/s in the period from July to mid-October and

2). water discharge ≥0.36 m^3/s in the period from mid-October to June.

Proposed minimum E-flow is corresponding to the average flow of the low flow period (Q_{30_avg}).

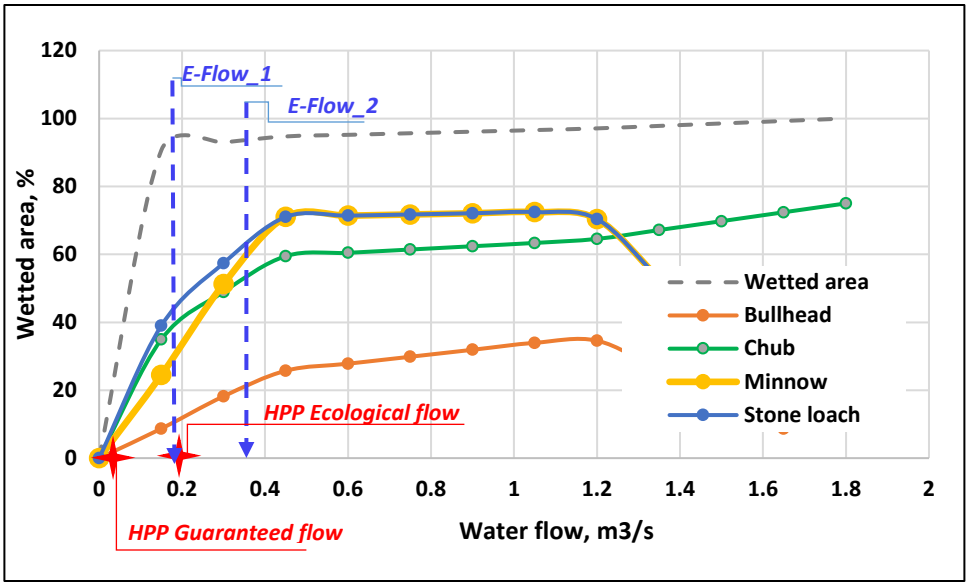


Figure 5.6.1. Habitat flow-rating curve for Zaņa River below Pampāļi HPP; blue arrow – E-Flow for summer (1) and winter (2), red stars – guaranteed and ecological flow in HPP permit

5.7. Zaņa River – Zaņa HPP

Using habitat-flow rating curve (Fig. 5.7.1) the $Q_{optimum}$ was defined as 1.18 m^3/s, which is close to low flow maximum flow. According to the E-flow calculation methodology, the suggested ecological flow regime of the Zaņa River below Zaņa HPP is following:

1). water discharge not less than 0.35 m^3/s in the period from July to mid-October and

2). water discharge ≥0.71 m^3/s in the period from mid-October to June.

Proposed minimum E-flow is corresponding to the average flow of the low flow period (Q_{30_avg}).

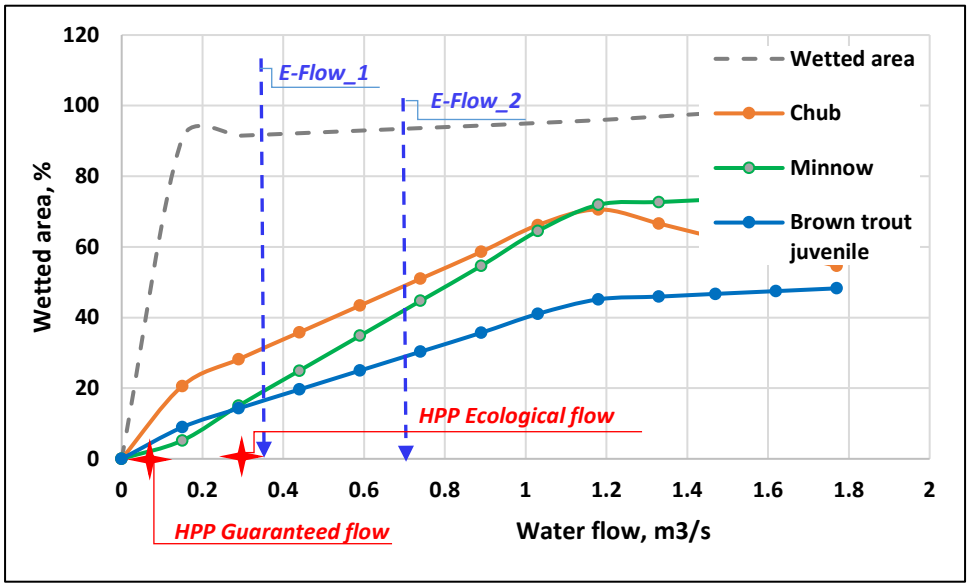


Figure 5.7.1. Habitat flow-rating curve for Zaņa River below Zaņa HPP; blue arrow – E-Flow for summer (1) and winter (2), red stars – guaranteed and ecological flow in HPP permit

The comparison of the proposed ecological flow values with daily discharges of year 2022 (and other years) shows that there are no natural obstacles for increasing of the ecological flow values. Table 6.1 illustrates water flow characteristics of the studded rivers derived from multi-year calculations.

Table 6.1. Main water flow characteristics

River	HPP name	Low flow period			Mean annual flow, m^3/s
		Minimum flow, m^3/s	Average flow, m^3/s	Maximum flow, m^3/s	
Aģe	Aģe	0.10	0.36	1.18	1.85
Auce	Bēne	0.030	0.13	0.28	0.64
Auce	Kroņauce	0.042	0.30	0.44	1.11
Mergupe	Krīgaļi	0.058	0.17	0.47	0.75
Mergupe	Brūni	0.20	0.58	2.00	2.99
Zaņa	Pampāļi	0.074	0.22	0.39	1.21
Zaņa	Zaņa	0.11	0.34	0.62	2.03

There are significant differences between ecological flows proposed within this LIFE project and ecological flows provided in state water use permits (Table 6.2). For some rivers (Auce below Bēne HPP, Zaņa below Pampāļi HPP and Zaņa below Zaņa HPP) our suggested E-flows for low flow period are similar to E-flows in permits. E-flow, specified in water use permit for Auce River below Kroņauce HPP, is more than 10 times smaller than long-term low flow minimum flow, indicating that hydroecosystem of this river is under significant hydrological pressure. Our results show that ecological flows for all surveyed HPPs are insufficient to achieve good ecological status, which is the main objective of WFD [5].

Table 6.2. Comparison of ecological flow values in pilot rivers

River	HPP name	Guaranteed flow / E-flow in permit, m3/s	Proposed E-flow summer, m3/s	Proposed E-flow winter, m3/s
Aģe	Aģe	0.015 / 0.09	0.36	0.72
Auce	Bēne	0.007 / 0.15	0.15	0.30
Auce	Kroņauce	0.003	0.33	0.66
Mergupe	Krīgaļi	0.015 / 0.12	0.24	0.48
Mergupe	Brūni	0.124 / 0.50	0.78	1.56
Zaņa	Pampāļi	0.039 / 0.20	0.18	0.36
Zaņa	Zaņa	0.069 / 0.32	0.35	0.71

VI. CONCLUSIONS

- Ecological flow modelling was done in two sites in Auce, Mergupe and Zaņa rivers and one site in Aģe River. Three of studied sites belongs to salmonid river type which is especially vulnerable to hydrological alterations caused by operating HPP.

- The currently existing ecological flows, provided in Water use permits, do not completely support the sustainability of aquatic ecosystems for most of the studied rivers. These flows in permits usually are too low and are in line with the requirements of healthy ecosystems.

- During period of 2017 – 2022 the E-flow was evaluated in 13 rivers regulated by HPP within Latvian territory. Moreover, the simplification method of the E-flow calculation on the base of water runoff data was developed in the frame of the ECOFLOW project and verified in the LIFE GoodWater IP project.

- For salmonid and cyprinid rivers, the ecological flow regime must be calculated differently because salmonid rivers are more vulnerable to artificial low flows as well as to temperature and oxygen fluctuations during non-natural low flow events. The optimum flow obtained for cyprinid rivers is very close to the average flow of the low flow period, which can be used as a threshold to define ecological flows for cyprinid rivers. For salmonid rivers, the optimum flow was higher and closer to the mean annual flow that might be used as a threshold for salmonid rivers.

- Proposed minimum E-flow is corresponding to the average flow of the low flow period for all river types.

- We didn’t find regional differences between the E-flow in four river basin districts within Latvia and in each of it the E-flow should be calculated using the same formula. Obviously, the river typology, based on fish communities, must be taken into account.

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