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REPORT OF E-FLOW REGIME MODELLING FOR HPP CASCADES

2022

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ABBREVIATIONS

ArcGIS	geographical information system software
CEIWR-HEC	U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center
CIS	Common Implementation Strategy for the Water Framework
DEM	digital elevation model
ECODAM	National Research Programme 'Sustainability of agro-, forest and water ecosystems' 2nd call project „Impact assessment of hydrotechnical structures on river runoff and sustainable water management for conservation and restoration of water ecosystems"
ECOFLOW	Interreg V-A Latvian-Lithuanian programme project "*Ecological flow estimation in Latvian - Lithuanian transboundary river basins", LLI-249*
E-Flow	ecological Flow
EU	European union
F300-42	Francis turbine
HecResSim	Reservoir System Simulation software
HMU	hydromorphic unit
HPP	Hydropower Plant
IH	habitat availability index
K-84, K-84A	vertical-axis propeller-type Kaplan turbine
LAS	Latvian normal height system
LT	Lithuania
LV	Latvia
MesoHABSIM	meso-scale habitat simulation model
Q_{annual_avg}	annual average flow
$Q_{environmental}$	environmental flow
$Q_{optimum}$	optimum flow

Q_{30_avg}	average flow of the low flow period
Q_{30_max}	maximum flow of the low flow period
Q_{30_min}	minimum flow of the low flow period
r	correlation coefficient
Sim-Stream	software combines all three parts of MesoHABSIM and simulates physical habitat suitability at different flow conditions
SK-85	horizontal-axis Kaplan turbine
TRANSWAT	"Joint management of Latvian – Lithuanian trans-boundary river and lake water bodies" project
UCUT	Uniform Continuous-Under-Threshold
WFD	Water Framework Directive

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1. INTRODUCTION

In the frame of the "Joint management of Latvian – Lithuanian trans-boundary river and lake water bodies" project (TRANSWAT), LLI-533 financed by the Interreg V-A Latvia–Lithuania Programme 2014-2020, modelling of operation of HPPs cascades is carried out in the selected regulated rivers (Ciecere, Losis (LV) and Varduva (LT)), and designed operational ecological flow regime for HPPs cascades is evaluated.

The main objectives of this activity are:

- preparation of a database of hydrological, HPP and reservoir parameters for modelling purposes;
- calibration of HPPs cascade operation models of the selected regulated rivers using HecResSim software;
- modeling of HPPs cascade operation in the selected rivers regulated according to different scenarios;
- design of an environmentally friendly operational regime for HPPs' cascade based on modelling results.

Habitat suitability modelling and E-flow evaluation results (Deliverable D.T1.5.1) are a part of this Report (E-flow regime modelling for HPPs cascades). The results of this modelling will include an evaluated E-flow regime for each HPP in the cascades of selected rivers. E-flow data will be the input data for the modelling of HPPs cascade operation.

Information about the results of this activity will be disseminated to stakeholders by the project web pages in LT and LV as well as during Stakeholders' meetings and the Project Final Conference.

The modelling of HPPs cascades operation was performed using HEC-ResSim software in the following pilot rivers:

Ciecere River: regulated by three HPPs, three work sites downstream of each HPP;

Losis River: regulated by two HPPs, two work sites downstream of each HPP;

Varduva River: regulated by five HPPs, five work sites downstream of each HPP.

2. OBJECTIVES OF HPPs CASCADE MODELLING

The Reservoir System Simulation (HEC-ResSim) software developed by the U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center (CEIWR-HEC) is used to model the HPPs cascade operation for a variety of operational goals and constraints (https://www.hec.usace.army.mil/software/hec-ressim/). In this report, the operational goal is to evaluate HPPs cascade operation patterns when environmental or ecological discharges are released through the dams.

HEC-ResSim represents a river-reservoir system as a georeferenced network of reservoir, routing reach, stream junction, and diversion elements. The model includes data that represents both the physical and operational aspects of the system. Physical data includes reservoir elevation-capacity tables, complex outlet works, power plant specifications, and river-reach routing parameters. Operational data is represented as rules stacks, which allow users to identify and prioritize multiple reservoir operation rules. The model supports the rules for at-site operations and system operation, for downstream control and system hydropower generation.

Why did we select HEC-ResSim model? The task of the TRANSWAT project is to estimate the ecological flow regime for HPPs cascades. The main issues are how the HPP cascades will work when it is necessary to pass the e-flow through the dams. HEC-ResSim software provides an opportunity to create models of the operation of the HPPs cascades, the results of which reflect the variation of reservoir parameters, water release through HPPs turbines and outlets, and HPPs energy production in various operating modes.

Simulations with HEC-ResSim software require a large amount of hydrological data. The hydrological situation of the rivers in 2021 was chosen as the basis when detailed hydrological measurements were carried out in the river stretches upstream and downstream of each HPP. The modelling alternatives are developed by evaluating the environmental and ecological dicharges and parameters of HPP constructions for every power plant.

3. HABITAT SUITABILITY MODELLING AND E-FLOW EVALUATION

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 transboundary Venta catchment. 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".

The River habitat modelling have been carried out for the following case-study sites within transboundary Venta river basin:

- Ciecere River: below Ciecere, Dzirnavnieki and Pakuli HPP (Latvia);
- Losis River: below Grantini and Lejnieki HPP (Latvia);
- Varduva River: below Juodeikiai, Kušėnai, Renavas, Ukrinai and Vadagiai HPP (Lithuania).

The habitat modelling results have shown that hydromorphological alterations, caused by operating HPP, considerably affect the ecological status of rivers.

Concept and application

Meso-scale habitat simulation model MesoHABSIM was used for habitat suitability calculations at different flows. It is based on habitat availability for selected fish species during different hydrological conditions.

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, stream 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.
Sim-Stream application was used to implement MesoHABSIM model.

Sim-Stream Model

Habitat flow-rating curves, habitat suitability and hydrological impact degree was assessed using SimStream software 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.

Model input data

Input data includes hydromorphological unit maps, water flow daily data series and fish data.

Hydromorphological units mapping and field works was done in ice-free period of 2020 and 2021. Hydromorphological type-specific, mesoscale river stretches were selected downstream of each studied HPP. Depending on river size, these river stretches were 100-500 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 mesohabitats (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 bad substrate within HMU have been used.
For each case study 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.

Fish data have been collected in each case study site where habitat field surveys were done. Fish fauna was sampled in all of HMU and if there were several units of the same type (pool, riffle etc.) sampling was performed in only one of them.
For habitat modelling a List of specific species of interest has been created for each river within the project area.

Ecological flow evaluation

In Latvia, ecological flows (E-flow) were determined using methodology, developed in ECOFLOW project (*Ecological flow estimation in Latvian - Lithuanian transboundary river basins, LLI-249*) and full methodical description can be found in ECOFLOW deliverable "*Methodology of E-flow evaluation on the base of Venta and Lielupe Latvian-Lithuanian transboundary river basins*".
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.
Based on expert judgement and WFD guidelines is assumed that 60% of the $Q_{optimum}$ is sufficient value for presence and development of fish fauna during spawning and rearing period (mid October – June). For the rest of a year 30% of the $Q_{optimum}$ is necessary to protect the aquatic fauna and flora during the dry season.
In Lithuania, the discharge which corresponds to the concept of ecological flow (E-flow), was determined for the first time during the ECOFLOW project (Interreg V-A Latvian-Lithuanian programme project "*Ecological flow estimation in Latvian - Lithuanian transboundary river basins", LLI-249*) and full methodical description can be found in ECOFLOW deliverable "*Methodology of E-flow evaluation on the base of Venta and Lielupe Latvian-Lithuanian transboundary river basins*". The ecological discharge was repeatedly determined during the ECODAM project (National Research Programme 'Sustainability of agro-, forest and water ecosystems' 2nd call project „Impact assessment of hydrotechnical structures on river runoff and sustainable water management for conservation and restoration of water ecosystems"; Project registration number SIT-20-3, Research Council of

Lithuania). During the ECODAM project, the ecological discharge was determined based on the analysis of Uniform Continuous-Under-Threshold (UCUT) curves, and the validation was performed based on the analysis of the habitat area – discharge rating curves. The ecological flow determined by both methods during mentioned projects is close to Q_{30_avg}.

3.1. Ciecere River HPPs cascade

3.1.1. Ciecere River – below Ciecere HPP (Ciecere1)

This stretch of Ciecere River is not included into list of priority fish waters, but habitat is more suitable for salmonid fish species. Ciecere HPP is most upstream of three HPP and only 2.8 km from Lake Ciecere. According to Water use permits, guaranteed water discharge is determined as 0.061 m^3/s. Ecological flow is the same as guaranteed water discharge.

Habitat curves for selected fish species depending on flow rate are shown in Figure 4.1.1. These curves were modelled for each fish species of interest (adult common dace, adult bullhead, juvenile brown trout, adult stone loach) that was pre-selected by fish expert especially for Ciecere River, site 1. It is evident that for some of species habitat area increases with increasing water discharge (bullhead, common dace), but for other species available habitat reaches it's maximum (stone loach) or even starts to decrease (brown trout) with increased water discharge.

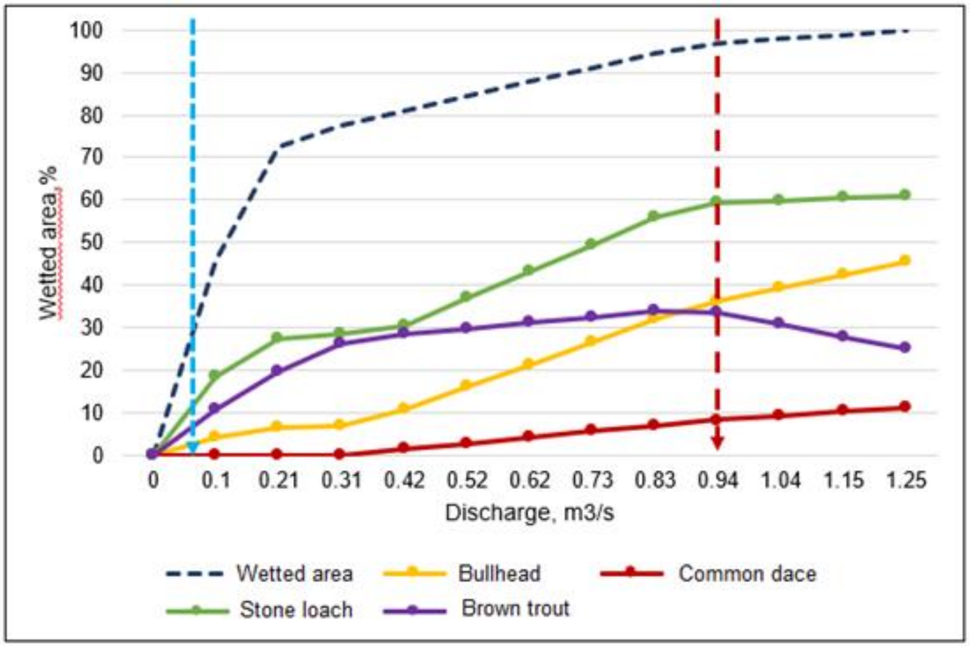


Figure 3.1.1.1. Habitat flow-rating curve for Ciecere River below Ciecere HPP (red arrow – optimum flow, blue arrow - ecological flow in permit)

Figure 3.1.1.2 shows habitat suitability maps for brown trout that is species of high priority for Ciecere River. It is evident that available habitat (optimal and suitable habitats) rapidly increases when discharge increases from Q_{30_min} to Q_{30_avg} and small even increase can be observed until discharge reaches Q_{30_max}. When discharge reaches Q_{annual}, available habitat area starts to decrease because water velocity is too large for juvenile brown trout.

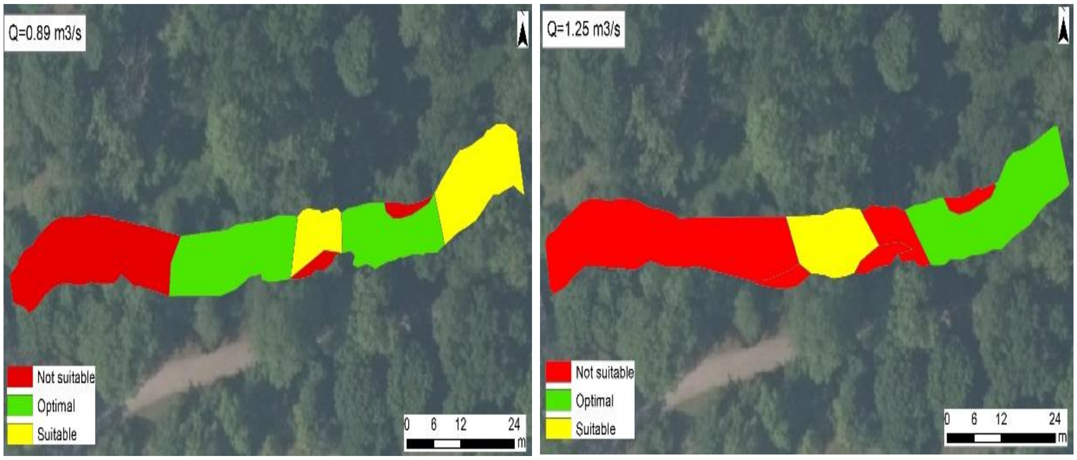


Figure 3.1.1.2. Habitat suitability maps for juvenile brown trout in four different flow conditions

Figure 3.1.1.3 shows the habitat distribution in time during 2021 that is a year with normal water runoff. For juvenile brown trout most of habitats during summer are below Q97 threshold, indicating that water level in river is too low and summer period ecological flow must be increased.

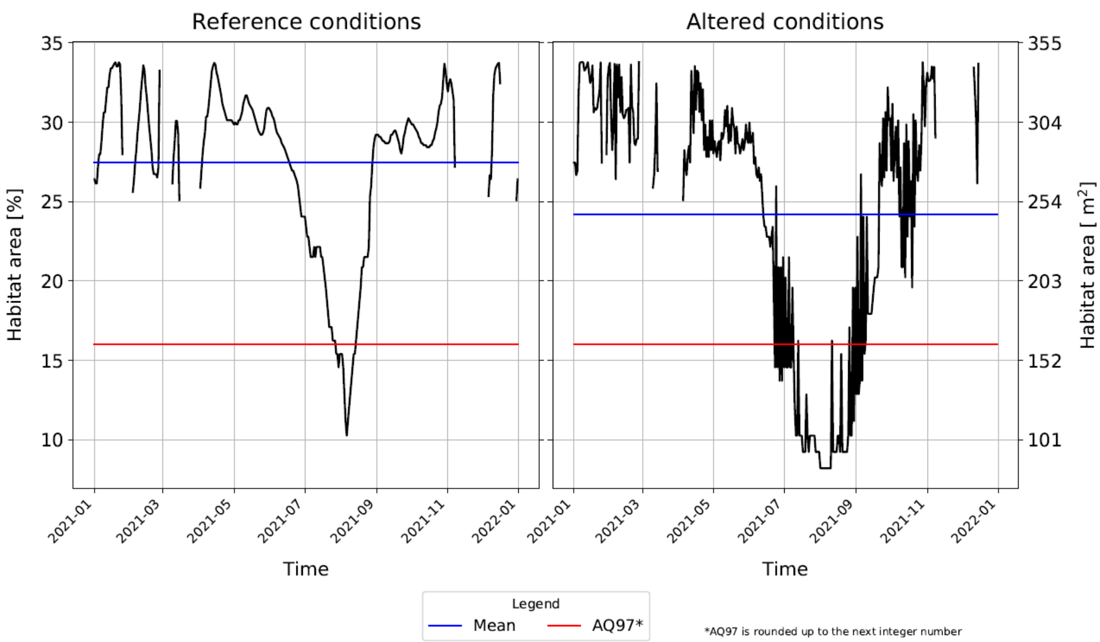


Figure 3.1.1.3. Habitat time series of the juvenile brown trout in reference and altered conditions

Using habitat-flow rating curve (Fig. 3.1.1.1) the $Q_{optimum}$ was defined as 0.95 m^3/s, which is closed to Q_{annual_avg}. According to the E-flow calculation methodology (ECOFLOW Project report, 2019), the suggested ecological flow regime of Ciecere

River below Ciecere HPP is following: 1) water discharge not less than 0.25 m^3/s in period from July to mid-October and 2) water discharge ≥0.50 m^3/s in 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 3.1.1.4 shows that river had enough water to provide the ecological flow regime during most of year 2021. River Ciecere below Ciecere HPP is located very closed to the river source at the Ciecere Lake. During most of summer days this river stretch has naturally very low discharge values and can't provide sufficient E-flow. Therefore, the Ciecere HPP must stop working during the dry summer.

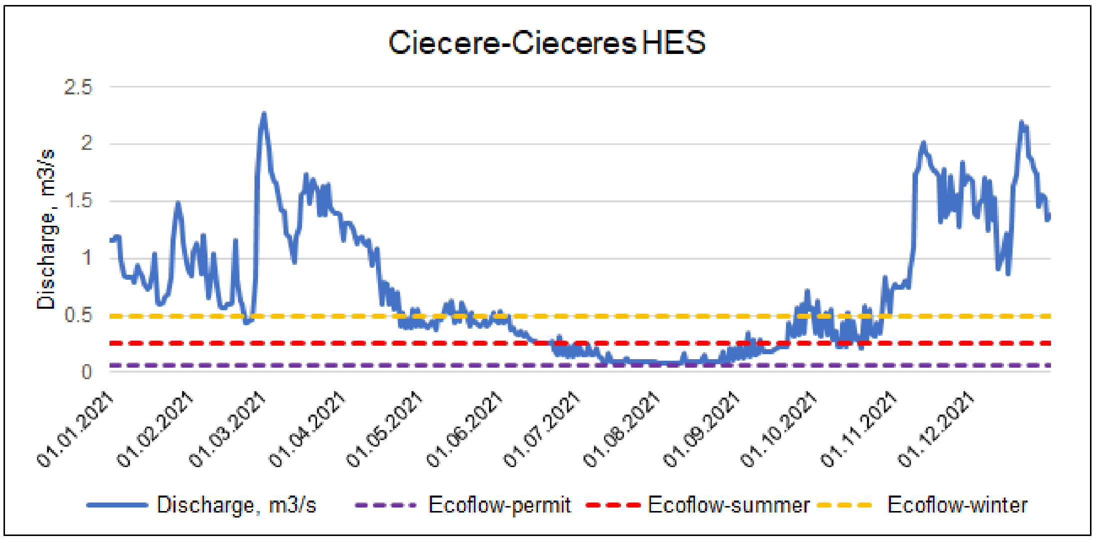


Figure 3.1.1.4. Comparison of daily discharge and ecological flows specified in water use permits and proposed in TRANSWAT project for Ciecere River below Ciecere HPP

3.1.2. Ciecere River – below below Dzirnavnieki HPP (Ciecere2)

This stretch of Ciecere River is not included into list of priority fish waters, but habitat is more suitable for salmonid fish species. Dzirnavnieki HPP is middle of three HPPs. According to Water use permits, guaranteed water discharge is determined as 0.30 m^3/s. Ecological flow is the same as guaranteed water discharge.

Habitat curves for selected fish species depending on flow rate are shown in Figure 3.1.2.1. These curves were modelled for each fish species of interest (juvenile brown trout, adult chub, adult bullhead, adult stone loach) that was pre-selected by fish expert especially for Ciecere River, site 2. It is evident that for some of species habitat area increases with increasing water discharge (bullhead, chub), but for other species available habitat reaches it's maximum or even starts to decrease (stone loach, brown trout) with increased water discharge.

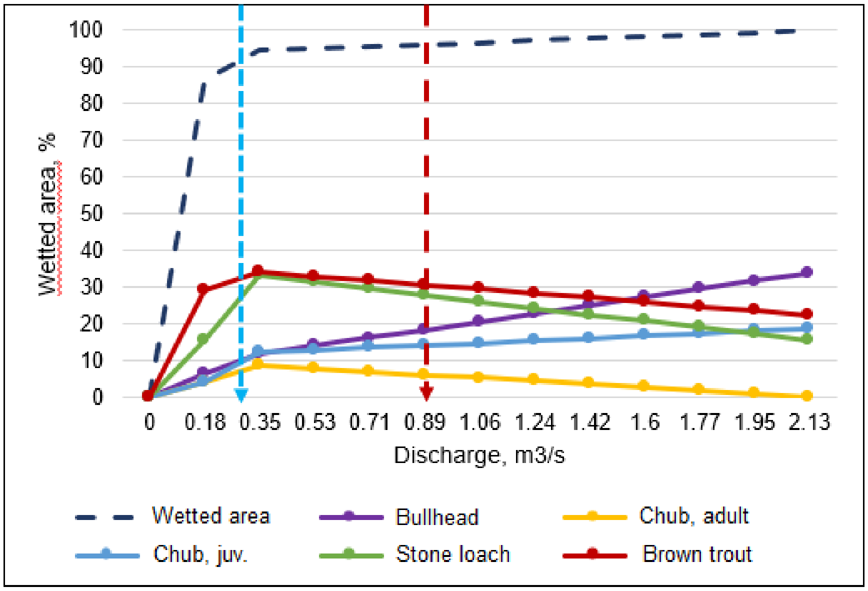


Figure 3.1.2.1. Habitat flow-rating curve for Ciecere River below Dzirnavnieki HPP (red arrow – optimum flow, blue arrow - ecological flow in permit)

Figure 3.1.2.1. shows habitat suitability maps for brown trout that is species of high priority for Ciecere River. In total, Ciecere2 has very suitable habitats for brown trout. Our results shows that there are no significant habitat suitability fluctuations in summer low flow period. Riffle at the end of the stretch is especially suitable for brown trout. When discharge reaches Q_{annual_avg}, available habitat area starts to decrease because water velocity is too large for juvenile brown trout (Fig. 3.1.2.2). Figure 3.1.2.3 shows the habitat distribution in time during 2021 that is a year with normal water runoff. Results are different for the high priority fish species. It is evident that operating HPP don't have significant impact on available habitats for juvenile brown trout (Fig. 3.1.2.3) because of no obstacles downstream and free access for fish from the downstream.

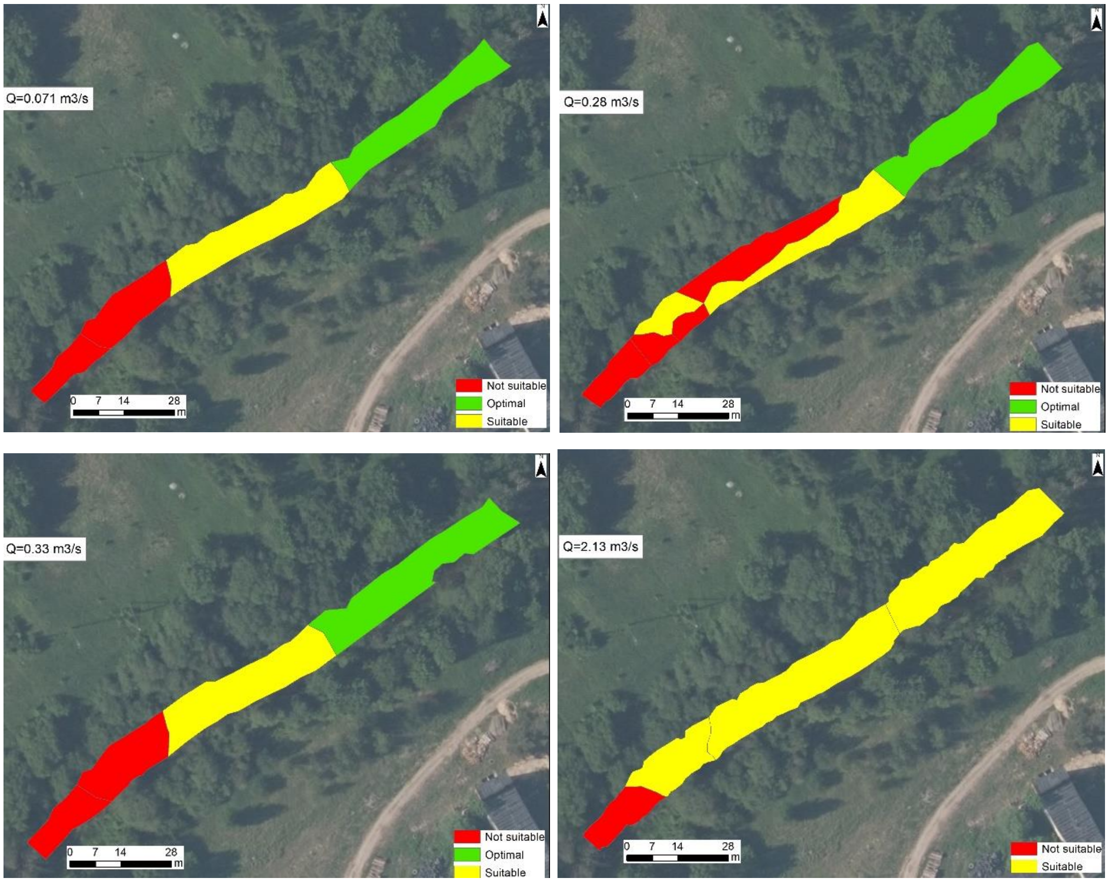


Figure 3.1.2.2. Habitat suitability maps for juvenile brown trout during four different discharges

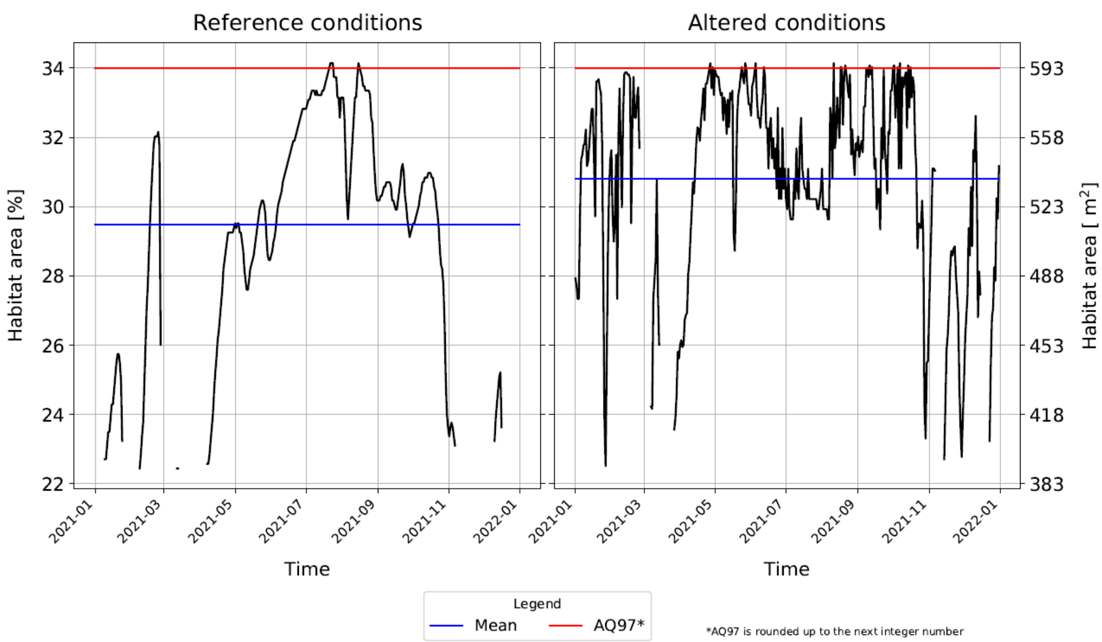


Figure 3.1.2.3. Habitat time series of the juvenile brown trout in reference and altered conditions

Using habitat-flow rating curve (Fig. 3.1.2.1), the $Q_{optimum}$ was defined as 0.92 m^3/s which is between Q_{annual} and Q_{30_max}. According to E-flow calculation methodology (ECOFLOW Project report, 2019), the suggested ecological flow regime of the Ciecere River below Dzirnavnieki HPP is following: 1) water discharge not less than 0.27 m^3/s in period from July to mid-October and 2) water discharge ≥0.55 m^3/s in period from mid-October to June. Proposed minimum E-flow is corresponding to the average flow of the low flow period (Q_{30_avg}).This value 0.27 m^3/s matches to the ecological flow value specified in water use permit (0.30 m^3/s) of the Dzirnavnieki HPP. It means that the HPP already has sustainable ecological flow regime during summer season but has to provide the E-flow also during high flow period. Proposed minimum E-flow value is corresponding to the average flow of the low flow period (Q_{30_avg}).

Figure 3.1.2.4 illustrates that river had enough water to provide proposed ecological flow regime during most of year 2021, including summer months.

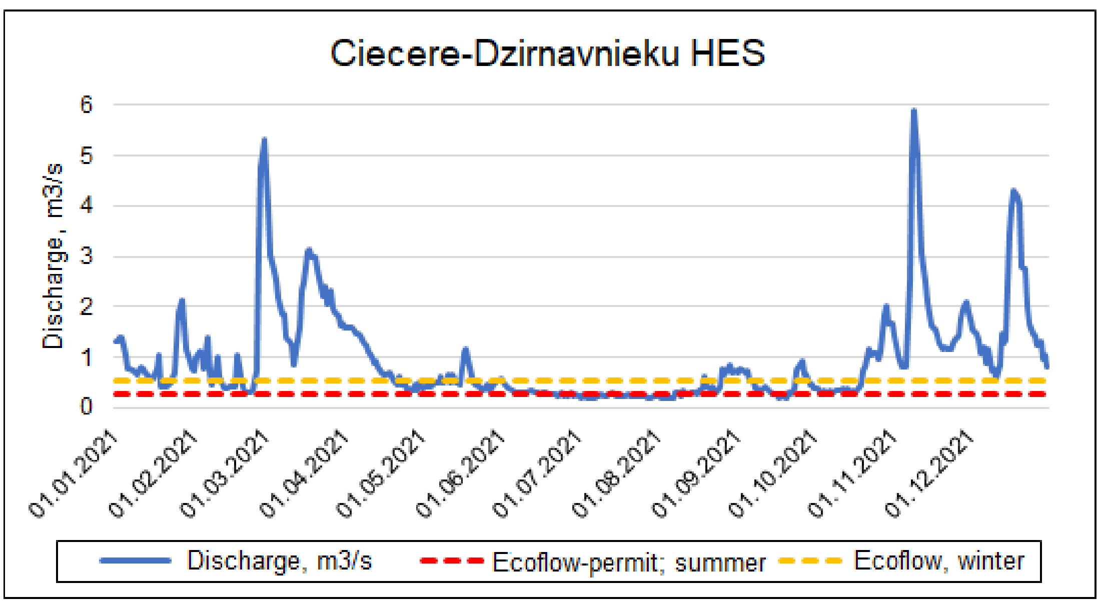


Figure 3.1.2.4. Comparison of daily discharge and ecological flows specified in water use permits and proposed in TRANSWAT project for Ciecere River below Dzirnavnieki HPP

3.1.3. Ciecere River – below Pakuli HPP (Ciecere3)

This stretch of Ciecere River is included into list of priority fish waters and belongs to salmonid fish waters. Pakuli HPP is the lowest of three HPPs and is located 32 km from river mouth. According to Water use permits, guaranteed water discharge is determined as 0.32 m^3/s. Ecological flow is 0.30 m^3/s.

Habitat curves for selected fish species depending on flow rate are shown in Figure 3.1.3.1. These curves were modelled for each fish species of interest (juvenile brown trout, adult chub, adult spirlin, adult stone loach, adult bullhead) that was pre-selected by fish expert especially for Ciecere River, site 3. It is evident that for some of species habitat area increases with increasing water discharge (bullhead, chub, spirlin), but for other species available habitat reaches it's maximum or even starts to decrease (brown trout) with increased water discharge.
Figure 3.1.3.2 shows habitat suitability maps for brown trout that is species of high priority for Ciecere River. Similarly to other salmonid fish waters, brown trout reaches it's maximum available habitat when discharge is close to Q_{30_max}.

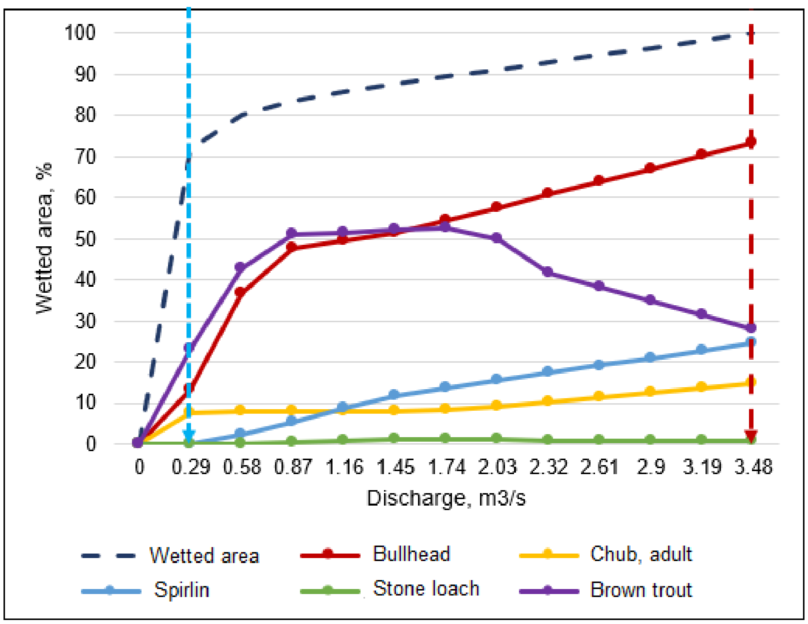


Figure 3.1.3.1. Habitat flow-rating curve for Ciecere River below Pakuli HPP (red arrow – optimum flow, blue arrow - ecological flow in permit)

When discharge reaches Q_{annual_avg}, available habitat area starts to decrease because water velocity is too large for juvenile brown trout (Fig. 3.1.3.2).

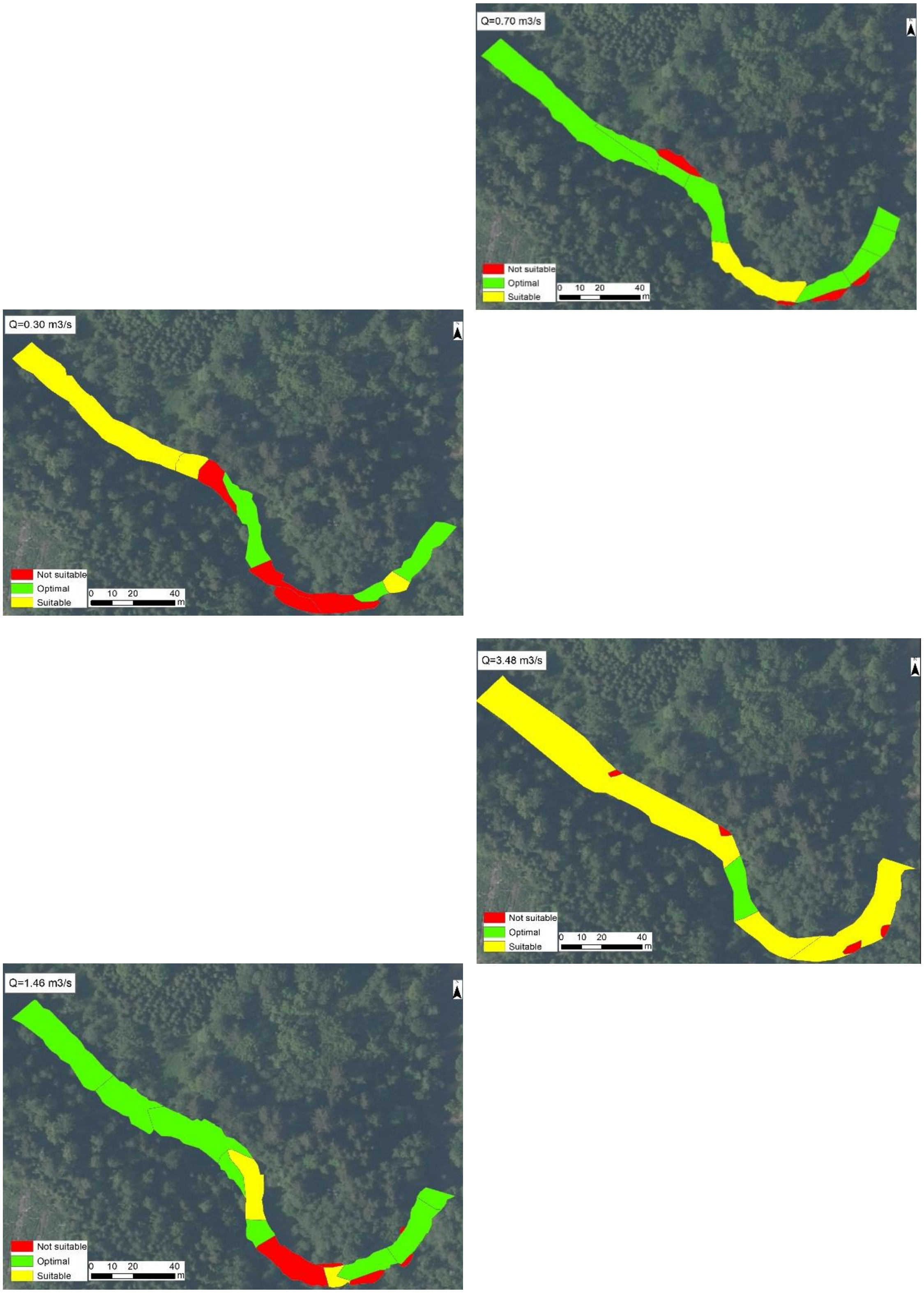


Figure 3.1.3.2. Habitat suitability maps for juvenile brown trout during four different discharges

Figure 3.1.3.3 ilustrates the habitat distribution in time particularly during 2021 that is a year with normal water runoff. Results show that operating HPP don't have significant impact on available habitat area for juvenile brown trout. This river stretch is naturally suitable for salmonid fish species in most of year, although we can observe some habitat decrease in spring and late autumn season when water discharge is naturally very high.

Using habitat-flow rating curve (Fig. 3.1.3.1), the $Q_{optimum}$ was defined as 3.45 m^3/s, which is closed to the Q_{annual_avg}. According to the E-flow calculation methodology (ECOFLOW Project report, 2019), the suggested ecological flow regime of the Ciecere River below Pakuli HPP is is following: 1) water discharge not less than 1.05 m^3/s in period from July to mid-October and 2) water discharge ≥2.10 m^3/s in period from mid-October to June. The proposed minimum E-flow value is corresponding to the average flow of the low flow period (Q_{30_avg}).These numbers are the same as in previous ECOFLOW project (ECOFLOW Project report, 2019).

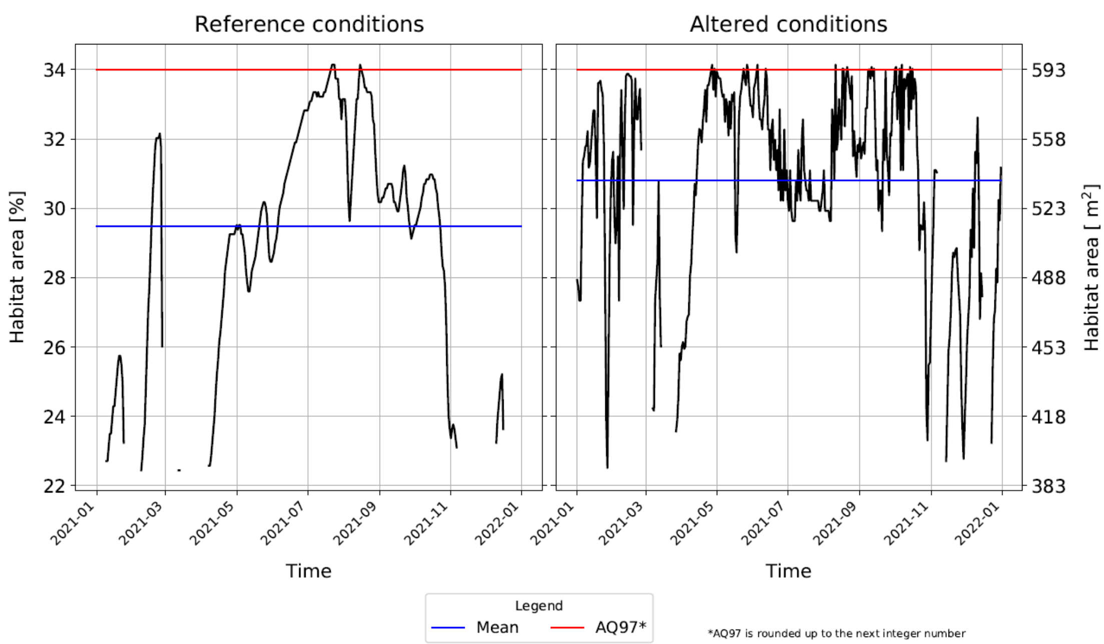


Figure 3.1.3.3. Habitat time series of the juvenile brown trout in reference and altered conditions

Figure 3.1.3.4 shows that the Ciecere River had enough water to provide the proposed ecological flow regime during most of year 2021 except some low flow periods during dry summer and autumn.

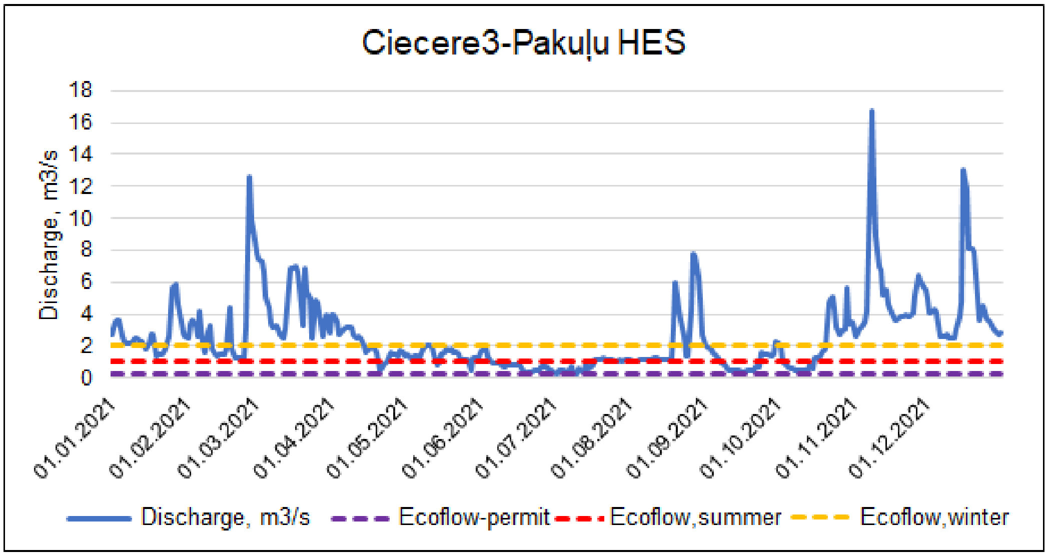


Figure 3.1.3.4. Comparison of daily discharge and ecological flows specified in water use permits and proposed in TRANSWAT project for Ciecere River below Pakuli HPP

3.2. Losis River HPPs cascade

3.2.1. Losis River – below Lejnieki HPP (Losis1)

Losis River is not included into list of priority fish waters, but according to field surveys this site may belong to salmonid fish waters. Lejnieki HPP is lowest of two HPPs and is located 2 km from river mouth. According to Water use permits, guaranteed water discharge is determined as 0.093 m^3/s. Ecological flow is 0.20 m^3/s.

Habitat curves for selected fish species depending on flow rate are shown in Figure 3.2.1.1. These curves were modelled for each fish species of interest (adult common dace, adult bullhead, juvenile brown trout, adult stone loach, chub) that was pre-selected by fish expert especially for Losis River, site 1. For most of modelled fish species available habitat area increases with increasing water discharge and optimum flow can be determined only for adult stone loach. Available habitat area for most of modelled fish species are below 20% of river stretch indicating that this part of river is under significant hydromorphological pressure.

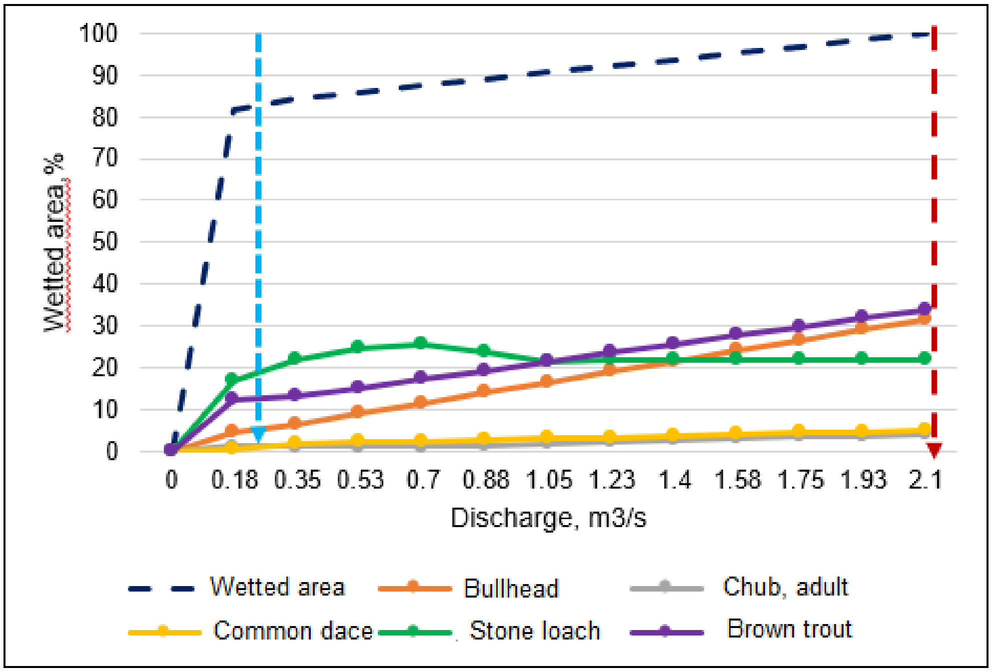
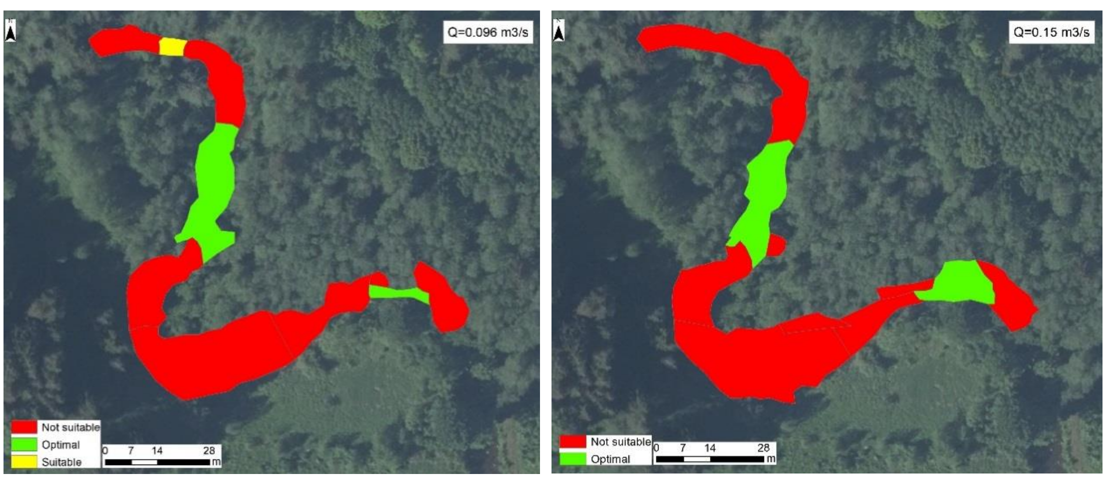


Figure 3.2.1.1. Habitat flow-rating curve for Losis River below Lejnieki HPP (red arrow – optimum flow, blue arrow - ecological flow in permit)

Figure 3.2.1.2 shows habitat suitability maps for brown trout that is species of high priority for Losis River. Habitat availability (sum of suitable and optimal habitats) show only insignificant increase, when water discharge increases from Q_{30_min} to Q_{30_max}, but it rapidly reaches it's maximum when discharge is closed to Q_{annual_avg}.



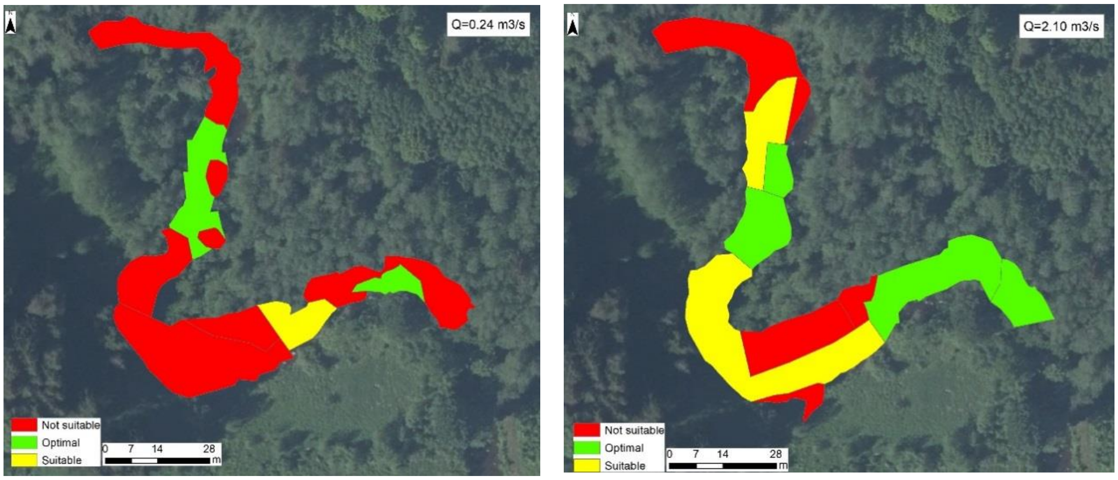


Figure 3.2.1.2. Habitat suitability maps for juvenile brown trout during four different discharges

Figure 3.2.1.3 ilustrates the habitat distribution in time particularly during 2021 that is a year with normal water runoff. Results are very similar for all modelled fish species in Losis1 and show that this river stretch is strongly affected by hydrological pressure caused by HPP. Almost half of potential habitats for brown trout are lost due too low water level below HPP and available habitat depletion starts already in May, just after spring high flows.

Using habitat-flow rating curve (Figure 3.2.1.1), the $Q_{optimum}$ was defined as 2.1 m^3/s which is closed to Q_{annual_avg}. According to the E-flow calculation methodology (ECOFLOW Project report, 2019), the suggested ecological flow regime of the Losis River below Lejnieki HPP is following: 1) water discharge not less than 0.65 m^3/s in period from July to mid-October and 2) water discharge ≥1.25 m^3/s in period from mid-October to June. The proposed minimum E-flow value is corresponding to the average flow of the low flow period (Q_{30_avg}).

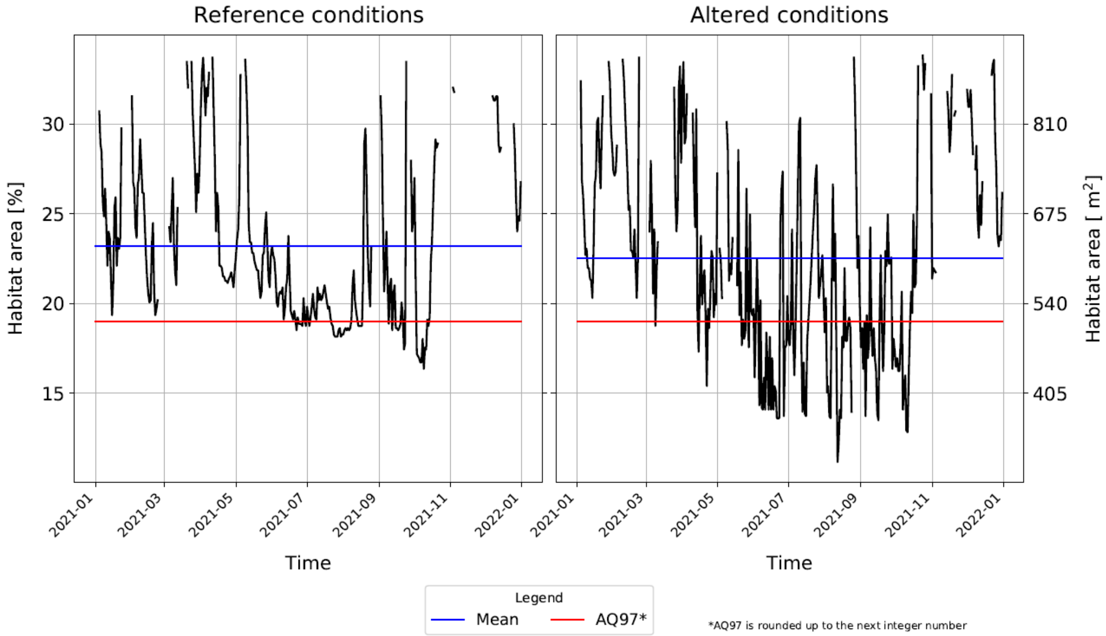


Figure 3.2.1.3. Habitat time series of the juvenile brown trout in reference and altered conditions

Figure 3.2.1.4 shows that river had enough water to provide proposed ecological flow during most of year 2021, except some small low flow events during summer and autumn.

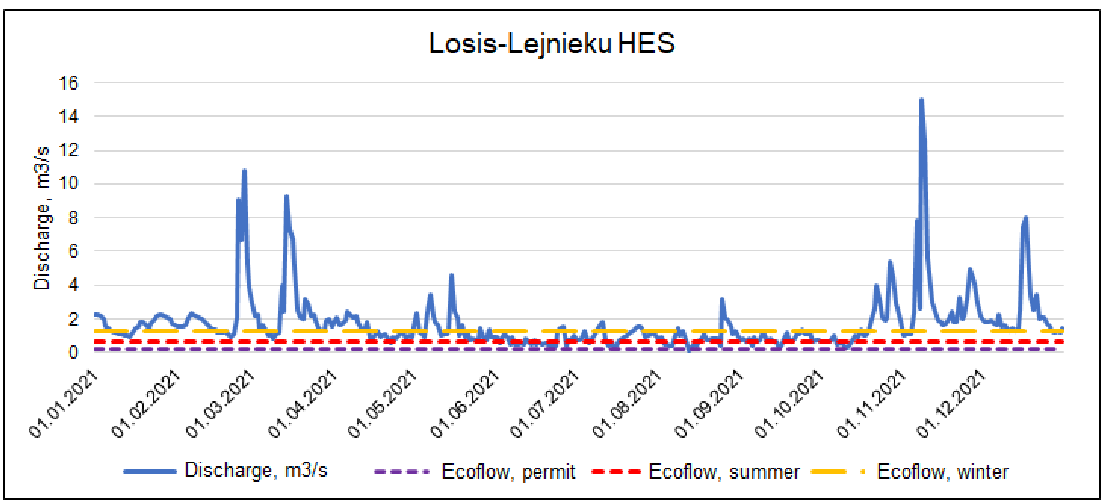


Figure 3.2.1.4. Comparison of daily discharge and ecological flows specified in water use permits and proposed in TRANSWAT project for Losis River below Lejnieki HPP

3.2.2. Losis River – below Grantini HPP (Losis2)

Losis River is not included into list of priority fish waters, but according to field surveys this particular site may belong to cyprinid fish waters. This site is located between two HPP and have altered habitat conditions. Grantini HPP is highest of two HPPs and is located 7.3 km from river mouth. According to Water use permits, guaranteed water discharge is determined as 0.029 m^3/s. Ecological flow is 0.20 m^3/s.

Habitat curves for selected fish species depending on flow rate are shown in Figure 3.2.2.1. These curves were modelled for each fish species of interest (adult common dace, adult bullhead, juvenile brown trout, adult stone loach, adult chub) that was pre-selected by fish expert especially for Losis River, site 2. For most of modelled fish species available habitat area increases with increasing water discharge and optimum flow can be determined only for adult stone loach. This indicates that this river stretch is strongly affected by operating HPP.

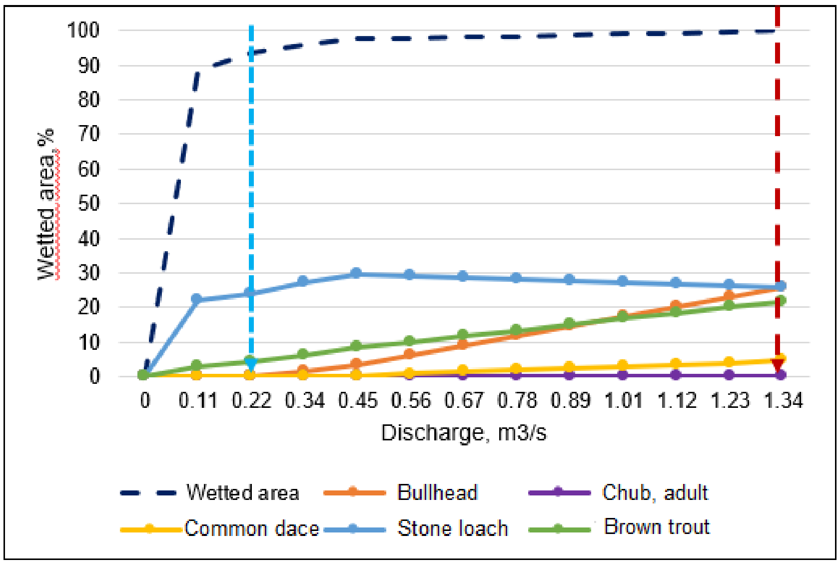


Figure 3.2.2.1. Habitat flow-rating curve for Losis River below Grantini HPP (red arrow – optimum flow, blue arrow - ecological flow in permit)

Figure 3.2.2.2 shows habitat suitability maps for brown trout that is the species of high priority for Losis River. In general, this particular river stretch of Losis2 is not very suitable for brown trout, probably because of natural reasons and hydromorphological alterations caused by local village and operating HPP. During low flow period Q_{30_min} – Q_{30_max} only habitats in two artificial riffles are available for brown trout (Fig. 3.2.2.2). The rapid available habitat increase could be observed, when water discharge reaches Q_{annual_avg}, but only in units with hard substrate.

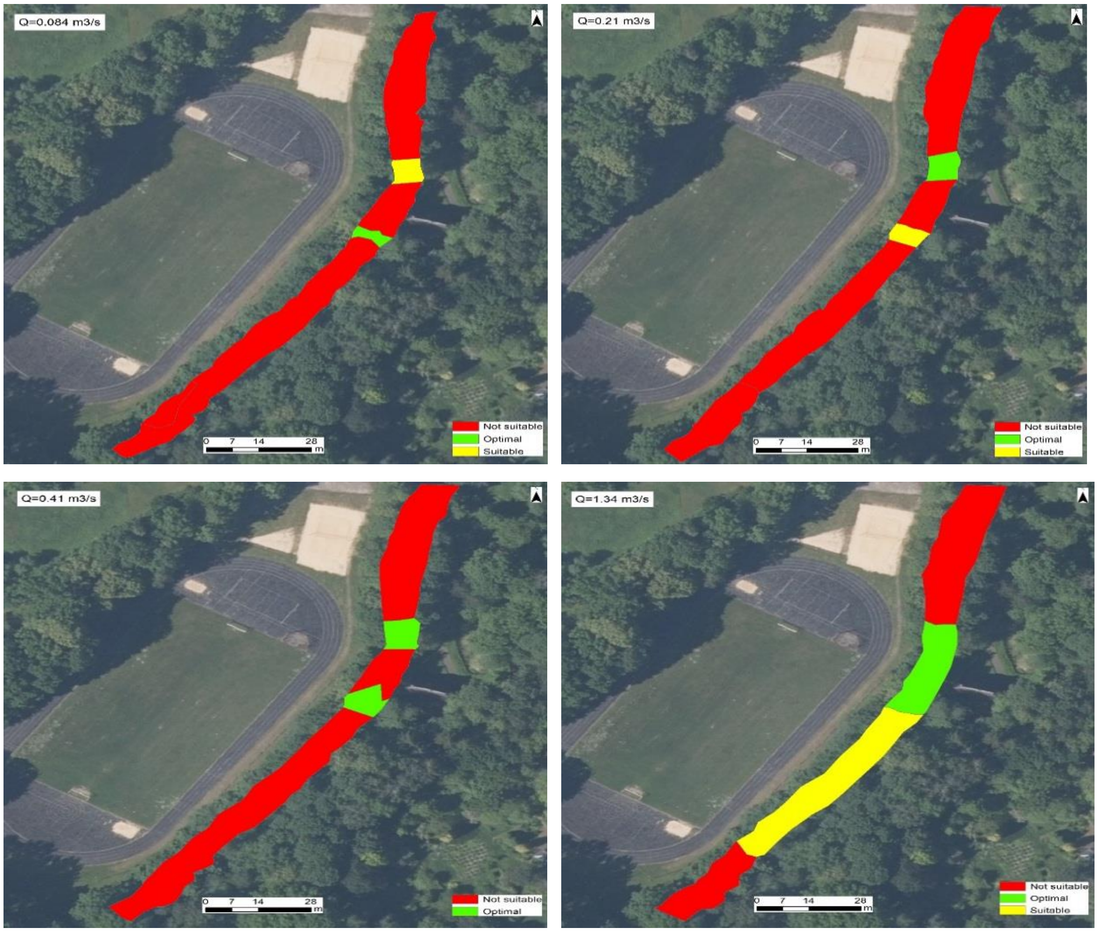


Figure 3.2.2.2. Habitat suitability maps for juvenile brown trout during four different

Figure 3.2.2.3 show the habitat distribution in time particularly during 2021 that is a year with normal water runoff. Obtained results are very similar for all modelled fish species, except stone loach. Results show that operating HPP cause enormous decrease of habitat availability for brown trout and habitat depletion starts already in late spring.

Using habitat-flow rating curve (Figure 3.2.2.1), the $Q_{optimum}$ was defined as 1.30 m^3/s which is closed to the Q_{annual}. According to the E-flow calculation methodology (ECOFLOW Project report, 2019), the suggested ecological flow regime of the Losis River below Grantini HPP is following: 1) water discharge not less than 0.40 m^3/s in period from July to mid-October and 2) water discharge ≥0.80 m^3/s in period from mid-October to June. The proposed minimum E-flow value is corresponding to the average flow of the low flow period (Q_{30_avg}).

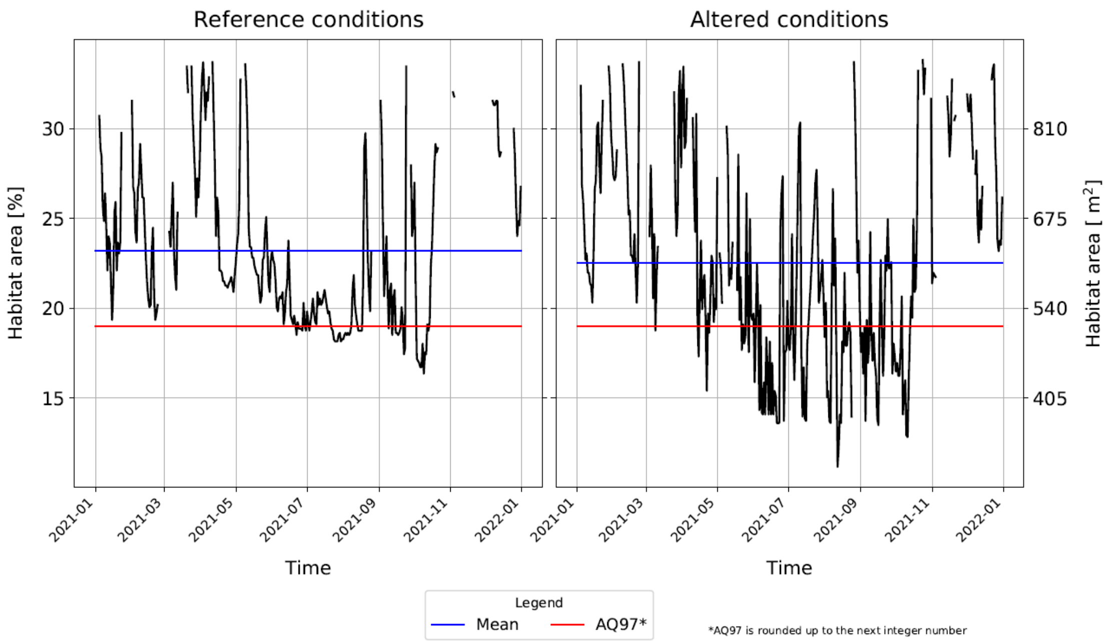


Figure 3.2.2.3. Habitat time series of the juvenile brown trout in reference and altered conditions

Figure 3.2.2.4 shows that river had enough water to provide proposed ecological flow during most of year 2021, even during summer low flow periods.

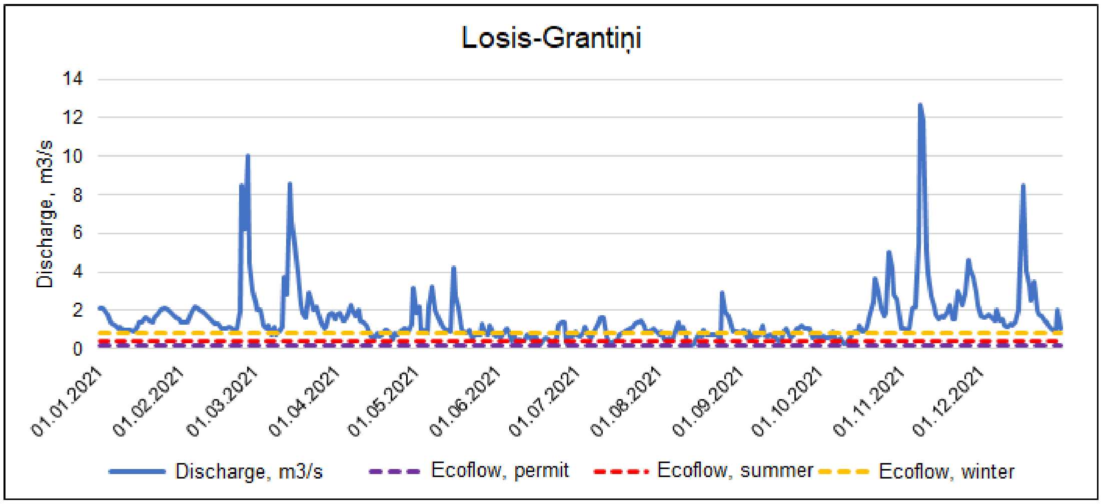


Figure 3.2.2.4. Comparison of daily discharge and ecological flows specified in water use permits and proposed in TRANSWAT project for Losis River below Grantini HPP

3.3. Varduva River HPPs cascade

3.3.1. Varduva River – below Kulšėnai HPP

Kulšėnai HPP is most upstream of five HPP in the Varduva. According to the Rules for the operation of the hydropower plants, guaranteed water discharge is determined as 0.2 m^3/s.

Habitat curves for fish species of interest (juvenile salmon, juvenile brown trout, adult vimba, adult spirlin, adult bullhead) depending on discharge are shown in Figure 3.3.1.1. The habitat area of bullhead and juvenile brown trout increases significantly up to the discharge of ~0.7 m^3/s and then tends to stabilize. The habitat suitable for juvenile salmon occurs in the stretch at a discharge of 0.4 m^3/s, the most rapid increase being within the discharge of 0.5-0.7 m^3/s. The habitat area of spirlin and vimba increases almost uniformly with increasing flow; however, the river stretch becomes suitable for vimba only at a disharge greater than 0.5 m^3/s.

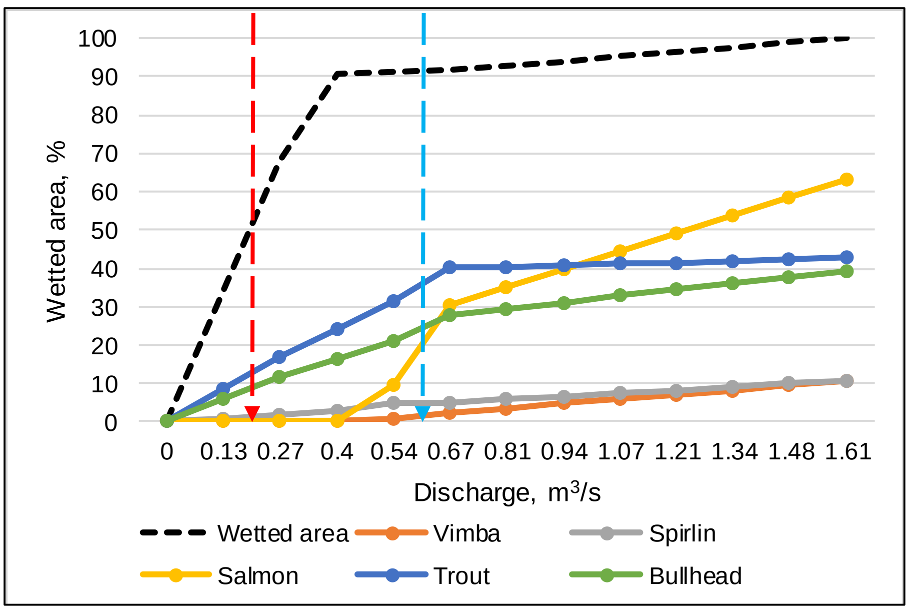


Figure 3.3.1.1. Habitat flow-rating curve for Varduva River below Kulšėnai HPP (red arrow – guaranteed flow, blue arrow – ecological flow proposed in TRANSWAT)

Figure 3.3.1.2 show habitat suitability maps for spirlin and juvenile brown trout, which are expected to be present in the Varduva downstream Kulšėnai HPP irrespective of migration barriers. At conditions close to very low flow conditions

(0.36 m^3/s; Q_{30_min} = 0.20 m^3/s) the area of suitable habitat for spirlin is very small, but at Q_{30_avg} (0.62 m^3/s) it already covers almost twice as much of the reach. Suitable habitats for juvenile brown trout are present even at very low flows, but the maximum area of optimal habitat is reached at Q_{30_avg} and then stabilises.

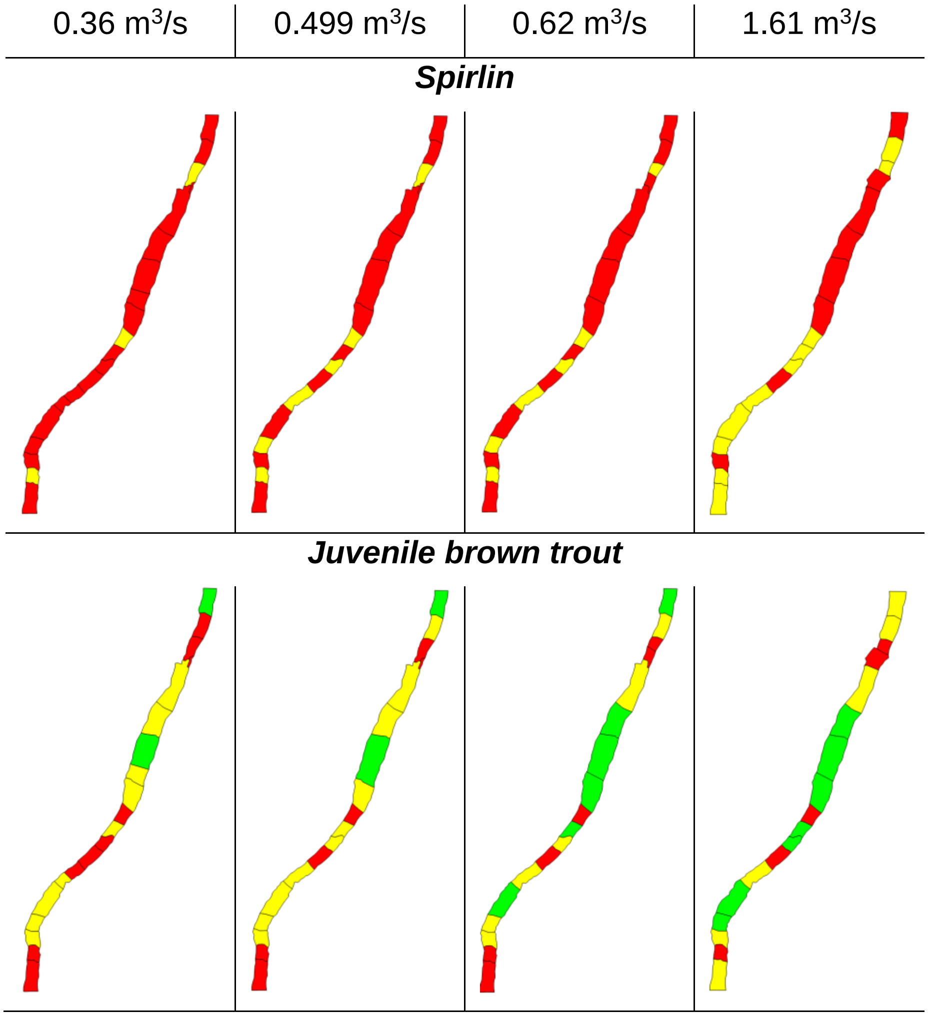


Figure 3.3.1.2. Habitat suitability maps for juvenile brown trout and spirlin during four different discharges

Figures 3.3.1.3 and 3.3.1.4 show the habitat distribution in time during 2021 that is a year with normal water runoff. 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. The results show that the impact of the operation of the Kulšėnai hydropower plant on the habitat availability of the modelled fish species is relatively low. Some reduction in the area of habitats suitable for the species of interest occurs during the low flow period, but this is relatively minor and of short duration. The value of the habitat availability index IH=0.73, which indicates the overall deviation of the spatial and temporal availability of habitats from natural conditions due to the operation of the HPP, indicates that the impact of the Kulšėnai HPP on habitat availability is the lowest in the Varduva HPP chain.

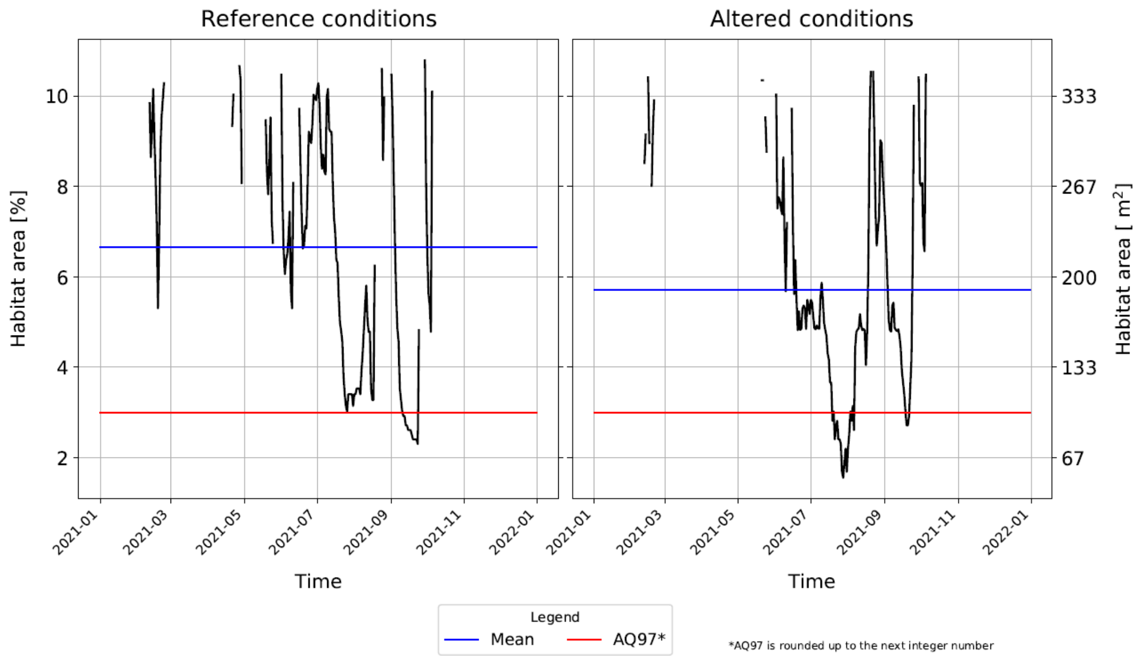


Figure 3.3.1.3. Habitat time series of the spirlin in reference and altered conditions

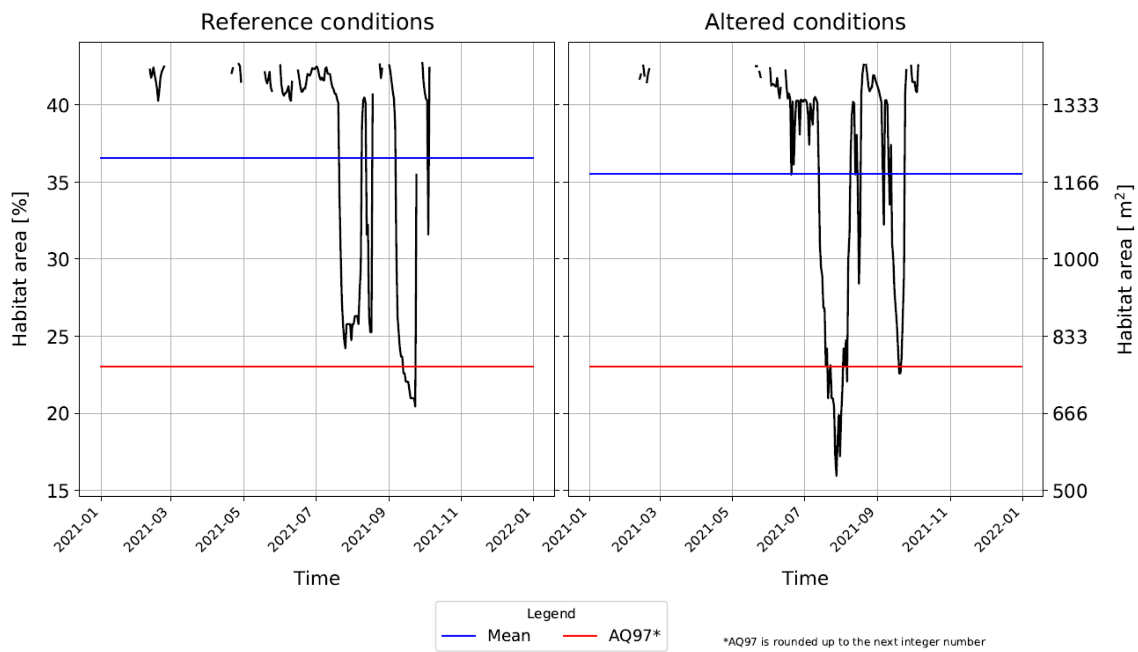


Figure 3.3.1.4. Habitat time series of the juvenile brown trout in reference and altered conditions

According to E-flow calculation methodology, the suggested ecological flow for the Varduva River below Kulšėnai HPP is 0.62 m^3/s. The proposed minimum E-flow value is corresponding to the average flow of the low flow period (Q_{30_avg}) and is compared with daily discharge of year 2021 (normal hydrological conditions) and existing guaranteed flow (Figure 3.3.1.5.).

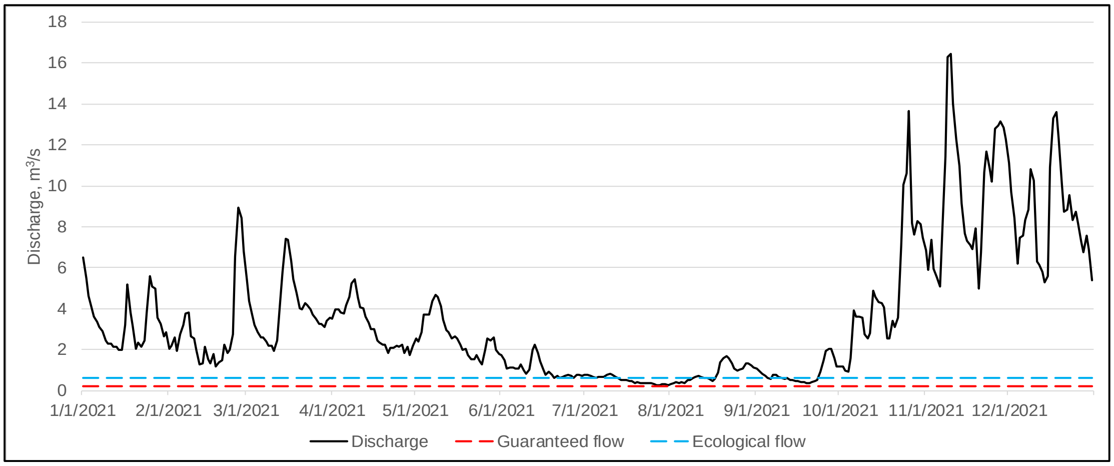


Figure 3.3.1.5. Comparison of daily discharge and guaranteed discharge specified in reservoir exploitation rules and ecological flow proposed in TRANSWAT project for Varduva River below Kulšėnai HPP

3.3.2. Varduva River – below Renavas HPP

Renavas HPP is the second from the upstream in the chain of five HPP in the Varduva. According to the Rules for the operation of the hydropower plants, guaranteed water discharge is determined as 0.39 m^3/s.

Habitat curves for fish species of interest (juvenile salmon, juvenile brown trout, adult vimba, adult spirlin, adult bullhead) depending on discharge are shown in Figure 3.3.2.1. Due to specific morphology of the river channel, suitable habitats for juvenile salmon and bullhead are almost absent in the studied stretch, occupying only up to 2.3% of the wetted area. Variation of habitat area suitable for juvenile brown with flow is small: it increases slightly up to a discharge of ~0.9 m^3/s and then tends to stabilize. Suitable habitats for vimba only occurs in the stretch at flows above 1.0 m^3/s. At very low flows (<0.2 m^3/s), there is no suitable habitat for spirlin in the studied reach, but as the flow increases above 0.2 m^3/s, the area of habitat suitable for spirlin increases almost continuously.

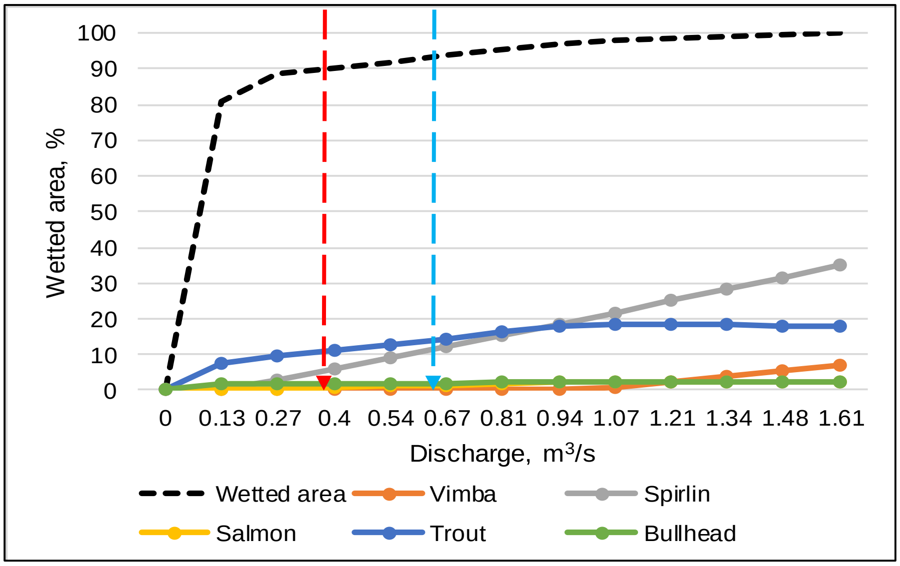


Figure 3.3.2.1. Habitat flow-rating curve for Varduva River below Renavas HPP (red arrow – guaranteed flow, blue arrow – ecological flow proposed in TRANSWAT)

Figure 3.3.2.2 show habitat suitability maps for spirlin and juvenile brown trout, which are expected to be present in the Varduva downstream Renavas HPP irrespective of migration barriers. At a very low flow (0.162 m^3/s), which twice less than Q_{30_min} (0.39 m^3/s), there are no suitable habitat for spirlin at all. At Q_{30_avg} discharge, it already occupies more than 12% of the wetted area, while at >1 m^3/s it covers most of the reach. Suitable habitat for juvenile brown trout is present even at very low flows, but habitat area increases with increasing flow.

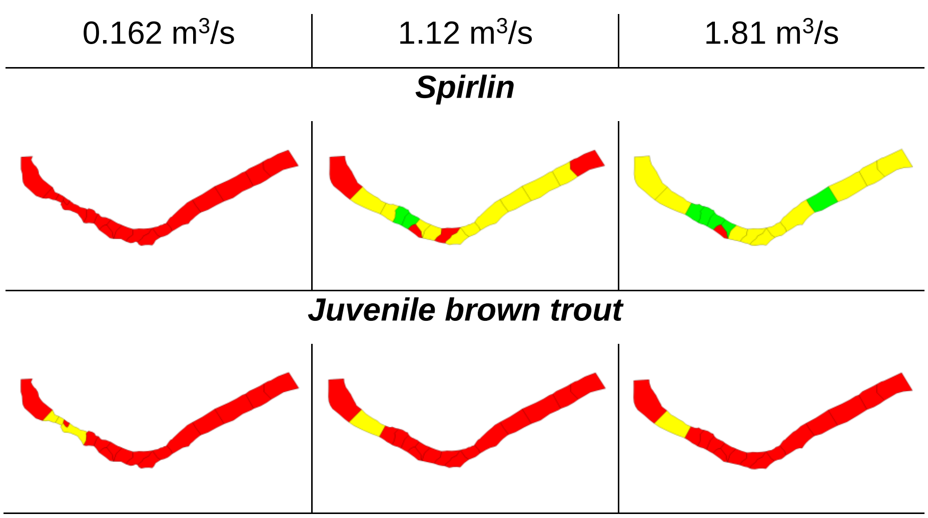


Figure 3.3.2.2. Habitat suitability maps for juvenile brown trout and spirlin during four different discharges

Figures 3.3.2.3 and 3.3.2.4 show the habitat distribution in time during 2021 that is a year with normal water runoff. 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. The results show that the impact of the operation of the Renavas hydropower plant on the habitat availability of the modelled fish species is very strong. When the power plant operates during the dry season, there is almost no suitable habitat for the spirlin and the area of suitable habitat for juvenile brown trout is significantly reduced. The habitat availability index IH=0.40, indicating the total spatial and temporal deviation of habitat availability from natural conditions due to the HPP, shows that the impact of the Renavas HPP on the availability of habitats for the species of interest is very strong, and is the strongest in the Varduva hydropower plant network.

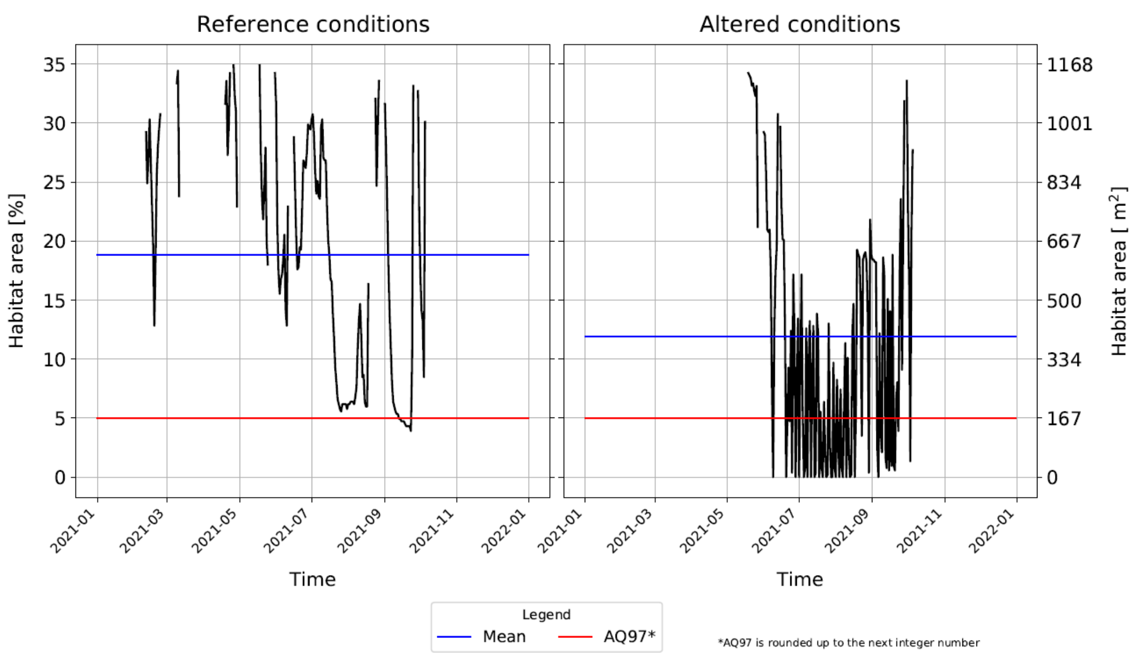


Figure 3.3.2.3. Habitat time series of the spirlin in reference and altered conditions

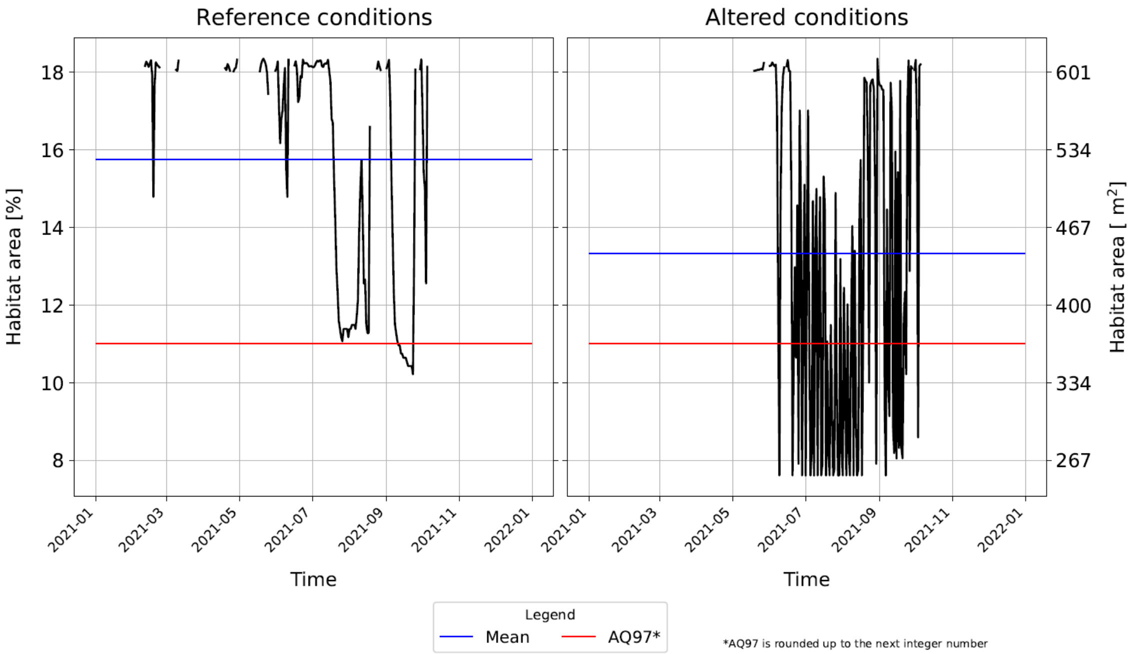


Figure 3.3.2.4. Habitat time series of the juvenile brown trout in reference and altered conditions

According to E-flow calculation methodology, the suggested ecological flow for the Varduva River below Renavas HPP is 0.66 m^3/s. The proposed minimum E-flow value is corresponding to the average flow of the low flow period (Q_{30_avg}) and is compared with daily discharge of year 2021 (normal hydrological conditions) and existing guaranteed flow (Figure 3.3.2.5.).

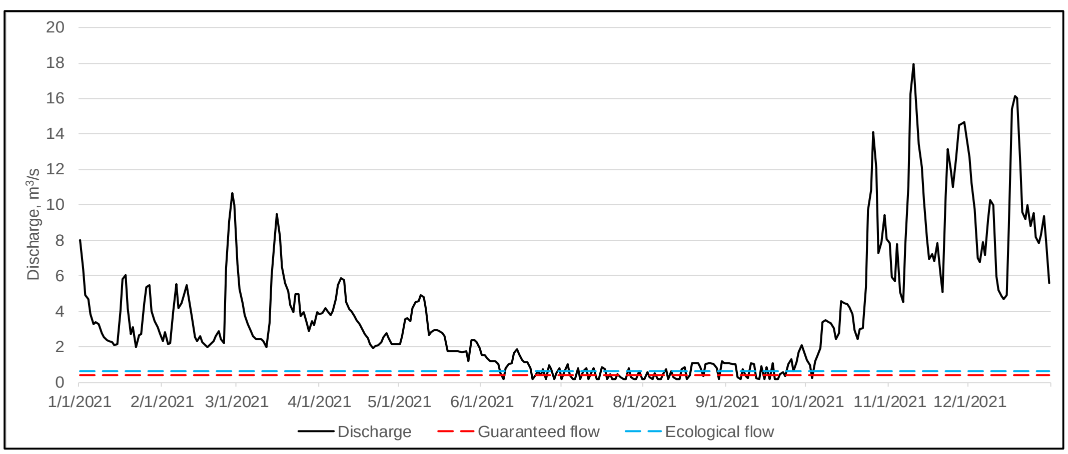


Figure 3.3.2.5. Comparison of daily discharge and guaranteed discharge specified in reservoir exploitation rules and ecological flow proposed in TRANSWAT project for Varduva River below Renavas HPP

3.3.3. Varduva River – below Vadagiai HPP

Vadagiai HPP is the third from the upstream in the chain of five HPP in the Varduva. According to the Rules for the operation of the hydropower plants, guaranteed water discharge is determined as 0.41 m^3/s.

Habitat curves for fish species of interest (juvenile salmon, juvenile brown trout, adult vimba, adult spirlin, adult bullhead) depending on discharge are shown in Figure 3.3.3.1. The habitat area of spirlin and bullhead increases almost uniformly with increasing flow. The habitat area of juvenile brown trout increases significantly up to the discharge of ~0.8 m^3/s and then tends to stabilize. The river stretch becomes suitable for vimba and juvenile salmon only at a discharge greater than 0.8 m^3/s, but as the flow increases above 0.8 m^3/s, the area of suitable habitat increases almost continuously.

Figure 3.3.3.2 show habitat suitability maps for spirlin and juvenile brown trout, which are expected to be present in the Varduva downstream Renavas HPP irrespective of migration barriers. At a very low flow (0.163 m^3/s), which more than twice less than Q_{30_min} (0.41 m^3/s), the area of habitat suitable for spirlin covers less than 1% of the wetted area. At a discharge of 0.967 m^3/s, which is quite close to Q_{30_avg} (0.68 m^3/s), it already occupies nearly 8% of the wetted area. Suitable habitat for juvenile brown trout is present even at very low flow, but at a discharge close to Q_{30_avg} it covers most of the river stretch studied.

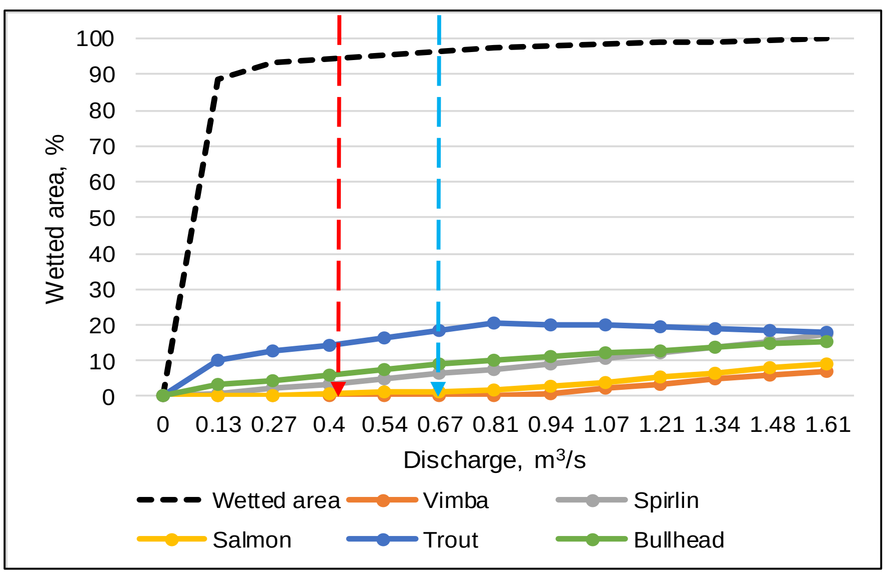


Figure 3.3.3.1. Habitat flow-rating curve for Varduva River below Vadagiai HPP (red arrow – guaranteed flow, blue arrow – ecological flow proposed in TRANSWAT)

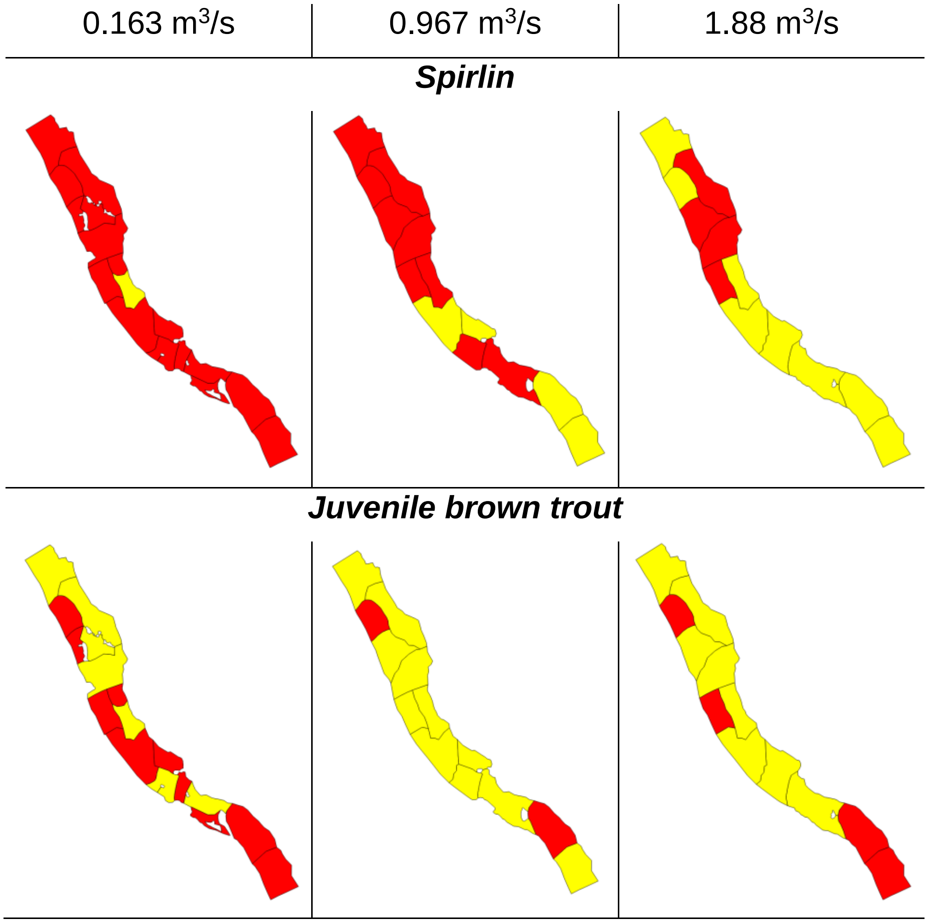


Figure 3.3.3.2. Habitat suitability maps for juvenile brown trout and spirlin during four different discharges

Figures 3.3.3.3 and 3.3.3.4 show the habitat distribution in time during 2021 that is a year with normal water runoff. 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. The results show that spatial and temporal availability of habitats suitable for spirlin and juvenile brown trout is significantly reduced. However, they reflect the impact of the Renavas hydropower plant, as the Vadagiai HPP does not operate during the low-flow season. The habitat availability index IH=0.45, indicating the overall spatial and temporal deviation of habitat availability from natural conditions due to the HPP, shows once again that the impact of the Renavas HPP on the habitat availability of the species of interest is very strong and can be felt over a large distance from the Renavas HPP, even on the section of the river downstream of the Vadagiai HPP.

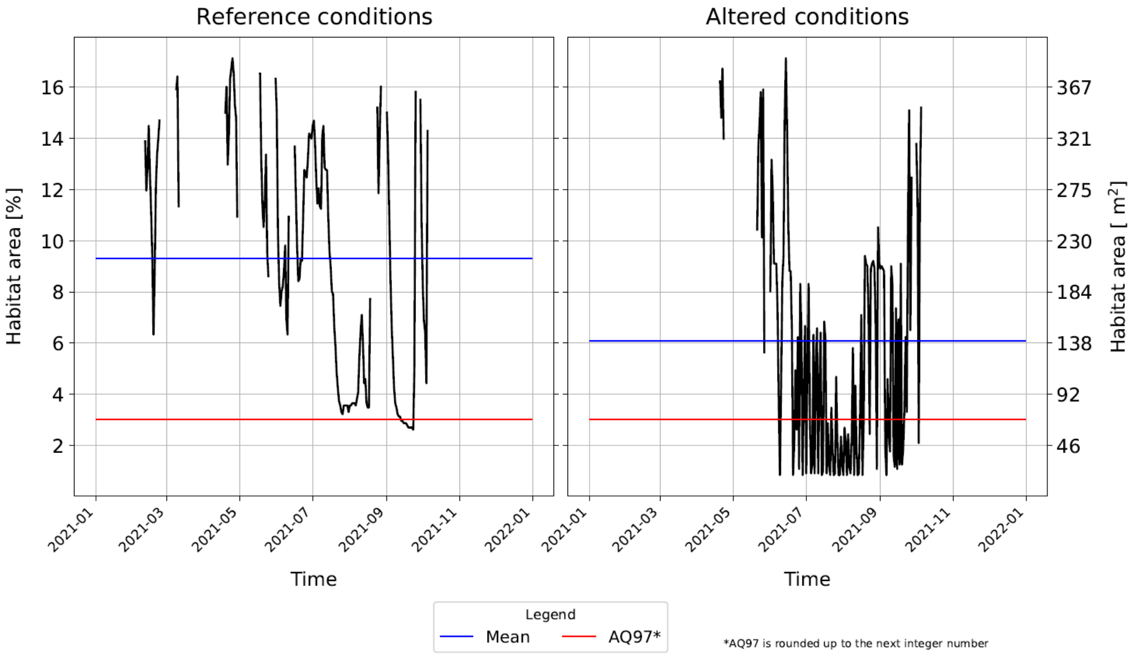


Figure 3.3.3.3. Habitat time series of the spirlin in reference and altered conditions

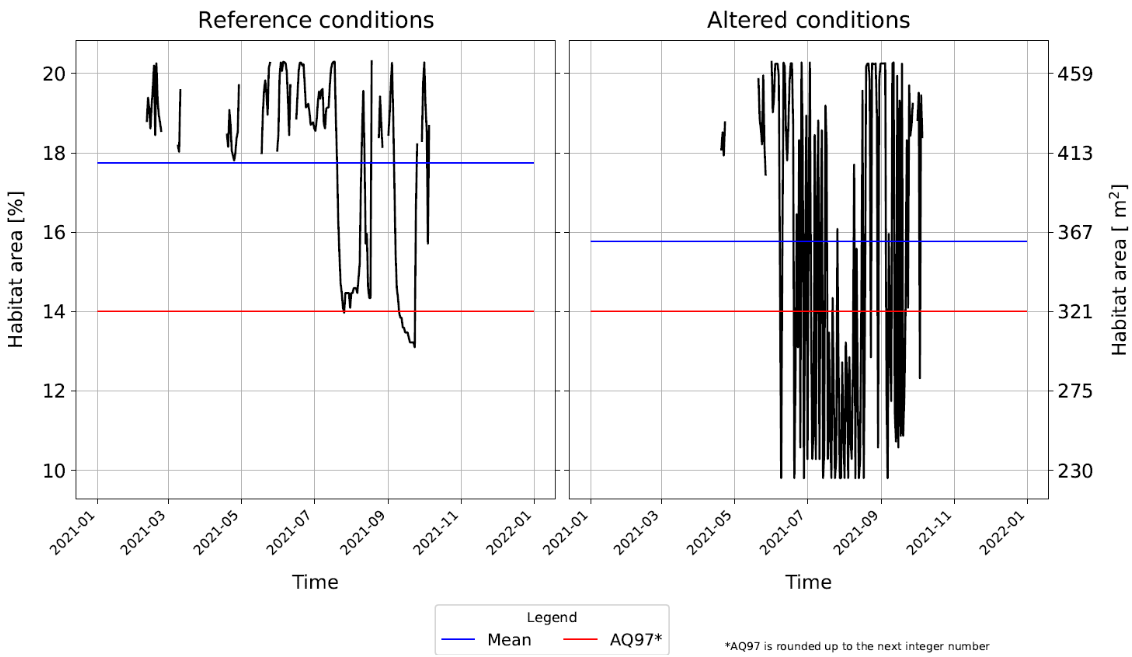


Figure 3.3.3.4. Habitat time series of the juvenile brown trout in reference and altered conditions

According to E-flow calculation methodology, the suggested ecological flow for the Varduva River below Vadagiai HPP is 0.68 m^3/s. The proposed minimum E-flow value is corresponding to the average flow of the low flow period (Q_{30_avg}) and is compared with daily discharge of year 2021 (normal hydrological conditions) and existing guaranteed flow (Figure 3.3.3.5.).

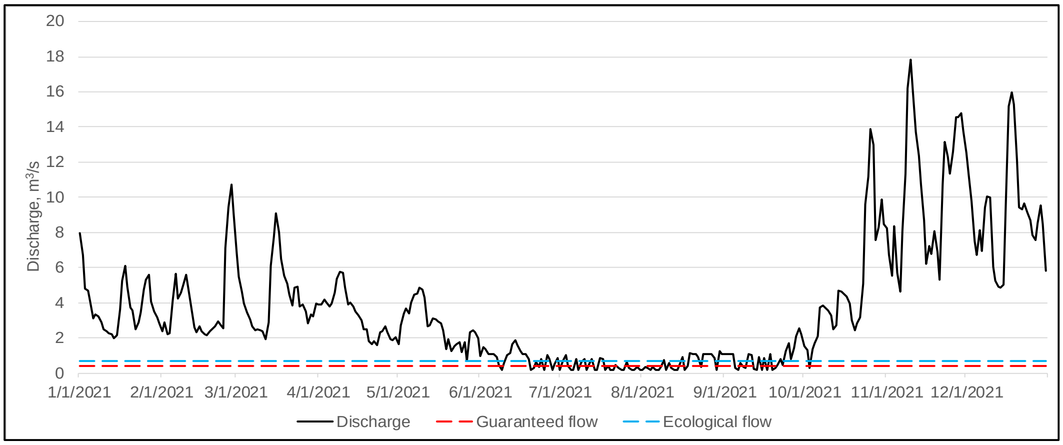


Figure 3.3.3.5. Comparison of daily discharge and guaranteed discharge specified in reservoir exploitation rules and ecological flow proposed in TRANSWAT project for Varduva River below Vadagiai HPP

3.3.4. Varduva River – below Ukrinai HPP

Ukrinai HPP is the fourth from the upstream in the chain of five HPP in the Varduva. According to the Rules for the operation of the hydropower plants, guaranteed water discharge is determined as 0.46 m^3/s.

Habitat curves for fish species of interest (juvenile salmon, juvenile brown trout, adult vimba, adult spirlin, adult bullhead) depending on discharge are shown in Figure 3.3.4.1. Due to specific morphology of the river channel, suitable habitats for vimba are absent in the studied stretch. The habitat area of bullhead, juvenile brown trout and juvenile salmon increases up to the discharge of ~0.8 m^3/s and then tends to stabilize. The habitat area of spirlin increases almost uniformly with increasing flow.

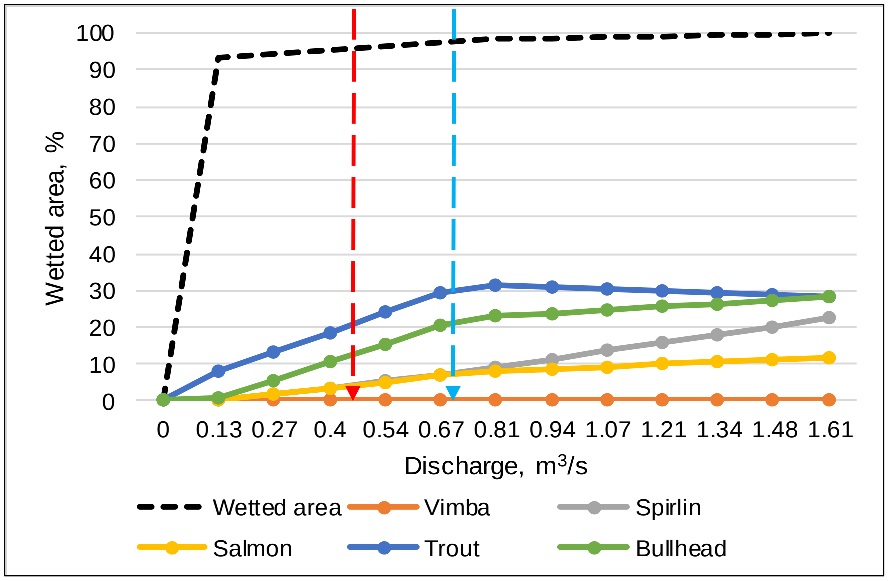


Figure 3.3.4.1. Habitat flow-rating curve for Varduva River below Ukrinai HPP (red arrow – guaranteed flow, blue arrow – ecological flow proposed in TRANSWAT)

Figure 3.3.4.2 show habitat suitability maps for spirlin and juvenile brown trout, which are expected to be present in the Varduva downstream Kulšėnai HPP irrespective of migration barriers. At a very low flow (0.15 m^3/s), which three times less than Q_{30_min} (0.46 m^3/s), there are no suitable habitat for spirlin at all. At a discharge of 0.82 m^3/s, which is close to Q_{30_avg} (0.71 m^3/s), it already occupies 8% of the wetted area. Suitable habitat for juvenile brown trout is present even at very low flow, but at a discharge close to Q_{30_avg} it covers most of the river stretch studied.

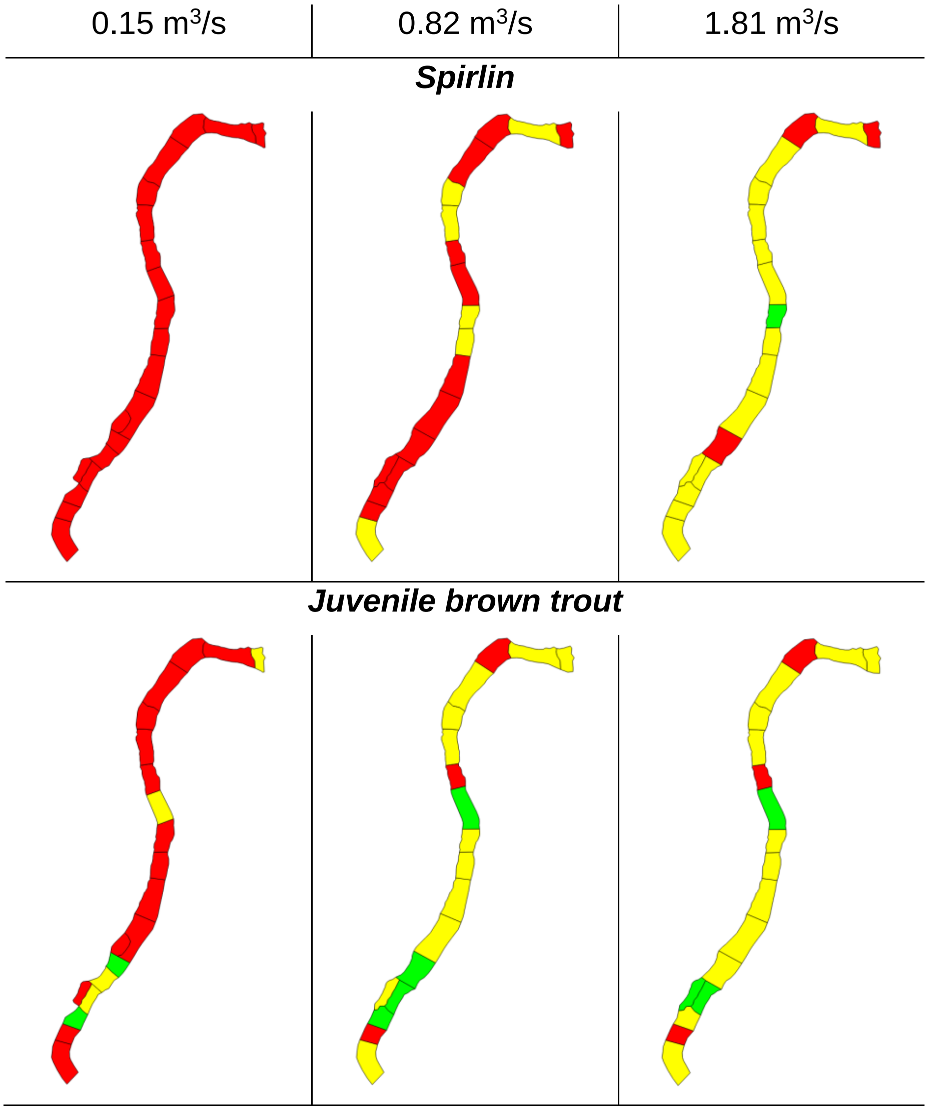


Figure 3.3.4.2. Habitat suitability maps for juvenile brown trout and spirlin during four different discharges

Figures 3.3.4.3 and 3.3.4.4 show the habitat distribution in time during 2021 that is a year with normal water runoff. 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. The results show that the impact of the operation of the Ukrinai hydropower plant on the habitat availability of the modelled fish species is relatively strong. During periods of low water flow, the operation of HPP temporarily deprives both spirlin and juvenile brown trout of some of their suitable habitat. The habitat availability index IH=0.61, indicating the overall spatial and temporal deviation of habitat availability from natural conditions due to the HPP, shows that the impact of the Ukrinai HPP on habitat availability for the species of interest is quite significant.

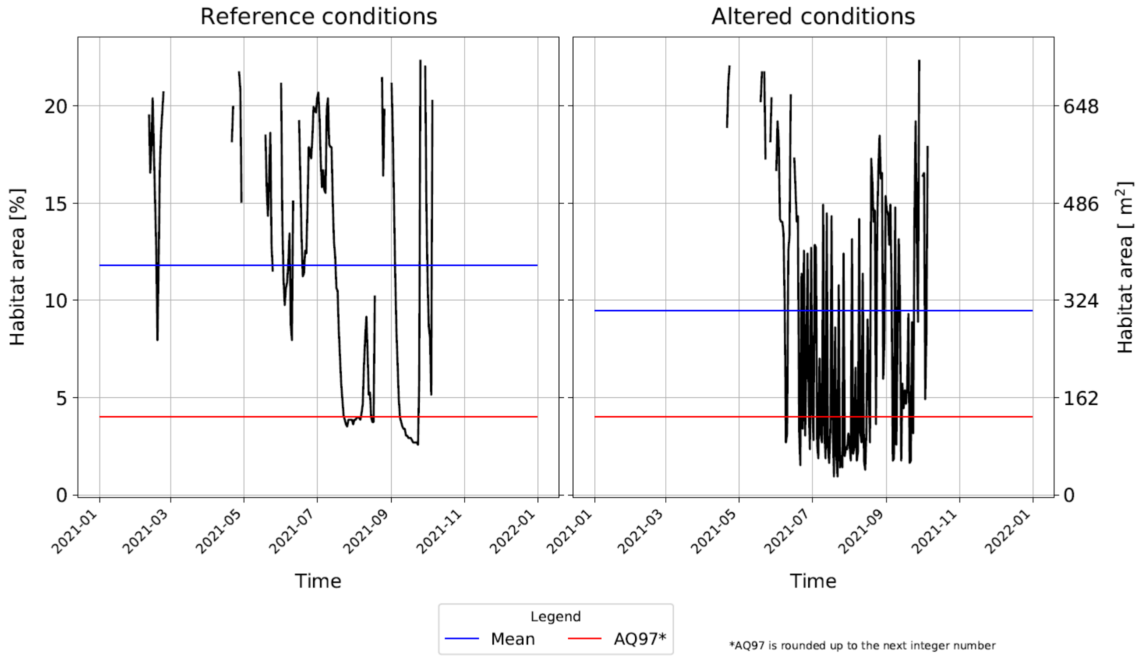


Figure 3.3.4.3. Habitat time series of the spirlin in reference and altered conditions

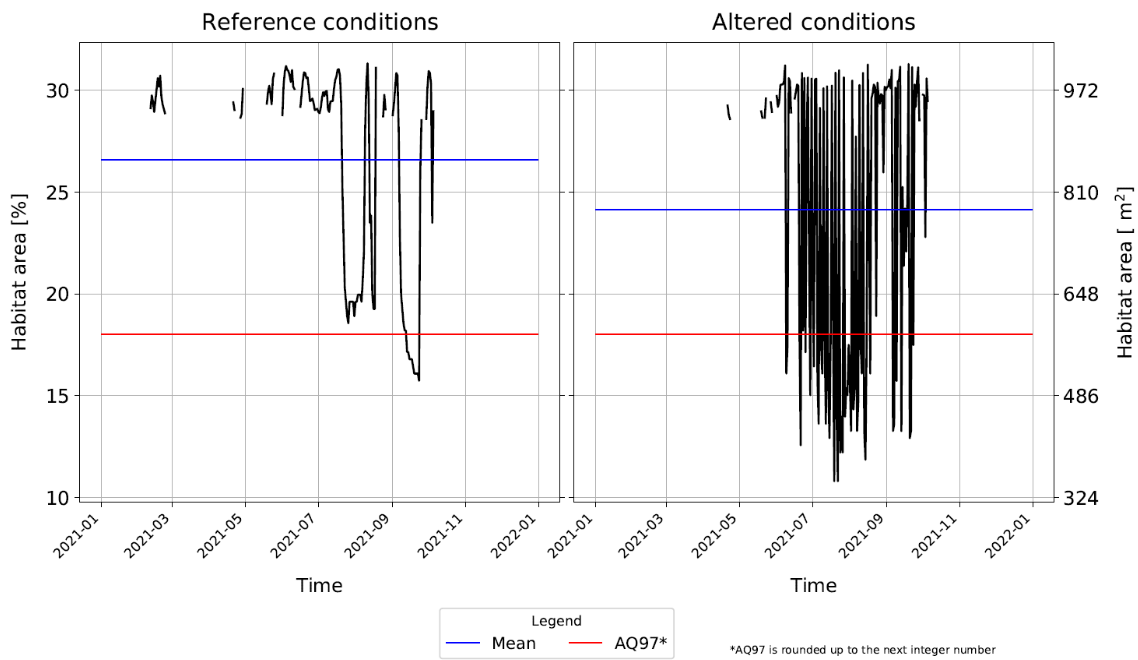


Figure 3.3.4.4. Habitat time series of the juvenile brown trout in reference and altered conditions

According to E-flow calculation methodology, the suggested ecological flow for the Varduva River below Ukrinai HPP is 0.71 m^3/s. The proposed minimum E-flow value is corresponding to the average flow of the low flow period (Q_{30_avg}) and is compared with daily discharge of year 2021 (normal hydrological conditions) and existing guaranteed flow (Figure 3.3.4.5.).

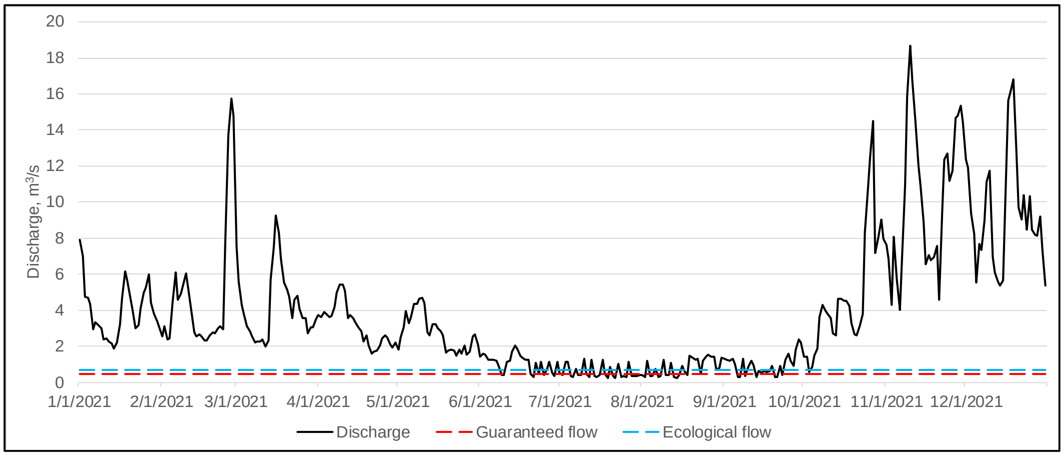


Figure 3.3.4.5. Comparison of daily discharge and guaranteed discharge specified in reservoir exploitation rules and ecological flow proposed in TRANSWAT project for Varduva River below Ukrinai HPP

3.3.5. Varduva River – below Juodeikiai HPP

Juodeikiai HPP is the last from the upstream in the chain of five HPP in the Varduva. According to the Rules for the operation of the hydropower plants, guaranteed water discharge is determined as 0.91 m^3/s.

Habitat curves for fish species of interest (juvenile salmon, juvenile brown trout, adult vimba, adult spirlin, adult bullhead) depending on discharge are shown in Figure 3.3.5.1. The habitat area of spirlin and vimba increases almost uniformly with increasing flow; however, the river stretch becomes suitable for vimba only at a discharge greater than 0.5 m^3/s. The habitat area of juvenile salmon increases up to the discharge of ~0.7 m^3/s and then tends to stabilize. The maximum area of habitat for juvenile brown trout peaks at a discharge of ~0.5 m^3/s, and for bullhead at a discharge of ~0.7 m^3/s, with the habitat areas of both species beginning to decline as discharge further increases.

Figure 3.3.5.2 show habitat suitability maps for spirlin and juvenile brown trout, which are expected to be present in the Varduva downstream Kulšėnai HPP irrespective of migration barriers. At a very low flow (0.274 m^3/s), which three times less than Q_{30_min} (0.91 m^3/s), the area of habitat suitable for spirlin is very small, but at a discharge of 0.998 m^3/s, which is close to Q_{30_avg} (1.07 m^3/s), it covers nearly half of the river stretch studied. Suitable habitat for juvenile brown trout is present even at very low flow, but at a discharge close to Q_{30_avg} the area of habitat, which is optimal for this species, reaches its maximum.

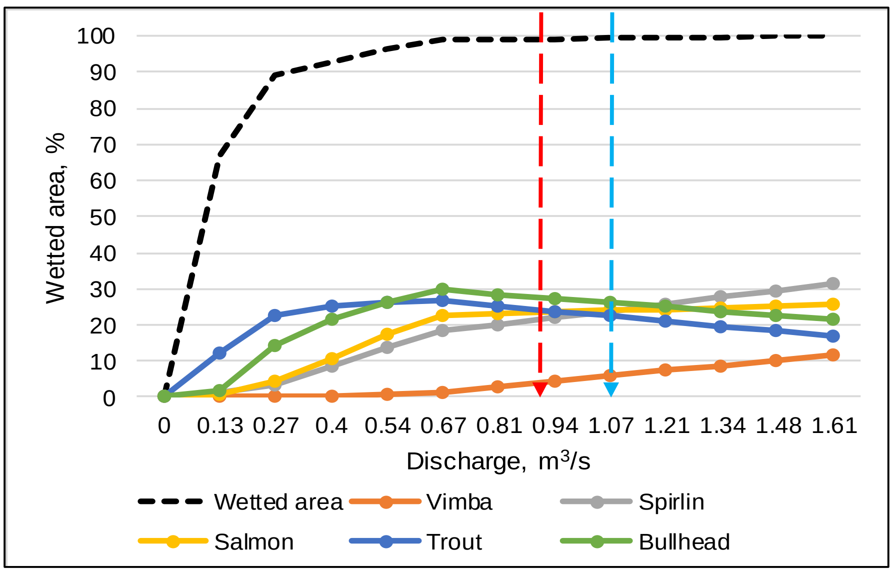
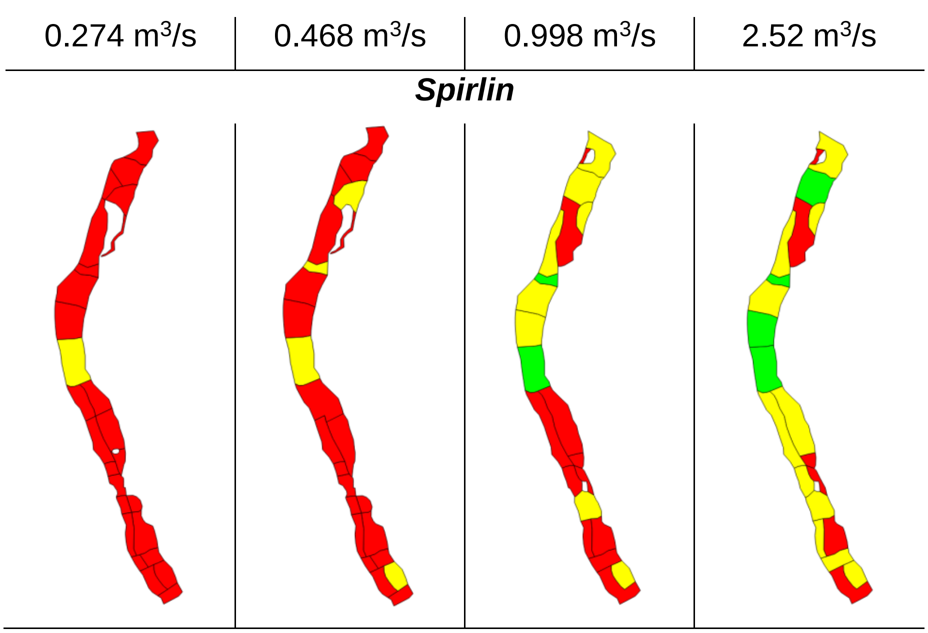


Figure 3.3.5.1. Habitat flow-rating curve for Varduva River below Juodeikiai HPP (red arrow – guaranteed flow, blue arrow – ecological flow proposed in TRANSWAT)



Juvenile brown trout

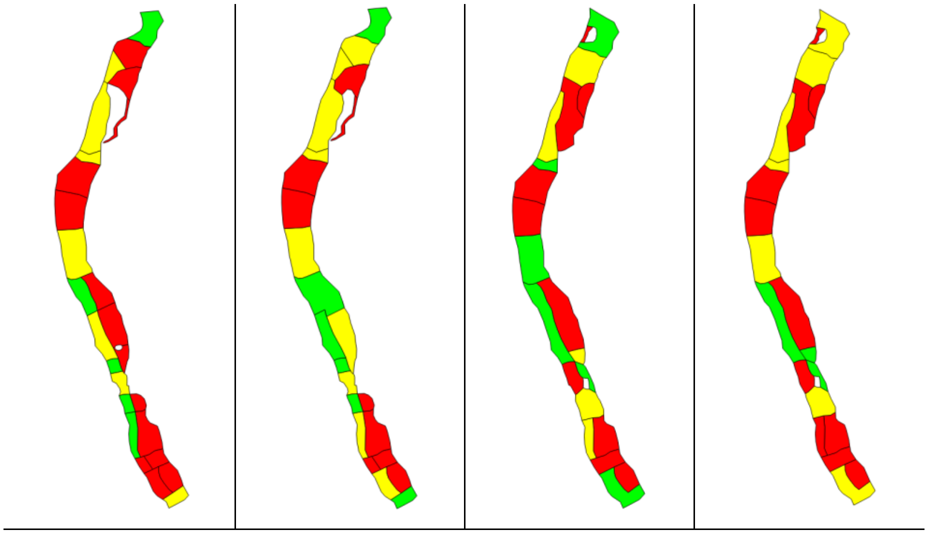


Figure 3.3.5.2. Habitat suitability maps for juvenile brown trout and spirlin during four different discharges

Figures 3.3.5.3 and 3.3.5.4 show the habitat distribution in time during 2021 that is a year with normal water runoff. 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. The results show that the impact of the operation of the Juodeikiai hydropower plant on the habitat availability of the modelled fish species is relatively low. Some temporal reduction in the area of habitat suitable for spirlin occurs during the low flow period, while the habitat of the brown trout is not at all affected by the operation of this hydropower plant. However, the habitat availability index IH=0.61, indicating the overall spatial and temporal deviation of habitat availability from natural conditions due to the hydropower plant, shows that the Juodeikiai hydropower plant does have an impact on the availability of habitats suitable for certain species of interest.

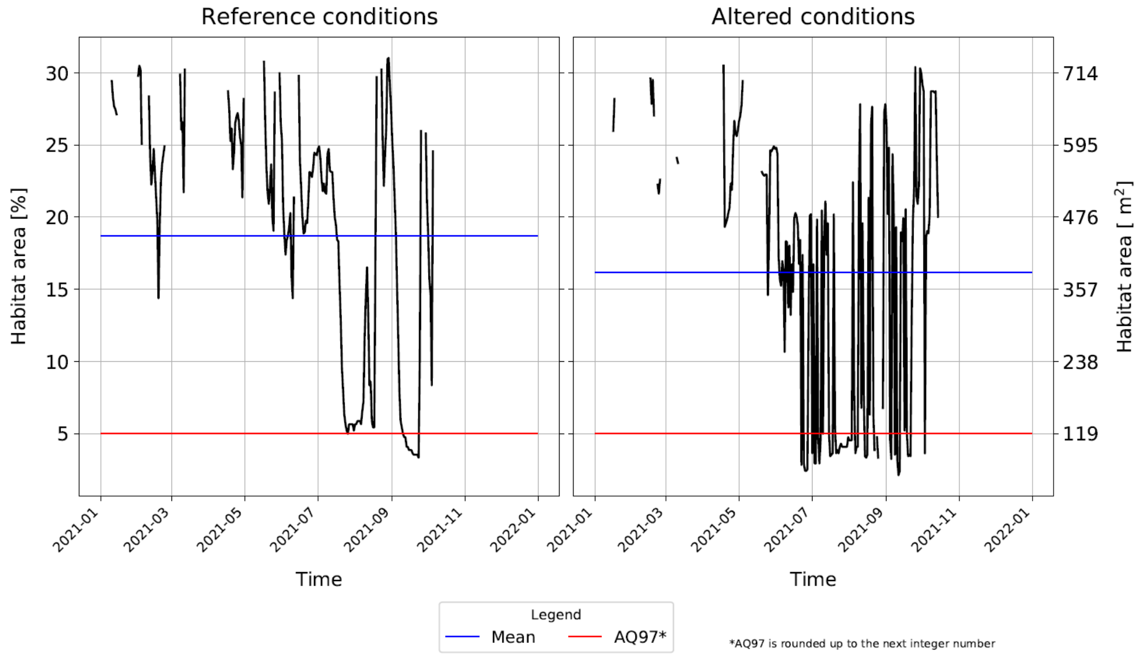


Figure 3.3.5.3. Habitat time series of the spirlin in reference and altered conditions

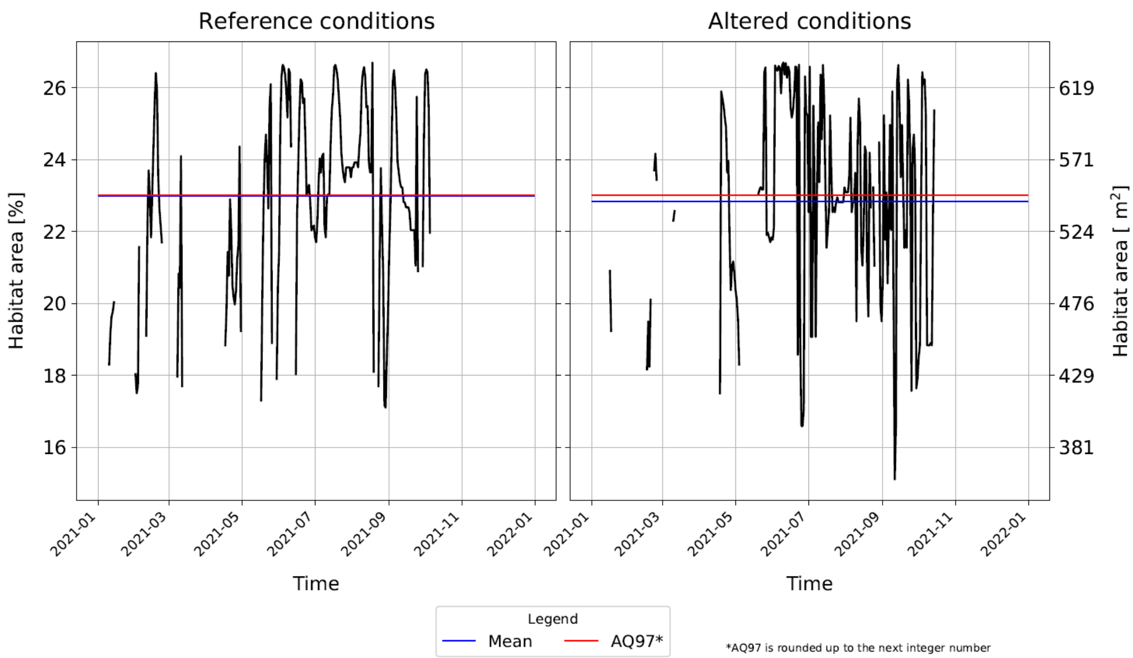


Figure 3.3.5.4. Habitat time series of the juvenile brown trout in reference and altered conditions

According to E-flow calculation methodology, the suggested ecological flow for the Varduva River below Juodeikiai HPP is 1.07 m^3/s. The proposed minimum E-flow value is corresponding to the average flow of the low flow period (Q_{30_avg}) and is compared with daily discharge of year 2021 (closer to dry hydrological conditions) and existing guaranteed flow (Figure 3.3.5.5.).

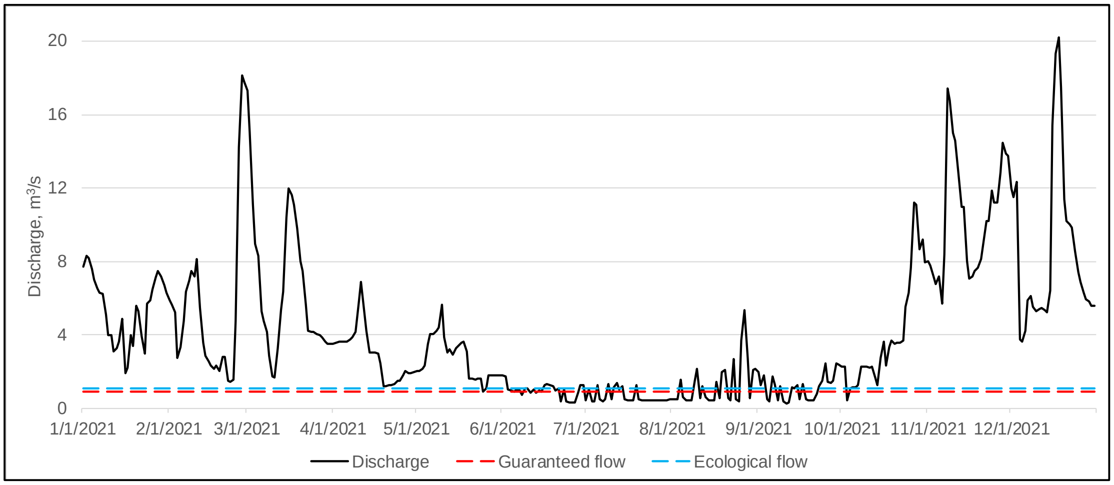


Figure 3.3.5.5. Comparison of daily discharge and guaranteed discharge specified in reservoir exploitation rules and ecological flow proposed in TRANSWAT project for Varduva River below Juodeikiai HPP

4. INPUT DATA AND CALIBRATION OF HPPs CASCADE MODELLING OF SELECTED RIVERS USING HEC-RES SOFTWARE

4.1. Ciecere River HPPs cascade

4.1.1. Morphology of the Ciecere River

The Ciecere River is a right tributary of the Venta River. It outflows from the Ciecere Lake and inflows to the Venta River.

The Ciecere River Basin area is 539 km^2. The river is 58 km long, the river bed gradient is 1.7 m/km in upper stretch and 1.0 m/km in down stretch. An elevation of the river basin varies from 23 to 101 m LAS. The Ciecere River in the section from Pakuli reservoir to the estuary has been identified as a priority fish water as a type of salmonid water. Due to appropriate physical geographical conditions and high slopes, 3 hydropower plants were installed in the Ciecere River: Ciecere, Dzirnavnieki and Pakuli HPPs (Fig. 4.1.1.1).

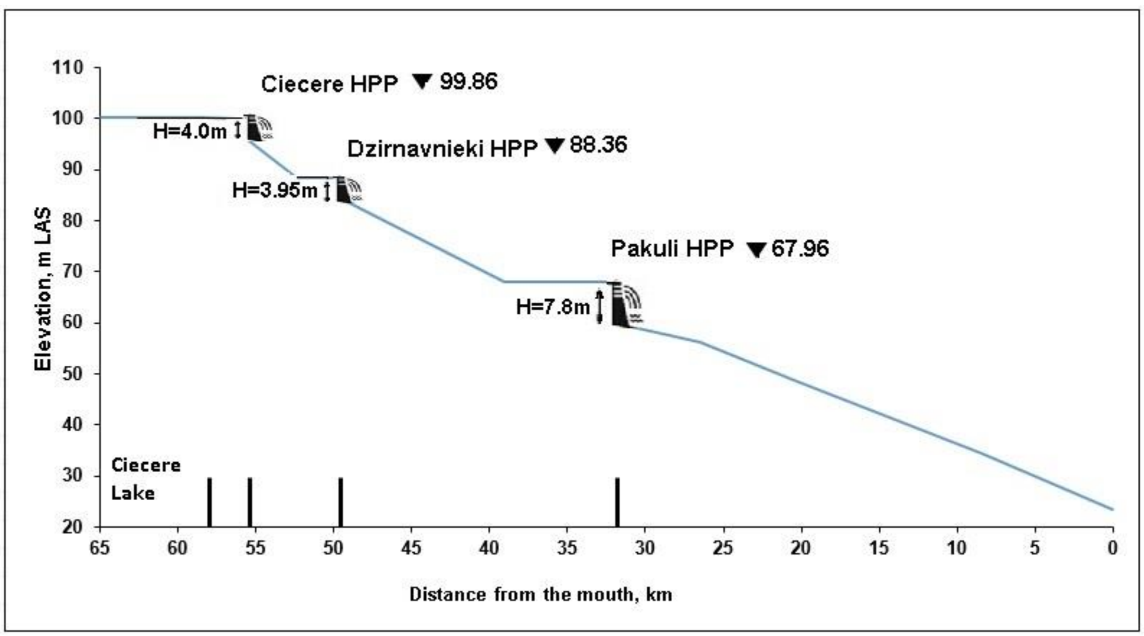


Figure 4.1.1.1. Hydropower plants in the Ciecere River

4.1.2. Input data for HPPs cascade modelling in the Ciecere River

There are two main groups of input data for HPPs cascade modelling: physical and operational data. Physical data consists of hydrological, reservoir, dam and tailwater data. Operational data defines the reservoir operation sets, the zones and rules that describe the operating plan for the reservoir.

Hydrological data

The inflow to the reservoir system (flow values above the first reservoir of the cascade) has to be calculated. For the Ciecere River these data are prepared according to field survey measurements in 2021. Figure 4.1.2.1 shows the inflow data series to the Ciecere River reservoirs system. The average annual inflow was 0.78 m^3/s and varied from 0.10 m^3/s in August to 2.19 m^3/s in March. In winter (January – February) the average water discharge was 0.97 m^3/s, in spring (March – May) – 0.96 m^3/s, in summer (June – September) - 0.33 m^3/s, and in autumn (October – November) – 0.97 m^3/s. This aligned hydrological regime is related to the affect of the Ciecere Lake that changes the magnitude and timing of the outflow. Compared to multiannual data, in 2021, hydrological conditions were close to the normal year.

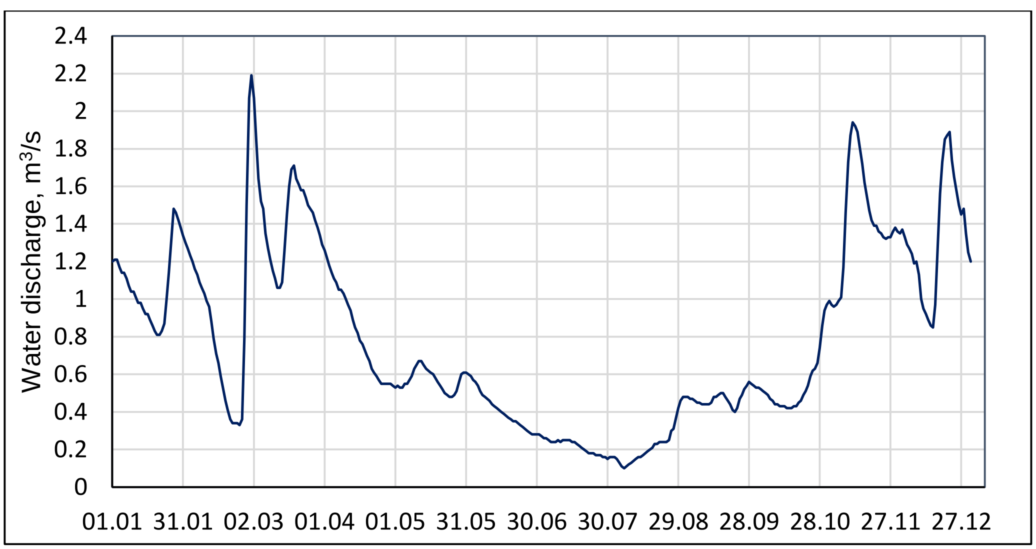


Figure 4.1.2.1. Main inflow to the reservoir system of the Ciecere River in 2021

According to the 2021 hydrological measurements, daily discharges below each HPP dam were calculated (Fig. 4.1.2.2). These data are necessary for calibration of the Ciecere River HPPs cascade model. The impact of each HPP activity is very noticeable during the dry season. The phenomena of hydropeaking are visible even in the daily discharge step.

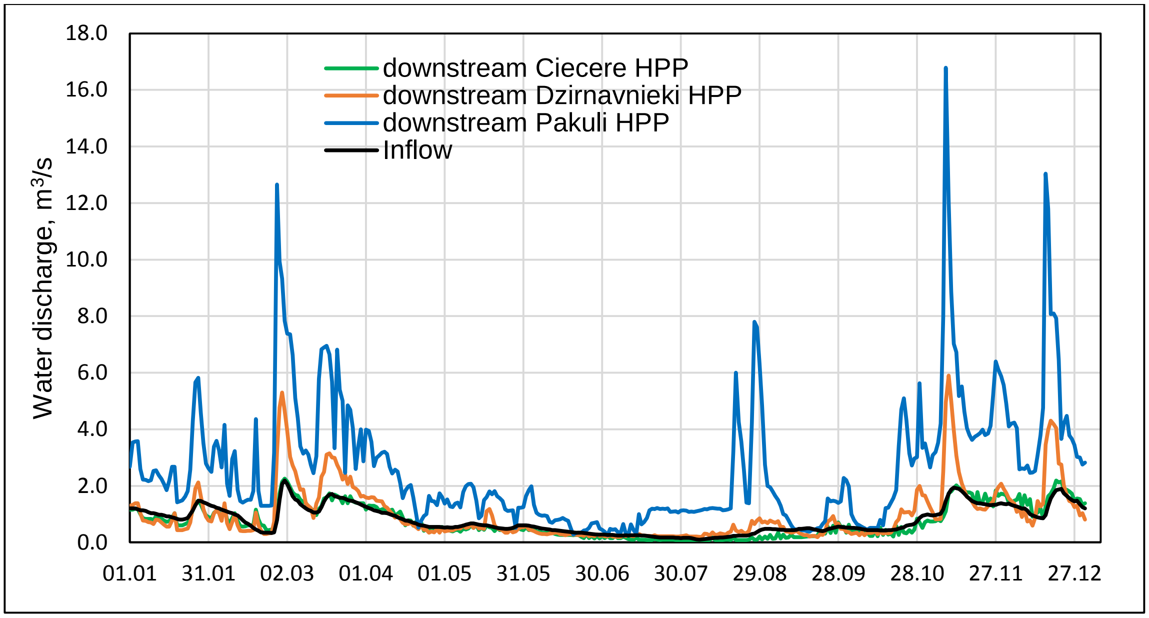


Figure 4.1.2.2. Hydrographs below each HPP in Cievere River, 2021

Physical characteristics of the reservoirs

A large amount of initial information, such as physical characteristics of the reservoirs, technical characteristics of the hydropower plants as well as operation and tailwater data, is crucial for the development of reservoir system.

The Ciecere River reservoir system consists of three HPPs with three reservoirs. The time-consuming process is to create accurate reservoir water level-volume-area curves. During the field surveys in 2021, the measurements of the Ciecere River cross-sections were carried out for the further riverbed elevation data processing, using ArcGIS software and digital elevation model (DEM). Calculations and water level-volume-surface area curves were made for Ciecere, Dzirnavnieki and Pakuli reservoirs (Fig. 4.1.2.3).

Other very important information is reservoir water levels in the specific zones (Table 4.1.2.1). The water level of the Inactive zone corresponds to reservoir level when it is filled with only 25 percent of its water volume. Buffer, Conservation and Flood control zones correspond to the lowest, average (normal) and highest levels of the reservoir, which are defined in the “Water resources use permits” issued by the Regional Environmental Boards of the State Environmental Service.

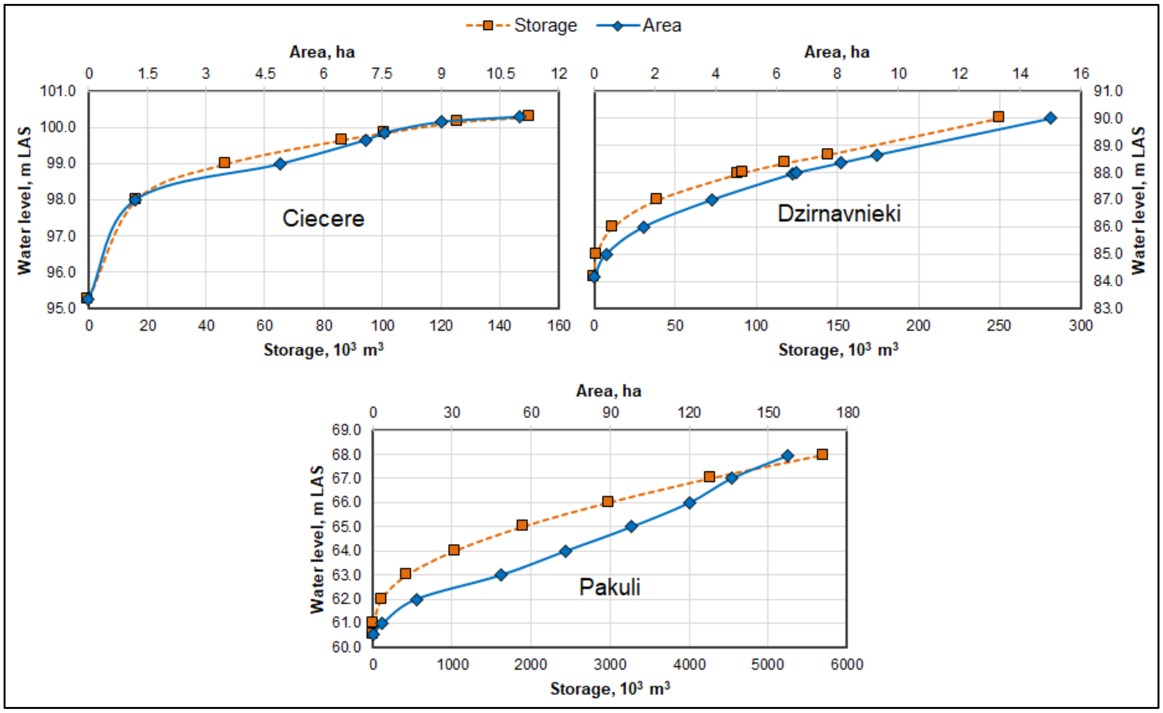


Figure 4.1.2.3. Water level-storage and water level-surface area curves of the Ciecere River reservoirs

Table 4.1.2.1. Water levels of the various zones in the Ciecere River reservoirs

River	Reservoir	Water level in zones, m LAS				
		Inactive	Buffer	Conservation	Flood Control	Top of dam
Ciecere	Ciecere	98.3	99.66	99.86	100.16	100.96
	Dzirnavnieki	86.66	87.96	88.36	88.66	90.16
	Pakuli	64.44	67.76	67.96	67.96	70.16

Technical characteristics of the hydropower plants

The main technical characteristics of the hydropower plants in Ciecere River are presented in Table 4.1.2.2. These data were taken from the “Water resources use permits”. The coefficient of efficiency of the HPPs represents a percentage of the total potential energy the power plant could theoretically generate. Information about these coefficients is not available. Therefore, they were assumed to be 0.8, i.e. 80 percent for each power plant.

Table 4.1.2.2. Main characteristics of the HPPs in Ciecere River

River	HPP	Capacity, MW	Head, m	$Q_{environmental}$, m^3/s	Turbine operating discharge, m^3/s	
					Min	Max
Ciecere	Ciecere	0.150	4.0	0.061	0.5	3.0
	Dzirnavnieki	0.150	3.95	0.16	0.5	5.0
	Pakuli	0.400	7.80	0.32	0.6	5.6

Tailwater data

In the developed model, the discharge-water level curves in the river reach below each power plant were created according to the field hydrological measurements in 2021 (Fig. 4.1.2.4). These curves are useful for the calculation of daily head (the difference between reservoir elevation and tailwater) for the purpose of computing power generation.

Operation data

The Operation zones are first described in the Operation set. The reservoir zones (Top of Dam, Flood Control, Conservation, Buffer and Inactive) are generated for each reservoir from the Ciecere River HPPs cascade. The data of these zones are given in Table 4.1.2.1.

Operation Rules are added to the zones. A Release Function is used to describe daily flow through the HPP turbines. This rule defines that the HPP does not operate if the daily inflow to the reservoir is less than the minimum turbine operating discharge. In this case, the transit flow of the river must be passed through the hydrotechnical structures. The values of minimum turbine operating discharges depend upon HPP turbine type and diameter of the turbine wheel. This information can be found in the “Water resources use permits”.

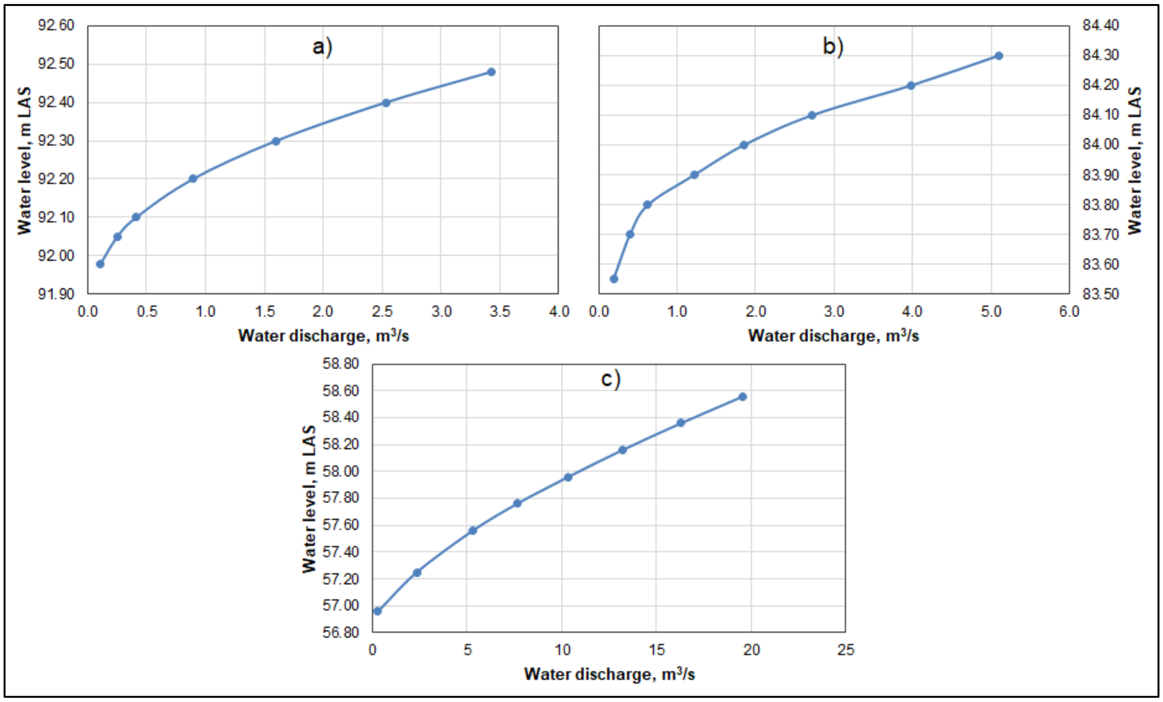


Figure 4.1.2.4. Water level–discharge curves below HPPs: a) Ciecere, b) Dzirnavnieki and c) Pakuli

4.1.3. Calibration of the Ciecere River HPPs cascade model

The task of model calibration is to achieve that the measured values of the parameters correspond as closely as possible to the modelled ones. When simulating the operation of HPP cascades, the daily discharges of the river reach below each HPP were selected as parameters for evaluation of the calibration process. The measured parameters are the daily discharges in the Ciecere River below each HPP, determined during the hydrological surveys in 2021. Using the HecResSIM software, the daily discharges were modelled for each of the three downstream stretches of the Ciecere River HPPs cascade.

A comparison of the observed and modelled discharges is presented in Figure 4.1.3.1. The highest correlation coefficient between these time series is calculated for the Ciecere River below Ciecere HPP (r=0.96), and the lowest – below Pakuli HHP (r=0.70).

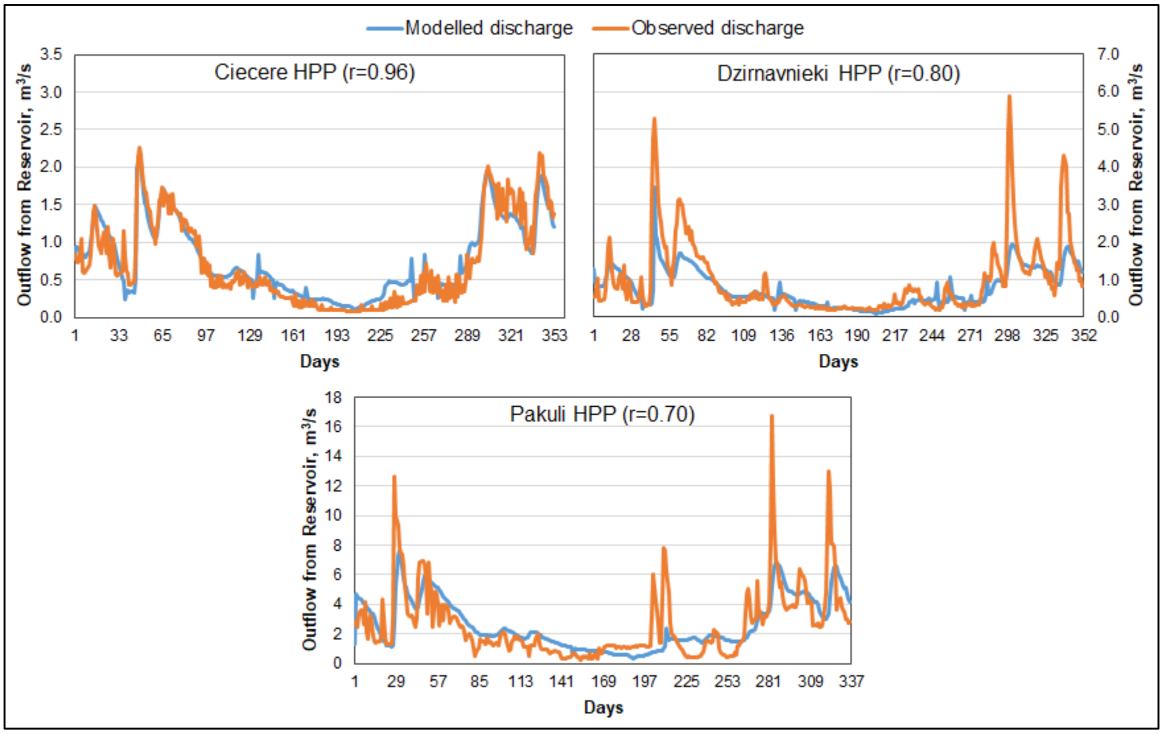


Figure 4.1.3.1. Comparison of observed and modelled daily discharges in Ciecere River stretches below HPPs

The main challenge in calibration process is a visibility of hydropeaking phenomena in the measured discharge time series. While the modelling of the daily discharge time series has been chosen, the phenomena of hydropeaking can happen even in an hourly step. Therefore, the difference between measured and modelled values may be quite strong, like in a case of Ciecere River stretch below Pakuli HPP, i.e. correlation coefficient (r) is only 0.70 (Fig. 4.1.3.1). The correlation coefficients are also calculated for river stretches below Ciecere HPP (r=0.96) and below Dzirnavnieki HPP (r=0.80). Thus, the Ciecere River model is prepared to simulate the operating regime of HPPs cascade.

4.2. Losis River HPPs cascade

4.2.1. Morphology of the Losis River

The Losis River is a left tributary of the Venta River. In the upper reach the river flows in a northerly direction from the Berztvu forest in Lithuania to Latvian border, then turns east and 22.1 km is the Latvian-Lithuanian border river. River turns north before Kalni village and after 7.2 km flows into the Venta River. The Losis River

Basin area is 111 km^2. The river is 37.5 km long, the river bed gradient is 2.14 m/km. An elevation of the river basin varies from 46 to 174 m LAS. According to field surveys this site may belong to salmonid fish waters. Due to appropriate physical geographical conditions and high slopes, 2 hydropower plants were installed in the Losis River: Grantini and Lejnieki HPPs (Fig. 4.2.1.1).

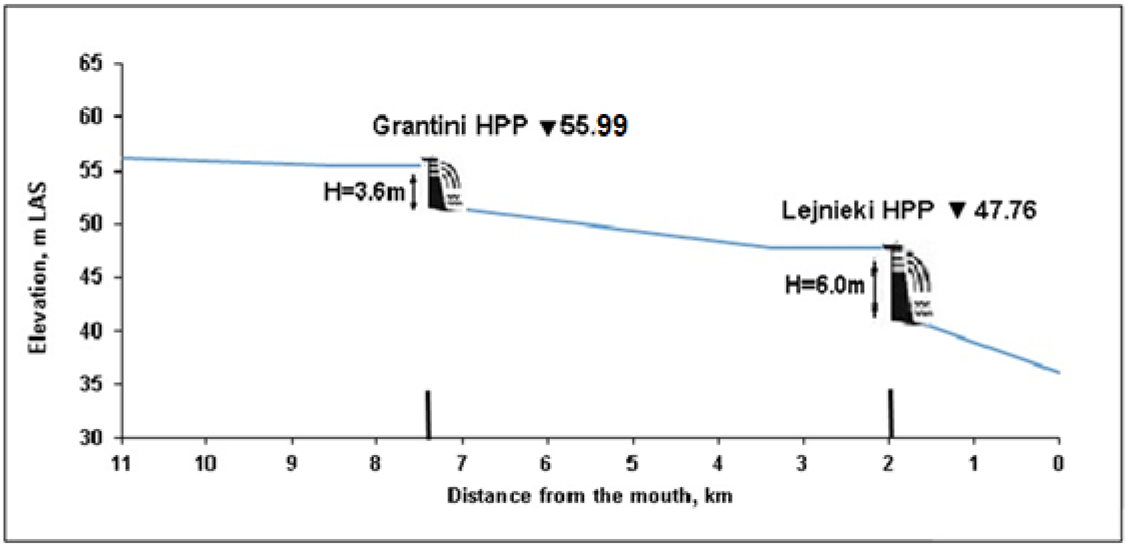


Figure 4.2.1.1. Hydropower plants in the Losis River

4.2.2. Input data for HPPs cascade modelling in the Losis River

There are two main groups of input data for HPPs cascade modelling: physical and operational data. Physical data consists of hydrological, reservoir, dam and tailwater data. Operational data defines the reservoir operation sets, the zones and rules that describe the operating plan for the reservoir.

Hydrological data

The inflow to the reservoir system (flow values above the first reservoir of the cascade) has to be calculated. For the Losis River these data are prepared according to field survey measurements in 2021. Figure 4.2.2.1 shows the inflow data series to the Losis River reservoirs system. The average annual inflow was 1.80 m^3/s and varied from 0.53 m^3/s in October to 16.34 m^3/s in November. In winter (January – February) the average water discharge was 2.07 m^3/s, in spring (March – May) – 1.60 m^3/s, in summer (June – September) – 0.99 m^3/s, and in autumn (October – November) – 3.14 m^3/s. Compared to multiannual data within Venta RB, in 2021, hydrological conditions were closed to the normal year.

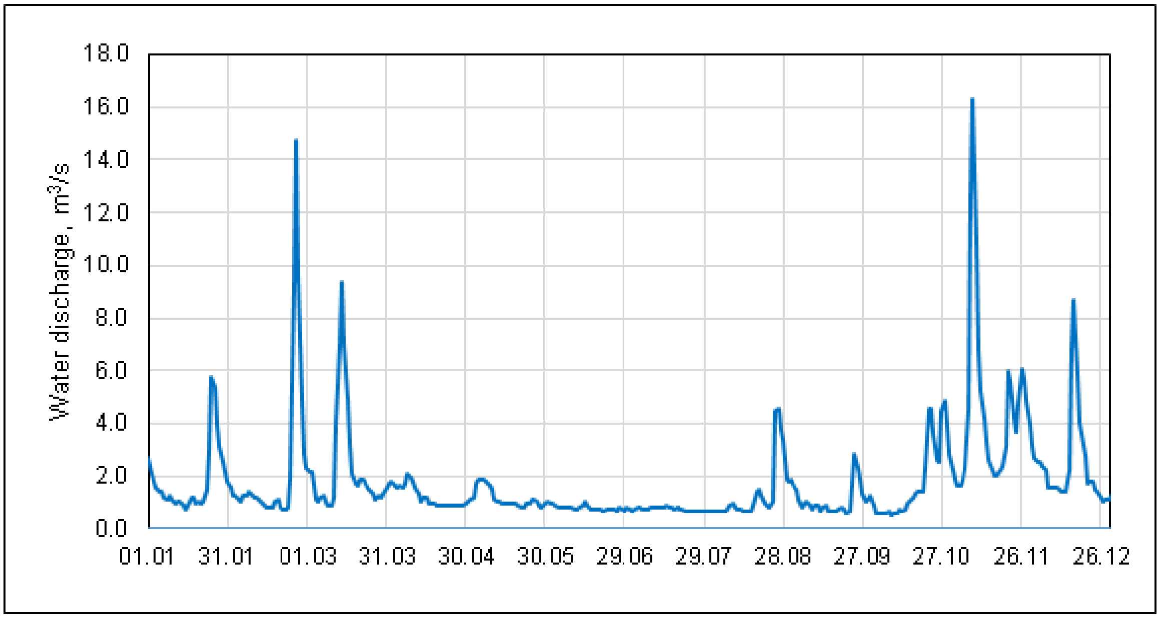


Figure 4.2.2.1. Main inflow to the reservoir system of the Losis River in 2021

According to the 2021 hydrological measurements, daily discharges below each HPP dam were calculated (Fig. 4.2.2.2). These data are necessary for calibration of the Ciecere River HPPs cascade model. The impact of each HPP activity is very noticeable during the dry season. The phenomena of hydropeaking are visible even in the daily discharge step.

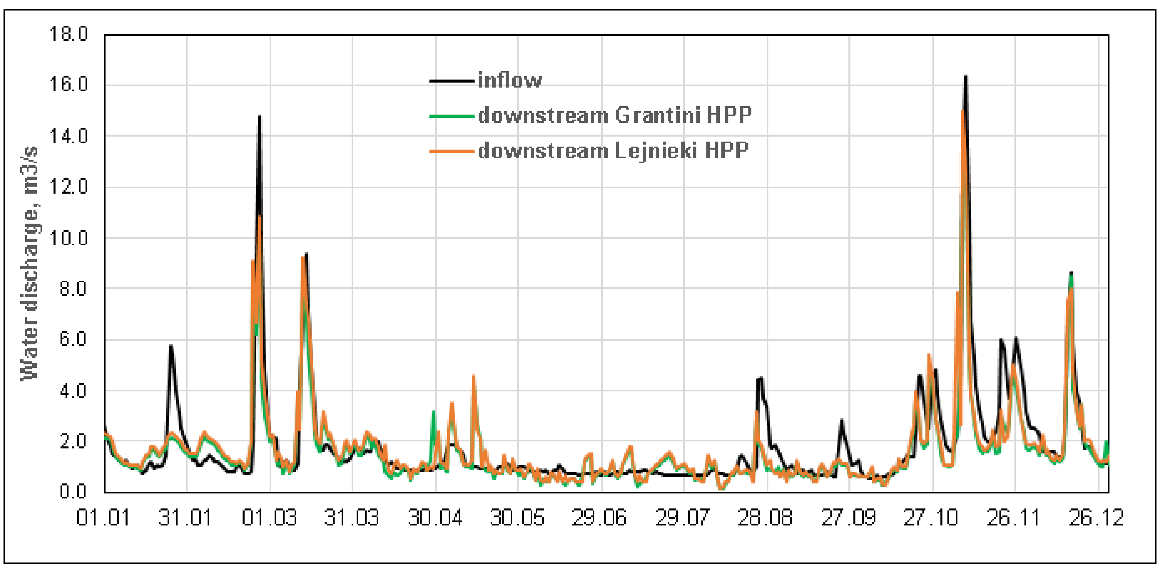


Figure 4.2.2.2. Hydrographs below each HPP in Losis River, 2021

Physical characteristics of the reservoirs

The Losis River reservoir system consists of two HPPs with two reservoirs. During the field surveys in 2021, the measurements of the Ciecere River cross-sections were carried out for the further riverbed elevation data processing, using ArcGIS software and digital elevation model (DEM). Calculations and water level-volume-surface area curves were made for reservoirs of Grantini HPP and Lejnieki HPP (Fig. 4.2.2.3).

As it was previously mentioned, the lowest, average (normal) and highest water levels in the specific zones of reservoirs are defined in the "Water resources use permits" and presented in Table 4.2.2.1.

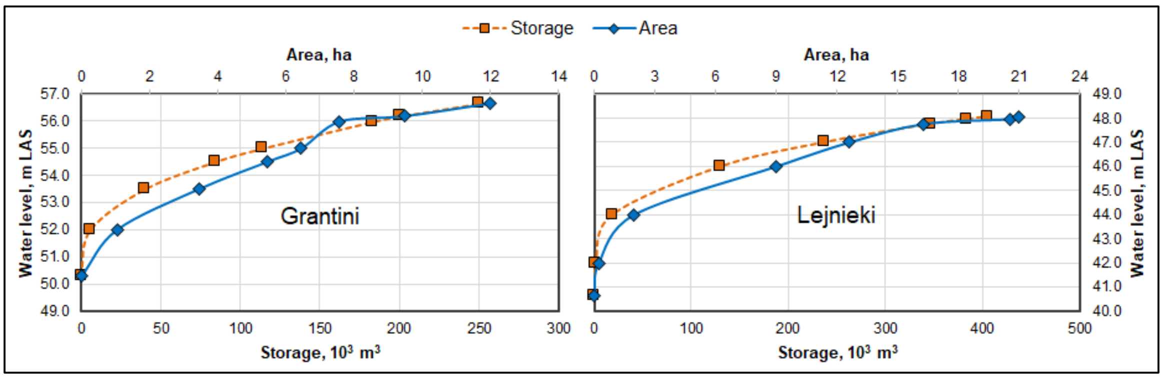


Figure 4.2.2.3. Water level-storage and water level-surface area curves of the Losis River reservoirs

Table 4.2.2.1. Water levels of the various zones in the Losis River reservoirs

River	Reservoir	Water level in zones, m LAS				
		Inactive	Buffer	Conservation	Flood Control	Top of dam
Losis	Grantini	53.65	55.79	55.99	56.19	56.66
	Lejnieki	45.46	47.56	47.76	47.96	49.36

Technical characteristics of the hydropower plants

The main technical characteristics of the hydropower plants in Losis River are presented in Table 4.2.2.2. These data were taken from the "Water resources use permits". The coefficient of efficiency of the HPPs represents a percentage of the total potential energy the power plant could theoretically generate. Information about these coefficients is not available. Therefore, they were assumed to be 0.8, i.e. 80 percent for each power plant.

Table 4.2.2.2. Main characteristics of the HPPs in Losis River

River	HPP	Capacity, MW	Head, m	$Q_{environmental}$, m^3/s	Turbine operating discharge, m^3/s	
					Min	Max
Losis	Grantini	0.092	3.60	0.029	0.4	3.0
	Lejnieki	0.252	6.0	0.093	0.5	5.0

Tailwater data

In the developed model, the discharge-water level curves in the river reach below each power plant were created according to the field hydrological measurements in 2021 (Fig. 4.2.2.4). These curves are useful for the calculation of daily head (the difference between reservoir elevation and tailwater) for the purpose of computing power generation.

Operation data

The Operation zones are first described in the Operation set. The reservoir zones (Top of Dam, Flood Control, Conservation, Buffer and Inactive) are generated for each reservoir from the Losis River HPPs cascade. The data of these zones are given in Table 4.2.2.1.

Operation Rules are added to the zones. A Release Function is used to describe daily flow through the HPP turbines. This rule defines that the HPP does not operate if the daily inflow to the reservoir is less than the minimum turbine operating discharge. In this case, the transit flow of the river must be passed through the hydrotechnical structures. The values of minimum turbine operating discharges depend upon HPP turbine type and diameter of the turbine wheel. This information can be found in the “Water resources use permits”.

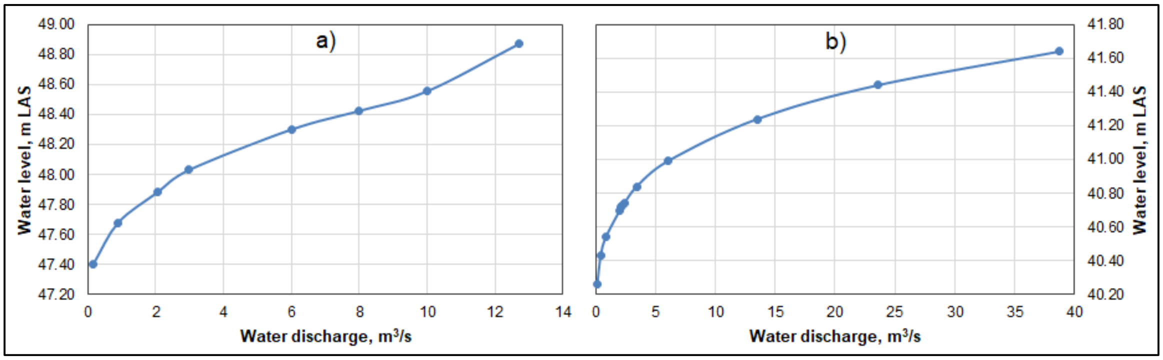


Figure 4.2.2.4. Water level–discharge curves below HPPs: a) Grantini, b) Lejnieki

4.2.3. Calibration of the Losis River HPPs cascade model

The task of model calibration is to achieve that the measured values of the parameters correspond as closely as possible to the modelled ones. When simulating the operation of HPP cascades, the daily discharges of the river reach below each HPP were selected as parameters for evaluation of the calibration process. The measured parameters are the daily discharges in the Losis River below each HPP, determined during the hydrological surveys in 2021. Using the HecResSIM software, the daily discharges were modelled for each of the two downstream stretches of the Losis River HPPs cascade.

A comparison of the observed and modelled discharges is presented in Figure 4.2.3.1. The correlation coefficients (r) between these time series are assessed as sufficiently high: 0.85 – for the Losis River downstream of Grantini HPP and 0.83 – for the river stretch downstream of Lejnieki HHP.

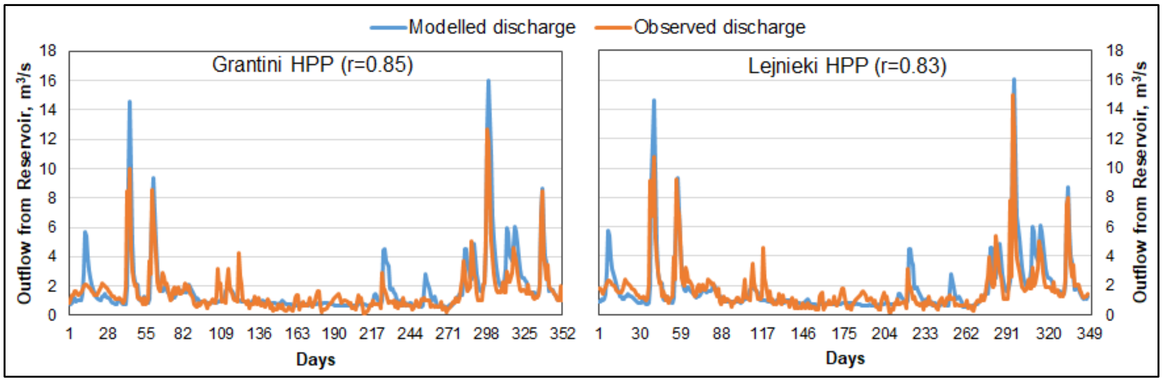


Figure 4.2.3.1. Comparison of observed and modelled daily discharges in Losis River stretches below HPPs

Hydrographs of the measured daily discharges downstream from Grantini and Lejnieki HPPs illustrate that hydropeaking phenomena were recorded even during the low flow period of 2021 (Fig. 4.2.3.1). However, there are no hydropeaking phenomena in the modelled discharge time series due to the chosen simulation time step (day) because the hydropeaking can happen even in an hourly step.
The Losis River model is prepared to simulate the operating regime of HPPs cascade, taking into consideration statistically significant correlation coefficients (0.83 – 0.85).

4.3. Varduva River HPPs cascade

The Varduva River is the third largest tributary of the Venta River (in the territory of Lithuania); the drainage area is 586.7 km^2. The length of the river is 90.3 km. The Varduva is a relatively meandering river with a sinuosity index of 2.60. The Varduva River has a high-density drainage basin – of 1.32 km/km² (the total average drainage density in Lithuanian territory is 0.99 km/km²) (Kilkus, Stonevičius, 2011). The average stream gradient of the Varduva River is 0.94 m/km; while in some stretches of the river, for example, from 35 to 39 km from the mouth, this measurement reaches 1.75 m/km. Due to appropriate physical geographical conditions and high slopes, 5 hydropower plants were installed on the Varduva River (Fig. 4.3.1).

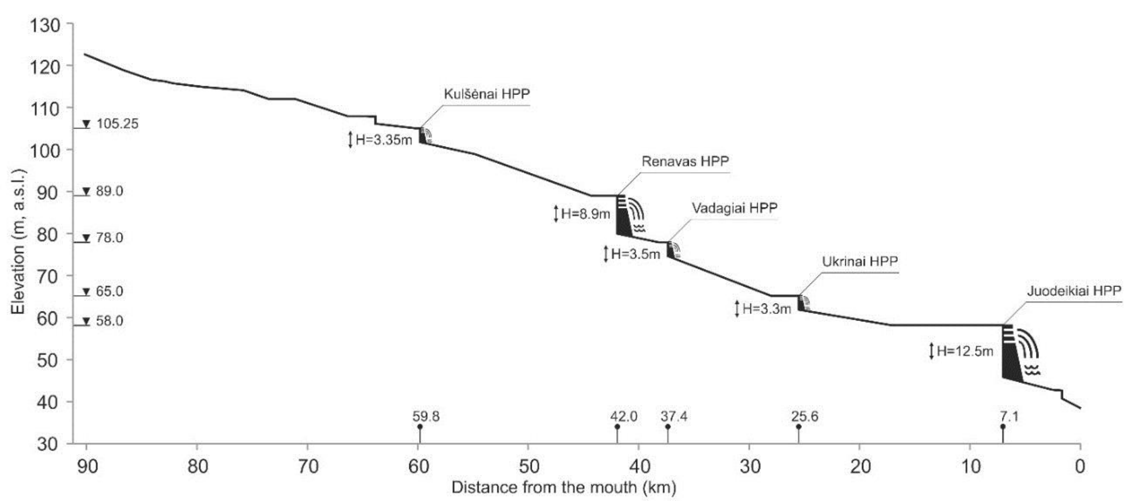


Figure 4.3.1. Hydropower plants on the Varduva River

4.3.1. Input data for HPPs cascade modelling in the Varduva River

There are two main groups of input data for HPPs cascade modelling: physical and operational data. Physical data consists of hydrological, reservoir, dam and tailwater data. Operational data defines the reservoir operation sets, the zones and rules that describe the operating plan for the reservoir.

Hydrological data

The inflow to the reservoir system (the river discharge above the first reservoir of the cascade) has to be defined. In the case of the Varduva River, these data are prepared according to field survey measurements in 2021. The main inflow to the Varduva reservoirs system is presented in Figure 4.3.1.1. The average annual inflow was 3.48 m^3/s and varied from 0.33 m^3/s in September to 14.9 m^3/s in November. In autumn, the average discharge was 5.17 m^3/s, in winter – 4.71 m^3/s, in spring – 2.96 m^3/s, and in summer – only 1.13 m^3/s. Hydrological observations in the Varduva River were carried out only in 1956-1973. The average discharge at Ruzgai water gauging station in this period was 5.16 m^3/s. The discharge during winter–spring flood was 116 m^3/s, and the 30-day low flow minimum was 0.37 m^3/s. Compared to multiannual data, in 2021, hydrological conditions were close to an average dry year.

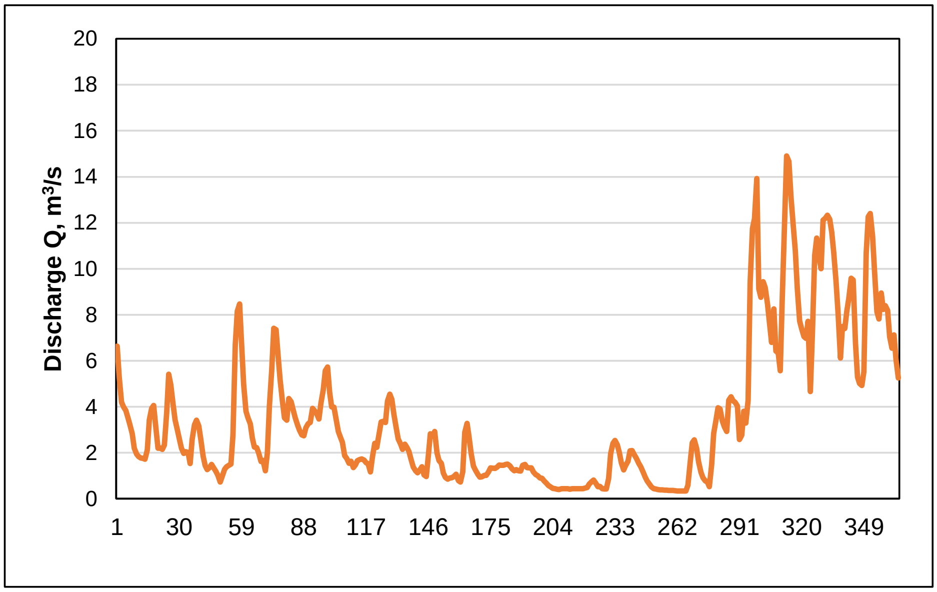


Figure 4.3.1.1. Main inflow to the reservoir system of the Varduva River in 2021

According to the 2021 hydrological measurements, daily discharges below each HPP dam were calculated (Fig. 4.3.1.2). These data are necessary for calibration of the Varduva River HPPs cascade model. The impact of each HPP activity is very noticeable during the dry season. The phenomena of hydropeaking are visible even in the daily discharge step.

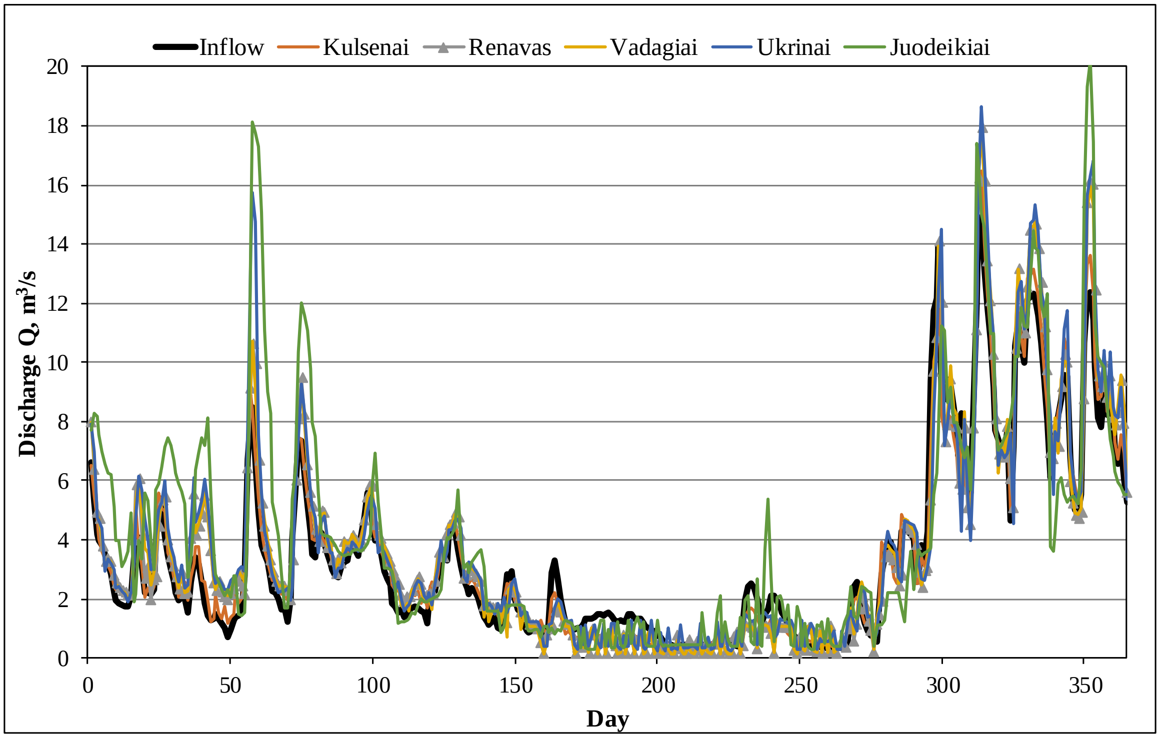


Figure 4.3.1.2. Hydrographs below each HPP in 2021

Physical characteristics of the reservoirs

The development of the Varduva reservoirs system required a large amount of initial information, such as the physical characteristics of the reservoirs, etc. The Varduva reservoirs system consists of five HPPs with five reservoirs. The time-consuming process is to create accurate reservoir water level-volume-area curves. During the field surveys in 2021, these curves were made for Kulšėnai, Renavas, Vadagiai and Ukrinai reservoirs (Fig. 4.3.1.3). Juodeikiai reservoir is the largest (area of 253900 ha); its water level-volume-area curves were taken from the Reservoir rules.

Other very important information is the reservoirs water levels in the specific zones (Table 4.3.1.1). This information was taken from the “HPPs Reservoir Exploitation Rules” (HPPs Reservoir Exploitation Rules, 2005-2017). The water level of the

Inactive zone corresponds to the level of the reservoir when it is filled with only 25 percent of its water volume. Buffer, Conservation and Flood control zones correspond to the lowest, average and highest levels of the reservoir, which are defined in the “HPPs Reservoir Exploitation Rules” (HPPs Reservoir Exploitation Rules, 2005-2017).

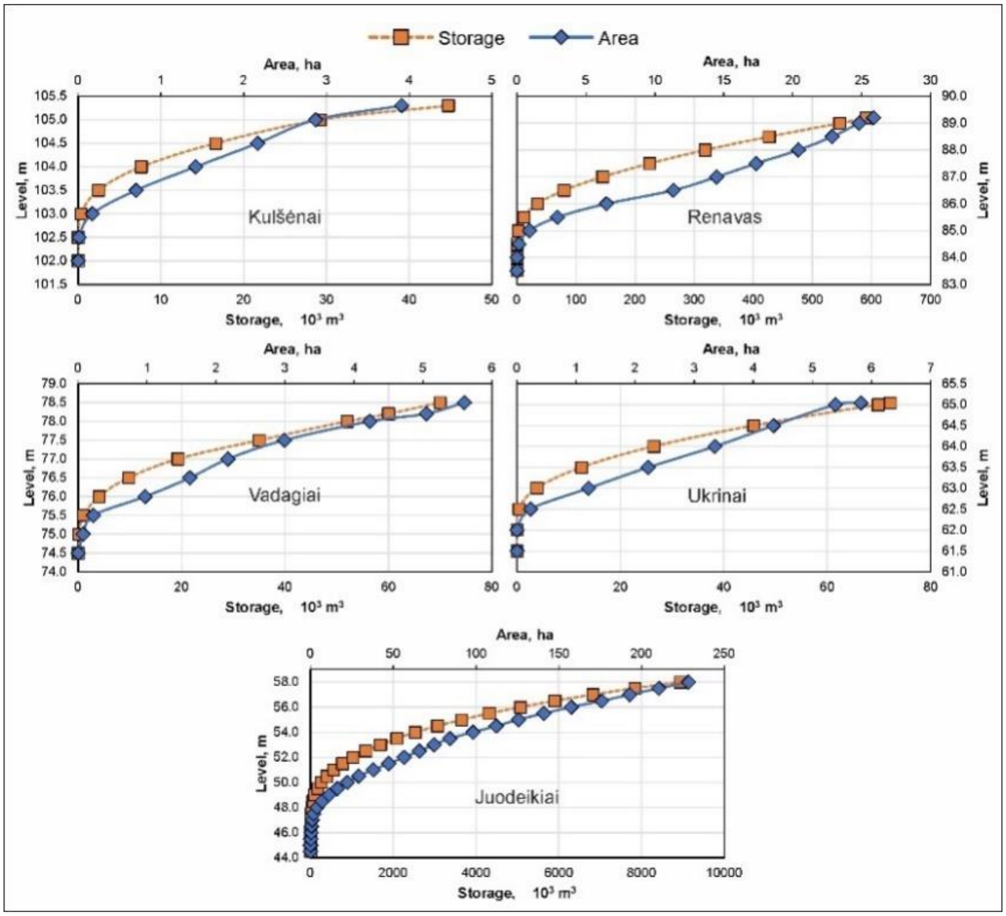


Figure 4.3.1.3. Water level-storage and water level-area curves of the Varduva reservoirs

Table 4.3.1.1. Water levels of the various zones in the Varduva reservoirs

River	Reservoir	**Water level in zones, m**				
		Inactive	**Buffer**	**Conservation**	**Flood Control**	**Top of dam**
Varduva	Kulšėnai	104.25	105.15	105.25	106.15	106.20
	Renavas	87.02	88.05	89.05	89.35	90.85
	Vadagiai	76.76	77.90	78.00	79.35	79.40
	Ukrinai	63.69	64.90	65.00	66.40	66.41
	Juodeikiai	53.65	57.25	58.00	58.40	59.80

Technical characteristics of the hydropower plants

It is very important to accurately describe the physical characteristics of hydropower plants. The main characteristics of hydropower plants are presented in Table 4.3.1.2. This information also was taken from the "HPPs Reservoir Exploitation Rules" (HPPs Reservoir Exploitation Rules, 2005-2017). The coefficient of efficiency of HPPs represents a percentage of the total potential energy the power plant could theoretically generate. There is no concrete information about these coefficients. Therefore, they were evaluated only theoretically, i.e. 0.8 for each power plant.

Table 4.3.1.2. Main characteristics of the HPP in Varduva River

River	HPP	Capacity, MW	Head, m	$Q_{environmental}$, m^3/s	Turbine operating discharge, m^3/s	
					Min	Max
Varduva	Kulšėnai	0.115	3.35	0.20	0.5	6.0
	Renavas	0.300	8.90	0.39	2.4	9.0
	Vadagiai	0.110	3.50	0.41	1.2	5.7
	Ukrinai	0.110	3.30	0.46	0.5	6.0
	Juodeikiai	0.820	12.50	0.91	1.5	8.0

Tailwater data

In the developed model, the discharge-water level curves in the river reach below each power plant were created according to the field hydrological measurements in 2021 (Fig. 4.3.1.4). These curves are useful for the calculation of daily head (the difference between reservoir elevation and tailwater) for the purpose of computing power generation.

Operation data

The Operation zones are first described in the Operation set. The reservoir zones (Top of Dam, Flood Control, Conservation, Buffer and Inactive) are generated for each reservoir from the Varduva River HPPs cascade. The data of these zones are given in Table 4.3.1.1.

Operation Rules are added to the zones. We used a Release Function to describe the daily flow through the HPP turbines. This rule defines that the HPP does not operate if the daily inflow to the reservoir is less than the minimum turbine operating discharge. In this case, the transit flow of the river must be passed through the hydrotechnical structures. The minimum turbine operating discharges of the Varduva HPPs cascade are described in “HPPs Reservoir Exploitation Rules” (HPPs Reservoir Exploitation Rules, 2005-2017) (Table 4.3.1.2).

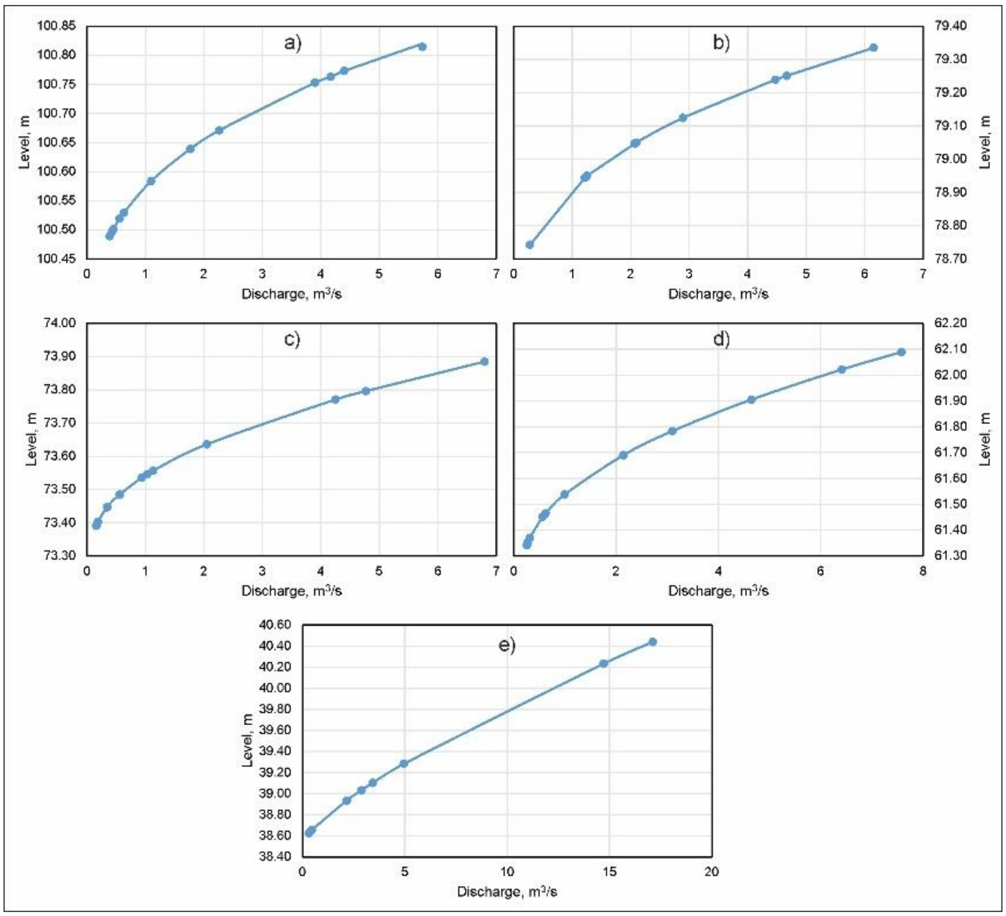


Figure 4.3.1.4. Water level–discharge curves below HPP: a) Kulšėnai, b) Renavas, c) Vadagiai, d) Ukrinai, and e) Juodeikiai

4.3.2. Calibration of the Varduva River HPPs cascade model

The task of model calibration is to achieve that the measured values of the parameters correspond as closely as possible to the modeled values. When simulating the operation of HPP cascades, the daily discharges of the river reach below the HPP were selected as parameters for evaluation of the calibration process. The measured parameters are the daily discharges in the Varduva River below each HPP, determined during the hydrological surveys in 2021. Using the HecResSIM software, we modeled the daily discharge values in the identical cross-sections of the Varduva River.

A comparison of the observed and modeled discharges is presented in Figure 4.3.2.1. The biggest correlation between these time series is calculated in the river below Kulšėnai HPP (r=0.95), and the lowest – below Ukrinai and Juodeikiai HHPs (r=0.87).

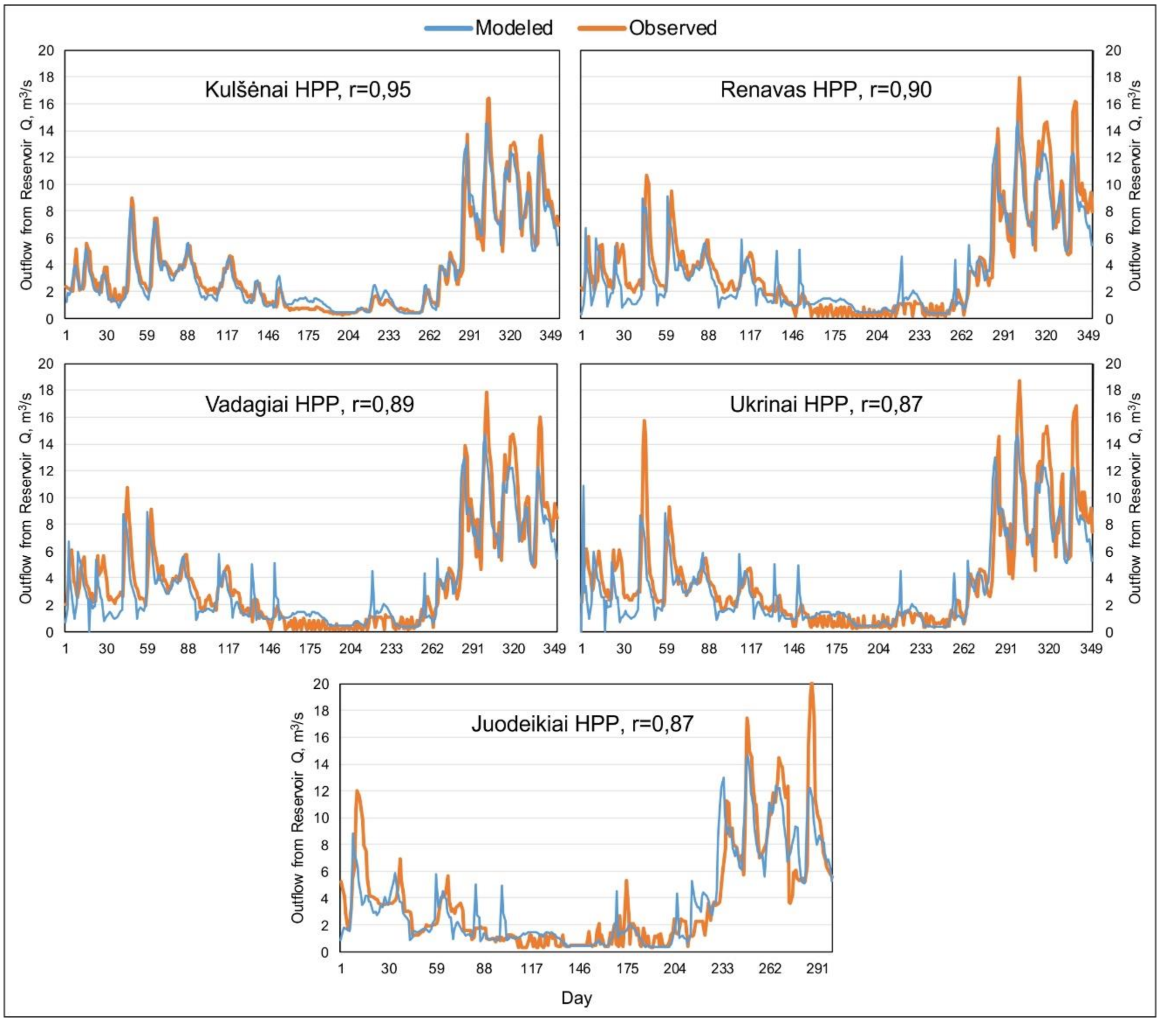


Figure 4.3.2.1. Comparison of observed and modeled daily discharges in the Varduva River reaches below HPPs

During the dry period, Kulšėnai HPP did not operate, so hydropeaking phenomena were not recorded below this HPP. Therefore, the measured and modeled values of the water discharges differed very little (high correlation coefficient). All other HPPs worked during the dry season in 2021 (Fig. 4.3.2.1). The measured discharge time series confirm that during the summer period below the HPPs, a significant fluctuation of discharges, caused by hydropeaking, is visible. There are no hydropeaking phenomena in the modeled discharge time series due to the chosen simulation time step (day) because the phenomena of hydropeaking can happen even in an hourly step.

All the calculated correlation coefficients are high enough (0.87 – 0.95), therefore the Varduva River model is prepared to simulate the activity of HPPs cascades under various conditions.

5. ENVIRONMENTALLY FRIENDLY OPERATIONAL REGIME FOR HPPs CASCADE BASED ON THE MODELLING RESULTS

5.1. Ciecere River HPPs cascade

The analysis of the modelled operational regime of HPPs cascade of the Ciecere River is performed for each HPP separately. Some characteristics of the reservoirs and HPPs, required for analysis of modelling results, are presented in Table 5.1.1.

Table 5.1.1. Characteristics of the reservoirs and HPPs in the Ciecere River required for analysis of the modelling results

	Ciecere HPP	Dzirnavnieki HPP	Pakuli HPP
Distance from mouth, km	55.4	49.5	32.0
Height of pressure, m	4.0	3.95	7.80
Area of reservoir, ha	6.1	8.1	162
Installed capacity, kW	150	150	400
Environmental discharge, m^3/s	0.061	0.16	0.32
Ecological discharge, m^3/s	0.061	0.30	0.30
Permeability of turbines (min/max), m^3/s	0.5 / 3.0	0.5 / 5.0	0.6 / 5.6

When analyzing the simulation results of HPPs cascade activity, great attention will be paid to water level fluctuations in the reservoir, discharges release through the HPP turbine and the outlets and generation of HPP power in daily step.

Ciecere HPP

Ciecere HPP is equipped with two turbines. Each vertical-axis propeller-type turbine (K-84A) has a wheel diameter of 840 mm and a power capacity of 75 kW (150 kW for both turbines). Permeability of turbines (min/max) is 0.5/3.0 m^3/s.

According to “Water resources use permit”, the environmental discharge (guaranteed discharge with 95% probability) is equal to the ecological discharge (0.061 m^3/s). The environmental and ecological discharges are released through a controlled outlet during the opening of five gates.

In the modelling of the Ciecere HPP operation, the main rule is that when the value of inflow to the Ciecere reservoir is greater than 0.5 m^3/s (a minimum permeability of turbine), the water will flow through the HPP turbines. When the inflow to the reservoir is less than 0.5 m^3/s, the transit discharge, which corresponds to the inflow to the reservoir minus water losses, must be passed downstream through the HPP outlet. The environmental and ecological discharges (0.061 m^3/s) are considerably lower than the minimum discharge of the turbine permeability (0.5 m^3/s). Releasing transit discharge through the HPP outlet will ensure only the minimum conditions for the existence of the river ecosystem defined by both environmental and ecological discharges.

The simulation results indicate that according to the data of 2021, Ciecere reservoir water levels can range between the conservation and flood zones (Fig. 5.1.1). Water discharges through the HPP turbines or through the outlet depend on the defined turbine permeability. In a case of Ciecere HPP operation in 2021, the power plant did not operate for 137 days; during this period, only the transit discharge was released through the outlet (Fig. 5.1.1). The HPP produced electricity only for the rest of the days. During the summer, the HPP almost did not work due to the small inflow to reservoir. The estimated usage factor of the installed power is 0.59.

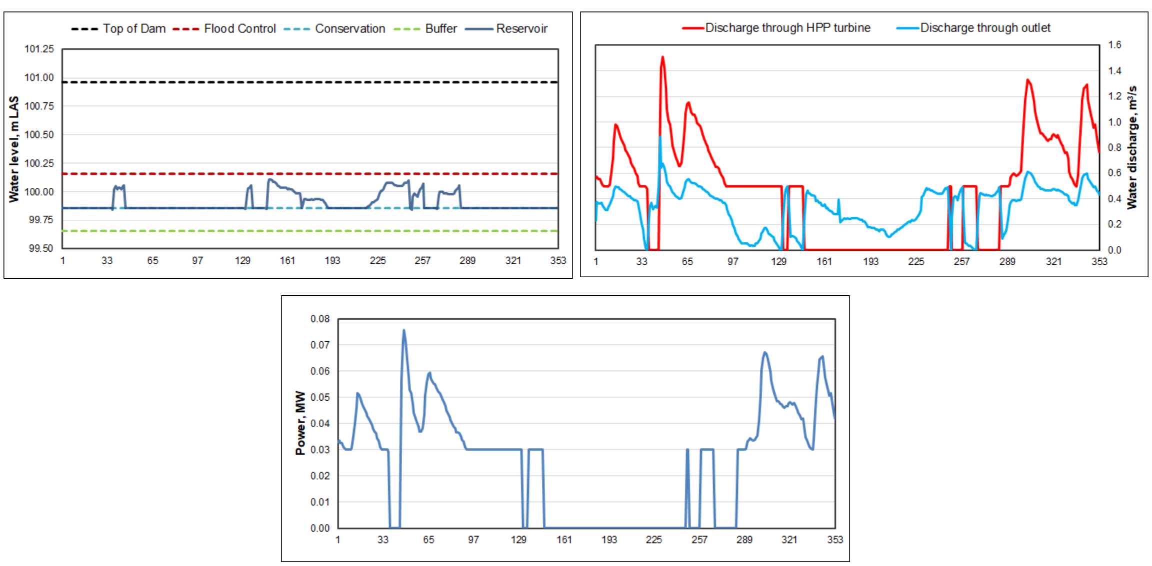


Figure 5.1.1. Operation of Ciecere HPP: a) water level fluctuations in the reservoir (m LAS); b) water discharges through the HPP turbines and through the outlet (m^3/s); c) changes of HPP generated power (MW)

Dzirnavnieki HPP

Dzirnavnieki HPP is equipped with two Kaplan turbines (K-84). Each turbine has a wheel diameter of 840 mm and a power capacity of 75 kW (150 kW for both turbines). Permeability of turbines (min/max) is 0.5/5.0 m^3/s.

According to "Water resources use permit", the environmental discharge (guaranteed discharge with 95% probability) is 0.16 m^3/s, it is released through a gate of the regulated outlet.

Ecological discharge is 0.30 m^3/s – it could be passed through unclosed water pipes of the HPP turbines and outlet gates. If the HPP does not operate, the ecological discharge could be released by raising the bottom outlet valve.

In a case of the modelling of the Dzirnavnieki HPP operation, the main rule is that when the value of inflow to the Dzirnavnieki reservoir is greater than 0.5 m^3/s (a minimum permeability of turbine), the water will flow through the HPP turbines. When the inflow to the reservoir is less than 0.5 m^3/s, the transit discharge, which corresponds to the inflow to the reservoir minus water losses, must be passed downstream through the HPP outlet. The environmental (0.16 m^3/s) and ecological (0.30 m^3/s) discharges are lower than the minimum discharge of the turbine permeability (0.5 m^3/s). The passing transit discharge through the HPP outlet will ensure the conditions of releasing the environmental or ecological discharges if their values are bigger than the inflow to reservoir.

The simulation results show that according to the data of 2021, the variation in Dzirnavnieki reservoir water levels is near the conservation zone (Fig. 5.1.2). Water discharges through the HPP turbines or through the outlet depend on the defined minimal turbine permeability (0.5 m^3/s). In 2021, the Dzirnavnieki power plant did not operate for 138 days (mainly in the summer), when the inflow to the reservoir was less than 0.5 m^3/s (Fig. 5.1.2). The HPP produced electricity only in the remaining days. The usage factor of the installed power is 0.41.

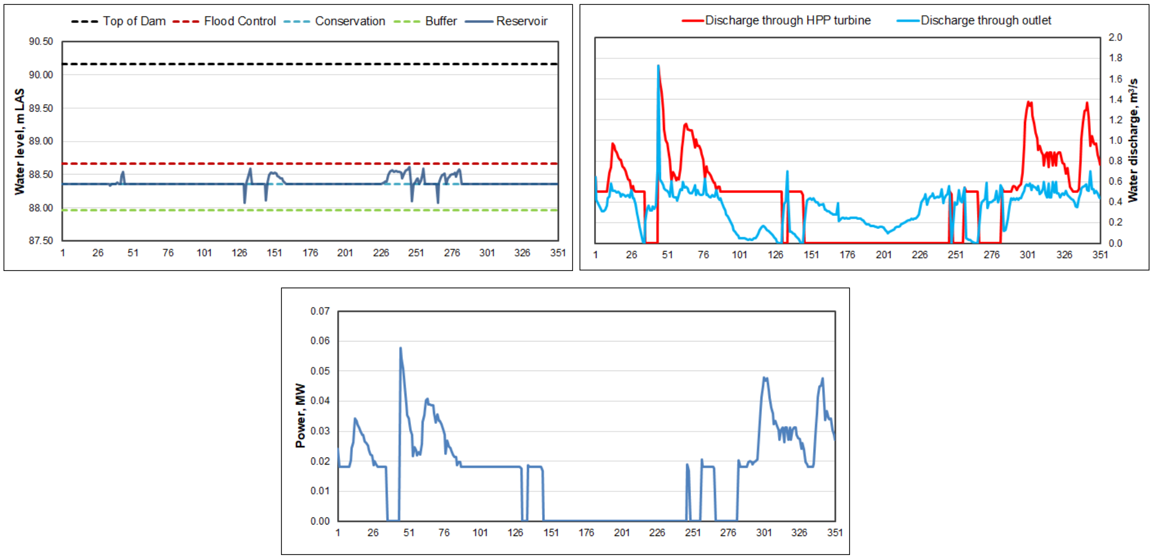


Figure 5.1.2. Operation of Dzirnavnieki HPP: a) water level fluctuations in the reservoir (m LAS); b) water discharges through the HPP turbines and through the outlet (m^3/s); c) changes of HPP generated power (MW)

Pakuli HPP

Pakuli HPP is equipped with two horizontal-axis Kaplan turbines (SK-85). Each turbine has a wheel diameter of 850 mm and a power capacity of 200 kW (400 kW for both turbines). Permeability of turbines (min/max) is 0.6/5.6 m^3/s.

According to “Water resources use permit”, the ecological discharge (0.30 m^3/s) is released through a gate of the controlled outlet. When the inflow to Pakuli reservoir is from 0.3 up to 0.6 m^3/s, the transit discharge, which corresponds to the inflow to the reservoir minus water losses, must be passed downstream through the HPP outlet subject to raising a gate by 3 cm.

In the modelling of the Pakuli HPP operation, the main rule is that when the inflow to the Pakuli reservoir is greater than 0.6 m^3/s (a minimum permeability of turbine), this discharge will flow through the HPP turbines. The environmental (0.32 m^3/s) and ecological (0.30 m^3/s) discharges are lower than the minimum discharge of the turbine permeability (0.6 m^3/s). The passing transit discharge through the HPP outlet will ensure the conditions of releasing the environmental or ecological discharges if their values are bigger than the inflow to reservoir.

The simulation results reveal that according to the data of 2021, the variation in Pakuli reservoir water levels is similar to the conservation zone level, which also corresponds to the flood control level for the Pakuli HPP (Fig. 5.1.3). The Pakuli reservoir has a large volume, so the small inflow to this reservoir could not affect water level fluctuations of the reservoir. The flowing of discharges through the HPP turbines or through the outlet depends on the defined turbine permeability. In a case of Pakuli HPP operation, in 2021, the power plant did not work for only 19 days (in summer season); during this period only the transit discharge was passed through the outlet (Fig. 5.1.3). The electricity was produced during the remaining days. The usage factor of the installed power is 0.67.

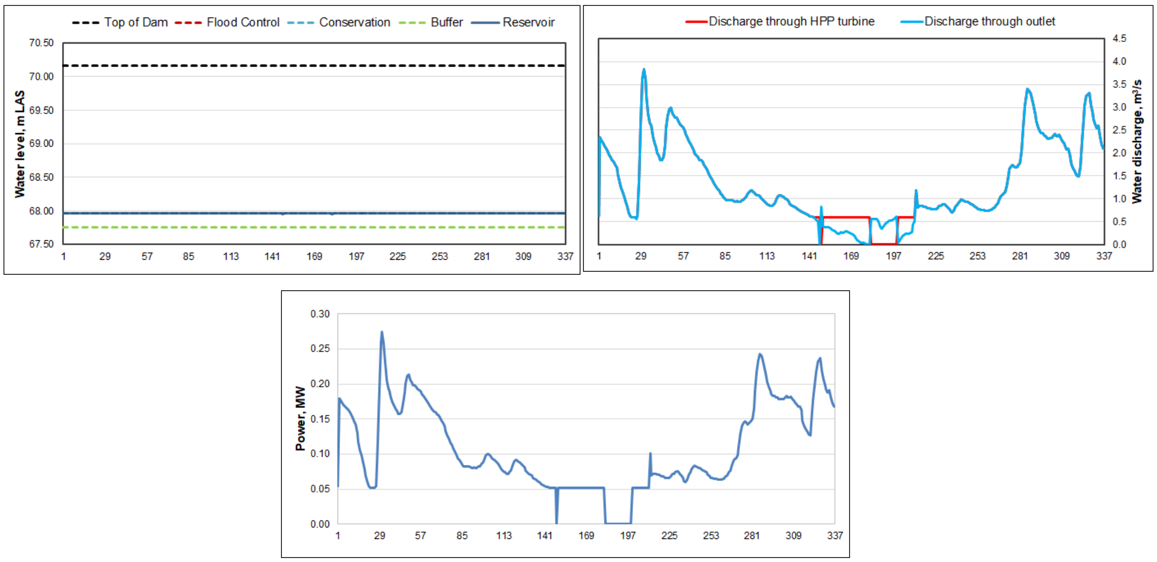


Figure 5.1.3. Operation of Pakuli HPP: a) water level fluctuations in the reservoir (m LAS); b) water discharges through the HPP turbines and through the outlet (m^3/s); c) changes of HPP generated power (MW)

5.2. Losis River HPPs cascade

The analysis of the modelled operational regime of HPPs cascade of the Losis River is performed for each HPP separately. Some characteristics of the reservoirs and HPPs, required for analysis of modelling results, are presented in Table 5.2.1.

Table 5.2.1. Characteristics of the reservoirs and HPPs in the Losis River required for analysis of the modelling results

	Grantini HPP	Lejnieki HPP
Distance from mouth, km	7.3	2.0
Height of pressure, m	3.60	6.0
Area of reservoir, ha	7.4	21.2
Installed capacity, kW	92	252
Environmental discharge, m^3/s	0.029	0.093
Ecological discharge, m^3/s	0.20	0.20
Permeability of turbines (min/max), m^3/s	0.4 / 3.0	0.5 / 5.0

When analyzing the simulation results of HPPs cascade activity, great attention will be paid to water level fluctuations in the reservoir, discharges release through the HPP turbines and the outlet and generation of HPP power in daily step.

Grantini HPP

Grantini HPP is equipped with two turbines. One of the turbines is of the Kaplan-type (K-84) and has a wheel diameter of 840 mm and a power capacity of 75 kW. The second one – Francis turbine (F300-42) has a wheel diameter of 420 mm and a power capacity of 17 kW. The total installed capacity of the HPP turbines is 92 kW. Permeability of turbines (min/max) is 0.4/3.0 m^3/s.

According to “Water resources use permit”, the environmental discharge (guaranteed discharge with 95% probability) is 0.029 m^3/s and the ecological discharge is 0.20 m^3/s. Both discharges are released through 3 gates of the hydrotechnical structure (controlled outlet).

In the modelling of the Grantini HPP operation, the main rule is that when the inflow to the reservoir is greater than 0.4 m^3/s (a minimum permeability of turbine), this discharge will flow through the HPP turbines. The environmental (0.029 m^3/s) and ecological (0.20 m^3/s) discharges are lower than the minimum discharge of the turbine permeability (0.4 m^3/s). The passing transit discharge through the HPP outlet will ensure the conditions of releasing the environmental or ecological discharges if their values are bigger than the inflow to reservoir.

The simulation results indicate that according to the data of 2021, the reservoir water level fluctuations are near the conservation zone (Fig. 5.2.1). Water discharges through the HPP turbines or through the outlet depend on the defined turbine permeability. It is evident that during 2021, the Grantini HPP operated every day, even during summer low flow period (Fig. 5.2.1), taking into consideration the fact that the minimum daily discharge, i.e. minimum inflow to the reservoir (0.53 m^3/s) exceeded the minimum discharge of the turbine permeability (0.4 m^3/s). According to the modelling results, the Grantini HPP generated electric power for the whole year. The usage factor of the installed power is estimated as very high (0.96).

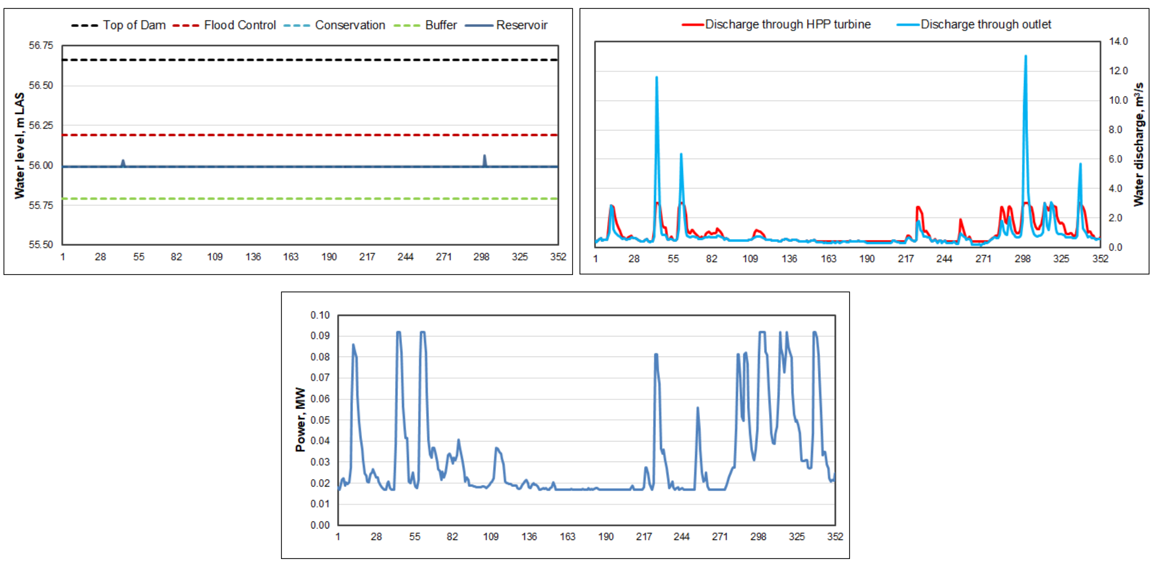


Figure 5.2.1. Operation of Grantini HPP: a) water level fluctuations in the reservoir (m LAS); b) water discharges through the HPP turbines and through the outlet (m^3/s); c) changes of HPP generated power (MW)

Lejnieki HPP

Lejnieki HPP is equipped with two vertical-axis Kaplan turbines (K-84). Both of them have a wheel diameter of 840 mm. The total installed capacity of the HPP turbines is 252 kW. Permeability of turbines (min/max) is 0.5/5.0 m^3/s.

According to “Water resources use permit”, the environmental discharge (guaranteed discharge with 95% probability) is 0.093 m^3/s and the ecological discharge is 0.20 m^3/s. Both discharges are released through the spillway gates.

In the modelling of the Lejnieki HPP operation, the main rule is that when the inflow to the reservoir is greater than 0.5 m^3/s (a minimum permeability of turbine), this discharge will flow through the HPP turbines. The environmental (0.093 m^3/s) and ecological (0.20 m^3/s) discharges are lower than the minimum discharge of the turbine permeability (0.5 m^3/s). The passing transit discharge through the HPP outlet will ensure the conditions of releasing the environmental or ecological discharges if their values are bigger than the inflow to reservoir.

The simulation results reveal that according to the data of 2021, water level fluctuations are not recorded as they are similar to the conservation zone level due to a quite large volume of the Lejnieki HPP reservoir (Fig. 5.2.2). The flowing of discharges through the HPP turbines or through the outlet depends on the defined turbine permeability. Similar to the operating regime of the Grantini HPP, the Lejnieki HPP worked every day because the minimum inflow to the reservoir was larger than the minimum discharge of the turbine permeability (Fig. 5.2.2). Accordingly, electric power was generated every day. The usage factor of the installed power is also very high (0.93).

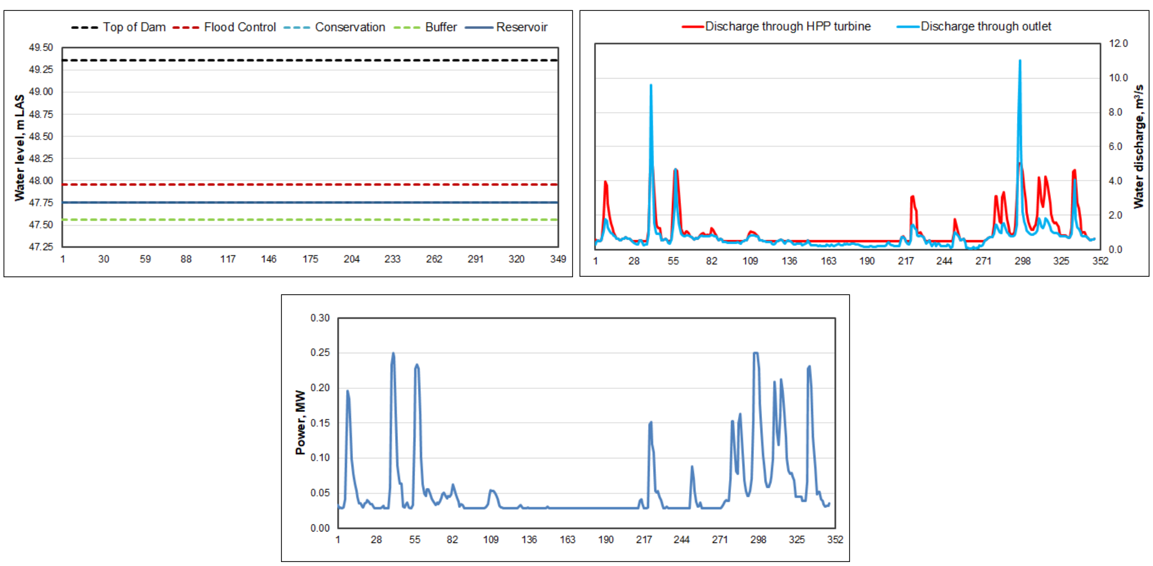


Figure 5.2.2. Operation of Lejnieki HPP: a) water level fluctuations in the reservoir (m LAS); b) water discharges through the HPP turbines and through the outlet (m^3/s); c) changes of HPP generated power (MW)

5.3. Varduva River HPPs cascade

The analysis of the modelled operational regime of HPPs cascade of the Varduva River is performed for each HPP separately. Some characteristics of the reservoirs and HPPs, required for analysis of modelling results, are presented in Table 5.3.1.

Table 5.3.1. Characteristics of the reservoirs and HPPs in the Varduva River required for analysis of the modelling results

	Kulšėnai HPP	Renavas HPP	Vadagiai HPP	Ukrinai HPP	Juodeikiai HPP
Distance from mouth, km	59.8	41.4	34.6	23.8	7.1
Height of pressure, m	3.40	6.00	3.50	3.00	12.5
Area of reservoir, ha	2.2	31.0	5.6	9.6	261.4
Installed capacity, kW	115	300	110	110	1018
Environmental discharge, m^3/s	0.20	0.39	0.41	0.46	0.91
Ecological discharge, m^3/s	0.62	0.66	0.68	0.71	1.07
Permeability of turbines (min/max), m^3/s	0.5 / 6.0	2.4 / 9.0	1.2 / 5.7	0.5 / 6.0	1.5 / 8.0

When analyzing the simulation results of HPP cascade activity, great attention will be paid to water level fluctuations in the reservoir, discharges release through the HPP turbine and the outlets and generation of HPP power in daily step.

Kulšėnai HPP

Kulšėnai HPP is equipped with one 0.115 MW turbine. Permeability of turbine (min/max) is 0.5/6.0 m^3/s. The environmental discharge is 0.20 m^3/s; it is released through a 0.3 m diameter pipe into the old ditch. Excess water is released through an unregulated outlet.

In the modelling of the Kulšėnai HPP operation, we used two alternatives:

1. Environmental discharge (0.20 m^3/s) could be released through a 0.3 m diameter pipe when the inflow to the Kulšėnai reservoir is less than 0.5 m^3/s (minimum discharge of the turbine permeability).
2. Ecological discharge (0.62 m^3/s) could be released through the HPP turbine; therefore, a separate pipe for passing the environmental discharge is not necessary. If the inflow to the Kulšėnai reservoir is less than 0.5 m^3/s, then the daily transit discharge, which corresponds to the inflow discharge to the reservoir minus water losses, must be passed through the HPP outlet.

The simulation results, according to the 1st alternative, show that the variation of the Kulšėnai reservoir water levels according to the 2021 data can range between conservation and flood zones (Fig. 5.3.1). The discharges through the HPP turbine or through the outlet depend on the defined turbine permeability. In the case of Kulšėnai HPP operation when environmental discharge is released, in 2021 the power plant did not work for 45 days (Fig. 5.3.1). The HPP produced electricity only in the remaining days. During the summer season, the HPP practically did not work due to the small inflow to the Kulšėnai reservoir. The usage factor of the installed power is 0.84.

According to the 2nd alternative, the modelling results do not differ significantly. In the case of Kulšėnai HPP operation when the ecological discharge is released through HPP turbine, in 2021, the power plant did not work for 54 days (Fig. 5.3.2). The usage factor of the installed power is a little smaller than for the 1st alternative (0.82).

The Kulšėnai HPP activity could be carried out according to the 2nd alternative:

- the water will flow through the HPP turbines when the inflow to the Kulšėnai reservoir is greater than 0.5 m^3/s (minimum permeability of turbine),
- when the inflow to the reservoir is less than 0.5 m^3/s, the transit discharge, which corresponds to the inflow to the reservoir minus water losses, must be passed through the HPP outlet.

In this case, the Kulšėnai HPP would produce slightly less energy (the usage factor of the installed power is 0.82 compared to 0.84 according to the 1st alternative) and would not operate several days longer (54 days compared to 45 days according to the 1st alternative).

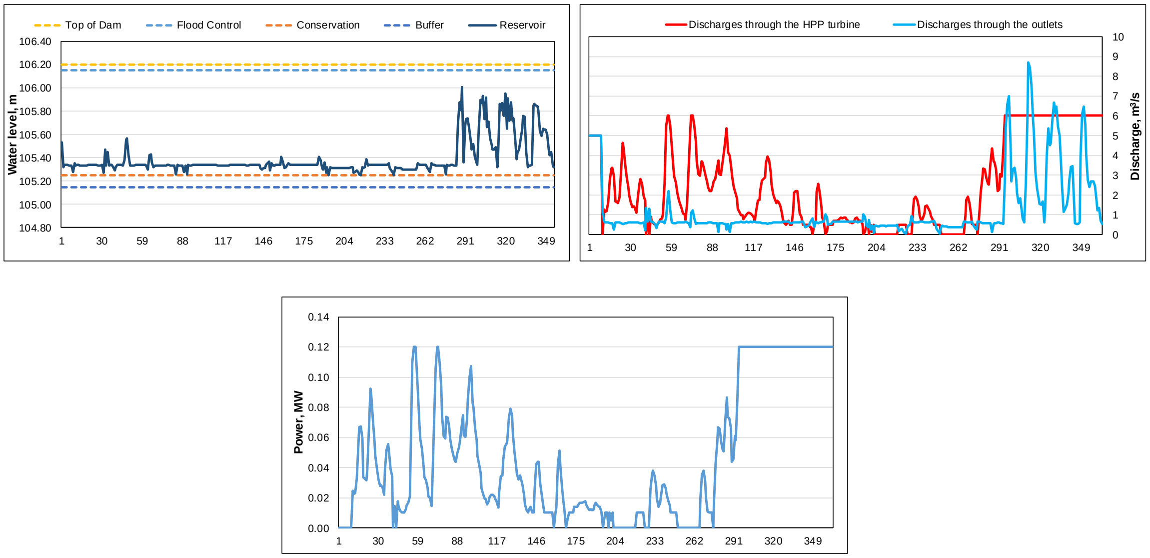


Figure 5.3.1. Operation of Kulšėnai HPP according to enviromental discharge requirements: a) water level variation in the reservoir (m); b) discharges through the HPP turbine and through the outlets (m^3/s); c) changes of HPP generated power (MW)

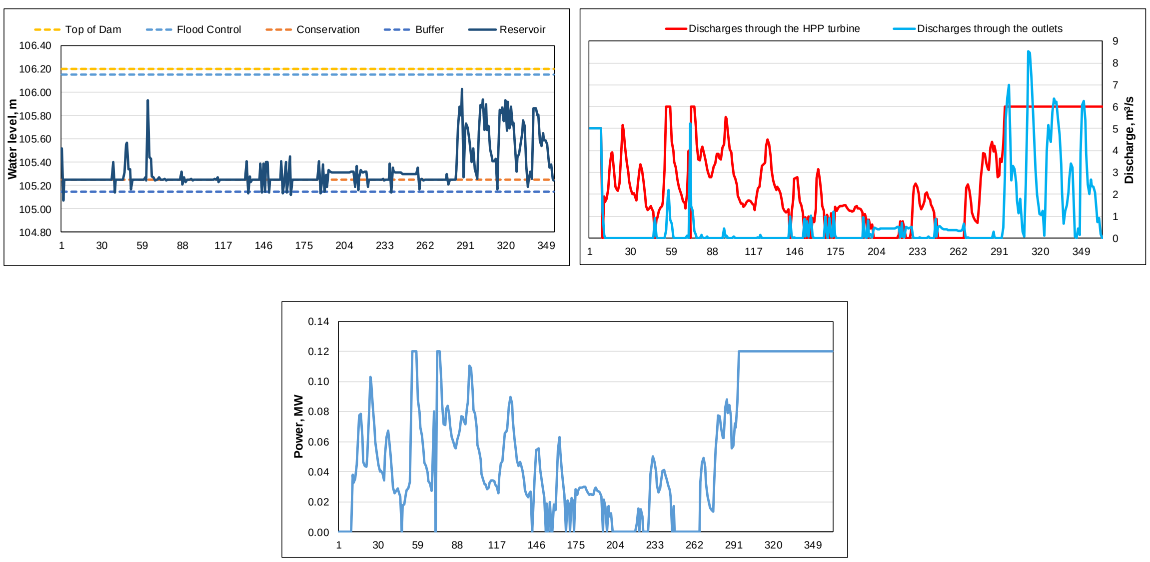


Figure 5.3.2. Operation of Kulšėnai HPP according to ecological discharge requirements: a) water level variation in the reservoir (m); b) discharges through the HPP turbine and through the outlets (m^3/s); c) changes of HPP generated power (MW)

Renavas HPP

Renavas HPP is equipped with one 0.300 MW turbine. Permeability of turbine (min/max) is 2.4/9.0 m^3/s. The environmental discharge is 0.39 m^3/s. It is released through the culvert. Excess water is discharged through three controlled outlets with dimensions of 3.2x2.5m. The environmental discharge is released through one of these outlets.

In the modelling of the Renavas HPP operation, the main rule is that when the inflow to the Renavas reservoir is greater than 2.4 m^3/s (that is a minimum permeability of turbine), this discharge will flow through the HPP turbines. When the inflow to the reservoir is less than 2.4 m^3/s, the transit discharge, which corresponds to the inflow discharge to the reservoir minus water losses, must be passed through the HPP outlets. The environmental and ecological discharges are 0.39 m^3/s and 0.66 m^3/s, respectively. These discharges are considerably lower than the minimum discharge of the turbine permeability (2.4 m^3/s). Releasing transit discharge through the HPP outlets will ensure only the minimum conditions for the existence of the river ecosystem defined by both environmental and ecological discharges.

The simulation results indicate that according to the 2021 data, the Renavas reservoir water levels can range between conservation and flood zones (Fig. 5.3.3). The most stable water level in the reservoir was determined in the last months of the year, when the inflow to the Renavas reservoir was the largest. The discharges through the HPP turbine or through the outlets depend on the defined turbine permeability. In the case of Renavas HPP operation in 2021, the power plant did not work for 183 days; during this period, only the transit discharge was released through the outlets (Fig. 5.3.3). The HPP produced electricity only for the rest of the days. In the summer, the HPP almost did not work due to the small inflow to reservoir. The estimated usage factor of the installed power is only 0.38. This is due to the high installed minimum turbine permeability discharge, which prevents the use of inflow discharge for electricity generation.

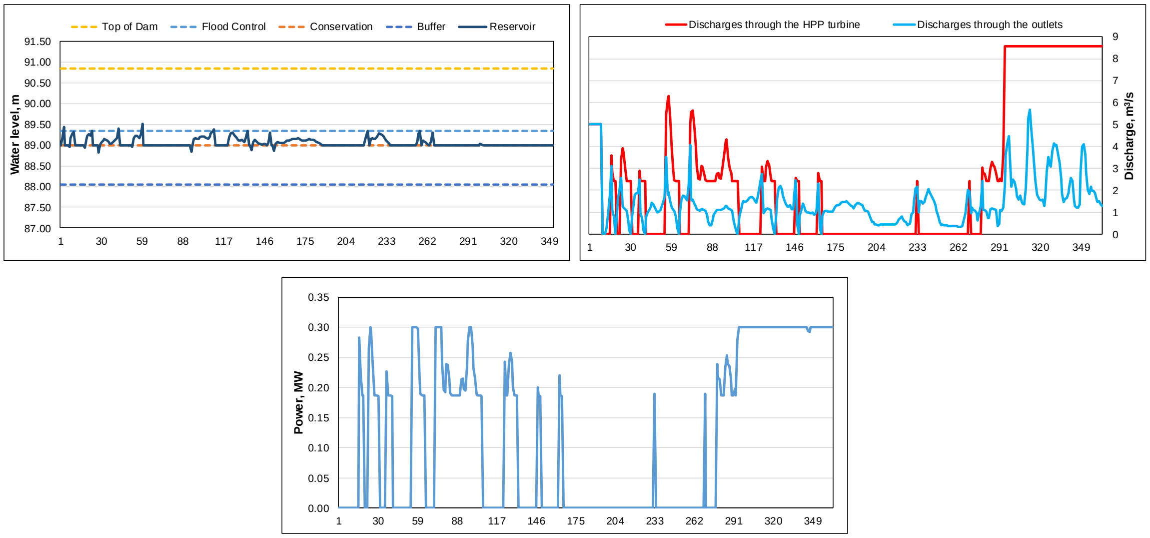


Figure 5.3.3. Operation of Renavas HPP: a) water level variation in the reservoir (m); b) discharges through the HPP turbine and through the outlets (m^3/s); c) changes of HPP generated power (MW)

Vadagiai HPP

Vadagiai HPP is equipped with one 0.110 MW turbine. Permeability of turbine (min/max) is 1.2/5.7 m^3/s. The environmental discharge is 0.41 m^3/s. Excess water is released through uncontrolled outlet. The environmental discharge is passed through the outlet withdimensions of 0.3x0.3 m.

In the case of the modelling of Vadagiai HPP operation, the main rule is that when the discharge of the inflow to the Vadagiai reservoir is greater than 1.2 m^3/s (minimum permeability of turbine), the water will flow through the HPP turbine. When the inflow to the reservoir is less than 1.2 m^3/s, the transit discharge, which corresponds to the inflow to the reservoir minus water losses, must be released downstream through the HPP outlet. As in the other described cases, the environmental and ecological discharges (0.41 m^3/s and 0.68 m^3/s, respectively) are lower than the minimum discharge of the turbine permeability (1.2 m^3/s). However, in this case, the passing of transit discharge through the HPP outlet can guarantee the flowing of environmental or ecological discharges downstream of HPP if their values will be higher than the inflow to reservoir.

The simulation results demonstrate that the changes of the Vadagiai reservoir water levels, according to the 2021 data, exceed the conservation zone (Fig. 5.3.4). The flowing of discharges through the HPP turbine or through the outlets depends on the determined turbine permeability. In 2021, this power plant did not produce electricity for 102 days (mostly in the summer season), during this period only the transit discharge was passed through the outlet (Fig. 5.3.4). The usage factor of the installed power is 0.60. The high installed discharge of minimum turbine permeability does not allow using the inflow discharge for electricity generation.

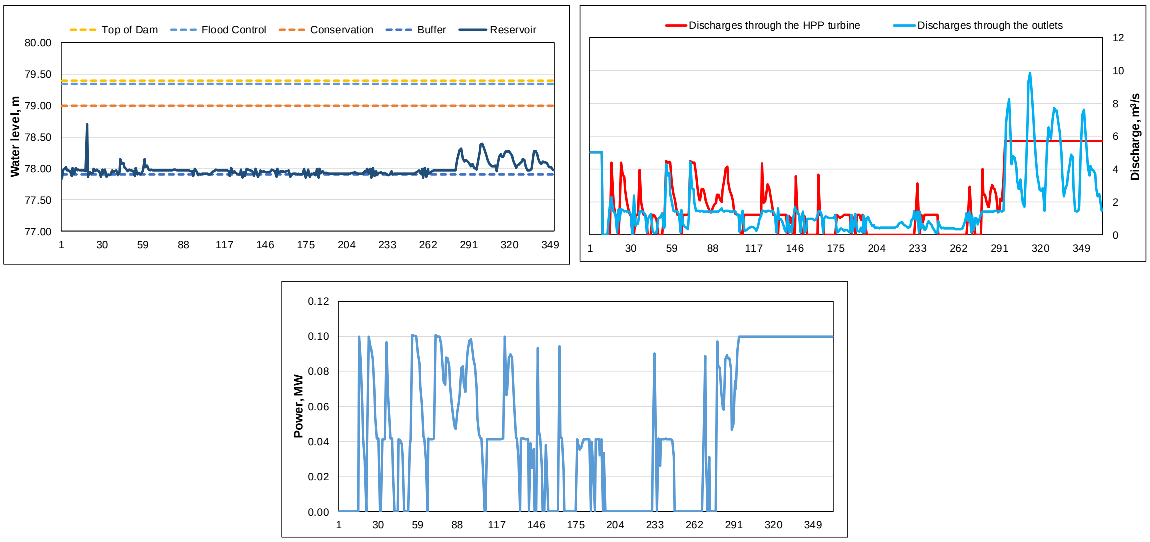


Figure 5.3.4. Operation of Vadagiai HPP: a) water level variation in the reservoir (m); b) discharges through the HPP turbine and through the outlets (m^3/s); c) changes of HPP generated power (MW)

Ukrinai HPP

Ukrinai HPP is equipped with one 0.110 MW turbine. Permeability of turbine (min/max) is 0.5/6.0 m^3/s. The environmental discharge is 0.46 m^3/s. It is released through HPP turbine (if this plant is in working regime) or through a 0.5 m diameter pipe into the old ditch (if the plant is not operating). Excess water is released through an unregulated outlet.

In the modelling of Ukrinai HPP operation, the main rule is that when the discharge into the Vadagiai reservoir is greater than 0.5 m^3/s (minimum permeability of turbine), the water will flow through the HPP turbine. When the inflow to the reservoir is less than 0.5 m^3/s, the transit discharge, which corresponds to the inflow discharge to the reservoir minus water losses, must be passed through the HPP outlet. The defined environmental and ecological discharges are 0.46 m^3/s and 0.71 m^3/s, respectively. These discharges are similar to the minimum discharge of the turbine permeability (0.5 m^3/s). Therefore, these discharges can be released through the HPP turbine.

The simulation results show that according to the 2021 data, the variation of the Ukrinai reservoir water levels is near the conservation zone (Fig. 5.3.5). The discharges through the HPP turbine or through the outlets depend on the defined minimal turbine permeability (0.5 m^3/s). In 2021, Ukrinai power plant did not operate for 75 days (mainly in the summer), when the inflow discharge to the reservoir was less than 0.5 m^3/s (Fig. 5.3.5). The usage factor of the installed power is 0.47.

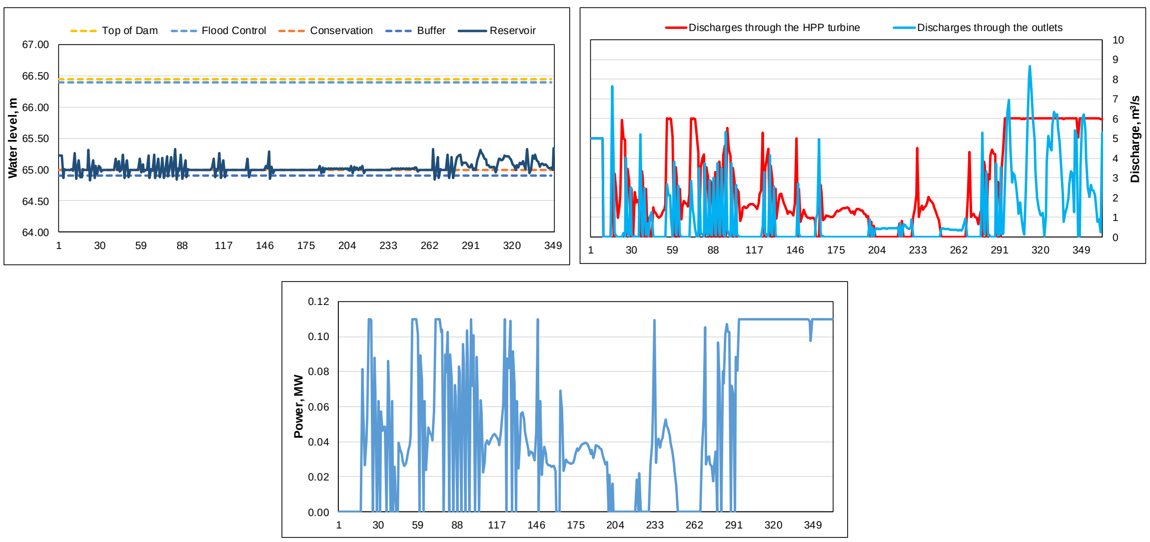


Figure 5.3.5. Operation of Ukrinai HPP: a) water level variation in the reservoir (m); b) discharges through the HPP turbine and through the outlets (m3/s); c) changes of HPP generated power (MW)

Juodeikiai HPP

Juodeikiai HPP is equipped with two 0.820 MW turbines. Their permeability (min/max) is 1.5/8.0 m^3/s. The environmental discharge is 0.91 m^3/s. It is released through HPP turbine (if this plant is operating) or through excess water outlet (if the plant is not operating). Excess water is released through two controlled outlets, the dimensions of which are 6.0x4.5 m.

In the modelling of Juodeikiai HPP operation, the main rule is that when the discharge of the inflow to the Juodeikiai reservoir is greater than 1.5 m^3/s (minimum permeability of turbine), the water from the reservoir will flow through the HPP turbine. When the inflow to the reservoir is less than 1.5 m^3/s, the transit discharge, must be passed through the HPP outlet. The environmental (0.91 m^3/s) and ecological (1.07 m^3/s) discharges are lower than the minimum discharge of the turbine permeability (1.5 m^3/s). The passing transit discharge through the HPP outlet will ensure the conditions of releasing the environmental or ecological discharges if their values are bigger than the inflow to reservoir.

The simulation results reveal that according to the 2021 data, the variation of the Juodeikiai reservoir water levels are similar to the conservation zone level (Fig. 5.3.6). The Juodeikiai reservoir has a large volume, so the small inflow to this reservoir could not affect the reservoir water level fluctuations. The flowing of discharges through the HPP turbine or through the outlets depends on the defined turbine permeability. In the case of Juodeikiai HPP operation, in 2021, the power plant did not work for 129 days (especially in the summer season); during this period only the transit discharge was passed through the outlet (Fig. 5.3.6). The electricity was produced only during the remaining days. The usage factor of the installed power is very low – only 0.24. The high installed discharge of minimum turbine permeability does not allow using the inflow discharge for electricity production.

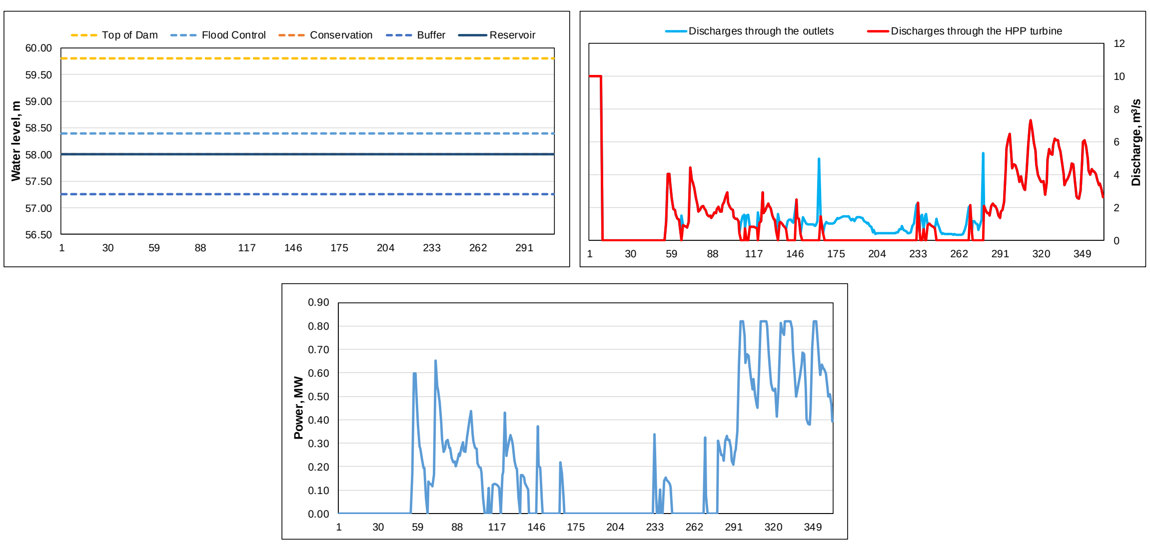


Figure 5.3.6. Operation of Juodeikiai HPP: a) water level variation in the reservoir (m); b) discharges through the HPP turbine and through the outlets (m3/s); c) changes of HPP generated power (MW)

5.4. The main challenges in modelling the operation of the hydropower plant cascades in the Ciecere, Losis and Varduva Rivers

After the simulation of HPP cascades operation in the Ciecere, Losis and Varduva Rivers, conclusions can be drawn about the suitability of the HecResSIM model and possible modeling inaccuracies. The main sources of uncertainty in the results are related to the accuracy of the input data:

- It is impossible to obtain all the necessary accurate information for modelling. Not all data is available, or the data is outdated in the main data source ("HPP exploitation Rules" and "Water resources use permits").
- The exact efficiency coefficients of hydro aggregates are not known.
- The measurements of the reservoir bathymetry and calculations of volume and area curves showed that the volume and area curves of the reservoirs are not correctly defined in the "HPP exploitation Rules". It would be useful to apply the new curves from the current measurements in the modelling of HPPs cascades. In Latvian case, there is no information about reservoir volumes and surface areas at different stages (water levels) available in the "Water resources use permits". The field measurements of the river cross-sections and digital interpolation are used as a single approach to calculate the data and make the relevant curves.
- Model calibration is complicated due to the chosen simulation time step (day) because HPP activity is related to hydropeaking (hour time step).

All the mentioned reasons influence the accuracy of the simulation results, so we consider the obtained results only as certain tendencies of how HPP cascades would operate under certain defined conditions. This is not an accurate calculation of each day's reservoir parameters or HPP characteristics values.

6. CONCLUSIONS AND RECOMMENDATIONS

Latvia

Each hydropower plant activity is strongly related to the inflow to a reservoir and a minimum discharge of the turbine permeability. According to the daily discharge data series of 2021, the main inflows to most upstream reservoirs in the Ciecere and Losis Rivers exceeded the environmental (guaranteed) and ecological discharges, which are specified in “Water resources use permits”. The results of simulation of HPP cascade operation in the Ciecere River confirmed that during 2021, all HPPs worked most days, excluding summer season, releasing defined ecological discharge downstream of each HPP. The inflow to reservoirs of the Losis River was continuously higher than the minimum permeability of the turbines. Therefore, HPPs cascade in the Losis River operated every day, producing electric power.

It is evident that small HPPs in the cascade affect the hydrological regime in the lower reaches of the rivers. According to the measured and modelled discharge data series, the phenomena of hydropeaking are visible even in the daily discharge step. Therefore, it is recommended to update the regulations of the “Water resources use permits” based on more detailed investigations related to the assessment of the impact of hydropower plants on the lower reaches of the rivers, also including the modelling results on ecological flow regime.

Lithuania

The results of simulation of HPP cascade operation in the Varduva River confirmed that all HPPs could work in a cascade releasing the ecological discharge (the average minimum 30-day flow (Q_{30_ave}) in the warm period) instead of the previously defined environmental discharge (Q_{30_ave} of 95% probability).

Small HPPs in the cascade affect the hydrological regime in the lower reaches of the river. It is recommended to update „ Regulations for the use and maintenance of HPP reservoirs“ based on more detailed investigation related to assessing the impact of hydropower plants on the lower reaches of the river.

“Regulations for the use and maintenance of HPP reservoirs” were prepared 20-30 years ago. It is necessary to update the data in them and introduce the concept of an ecological flow regime instead of the current environmental discharge (when the ecological flow regime will be legalized in legislative documents).

In future, instead of LAND 2-95 (which obliges the HPP owners to create “Regulations for the use and maintenance of HPP reservoirs”), a new system of permits for HPP exploitation should be created.

Some recommendations for the operation of HPP in order to pass the ecological discharge to the river below the dam:

- If the inflow to the reservoir is lower than the ecological discharge, it is necessary to ensure the passing of the transit discharge through hydrotechnical structures.
- If the installed minimum HPP turbine power discharge differs from the defined value of the ecological discharge, it is recommended to change the turbines to ones with a minimum discharge close to the ecological flow. This would help prevent hydropeaking in the lower reaches of the river.

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