WP4.4

HP Kirchbichl Description, Alternatives and MCA-Tree

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Summary

Short Description
This document intends to describe the structure of the SESAMO trees project and the MCA application to the Pilot Case Study of Inn river

Document Control

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Introduction

The hydropower-plant near Kirchbichl (Tyrol, Austria) is one of the biggest diversion-type hydroelectric plant in Tyrol. The total water discharge of the river Inn between October and May for the operation of the hydropower-plant is used, hence no water donation for residual flow is available for several months. For the implementation of the WFD and in order to reach (maintain) the status "good ecological potential, several pilot investigation are planned. One of these will measure the dotation of the residual-water and in the framework of this different discharge experiments (depth-velocity measurements) will be conducted. The discharge experiments at the Inn meander were planned and realized by the TIWAG (the Tyrolean Hydropower Company) and included the field works assessing different hydromorphological components like water discharge, water velocity, water depth and width of the riverbed. The next step was the comparison of these results with the national guidelines regarding the minimum ecological requirements.

Image 1: Powerhouse, water channel, residul-water and weir of the hydropower-plant Kirchbichl in the river Inn (Picture: TIWAG).

Description of the pilot study area, Inn meander at Kirchbichl

The significant meander (app. 3.5 km length) between Wörgl and Oberlangkampfen is the SHARE pilot study area of PP7, where heavy effects of the diversion-type HP plant Kirchbichl on the ecological integrity are obvious (image 1). The HP plant near Kirchbichl is one of the biggest diversion-type HP in Tyrol. The total water discharge between October and May is used for the operation of the hydropower plant. Because there´s no water dotation set up for the meander it is subjected to draught from autumn till spring and to a high variability in the discharge in the summer months due to hydro-peaking or floods. The lack of water discharge has several negative ecological impacts. For the implementation of the WFD and in order to reach (maintain) the status of a “good ecological potential” for heavily modified water bodies, several pilot investigations are planned. Image 1 shows a general view over the River Inn meander, the hydro-electric facility, and the two approximate position of the gauging stations at the Inn meander and below to the HP plant.

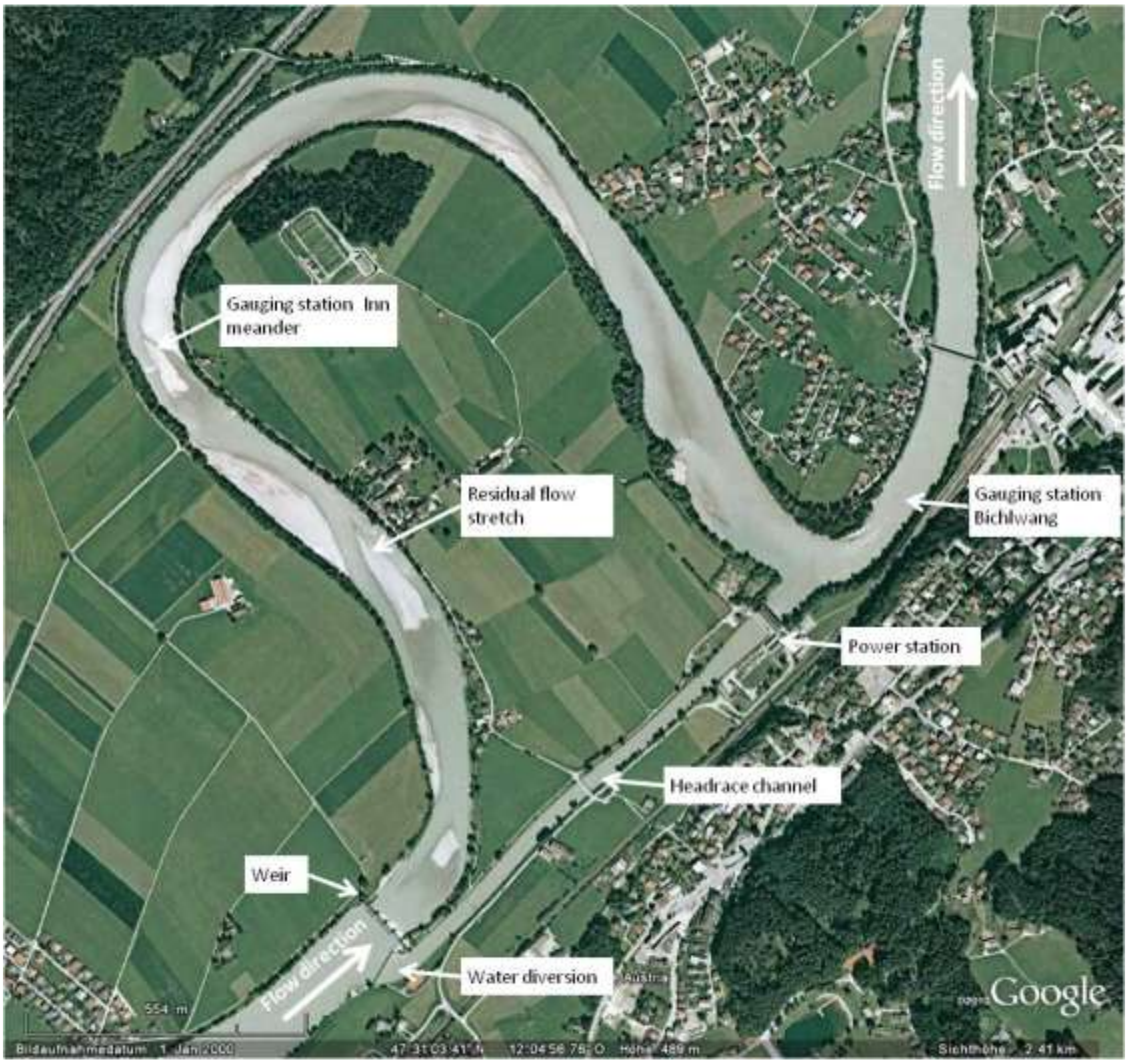

Image 1: Inn meander and the description of the hydro-electric facilities.

Habitat characterization of the Inn Meander

The meander can be divided into four sections. The first section reaches from down the weir to the first groin (image 2 and 3). Significant is a large plain of gravel fallen dry (especially in winter). Only just at the weir water can be found. The dominating substrate is microlithal. The left bank is a natural stone wall jointed with concrete with bushy stocks of *Salix sp.* and *Rubus sp*. The opposite bank is a loose riprap with herbaceous vegetation.

The second section (image 4) has four groins on the right side to lead the flow. On the left side just at the beginning a discharge for run-of water is installed, which normally doesn't have water at low water levels. On both sides the shore line is secured with riprap with the continued vegetation type on each side. A large plain of sand and substrate is fallen dry on the left side of the riverbed. As river substrate grain sizes from psammal to mesolithal can be found.

The Section three (image 5) starts with the water gauge control-point from the TIWAG (Tyrolean Hydropower Corporation). The control point is an artificial vertical drop which slope is flattened with a loose block ramp. The bank is completely sheeted with riprap on the left side and partially sheeted on the right side. The banks are mainly inhabited by shrubs as riparian vegetation. The predominant grain sizes are akal, microlithal, and mesolithal. The soil is pointly sheeted.

The last section (image 6) of the meander is already influenced from the backwater of the HP-plant Langkampfen. Shrubs are the predominant both-sided riparian vegetation. The left bank is secured with riprap. The right side of the river bed forms an expended gravel plain.

Image 2: The weir at the upper side of the meander (picture: Baldes)

Image 3: The first section of the meander (picture: Baldes).

Image 4: The second section of the Inn Meander (picture: Baldes).

Image 5: The third section of the meander with the gauging station (picture: Baldes).

Image 6: The last section of the meander (picture: Baldes).

Ecological impact of the residual-type hydropower plant

This type of hydropower plant is characterized by a diversion of water and a lack of water downstream the plants while the headwater is dammed by a weir. The section of the residual-water is manly characterized by:

- reduction of discharge
- equalization of water flow velocity
- reduction of water depth and a decrease of the ground-water level
- deficit of microhabitat diversity
- shift of the physicochemical parameters
- deficits in the aquatic flora and macrobenthic and fish fauna

These impacted hydrological conditions of the residual-water affect the macroinvertebrate communities downstream, resulting in a disappearance of the usual rheotypical variety of makroinvertebrate species. The lack of water and the low near-bed water velocity have reduced the habitat diversity of the river bed and further riverbed clogging. Furthermore dams and weirs interrupt the river connectivity and prohibit the distribution of different fish species. Particular the migration of Cyprinids and Salmonids are interrupted.

Multi Criteria Analysis and SESAMO decision tree

For the multi criteria analysis of the different management alternatives for the residual flow stretch of the Inn meander we used the CASiMiR model to evaluate the environment requirements for fish species and benthic macroinvertebrates. Further criteria are the connectivity of the Inn meander for fish species, landscape aesthetical value and the annual energy production in relation to the instream flow of the Inn meander.

Management alternatives and the MCA decision tree

This chapter intends to describe the alternatives and the MCA decision tree (image 7) of the HP Kirchbichl which are used in the SESAMO program. To evaluate the best management alternative we compare the actual situation (minimal discharge, no fish bypass) with fourteen different alternatives which include two kinds of fish bypasses and different discharges. Image 8 shows the screenshot of the program SESAMO with the listed management alternatives, and the actual situation. The actual situation and the management alternatives related to the winter months with minimum flow conditions. The alternative 1 to 7 shows the discharge measures between 2.1m^3/s and 72.1m^3/s with a fish ladder on the weir. The alternatives 7 to 14 shows the flow conditions between 2.1m^3/s and 72.1m^3/s with a near natural fish bypass beside the weir.

- Actual situation: Low_discharge_no_fish_ladder_Q=2_1m³/s
- Alternative 1:_Discharge_Q=2_1m³/s_fish_ladder
- Alternative 2:_Discharge_Q=5m³/s_fish_ladder
- Alternative 3:_Discharge_Q=7_1m³/s_fish_ladder
- Alternative 4:_Discharge_Q=15m³/s_fish_ladder
- Alternative 5:_Discharge_Q=18_5m³/s_fish_ladder
- Alternative 6:_Discharge_Q=30m³/s_fish_ladder
- Alternative 7:_Discharge_Q=72_5m³/s_fish_ladder
- Alternative 8:_Discharge_Q=2_1m³/s_fish_bypass
- Alternative 9:_Discharge_Q=5m³/s_fish_bypass
- Alternative 10:_Discharge_Q=7_1m³/s_fish_bypass
- Alternative 11:_discharge_Q=15m³/s_fish_bypass
- Alternative 12:_Discharge_Q=18_5m³/s_fish_bypass
- Alternative 13:_discharge_Q=30m³/s_fish_bypass
- Alternative 14:_Discharge_Q=72_1m³/s_fish_bypass

Image 7: Listing of the alternatives in SESAMO.

- Inn_River
  - Environment
    - Biological_Quality
      - Macroinvertebrates_hyraulic_habitat_suitability_index
        - Macroinvertebrates_HHS_Allogamus_auricollis (F)
        - Macroinvertebrates_HHS_Baetis_alpinus (F)
      - Fish_hydraulic_habitat_suitability_index
        - Fish_HHS_Hucho_hucho
          - Fish_HHS_Hucho_hucho_adult (F)
          - Fish_HHS_Hucho_hucho_juvenile (F)
        - Fish_HHS_Chondrostoma_nasus
          - Fish_HHS_Chondrostoma_nasus_adult (F)
          - Fish_HHS_Chondrostoma_nasus_juvenile (F)
        - Fish_HHS_Barbus_barbus
          - Fish_HHS_Barbus_barbus_adult (F)
          - Fish_HHS_Barbus_barbus_juvenile (F)
        - Fish_HHS_Thymallus_thymallus
          - Fish_HHS_Thymallus_thymallus_adult (F)
          - Fish_HHS_Thymallus_thymallus_juvenile (F)
    - Hydromorphological_quality_and_connectivity_for_fish
      - Discharge_requirements_for_fish
        - Depth (F)
        - Flow_velocity (F)
      - River_connectivity_fish_ladder_or_fish_bypass
        - fish_ladder (F)
        - fish_bypass (F)
  - Landscape
    - Landscape_aesthetical_value (F)
  - Energy_production
    - Annual_energy_production_Gwh_per_year_rough_estimation (F)

Image 8: SESAMO decision tree for the Inn meander and the HP plant Kirchbichl.

Criteria and Utility Functions

CASiMiR modeling

The field work and the data collection for the CASiMiR model were conducted between 13th and 14th November 2011. A total of about 1000 points for the creation of terrain models were adopted. The points were usually collected in the form of cross sections, however, partially adapted to the track morphology to represent special structures. For the calibration of hydraulic model would be implemented addition flow measurements with 2.1 m³/s, 7.1 m³/s, 18.5 m³/s, and 72.5 m³/s are conducted. This discharges measured by a working group in of the TIWAG. The hydraulic model of the Inn meander was programmed by the Institute for modeling hydraulic and environmental systems of the University of Stuttgart.

Fish Fauna

Due to the relative high lifetime and the life cycle, hence fish species are good indicators for the ecological and hydromorphological status of rivers and streams. The assessment of the fish fauna based on the CASiMiR habitat hydraulic model. For the project case study four fish species was observed by this method: *Hucho hucho, Barbus barbus, Thymallus thymallus,* and *Chondrostoma nasus*. The program CASiMiR calculates the hydraulic habitat suitability index (HHS) and the usable wetted areas for each of this species in a river section of the Inn meander, and for different discharges. The important parameters to assess the hydraulic habitat suitability are the flow velocity, water depth, and the river bed structure. The measurement at the Inn meander and the preparation of the digital terrain model was implemented by the IWS (PP11, University of Stuttgart, Institute for Modeling Hydraulic and Environmental Systems). Image 9 show an example of the hydraulic habitat suitability for *Thymallus thymallus* for different discharge (2.1 m³/s, 5.0 m³/s, 7.1 m³/s, 15.0 m³/s, 18.5 m³/s, 30.0 m³/s, 72.5 m³/s).

Utility function for the hydraulic habitat suitability (HHS)

The utility function based on the hydraulic habitat suitability (HHS) calculates by the CASiMiR software. The HHS index ranged from 0 (=no suitability) to 1 (=high suitability). To compare the habitat suitability of each fish species it is necessary to adjust the HHS values. The highest HHS value of each fish species will be replaced by the value 1. All other HHS values are relative to the highest

HHS values. Table 1 shows the values of the HHS and the adjusted HHS values of each fish species and discharge.

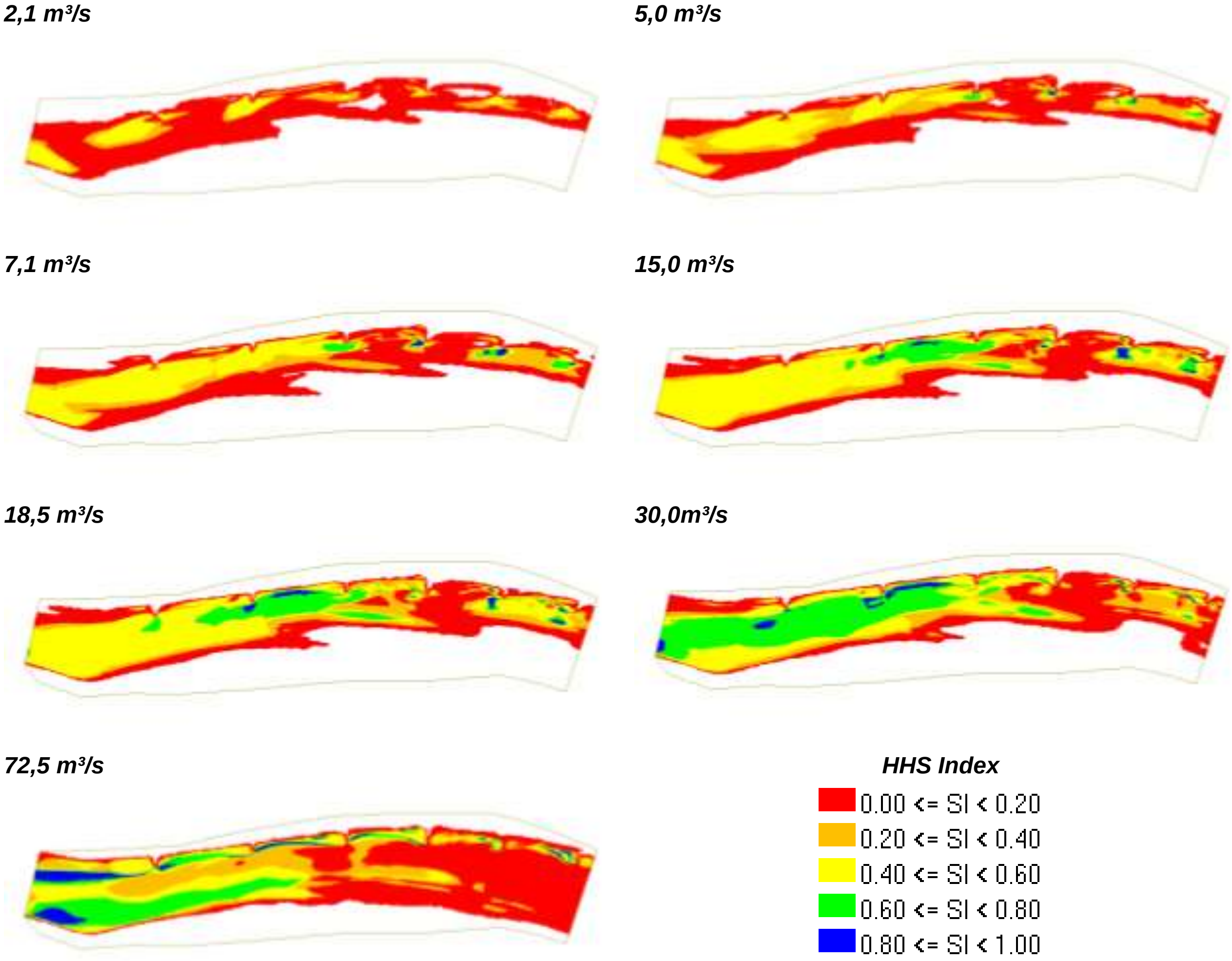

Image 9: The pictures show the hydraulic habitat suitability (HHS) in the river section for adult grayling (*Thymallus thymallus*) for different discharges (2.1 m^3/s, 5.0 m^3/s, 7.1 m^3/s, 15.0 m^3/s, 18.5 m^3/s, 30.0 m^3/s, 72.5 m^3/s).

Table 1: Hydraulic habitat suitability and the adjusted HHS for the fish species: *Hucho hucho, Barbus barbus, Thymallus thymallus,* and *Chondrostoma nasus.*

***Barbus barbus*, adult**

Discharge [m³/s]	2.1	5.0	7.1	15.0	18.5	30.0	72.5
HHS	0.31	0.35	0.37	0.41	0.42	0.38	0.28
adjusted HHS	**0.74**	**0.83**	**0.88**	**0.98**	**1.00**	**0.90**	**0.67**

***Barbus barbus*, juvenile**

Discharge [m³/s]	2.1	5.0	7.1	15.0	18.5	30.0	72.5
HHS	0.58	0.52	0.48	0.39	0.36	0.28	0.2
adjusted HHS	**1.00**	**0.90**	**0.83**	**0.67**	**0.62**	**0.48**	**0.34**

***Hucho hucho*, adult**

Discharge [m³/s]	2.1	5.0	7.1	15.0	18.5	30.0	72.5
HHS	0.34	0.37	0.38	0.38	0.36	0.31	0.2
adjusted HHS	**0.87**	**0.95**	**0.97**	**0.97**	**0.92**	**0.79**	**0.51**

***Hucho hucho*, juvenile**

Discharge [m³/s]	2.1	5.0	7.1	15.0	18.5	30.0	72.5
HHS	0.73	0.69	0.66	0.57	0.53	0.43	0.28
adjusted HHS	**1.00**	**0.95**	**0.90**	**0.78**	**0.73**	**0.59**	**0.38**

***Chondrostoma nasus*, adult**

Discharge [m³/s]	2.1	5.0	7.1	15.0	18.5	30.0	72.5
HHS	0.27	0.33	0.36	0.44	0.47	0.49	0.36
adjusted HHS	**0.55**	**0.67**	**0.73**	**0.90**	**0.96**	**1.00**	**0.73**

***Chondrostoma nasus*, juvenile**

Discharge [m³/s]	2.1	5.0	7.1	15.0	18.5	30.0	72.5
HHS	0.57	0.47	0.44	0.33	0.29	0.22	0.18
adjusted HHS	**1.00**	**0.82**	**0.77**	**0.58**	**0.51**	**0.39**	**0.32**

***Thymallus thymallus*, adult**

Discharge [m³/s]	2.1	5.0	7.1	15.0	18.5	30.0	72.5
HHS	0.18	0.25	0.28	0.35	0.37	0.41	0.33
adjusted HHS	**0.44**	**0.61**	**0.68**	**0.85**	**0.90**	**1.00**	**0.80**

***Thymallus thymallus*, juvenile**

Discharge [m³/s]	2.1	5.0	7.1	15.0	18.5	30.0	72.5
HHS	0.57	0.56	0.54	0.43	0.39	0.31	0.21
adjusted HHS	**1.00**	**0.98**	**0.95**	**0.75**	**0.68**	**0.54**	**0.37**

Benthic Macroinvertebrates

For the assessment of the benthic macroinvertebrates and their habitat suitability we use the CASiMiR software. The program CASiMiR calculates the hydraulic habitat suitability index (HHS) and the usable wetted areas for each of this species in a river section of the Inn meander, and for different discharges. The important parameters to assess the hydraulic habitat suitability are the flow velocity, water depth, and the river bed structure. The measurement at the Inn meander and the preparation of the digital terrain model was implemented by the IWS (PP11, University of Stuttgart, Institute for Modeling Hydraulic and Environmental Systems). Image 10 show an example of the hydraulic habitat suitability for *Allogamus auricollis* for different discharge (2.1 m^3/s, 5.0 m^3/s, 7.1 m^3/s, 15.0 m^3/s, 18.5 m^3/s, 30.0 m^3/s, 72.5 m^3/s).

Utility function for the hydraulic habitat suitability (HHS)

The utility function based on the hydraulic habitat suitability (HHS) calculates by the CASiMiR software. The HHS index ranged from 0 (=no suitability) to 1 (=high suitability). To compare the habitat suitability of each species it is necessary to adjust the HHS values. The highest HHS value of each species will be replaced by the value 1. All other HHS values are relative to the highest HHS values. Table 2 shows the HHS values and the adjusted HHS values of Allogamus auricollis and Baetis alpinus and the discharges (2.1 m^3/s, 5.0 m^3/s, 7.1 m^3/s, 15.0 m^3/s, 18.5 m^3/s, 30.0 m^3/s, 72.5 m^3/s).

Table 2: Hydraulic habitat suitability and the adjusted HHS for the benthic macroinvertebrates species *Allogamus auricollis and Baetis alpinus*

Allogamus auricollis

Discharge [m³/s]	2.1	5.0	7.1	15.0	18.5	30.0	72.5
HHS	0.22	0.28	0.31	0.42	0.45	0.42	0.26
adjusted HHS	**0.49**	**0.62**	**0.69**	**0.93**	**1.00**	**0.93**	**0.58**

Baetis alpinus

Discharge [m³/s]	2.1	5.0	7.1	15.0	18.5	30.0	72.5
HHS	0.12	0.13	0.14	0.15	0.16	0.18	0.23
adjusted HHS	**0.46**	**0.50**	**0.54**	**0.58**	**0.62**	**0.69**	**0.88**

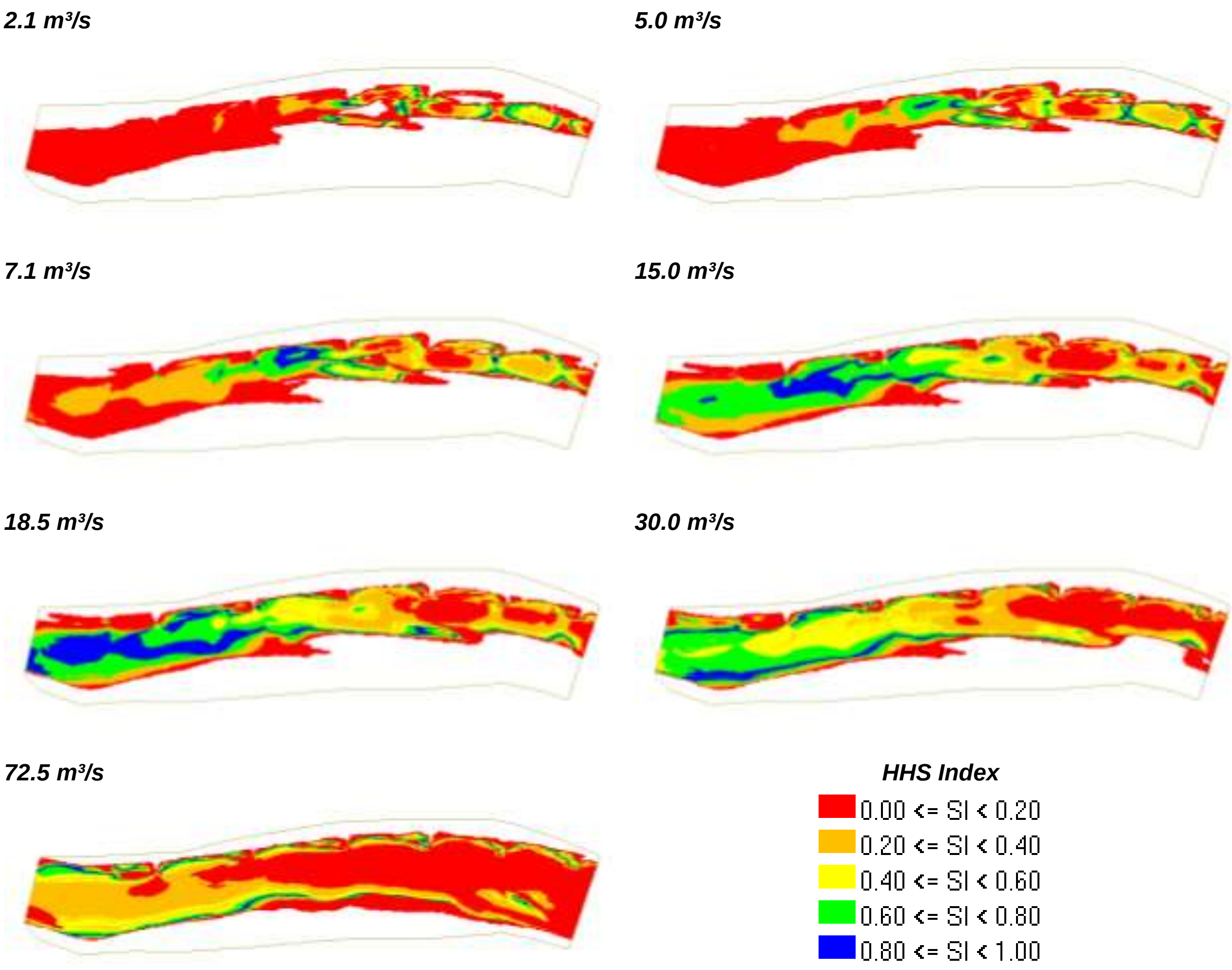

Image 10: The pictures show the hydraulic habitat suitability (HHS) in the river section for *Allogamus auricollis* for different discharges (2.1 m^3/s, 5.0 m^3/s, 7.1 m^3/s, 15.0 m^3/s, 18.5 m^3/s, 30.0 m^3/s, 72.5 m^3/s).

Discharge requirements for fish and connectivity

This criterion bases also on the digital terrain model and the CASiMiR model of the Inn meander and used the depth and flow velocity information of the CASiMiR model. The model shows the flow velocity and depth distribution of the river section. For example, the images 11 and 12 show the depth (m) and the flow velocity (m/s) distribution of different discharges. The flow velocity values of different residual water discharges in the Inn meander, and compares this with limit values. The quality classes of the flow velocity and water depth are described in the "QZV Ökologie" (Quality Objectives Ordinances Ecology - Surface Waters). The minimum flow velocity in the lower Tyrolean

Inn is defined as >0.3 m/s, and the minimum water depth for fish are 30 cm. In the spawning time 40cm.

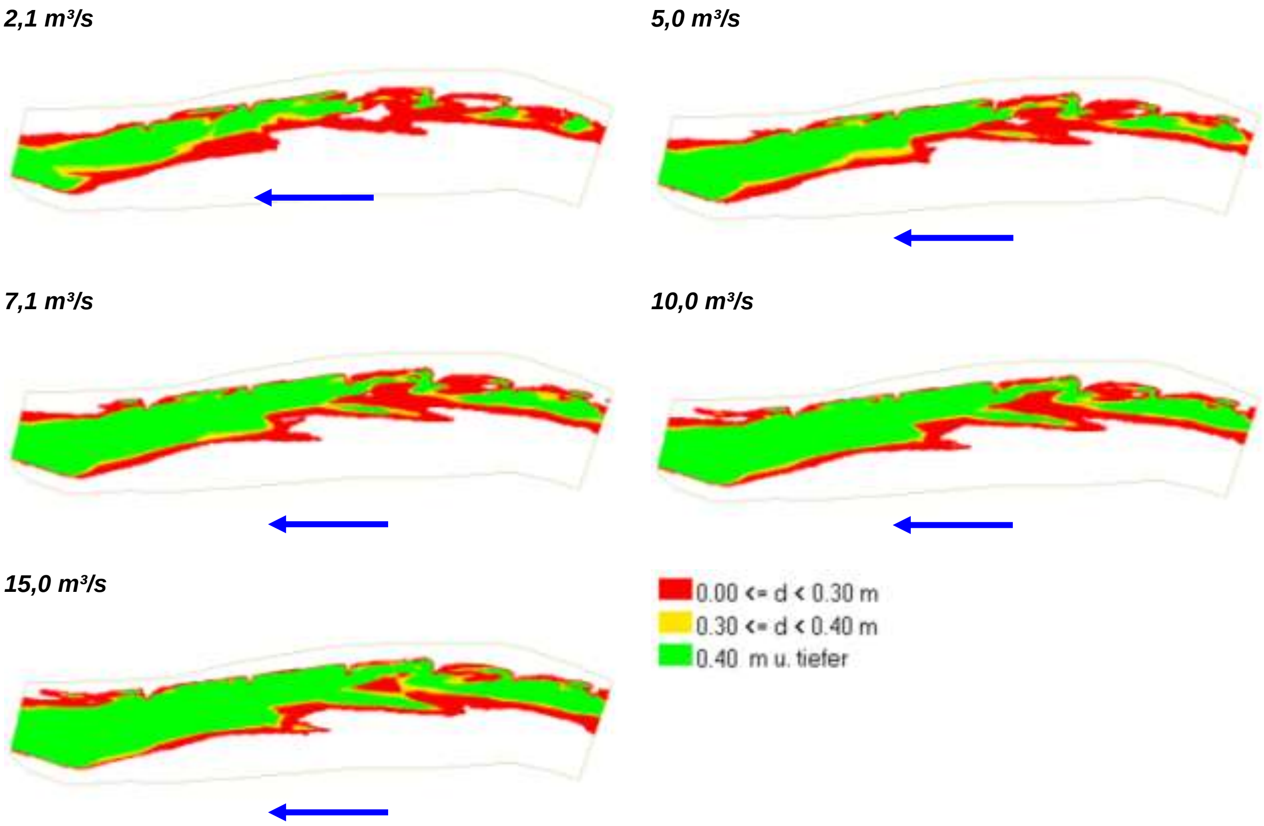

Image 11: Example of the water depth distribution of the Inn meander section. The images shows

Table 3: Utility function for the criteria depth [m]

Depth [m]	UF
0 – 0.20	0
0.21 – 0.30	0.5
0.31 – 0.40	0.75
0.41 - >	1

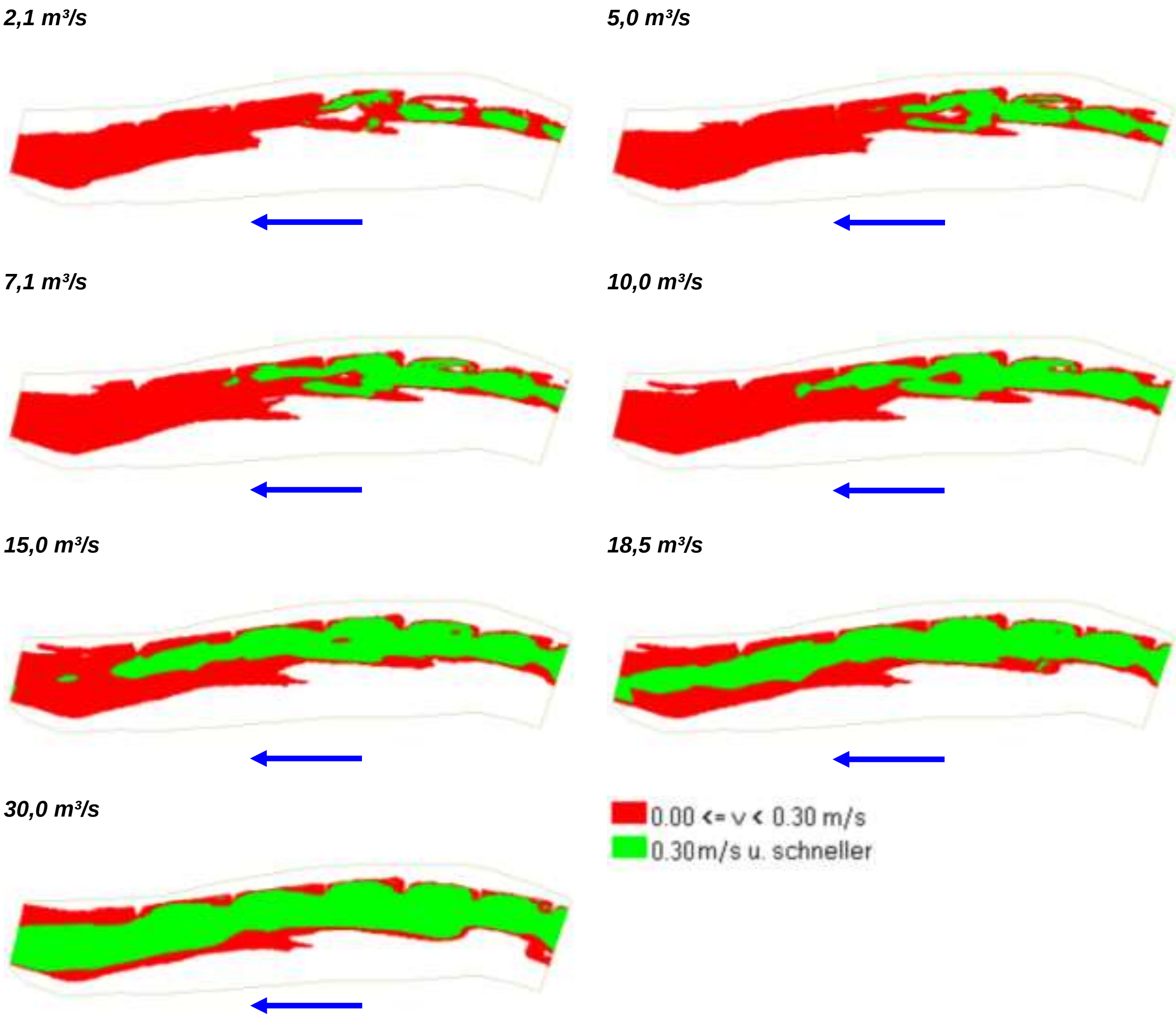

Image 12: Example of the flow velocity distribution of the Inn meander section (discharge 15m³/s).

Table 4: Utility function for the criteria flow velocity (m/s)

Flow velocity	UF
0 – 0.29	0
0.3 - >	1

River connectivity (fish ladder or fish bypass)

This criterion defines the kind and structure of fish passes. The fish ladder is defined as a concrete structure like a classic fish ladder (image 13) beside the hydropower plant or dam, and the fish bypass is defined as a near natural shaped small brook beside the hydropower facility (image 14). The river connectivity is an important quality component for fish migration. The fish bypass is in the case of the PCS Inn the better alternative as the classic fish ladder. Near natural fish passes have similar ecological conditions like natural rivers or brooks.

Table 5: Utility function for the criteria river connectivity

Fish ladder	UF
yes	0.5
no	0

Fish bypass	UF
yes	1
no	0

Image 13: Fish ladder (Picture: Baldes)

Image 14: Fish bypass (Picture: Baldes)

Annual energy production (GWh/a)

The annual energy protection for the HP Kirchbichl is stated with 131 GWh/a. This Indicator shows the energy production in case of the residual water flow into the Inn meander, is unavailable for hydro-electric exploitation. Falser (2008) calculated yearly energy loss and the finance loss of the residual water flow in the Inn meander. The yearly energy loss was calculated as energy production loss per year (GWh/a) per 1 m³/s residual water flow (table 6).

Table 6: Residual water flow and the yearly energy production of the hydro power plant Kirchbichl.

Residual water flow	Energy production (GWh/a)
2.1 m³/s	130.1 GWh/a
5.0 m³/s	128.8 GWh/a
7.1 m³/s	127.8 GWh/a
15.0 m³/s	124.3 GWh/a
18.5 m³/s	122.7 GWh/a
30.0 m³/s	116.7 GWh/a
72.5 m³/s	96.5 GWh/a

Aesthetic landscape value

Functional changes in river basins also have an aesthetic component. This directly affects the experience and the recreational value a section of river. The indicator "aesthetic landscape value" measures the change in aesthetic experience of landscape value. This evaluation method based on a questionnaire to the aesthetical landscape value (Nohl 1977).

Literature

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