REHABILITATION OF GAULWERK HYDROPOWER PLANT CONSIDERING ENVIRONMENT, SEDIMENT MANAGEMENT AND FLOOD PROTECTION

C. AUEL, E. GRUBER, F. KIRCHER AND R. FRITZER
ILF Consulting Engineers, Austria

C. MORITZ
Limnology Consultant, Austria

T. HUBER
Stadtwerke Imst, Austria

ABSTRACT

The Gaulwerk hydropower plant (HPP) has a design discharge of 3.5 m³/s and generates about 6.5 GWh per year. The HPP has been in operation since 1963 and uses the flow of two alpine streams. The HPP impounds a 300 m long reservoir with a 6.50 m high weir. The storage is completely filled with sediments and is classified as a valuable habitat for fauna and flora. Due to the sedimentation, the area upstream of the reservoir head inundates about two to three times per year during small flood events, leading to complaints from affected landowners and adjacent municipalities. To investigate sustainable solutions, a study of alternatives has been carried out in which three alternatives to im-prove both the sediment and flood situation are being investigated. In addition, the residual flow release will be adjusted and fish facilities realized in all alternatives. The paper will summarize the analysis of the alternatives encompassing the (1) flood situation, (2) sediment management, (3) reha-bilitation measures of the hydraulic structures and their costs and (4) the environmental impact.

1. INTRODUCTION

The Gaulwerk hydropower plant (HPP) is owned by Stadtwerke Imst, the municipal utility company of the city of Imst in Tyrol, Austria. The HPP has been in operation since 1963 and uses the flow of the two alpine streams, the Gurglbach and the Salvesenbach. The HPP has a design discharge of 3.5 m3/s and generates about 6.5 GWh per year.

The 6.50 m high weir impounds an about 300 m long reservoir (Figure 1a and b). Since the 1990s the storage is completely filled with sediments and is classified as a valuable habitat for fauna and flora (Figure 1c).

Due to the sedimentation, the area upstream of the reservoir head inundates about two to three times per year during small flood events, leading to complaints from affected landowners and adjacent municipalities. Figure 1d shows the Knappenwelt Bridge at the reservoir head having very little free-board between water surface and lower bridge slab. It is evident that no additional sediment storage is available and sediment management has to be performed in the near future.

Therefore, a study of alternatives has been carried out in which three alternatives to improve both the sediment and flood situation are investigated. For all alternatives, the environmental impact on the habitat was studied in detail. In addition, the residual flow release will be adjusted, fish facilities realized and the weir rebuilt or renovated.

Figure 1 : (a) Gaulwerk weir with two gates and two overflow sections, (b) view downstream from reservoir to weir, (c) view upstream from weir to reservoir. Reservoir completely filled with sediments, d) Knappenwelt Bridge at the reservoir head with almost no freeboard left between bed and bridge. Photographs by C. Auel.

2. THE ALTERNATIVES

2.1 Alternative A

The existing weir will be renovated, Figure 2). The vertical sliding gates will be replaced by roller gates. The reservoir level will not change and corresponds to the overflow edge of the fixed weir.

Active sediment management will be carried out using sediment sluicing. The gates will be opened during flood events, the reservoir draws down and the sediment-laden flows are directed downstream. This should be done once or twice a year for a few days. Through this process, a channel will form over the years with a longitudinal slope gradually corresponding to the original bed. In the vicinity of the weir, this channel will correspond approximately to the gate width (around 5 m) while the bank slope will correspond to the friction angle of sediment (approx. 30°). The formation of a deep channel is accelerated by dredging. This dredging intends to prevent an increased sediment load downstream during sluicing in the first years. The excavated volume will be about 13,000 m^3.

A log boom will likely be installed in the reservoir to prevent driftwood clogging at the intake. The trash rack and cleaning machine will not be renovated for the time being.

A fish passage will be built on the orographic right side. The total height to be overcome is approx-imately 4.5 m. The passage will be designed as a vertical slot pass with 25 pools, each 2.6 m long and 1.7 m wide. The upper part will be designed as an open channel. The outflow in the fish pass is assumed to be 250 l/s.

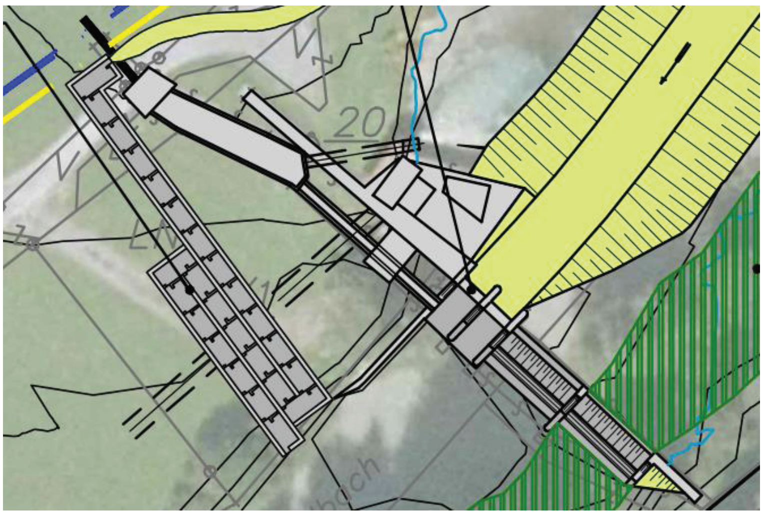

Figure 2 : Plan view of existing weir and new fish passage. Flow from upper right to lower left.

2.2 Alternative B

In Alternative B, a new weir will be built upstream of the Knappenwelt Bridge. Active sediment management will be carried out identically to Alternative A by means of sediment sluicing. The in-flatable weir will be lowered once or twice a year for a few days during flood events and the sediment passes through (Figure 3).

Levees generate a new small storage space and protect the residents from flooding. The levee crest will be dimensioned for a hundred-year flood (HQ100) event with a freeboard of 50 cm. The levee height will be maximum 1.50 m on the air side and 3.50 m on the water side. The volume of the levee body will be 1,800 m^3.

The flow will be dammed using an inflatable weir with a width of 10 m. A desander is planned to be placed in the vicinity of the existing weir. This has the advantage that the water from the Salvesen-bach can also be captured in the desander. The desander will consist of two chambers, each 2.5 m wide and 30 m long.

A new 456 m long pipe DN1500 will lead along the existing road from the new weir to the de-sander. The pipeline will have a maximum gradient of 0.3% and will be operated under free-surface conditions. The flow velocity in the pipe will be about 1.5 to 2.5 m/s, with a flow rate of 0.5 to 3.5 m3/s. Sediment deposits are not expected. Sediment particles larger than 5-10 mm are not to be ex-pected in the pipe, since sediment is diverted at the intake.

The existing bed of the Gurglbach upstream of the Knappenwelt Bridge will be excavated over a length of around 300 m in order to erect the new weir on the one hand, and to ensure flood protection on the other. The volume removed will be about 16,200 m^3.

The old weir will be deconstructed and the gates will be dismantled. The gates will be removed step by step over several years, since the accumulated sediment has to be flushed in single lamellas over a long period of time. Instead of the gates, stackable boards can be installed, which can be re-moved in steps of 50 cm.

The fish pass will be arranged as a vertical slot pass on the orographically left bank next to the weir. The total height to be overcome will be about 2.5 m. The fish pass will be designed as a vertical slot pass with 14 pools, each 2.6 m long and 1.7 m wide. The outflow in the fish pass is assumed to be 250 l/s.

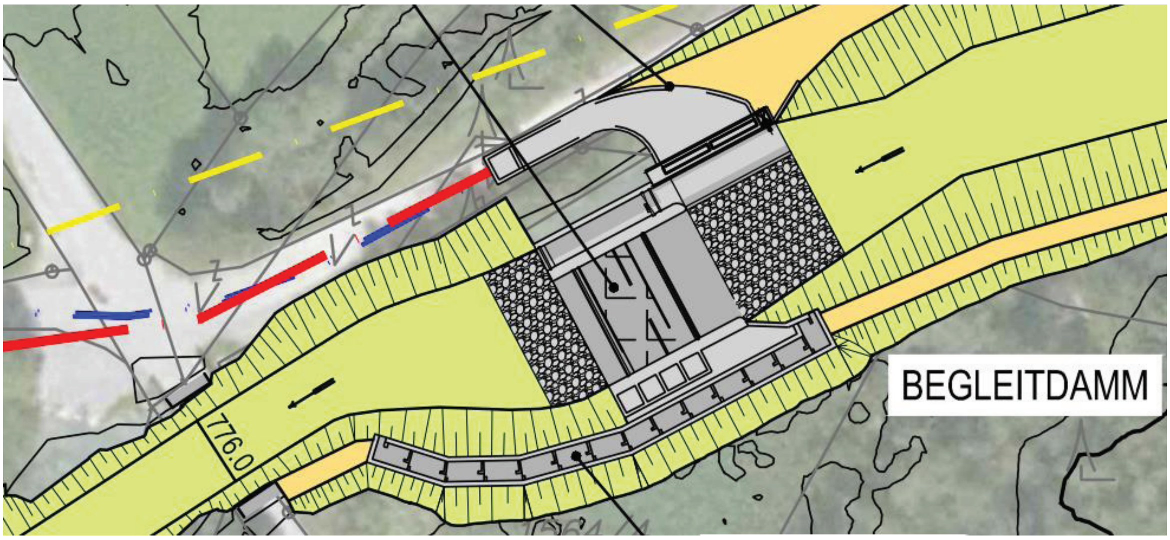

Figure 3 : Plan view of new weir and new fish passage. Flow from upper right to lower left.

2.3 Alternative C

The existing weir will be renovated identically to Alternative A. The vertical sliding gates will be replaced by roller gates. The reservoir level will not change and will correspond to the overflow edge of the fixed weir. Also, the fish passage will be constructed identically to Alternative A.

In order to check the function of the gates, they are opened a few hours once a year. This means that no deep channel forms and the biotope area in the reservoir area will be preserved. There is no active sediment management as with Alternative A.

Downstream of the Knappenwelt Bridge a sediment trap of 4100 m3 size will be constructed with an area of around 2000 m^2 (Figure 4). The deposited sediments will be dredged (annually) as required and then recycled or deposited.

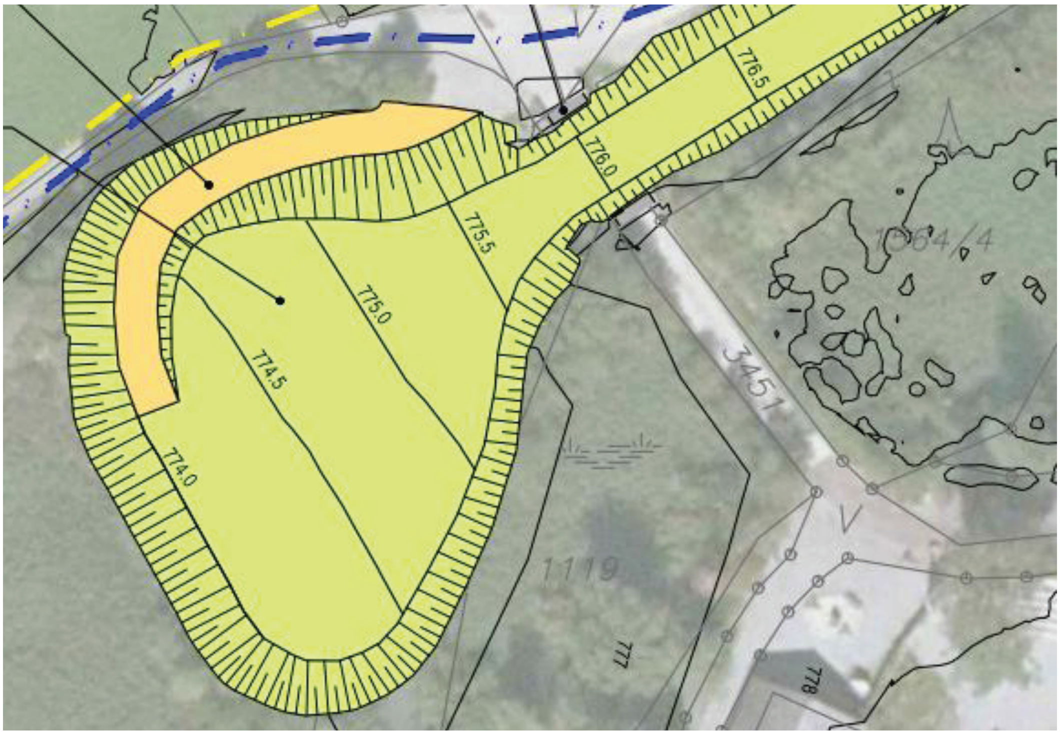

Figure 4 : Plan view of sediment trap at the reservoir head. Flow from upper right to lower left.

3. HYDROLOGY

The flow duration curves at the Nassereith Wiesenmühle gauging station some 8 km upstream of the HPP were obtained from the daily mean values from 1981 to 2015 (Figure 5). The mean flow (MQ) over the entire period is 1.9 m^3/s.

The flow duration curve for the Gaulwerk reservoir is also shown in Figure 5. The catchment area at the Nassereith station is 78.3 km^2, the catchment at the Gaulwerk HPP is 121.2 km^2. The recorded discharge was converted using the catchment ratio. The MQ at Gaulwerk reservoir is 2.9 m^3/s.

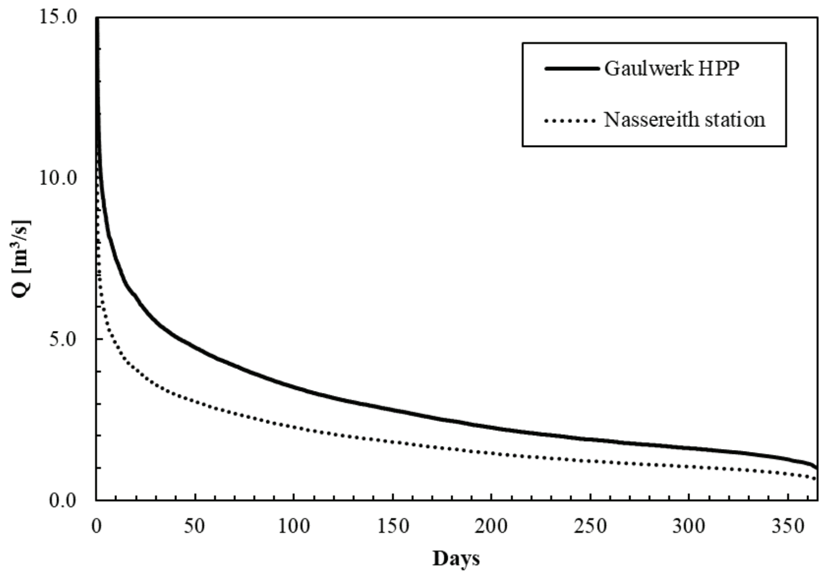

Figure 5 : Flow duration curves of Gaulwerk HPP and gauging station at Nassereith.

4. NUMERICAL MODELLING

4.1 Hydrodynamic model

In order to analyze the effects of small and large floods in the upstream reservoir area, two-dimen-sional hydrodynamic modeling is carried out and the flow depths, flow velocities, bed shear stresses and other hydraulic parameters are determined. The two-dimensional (2D) hydrodynamic model HEC-RAS 5.0.7 by the US Army Corps of Engineers was used for the modelling.

A three-dimensional terrain model was set up using the official laser scan data of the province of Tyrol, with a resolution of 0.5 m × 0.5 m, a geodetic survey of the reservoir area and the original project plans. These data were combined to form a Digital Terrain Model (DTM). The geometry of the Knappenwelt Bridge was modeled without surface cover plate.

The upstream boundary condition for the hydraulic model is a steady-state inflow condition. The Manning roughness coefficients were used for the simulations in order to estimate the surface rough-ness. The Manning values used are based on both literature and experience. The values were estimated based on the site visit and available photographs of the modeled area, including ground and aerial photographs. The following values were used:

- Foreland $n = 0.035\ s/m^{1/3}$
- River bed $n = 0.03\ s/m^{1/3}$
- Reed (reservoir area) $n = 0.05\ s/m^{1/3}$

In total, 10 simulations were performed for the current state and the three alternatives using the following discharges:

- MQ = 2.9 m^3/s
- HQ1 = 10 m^3/s
- HQ2 = 13.9 m^3/s
- HQ100 = 78 m^3/s

4.2 Results

The simulation results reveal that in the current state the flow stays in the riverbed during the mean annual flow (Figure 6a). However, during annual flood events (HQ1) the area upstream of the reser-voir is inundated, which confirms the local observations (Figure 6b). Comparable simulations were performed for Alternative C (Figure 6c and d) revealing less inundations for HQ1 due to the dredged river bed and sediment trap. These simulations assume that the sediment trap is empty prior the flood event. Figure 7 shows the cross section upstream of the Knappenwelt Bridge, also revealing that Alternative C leads to slightly lower flow depths in the HQ1 event.

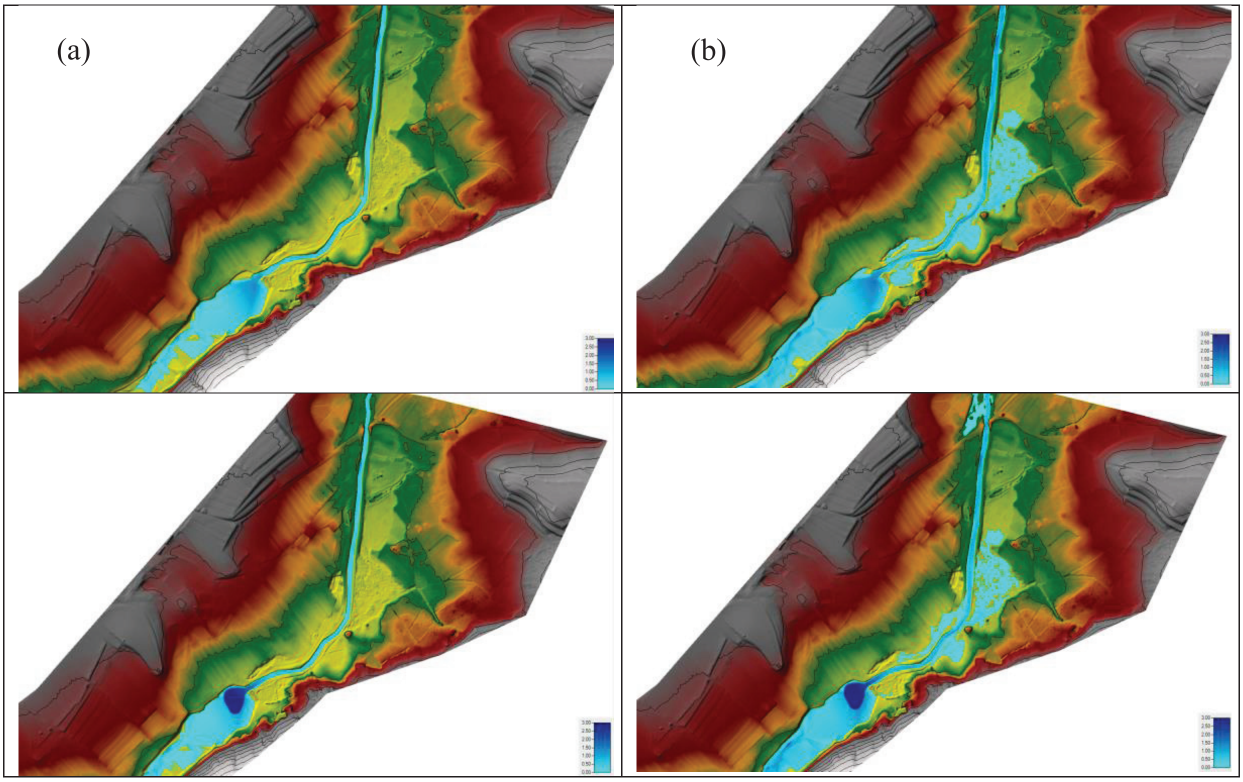

Figure 6 : Plan view of flow depth results. (a) Current state. MQ = 2.9 m^3/s, (b) current state HQ1 = 10.0 m^3/s, (c) Alternative C MQ = 2.9 m3/s, d) Alternative C HQ1 = 10.0 m3/s.

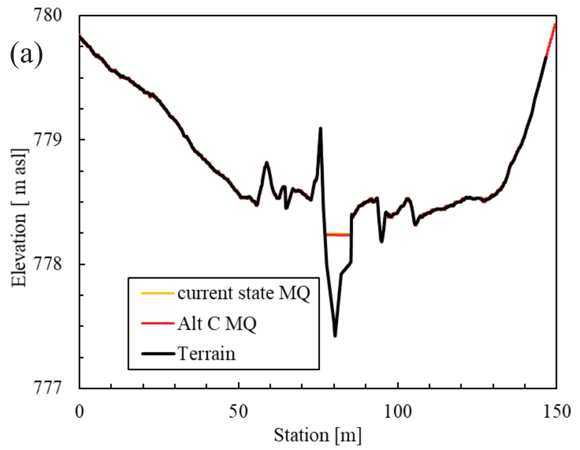

Figure 7 : Cross section upstream of Knappenwelt Bridge showing flow depth results for the current state and Alternative C. (a) MQ = 2.9 m^3/s, (b) HQ1 = 10.0 m3/s.

During a HQ100 flood event, large inundations occur upstream of the reservoir for the current state and Alternatives A and C, while the levees in Alternative B prevent the area from flooding (Figure 8a to d). This indicates that levees would have to be constructed for all the three alternatives, given that a flood protection against a HQ100 flood is desired.

Alternative A and B also show that the entire flood is conveyed through the dredged open channel as the gates are completely opened and the reservoir is drawn down.

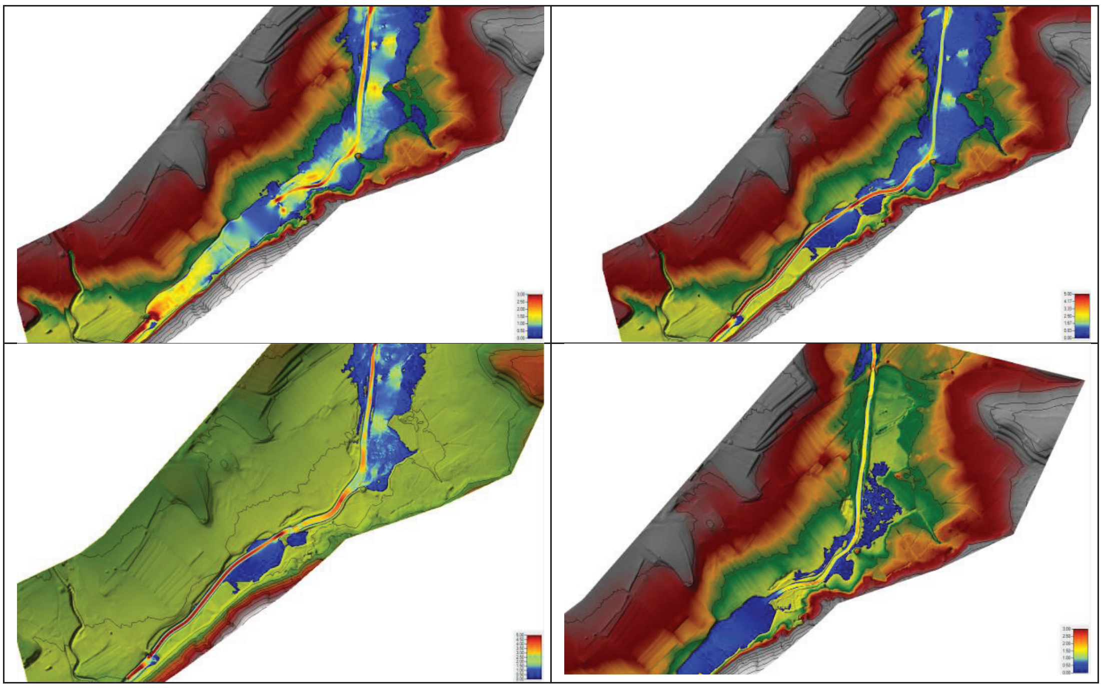

Figure 8 : Flow velocities at HQ100 = 78.0 m^3/s. (a) current state, (b) Alternative A, (c) Alternative B, (d) Alterna-tive C

The results show that all three alternatives increase the flood safety in the upstream area. A levee is recommended for all alternatives but only necessary if a higher flood protection level is required.

Alternatives A and B divert the sediments into the downstream reach of the Gaulwerk reservoir. This will lead to morphological changes in the river, which could increase the risk of flooding. Further in-depth investigations would be necessary.

5 ENVIRONMENTAL ASSESSMENT

5.1 Terrestrial ecology

5.1.1 *Plants*

The biotope types at risk in the area under investigation are

- Natural lowland meadows (FFH-LRT 6510) and
- White willow (FFH-LRT 91 * E0)

The lowland meadows are unlikely to be influenced by all three alternatives due to their topograph-ical location, but for the white willow the effects of the three alternatives are very different. Com-pletely protected species were identified as part of the vegetation mapping in the area of the sparse pine forest (water iris) found 400 m upstream of the Knappenwelt Bridge and in the area of the spruce and pine forest downstream of the bridge.

Due to the extensive preservation of the white willow and the slowly flowing areas of the Gur-glbach with the reed areas below the Knappenwelt Bridge, Alternative C is preferred from a vegeta-tion point of view. It is assumed that when the weir is built directly upstream of the Knappenwelt Bridge (Alternative B), a considerable area of white willow will be permanently lost due to damming, and also large parts of the reed areas existing downstream of the bridge, through the design of a deep channel. Alternative B is rated the worst, as it is likely that the groundwater level in the current sedi-mentation area in the reservoir will be lost in the long term.

With Alternative A it can be assumed that these areas will be affected much less, even if the deep channel changes dynamically over the years and some currently wet areas will dry out. However, the groundwater level will remain essentially unchanged, and as a result, the impact on wetlands will be significantly lower than in Alternative B.

5.1.2 *Animals*

For the birds, especially the shallow water areas with reeds represent a high-quality habitat. Species that are endangered because they depend on these habitats are primarily the marsh warbler.

The shallow water areas and reed stands are potential habitats for grass frogs, European toads and grass snakes (all three protected according to Tyrolean regulation). Due to its topographical location, no negative impact is to be expected on the habitats of the yellow-bellied toad as they are upstream outside the project-relevant area. For all three alternatives there are no influences from a flood-related point of view and no project-related changes in groundwater are to be expected.

Based on the assumptions and statements already made in the previous chapter regarding the con-servation of the reed areas / white willow, Alternative C is rated best and B worst.

5.1.3 *Landscape*

According to the Tyrolian law, the recreational value is closely linked to that of the landscape. There-fore, the two criteria for comparing and evaluating the alternatives are combined. Tourism also plays a significant role in the Gurgltal valley, and in rural areas it is also inevitably linked to the landscape.

The least impact on landscape and recreational value can be expected with Alternative C, since this alternative has the least impact on the visible and tangible natural landscape. The sediment trap in the area of the Knappenwelt Bridge could be used by recreation seekers as a bathing facility if it is de-signed appropriately. In this respect, one could even speak of a slight revaluation in this area in terms of recreational value.

Alternative A and Alternative B differ in terms of landscape and recreational value, especially through the new construction of the weir above the Knappenwelt Bridge in Alternative B. Further-more, with Alternative B, a change in the wetlands towards the free-flowing river section below the Knappenwelt Bridge can be assumed, the shallow reed areas will be lost to a considerable extent.

5.2 Aquatic ecology

5.2.1 *Current situation*

The river lies in the Northern Limestone Alps and belongs to the lower trout region, with the fish species brown trout and bullhead, rare species are the burbot and grayling.

The ecological condition is poor and can be attributed to the hydromorphological quality compo-nent. Apart from the monotonous regulation over long stretches and the sedimented storage area, the delivery of residual water has not yet been prescribed for the Gaulwerk weir nor the Salvesenbach. Fish passage is also not possible in both rivers as there are no fish ladders.

Due to the more or less complete sedimentation in the reservoir, at least the flow character has been restored to the original state prior to damming, although the gradient is significantly smaller than in the original terrain.

According to the Austrian National Water Management Plan (Nationaler Gewässerschutzplan – NGP) 2015, fish continuity and environmental flow release is therefore planned to be achieved by 2021 and at the latest in 2027.

5.2.2 *Effects on the reservoir*

In Alternative A, the sediment sluicing associated with the drawdown during flooding while main-taining the reservoir level will result in a lake-like water body. This represents a significant deterio-ration compared to the current situation.

Alternative B leads to two different, conflicting mechanisms. On the one hand, it should be posi-tively assessed that free flowing water with a site-appropriate gradient is developing in the reservoir. It is to be expected that the base substrate will then be somewhat coarser and thus a benthic coenosis more in line with the policy guidelines. On the other hand, a new standing water body will develop compared to the current state, since the new weir is moved upstream. Weighing up these two effects is difficult, the situation is therefore classified as constant.

With Alternative C, nothing changes compared to the current state.

5.2.3 *Sediment connectivity and effects on downstream river*

Sediment sluicing in the first years also implies sediment flushing, which means that the accumulated sediments in the reservoir will be flushed resulting in adverse effects on the biota (gill damage of fish, colmation of the bed, etc.). Both Alternative A and Alternative B have clearly disadvantageous effects downstream in the first few years, while for Alternative C nothing changes.

The aquatic ecological requirement of connectivity affects not only fish passability, but also sedi-ment connectivity. The sluicing of the incoming sediment is positive in general. Both Alternatives A and B are rated positive in this regard, while with Alternative C nothing changes compared to the actual state.

The negative effects of complete sediment retention due to damming on the aquatic environment have been documented in numerous works (e.g. increased algae growth, bed consolidation due to latent erosion, etc.). In principle, the entire downstream reaches are affected. However, in this specific case, this criterion is not of high importance as the negative effects primarily affect the 150 m long stretch from the weir to the Salvesenbach confluence. Due to large sediment entrainment by the Salvesenbach, the bed below it is apparently already much more natural (loose limestone gravel with dominating mesolite portion) than the 150 m stretch.

5.2.4 *Fish passage*

It should be noted that a fish passage must be constructed in any case, in accordance with the NGP 2015, regardless of the alternative. The differences between the alternatives are the different heights of the weir and thus a more or less easy implementation. Alternative B performs best here with a height difference that is 2 m lower than the current weir. With Alternatives A and C the reservoir level does not change and the establishment of a fish passage is a bit more difficult to implement.

5.2.5 *Reservoir bed level and dredging*

In Alternative A, the bed is much lower than today, but is flooded and therefore somewhat disadvan-tageous in terms of aquatic ecology. Alternative B, on the other hand, is significantly more positive, since a low bed level is created similar to the original one prior the construction of the weir. Alterna-tive C is clearly the most disadvantageous, since there is continuous dredging in an large settling area.

6. COSTS

The prime costs estimated in the current project phase correspond to AACE class 5, with a variation of -50% to +100%:

- Alternative A: more than one million Euro
- Alternative B: more than four million Euro
- Alternative C: more than one million Euro

These prime costs do not include services such as planning, approval, land acquisition and con-struction supervision.

With Alternative C, in addition to the usual operating costs, which are not assessed here, there is the annual removal of the sediment in the sediment trap. The following assumptions are made:

- 10 m^3 per tipper (three-axle tipper)
- 4,000 m^3 sediment input per year
- Landfill <20 km away

This leads to 400 trucks a year leading to annual costs of about 80,000 €.

7. COMPARISON OF ALTERNATIVES

The alternatives are compared using a matrix. The classification is carried out as follows:

- Engineering works 35%
- Environment 35%
- Costs 30%

The evaluation is carried out in three categories by awarding points. If two alternatives are almost equivalent, the same points can be awarded in both alternatives:

- Best alternative 5
- Medium alternative 3
- Worst alternative 1

The evaluation shows that Alternative C with 3.58 points is slightly better than Alternative A with 3.57 points. Alternative B with 2.74 points is the worst alternative, mainly because of the high costs.

8. CONCLUSIONS

As of 2020, the reservoir created by the Gaulwerk weir is almost completely filled with sediments and is classified as a valuable habitat for fauna and flora. Due to the sedimentation, the upstream area is frequently flooded even during minor flood events.

A study of alternatives has been carried out in which three alternatives to improve both the sedi-ment and flood situation are investigated. For all alternatives the environmental impact on the habitat was studied in detail.

In Alternative A, the existing weir will be renovated. In the event of floods, the gates are opened, the reservoir level is lowered and the sediment passes through the reservoir into the tailwater. In Alternative B, the existing weir is abandoned and a new weir upstream of the Knappenwelt Bridge is built. In a flood event, the newly erected inflatable weir is lowered and the sediment is led directly downstream.

In Alternative C, the existing weir will be renovated as in Alternative A. However, the gates are not opened during floods. The sediments entering the reservoir are collected in a sediment trap at the reservoir head and dredged, and removed by truck every year.

From a flooding point of view, the area upstream of the reservoir is roughly equivalent for all alternatives. Alternative B is best, since accompanying levees must be erected. However, in order to protect the area from an HQ100, also in Alternative A and C, accompanying levees would always have to be erected. The simulation results show that the improvement in flood protection for Alterna-tive C for small floods is small but noticeable compared to the actual state.

Downstream of the Gaulwerk weir, Alternative C is advantageous from a flooding perspective, since the sediments do not reach the tailwater but are dredged. The sediment passage in Alternatives A and B leads to morphological changes that could increase the risk of flooding downstream. These effects would have to be studied in more detail.

From an aquatic ecological point of view, Alternative B performs best. Alternatives A and C are roughly equivalent.

The evaluation with a matrix shows that Alternative C with 3.58 points is slightly better than Al-ternative A with 3.57 points. Alternative B with 2.74 points is the worst alternative mainly because of the high costs.

It was decided to further elaborate Alternative C in 2020. However, this alternative leaves the possi-bility to use the refurbished gates for sediment sluicing, that means to switch to Alternative A once sediment connectivity will be mandatory after 2027.