Upgrade of the Perlenbach Dam in Germany – A multi-purpose sustainability project

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ABSTRACT: Perlenbach dam is located within the catchment of the Rur River close to the city of Monschau in West Germany at the border to Belgium. The main purpose of the reservoir is water supply, but it also serves the minimum flow requirements, recreation and hydropower.
During the devasting flood incident in July 2021 in western Germany the reservoir faced inflows exceeding a $HQ_{10.000}$ event. Thanks to the conservative design of the existing spillway major harm did not occur. Contrary to the flood event, the 2018 and 2022 dry periods revealed that the capacity of the reservoir is not sufficient to cover such extreme droughts. The water supply association Perlenbach was forced to purchase water from other suppliers of the region.
The existing scheme is a reservoir volume of only 750.000 m^3 which represents only 1.7 % of the annual mean inflow. The increase of the reservoir volumes shows positive effects not only onto the water supply security but also the energy production and minimum flow periods. Additionally, the reservoir could contribute to flood retention since the Perlenbach comprises about one third of the Rur catchment at its mouth. Particularly in summer the reservoir could contribute essentially to flood control downstream.
The existing dam is an earth-rockfill dam with an asphaltic surface sealing and a height of 18 m. The upgrade requires the heightening of the existing dam by approx. eight meters. All dam facilities need to be adjusted, the spillway has to be completely reconstructed and existing sediments need to be removed from the reservoir.
Upstream of the reservoir valuable fauna flora habitats are located which are affected by the future reservoir. This impact is a critical aspect and compensation is strongly required. An early participation of all stakeholders is anticipated in order to find a realizable solution.

1 INTRODUCTION

Climate change leads to extreme water regimes which include devasting floods and droughts as well. The unequal distribution of water resources leads to challenges in both flood protection measures and water supply assets among other knock-on impacts such as various supply chains, damage of critical infrastructure, endanger of life and property. Social welfare and safety may suffer from serious long-term destabilization with local and global range.

"Climate change is one of the great dangers we face, and it's one we can prevent if we act now." (Stephen Hawkin, 1942 – 2018) This statement of one of the masterminds in physics summarizes precisely the urgency of taking counter measures to diminish the effects of climate change. Up-to-date IPCC (2021) reports document that now is over and CO_2 emissions and subsequent temperature increase are inevitable.

Climate adaptation measures need to be realized in order to guarantee basic services and supply in terms of water, energy, communication, traffic, etc. Drinking water supply is one of the most critical services which are sensed as self-evident in most of the western countries such as Germany. Remarkable droughts during the past years have revealed the vulnerability of the water supply mains. In 2018 Germany suffered from a long drought period which lasted several months.

Also, for the Perlenbach Water Supply Association which is owner of the Perlenbach Dam the year 2018 was critical. During approximately 155 days almost no inflows entered the reservoir. The reservoir could not meet the requirements of the drinking water demand, so drinking water had to be purchased from a nearby water supply association. This experience and pessimistic prognosis triggered the preparation of studies which investigated feasible solutions and adherent measures and costs.

2 THE PERLENBACH DAM REGIME AND WATER SUPPLY REQUIREMENTS

The Perlenbach Dam is located on the Perlenbach river close to the city of Monschau in the western part of Germany very close to the Belgium border. The Perlenbach River flows into the Rur River two kilometer downstream. The Rur River discharges into the reservoir of the Rurtal Dam further downstream.

The Perlenbach Dam's main purpose is drinking water supply for 50,000 people and it is operated by the Water Supply Association Perlenbach. In emergency cases the association withdraws drinking water from adjacent associations of a volume of 0.3 Mio. m³ per year. The storage volume of the current reservoir is 0.76 Mio. m³ whereas the annual average inflow is 45 Mio. m³ from a catchment area of 61 km². The utilization is less than 1.7 % which is the main reason that longer periods without rain or droughts leads to supply lacks.

The daily average supply demand is ranging between 8,190 and 8,800 m³/d and maxima of 10,500 and 12,900 m³/d, respectively. The peak factors result in values from 1.23 to 1.51. The raw water withdrawal from the reservoir is approx. 2.87 to 3.62 Mio. m³ per year. Losses are reaching maximum 11 %.

Accounting for climate change effects, a safety factor of 20 % for the drinking water demand and a safety factor of 1.6 for the daily peak demands shall be considered. These values are recommended by different professional and scientific associations (DVWG et al., 2021). Hence, the future scheme of the Perlenbach reservoir has to guarantee a daily supply of 13,700 m³/d or 3,75 Mio. m³/a drinking water which requires a raw water withdrawal of approximately 4.12 Mio. m³/a in consideration of 10 % process losses.

The dam itself is of embankment/rockfill type with an asphalt surface sealing. According to the national classification scheme of the DIN 19700 it is a class 1 dam; according to ICOLD criteria it is a large dam. The dam was commissioned in 1956. It is a multipurpose dam serving for drinking water supply, hydropower production, and low flow regulation. A hydropower station is placed nearby the downstream dam toe; it hosts a Francis turbine since 1956, and since 2004 an Ossberger turbine. The main characteristics are given in the table below.

Table 1. Main characteristics of the Perlenbach Dam and reservoir.

General data / hydrology	
Catchment area A_{EO}	60.93 km²
Dam structure	
Type	Rockfill dam with asphalt surface sealing
Maximum height H_D	18.30 m (above foundation level)
Dam length L_D	117.00 m
Crest width W_C	4.75 m
Crest elevation	467.00 m asl
Freeboard height f	1.94 m
Reservoir data	
Total reservoir volume V_{tot}	925,000 m³ (= utilized volume)
Degree of utilization α	1.7 %
Minimum reservoir level Z_{min}	452.35 m asl
Operation water level Z_S	464.25 m asl
Flood water level Z_{H1}	465.06 m asl
Flood water level Z_{H2}	465.20 m asl
Hydrological data	
Lowest low discharge NNQ	0.040 m³/s
Average low discharge MNQ	0.129 m³/s
Average discharge MQ	1.5 m³/s
Average flood discharge MHQ	18.39 m³/s
Flood discharge HQ_{10}	21.2 m³/s
Flood discharge HQ_{25}	29.0 m³/s
Flood discharge HQ_{50}	32.2 m³/s
Flood discharge HQ_{100}	36.1 m³/s
Design flood discharge BHQ_1 = $HQ_{1.000}$	40.5 m³/s
Design flood discharge BHQ_2= $HQ_{10.000}$	55.75 m³/s
Maximum recorded flood discharge HHQ	56.00 m³/s (before flood in July 2021)
Operation facilities	
Spillway type	Overflow weir with one flap gate
Spillway length	28.6 m weir and 8.5 m gate
Raw water steel supply pipes diameter	2 x 300 mm
Steel bottom outlet diameter	1 x 800 mm
Concrete penstock pipe diameter	1 x 800 mm
Inflow pipe diameter (Francis turbine)	1 x 800 mm
Inflow pipe diamater (Ossberger turbine)	1 x 1.500/1.600 mm

In July 2021 a major flood incident struck Europe that especially impacted, Western Germany. The catchment of the Perlenbach Dam was affected, which resulted in a peak outflow of the reservoir of approximately 62 m³/s. This discharge represents a recurrence period larger than T = 10,000 a. Although, the flow was extreme the reservoir, dam and also the downstream region downstream to the Rurtal Dam were not severely harmed. The existing spillway shows a relatively long overflow crest and the flap gate was lowered so that the water level in the reservoir could be handled safely.

Due to the small reservoir volume and the relatively large inflow and the relatively high-water level there was no retention effect, such that the inflow equalled the outflow over the spillway.

3 FUTURE WATER DEMAND AND ADDITIONAL RESERVOIR VOLUME

The thread of climate change which is causing long drought periods were documented by the years 2018 and 2020 at the Perlenbach River. During both years the dam owner needed to purchase drinking water from other neighbouring association since the reservoir volume of the dam was not sufficient. A future prognosis scenario needed to be developed in order to define the required additional reservoir volume. For this purpose, the recorded inflow data of the year 2020 was considered and a longer drought period of 5.5 month was considered. A minimum reservoir volume of 400,000 m³ was considered to have the required safety margin and water quality guarantee.

The result is shown in Figure 1. The simple modelling approach results in a required initial reservoir volume of 2.3 Mio. m³ also considering an increased future demand. The prognosis was prepared for the year 2040.

The adjacent water treatment plant refurbishment or replacement was not addressed in the feasibility study.

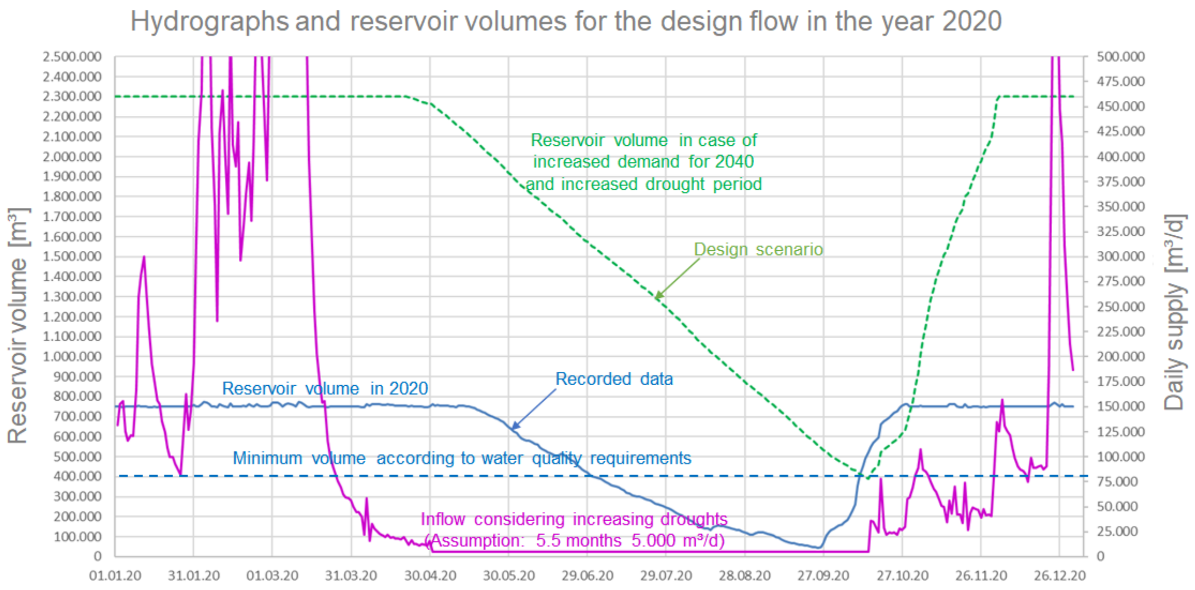

Figure 1. Determination of a required reservoir volume for a selected drought scenario.

4 STRUCTURAL ADAPTATION MEASURES

The need for a larger reservoir volume in order also to cover future drought scenarios results in several adaptation measures of the existing dam scheme which include following:

- Increase of the dam body by approximately 8 to 9 meters
- Strengthening of the downstream dam slope by additional fill
- Adaptation and heightening of the left public road
- Adaptation and rehabilitation of the surface sealing
- Adaptation of the existing hiking tracks along the reservoir
- Adaptation/rehabilitation of the operation facilities such as bottom outlet and other operation outlets for water supply and hydropower
- Adaptation of the dam crest road and right bank bridge
- Renewal of the spillway
- Adaptation and refurbishment of the survey works and measurements

The new reservoir levels are as follows:

- Operation level Z_S: 473,00 m asl
- Flood water level Z_{H2}: 474,00 m asl
- Crest level: 474,75 m asl

The current reservoir shows also a sedimented volume of approximately 100,000 m³ which could be treated hand in hand with the general works. This also counts for future maintenance and renewal works for the bottom outlet inlet structure as well as for other components that need treatment.

Due to continuous sedimentation processes, the placement of an upstream sedimentation dam is discussed in order to keep sediments away from the main storage. With the increasing water level, the reservoir also increases and elongates upstream where single housing and another public road are affected.

In Figure 2 the adaption/heightening measures within the main dam area is illustrated.

Figure 2. Structural adaption measures within the main dam area.

5 ENVIRONMENTAL IMPACT

Since the water level needs to be increased by 8 to 9 meters the reservoir also extends several kilometres upstream. There, environmental protection areas and biotopes are affected. The affected area is considerable and according to European and national environmental laws compensation is required. During the feasibility study initial coordination meetings with the environmental agencies were held which revealed serious concerns as strictly protected biotopes and species could be affected.

Although, a study and evaluation of alternatives was performed within a forerunner study the extent of environmental impact is critical so that again general alternatives such as also abandoning the Perlenbach reservoir and subsequent affiliation of the complete association to an neighbouring association. Before going ahead with the planning and realization of upgrading the Perlenbach Dam the fundamental feasibility of compensation had to be clarified and be evaluated in consideration of basic aims such as guaranteeing the water supply for the future, strengthening the autarchy of the local supplier and utilizing the local water resources.

6 FLOOD PROTECTION AND RETENTION BENEFITS

By increasing the reservoir volume, the retention volume is increased which may create flood detention potential especially when the reservoir level is low due to normal consumption and low inflows during the summer times.

The reservoir characteristic is given in Figure 3. The reservoir volume increase is 1.6 Mio. m³ from 0.75 to 2.35 Mio. m³. The operation water level is increased from $Z_{S,old}$ = 464,286 m asl to $Z_{S,new}$ = 473,00 m asl. The recorded flood hydrograph 2021 was considered for modelling flood hydrographs with different peak flows corresponding to selected recurrence periods (see Figure 4). Since the 2021 event was a supercell storm event, the duration of the hydrograph is limited to 24 hours from mean flow to the peak flow. Recorded winter/spring flood events show longer durations.

The flood routing results for a selected flood event and operation scenario is shown in Figure 5. In this case, a lowering of the reservoir level was considered so that the outflow only reached approximately 2/3 of the peak inflow. The larger the flood volumes and its peaks the smaller the detention effect. This is reflected by the diagram in Figure 6.

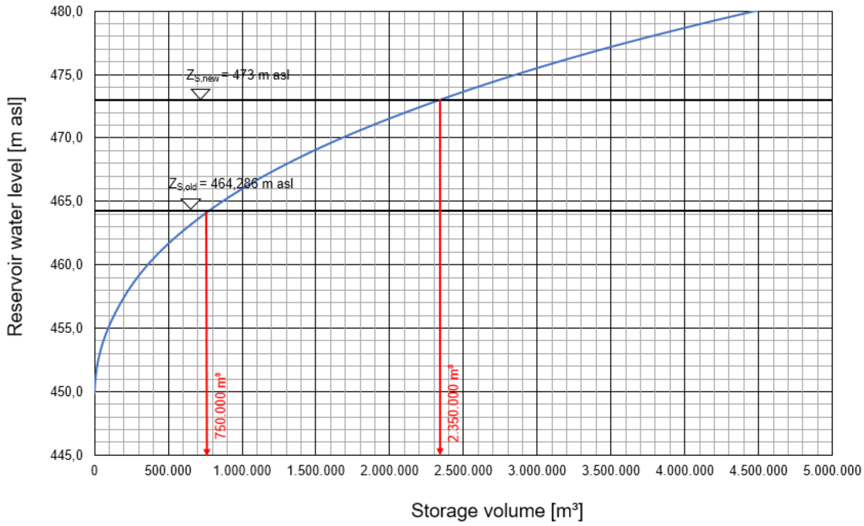

Figure 3. Reservoir characteristic and storage volume before and after heightening.

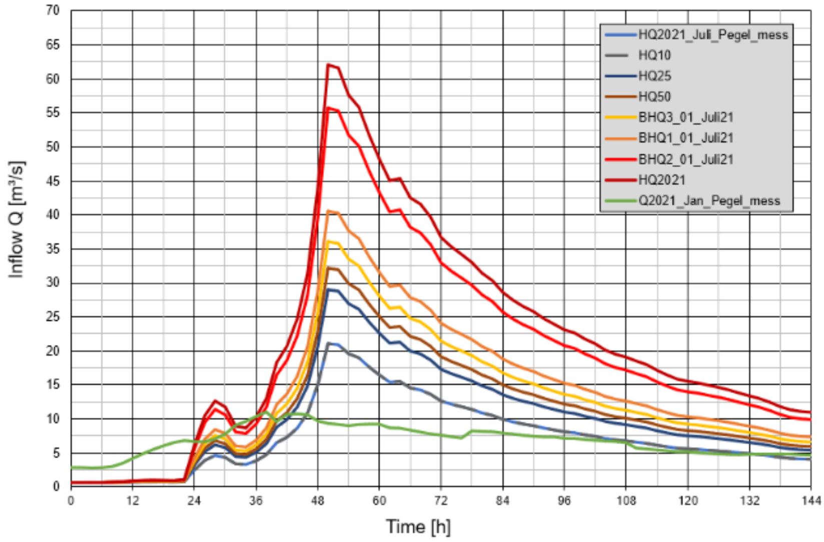

Figure 4: Considered flood hydrographs for flood routing.

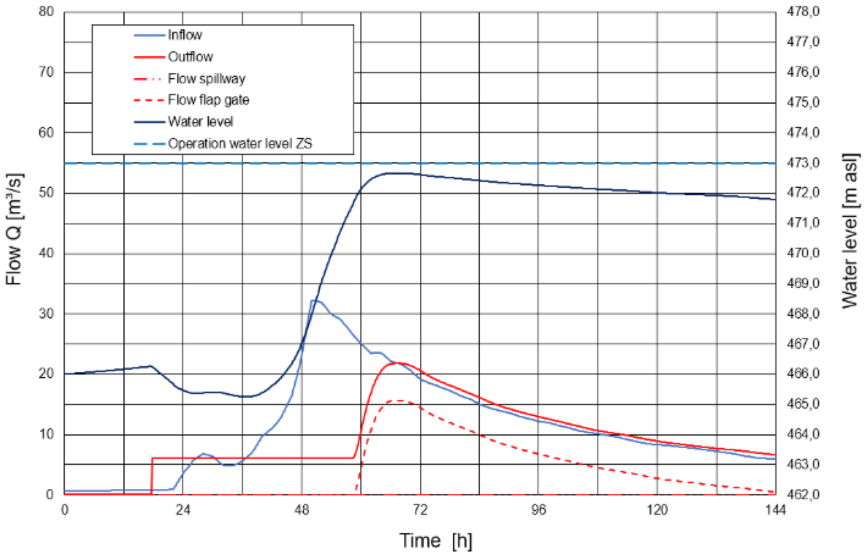

Figure 5: Flood routing results (selected flood scenario)

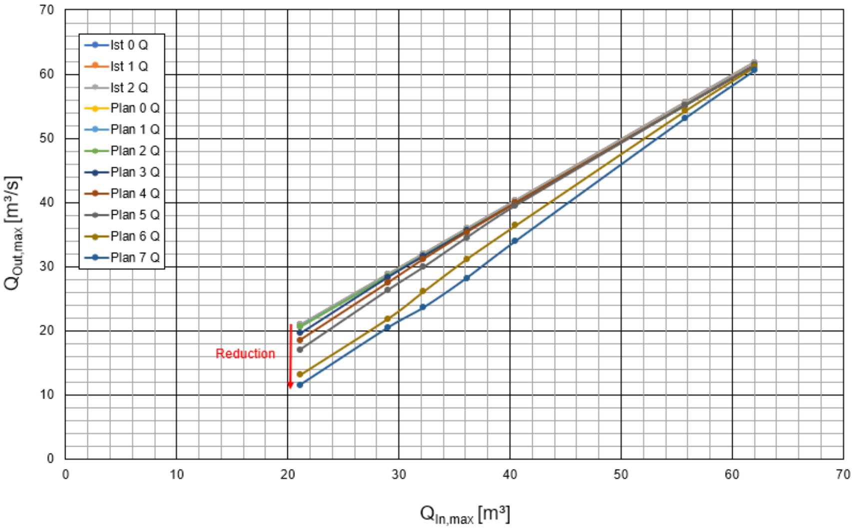

Figure 6. Detention effect by illustration of inflows and outflows of the reservoir.

For floods such as 2021 with a recurrence period T > 10,000 a no detention is achieved but for smaller floods with recurrence periods of T = 10 to 50 the inflow peaks could be decreased by 30 to 50 % if corresponding adaptations are done.

Thus, the increase of the Perlenbach reservoir does not only show a positive effect on the water supply security but also on flood safety for summer times, when also the Rurtal Dam provides only limited flood retention volume due to the reservoir operation scheme there.

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