Technical note about the monitoring of hydromorphological restoration/management of the Salzach River (Salzburg, Upper Austria/Bavaria, Austria/Germany)

List of involved PPs

BAW-IWB

1 General presentation of the study site

The river Salzach leaves the northern Eastern Alps near the town Salzburg and flows along the Austrian and Bavarian border through the Alpine foothills. The river has its source in the Kitzbühler Alpen/Österreich (greywacke zone[1]) at a height of 2300 m ü. A. and flows into the Inn at a height of 344 m ü. NN[2]. The bed level difference is, thus, appr. 1956 m over a length of 225 km.

The mean annual precipitation in Oberndorf/Laufen (Fkm 47,5) is 1124 mm.

The concerned river section – called Untere Salzach – beginns north of the town Salzburg and reaches from the Saalach river mouth (km 59,3) to the mouth of the Salzach into the Inn. This section is subdivided into 2 basins (Freilassing Basin, Tittmoning Basin) and 2 Narrows (Laufen Narrow, Nonnreit Narrow) (see Figure 1). The bed level difference between km 59,3 and km 12,0 is 46,5 m.

Figure 1: Case Study – Untere Salzach (Lower Salzach)

[1] The greywacke zone is a band of Paleozoic metamorphosed sedimentary rocks that forms an east-west band through the Austrian Alps.
[2] m ü.A. = m ü NN + 0,34 m

Figure 2: Case Study – Untere Salzach – in Google Earth


Figure 3: Untere Salzach – a straightened and monotonous river (Stockhammer 2004)

Pilot Site	Untere Salzach
Drainage area at km 0 (km²)	6727,5
Drainage area at Laufen (km 47,5) (km²)	6118,8
Drainage area at Burghausen (km 11,4) (km²)	6655,1
Location	59,3-0
Length of the study reach (km)	59,3
Active channel width (m)	90-100
Channel slope (m/m)	0,001
Planform morphology	straightened river
	alternate bars

* At the monitoring reach

Table 1. Main physical features of the pilot site

2 Hydromorphological restoration/management

2.1 Human-induced alterations of the channel morphology and the consequences

In 1817 the river Salzach was a braided river taking almost the whole valley area (Figure 4).

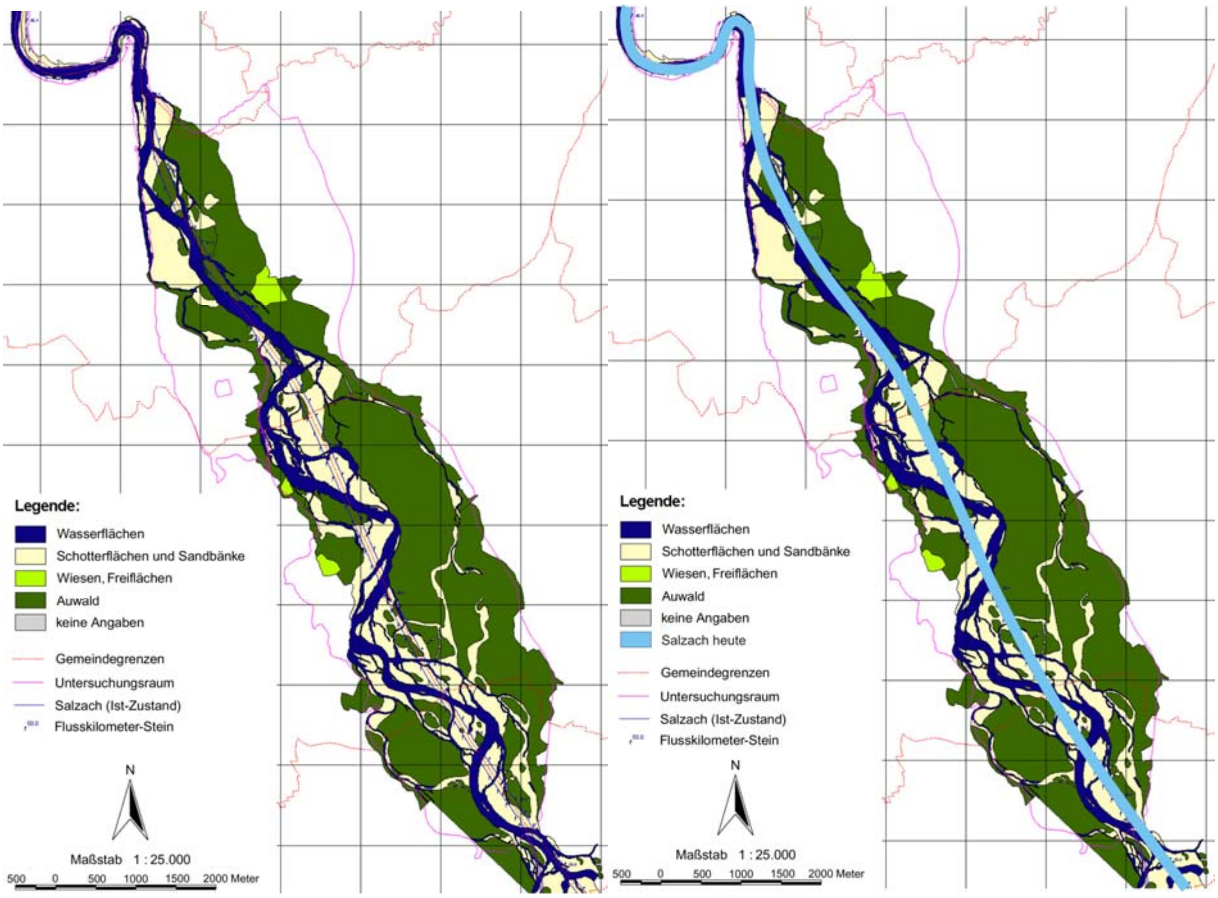

Figure 4: Salzach (Freilassinger Basin) in 1817 (left) and today (right)

Currently the river shows a heavy degradation process which has evolved from various human activities in the past:

- In the nineteenth century, training measures in the basins forced the formerly braided river into a straight bed 100 m wide. These measures were introduced to initiate the degradation process in order to gain new agricultural areas and to reduce the annual floods. Since that time, the river Salzach has been in a state of degradation and the amount of degradation already exceeds 4 m near the upper border of the study reach.
- Bed load is entrapped in the higher regions of the catchment or upstream of hydroelectric power stations such as Salzach/Sohlstufe Lehen, Salzach/Urstein or Saalach/Rott-Freilassing with too little bed load transport capacity.
- Gravel was dredged from the river bed for various purposes.

These activities resulted in heavily modified and impaired bed load transport. As a typical consequence the river system adjusts in a long-term geomorphological manner to these human influences. Bed erosion of the river has progressed to such an extent that bank structures as well as bridge piers have become endangered. The groundwater table has decreased remarkably. The river wetlands have been cut off from the river itself, which is closely connected to a loss of habitats and of population diversity in the wetland ecosystems. In addition, the flood run-off occurs chiefly on the main channel. Thus, wetlands are flooded less and tributaries are detached from the main river. Loss of retention areas deteriorates the downstream flood protection as well as the wetland ecosystems.

Even more unfavourable, if not dangerous, is a phenomenon called "Sohldurchschlag" or sudden river-bed break-through, which could be observed at the Salzach, e.g. Hengl, 2000, WRS, 2000. The term describes a change in the erosion process due to the presence of fine sand, silt or clay layers below the gravel bed of a river (see Figure 5). If the mean river bed intersects the gravel bed because of the progressive erosion process and reaches these fine sediment layers below the gravel bed, the geomorphological consequences can no longer be predicted.

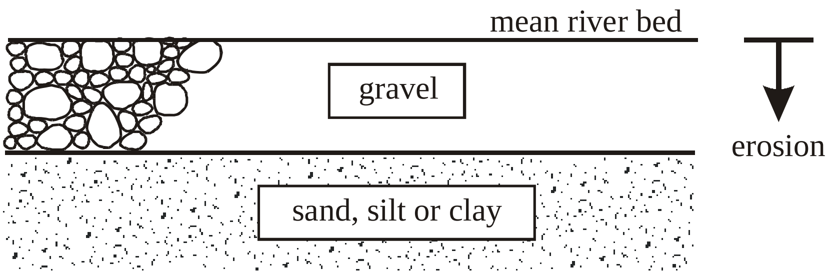

Figure 5: Fine sediment layers (sand, silt or clay) below the gravel bed of a river

The erosion process is increased tremendously because of the greatly increased erosion potential of these fine materials. The extent of damage from the above mentioned effects, i.e. endangering of buildings near the river bank and in the river, decreasing groundwater table, destruction of bank protection works, among others, is intensified.


Figure 6: River-bed break-through at the Salzach (Amt der Salzburger Landesregierung 1969)

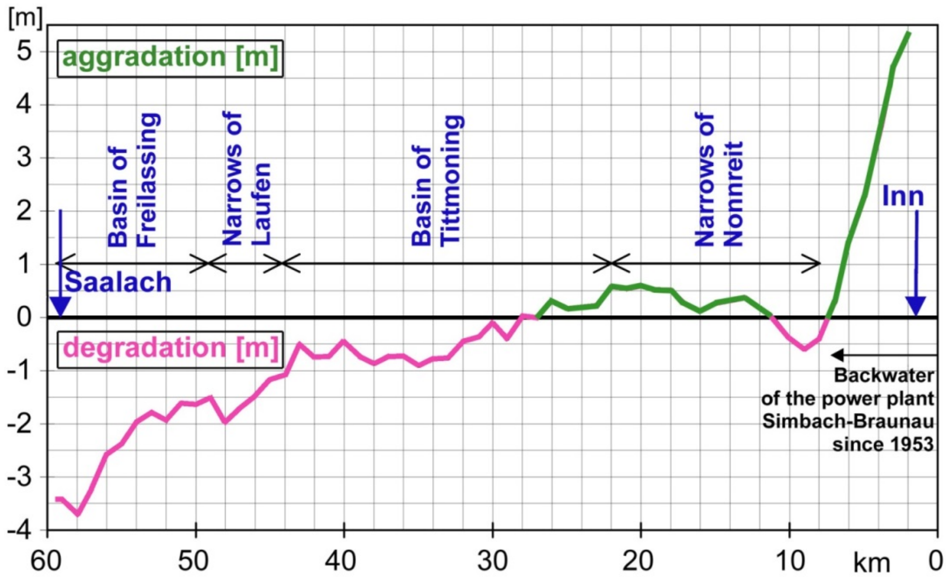

Figure 7: Difference of the low water levels 1996-1905

Figure 8: Inlet structure of the water treatment plant Siggerwiesen (km 58,4) Nov. 1986 (Q = 90 m³/s) (1); August 2004 (Q = 200 m³/s) (2); May 2017 (Q = 288 m³/s) (3)

2.2 Investigations

To stop the erosion process and to raise the mean level of the river bed, extensive bilateral and interdisciplinary investigations were conducted:

- WRS – Wasserwirtschaftliche Rahmenuntersuchung Salzach (1990-2000), interdisciplinary study (river and floodplains, ecology)
  WRS included:

- 2 physical model tests with different solutions to stop the erosion process and to raise the mean level of the river bed. The main features of theses tests were widening of the river bed in the basins (140 - 200 m) and fixing the bed levels by either with riprap sections or ramps. Additionally, the currently straight morphology should be converted into a meandering one due to a self-acting bank erosion process.
- Numerical bed load transport modelling with 2 different 1D-models.
- Numerical ground water simultions
- 2D-modelling of flood run off for all solutions

• GUS – Gesamtuntersuchung Salzach (1991-1997) including a floodplain-concept

• RAS – Risikoanalyse Salzach (2003-2004), risk, costs and consequences of the bed erosion without any restructuring of the river

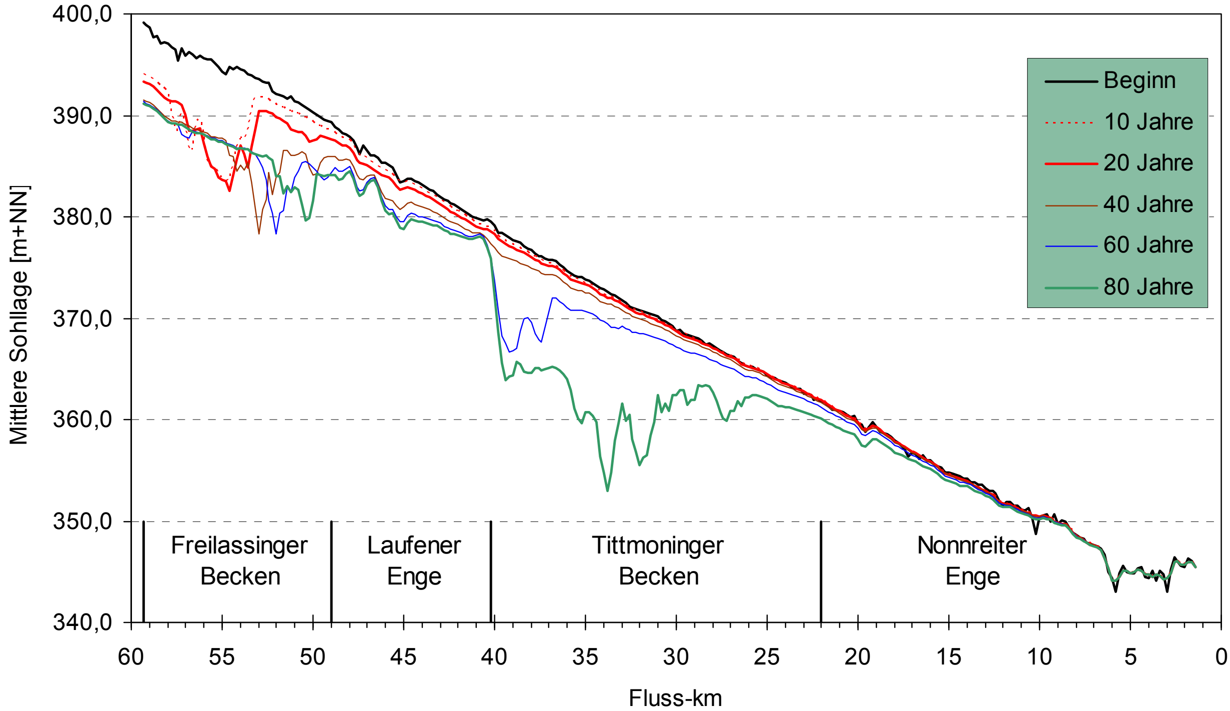

Figure 9: Forecast of bed level changes within 80 years beginning with 2004 (1D-Modelling of bed load transport)

• 3 additional physical model tests were conducted refining the concepts of bed fixations (see WRS) by developing a step-pool-ramp including a boat lane and an improved version of rip-rap.

2.3 Restoration/management actions

• 2008-2009 construction of a rip rap-section/revetment (km 46,2) for stabilising the river bed in the Laufener Narrow
Design: The riprap is a stone cover of coarse stones on the river bed with a low cover density leaving a considerable area of the original river bed uncovered by stones. These large stones of the bed cover increase the flow resistance and, thus, reduce both the near-bed flow velocity as well as the erosion of the subjacent bed material.


Figure 10: Construction of the rip rap by an evenly spaced stone cover

Figure 11: Construction of the rip rap during winter time (low flow period)

Figure 12: Stone cover of the river bed/rip rap as a bed protection against erosion

- 2009-2010 construction of the step-pool-ramp (km 51,9) including an improved connectivity of river and floodplains

Design: The step-pool-ramp was situated 13° swivelled against the axis of the river to initiate bank erosion by directing the flow towards the river bank. In addition, the bank protection downstream of the ramp was removed to enable bank erosion. These so-called "soft" river banks serve as sediment deposits to meet the bed load transport capacity of the river, since the step-pool-ramp currently operates as a sediment trap for the upstream arriving bed load material. In addition, the conductivity of main river and tributary streams was improved.

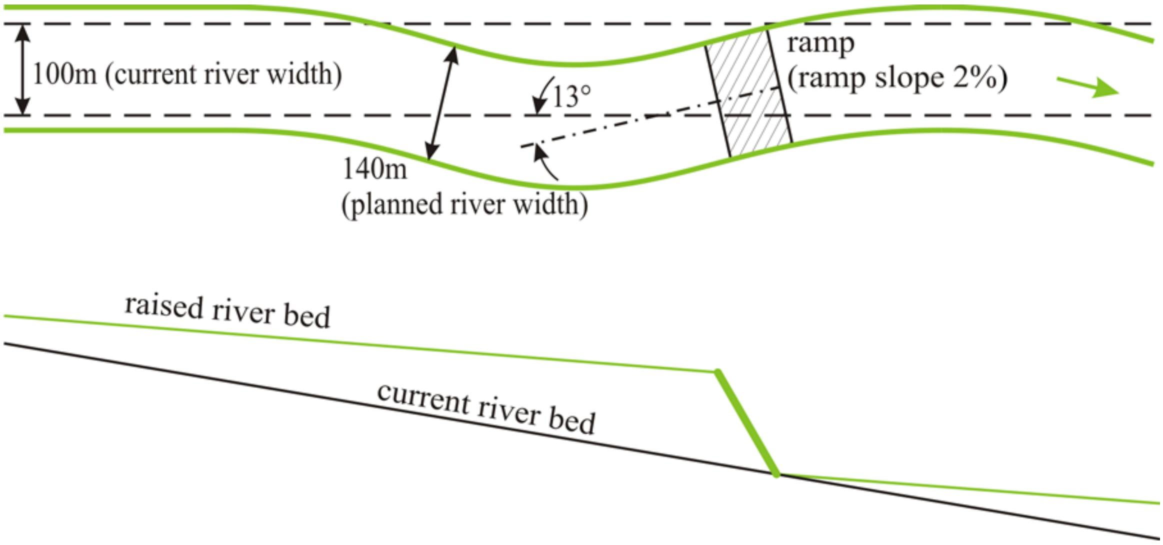

Figure 13: Schematic plan and side view of the step-pool-ramp

Figure 14: Construction of the step-pool-ramp km 51,9 (Amt der Salzburger Landesregierung 2009)

Figure 15: Step-pool-ramp with a boat lane (Amt der Oberösterreichischen Landesregierung 2011)

Figure 16: Salzach km 51,9, upstream view, bank erosion and old bank protection

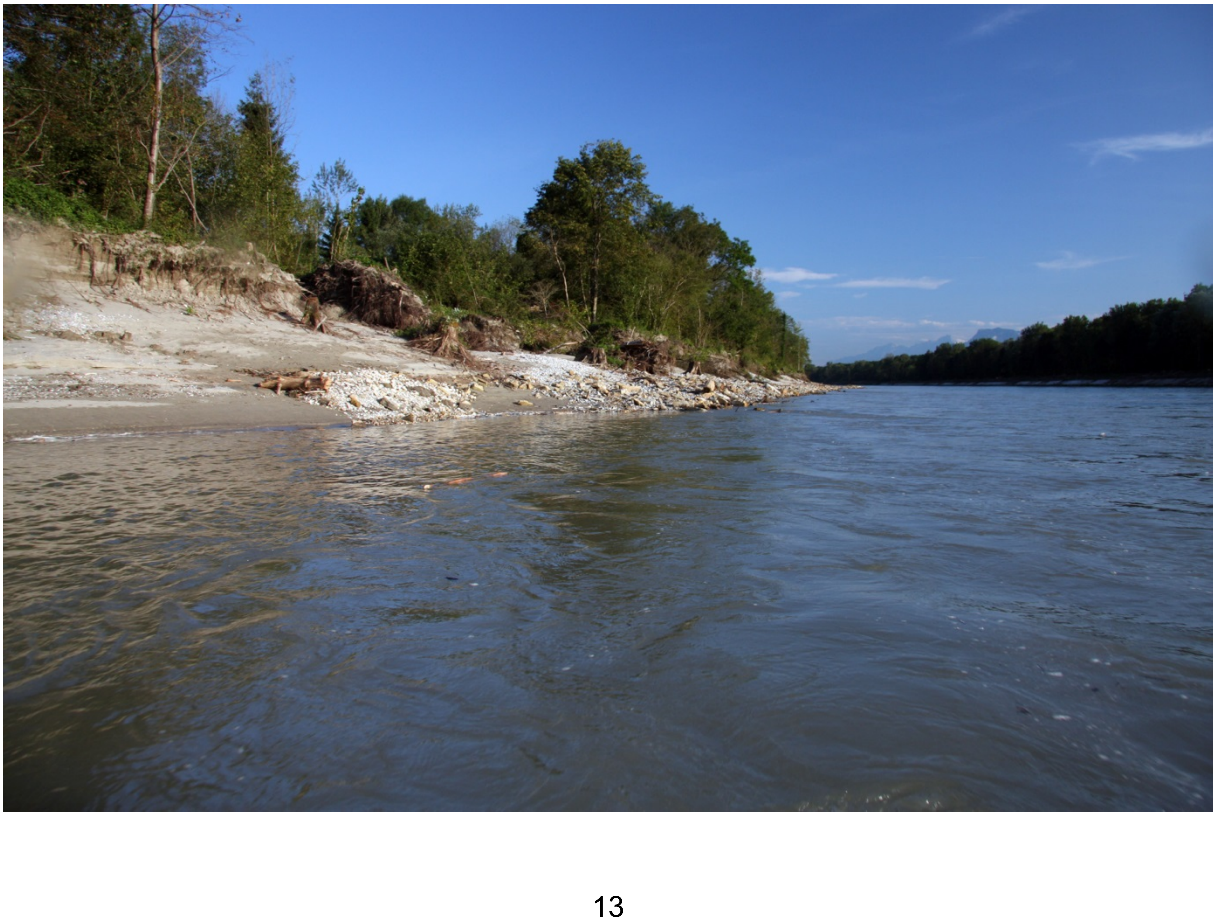

Figure 17: "soft" river banks, Austrian side of the Salzach (Amt der Salzburger Landesregierung 2012)

3 Monitoring activities

3.1 General objectives of the monitoring program

The general purpuse for all monitoring activities was to get a reliable and underlying data base for all further investigations and restoration activities mainly concerning bed level measurements, discharge measurements, measurements of the bed material in the river and in the flood plains.

3.2 Physical monitoring

Discharge measurements:

River	Gauge	Time	Comment
Salzach	Salzburg	1951-1995	Outage between 7.9.1959 and 29.2.1960
Salzach	Laufen	1951-1955 u. 1957-1995	
Salzach	Burghausen	1951-1995	
Saalach	Staufeneck	1951-31.10.1959	
Saalach	Siezenheim	1.11.1959-1995	

Water level fixations:

River	Date	km	Discharge [m³/s]	Gauge	Comment	Datenquelle WSP-Fixierung
Salzach	1.8.1977	59,3 – 1,4	2287 2341	Laufen Burghausen	high flow	WWA Traunstein
Salzach	31.1.1978	59,3 – 1,4	55 – 90	Laufen	low flow	WWA Traunstein
Salzach	31.1.1990	59,3 – 6,6	91 – 74	Laufen	low flow	WWA Traunstein
Salzach	3.8.1991	59,3 – 6,6	2172 2250	Laufen Burghausen	high flow	WWA Traunstein
Salzach	16.2.1994	59,3 –12,0	88 – 114	Laufen	low flow	WWA Traunstein
Salzach	5.5.1994	49,0 – 47,0	683	Laufen	in the curve	WWA Traunstein
Salzach	26.6.1995	59,3 – 3,2	2123 2150	Laufen Burghausen	high flow	WWA Traunstein
Salzach	12.2.1996	59,3 – 6,0	73 – 113	Burghausen	low water	WWA Traunstein
Salzach	13.2.1996	59,3 – 6,0	71 – 140	Burghausen	low flow	WWA Traunstein
Salzach	29.2.1996	74,8 – 59,4			low flow	Amt der Salzburger LR
Salzach	22.4.1996	74,8 – 59,2			low flow	Amt der Salzburger LR
Salzach	21.5.1996	59,3 – 6,6	310 – 370		low flow	WWA Traunstein
Salzach	6.7.1997	59,3 – 21,4	1900	Tittmoning	high flow	WWA Traunstein
Salzach	2.2.1998	59,3 – 21,4	97	Laufen	low flow	WWA Traunstein
Saalach	26.6.1995	2,2-0,2	841	Siezenheim	high flow	WWA Traunstein

Bed level measurements:
Bed level measurements were conducted since 1977 every 3-4 years and additionally after floods.

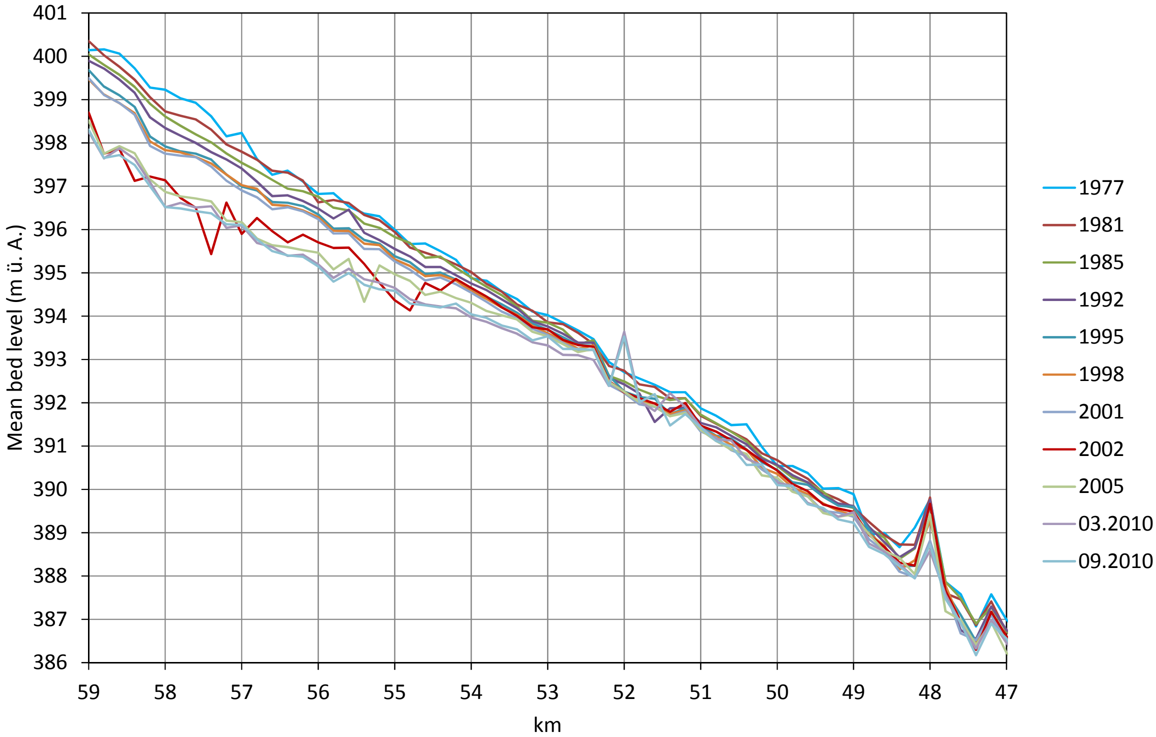

Figure 18: Example of bed level measurements: Mean bed levels within km 59 and 47 (Basin of Freilassing) between 1977 and 2010 (Note the bed level measurement of 2002, where a river bed breakthrough could be observed between km 59 and 55)

Measurements of the grain size distribution of the bed load and bed material:

Year	km	Number	Kind of measurement	Country
1895	59,3 - 0,0	3	Gravel bars – mixed surface and sub surface measurement	Austria
1931	84,7 - 5,8	14	Gravel bars – (Method not known)	Austria
1952	8,55 - 5,8	9	Gravel bars	Bavaria
1961	82,85 - 46,6	16	Gravel bars – surface / sub surface layer	Austria
1962	40,4 - 39,25	8	Gravel bars - surface / sub surface layer	Austria
1963	71,2 - 39,1	31	Gravel bars - surface / sub surface layer	Austria
1966	57,4 - 7,5	48	Gravel bars - surface / sub surface layer	Bavaria
1976	59,3 - 7,5	88	Gravel bars - surface / sub surface layer	Bavaria
1991	59,3 - 9,8	122	Gravel bars - surface / sub surface layer	Bavaria
1991	59,3 - 39,2	35	Well	Bavaria
1992	47,8 - 13,0	76	Gravel bars - surface / sub surface layer	Bavaria
1992	119,95 - 85,4; 38,1	34	Gravel bars - surface / sub surface layer	Austria
1992	38,8 - 15,0	47	Well	Bavaria
1992/93	47,5	several	Bed load measurement	Bavaria
1993	57-39,2; 13,6-11,2	21	Well	Austria
1996	69,2 - 60,15	22	Gravel bars - surface / sub surface layer	Bavaria
1996	60,15; 59,27; 54,0	several	Movies of the surface layer in the river	Bavaria

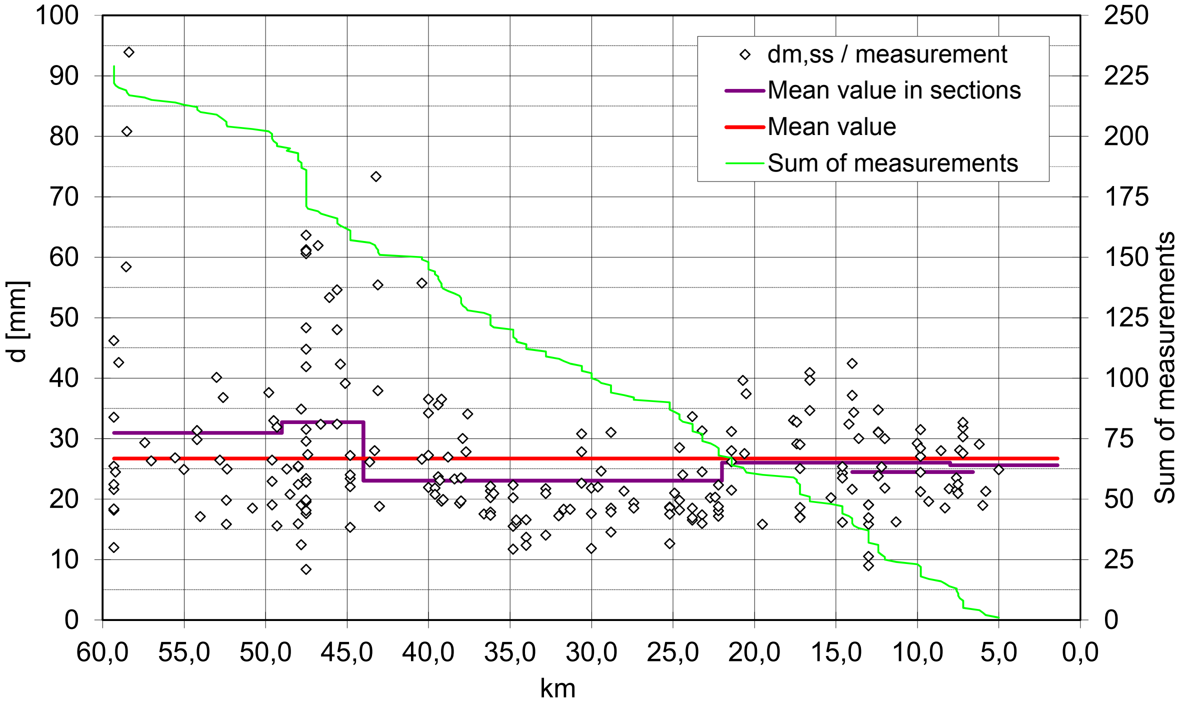

Figure 19: Mean grain size of the sub surface (ss) layer (229 measurements)

Measurements of bed load transport rates:

Date	Q [m³/s]	bed load transport rate [kg/s]	σ [kg/s]	d_m [mm] Transport gemittelt
25.05.1992	420,0	13,81	2,13	30
14.07.1992	260,0	3,81	0,92	27
15.07.1992	264,0	0,59	0,34	fehlt
24.03.1993	360,0	1,14	0,25	37,2
22.07.1993	506,0	15,93	4,22	30

Geological longitudinal profile:

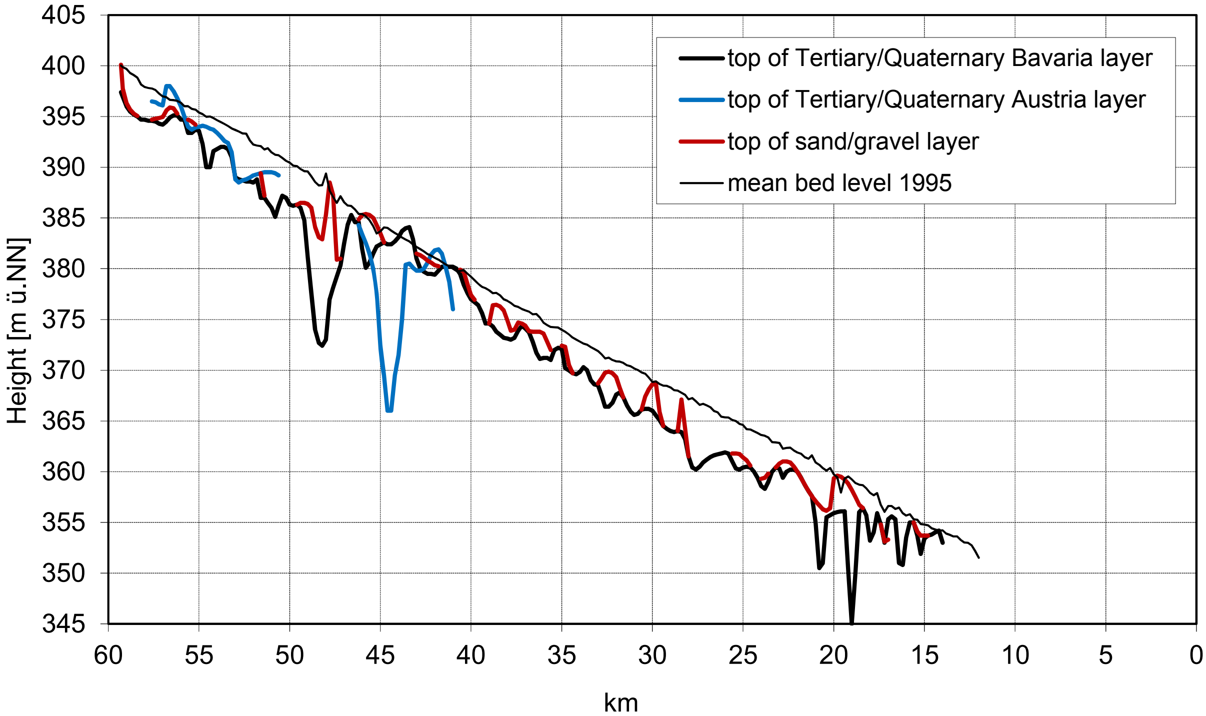

Figure 20: Geological longitudinal profile (simplified) (Tertiary/Quaternary layer means a layer of fine sediment with a low resistance against erosion)

Annual bed load removal at the head of the hydro power plant reservoir Simbach/Braunau (downstream end of study reach):

Jahr	Kiesentnahme [m³]	Jahr	Kiesentnahme [m³]	Jahr	Kiesentnahme [m³]
1955	106 000	1969	141 500	1983	43 660
1956	145 500	1970	135 700	1984	76 200
1957	162 700	1971	155 900	1985	68 280
1958	157 800	1972	152 600	1986	90 350
1959	268 900	1973	120 000	1987	144 210
1960	93 600	1974	37 100	1988	106 150
1961	113 600	1975	88 800	1989	57 270
1962	134 500	1976	148 600	1990	118 150
1963	110 700	1977	147 900	1991	54 500
1964	117 200	1978	98 470	1992	105 200
1965	124 000	1979	47 890	1993	107 560
1966	123 200	1980	83 680	1994	89 770
1967	134 200	1981	130 000	1995	27 480
1968	146 100	1982	91 970		

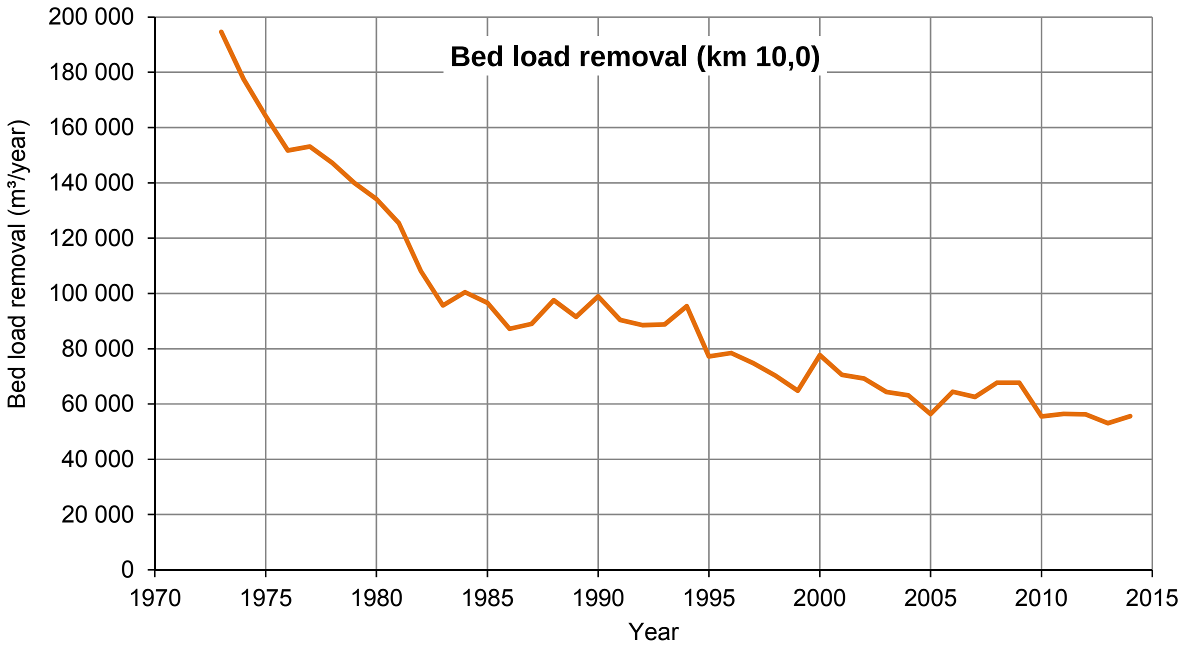

Figure 21: Bed load removal between 1969 and 2014 (moving average over 5 years)

Monitoring activities close to the restoration project "step-pool-ramp"
Bed level measurements every 200 m using a terrestrial surveying method have been done since 1977. These measurements are within the responsibility of Salzburg's Provincial government and the Water Resources Board Traunstein. In 2005 the method changed and an echo sounding system was used additionally. 2015, again a new method was introduced - airborne laser scanning (laser bathymetry). Since this method is not suitable for high water levels (especially in deep scour holes) in case of moderate to high turbidity the airborne laser scanning was to be combined with a subsequent echo sounding of gaps in airborne data. Unfortunately, the echo sounding was done appr. 6 months after the airborne laser scanning, i.e. after a flood, so that the bed levels changed in the meantime. Thus, the airborne data are not complete and reveal considerable gaps. However, the measurements downstream the step-pool-ramp (main restoration measure) do not reveal any gaps. But so far, due to the imperfection of the measurements these

data were purchased neither by the Salzburg's Provincial government nor the Water Resources Board Traunstein and, therefore, are not yet available for further investigations.

Nevertheless, airborne laser scanning (laser bathymetry) are planned for the whole Salzach reach from km 60 to km 12 (14 km²) for 2018. Results might be available in 2019.

spatial resolution	0,40 m or less
point density	> 6,25 points/m²
spatial accuracy	≤ 0,10 m in vertical direction, ≤ 0,20 m in horizontal direction

Thus, bed level measurements (long profile, cross sections, active channel width) are currently available every 200 m for the unrestored reach as well as the restored reach. High-resolution DEM for the restored reach will probably be available for 2015 and 2018.

3.3 Ecological monitoring

Currently the Lower Salzach misses the target of reaching a good ecological status. Both assessment methods, Fisch Index Austria (FIA in Austria) and the fish-based assessment procedure (fiBS in Germany) show a "moderate" ecological status. According to the FIA the status is even "bad" since the amount of fish biomass is appr. 13-18 kg/ha and, thus, less than 25 kg/ha. The following major deficits can be identified:

- bad structure of the population of both, dominant and companion potamal fish species
- population of hocho (*Hucho hucho*) not detectable
- fish biomass less than 50 kg/ha (FIA)

These biological deficits evolved from human pressures as mentioned in chapter 2.1 destroying structure and conductivity of the river in the past.

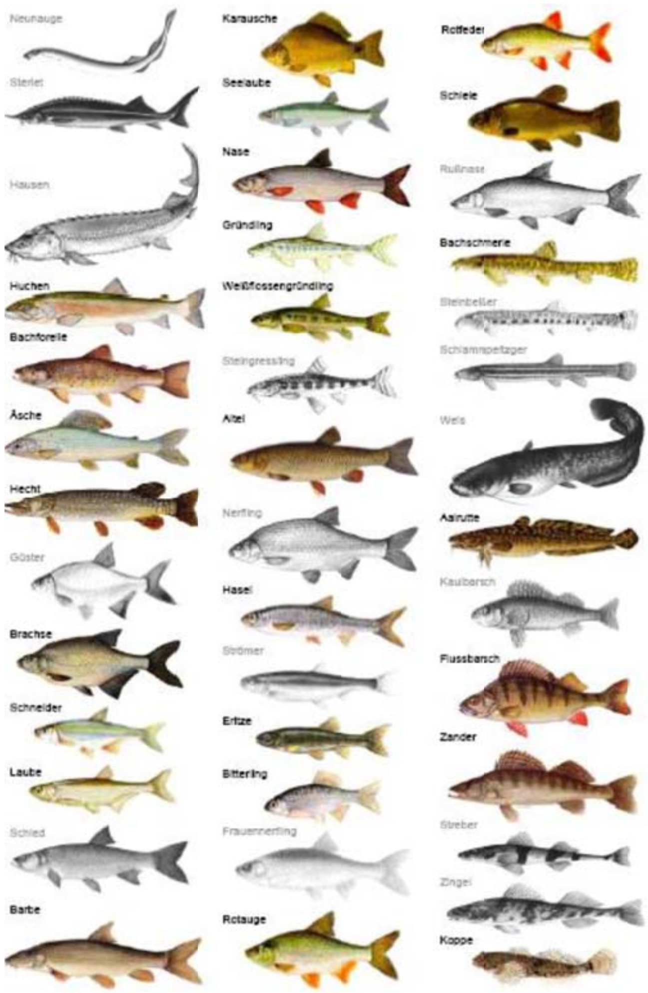

Figure 22: Current (coloured) and missing (grey) fish species at the Lower Salzach (Zauner et al., 1994)

4 References

Hengl, M. (2000). An Ecological and Hydraulic Redevelopment – Case Study Untere Salzach. Kongress Wasser Berlin 2000. 23.-27.10.2000. Berlin.

WRS (2000). Wasserwirtschaftliche Rahmenuntersuchung Salzach. Untersuchungen zur Flussmorphologie der Unteren Salzach. Bayerisches Landesamt für Wasserwirtschaft. München

Zauner, G., Jungwirth, M., Eberstaller, J. et al. (1994): Gesamtuntersuchung Salzach (GUS). Teiluntersuchung 1.4.2 Fischökologische Untersuchung. Schlussbericht. Österreichisches Institut für Raumplanung i. A. d. Salzburger Landesregierung, BMFL. 137 pp.