PLANNING AND CONSTRUCTION OF COMPENSATIVE REPRODUCTION CHANNELS FOR SALMONID FISH

JUKKA JORMOLA, SAIJA KOLJONEN & JARI KOSKIAHO
Freshwater Centre, Finnish Environment Institute (SYKE), PO.Box 140
00251 HELSINKI, FINLAND

SIMO TAMMELA
WSP Finland, Kiviharjunlenkki 1D
90220 OULU, FINLAND

MARKUS TAPANINEN
Southeast Finland ELY Centre, PO Box 1041
45101 KOUVOLA, FINLAND

Construction of new artificial reproduction habitats is needed to compensate the adverse impacts of hydro power and loss of original sites for spawning and rearing. In Imatra, Finland, a 1 km long reproduction channel was constructed in 2014, to create a habitat mainly for brown trout (*Salmo trutta* L.). In the planning and construction the gradients and details of the channel were defined, aiming for the maximum habitat area and quality within the site which was available. Also values for landscape and tourism were considered. 2D flow and habitat modeling was used during the planning. After construction, measurements were done to evaluate the hydraulic circumstances of the channel. The results were compared with the plan and the preference conditions for brown trout which were used in the modeling. The measurements showed that even if the plan was not implemented exactly, the overall hydraulic features correspond to the preferences of the target species. The first monitoring showed colonization of fish and invertebrates, but further monitoring is needed about trout reproduction. The channel will serve as an example for similar projects, to revive fish stocks in constructed rivers and increase the knowledge of planning and construction in the area of eco-hydraulics, landscape design and restoration ecology of compensative habitats.

1 INTRODUCTION

In the Water Framework Directive of the European Union there are demands of measures for the hydro morphology of heavily modified water bodies to gain the maximum ecological potential. This stage is reached once all mitigation measures have been taken to ensure the best approximation to ecological continuum, in particular with respect to migration of fauna and appropriate spawning and breeding grounds [1]. It means that fish passes and possibility for migration alone are not sufficient but also measures to mitigate habitats for reproduction must be accomplished. The demand to mitigate and compensate the loss of habitats corresponds to the environmental legislation of several countries in Europe and also in USA and Canada.

1.1 Compensation in Germany

In the new regulations to implement the Nature conservation act in Germany, measures to compensate the connectivity and functions of habitats and restore streaming waters to support the life cycles of animals are emphasized [2]. An example of compensation measures, largest of its kind in Europe, is the bypass channel of the Rheinfelden power plant at the Rhine. To compensate for the decline of stream water habitats through raising the dam level and lowering the tailrace water level, a 1 km long and 50 meters wide bypass channel was constructed in 2012 at the place of the old power plant channel at the German side of the river. Discharge is 10 $m^3 s^{-1}$ and 25 $m^3 s^{-1}$ can be obtained for flushing. The velocities are 0.75-1.45 $m s^{-1}$. The channel begins with a gentle slope and the gradient in the middle section is 0.8 %. The entrance flow to the river is made with steps and pools with gradient of 3%. The entrance of the channel is 800 m downstream from the dam, and to ensure fish find the bypass, an additional cascade type step and pool fish pass with discharge 0.6 m^3/s was constructed as a diversion from the bypass channel towards the dam [3]. A vertical slot fish way was constructed at the power house at the Swiss side. The bypass channel is designed with two parallel sections, one having step-pool character with depth 0.8 m and the other half more as riffles covered with cobbles of 80-200 mm diameter, suitable for spawning of barbel *(Barbus barbus)* and the endangered nase (*Chondrostoma nasus)* [4]. The results of the first fish monitoring have been unexpectedly high. Up to 34 500 fish individuals of 33 species were found in 2012 in the counter of the bypass channel, whereas in the vertical slot fish way at the power plant there were 4 800 individuals of 22 species [5]. The amount of individuals and species in the bypass channel, even if the entrance was not supposed to be in an ideal place, is many fold to the numbers in all other fish passes of the area. It seems that the big discharge serves for good attraction.

1.2 Spawning and rearing channels in Canada

In Canada there is a long history of constructing spawning channels. To compensate for the decline of Pacific salmon species by hydro power and log floating, constructing of spawning channels begun in the 1950's. The first aim was to increase the incubating rate of the eggs of red salmon *(Oncorhynchus nerka)* and pink salmon *(O. gorbuscha)* [6]. In a typical spawning channel, Weaver Greek, with length 2.8 km and width 6 m, the discharge of the channel is 0.43 m^3 s^{-1}, depth 0.24 m and overall gradient 0.065% [7]. In the 2000's some of the old spawning channels have been modified and complexed to serve as rearing habitats for juveniles of coho salmon *(O. kisutch),* chinook salmon *(O. tsawytscha)* and steelhead *(O. mykiss)* [8].

The construction of rearing channels has now begun also in the eastern region of Canada for Atlantic salmon. During the construction of the Granite Canal hydro power plant in Newfoundland, opened in 2003, a reproduction channel with length of 2 km and width 15 m was constructed. The aim was to compensate for the loss of 45 000 m^2 of spawning and rearing habitat of landlocked Atlantic salmon (Ouananiche) (*Salmo salar*) and brook trout (*Salvenilus fontinalis*) by creating similar habitat near to the project site [9]. The minimum discharge is 1.25 to 2.5 m^3 $s^{-1}$and the maximum 5.5 m^3 s^{-1}. The height difference is 1.5 m and average gradient 0.075 %. Three types of habitats, pools, runs and riffles were planned in sequences of 20, 20 and 45 meters. The preferred velocities were designed to be for fry 0.15-0.70 m $s^{-1}$and for parr 0-0.95 m s^{-1}. According to remote sensor rates in 2007 the mean velocities were 0.149-0.363 m s^{-1} and depths 0.15-0.38 m s^{-1}. Salmon adopted the spawning sites and more than 1000 redds were counted in 2007. In electrofishing juvenile densities of 45-155 individuals/100 m^2 were calculated, which exceeds the densities in natural streams.

1.3 Research in Sweden

At the Eldforsen hydroelectric station a bypass channel, so called biocanal, was constructed in 2009, to compensate for the loss of habitats. The channel is 500 m long and with the height 5 m the average gradient is 1 %. The channel contains pools, floodplains with winding channel, braided habitats and riffles. The development of benthic fauna was monitored in the new channel and was compared with other streams in 2010 and 2011. 37 benthic organism families were found in the biocanal and 55 in other streams [10]. The research showed that during two years the diversity and functional organization of the benthic fauna in the biocanal were approaching that of the reference streams.

1.4 Nature-like bypass channels in Finland

In Finland nature-like bypass channels have been constructed since 1987 and they are the most common type of fish passes in southern Finland. Steep fish passes have normally a step-pool character, but many of them resemble natural brooks. Some bypass channels have been specially constructed as gentle sloped with habitats for spawning and juveniles. In the Sääkskoski bypass channel at the Kaitfors powerplant, salmon *(Salmo salar)* juveniles have been detected in electro fishing. Bypass channels with habitats have been proposed also to several heavily modified big rivers, aiming for compensation of habitats and to help establishing natural reproduction instead of stockings [11, 12].

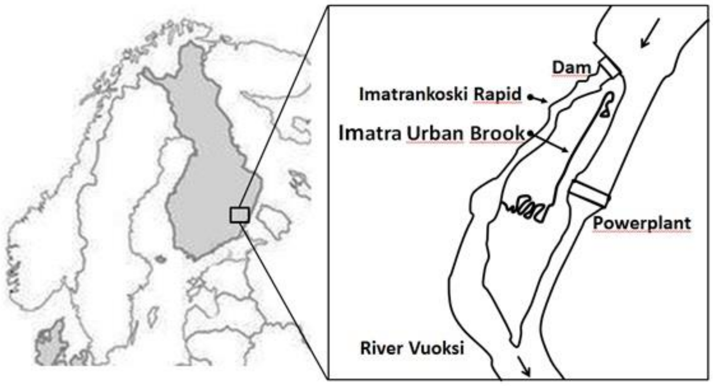

Figure 1. Imatra Urban Brook between Imatrankoski rapid and the power plant

2 MATERIALS AND METHODS

2.1 Evaluation of the Imatra Urban Brook

The Imatra Urban Brook is a new constructed bypass channel for the Imatrankoski rapid, which once drained waters from the biggest lake system in Finland, Saimaa, through river Vuoksi to Lake Ladoga in Russia (Figure 1). The rapid dried out after constructing a dam and a power plant between 1929 and 1951. The area is still important for tourism because of occasional release of water for rapid shows in summer. The urban brook is situated in an island between the rapid and the channel of the power plant.

In the planning of the Imatra urban brook the task was to construct a habitat for local brown trout living in the river Vuoksi. Also creating new values for landscape and tourism was a goal (Figure 2). The planning was accomplished by a consortium of MA-arkkitehdit, Finnish Environment Institute SYKE and Ecoriver Oy. Fish issues during the planning were evaluated by Kala- ja vesitutkimus Oy and the modeling was done by Simo Tammela at Ponvia Oy. The aim of this study is to compare the constructed brook with the plan and to find out in which extent the intended hydraulic properties could be achieved. The comparison is needed to make guidelines for the planning of further similar projects. First results of colonization of invertebrates and fish could be gained. The monitoring will continue to evaluate the performance of the channel for juvenile habitat and overall trout production.

2.2 Planning of the channel

The length of the channel is 1 km and elevation about 25 m, which gives the average gradient 2.5 %. Water is lead to the channel through two pipes with length about 50 m, as the channel was not supposed to be a fish pass. However, fish migration through the pipes may be possible at least downstream, perhaps also upstream. The planned discharges were 0.3 $m^3 s^{-1}$ in summertime and 0.18 $m^3 s^{-1}$ in wintertime after trout spawning. About 0.03 $m^3 s^{-1}$ of the amount is lead to a seepage water brook, where a population of trout has been living.

The pipes lead the water into two ponds, which are prominent in the street scenery and important for the touristic surroundings (Figure 2). After a turn to the south the brook is lead rather straight along the site of a former log floating chute. The brook flows in a resemblance of the chute over the steep valley of the seepage water brook. The downstream part where more space was available is designed as a curving habitat section, to increase the length of the channel and to decrease the gradient to be more suitable for habitats (Figure 3). After a natural wetland the channel flows through a steep section to the river Vuoksi. In the plan for the habitat section the gradients were defined to be small, 0.025 and 0.5 % in the upstream part, suitable as rearing habitat for small juveniles. Pools over 1 m deep were planned to be the wintering habitats. Spawning gravel was planned into the places where the velocity begins to increase at the end of the ponds, pressing water flow inside the gravel. The channel in the plan had steeper sections before flowing to the existing wetland and further to the river. Tree trunks were planned to be installed as woody debris. Cross sections, containing bottom materials and layers to prevent leakage of water to the permeable soil were part of the planning scheme.

Figure 2. The upper section is planned to be a touristic attraction

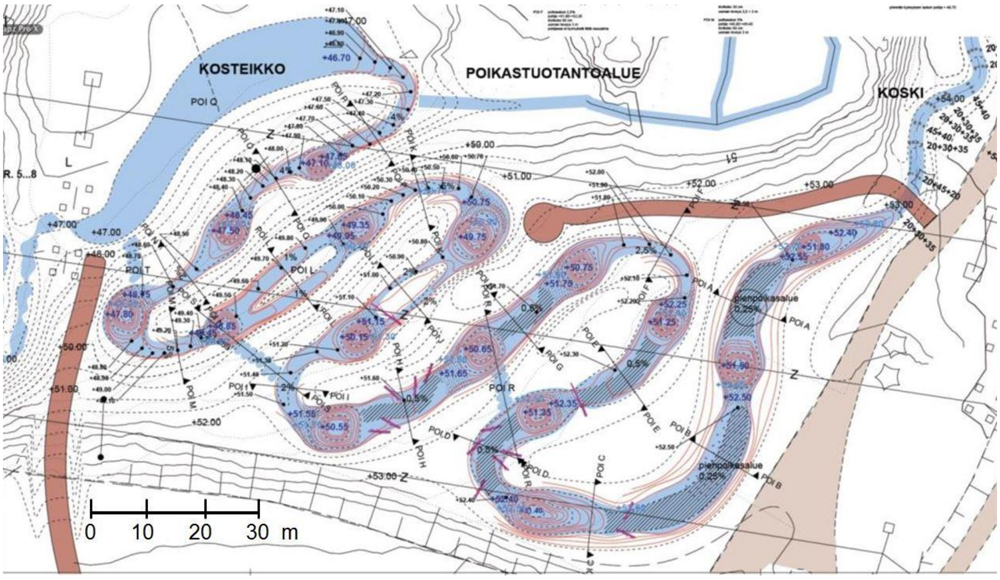

Figure 3. Plan of the habitat section with contours, elevation points and gradients

2.3 Flow and habitat modeling

Habitat modeling was done for the habitat section of the plan by a 2D flow model program FESWMS FST 2DH, with discharges 300 l s^{-1} and 150 l s^{-1}. The flow model showed velocities 0.2 to 0.4 m s^{-1} for the juvenile habitats with low gradient and velocities up to 1 m s^{-1} for the steeper sections (Figure 4). The depths were mostly between 0.2 - 0.4 m, except for the deeper pools. With smaller discharge the depths for spawning habitats were mostly under 0.2 m and at the rearing habitats under 0.3 m. In the habitat model the bottom substrate size was determined according to the plan. Habitat preference data for brown trout spawning and juvenile nursery habitats in natural rivers were used in the model [13, 14, 15]. With the three parameters; velocity, depth and grain size the habitat model showed best quality of habitat especially for small juveniles under 10 cm. The depths of the channel tended to be too low for bigger juveniles, to be ideal.

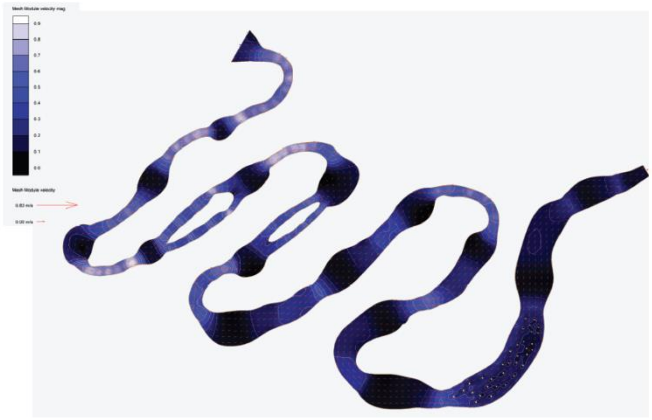

Figure 4. The flow model with discharge 150 l s^{-1}.showed velocities up to 1 m s^{-1} (light areas)

2.4 Construction and first monitoring

The channel was constructed during 2014. The construction was led by the city of Imatra and accomplished by a nationwide operating construction company VRJ Group. The finalizing was guided by the Southwest Finland ELY center which has a good experience in river restoration. As measurement showed that the habitat section was made too deep, a part of the pools were filled with fine material and then finalized by stone material and tree trunks and stumps (see Fig. 5 and 6.). Spawning gravel was added by voluntary work by hand. In January 2015, during a sudden cold period, slush ice was noticed in the channel. The water begun to rise over the banks at the bends of the habitat section. In some places stones and trunks were removed from the center or the channel to improve the flow and decrease the water level.

The channel was scanned above water in June 2015 with a terrestrial laser scanning, TLS. (Figure 5) By the elevation of the water levels from the scanning the gradients of the channel were determined. Velocities and water depths were measured in several cross sections of the whole length of the channel by flow meters OTT C31 and Schiltknecht MiniAir.

In June and September 2015 altogether 83 brown trout, length mostly 10 to 20 cm, were released to the channel. The trout were caught from the neighboring brook and they represent genetically the original stock of river Vuoksi. Six of them were tagged by marks which are easy to see in the back of the fish if noticed in the brook. Electrofishing samples were performed in August 2015. Additionally, visual remarks by local people about fish in the brook were collected. An initial monitoring of benthic invertebrates was made in August 2015 by kick-netting to evaluate colonized invertebrates in four spots with four samples each.

Figure 5. Scanning of the accomplished habitat section shows details like stones, tree trunks and stumps

3 RESULTS

3.1 Channel and gradients

The scanning of the habitat section showed the morphology and details (individual stones, tree trunks and stumps) of the brook (Figure 5). The water elevation of the pools could be determined and the gradients between pools were then calculated. The average gradient of the 400 m long habitat section, between the pool near to the power plant and the natural wetland is 1.4 %. At the upper part two sections between pools had planned gradients of 0.25 % but in the real situation gradients of 0.9 %, 2.4 % and 0.5 % were calculated. Thus the 70 m long upper section is steeper than planned. The next section of 20 m, which was planned to be 0.5%, is now 1 %. The first steep bend is 2.5%, same as planned. The next straight section is 0.6 %, which is near to the planned gradient of 0.5 %. Further downstream to the wetland there are long sections of pools and steep rapids with gradient 6 % between them. The lowest section from the wetland to the river is very steep. There are section with gradients of 16 % and 12%, with some small resting pools.

3.2 Velocities and depths

Velocity and depth were measured mainly for three channel types: 1) Spawning gravel areas, 2) Gentle sloped sections, where the model showed rather low depths for bigger juveniles, 3) Steep sections to evaluate maximum velocities for migration. Velocities were measured with discharge 220 l s^{-1} and 110 l s^{-1} in May and 200 l s^{-1} in September 2015. The upmost gravel area, above the section of 0.9 % gradient, had depth 0.15 m and velocities 0.45 to 0.65 m s^{-1} with 220 l s^{-1}. At a discharge of 110 l s^{-1} it had depth 10 cm and velocities 0.05-0.55 m s^{-1}. The gravel area above the section of 2.5 % gradient, had depth 25 cm and velocities 0.55 to 0.75 m s^{-1}. At a discharge of 110 l s^{-1} it had depth 20 cm and velocities 0.15-0.70 m s^{-1}. The depths and velocities were near to the ones in the modeling and probably sufficient for spawning.

The gentle sloped rearing habitats were measured in September with 200 l s^{-1}. The upper section with gradient 0.5% had depth 0.40 m and showed velocities 0.20 to 0.60 m s^{-1} in the bottom and 0.25 to 0.50 m s^{-1} in the surface. The section with gradient 1% had depth 0.30 m and velocities 0.10 to 0.30 in the bottom and 0.30 to 0.85 in the surface. The section with gradient 0.5 % had depth 0.35 m and velocities 0.10 to 0.25 m s^{-1} in the bottom and 0.5 to 0.28 m s^{-1} in the surface. The depths for rearing habitats were bigger than in the model, even if the discharge was smaller than the planned summer discharge. The sections should be good for all juveniles.

Velocities at the bend with 2.5 % gradient at the habitat section showed velocities from 0.70 to as much as 1.90 m s^{-1}. This is much more than in the model. One reason might be that the middle of channel was left rather free from stones to prevent slush. The steep section downstream, with gradient 16 %, had velocities 0.90 to 1.95 m s^{-1}. Despite the steepness, in this case the slots between the stones were rather small and roughness big, keeping the velocities under 2 m s^{-1}.

Velocities were measured in the pipes leading water to the brook. The maximum velocity in the center of the pipe to the upper pond was 0.95 m s_{-1}. The lower pipe, which is smaller and has more elevation and pressure, showed 1.45 m s_{-1} velocity. This indicates that the larger pipe with lower velocity might be possible for some fish to migrate up, as the velocity is on the limit of endurance swim speed of several species.

Figure 6. The same site of the habitat section as indicated in Figure 5, with gradient 0.5%

3.3 Fish

The first evidence of fish in the Imatra Urban Brook was the migration of roach *(Rutilus rutilus*) in May. Fish were seen to swim upwards at the habitat section, showing that they had been able to migrate up the steep sections. The roaches gathered in big amounts to the upmost ponds and near to the pipes. After the stocking of the trout in June, one trout with the tag was seen regularly with the roaches at the entrances of the upper pipe in the pond where it had been released. Some trout have been seen 100 m downstream of the pond. A whitefish *(Coregonus lavaretus)* was seen in the upper pond, probably descended through the pipe. In the electrofishing in August juveniles of roach and bleak *(Albumus albumus)* were caught in the habitat section. Instead of roach, adult bleaks were seen in the upper ponds in big quantities. A trout was seen again in the pond, this time among bleaks. One perch *(Perca fluvitatilis)* was caught in the habitat section and also a pike *(Esox Lucius)* was seen.

3.4 Invertebrates

The invertebrate monitoring gave samples of altogether for 18 families. In the upstream site nine different families were caught, in the rather steep middle section five families and in the habitat section and steep downstream section seven families in both. Most amounts of individuals were in the upstream section with high velocity, dominated by nonbiting midge *(Chironomidae),* blackfly *(Simulidae)* and caddisfly (*Polycentropodidae).* The middle section had same families as the upper section, but also one individual of another family of caddisflies *(Hydroptilidae).* In the habitat section, where velocities were smaller, three other families of net-spinning caddisfly *(Arctopsychidae),* stonefly (*Nemouridae)* and one family of mayfly *(Leptophlebiidae)* were caught. At the steep downstream section a northern species of caddisflies *(Arctopsyche ladogensis)* and samples of *Limoniidae* were caught. The result show dominance of small fast spreading species in the upper section with stony ground and fast velocity and species of more stable circumstances in the habitat and downstream sections. The samples can be divided in functional groups (Table 1).

Table 1. Functional groups of invertebrates in the samples

	Individuals	No. of families
Gatherer/collector	278	7
Filter/collector	146	3
Shredder	21	4
Predator	16	2
Scraper	7	2

4 DISCUSSION

In the planning phase the results of the modeling gave a doubt that conditions in the habitat section would be too shallow for big juveniles. This might be due to the used preferences which are normally for larger streams. However, the situation in the accomplished channel showed deeper conditions than in the model which is probably due to more heterogeneity in the cross sections than anticipated. In practice big stones and woody debris create roughness and a damming effect so that velocities increase between obstacles. This could be seen in the diversified velocities of the cross sections. The gradients in the constructed channel differ from the plan but this does not seem to weaken the habitats, rather they are better than the modeling of the plan shows.

Slush could be dangerous for the overwintering of juveniles. To promote the formation of ice, which protects the water from cooling under zero degrees centigrade, needs further monitoring. Spring spawning fish found the brook, but a question remains to which extent they move from downstream or descend through the pipes and if the pipes can be used for upstream migration. In order to promote colonization it is useful to transfer more individuals to the brook but at the same time it would be good to study natural migration of brown trout from the river to the constructed environment for example with telemetry. The benthic invertebrate monitoring showed a dominance of small fast colonizing species especially in the upper section with stony ground and fast velocity. Species of more stable velocity patterns were found from the lower sections of the brook. The invertebrates show a dominance of gatherers, even if the channel is new and only some debris was available. Until now, vegetation was scarce in the channel and its banks. Introducing macrophytes and herbage and trees on the banks to maximize the shedding would be good to promote natural ecosystem functions.

5 CONCLUSIONS

The construction of the Imatra Urban Brook showed the need for accuracy in implementation, to ensure habitat constructions according to plans. In this case a good result was based on skilful finalizing, but in further projects additional construction work should be avoided. 2D modeling was useful for overall evaluation of the plan, but measurements of hydraulics proved to be essential to verify the conditions in practice. Exact comparison of the planned and accomplished situation would need scanning of the channel bottom and a new 2D or even 3D modeling. To increase diversity like number of invertebrate species, much can be left for natural processes, but ways of guiding the development by introducing aquatic vegetation and suitable debris should be investigated. To ensure the performance of habitats for target fish species, adequate monitoring should be continued, taking also in account the interaction between other species and food chains. The initial stage of monitoring gave confidence that viable ecosystems can be created by planning and constructing compensative habitats.

ACKNOWLEDGMENTS

The laser scanning was conducted by Matti Vaaja, Matti Kurkela and Johanna Jalonen from Aalto University the scanned information was prepared to maps by Mikko Sane from Finnish Environment Institute (SYKE).
The invertebrate samples were analyzed by Merle Pöntynen and composition commented by Kristian Meissner from the Finnish Environment Institute (SYKE).

REFERENCES

[1] The European Parliament and the Council of the European Union. *"DIRECTIVE 2000/60/EC … establishing a framework for Community action in the field of water policy"* (2000)

[2] Bundesrat. "Verordnung über die Kompensation von Eingriffen in Natur und Landschaft (Bundeskompensationsverordnung - BKompV)" *Drucksache.* 332/13. (2013). https://www.bfn.de/fileadmin/MDB/images/BR-Drs_332-13.pdf

[3] Gebler R-J & Lehmann P.. "Naturnahes Fließgewässer am neuen Kraftwerk Rheinfelden". *WasserWirtschaft.* 6 (2013) (pp.48-53*).* www.ib-gebler.de/WasserWirtschaft.pdf

[4] Ulrich J. "Ökologische Maßnahmen im Umfeld des neuen Wasserkraftwerks Rheinfelden". *WasserWirtschaft.* 6 (2013) (pp. 43-47)

[5] Ulrich J. "Zwishenergebnis der Fischzählung am neuen Wasserkraftwerk Rheinfelden". *WasserWirtschaft 6* (2013) (pp. 54-57)

[6] Roos J.F. *"Restoring Fraser river salmon. A History of the International Pacific Salmon Comission 1937-1985".* The Pacific Salmon Commission, Vancouver, Canada (1991).

[7] Leung Y.-W.. Spawning channels in Pacific Canada. *1994 River Front – Fish habitat and stream improvment forum.* Tokyo, Niigata, Japan (1994)

[8] Adolph B. "*Lower Seton spawning channel complexing project 2003"*. Cayoose Creek Fisheries. (2003).

[9] McCarthy J.H. & Sellars B. "Can Engineering Drawings Create Fish Habitat?". *Waterpower XVI*. PennWell Corporation. (2009)

[10] Gustafsson S.. *" The Macroinvertebrate Community in a Naturelike Fishway with Habitat Compensation Properties"*. Licentiate thesis. Karlstad University Studies 2012:48. (2012*)*

[11] Järvenpää L., Jormola J. & Tammela S.*"Planning of nature-like bypass channels in a constructed river"* (In Finnish). Suomen ympäristö 5 (2010). *https://helda.helsinki.fi/handle/10138/37987*

[12] Koljonen S., Jormola J. & Koskiaho J. *Bypass channels can serve as compensative reproduction habitat for salmonids".* Proceedings of the International Conference on Ecohydraulics 2016, Melbourne. (2016)

[13] Mäki-Petäys A., Huusko A., Erkinaro J. & Muotka T. (2002) "Transferability of habitat preference criteria of juvenile Atlantic salmon (Salmo salar)". *Canadian Journal of Fisheries and Aquatic Sciences.* 59 (2002). pp. 218-228.

[14] Mäki-Petäys A., Erkinaro J., Niemelä E., Huusko A. & Muotka T. " Spatial distribution of juvenile Atlantic salmon (Salmo salar) in a sub-arctic river: size-specific changes in a strongly seasonal environment". *Canadian Journal of Fisheries and Aquatic Sciences*. 61 (2004). pp.2329-2338.

[15] Huusko A.,Kreivi P., Mäki-Petäys A., Nykänen M., Vehanen T. " *Environmental requirements of streamwater fish – Basic data for habitat modeling"* (In Finnish). Kala- ja riistaraportteja 284. RKTL (2003) *www.rktl.fi/www/uploads/pdf/raportti284.pdf*