Report of the Workshop on
Fish Passage in Southeast Asia

Principles of improved fish passage at cross-river obstacles, with relevance to Southeast Asia

(Full Report with PowerPoint Presentation)

17-20 March 2013, Khon Kaen Province, Thailand

The Workshop was organized by
the Food and Agriculture Organization of the United Nations (FAO)
and the Southeast Asian Fisheries Development Center (SEAFDEC)

in collaboration with
the Mekong River Commission (MRC)
and the Australian Centre for Agricultural Research (ACIAR)

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SEAFDEC

MEKONG RIVER COMMISSION MRC FOR SUSTAINABLE DEVELOPMENT

Australian Government

Australian Centre for International Agricultural Research

REPORT OF

THE WORKSHOP ON FISH PASSAGE IN SOUTHEAST ASIA: PRINCIPLES OF IMPROVED FISH PASSAGE AT CROSS-RIVER OBSTACLES, WITH RELEVANCE TO SOUTHEAST ASIA

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EXECUTIVE SUMMARY

The Workshop on "Fish Passage in Southeast Asia: Principles of Improved Fish Passage at Cross-river Obstacles, with Relevance to Southeast Asia" was organized by the Food and Agriculture Organization of the United Nations (FAO) and the Southeast Asian Fisheries Development Center (SEAFDEC), in collaboration with the Mekong River Commission (MRC) and the Australian Centre for Agricultural Research (ACIAR), and held on 17-20 March 2013 in Khon Kaen, Thailand.

The Workshop was participated in by a total of 49 participants, which include representatives from the Southeast Asian countries, namely Cambodia (4), Indonesia (3), Lao PDR (8), Malaysia (2), Myanmar (2), Philippines (3), Thailand (9) and Vietnam (4); the SEAFDEC Secretary-General and officers of the SEAFDEC Secretariat and Training Department; the representatives from the Food and Agriculture Organization of the United Nations (FAO) and the Mekong River Commission (MRC); as well as *Mr.– Ing. Rolf-Jürgen Gebler* and *Mr. Andreas Zitek* as resource persons of the Workshop.

During the Workshop, participants noted the importance of inland fisheries, and the characteristics of inland fisheries where several fish species require migration and movement in order to satisfy their life cycle requirements. At the same time, there are also wide range of stakeholders involved in the utilization of inland water resources, resulting in impacts across the sectors, including those from cross-river obstacles on the inter-connectivity of habitats and biodiversity of aquatic species. From the countries' presentations, however, only few countries in the region had incorporated fish passage(s) in the construction of cross-river obstacles, and most of the existing fish passages did not demonstrate to have very good performance.

During the Workshop, considerations were raised on specific requirements of different species and stages of fish that should be taken into consideration in designing, construction and operation of fish passage. On the several types and designs of fish passage that could have advantages and disadvantages over different circumstances, it was noted that particular attention should be given on position of the entrance; while the design of fishway needs to also take into consideration both biological and hydrological aspects in order to provide free passage of fish up- and down-stream. In addition, the specificity of habitats and typical cross-river obstacles in the region, having big differences between upstream and downstream water levels, as well as between rainy and dry seasons, should be carefully considered in designing of fish passage.

The important recommendations from the workshop included the necessity to collect/compile biological information of important fish species as a basis for designing of fish passage, and that the construction of fish passages should be incorporated into the dam project at the initial phase of its planning and construction. Methodologies to evaluate the benefits from fish passage are therefore necessary, while relevant information, *e.g.* on potential impacts from cross-river obstacles, and mitigation of impacts through fish passages, should be packaged and publicized to raise awareness on this issues. In addition, it was also emphasized that there are very large number of low-head weirs, which created impacts particularly to upstream-downstream migration of fish; appropriate solution(s) should be explored to address and mitigate impacts from this common construction.

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REPORT OF THE WORKSHOP ON FISH PASSAGE IN SOUTHEAST ASIA: PRINCIPLES OF IMPROVED FISH PASSAGE AT CROSS-RIVER OBSTACLES, WITH RELEVANCE TO SOUTHEAST ASIA

17-20 March 2013, Khon Kaen, Thailand

1. The Workshop on "Fish Passage in Southeast Asia: Principles of Improved Fish Passage at Cross-river Obstacles, with Relevance to Southeast Asia" was organized by the Food and Agriculture Organization of the United Nations (FAO) and the Southeast Asian Fisheries Development Center (SEAFDEC), in collaboration with the Mekong River Commission (MRC) and the Australian Centre for Agricultural Research (ACIAR), and held on 17-20 March 2013 in Khon Kaen, Thailand. The Workshop Programme appears as **Annex 1.**

2. The Workshop was participated in by representatives from agencies responsible for fisheries and construction/operation of cross-river obstacles from eight SEAFDEC countries, namely Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand and Vietnam. Present were also the SEAFDEC Secretary-General and officers of the SEAFDEC Secretariat and Training Department, the representatives from the Food and Agriculture Organization of the United Nations (FAO) and the Mekong River Commission (MRC) as well as *Mr. Rolf-Jürgen Gebler* and *Mr. Andreas Zitek* as resource persons of the Workshop. The List of Participants appears as **Annex 2**.

I. OPENING OF THE WORKSHOP

3. *Mr. Chumnarn Pongsri*, Secretary-General of SEAFDEC, welcomed the participants to the Workshop. He outlined the importance of inland fisheries to people in Southeast Asia and highlighted the characteristics of inland fisheries in the region that involve large numbers of small-scale fishers, are multi-species based, and have high seasonal variation. He also emphasized that there is a wide range of stakeholders involved in the utilization of the inland water resources which results in impacts across the sectors, including those from cross-river obstacles on the inter-connectivity of habitats and the biodiversity of the fishery resources. He therefore expressed his wish that this Workshop would contribute to a better understanding of the status of, and issues relevant to, fish passage in the region, and pave the way for the improvement of fish passage for the sustainability of inland fisheries in the future. His remarks appear as **Annex 3**.

4. *Mr. Gerd Marmulla*, FAO, welcomed the participants to the Workshop. He expressed appreciation to SEAFDEC for the hosting arrangements for the Workshop, and to countries and partner organizations for participating in this Workshop. He pointed out that there exist several important inland aquatic species in the region that depend on migrations and movements to satisfy their life cycle requirements and ensure their survival in the ecosystems. It was noted that the construction of cross-river barriers might have negative impacts on fish migration and thus on biodiversity and resilience of fish populations, and ultimately impact the fisheries. Although there are initiatives to rehabilitate the resources, *e.g.* through releasing of fish in the natural ecosystems, this could not replace natural reproduction in the long-term. The protection and conservation of the natural aquatic environment is therefore necessary and this had been recognized by several international instruments. This Workshop, therefore, aimed at raising general awareness on the usefulness, but also on the limitations, of fish passage facilities, and at sharing the experience of the resource persons with the SEAFDEC countries in order to come up in future with a better design for fish passage facilities in the region. He then declared the Workshop opened. His remarks appear as **Annex 4**.

II. IMPORTANCE OF FISH PASSAGE

5. *Mr. Marmulla* made a presentation on "Importance of Conservation and Rehabilitation of Fish Passage" (**Annex 5**). He outlined a number of efforts undertaken by FAO in enhancing/improving food security and livelihoods, the inland aquatic environment, fisheries and aquaculture. It was noted that countries in the Southeast Asian region contribute a very high percentage to the total global inland fish production. While inland fisheries are recognized to be a very important source of animal protein for the

region, this inland fisheries production can be regarded as still highly underestimated. It was also recognized that several sectors (*e.g.* agriculture, hydropower, navigation, water supply and distribution) are involved in the utilization of the inland aquatic resources which has negative impacts on running waters, aquatic animal/plant resources and fisheries. Particularly, the construction of cross-river obstacles is of high relevance, creating both direct and indirect impacts on habitats and fisheries.

6. The Workshop noted that several international instruments had recognized the necessity for protection and conservation of the aquatic environment and its biodiversity. In particular, the FAO Code of Conduct for Responsible Fisheries and the related Technical Guidelines also recognized the need for healthy ecosystems and biodiversity, and especially the need for the conservation of aquatic ecosystems, as well as the protection and restoration of fish movements across the obstacles constituting barriers to migration. One of the ways to mitigate impacts from such cross-river obstacles to fisheries and biodiversity could be the construction of fish passage facilities for upstream and downstream passage, which comprises several types and designs. Several factors, however, should be taken into consideration to ensure the effectiveness of fish passage, while monitoring and evaluating the effectiveness of fish passage should also be undertaken at least during 1-2 years after the construction.

7. In concluding his presentation, *Mr. Marmulla* drew attention to the efforts of FAO in promoting the concept of sustainability in the utilization of resources, not only through mere fisheries management, but also through ecosystem management. Furthermore the application of a basin approach and stakeholder consultation/involvement were presented as a key factor for long term success and sustainability. The mitigation of impacts caused by cross-river obstacles, *e.g.* to allow fish again to migrate upstream and downstream, was also advocated as an important means to improve fish stocks and biodiversity. However, the development of suitable technologies to facilitate such migrations of different fish species requires the involvement of people with different backgrounds and expertise, *e.g.* biologists, engineers, administrators and managers, and their concerted efforts in order to ensure the effectiveness of the implemented measures.

III. COUNTRY REPORTS

3.1 Cambodia

8. *Mr. Chheng Phen* from the Fisheries Administration of Cambodia made a brief presentation on "Fish Passage in Cambodia" (**Annex 6**). With a production up to 625,000 MT per year, inland fisheries are very important for the livelihoods of people in Cambodia. Cambodia had constructed a number of cross-river obstacles, at different scales and for various purposes, *e.g.* for irrigation, domestic water supply, hydropower, including multi-purpose dams. It was, however, noted that the construction of fish passage facilities is not compulsory by law, and there is only one fish pass in the country (in Stung Chinit, constructed approximately 10 years ago under the Ministry of Water Resources), which has a vertical slot design. From monitoring, it was found that 50 species (from a total of over 100 species found in the river) could pass through this fish pass. But there were also problems noted, *e.g.* people coming to catch fish that gathered in or crossed through the fish pass.

9. The Workshop took note that MRC had supported studies to monitor the effectiveness of the fish pass in Stung Chinit during the past years, and will provide support to conduct monitoring again this year. It is therefore expected that the results of these studies would allow to release time series data on the effectiveness of this fish pass.

3.2 Indonesia

10. *Ms. Masayu Rahmia Anwar Putri* from the Research Institute for Fisheries Enhancement and Conservation of Indonesia made a presentation on "Fish Passage in Indonesia" (**Annex 7**). Inland ecosystems and fisheries are considered as very important for Indonesia, and there are several stakeholders involved in the utilization of inland water resources. In Indonesia, all activities that are likely to cause impacts on the environment must comply with the requirements of the EIA; however, there is no regulation concerning the construction of fish passage facilities. There are various management authorities (*e.g.* for the aspects of irrigation, hydropower, fisheries, tourism, sports, etc.) involved in the construction/operation of cross river obstacles. The decline of several fish species, as

well as impacts on water quality and flows, were observed after the construction of several cross-river obstacles. However, most of the constructions don't have a fish passage facility as such facilities were constructed only when strongly required or upon pressure by the community or other bodies (*e.g.* for Perjaya Dam and Sulewana Dam). The problems concerning the construction of fish passage facilities include the lack of awareness and knowledge of the appropriate design of fish passage facilities.

3.3 Lao PDR

11. *Mr. Douangkham Singhanouvong*, Deputy-Director of Living Aquatic Resources and Research Centre (LARReC), made a presentation on "Fish Passage in Lao PDR" (**Annex 8**). It was noted that while Lao PDR had no fish passage facilities at high dams, the country has conducted a Fish Passage Project (2008-present) with the support from ACIAR, aiming to support the sustainable development of water infrastructures in Lao PDR by maintaining upstream and downstream fish passage, improving understanding of technology to facilitate fish migrations onto and from floodplains, and enhancing the ability of the country to apply low-head fish passage technology at various levels, and improve biodiversity in the floodplains. Under this project, experiments were conducted to establish design criteria for vertical slot fishways.

12. In addition to the above project, Lao PDR with support from ACIAR is also undertaking some other projects, namely: Pilot study for the development of fish-friendly irrigation design criteria for application in the Mekong and Murray-Darling Basins (2012-2013); Optimising fish-friendly criteria for incorporation into the design of mini-hydro schemes in the Lower Mekong Basin (2013); Development of fish passage technology to increase fisheries production on floodplains in the Lower Mekong and Murray-Darling River Basin (2010-2015); and Increasing uptake and application of fish passage technology in Lower Mekong Countries (2014-2017). A draft proposal on Mekong mainstream dam upstream and downstream fish passage is being developed for further funding support.

13. Considering that there are several projects undertaken in Lao PDR with support of ACIAR while MRC also have several projects undertaken with a similar concept, the representative from the MRC Fisheries Programme suggested that information exchange should take place between these projects and MRC in order to enhance the synergy of activities in the future.

3.4 Malaysia

14. *Mr. Hasbullah bin Harun* from the Department of Fisheries of Malaysia made a brief presentation on "Fish Passage in Malaysia" (**Annex 9**). There are 37 cross-river obstacles in the country (five are large dams), but none of them has a fish passage facility. There are another two dams under construction, which also have no fish passage facilities. The obstacles for constructing fish passes in Malaysia could be the lack of awareness and knowledge of fish passage; however, the government may consider this in the future construction of cross-river obstacles.

3.5 Myanmar

15. *Mr. Zaw Win Chit* from Irrigation Department of Myanmar made a presentation on "Fish Passage in Myanmar" (**Annex 10**). Noting the importance of agriculture and fisheries for the socio-economics of Myanmar, he reported that there are several initiatives to release fish fingerlings (including release into reservoirs) to restore the natural fishery resources, increase fish production, and enhance food sufficiency of the people of Myanmar. Several cross-river obstacles have been constructed and others are planned to be constructed in the country; however, there haven't been many studies on the impacts of such cross-river obstacles; and there is also no construction of fish passage facilities in Myanmar.

3.6 Philippines

16. *Mr. Enrique B. Marquez* from the Natural Freshwater Fisheries Technology Center (NFFTC) of the Philippines briefly presented on "Fish Passage in the Philippines" (**Annex 11**). There are several inland aquatic systems in the Philippines that provide services for people in the country, *e.g.* lakes, rivers, reservoirs (mostly for power generation), etc. However, reservoirs are mostly for power

generation and irrigation purposes, while fish production is considered to be of secondary importance. It was also recognized that inland waters are the most threatened of all ecosystems types; and the yield from inland fisheries is declining. There are seven major dams (for hydropower and irrigation purposes) that have negative impacts on the socio-economic conditions of the people and on some migratory fish species in these areas. While there is no fish pass construction in Philippines at this moment, it is expected that fish passage facilities could be constructed in the future, and could be incorporated in the country's policy for future construction of cross-river obstacles in order to achieve sustainable fisheries in the future.

3.7 Thailand

17. The country paper on "Fish Passage in Thailand" which was not presented orally appears as **Annex 12**.

3.8 Vietnam

18. *Mr. Mai Viet Van* made a brief presentation on "Fish Passage in Vietnam" (**Annex 13**). He outlined the importance of the inland aquatic resources in Vietnam which comprise over 600 freshwater fish species. It was noted that up to 2012 there were 2,000 hydropower and hydraulic dams constructed in Vietnam creating ranges of impacts on fishery resources. There are actions aiming to enhance fishery resources, *e.g.* release of fingerlings, community-based fisheries management, protection of breeding grounds for fish species, etc. There is no construction of fish passes at the moment due to lack of information and knowledge on fish passage facilities; however the country recognized the need for fish passes in the future.

IV. GENERAL ECOLOGICAL CONSIDERATIONS FOR BUILDING FISH PASSES

19. *Mr. Andreas Zitek* informed the Workshop about the general ecological considerations for building fish passes (**Annex 14**). He mentioned that it was now largely recognized that inland aquatic species are threatened by various factors, *e.g.* pollution, damming, river regulation, unsustainable fishery and introduction of alien species, but that it was also necessary to recognize the requirements of different species, particularly their specific needs to complete their life cycle successfully, in order to ensure sustainable planning and fisheries management. It was noted that, while there are species that need to undertake migrations from the sea towards inland areas for spawning and larval rearing, also most freshwater fishes require open migration corridors in upstream and downstream directions, as well as in the lateral dimension, to complete their lifecycle. Habitat connectivity (both laterally and longitudinally) is therefore necessary to satisfy migratory requirements of the species and ensure their existence in the habitats. Examples from the Danube River and other Austrian rivers were cited where several impassable migration barriers exist that create strong impacts on the existence of species, particularly on those that are dependent on long-distance and medium-distance migrations. Across Europe about 37 % of the 550 existing freshwater fish species are threatened, with about half of them suffering from the loss of river continuity. It was noted that, therefore, in Europe building of fish passes has become a priority and is embedded in EU legislation (EU Water Framework Directive).

V. SWIMMING AND ORIENTATION BEHAVIOR OF FISHES IN UPSTREAM DIRECTION

20. *Mr. Zitek*, while making a presentation on "Swimming and Orientation Behaviour of fishes in Upstream Direction" (**Annex 15**), stressed that fish behaviour was one of the very important criteria in designing appropriate fish passage facilities as different species of fish (with different body shapes, swimming behaviour and swimming performances) have different abilities to move/migrate across the habitats. Fish rheoreaction (*i.e.* orientation and swimming against the water current) is influenced by the flow velocity, temperature, level of illumination, degree of turbulence, and the physiological condition of the fish. Therefore, basic data, *e.g.* fish size (body length, body width), the critical burst speed of the fish (*i.e.* swimming speed that can be maintained for 20 sec), critical velocity for rheoreaction and flow velocity preferences during up- and downstream migration, and other behaviour, should be collected and considered in designing and constructing appropriate passes. In addition, the requirements of different

life stages of fish (particularly those of the small juveniles) should also be considered when designing fish passage facilities to allow a wide range of age classes passing through the facility.

21. The Workshop also noted other factors that affect the effectiveness of fish passes, including *inter alia* water turbulence (*i.e.* too high a turbulence reduces the swimming capacity of fish, leads to disorientation, exhaustion and injuries of fish); position of the entrance of the fish pass (the appropriate position depends on the fish behaviour, *e.g.* whether the fish are swimming along the shoreline, in the main current, or at the surface/bottom, etc.); size of the fish pass and the volume and flow characteristics of the attraction flow compared to the size of the river (the flow volume should be large enough to attract fish); and schooling behaviour or mass migration of different species of fish. The appropriate period of operation of the fish pass should also be considered, *i.e.* whether the fish pass should function all year round, or only during specific times, *e.g.* during the migration period(s).

22. As an answer to the inquiry made by Indonesia on appropriate passage facilities for eel, it was noted that there exist fish passes specifically designed to facilitate upstream migration of eel (successfully established, for example, at various weirs in France). It is, however, much more difficult to facilitate downstream migration of eel, and fish passage facilities were found to be largely inappropriate for downstream passage in larger rivers. In several cases, where hydropower installations create obstacles to the downstream migration of eels, an agreement was reached with the hydropower companies to stop the operation of the hydropower plants for a certain period in order to allow safe eel downstream migration.

23. The Workshop also noted that, considering the differences in swimming behaviour of the fish species in the SEAFDEC region, the vertical slot design for fish passage was thought to be possibly the most versatile as fish can choose the level at which to swim in the water column (between the bottom and the surface) when passing the slot, meaning that they can select from a variety of water velocities (decreasing from the surface to the bottom).

VI. LOCATION OF FISH PASSAGE FACILITIES AND ATTRACTION

24. *Mr. Rolf-Jürgen Gebler* made a presentation on "Location and Attraction of Fishways" (**Annex 16**). He stressed the importance of science as basis for the design and construction of fishways, emphasizing that biologists and engineers need to work closely together in order to come up with the appropriate fish passage designs. He further pointed out that the location of the fish pass entrance was the most important factor to ensure the effectiveness of the passage as the entrance must be easily detectable by the fish so that fish can enter the fish pass.

25. Recommendations for good entrance conditions, including factors defining them, were given, *e.g.* the entrance should be located at the bank side of the weir structure rather than in the middle of the weir; the mouth of the fish pass (fish pass entrance[1]) should be close to the weir foot or turbine outlet; the location of the entrance at the pointed angle (between riverbank and weir) is better than at the obtuse angle; whenever possible, the entrance of a fishway should be positioned near the powerhouse (and not on the bank distant from the powerhouse) to make use of the turbine discharge to attract fish towards the fish pass entrance. In addition to the position of the entrance, the direction of discharge from the fish pass should also be considered and it should be the same as the one of the discharge from the powerhouse while the water velocity and the ratio of the discharge from the fish pass outlet and the discharge from the turbine outlet should be sufficient to attract fish into the fish pass. In the case of highly turbulent water in the downstream section of the powerhouse (where the water is released from the draft tube or tubes), there is also the need to study the flow patterns in detail so as to detect those zones with adequate water flow in order to determine the right position of the entrance and direct the attraction flow in such a way that it can be detected by the fish. Furthermore, in the case where there are several active or potentially active water outlets in the same area of a weir (*e.g.* through the powerhouse, navigation channel, spilling over the weir, etc.), the channel through which most of the flow passes (and which therefore probably attracts most fish) should be chosen for the construction of fish passage facility. However, in many situations, due to the different migratory behaviour of the fish, several fish passes and/or multiple fish pass entrances might be needed. This is particularly true for large or very

[1] Fish pass entrance = water outlet; fish pass exit = water intake

large weirs and for weirs where the powerhouse and one or all other water outlets (*i.e.* spill gates and/or navigation locks) are distant or spatially separated (*e.g.* by an island or islands) from the powerhouse.

26. It was observed by the representative of MRC that the examples presented by the resource persons mainly concerned dams and weirs with hydropower plants, which not infrequently have a rather stable water discharge. However, in Southeast Asia, a large number of cross-river obstacles is used for irrigation purposes with high seasonal variations, as the water is generally abstracted during the dry season and spilled over the weir during the rainy season. In addition, the observation was made by Lao PDR that in the Southeast Asian region, many hydropower dams are constructed by creating large upstream reservoirs, and the conditions are therefore different compared to barriers built as run-of-the-river schemes which are more common in Europe.

27. The Workshop participants further took note of the fact that the effectiveness of attracting fish into a fish pass is the most critical aspect that should be considered in the construction of any fish passage facility. However, for judging the overall usefulness of a fish pass, attention must also be given to the existence and the status of upstream habitats and it must be evaluated whether or not those are still suitable for fish .

VII. FISH SPECIES AND BEHAVIOUR OF DIFFERENT SPECIES IN SOUTHEAST ASIA

28. *Mr. Zitek* made a presentation on "Fish Species and Migration Behaviour of Different Species in Southeast Asia" (**Annex 17**). He noted that inland fishes in the Southeast Asian region have very high biological and behavioural diversity, with a high number of species being endemic and having complex life cycles that involve both short and long distance migrations. According to existing size distribution studies, a high percentage of fish is relatively small, and only a low percentage of fish can be considered as large. Fish migrations can be classified according to three generic migration patterns, *i.e.* upstream, downstream and lateral migrations. The most important factor that triggers migration in the Mekong is the change in water discharge; however, the migration period for different species of fish can be different, *e.g.* some species migrate during the dry season, some migrate all year round (during both dry and wet seasons) while some migrate mainly at the beginning of the rainy season during the first increase in discharge.

29. Taking into consideration the above-mentioned differences in the migratory behaviour, it is necessary to properly study these migration patterns of important fish species (*e.g.* what triggers the fish movement, migration period during the year, etc.) in order to use this knowledge as a basis for the design and operation of fish passes. It was further noted that the Mekong Basin has very high species diversity and that intense fish migrations occur during certain periods of the year. Although there have been carried out studies on the appropriate design of fish passage facilities, *e.g*. the vertical slot design, for European and North American species, such designs might only be suitable for a particular range of discharge conditions, and for certain species and sizes of fish (depending on the chosen dimensions of the pass). Adaptation to local conditions is therefore required to enhance/ensure the application of the most appropriate designs under different conditions and in different locations such as in Southeast Asia.

30. The representative of MRC informed the Workshop that MRC produced a database on the biology of over 900 species of fish in 2003, and most of this information is made available on the MRC website and could be utilized as a basis for the development of generic design criteria for specific groups of fish.

VIII. COMMON TYPES OF FISHWAYS

31. *Mr. Gebler* made a presentation on "Common Types of Fishways existing in Europe" (**Annex 18**). He noted that fishways are facilities that provide free passage for fish at cross-river obstacles (for both upstream and downstream migration), and the selection of appropriate types of fishways would depend mainly on the size of the weir (*e.g.* the head) and the availability of space for the construction of the fishway. The Workshop was then informed about the different types of fishways for low-head weirs (*e.g.* rock ramp; fish ramp; pool pass; bypassing water course) and their design features (*i.e.* pool structure, pool-riffle structure, pool pass structure, vertical slot, pool pass with notches and orifices

(which, by the way, is an outdated design and in most cases replaced by the more modern vertical-slot design)), as well as the advantages and disadvantages of different types and structures of fishways.

32. Also methods/facilities to provide fish passage especially at high obstacles were presented, *e.g.* fish lock (fish enter the lock, the entrance is closed, and fish have to wait until the upper sluice gate opens so that they can leave in the upstream direction); fish lift; and the “trap and transport” method. However, these methods do not allow continuous migration, can be selective (*i.e.* might work well only for certain species, depending on the chosen dimensions) and usually have high operating costs. Some of them can have a high efficiency, depending on the target species and the mode of operation. It was noted that many fish locks were constructed in France but were found to provide unsatisfactory results and are rarely used now.

33. In response to the question on the construction costs for fish lifts and on how to sustain their operation, an example from Germany was given where the construction of a fish lift at a weir with a height of 6,5 m cost approximately 200,000 EURO (~300,000 USD). The operation cost was shouldered by the power company. It was also noted that usually 5-10 percent of the hydropower plant construction cost are allocated for environmental measures in Germany; and approximately 1-2 percent is typically invested for fish passage.

34. Regarding the inquiry on the most effective types of fish passes with minimum maintenance cost, it was clarified that this depends on the height of water head. For weirs with a low water head (until 2-3 meters), the natural rock ramp type (covering the entire river width [rock ramp in the strict sense] or only part of the river width [fish ramp]) is found to be the most effective fish pass, with lowest construction and maintenance costs; while for weirs with higher water heads (more than 3-4 meters), the vertical slot design can be considered more appropriate. Regarding the types and design of fish passage facilities that could be used to facilitate migration of large fish (*e.g.* over 1 meter in length in the Mekong River), it was stressed that regardless of the design chosen, first and foremost the dimensions of the pass have to be appropriate. Pool passes (*e.g.* vertical slot passes) could be appropriate provided the dimensions of the pools are correctly defined, *e.g.* the length of the pools should be at least three times of the fish length. However, the construction of fish passes of this size will require a lot of space. In case of a fish lift, the dimensions of the holding tank have to be correctly chosen.

IX. FUNCTIONALITY OF DIFFERENT TYPES OF FISH PASSES

35. *Mr. Zitek* made a presentation entitled “Analysis of Functionality of Different Types of Fish Passes” (**Annex 19**). Such an analysis could be done by comparing the amount of fish downstream of the weir and the amount of fish caught in the trap at the upper end of the fish pass. When determining the effectiveness of a fish pass, this effectiveness could be classified by rating the upstream migration (a) qualitatively, *i.e.* “fully operative” (all species and age classes can migrate), “operative” (all species except rare ones and nearly all age classes can migrate), “limitedly operative” (most abundant species and most age classes can migrate), “little operative” (only a few species and/or age classes can migrate), and “not operative” (no or only individual species and/or age classes can migrate), and (b) quantitatively (judgment of the ratio of the number of all individuals approaching the weir and the number of those able to pass), *i.e.* “fully operative” (all or nearly all individuals pass), “operative” (most individuals pass), “limitedly operative” (many individuals pass), “little operative” (few individuals pass), and “not operative” (only single individuals pass). The quantitative judgment of the total number of individuals passing is done separately for medium and short distance migrants. Finally, all three judgments done along a 5-tiered scheme (species and age classes, proportion of the total number of individuals of medium distance migrants, proportion of the total number of individuals of short distance migrants) are combined into an arithmetic mean value representing the overall functionality of the fish pass (rated from “1” – “fully operative” to “5” – “not operative”). The result of the analysis of fish passes in Austria indicated that 50% of fish passes had limited functionality. It was also found that “pool and weir passes” were less operative, while “vertical slot passes” and “nature-like passes” were more effective. This could be mainly attributed to the inadequate construction of the steps between pools (too high, no bottom connection, etc.).

36. The study of the fish pass efficiency in Austria also identified the major causes for the non-functioning of the fish passes. The major problems concerning the *entrances* were: entrances positioned too far from the weir or not at the migration route of fish; entrances not reachable due to insufficient minimum flow downstream of the weir (*e.g.* at water abstraction sites, fish were not able to reach the weir); entrances not adapted to the prevailing water level (*i.e.* entrances "hanging in the air" so that fish cannot enter). Concerning the *fish pass channels*, the main problems were *inter alia*: channels with too steep slopes or fed by too high a discharge, leading to too high flow velocities in the chute (*i.e.* beyond the swimming capacity of fish); pool drops too high for fish to go over; discharge and water depth too low. In addition, the fish pass exit (water inlet) might have too high flow velocities and high turbulence, and might also be too close to the weir.

X. MORE DETAILED INFORMATION ABOUT RELEVANT TYPES FOR SOUTHEAST ASIA

37. *Mr. Gebler* presented examples of fishways that could also be suitable for the Southeast Asian region (considering the weir/dam heights), *e.g.* rock ramps, fish ramps, bypassing water courses (suitable for small/low head wear); vertical slot passes, or fish lifts (suitable for large/high weir or small power stations of 3-20 meters head). However, for large dams that create high impacts to the ecosystems, it was noted that it was not easy to restore fish passage and that careful studies would have to be carried out for each location so as to come up with potential solutions.

- ***Rock ramps:*** Rock ramps could be created by placing rocks to reduce water flow, or creating pool structures formed by rocks to allow fish to migrate upstream. There are several designs of rock ramps, *e.g.* irregular placement of the rocks, pool structure, rock cascade, etc.

- ***Fish ramps:*** A fish ramp is a sectional rock ramp (at a certain part or at one side of the weir). Fish ramps should be placed at the sharp angle of an oblique weir as fish are usually attracted to this point by the current; fish are thus guided towards the entrance of the ramp.

- ***Bypassing water courses:*** This type can be built in different ways, *e.g.* with pool or riffle structure (*i.e.* with a combination of deep/shallow sections, or steep sections). Bypassing water courses can also be combined with other structures, *e.g.* a collection gallery, a vertical slot fish pass etc., at the inlet or outlet area to regulate the water discharge, attract fish and facilitate their upstream migration.

  It should be noted that in Europe bypassing water courses often are designed to fulfil two objectives, *i.e.* firstly to facilitate fish migration and secondly to create instream habitats for fish breeding and nursing in order to mitigate hydropower impacts. However, note should be taken that the construction of bypassing water courses requires very large space.

- ***Vertical slot passes:*** Construction of vertical concrete walls to create pools. Two consecutive pools are connected by one or two vertical slots. As for other fish pass types, the position of the entrance is the most important factor to allow fish to detect the fish pass and to enter it. The pool bottom should be covered by coarse material (*i.e.* gravel or small stones or rocks) to create a zone of low flow velocity.

38. In response to the comment that the Southeast Asian region has very high seasonal fluctuations in the water discharge (due to very high precipitation during rainy season), it was clarified that bypassing water courses may not be very suitable for this situation. Vertical slot fish passes with multiple entrances at different levels could be considered in order to allow fish to enter at different downstream water levels. Often a vertical slot pass is used at the downstream and/or upstream part of a bypassing water course to balance fluctuation of water levels.

39. It was also noted that the incorporation of fish passage facilities already at the initial planning phase of a dam construction project would allow the placing of fish passage entrance at the right position, and allow the construction to be done with the most suitable structure maximizing the effectiveness for fish migration. In connection to this, it was suggested by the audience that

methodologies should be developed to evaluate the benefits created by improved fish passage (taking into consideration its contribution to economics, improved ecosystems, people's well-being, food security, as well as other values) in order to incorporate this information into any proposal for the construction of a fish pass and thus make it much stronger. However, it was noted that the incorporation of fish passage in dam construction projects is of different priority in different countries.

40. A question was raised concerning the potential problem of people taking benefit from fish attracted to or into the fish pass or accumulating below the weir, abusing this situation for illegally, but very successfully, catching fish there. While noting that in Europe fish passes are constructed very often as part of a hydropower plant where public access is not allowed, it was suggested that awareness building activities are always crucial and might help also in Southeast Asia to inform people on the negative consequences of catching fish illegally below weirs in high quantities.

XI. ECOLOGICAL REQUIREMENTS FOR THE CONSTRUCTION OF FISH PASSES

41. *Mr. Zitek* gave a presentation outlining the ecological requirements for the construction of fish passes (*i.e.* how to establish/select the main parameters important for passage) (**Annex 20**). He explained that in Europe the ecological requirements and the size of fish, particularly of the dominant and sub-dominant species, need to be taken into consideration when discussing fish pass construction and the design of fish passes in order to ensure the provision of a migration corridor at the weir for the fish species concerned.

Decisions to be made include:

- ***Type of fish pass:*** this depends on weir height, stream type, fish species/behaviours
- ***Entrance situation:*** need to consider appropriate location, connection to the river bottom, attraction flow (amount of water, *i.e.* 1-5% of river or competing discharge; velocity of the water; flow patterns), fish species/behaviours, etc.
- ***Dimensions:***

  Pool passes:
  - *volume of discharge* corresponding to river size or competing flow
  - *Pool length/width/depth* depend on the size of largest fish: minimum length = 3 times body length of fish, minimum width = 2 times body length, minimum pool depth = 5 times body height

  Minimum slot width: 3 times body width (minimum 20 cm to avoid clogging)

  For Nature-like pool passes:
  - *Minimum pool depth* = 70-120 cm
  - *Minimum depth at pool connection* = 2.5 times body width (minimum 20 cm)
  - *Bottom roughness*: to reduce water velocity
- ***Slope:*** depending on swimming capacity of weakest fish
- ***Turbulence:*** in a river, turbulence naturally increases from downstream to upstream; could be = 30-50 Watt/m^3 (for lowland tropical rivers)
- ***Periods of the year, when the fish pass should work:*** depend on the migration patterns of fish (all year, dry season, wet season, etc.).
- ***General features:*** protection of the entrance, changing water levels upstream and downstream; precaution measures for extreme events, etc.

42. It was further noted that for ecosystems with fish communities, where different species have different requirements, multiple entrances with different conditions might be necessary to attract different fish species. Fishes could also be grouped and categorized based on their behaviour and a compromise solution for the dominant and sub-dominant species could be sought and considered when designing a fish pass.

XII. HYDRAULIC DESIGN OF THE FISHWAYS

43. Illustrated by examples of "close to nature fish passes" at weirs (**Annex 21**), *Mr. Gebler* presented basic hydraulic calculations needed for the hydraulic design of the fishways (**Annex 22**). Taking into consideration the above-mentioned ecological requirements and the hydraulic requirements of different fish species, it was noted that the *maximum flow velocity* in the passes depends on the *weakest* natural local fish species. However, the velocity is influenced by the height of drop (water head) between two pools. Other factors that control the velocity are *e.g.* the bottom substrates that create a rough bottom surface that reduces the velocity at the bottom layer. The discharge is controlled by the cross section area of the openings (slots).

44. It can be noted that it might be opportune to add water into the lower part of the fish pass (close to the fish pass entrance) so as to create a better attraction flow.

45. From the hydraulic design perspective, the following are the recommended dimensions of vertical slot passes:

- ***Slot width*** = 3 times body width of largest fish
- ***Pool length*** = 10 times slot width
  (Minimum pool length = 3 times body length of largest fish)
- ***Pool width*** = 7.5 times slot width
  (Minimum pool width = 2 times body length of largest fish)
- ***Pool width/length ratio*** = 0.75

46. A good vertical slot design should aim to have no short circuit current in the pool to have good energy distribution and dissipation. In addition, there should be no swelling current along the sidewall. There are different designs of vertical slot hooks that control the direction of water flow. The number of crosswalls, defining the number of slots and pools, depends on the height difference between the maximum upstream and the minimum downstream water levels (*i.e.* head) and the difference in drop chosen as a function of the swimming capacity of the fish at this location (in order to achieve an adequate slope). However, as the upstream and downstream water levels may vary during different periods of the year, the design should create conditions that are favourable for migration at least during the migration period/periods, if not the whole year round.

47. Myanmar inquired on a fish pass design that could be appropriate for a water storage dam which stores water during rainy season and releases water for agricultural and other purposes during the dry season. In reply, it was suggested that in any case the water level differences between upstream and downstream at times of fish migration need to be assessed. Considering that the difference between the water level difference (*i.e.* head) during the rainy season and the dry season could be more than 10 meters, it was recommended that a fish lift could be an appropriate solution as the lift could release fish at different levels into the upstream reservoir. However, the representative of MRC raised concern that a fish lift has high operation costs, and therefore in long term, this may not be appropriate for the region compared to a "bypassing water course".

48. SEAFDEC suggested that in such case the migration peak of dominant species should be studied and a fish pass could maybe be constructed in such a way as to be adapted to the water levels (height) prevailing during such peak migration in order to operate and facilitate migration during the peak. SEAFDEC further raised the issue of very high hydropower dams with water release pipes fixed at a very deep point in the water column which means that the water released downstream is very cold and often has a low oxygen content and high amounts of toxic substances. SEAFDEC suggested that in future designs of such high hydropower dams, the water outlet pipes should be constructed in such a way as to be able to adjust the water outlet in order to always release surface water which is more suitable for fish.

XIII. TECHNICAL DETAILS

49. *Mr. Gebler* informed further on technical details of fish passes (**Annex 23**). In addition to hydraulic considerations, there are other issues that need to considered to enhance the effectiveness of fish passes, such as:

- The ***location of the exit*** should be far enough from the weir/powerhouse.
- **A *beam (downflow baffle)*** could be installed (parallel to the main water current, with the lower edge 30 cm below the water level) to keep floating debris out of the fishway.
- ***Bottom connection*** should be established between river floor and fish pass entrance
- ***Auxiliary flow into a fishway*** to provide additional discharge to better attract fish; the water can be sent through a pipe, then passed through a pivoting screen to reach the entrance of fishway.
- If needed due to the volume of the competing discharge, the ***discharge at the entrance*** could be much higher than the discharge in the pass itself in order to attract fish to enter.
- ***Lighting conditions*** need to be considered. Fishways should be exposed to natural light, and should not be covered. If cover is necessary, it should be translucent. If illumination is necessary, this should be done according to natural light conditions and/or the preferences of the species (if known).

50. Replying to the inquiry on the accumulation of sediment in the bottom substrates of bypassing water courses, it was said that the bottom substrates need to be flushed regularly (*e.g.* every 5-10 years) in order to keep them clean so that they can serve as spawning ground for fish. An inquiry was also made with regard to potential solutions in the case that the biological and hydraulic requirements are different and do not match with each other. It was clarified that the first priority should be the biological requirement in order to determine appropriate pool width and length and flow velocity; other design criteria should then be adapted.

51. It was also recommended that local/natural materials (*e.g.* rocks, wood, bamboo, etc.) should be used as much as possible to reduce cost, but also to improve the appearance of fish passes so that they are environmentally friendly and better blend with the landscape. It was further mentioned that FAO is preparing a publication dealing with the construction criteria of nature-like fish passes which could serve as reference for the construction of nature-like fish passes in the near future.

XIV. OVERVIEW OF RIVER TYPES AND RELEVANT FISH FAUNA

52. *Mr. Zitek* further presented an overview of river types and their relevant fish fauna (**Annex 24**). When dealing with the design and construction of fish passes, river ecosystems could be simplified into different "*biocoenotic stream types"* which take into consideration the ecoregions (large areas with a distinct ecosystem and biodiversity) and abiotic settings as well as the typical longitudinal ecological zonations of rivers (with the assumption that the same zone should comprise species with the same bio-ecological characteristics and behaviours). A species composition characteristic for "*biocoenotic stream types*" could be used to develop design criteria for fish passage facilities transferable between similar *biocoenotic stream types*.

53. With reference to the above-mentioned procedure of classification, the Mekong River, if taken as an example, could be divided into six zones. However, it was noted that while the information on important fish species in Mekong has been documented, information on biology and migratory behaviour of other fish was still very limited. In response, it was recommended that research studies should be undertaken to gradually build up databases on the biology and migration behaviour of more fish species. Considering the very large number of species in the area it was, however, suggested that – as a starting point for the purpose of developing appropriate fish pass designs – the study should first focus on migratory species and should in the beginning not include species that stay in stagnant water. While it was suggested that countries in the region should consider applying knowledge that may already be available from places that fall in the same ecoregion, consideration should still be given to the differences among localities and therefore appropriate adaptations may be required to ensure the applicability for specific localities.

54. It was also emphasized that the construction of fish passage facilities should be incorporated right from the beginning of dam construction project in order that appropriate design and position could be ensured. In addition, emphasis should be given to the construction of fish passes at low-head weirs which are very common in the region and create a large extent of impacts by disconnecting aquatic habitats. Furthermore, it was stated that fish passes only serving longitudinal migrations of fish might not be sufficient as the connectivity between the river and the floodplains also needs to be enhanced. However, this will require specific types of passes and criteria that take into consideration particular localities and the requirements of the species concerned.

55. On the monitoring of the effectiveness of fish passage facilities and their impacts on the upstream fish communities, it was suggested that such monitoring should not only be conducted in an area close to the fish pass outlet but also further away at the upstream habitats, as migrating fish will normally continue to migrate up until reaching their favourable habitats, *e.g.* for spawning.

XV. SUSTAINBLE IRRIGATION AND MINI HYDRO DEVELOPMENT IN THE ASIA-PACIFIC

56. *Mr. Gary Thorncraft* from the National University of Laos made a presentation on "Sustainable Irrigation and Mini Hydro Development in the Asia-Pacific" (**Annex 25**). He noted that at present 90% of global water consumption was used for irrigation purposes, while it is anticipated that the demand for water for non-irrigation purposes including hydropower production will continue to increase in the near future. New research is therefore being undertaken to study the possibility of rebuilding mini hydros from existing small-size and low-head weirs that are already existing in the Mekong basin (Northeast Thailand, Lao PDR, and Cambodia) in order to serve as multipurpose dams.

57. It was, however, found that the fish species (*i.e.* both small and large species, including juveniles) are injured or die when passing through turbines at weirs. The cause of such mortalities was mainly the hydraulic change (big changes in pressure and increase in turbulent shear) when water and fish pass through the turbines, causing swollen swim bladders and death of fish. At larger hydropower plants, fish that passed through turbines also faced rapidly increasing/decreasing pressures, crunching, and mortality. Research therefore focuses on studying the actual cause and the critical thresholds for the process of turbine passage in order to improve the design and construction of turbines to make them more fish-friendly and allow safer downstream migration of fish.

58. While noting the general perception of people that downstream migration of fish was not a problem, this initiative was recognized by the Workshop to be very useful in addressing the need for effective and safe downstream migration of fish, including small larvae and juveniles, in order to fulfil their life-cycle requirements.

XVI. VERTICAL SLOT PASS AT THE POWER STATION

59. *Mr. Gebler* continued to provide more examples on vertical slot passes at power stations (**Annex 26**). An inquiry was made on the availability of scientific studies to quantify the cost-benefit (direct and indirect benefits, including non-use value) from the construction of fish passes. In response, it was clarified that taking the example of the vertical slot pass at the power plant Koblenz, Germany (River Moselle; head 6,5 m), the construction cost was approximately 5 million USD. 25 out of 30 species were found to be able to pass upstream. Thus, it is shown that the ecological status had been enhanced, but it is difficult to quantify this in terms of monetary value. While noting that cost-benefit analyses are required to justify the construction of fish passage in countries of the Southeast Asian region, it was explained that in the EU the "polluter pays" principle applies and therefore the owner(s) of a hydropower plant is (are) responsible to mitigate negative impacts to the environment caused by his (their) activities. Based on provisions in the EU-Water Framework Directive, this includes also the provision of free fish passage. .

60. The representative of MRC expressed concern that the awareness of dam constructors and policy makers in the Southeast Asian countries were very limited concerning the impacts of dam construction on fishery resources, and recommended that the lessons learnt from other parts of the world, *e.g.* Europe and North America, should be properly communicated to the relevant people in order

to enhance awareness. Understanding the relevant issues needs also to be enhanced, including understanding the need for at least 1-5% of water for sufficient attraction of fish into fish passes. This does, however, not necessarily reduce the benefit from hydropower generation, as nowadays small turbines can be installed to use the additional water (often only a couple of cubic meters) for power generation before it is released into the lower part of the fish pass.

XVII. MONITORING UPSTREAM MIGRATION

61. *Mr. Zitek* gave a presentation on "monitoring of upstream migration" (**Annex 27**). While reiterating that ecological benefits can be obtained from the construction of fish passes, he emphasized that it is generally necessary to carry out appropriate monitoring in order to learn about the behaviour and migration of different species of fish, as well as to evaluate the effectiveness of fish passes.

62. The monitoring of the effectiveness of fish passes should include two aspects, which are (1) the monitoring of the entrance efficiency; and (2) the monitoring of the passage efficiency. Monitoring could be done by using different methods, *e.g.* a fish counter, video monitoring, passive/active gears to collect fish, telemetry (*e.g.* with radio transmitters), etc. The data to be collected include *biotic data* (*e.g.* species characteristics, number of species, number of fish, length, weight, age, developmental stadium, position, migration pathway), as well as *abiotic data* (*e.g*. temperature, discharge, time of year/day, moon phase, etc.). Monitoring and assessing the efficiency could *inter alia* provide information on the proportion of migrating fish at a specific fish pass (by using fish counts), the efficiency of multiple fish passes on a catchment level, and the effect of connectivity measures on fish populations.

63. Below are listed examples of methods for the monitoring of upstream migration:

- ***Trap monitoring*** – by setting a trap at the entrance of fish passage (lower trap), it is possible to monitor whether or not fish enter the pass; by setting a trap at the end of fish pass[2] (upper trap), one can monitor whether or not fish can master the entire length of the fish pass. Fish in the pass could also be tagged to monitor up to which step in the passage they could migrate and where probably delays occur. In using this method, the upstream outlet should be blocked in order to avoid that fish enter from upstream through the fish pass outlet (*i.e.* the water intake).

- ***Application of radio transmitters*** – fish are equipped by transmitters that are placed for example in their abdomens and send out radio signals allowing for a determination of the position of a fish. By this method, information on fish movements over a specific time period can be obtained, and this could demonstrate whether fish are attracted to the fish pass entrance or to another location below the weir (*e.g.* the turbine outlet). Using radiotelemetry, in connection with other data, therefore enables the expert to provide essential explanations on the reasons, why fish are not able to pass through the passage into the upstream water. Especially wrong entrance locations and inappropriate attraction flow conditions can be detected. Furthermore radiotelemetry studies might be useful before planning a fish pass to learn about the spatial behaviour of fish below an existing weir and to determine the most appropriate location of a fish pass entrance so as to avoid later problems or failure.

  The cost of radio telemetry studies and equipment can vary, depending on the data to be collected and the specific technique used. The major problems when using radio transmitters are that (1) the antenna that protrudes from the body of the fish could cause infection, and (2) the battery life of transmitters which could be short due to the tag/battery size or if tags are not stored properly. The efficiency of the transmitter also depends on the water depth and conductivity.

- ***Video monitoring*** – a video camera could be installed above the water surface (bird-eye view), or at an underwater window to monitor fish that swim through the pass. In this way, the number of fish might be counted while some species may also be identified based on the body shape, the characteristics of their movement, etc. However, this might only be suitable for the temperate

[2] *i.e.* at the fish pass exit (water intake)

areas with a small number of fish that can more easily be recognized, but might not be appropriate for the tropical countries with very large numbers of small fish and highly turbid water.

64. Where there are very large numbers of small fish, as is the case in many Southeast Asian countries, traps could be set for a certain period of time to get representative catches of fish. Samples could be taken to monitor the species composition and estimate the number of fish that pass during a specific time period, and the results could be used together with factors such as *e.g.* total volume of fish and swimming speed in order to estimate the total number of different fish species.

65. *Mr. Gebler* then explained some other common methods for monitoring of fish migration through the fishway (**Annex 28**). He mentioned the problems one is facing when using traps, *e.g.* that traps are selective gear (depending on mesh size). If a trap with a small mesh size is used, the trap could be clogged with fish and fish could be injured while if a large mesh size is used, small fish would be able to pass through the meshes. An alternative is to use a "capture basin" which is a specific construction feature aside the fish pass allowing to capture fish during their upstream migration. By closing the outlet of the fish pass (*i.e*. the water inlet), the water drains now through the capture basin where fish accumulate. As fish cannot leave this capture basin or the fish pass, they can be collected from this basin. By using this method, all sizes of fish can be collected. A disadvantage could, however, be that very large amounts of fish could accumulate in the capture basin; timely emptying the basin is therefore a condition.

XVIII. MAINTENANCE OF FISHWAYS

66. *Mr. Gebler* made a presentation on the maintenance of fishways (**Annex 29**). It was noted that regular maintenance is essential for the functionality of fish passes, and that thorough initial planning of the maintenance measures could reduce maintenance (*i.e.* frequency and duration of interventions) in the long-term (*e.g.* the installation of beams [downflow baffles] to reduce floating debris). It was also noted that different types of fish passes have different maintenance requirements, *e.g.* "rock ramps" need low maintenance, only collection of waste and sludge removal once in a while; "fish ramps" need some more maintenance; "bypass water courses" need regular maintenance (inlet and outlet); and "vertical slot passes", although having relatively low maintenance requirements in general, also need to be inspected after high water flows to remove debris that may have accumulated.

XIX. ECOLOGICAL REQUIREMENTS OF DOWNSTREAM MIGRATION

67. *Mr. Zitek* presented the ecological requirements of downstream migration (**Annex 30**). He informed the Workshop about the known types of downstream migration, *e.g.* post-spawning migrations, larval drift, juvenile drift or migration, wintering migrations, catastrophic drift. The results of a study undertaken in Europe showed that several species of fish do migrate upstream to spawn, and that these adults then perform post-spawning downstream migrations. Also larvae and sub-adults subsequently migrate downstream. There are various forms of downstream migration, *i.e.* passive migration (fish randomly move downstream); active-passive migration; and active migration (fish is heading straight downstream). It is important to understand the different types of downstream migration to design effective solutions for preventing fish entering the turbines and guiding fish towards a downstream fish passage facility. Fish of all age classes might suffer severe injuries during turbine passage by collision with parts of the turbine, quick pressure changes, turbulence and shear as well as cavitation.

68. Studies to assess the efficiency of fish passes for downstream migration can be done at various scales, *e.g.* experimental studies (reduced scale), field monitoring, etc.; however, at present there are still not many study results available concerning the effectiveness of downstream fish passage facilities.

69. An example of a study, where drifting larvae (using automatic sampling over 24 hours) were sampled, was given. Sampling stations were set at the upstream, middle stream, and downstream section of a canal along the river Danube in Austria to collect larvae; the larvae were identified to species level and measured. The study showed that there were larvae of different species, sizes and developmental stages, hatched from eggs spawned at different times of the year, in the same drift sample. The result also showed that there were differences in migration patterns, based on species, season, time of the day

(day-night), temperature, distance from shorelines, etc. The set-up of any monitoring of downstream migration of larvae and juveniles therefore needs to take these factors into consideration.

70. The Workshop also took note of equipment that could be used for monitoring of downstream migrations, which includes *inter alia* larval traps; acoustic telemetry (for assessing the 3D position of fish); and Passive Integrated Transponder (PIT) tags. It was also noted that by assessing turbine passage characteristics and turbine mortality of fish a model (simulation tool) could be developed to assess potential effects of a series of hydropower plants and turbines on downstream migration mortality and impacts on fish populations in the ecosystems as a whole.

XX. DOWNSTREAM MIGRATION FACILITIES

71. *Mr. Gebler* further presented the technical aspect of downstream migration facilities (**Annex 31**). He informed the Workshop about the aim of creating downstream migration facilities which need to solve two problems, *i.e.* first to prevent fish from entering the turbines and thus protect them from being injured, and second to offer them a way to swim downstream bypassing the turbines. Options for downstream migration include: 1) bypasses; 2) trap and transport; 3) adaptation of turbine and weir management (*e.g.* to stop the turbines for short time during intense migration periods); and 4) fish-friendly turbines (optimization of turbine discharge, blade angle, etc. to reduce fish mortality).

72. The common method that has been practiced to prevent fish from entering the turbines is the use of bar screens. However, fish could still be trapped and injured at the screen due to strong hydraulic power (water pressure). There are possibilities to reduce the likelihood of fish being trapped and/or injured at the screen, *e.g.* by reducing the bar interspaces and increasing the screen areas, thus reducing water velocity (and hence hydraulic pressure). Currently, some smaller hydropower plants are using horizontal screens to reduce fish mortalities by preventing fish from entering the turbines, but problems with accumulated debris exist, requiring regular cleaning. Note should, however, be taken that while a screen can prevent large fish from entering the turbine, small juveniles, larvae and fish eggs might still be injured by the turbine passage.

73. To facilitate downstream migration the provision of a bypass is common; this bypass, however, needs an attraction flow to guide fish to the entrance of the bypass. A sufficient amount of water is needed to provide free passage for downstream migration during a certain period of time. As bypasses for downstream and upstream migration might be different channels, an extra amount of water is often required for downstream migration purposes. Experiences from Thailand in guiding fish by bamboo stakes, that are normally used for constructing traditional fishing traps, were shared with the workshop participants as this may help guiding the fish into the bypass.

74. Furthermore, information was shared concerning a study undertaken in France where acoustic equipment was used to try to prevent fish from entering water intakes. It was pointed out that this study, however, showed that such equipment did not fulfil its purpose.

75. In summarizing, it was emphasized that a combination of several methods and strategies may be required to support downstream migration of different species and different developmental stages of fish.

XXI. FEEDBACKFROM PARTICIPANTS

76. Participants expressed their appreciation to the organizers for conducting this Workshop, and to the resource persons for sharing their knowledge on fish passage facilities from the ecological and engineering perspectives, including *inter alia* the basic aspects of fish biology and behaviour that are relevant to migration, different types of fish passes that allow migration, ecological and hydraulic requirements for enhancing the effectiveness of fish passes, as well as the requirements for monitoring, evaluation and maintenance of fish passes. Although examples were given based on the experiences in European countries and in North America, the knowledge gained from this Workshop could still provide basic concepts and ideas for adaptation and application, as well as inspiration for conducting relevant studies and experiments in the SEAFDEC region taking into consideration the specificity of this region. In this regard, planning and construction of fish passes in the region may start from the simple and low-

cost passage facilities for low-head weirs, which are common in the region, and focus on some important migratory species as placeholders for a much wider variety of existing species. But care has to be taken to also carefully consider the range of hydraulic needs of other highly abundant but smaller-sized species being of high importance for local fisheries.

77. As the issue of fish pass construction involves not only fisheries, but also several other sectors, information derived from studies on impacts of cross-river obstacles on fish and aquatic ecosystems, as well as on people's livelihoods and food security, should be publicized to enhance the awareness of policy makers and politicians. In addition, the issue of fish passage should not only be judged from a technical perspective.

78. The summary of the Workshop evaluation by participants appears as **Annex 32**.

79. *Mr. Marmulla* from FAO expressed his appreciation to all participants for their active participation and interactions during the Workshop. Based on the views conveyed by the SEAFDEC Member Countries, he expressed his appreciation that participants are looking forward to applying the knowledge gained from this Workshop in their respective home countries. He further informed on the possibility for countries to request FAO assistance through FAO's Technical Cooperation Programme (TCP) for addressing specific technical problems, including those related to fish passage. However, this is subjected to the priority identified by the respective government. In order to acquire support from the FAO/TCP, the relevant ministry of the respective country would have to include the issue in its priority list, and the request for support should be channelled through the FAO Country Representative. He further expressed his gratefulness for all comments made by the participants, and wished that this Workshop would contribute in one way or another to make fisheries more sustainable.

80. The resource person, *Mr. Gebler,* expressed his appreciation to the SEAFDEC Secretary-General and staff for the preparation and conduction of this Workshop and to all participants for sharing their views and providing inputs throughout the discussions. *Mr. Zitek* further added on the original intention of this Workshop to bring together the ecological and engineering aspects for designing effective fish passes, which has proved to be a good approach in Europe. The workshop, therefore, represented a good opportunity to share with all the participants the relevant information on what has been developed in Europe and North America through this kind of approach; this could be used as a basis to develop adequate solutions for the Southeast Asian region.

XXII. CLOSING OF THE WORKSHOP

81. *Mr. Pongsri* expressed his appreciation to all participants for their active participation in the Workshop. He informed that the intention of this Workshop was to bring together ecologists, biologists and engineers to discuss and review designs of appropriate fish passage facilities, taking into consideration the specificities of the region. It is, therefore, anticipated that this Workshop would be a starting point to enhance further coordination and communication among concerned officers in the respective countries. He further emphasized that in addition to fish passage facilities, there are also other methods and alternative ways to mitigate impacts from cross-river obstacles. In addition, as fishery is only a small sector among other priority sectors, fisheries may not receive high priority in the overall national development agenda. It is therefore necessary for the fishery sector to have at hand concrete technical information to support communication with the other relevant sectors and create awareness and understanding on relevant issues. He then highlighted the need for tools to quantify resources in terms of monetary value in order that the figures could be used for discussion/negotiation with other sectors when necessary. He further noted that as most countries in the region still have no fish passage facilities, the knowledge gained from this Workshop should be taken into account in proposing measures that could mitigate impacts from cross-river obstacles in the future. He then expressed his appreciation to FAO, ACIAR, MRC, the resource persons, as well as to all participants for their contributions and support, which allowed this Workshop to come up with successful results.

Annex 1

WORKSHOP PROGRAM

Saturday, 16 March 2013

Arrival of participants

Sunday, 17 March 2013

07.30-17.00 **Field scientific excursion to selected sites of interest for fish passage**

- Chonnabot Barrage, Chonnabot District, Khon Kaen Province
- Maha Sarakham Barrage, Kosumpisai District, Maha Sarakham Province
- Nong Wai Weir, Nam Phong District, Khon Kaen Province
- Ubolratana Dam, Ubolratana District, Khon Kaen Province

Monday, 18 March 2013

9:00

Opening of the Workshop

- Remarks by Dr. Chumnarn Pongsri, SEAFDEC
- Remarks by Mr. Gerd Marmulla, FAO

Importance of fish passage (G. Marmulla)

Short country presentations on existing fish passage facilities, the need for fish passage facilities, and fish passage facilities planned and/or under construction (Workshop participants)

- Cambodia
- Indonesia
- Lao PDR
- Malaysia
- Myanmar
- Philippines
- Thailand
- Vietnam

General ecological considerations for building fish passes (A. Zitek)

12:30 – 13:30 Lunch break

13:30 **Swimming and orientation-behaviour of fishes in upstream direction** (A. Zitek)

Location of fish passage facilities and attraction (R. Gebler)

- Optimal position of a fish pass (large-scale, weir, hydropower plant)
- Attraction flow at the outlet of a fish pass (discharge, angle, velocity)

Fish species and behaviour of different species in Southeast Asia (A. Zitek)

Common types of fishways – examples of well-functioning fish passes (R. Gebler)

Overview of close-to-nature (rock ramp, fish ramp, fish pass, bypassing water course) and technical (vertical-slot pass, pool pass) fishways with examples. In addition fish lock, fish lift and “Trap and Carry”.

Analysis of functionality of different types of fish passes – major reasons for disfunctionality (A. Zitek)

Tuesday 19 March 2013

8:30

More detailed information about relevant types for Southeast Asia (R. Gebler)
e.g. rock ramp, bypassing water course and vertical-slot pass

Ecological requirements for the construction of fish passes (A. Zitek) – How to establish/select the main parameters important for passage (a basic requirement to define design criteria)

General hydraulic design (R. Gebler)
- Elementary hydraulics
- Required amount of pools
- Required pool and opening/slot dimensions
- Flow velocity in an opening/slot
- Power density

Close-to-nature fishways (R. Gebler)
- Discharge and cross bar design
- Proof of stability

Vertical-slot passes (R. Gebler)
- Length/width – ratio of a pool
- Discharge

12:30 – 13:30 Lunch break

13:30 **Technical details** (R. Gebler)
- Design of the intake (headwater)
- Design of the outlet (tailwater)
- Lighting conditions
- Construction work

Overview of river types and relevant fish fauna (A. Zitek)

Case study: close-to-nature fish pass at a weir (R. Gebler)
- Basic evaluation (relevant fish, hydrology, etc.)
- Selection of the optimal construction type and inner design
- Spacial arrangement
- Determination of the required amount of pools
- Pool and opening design
- Proof of Stability

Wednesday, 20 March 2013

8:30 **Case study: vertical-slot pass at a power station** (R. Gebler)
- Basic evaluation (relevant fish, hydrology, etc.)
- Selection of the optimal construction type and inner design
- Spacial arrangement
- Determination of the required amount of pools
- Pool and opening design

	Monitoring (A. Zitek/R. Gebler)
	Maintenance of fishways (R. Gebler)
12:30 – 13:30	Lunch break
13:30	**Ecological requirements downstream migration** (A. Zitek)
	Orientation-behaviour of fishes in downstream direction (A. Zitek)
	Downstream migration facilities – technical aspects (R. Gebler)
	Feedback from the participants (C. Pongsri/G. Marmulla)
	Closing of the Workshop (C. Pongsri)

Thursday, 21 March 2013

8:30	Departure of the participants
10:00	**Wrap-up meeting** (C. Pongsri/G. Marmulla/A. Zitek)

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Annex 3

REMARKS

By Dr. Chumnarn Pongsri
Secretary-General, SEAFDEC

Delegates from the ASEAN Member Countries,
Representatives from FAO and MRC Fisheries Program,
Colleagues,
Ladies and Gentlemen,

Good morning!

First of all, I wish to welcome all of you once again to the "Workshop on Fish Passage in Southeast Asia: Principles of improved fish passage at cross-river obstacles, with relevance to Southeast Asia" to be organized from 17-20 March 2013; although we have already started part of the Workshop program since yesterday, with the excursion program to visit several fish passage facilities in Khon Kaen and nearby area. I hope that through the excursion yesterday, all of us would have some common grounds and understanding for further discussion during the Meeting sessions, starting from today until Wednesday.

The issue of fish passage is very relevant to the Southeast Asian region, considering the importance of inland fisheries for the livelihood and food security of people, particular the poor and the marginal groups. Inland fisheries in the region have been characterized by involving large number of fishers which in most case are only part-time, finding fish mainly for subsistence purpose. Fishing activities are highly seasonal; while the composition of catch are highly diversified with multi-species of fish. However, these aquatic species rely very much on the availability of different types of habitats in order to fulfill their life cycle, starting from breeding, nursing, and grow-out stages; and therefore the inter-connectivity of habitats is necessary to ensure their survival and biodiversity of species in the ecosystems. Fishery activities are also integrated closely with other sector sharing the same water resources, such as agriculture, irrigation, hydro-power generation, tourism, and many others; and therefore the impacts from one sector to another could not be avoided.

Fishery resources have however always been taken for grant for its existence. Due to the unavailable data and information that demonstrates its importance, the sector has received low recognition from planner and policy makers. Development projects, including the construction of cross-river barrier, which we will discuss at this Workshop, rarely take into account the possible impacts to fishery resources, particularly to the inter-connectivity of habitats, and created large extent of impacts to fishery resources and their biodiversity.

Although fish passage have been constructed in some countries, and even embedded as requirements for the construction of cross-river barrier like in Thailand; but these do not really lessen the impacts from cross-river obstacles, as there are several factors that need to be considered, particularly the construction and operation that need to take into consideration various aspects, including biological, environmental and hydrological aspects. This Workshop is therefore a good opportunity that we have participants with different backgrounds and expertise to discuss, in order that we could have better understanding on the status and issues relevant to fish passage for cross-river obstacles in your respective countries. And with your valuable inputs, I do believe that this workshop would be able to come up with fruitful results, which could pave the way towards the improvement of fish passage and the sustainability of inland fisheries in our region.

On behalf of SEAFDEC and the Member Countries, I am thankful to the important supporters to this workshop, particularly the Food and Agriculture Organization of the United Nations, and the Australian Center for International Agricultural Research that provide financial supports to this Workshop, as well as the Mekong River Commission that kindly also supports several participants from the riparian countries and the MRC Fisheries Programme to be here with us.

For SEAFDEC, although at this stage we don’t really have technical program that work on fish passage, but we always acknowledge the importance of this as ways and means to enhance the connectivity of inland habitats, and ensure the biodiversity of aquatic species as well as sustainability of inland fishery resources; and we would further explore possibility to include this into our programs of activities in the future.

With that, I wish to end my Remarks. Thank you very much, and wish you have a good day and fruitful discussion.

Annex 4

REMARKS

By Mr. Gerd Marmulla
Food and Agriculture Organization of the United Nations (FAO)

Distinguished Dr. Pongsri, Secretary-General of SEAFDEC,
Distinguished representatives of MRC and ACIAR,
Dear Workshop participants,
Dear colleagues and friends,
Ladies and Gentlemen,

On behalf of FAO, it is my great pleasure to welcome you to the Opening Ceremony of this Workshop.

First of all, it is a great pleasure for me to be here in Khon Kaen and I would like to express my deep appreciation to Dr. Pongsri for his words of warm welcome to Thailand and Khon Kaen. I would like to thank SEAFDEC for their willingness to organize this Workshop and for having so willingly engaged in the Agreement with FAO that covers this Workshop. My very particular thanks, however, go to Dr. Pongsri who, together with his team, tirelessly made all efforts to get all the practical issues so well arranged for this Workshop!

It is a great pleasure for me to welcome here participants from eight SEAFDEC Member Countries, *i.e*. Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Thailand and Vietnam, as well as participants and experts from partner organizations.

The countries of the region, that SEAFDEC covers, host a couple of important freshwater fish species, including the Mekong Giant Catfish, a flagship species. There exist, however, in the rivers of the Region also many other fish species that undertake even extensive migrations upstream and downstream – a need to satisfy their lifecycle requirements.

Migrations, be they long-distance migrations or shorter movements, are a critical lifecycle feature of many fish. Longitudinal and lateral passage in the form of movements or migrations is very important for many fish species to successfully complete their lifecycles. Physiological requirements of fish need to be satisfied, *e.g.* through migrations to reach spawning and nursing grounds; through feeding migrations to ensure food availability for growth; through migrations to satisfy seasonal habitat preferences and/or the need for shelter and protection against environmental influences or predators; through migrations for recolonization of river stretches after impacting events such as flooding or deterioration of water quality. All this is essential to the viability of populations of many riverine species.

Migrations and movements are also important to maintain genetic diversity and sometimes they even directly contribute to the influx and exchange of material such as nutrients. Hence, the diversity of communities of living aquatic organisms (including fish) is very important for the productivity, stability (in terms of resistance and resilience) and aesthetics of inland water ecosystems. It is well recognized that biodiversity in fish communities is important for fisheries as only genetically diverse fish communities and populations can form the basis of a shriving and sustainable fishery.

The construction of cross-river obstacles, *e.g*. dams and weirs, for various purposes including hydropower production, continues throughout this wider Region and many of these dams and weirs have a negative impact on fish by hampering or blocking migrations. Dams and weirs – and not only those on big rivers – negatively impact fish migrations, and hence the biodiversity and the resilience of fish populations. This, in turn, has impacts on the fisheries but these impacts are not seldom underestimated or downplayed, especially by the dam promoters and hydropower lobbyists. Stocking alone is not a viable option. In fact, it is often seen that released fingerlings have little or no chance to survive or grow due to the release conditions and the behavior which can be different from naturally grown-up fish. Therefore, it needs a more sustainable approach. In general, it is now widely recognized that stocking can not successfully replace the natural reproduction in the long term and therefore natural reproduction has to be fostered. In recognition of the importance of biodiversity and the role that natural reproduction plays in this respect, the protection and conservation of, and the access to, the relevant natural aquatic environment is receiving increased attention and is explicitly addressed by several international instruments, *e.g.* the Convention on Biological Diversity (CBD), the Ramsar Convention, the FAO Code of Conduct for Responsible Fisheries and related Technical Guidelines, as well as the EU Habitat and Water Framework Directives, to mention only a few. Fish passage facilities are generally aiming at re-establishing fish migrations at human-made barriers.

This Workshop on "Principles of Improved Fish Passage at Cross-river Obstacles, with Relevance to Southeast Asia" aims at raising the general awareness of the usefulness, but also of the limitations, of fish passage facilities. This Workshop is meant to show what has been developed concerning fish passage facilities on a global scale and what conclusions might be drawn from this knowledge for the Southeast Asian region. However, under **no circumstances**, this Workshop must be seen as an encouragement to construct new dams because we learnt how to design and construct fish passage facilities!

I do not want to go into details of the course curriculum now but I can promise you that my colleagues Dr. Gebler and Dr. Zitek, who are leading experts in fish passage issues on a global scale, both in terms of engineering and ecology, and who have a very long experience, as well as Dr. Pongsri and myself have done our best to put together an interesting programme covering both theoretical and practical aspects. Here, I would like to take the opportunity to express my sincere gratitude to Dr. Gebler and Dr. Zitek for having readily accepted to serve as resource persons for this Workshop.

With these remarks, and my renewed thanks to Dr. Pongsri and his team, I wish this Workshop every success.

Thank you.

IMPORTANCE OF CONSERVATION AND REHABILITATION OF FISH PASSAGE

By Gerd Marmulla

Importance of conservation and rehabilitation of fish passage

by

Gerd Marmulla

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The website of the Fisheries Department is:
http://www.fao.org/fi/default.asp
http://www.fao.org/fi/debut.asp
http://www.fao.org/fi/inicio.asp

Objective of this presentation

- Briefly introduce FAO
- Fisheries and environmental aspects
- Importance of biodiversity
- Fish passage: Relevant practices and a **WARNING**
- FAO's work in the field of fish passage
- Closing remarks

FAO/SEAFDEC Workshop „Fish Passage in Southeast Asia", Khon Kaen, Thailand, 16 - 21 March 2013

FAO – what it is

FAO was founded in 1945 with a mandate to:

- raise levels of nutrition on a global scale
- raise standards of living
- improve agricultural (fisheries) productivity
- better the condition of rural populations.

FAO today: UN lead agency for nutrition, agriculture, forestry, fisheries and rural development

FAO/SEAFDEC Workshop „Fish Passage in Southeast Asia", Khon Kaen, Thailand, 16 - 21 March 2013

FAO – what it does

Normative work

Information
- collects, analyses, interprets and disseminates information relating to nutrition, food, agriculture, forestry, fisheries and rural development

Advice to Governments
- provides independent advice on agricultural policy and planning

Neutral forum
- provides a neutral forum for discussion and policy formulation
- organizes specialized Conferences (e.g. on agriculture, nutrition, fisheries etc.)

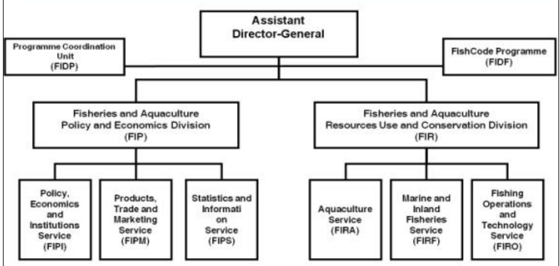
Field work (projects)

Development assistance
- gives practical help through technical assistance projects, (*integrated approach*, e.g. environmental, social and economic considerations)

http://www.fao.org/

FAO/SEAFDEC Workshop „Fish Passage in Southeast Asia", Khon Kaen, Thailand, 16 - 21 March 2013

Fisheries and Aquaculture Department



FAO/SEAFDEC Workshop „Fish Passage in Southeast Asia", Khon Kaen, Thailand, 16 - 21 March 2013

Fisheries and Aquaculture Resources Use and Conservation Division

Fisheries and Aquaculture Resources Use and Conservation Division (FIR)
- responsible for all programmes and activities related to the sustainable management of fisheries and aquaculture
- provides advice, assistance and information to FAO Members on the effective identification and appraisal of the world living aquatic resources in marine and inland ecosystems

Marine and Inland Fisheries Service (FIRF)
- responsible for all programmes and activities related to management and conservation of fisheries resources, including biodiversity and ecosystem maintenance, with particular emphasis on threatened species and vulnerable habitats in marine and inland waters

Inland Fisheries Group
- reviews and evaluates the use of inland water resources for fisheries, and promotes their better management
- promotes sound environmental management practices in all freshwater environments

FAO/SEAFDEC Workshop „Fish Passage in Southeast Asia", Khon Kaen, Thailand, 16 - 21 March 2013

World fish production in 2011 (Mio t)

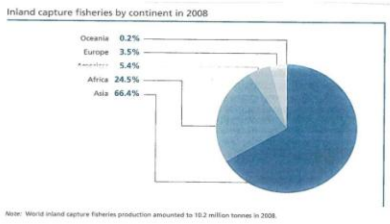
Total world fish production: 154.0

Inland capture fisheries: 11.5 (7.5%)

Global food security: 15-16% of total animal protein comes from fish

FAO/SEAFDEC Workshop „Fish Passage in Southeast Asia“, Khon Kaen, Thailand, 16 - 21 March 2013

INLAND CAPTURE FISHERIES BY CONTINENT (2008)



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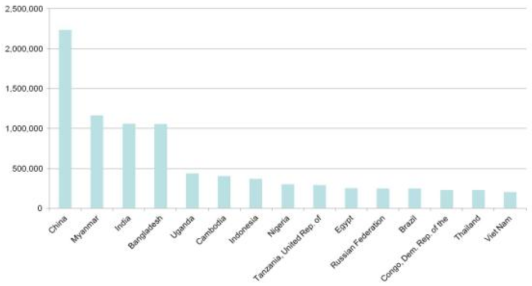
Top 15 countries in World Inland Capture Fisheries Production (t) in 2011



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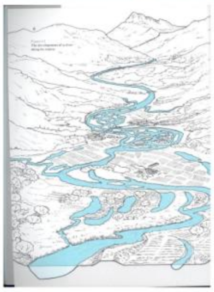
Aquatic biodiversity/river features



Riffles
Pools
Non-floodable land
Islands
Active side arms
Bottomlands
Blind side arms
Floodplain lakes
Floodable grassland
Natural levee
Main channel

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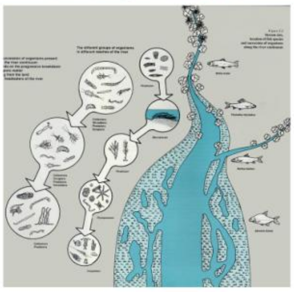
River continuum and succession of organisms



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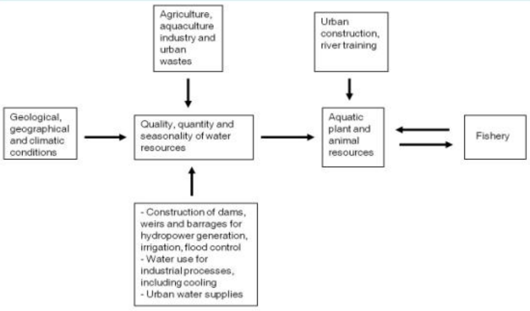
Multi-user impacts on aquatic resources



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THREATS TO FRESHWATER BIODIVERSITY


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In-stream barriers (e.g. dams and weirs)

- direct impacts
  - interrupt upstream and downstream migration
- indirect impacts
  - transform habitats (from riverine to stagnant)
  - change physical and chemical conditions of the water
  - change in species composition
  - increased predation

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Relevance of free fish passage for riverine biodiversity

Longitudinal and lateral fish passage

Free fish passage necessary to
- satisfy physiological needs of fish (and other aquatic animals)
  - spawning
  - nursing and feeding
  - habitat preferences (summer/winter habitat)
  - shelter
  - recolonization

→ essential to the viability of populations of many riverine species
- maintenance of genetic diversity
- ensure a nutrient influx in upstream river zones
  - absence of decaying salmonid carcasses led to nutrient impoverishment

Diversity of communities of living aquatic organisms is important for the productivity, stability (resistance and resilience) and aesthetics of inland water ecosystems

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International instruments

Recognition of importance of biodiversity

Protection and conservation of the aquatic environment and its biodiversity is required by several international instruments

Convention on Biological Diversity (CBD)
Ramsar Convention
FAO Code of Conduct for Responsible Fisheries
EU Habitat and Water Framework Directives

The value of the aquatic ecosystems lies in the sustained net benefits derived *from the many goods and services*

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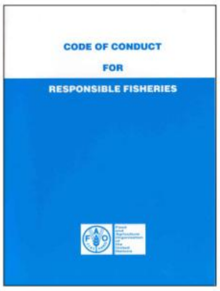
FAO Code of Conduct for Responsible Fisheries



- sets out principles and international standards of behaviour for responsible practices with a view to ensuring the effective conservation, management and development of living aquatic resources, **with due respect for the ecosystem and biodiversity**
- takes into account the biological characteristics of the resources and **their environment** and the interests of consumers and other users

The Code is voluntary but states and all those involved in fisheries are encouraged to apply the Code and give effect to it.

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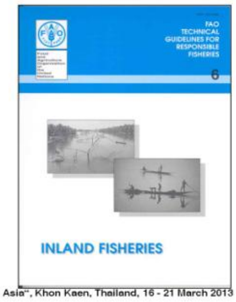
FAO Technical Guidelines for Responsible Fisheries

- Interpret the Articles of the Code
- Provide guidance for actions



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CCRF / Technical Guidelines

Technical Guidelines

Current fisheries management: three components
- Management of the fisheries: regulation of activities etc
- Management of the fish: stocking, introductions, etc.
- **Management of the environment:**
  - maintain or restore longitudinal and lateral connectivity in rivers in the interests of conserving fish migration
  - promoting physical improvements, including construction of fish passes, to increase the support capacity for fish

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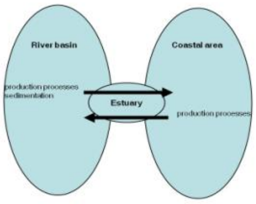
Conservation of the aquatic ecosystem



Technical Guidelines:

- Conservation of inland aquatic resources: **basin approach**, i.e. take into consideration *all uses* including fisheries
  ► Advocate sound management of the environment for fisheries
  ► Negotiating and arranging for adequate environmental conditions
- Reference to "*User-pays principle*" but first premise is: the users should **minimize any deleterious effects**
- Conservation much cheaper than rehabilitation or restoration!

Government, at all levels from central to local authorities should set up mechanisms to conserve living aquatic resources compatible with the sustainable use of the basin, the aquatic ecosystem and the water for the whole range of economic and social purposes.

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Protection and restoration of fish movements

Any obstruction (weirs, dams etc.) regardless of its height can constitute a barrier to migration

Upstream and downstream passage must be considered

Protection:
- avoid construction of cross-river obstructions, i.e. look for alternatives

Restoration:
- decommission (remove) an obstacle
- build fish passage facilities

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Protection of fish movements

- Avoid construction of cross-river obstructions, i.e. look for alternatives
  - As any obstruction (weirs, dams etc.) regardless of its height can constitute a barrier to migration
- Environmental Impact Assessment (EIA) should **look at the fish fauna**; Environmental Management Plans (EMPs) should be implemented during the design and pre-construction phase

Restoration of fish movements

For existing obstacles, first consideration should be: is decommissioning (removal) possible?

- restoration of connectivity
- restoration of habitat

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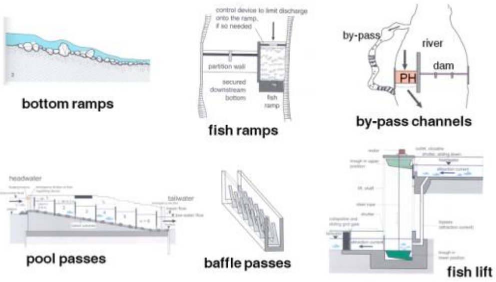
Second option: Different types of fish passes



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General requirements for all types of fish passes

- Positioning of the entrance: correct choice is most important
- Sufficient attraction: discharge through the pass in relation to turbine discharge
- Sufficient capacity: chose the right dimensions
- Design adapted to the swimming capacities of the fish (all life stages); important criteria: amount of volumetric power dissipation
- Permanently functional: ideally round the year and under different flow discharges (important: migration seasons!)
- Consider also downstream migration!

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Downstream migration

- Over the weir/dam (spill)
- Through turbines
- **Through bypass**
- **(Catch and transport)**

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Fish monitoring

Comprehensive monitoring programme:
- 1-2 years minimum
- to check if pass is functioning well
- to make predictions about the development of the fish population upstream
- Make improvements to the general design (important for future constructions)
- Based on monitoring, prepare/improve management plan of the upstream basin

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WARNING!!!!!

HAVING THE KNOWLEDGE ON HOW TO DESIGN AND CONSTRUCT FISH PASSES

MUST NOT

BE TAKEN AS A JUSTIFICATION TO CONSTRUCT DAMS AND WEIRS!

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FAO and fish passage (1)

Based on the CCRF and the Technical Guidelines, FIRF implements, *inter alia*, an activity on prevention of habitat degradation and rehabilitation of inland fisheries, including considerations regarding fish migration and mitigation measures

Normative work

- EIFAAC (until 2011: EIFAC)
  - WP on the Effects of Physical Modifications of Aquatic Habitats on Fish Populations (1990-1998)
  - Symposium on Hydropower, flood control and water abstraction: implications for fish and fisheries (2006) http://link.springer.com/journal/10750/609/1/page/1
  - Project on Fish Passage Best Practices (active)
- Cooperation with World Commission on Dams (1998-2000)
- Cooperation with UNEP Dams and Development Project
  - FAO Member of Dams and Development Forum (Compendium on relevant practices for improved decision-making, planning and management of dams and their alternatives)

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FAO and fish passage (2)

Normative work

- Inland fisheries (FAO Technical Guidelines for Responsible Fisheries; FAO, 1997) http://www.fao.org/DOCREP/003/W6930E/w6930e00.htm
- Revival of northern Europe's rivers offers lessons for elsewhere (http://www.fao.org/news/1997/970403-e.htm; FAO News and Highlights 1997)
- Rehabilitation of rivers for fish (FAO/Fishing News Books, 1998)
- Some aspects of rehabilitation and mitigation for inland fisheries (in: Review of the state of world fishery resources - Inland fisheries; FAO Fisheries Circular No. 942; FAO, 1999)
- Dams, fish and fisheries – Opportunities, challenges and conflict resolution (FAO Technical Paper No. 419; FAO, 2001) ftp://ftp.fao.org/docrep/fao/004/Y2785E/y2785e.pdf

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FAO and fish passage (3)

- Fish passes – Design, dimensions and monitoring (original in German by DVWK, 1996; English edition by FAO/DVWK, 2002) http://www.fao.org/docrep/010/y4454e/y4454e00.htm
- Fishways: biological basis, design criteria and monitoring (original in French by CSP, 1992; English edition by FAO/CSP/Cemagref, 2002)
- Dams, fish and fisheries: A challenge for fishery managers and engineers (in: The state of world fisheries and aquaculture; FAO, 2002)
- Mountain fisheries in developing countries (FAO, 2003) ftp://ftp.fao.org/docrep/fao/005/Y4633E/Y4633E00.PDF

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FAO and fish passage (4)

- Dams and fisheries (in: Review of the state of world fishery resources - Inland fisheries; FAO Fisheries Circular No. 942, Rev.1; FAO, 2003)
- FAO Technical Guidelines for rehabilitation of inland waters for fisheries ftp://ftp.fao.org/docrep/fao/011/i0182e/i0182e.pdf

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FAO and fish passage (5)

Field work

- TCP in Lithuania: Assistance in the restoration of the migration routes of the Baltic sea salmon
- TCP in Estonia: Re-opening of migration routes for salmon and other migratory fish in Estonian rivers
- TCP in Poland: Re-opening of migration routes for migratory fish in Polish rivers

Countries interested

- Azerbaijan, Georgia, Romania, Russian Federation, Serbia, Turkey,

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Closing remarks

- FAO promotes the concept of sustainability in the use of resources
- Sustainable development does not only mean improved fisheries management in *sensu strictu* but also sound ecosystem management
- Management advise on best practices can be based on existing agreed principles, e.g. the CCRF and the Technical Guidelines
- FAO strongly advocates to apply a basin approach
- Avoiding or mitigating negative impacts is very much a question of negotiations and consultations with other stakeholders in the basin
- FAO advocates the rehabilitation of the aquatic environment as a proper tool for management of inland waters for fish and fisheries
- where appropriate, FAO advocates the re-opening of obstructed fish passage for upstream and downstream migration, aiming at improved fish stocks and improved biodiversity
- Missing information not an excuse for doing nothing
- Develop suitable, adapted technologies (based on information exchange)
- **Work together: involve biologists, engineers, administrators and managers**

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Acknowledgements

Photos

- Decommissioned dam by **Dr. Michel Larinier**, Toulouse, France
- Fish kill: www.klamathforestalliance.org/Images/newsarti...

Drawings taken from

- FAO/Fishing News Books "Rehabilitation of rivers for fish"
- BFPP: Fishways – biological basis, design criteria and monitoring
- FAO/DVWK: Fish passes – Design, dimensions and monitoring

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Annex 6

FISH PASSAGE IN CAMBODIA

I. OVERVIEW

Cambodia covers an area of 181,035 km^2, approximately 450 km north-south and 580 km east-west. Two key physical features dominate the country: the Great Lake and the Mekong/Bassac/Tonle Sap river system. These, along with the coastal waters, provide the basis of the fishery of the country. Linked to the lake and river system is a fertile plain that stretches from the lake to the Mekong delta. There are some 35,000 km^2 of wetland in Cambodia of which 20,000 km^2 are on the edges of the Mekong and 15,000 km^2 are around the Tonle Sap Lake. The country enclosed by a circle of mountains that has historically focused development in the areas surrounding the lake and plains. The wet season, when 80% of the annual rain falls, is generally between May and October and the dry season is between November and April – this hydrological cycle has largely defined the phasing of the agricultural and fisheries activities of the rural people of Cambodia. The hydrological cycle results in the filling up and draining of the Great Lake and the inundation of adjacent forest areas, during which time the Great Lake increases its depth from 1-2 m up to 10 m and its surface area from 3,000 km^2 to between 10-14,000 km^2. Associated with this is the reversal of the flow of water in the Tonle Sap River: from June to November the Tonle Sap River flows north-west, for the rest of the year it flows south-east. The flooding of the forest around the Great Lake releases large amounts of nutrients into the water and provides access to food that is normally not available to the fish. This is a period of breeding for the fish that use the greatly increased flooded forest habitat as a nursery area and where food is plentiful. In general, the larger the flood is the greater fish production in a given year. The Tonle Sap Lake is 300 km long and 100km wide during the rainy season (compared with 160 km long and 35 km wide in the dry season).

Inland Fisheries have long been central to Cambodia lifestyles, particularly communities living in and around the Tonle Sap Lake. Fisheries from Tonle Sap areas contribute about 60 percent of Cambodian total inland fisheries production, or between 200,000 to 218,000 tonnes based on average productions from 2005-2010. Fishing is generally categorized into three types or scales: family fishing (or small-scale, including fishing in the rice field), middle scale fishing and large-scale fishing (or fishing lots). The national fisheries production of the country is ranked between 370,000 and 575,000 tonnes.

Recently study conducted by IFReDI found that, Cambodian diet is a combination of rice, fish and vegetables. After rice, aquatic resources are the second largest dietary component at about 18% of the total food intake. Inland fish consumption amounts to 40.3 kg/person/year, marine fish reaches 16.2 kg/person/year, and aquaculture contributes only 2%. Based on fish consumption figures, the annual yield of inland fish amounts to 570,000 tonnes, rising to 625,000 tonnes when other aquatic animals are included. Long distance migratory fishes (*i.e.* white fish such as *Henicorhynchus* mud carps -trey riel- or *Pangasius* catfishes –trey pra-) represent 25% of the total fish catch; this fish group is very sensitive to dam development due to blockage of migration routes. The economic values (first sale values) of freshwater fish and aquatic products are estimated at US$ 1 billion ($1.6/kg). If including all multiplier (value added, export, occupation etc..), the fishery is worth several times more than this figure and its replacement value is far higher. Inland fisheries are important in terms of both nutrition and income at both the family and national levels. Any changes to the availability of these resources are likely to have major negative impacts in terms of nutrition and income but also in terms of social equity.

II. CROSS-RIVER OBSTACLES IN CAMBODIA

Name of dam/weir	Height *(in meter above downstream water surface)*	Purpose & Responsible agency	Geographical location, river system, and hydraulic condition of the river	Important fish species in the ecosystems, and impacts from dams/weir to fisheries	Fish passage construction
Existing cross-river obstacles					
Stung Chinit	7	Irrigation/MOWRAM	Chinit river, Tonle Sap tributary, Kampong Thom province	NA	Yes

Name of dam/weir	Height *(in meter above downstream water surface)*	Purpose & Responsible agency	Geographical location, river system, and hydraulic condition of the river	Important fish species in the ecosystems, and impacts from dams/weir to fisheries	Fish passage construction
Chareuk	5	Irrigation/MOWRAM	Pursat river, Tonle Sap tributary, Pursat province	NA	No
Domnak Ampil	5	Irrigation/MOWRAM	Pursat river, Tonle Sap tributary, Pursat province	NA	No
Pursat	1.5	Weir, Domestic water use	Pursat river, Tonle Sap tributary, Pursat province	NA	No
Sangke	10	Weir, Irrigation	Sangke river, Tonle Sap tributary, Battambang province	NA	No
Tatay	NA	Hydro power/MIME	Tatay river, Kohkong province	NA	No
Reusey Chrum	NA	Hydro power/MIME	Tatay river, Kohkong province	NA	No
Atay	NA	Hydro power/MIME	Pursat river, Tonle Sap tributary, Pursat province	NA	No
Kamchai	NA	Hydro power/MIME	Kamchai river, Kampot province	NA	No
Kirirom	NA	Hydro power/MIME	Kirirom river, Kampong Speu province	NA	No
Au Romeas	NA	Hydro power/MIME	Au Romeas, Mondolkiri preovince	NA	No
Stung Prekthnoat	15	Irrigation/MOWRAM	Stung Prekthnoat, Kampong Speu	NA	No
Future plan cross-river obstacles					
Lower Sesan 2	NA	Hydro power/MIME	Sesan river, Stung Treng province	NA	No
Sre Pok 3	NA	Hydro power/MIME	Srepok river, Stung Treng province	NA	NA
Stung Treng	NA	Hydro power/MIME	Mekong river, Stung Treng province	NA	NA
Sambour	NA	Hydro power/MIME	Mekong river, Kratie province	NA	NA
Stung Staung	NA	Multi purposes Hydropower Dam/MIME/MOWRAM	Stung Staung river, Kampong Thom province	NA	NA
Pursat 1	NA	Multi purposes Hydropower Dam/MIME/MOWRAM	Pursat river, Tonle Sap tributary, Pursat province	NA	NA
Stung Sangke1-2	NA	Multi purposes Hydropower Dam/MIME/MOWRAM	Sangke river, Tonle Sap tributary, Battambang province	NA	NA
Stung Sen	NA	Multi purposes Hydropower Dam/MIME/MOWRAM	Stung Sen river, Kampong Thom province	NA	NA

III. FISH PASSAGES IN CAMBODIA

Any cross-river obstacles in Cambodia have to comply with numerous of low, regulation and guideline, *e.g.* EIA guideline, Fisheries Law, Water Law, however, the inclusion of fish passages in the construction is not compulsory.

Existing fish passage

Location *(name of dam/weir)*	**Type/design of fish passage**	**Responsible agency** *(operation)*	**Data on effects of existing dams/weirs on fisheries before and after fish passage construction**
Stung Chinit	Single-jet vertical slot	RUA/MOWRAM	DOM, MOWRAM

Fish passage is one amongst the fish migration management tool, however, the inclusion of the fish passage in the river obstacle construction is not compulsory by law, it's fully depended upon the EIA of the project for which decided through many steps of the consultation, line agencies EIA reviewing. The knowledge of fish passage is very new and limited for the region. The application of passage technics in the Mekong context is problematic due to huge amount of migrating species in the system. Thus, in order to have the effective passages to accommodate a certain amount of the migrants, the region and country need to understand well about bio-ecological of the Mekong species, the migration behaviors, their ability to pass the passages, appropriate water velocity, engineer design, level of the loss and its subsequences impact on fisheries natural resource and people livelihood, etc.

Annex 7

FISH PASSAGE IN INDONESIA

I. OVERVIEW

1.1 Geographical information

Indonesia lies in the tropics (Latitude 6 ° - 11 º N , longitude 95 º - 141 ºE) and lying between Pacific Ocean and Indian Ocean (Figure 1). Indonesia is an archipelagic country extending 5,120 km (3,181 mi) from east to west and 1,760 km (1,094 mi) from north to south. It encompasses an estimated 17,508 islands, only 6,000 of which are inhabited. It comprises five main islands: Sumatra, Java, Borneo, Sulawesi, and New Guinea; two major archipelagos (Nusa Tenggara and the Maluku Islands); and sixty smaller archipelagoes. Four of the islands are shared with other nations: Borneo is shared with Malaysia and Brunei, Sebatik, located eastern coast of Kalimantan, shared with Malaysia, Timor is shared with East Timor, and the newly divided provinces of Papua and West Papua share the island of New Guinea with Papua New Guinea. Indonesia's total land area is 1,919,317 km^2. (741,052 sq mi). Included in Indonesia's total territory is another 93,000 s km^2. (35,908 sq mi) of inland seas (straits, bays, and other bodies of water). The additional surrounding sea areas bring Indonesia's generally recognized territory (land and sea) to about 5 km^2. The government, however, also claims an exclusive economic zone, which brings the total to about 7.9 million km^2 (Faizah, 2011).

Indonesia has 5,590 main rivers with total length 94,573 km and about 65,017 small rivers. Inland open waters of Indonesia has a total surface area of 13.85 million ha consisted of 12.0 million ha rivers and flood plains, 1.8 million ha natural lakes and 0.05 million ha man-made lakes or reservoirs. Indonesia has around 840 lakes and 735 "*situ*" (small lakes) and around 162 reservoirs. An area of inland open waters equal to 65% from total area located in Kalimantan, 23% in Sumatra, 7.8% in Papua, 3.5% in Sulawesi, and 0.7% in Java, Bali and Nusa Tenggara. The area of inland waters is constantly changing due to fluctuating water between rain and dry season, and because the formation of new dams, reclamation of wetlands and conversion of waters inland land for other activities (Rahardjo *et al*., 2007).

1.2 Resources and Productivity

Inland water is a resource that has an important role and an absolute necessity for human beings and other creatures. Indonesia has fresh water resources about 1,789 km^3 of surface water (Lehmulusluoto, 2005), a volume that sufficient for the life of the people of Indonesia, where the quality and quantity can be maintained. (Rahardjo *et al*.,2007).

Among the capture fisheries of inland waters in the world, Indonesia on the fifth position of the 10 highest producers as shown in ***Figure 1*** (FAO, 2002). Contribution of fish production from 10 biggest producers of inland waters is 64% of the world's total fish production.

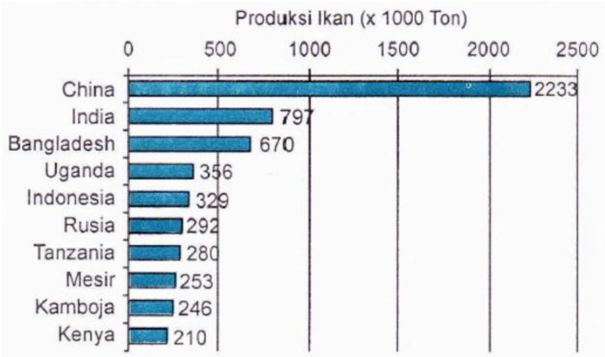

Figure 1. *World's fish production.*

An inland waters of Indonesia has a high diversity of fish species, so that the waters listed as one of the mega biodiversity in the world. Inland waters are containing up to 25% of the number of fish species in the world. In the inland waters of Indonesia includes Sumatra, Java, Borneo and Sulawesi is inhabited by more than 1000 species of fish (Kottelaat *et al*., 1993). Further explained that there are 798 sunda plat of freshwater fish species, in the Wallacea region there are 68 types of freshwater fish and Sahul plat are 106 types of freshwater fish. ***Figure 2*** shows the fish distribution region in Indonesia.

The most dominant species in lake catches located in Sundaland are native species such as *Barbonymus gonionotus*, *Puntius bramoides*, *Rasbora spp*, *Thynnichthys spp*, *Mystus spp*, *Channa striata* and *Oxyeleotris marmorata*. The dominant species catches in lakes located in Sahulland are native species of the family Apogonidae (*Apogon* spp), Eleothridae (*Ophiocara* spp, *Oxyeleotris* spp, *Glossogobius* spp) and Atherinidae (*Chilaterina* spp, *Atherinichthys* spp). In the reservoirs, the dominant fish species catches are mostly an introduced species such as Or*eochromis niloticus*, *O. mossambicus*, *Cyprinus carpio*, *Oxyeleotris marmorata*, and *Pangasianodon hypophthalmus*. The fish catches in the lakes/reservoirs are mostly the low trophic level species of plankton feeder or herbivorous as well as omnivorous species. The fish production in those lakes/reservoirs tends to increase and stabilize at an optimum level if the restocking activity conducted regularly and or the species introduced can spawn naturally. Generally, the fish catch composition in lakes/reservoirs tends to change and replaced by species introduced, especially by tilapia.

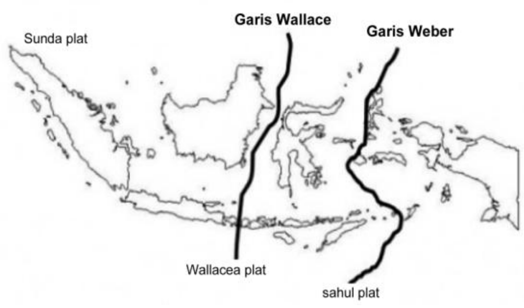

Figure 2. *Fish distribution region.*

The indonesian inland waters have the potency not only in resource of concumption but also the ornamental fish. Two freshwater fish of indonesia that been the export commodity are *Botia* sp. and *Scleropages* sp. (Dahuri, 2004). The estimation about fish productivity potential of inland water in Indonesia showed in ***Table 1*** (Aeron-Thomas *et al*, 2003 in Rahardjo *et al*, 2007). While the fish capture fisheries production of inland waters are presented in ***Figure 3*** (there is no special data of capture fish production in lakes/reservoirs).

Table 1. Fish productivity potential estimation of inland water in Indonesia.

Water ecosystem type	Area (ha)	Productivity potential estimation (ton / year)	Average Potential (kg/ha/year)
Lake	1.800.00	158.162	88
Reservoir	50.000	8.772	174
River and swamp	12.000.000	2.868.000	239

1.3 Stakeholders

An inland fisheries are a source of livelihood and employment for the poor and casual or seasonal workers. Work in 2002, fishermen operating in public waters around the mainland Indonesia recorded 618,500 people consisting of 141,000 full fishing, 370,000 primary part-time fisherman and 107,500 additional part-time fishermen (DG Fisheries, 2004). The number of fishermen are likely greater because many jobs other than fishermen engaged in fishing activities, such as fish traders, fish processors, boat builders and fishing equipment. In addition, fishing in inland public waters never have an identity and arrest of such license on fishing activities in the sea so that the number is difficult to set accurately.

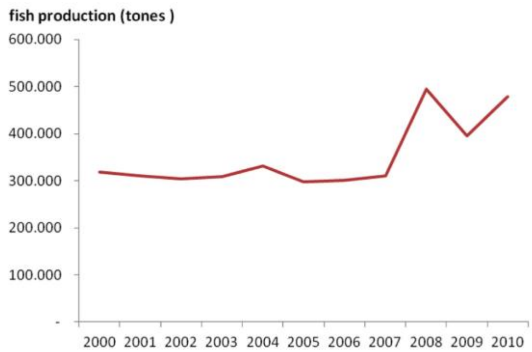

Figure 3. *Fisheries production of Indonesia inland waters.*

1.4 Cross-River Obstacles

In Indonesia, every business and/or activities that are likely to cause large and significant impacts on the environment must complete the requirements of the EIA (UU RI No. 23 of 1997: Article 18, paragraph 1). EIA assessment teams also come from various institutions including the central and local governments consist of government agencies, experts, organizations / NGOs, citizens of the affected communities. The activities related to cross river obstacle are (PP No. 27 Year 1999 on Environmental Impact Assessment), *i.e.*:

a. Conversion of landform and landscape;
b. Processes and activities that potentially can cause waste, pollution and environmental degradation, and the decline in the utilization of natural resources;
c. Processes and activities which could affect the natural environment, built environment, and the social and cultural environment;
d. Processes and activities which may affect the preservation of resource conservation and / or protection of cultural heritage;
e. Applied technology expected to have the potential effects for environment;

The process of issuing environmental impact of an activity (PP. 27 year 1999) shows in **Figure 4**.

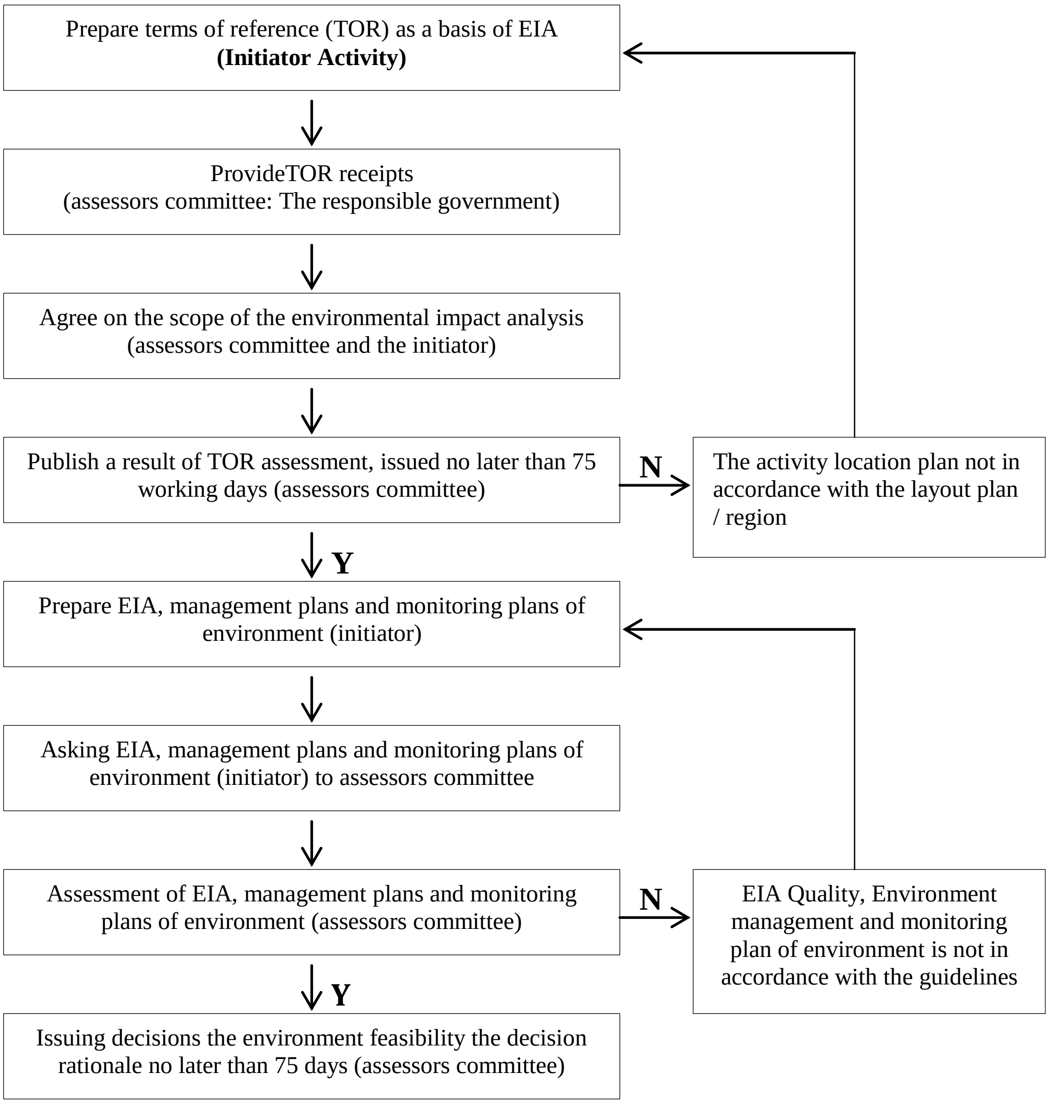

Figure 4. *The process of issuing the EIA in Indonesia*

At least 70% of Environmental Impact Analyses (EIA) in Indonesia examines the effects of a proposed project on freshwater ecosystem. An experienced limnologist (an expert on freshwater system) is not always available, and the researcher charged with this field is frequently a fisheries biologist. It is inevitable that the vast majority of fisheries biologist in Indonesia (in else where) are concerned primarily with those fish species with proven economic value. In the western and Sulawesi, this is perhaps less than 25 species – but there about 950 fish species in the region that live permanently or temporarily in freshwater. Clearly, such a large number of potentially or indirectly important species of vertebrae animals should not be overlooked. Many of these fish are not eaten, yet still play an important role in fisheries production by virtue of their position in the food web (Kottelat, 1993).

Problems in inland waters fisheries development is much happening today, one of them is fragmentation and habitat loss due to dam construction activities, irrigation and other infra structure. Another negative impact of dam construction activities are distrubing the fish flow migration, especially for fish that migrate for breeding purposes so fish populations cannot complete life cycle, at the end decline and even extinction. Hydropower plants and geothermal ranks second in the rankings after the energy supplier of biomass (firewood) in Indonesia, and continue to increase with average growth of 4.5%. The role of biomass predicted decline due to timber shortages and environmental problems related to forest conservation (Lubis, 1996). Indeed, than the other construction of power plants, hydropower is relatively safer from aspects of air and water pollution but also has an environmental impact. Hydropower development is often emphasized the positive aspects of the economic analysis, but sometimes not accurate in capturing the negative impacts of hydropower development. Over the country, 230 hydropower built.

By Lubis (1996), a number of challenges in implementing environmentally hydropower development are:

- Constructions of hydropower generally change the landscape significantly, causing the scale, distribution and scale (magnitude) becomes significant environmental impact;
- Construction of hydropower is often located in locations that have a large biodiversity (Borneo, New Guinea and Sulawesi) and the habitat of endangered species or historical sites;
- Hydroelectric Development in Java and other densely populated areas (Madura, Bali) has a socio-cultural impacts that very important, especially when it comes to resettlement and land compensation;
- Construction of hydropower, which takes a relatively long time lag causing the difficult identification, prediction and evaluation of impacts in the EIA study; and
- Construction of hydropower also cause cumulative impacts and regional impacts that often cannot be captured.

According to Kottelat (1993), the development project, including the construction of cross-river, may have one or more of the following effects:

- Direct destruction of habitat such as infilling of wetlands, removal of sand/gravel substrate, river channeling;
- Direct alteration of flow regime such as provision of in stream storage;
- Direct changes to the physical and chemical characteristic of the water such as discharge of chemical pollutants, temperature changes due to the discharge of cooling water from power plants;
- Alteration of watershed characteristic, such as loss of vegetation and resulting soil erosion, loss of storage due to land use changes resulting in accentuated flood or low flows; and
- Alteration of riparian or littoral vegetation. Exogenous food such as fruit and terrestrial invertebrates is important to many river fish, and the loss of waterside vegetation can have significant effects on fish communities.

II. CROSS-RIVER OBSTACLES IN INDONESIA

Name od Dam/Weir	Height (meter)	Purpose& Responsible agency	Geographical location river system and hydraulic condition of the river	Important fish species in the ecosystem and the impacts from dams/weirs to fisheries	Fish passage construction
Existing Cross-river Obstacles					
Lake Ranau, Silabung River, South Sumatera	550	PU	Discharge of water 18.5 m^3/s, area 508 Km^2, 4°51′45″S & 103°55′50″E	declining *Tor* sp. Population	no
Teluk Lake, Batanghari river, Jambi	16-23	PU	Lake Teluk 01°34 s and 103°35 E. Oxbow lake, atih area 40-60 ha, water volume 764,779 m^3. Batanghari River: area 8,704 km^2, volume $51.091x10^2$ m^3	Declining of fisheries production, fish structure comunity changes, conflict between fisherman, declining fisherman's income, nursery ground degradation	no
Perjaya Dam, komering River, South Sumatera (1991)		PU	Length 360 km, area 9,918 ha, discharge 195.1 m^3/s	Declining water discharge/flow, change of current pattern, sedimentation → fish structure community changing	yes
Kutopanjang Reservoir, Kampar River, Riau		PU	00°19'5,39" N, 100°44'3,79" E, area 24,548 km^2, Volume 5,231 km^3, discharge 750 – 1,000 m^3/s	Chitala sp., declining population of native and economic fish, changing of fish community	no
Cascade Dam (Saguling (1984), Cirata (1987), Jatiluhur (1965), Citarum River, West Java		PJB, PJT, Indonesian Power	6°31' S dan 107°23' E. length 270 km, volume =5.5 billion m^3, area 6,600 km^2.	Dam in Citarum River, has an impact on declining and lost of native fish populations. The number of native fish species prior to construction of the dam was built (in a period of 30 years), the number of species native ika only 3 species, and even then are rarely caught (Kartamihardja, 2004).	no
Kedung Ombo Reservoir , River Serang-Lusi-Juwana, Central Java		PU		Increasing the water level → disruption of fish habitat	no
Sermo, River Ngrancah and Bogowonto.Yogyakarta		PU	Area 157 ha, depth 13.7 volume between 10.4–18.3 million m^3	Loss of native species, structure community change	no
Reservoir Sempor, River Cincingguling, Central Java		PU		Loss of native species from Cincingguling River	no
Danau Moat, North Sulawesi		PU		Declining anguilla population	no
Under construction					
Sulewana Dam, Poso River, Central Sulawesi		PT. Poso Energy	0°10'-3 °40 S -& 120°10 - 123°23 E	May declining Anguilla population	yes

III. FISH PASSAGES IN INDONESIA

3.1 Legal issues

Until the day, Indonesia has not regulations related on building construction of fish passage. Perhaps the environment management plan in the EIA process planned the fish passage building to anticipate the water flow break that used for fish migration. However, the construction is currently unknown whether is adjusted based on the hydrological conditions in each area, or that are made on the generally basis constructions.

The outcome of the EIA process (the process is only 150 days of work), may not accommodate all the environmental aspects (*e.g*. population of fish resources and habitat conditions) that affected by the activity development (dam construction). Assessors committee will reject an activity if:

- A large and significant negative impacts will be generated by the business and / or activity in question cannot be addressed by the available technology; or
- A cost reduction of large and significant negative impact is greater than the benefit of a large and significant positive impact that will be generated by the business and/or activity concerned.

Mean, if the benefit of the construction finacially greater than the environment change, then the development of this cross-river obstacle will be implemented.

For the cross-river dam, we do not get concrete data or information on any fishery potential assessed in the EIA. Is including the loss of river native species even endemic fish or declining fish populations and economis fish production (*e.g.* eel)? Analysis of loss caused by this development may not carry out only within 150 days, as losses may not occur in the short term. This condition may minimize if the preparation of the EIA also included researchers of fisheries (fisheries biology, behavior, taxonomy, and potential).

3.2 Existing fish passage

Perjaya Dam, Komering River, South Sumatera

The impact: Causing the declining of river fish species (ornamental or economic fish)
Responsible agency: PU (Ministry of Public Works)

Figure 4. *Perjaya Dam*

3.3 Future fish passage (under construction)

Sulewana Dam, Poso River, Central Sulawesi

The impact: May cause the declining of Anguilla populations that migrate through the Poso river.
Responsible agency : PT. POSO Energy

Figure 5. *Sulewana Dam*

The cause that hampers in fish pass planning construction :

- Lack of design knowledge;
- Lack of awareness that fish passage facilities are needed.

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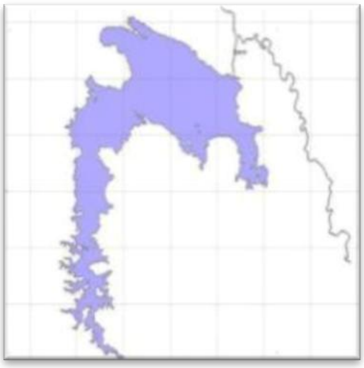
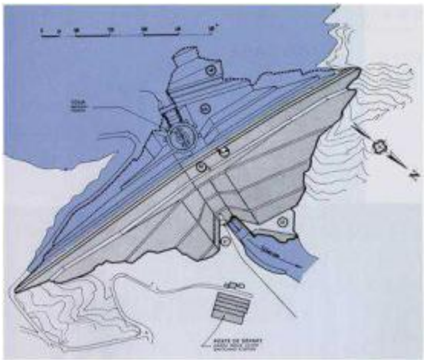
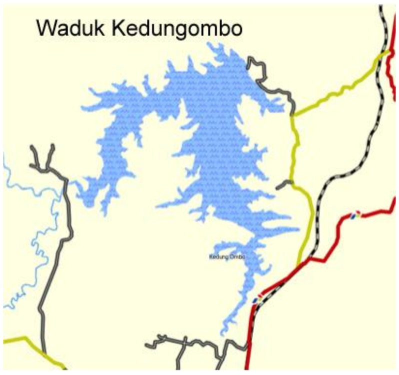
Figures of some dam or weir in Indonesia:





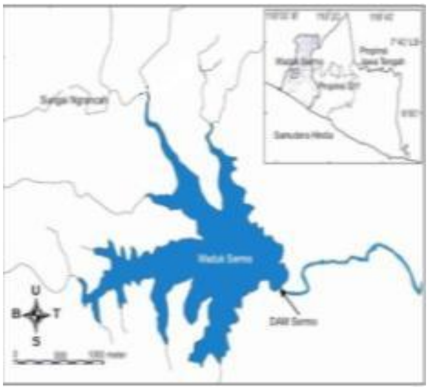
Jatiluhur dam construction

Cirata Dam Construction



Kedungombo Dam

Sempor Dam



Sermo dam

Table 2. Vast, depth, elevation and productivity of some lakes in Indonesia.

Lakes	**Vast** (hectare)	**Depth** (meter)	**Elevation** (meter above sea level)	**Productivity**
Sumatera:				
Laut Tawar	7,000	80	1,100	Mesotrofic
Toba	112,000	450	950	Oligotrofic
Maninjau	9,790	180	450	Mesotrofic
Singkarak	10,780	80	360	Oligotrofic
Diatas	3,600	36	1,100	Oligotrofic
Dibawah	1,200	80	800	Mesotrofic
Ranau	12,590	229	540	Mesotrofic
Kerinci	6,000	45	900	Mesotrofic
Borneo:				
Luar	15,000	6	25	Mesotrofic
Genali	18,000	6	24	Eutrofic
Sembuluh	33,750	10	15	Mesotrofic
Jempang	15,000	5	10	Eutrofic
Semayang	12,000	5	10	Eutrofic
Melintang	9,000	5	10	Eutrofic
Celebes:				
Limboto	4,500	4	15	Eutrofic
Tondano	6,000	30	500	Mesotrofic
Poso	32,300	450	1,000	Oligotrofic
Lindu	3,150	100	9	Oligotrofic
Tempe	10,000	5	293	Eutrofic
Towuti	56,100	590	382	Oligotrofic
Matano	16,500	203		Oligotrofic
Bali:				
Batur	1,590	80	1,000	Oligotrofic
Papua:				
Sentani	9,360	50	70	Mesotrofic
Paniai	14,150	20	1,742	Oligotrofic
Ayamaru	2,200	15	250	Oligotrofic
Yamur	3,750		90	Oligotrofic
Tage	2,400		1,750	Oligotrofic
Tigi	3,000		1,740	Oligotrofic

Sources: Saanin, 1982; Kartamihardja et al, 1992; and Kartamihardja et al, 1993

Table 3. Some multi-purpose Reservoirs in Indonesia (Ilyas et al, 1990; Kartamihardja, 2002)

Province/Reservoir	Vast (hectare)	Depth		Elevation (meter)	Main Function	Year built
		Max (meter)	**Min** (meter)			
West Java:						
Saguling	5,340	90	18	625	E, F, I	1985
Cirata	6,200	106	34	250	E, F, I	1987
Jatiluhur	8,300	95	37	110	W, E, F, I	1965
Central Java:						
Wonogiri	8,800	28	8	140	I, F, E	1981
Wadaslintang	1,460	85	30	115	I, F, E	1987
Kedungombo	6,100	50	16	100	I, F, E	1989
Mrica	1,500	45	13	231	E, F, I	1989
Sempor	1,300			77	I, E, F	1987
East Java:						
Karangkates	1,500	70	23	270	I, E, F	1972
Selorejo	400	46	16	600	E, I, F	1970
Lahor	260	50	14	300	I, E, F	1977
Wlingi	380	28	6	163	I, E, F	1983
Bening	570	10	8	11	I, F	1983
Sengguruh	290	24	7	296	E, I	1987
Nusa Tenggara:						
Batujai	890	14	2	4	I, F, W	1983
South Borneo:						
Riam Kanan	9,200	50	18			1983
Lampung:						
Way Rarem	1,400	25	6	60		1982
Way Jepara	220		15			1976

Note: *W = Drinking Water; E = Electricity Power; F = Flood Controller; I = Irrigation*

Annex 8

FISH PASSAGE IN LAO PDR

By Sommano Phounsavath[3], Sinthavong Viravong[4], Douangkham Singhanouvong[5]

I. OVERVIEW

1.1 General Information

Topography of Lao PDR

Lao PDR is located in the Indochina Peninsular (Mekong Region), bordered by China to the North, Vietnam to the East, Cambodia to the South, and Thailand and Myanmar (Burma) to the West and Northwest respectively. Lao PDR has a total land area of approximately 236,800 km², of which 87.7 percent of the land or catchment areas (207,674 km²) drains into the Mekong River and contributes about 35 percent of the Mekong River Basin flow. Another 12.3 percent of the north-eastern area produces a discharge to the north of Viet Nam before draining into the China Sea. Mountains are found in the Northern region, the Annamite Chain (forming most of the eastern border of the country), and in the South, posing a significant natural buffer to storms that occur in the region. However, the remaining 20 percent of the country comprises mostly flat floodplains along the Mekong River. The lowest altitude of Lao PDR is 200 meters and highest is 2,880 meters. Almost all Lao territory is of enormous importance both for fishery resources and for its rich aquatic biodiversity.

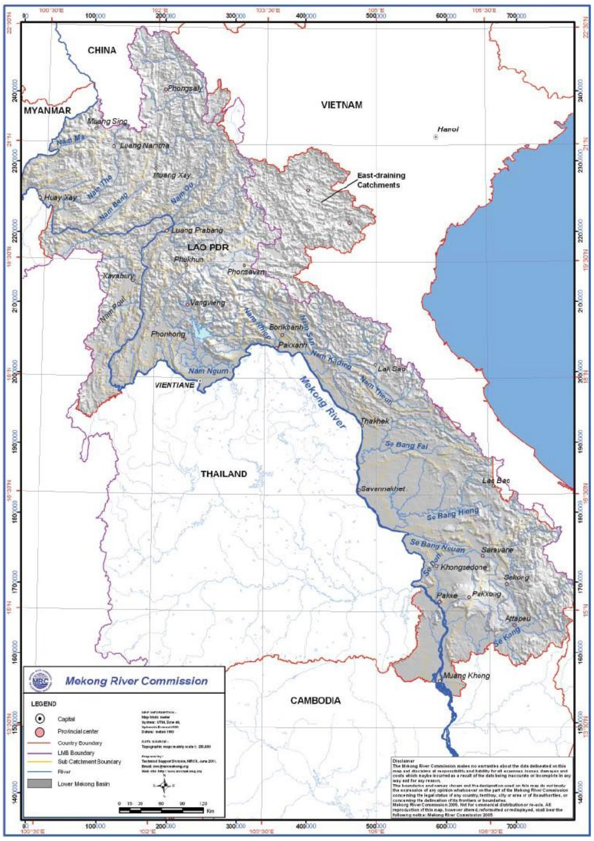


***Figure 1.** Topography and rivers of Lao PDR*

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Climate of Lao PDR

Lao PDR has a tropical climate, which is influenced by the southeast monsoon which causes significant rainfall and high humidity. The climate is divided into two distinct seasons: rainy season, or monsoon, from May to mid-October, followed by a dry season from mid-October to April. The average annual rainfall is about 1,300 – 3,000 mm. Average temperatures in the northern and eastern mountainous areas and the plateaus are 20°C , and in the plains 25-27°C. For the year 2006, the average temperature for the country was 26.5°C (National Statistic Center 2006). On the basis of its altitude, Lao PDR is divided into three different climatic zones, as follows: (1) The northern mountainous areas above 1,000m have a montane temperate and hilly sub-tropical climate. There are relatively dry, with an average rainfall between 1,500 to 2,000mm. Temperature ranges are lower than the rest of the country; (2) The central mountainous areas in the Annamite Chain range in altitude from 500-1,000 m (with some mountain peaks >2,000 m). They have a tropical monsoonal climate with a higher temperature and higher average rainfall than elsewhere which ranges from 2,500 to 3,500 mm; (3) The tropical lowland plain and floodplains along the Mekong River and its main tributaries include the plains of Vientiane, Borikhamxay, Khammouan, Savannakhet, Champasack, Saravane, and Attapeu Provinces. More than 50 percent of the population of Lao PDR lives in these areas. They have an average rainfall of 1,500 to 2,000 mm.

1.2 **Overview on inland aquatic ecosystems** (resources/productivity, hydrological phenomenon, seasonal changes, stakeholders involving in utilization of inland aquatic resources)

The Mekong river which is the main natural water resource flows through the territory of Lao PDR with a distance of 1,898 Km and has 14 tributaries. The country has a total volume of surface water of 332.5 sq.km. that makes an average of 55,000 cu.m. per capita / year which is considered as the highest rate in the ASEAN region (DWR, 2012). The abundant natural water resources and specific geographical conditions of the country landscape are the main driving factors that contribute to the overall national socio-economic development through various key sectors such as irrigation, domestic water supply, fisheries, eco-tourism, industry, transportation, etc. The traditional use of water resources has been mainly in the agricultural sector, for instance, irrigation, fisheries, agriculture and animal husbandry (DWR, 2012).

Water resources is of vital importance for the livelihood of Lao people throughout the country, who are mainly living close to natural water bodies such as the Mekong river and its tributaries as well as other types of aquatic ecological systems. The natural and well as artificial water resources, such as man-made reservoirs and ponds, are providing various aquatic products and services in the forms of food, income and employment to the local population especially in the rural and remote areas. All of these water resources are of enormous importance, both for fisheries and aquaculture development.

The total area of natural and man-made water resources that have potentials for fisheries development was estimated to be about 1,280,384 hectares, which include: the Mekong and its 14 main tributaries (including five north-eastern rivers) that cover an area of 304,704 hectares, large hydropower reservoirs 96,030 hectares, irrigation reservoirs and weirs 60,000 hectares, wetlands (shallow lakes, natural pools, peat swamps, etc.) 114,800 hectares, wet-season rice-fields 632,850 hectares, and seasonal flooded areas in the Mekong plain of more than 30,000 hectares (DLF, 2007).

Lao PDR has a total population of around six million of which 75 to 80 percent still live a rural lifestyle. In 2005 it was estimated that 32.7 percent of these people lived below the poverty line (ADB 2008). The people of Lao PDR, especially in the rural communities, still rely heavily on aquatic resources, *i.e.* fishes and other aquatic animals, as the most reliable sources of animal protein intake. As noted by Sjorslev (2001a) "fish, and other aquatic animal products, form the major component of the animal protein intake of rural communities". In Lao PDR, the most current estimated yield of inland fish amounts to 167,922 tonnes per year, while the yield of other aquatic animals comprises 40,581 tonnes per year. These figures have been based on consumption studies and expressed as fresh whole animal equivalent weights (FWAEs) (MRC 2007). The estimate of actual fish consumption per capita (kg/capita/year) of inland fish was 24.5 kg, while other aquatic animals comprised about 4.1 kg and marine products contributed 0.4kg to make a total of 29kg/capita/year. These figures were almost consistent with the Lao

Expenditure and Consumption Survey 3 (LECS3) conducted by the National Statistic Center in 2002/2003.

Due to the diversity of aquatic ecosystems, the structure of inland fisheries as well as their production can be characterized by various sub-types of capture and culture. Capture fisheries can be categorised by the use of various water resources such the Mekong and its tributaries; large hydropower reservoirs; natural pools, lakes and small specific wetlands; irrigation reservoirs, weirs and the large areas of wet season rice fields and seasonal Mekong flood plains. The majority of the catches of fish and other aquatic animals in the various water resources are still at the level of "subsistence and semi-subsistence fishing or artisanal fisheries", except in large reservoirs where the catches have been organized and normalized. As noted by Coates (1999), the general accessibility of aquatic resources to most local communities, and the high participation in exploitation and utilization of these resources are linked intimately. This type of catch is an integral part of the livelihood of entire communities, as most fishing effort is part-time and seasonal in nature. In contrast, aquaculture development in Lao PDR is progressing well, but is still encountering many difficulties that need to be overcome. The forms of production used for aquaculture include fish pond culture, community fish culture in oxbow lakes and in irrigation weirs, rice-cum-fish culture and cage fish culture.

Inland capture fisheries and aquaculture in Lao PDR are based mainly on water resource ecosystems consisting of rivers and their basins, hydropower and irrigation reservoirs, temporary or permanent diversion weirs, gates and dykes, small water bodies, flood plains and wet season rice fields. The total water resources for capture fisheries are believed to be more than 1.2 million ha. The estimated yield of inland fish in Lao PDR is approximately 167,922 tonnes per year while consumption of other aquatic animals is estimated at 40,581 tonnes per year. These estimated yields are conservatively valued at almost US$150 million per year (Phonvisay, 2010).

The people of Lao PDR, especially in the rural communities, which account for more than 75 percent of the population, still rely on the country's aquatic resources such as fishes and other aquatic animals as their most reliable sources of animal protein intake. The estimate of actual fish consumption per capita (kg/capita/year) of inland fish is 24.5 kg, while other aquatic animals account for about 4.1 kg and marine products around 0.4kg, to make a total of 29 kg of fish and aquatic products consumed per capita per year. More than 481 fish species have been identified in Lao PDR, including 22 fish species identified as exotic species. Only about 37 amphibians, seven species of crabs and 10 species of shrimps have been recorded, but these records would cover only about 15 percent of the estimated total.

In order to understand the ecosystem diversity and species diversity, it is very important to understand the migration patterns of Mekong fish species. And to justify or demonstrate the migration patterns, it is essential to examine studies based on local ecological knowledge, landing site surveys, logbook migration monitoring and larvae sampling of important fish species. These will reveal the distribution, the population structure, feeding habits, critical habitats, life cycles and the fisheries for these fish species. Inland capture, mostly qualified as subsistence and semi-subsistence fisheries, is complex in nature and involves a wide variety of activities undertaken by people from a wide spectrum of socio-economic backgrounds. The development of aquatic resources deserves to be given a higher priority by the Government of Lao PDR, as it is a key component in improving healthy food security. To confront the problems and challenges in the fisheries sector, two interlinked strategic frameworks or issues of resource assessment and management of capture fisheries should be developed in concert with the promotion of sustainability of culture fisheries (Phonvisay, 2009).

1.3 **Overview on construction of cross-river obstacles** (impacts from such construction to different sectors (particularly fisheries) and measures/actions undertaken for the mitigation of such impacts including the construction of fish passage)

The main types of cross-river obstacles are hydropower dams, irrigation dams and weirs. Although, hydropower and irrigation reservoirs contribute only 12% of the total area of water resources, but these two sectors are rapidly developing, which although are possible obstacles to natural fish migration (upstream and downstream), but also provide good opportunity for fisheries enhancement (*e.g.* fish restocking, fish conservation zone, habitat restoration, etc.) and aquaculture development (*e.g.* fish culture in cage and pen).

Large hydropower reservoirs

The hydropower sector is rapidly developing in Lao PDR especially in the Mekong tributaries. According to the Department of Energy Business[6], the Government of the Lao PDR has to date signed MOUs or is undertaking research studies on a total of more than 70 hydropower projects. Of these 14 are officially operational as listed in the **Table 1**.

Table 1. Operational hydropower projects in Lao PDR (DEB, 2012)

No.	Project Name	Location (Province)	Capacity (MW)	Completion	Reservoir Area (km^2)	Remarks
1	Selabam	Champasak	5.00	1970	0.55	Small hydropower plant
2	Nam Doung	Luangprabang	1.00	1970	NA	Small hydropower plant
3	Nam Ngum 1	Vientiane	155.00	1971	370.00	
4	Se Xet 1	Saravane	45.00	1990	0.10	
5	Nam Ko	Oudomxay	1.50	1996	NA	Small hydropower plant
6	Theun-Hinboun	Bolikhamxay	220.00	1998	NA	Small reservoir
7	Houay Ho	Champasak/Attapeu	152.00	1999	37.00	
8	Nam Leuk	Vientiane	60.00	2000	12.80	
9	Nam Mang 3	Vientiane	40.00	2004	10.20	
10	Se Xet 2	Saravane	76.00	2009	20.00	
11	Nam Lik 1-2	Vientiane	100.00	2010	24.40	
12	Nam Theun 2	Khammouane	1088.00	2010	450.00	
13	Nam Ngum 2	Vientiane	615.00	2011	122.20	
14	Nam Nhone	Bokeo	3.00	2011	NA	Small hydropower plant

The total reservoir area of at least 10 operational hydropower dams consists of about 1,047.25 sq.km. The largest reservoir is the Nam Theun 2 (450 sq.km.) followed by Nam Ngum 1 (370 sq.km.) and the Nam Ngum 2 (122 sq.km.). To be also added to the above list are: the newly completed in 2012, Theun Hinboun Expansion Hydropower Project (220 + 60 MW) located in Bolikhamxay province that has a reservoir with a surface area of about 107 sq.km., and the Nam Ngum 5 (120 MW), that is expected to be soon completed at the end of year 2012 – beginning of 2012. The latter will have a reservoir area of about 15 sq.km. at full supply level. Another hydropower project that is presently under construction in the Sekong province is the Xekaman 3 (250 MW) that will have a relatively small reservoir area of about 5 sq.km.

Figure 2. *Existing Hydropower Projects in Lao PDR (as of September 2009)*

[6] The Department of Energy Business is under the Ministry of Energy and Mines (see the following website for reference: http://www.poweringprogress.org)

Hydropower is seen as a cost-effective energy source in Lao which has a theoretical hydroelectric potential of about 26,500MW excluding the mainstream Mekong. Of this, about 18,000MW is technically exploitable, with 12,500MW found in the major Mekong sub-basins and the remainder in minor Mekong or non-Mekong basins. Less than 2% of the country's hydropower potential has been developed over the past 30 years, but under present government policy the rate of development will accelerate to supply electricity to the rapidly growing economies of the region. In 1996 at its 6th Party Congress, the Lao Government set a poverty reduction goal, which aimed to take the country from the group of Least Developed Countries by 2020. The power sector in Lao PDR serves two vital national priorities: (1) it promotes economic and social advancement by providing a reliable and affordable domestic power supply; (2) it earns foreign exchange from electricity exports. The power sector, and especially hydropower, has already become an important contributor to Lao PDR's economic growth and its national poverty eradication effort. In 2008 the export of electricity amounted to approximately 30% of all Lao PDR’s export levels. Agreements for future hydropower exports are in place with Thailand, Vietnam and Cambodia. In 2007 the Lao Government said that by 2015 it was committed to supply 7,000MW to Thailand, 5,000MW to Vietnam and 1,500MW to Cambodia. The government will use the profits from hydropower sales to fight poverty in the country. In addition to international supply commitments, domestic energy consumption is growing at 8% to 10% annually.

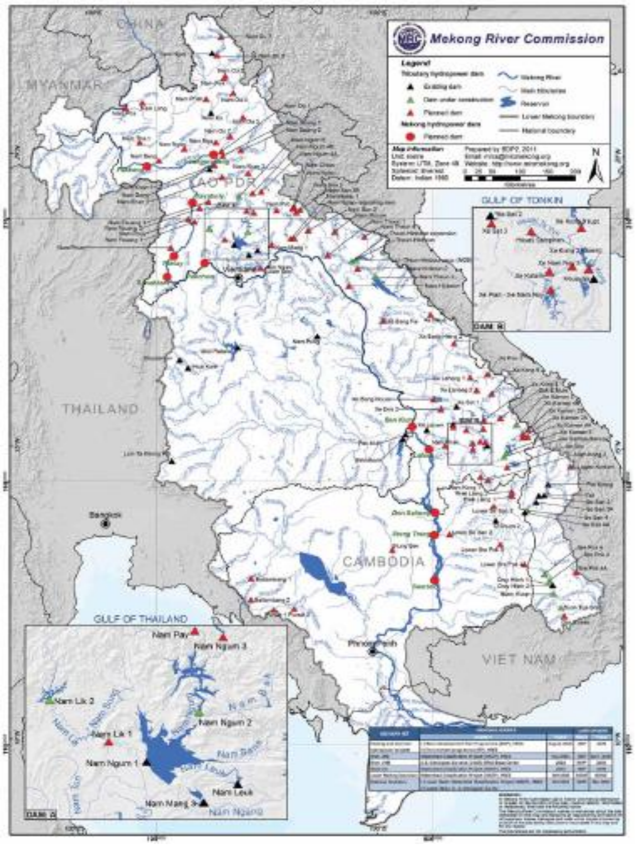

Figure 3. *Existing and Planned Hydropower Projects in the LMB (MRC, 2011)*

Irrigation reservoirs

The Lower Mekong Basin has more than 25,000 constructed reservoirs, most with less than one km^2 of surface area and used mainly for irrigation or flood control (Sverdrup-Jensen, 2002). The irrigation sector is the largest user in the LMB[7], consuming an estimated 41.8 billion cubic meters of freshwater resources of which 3.0 billion cubic meters are used in Lao PDR (MRC, 2010).

The government has given high priority to investment in the irrigation sub-sector since agriculture is the foundation of national economic development, necessary for food security and about 85% of the

[7] LMB – Lower Mekong Basin

population lives in rural areas. Six types of irrigation systems prevail in Lao PDR as following: (a) small weir schemes of less than 100 ha; (b) medium-scale weir schemes between 100 and 1,000 ha; (c) small to medium reservoir schemes between 100 and 1,000 ha; (d) medium and large reservoir schemes greater than 1,000 ha; (e) small-scale pumped schemes up to 100 ha; and (f) medium and large scale pumped schemes greater than 100 ha (MAF, 1999).

In 1997, traditional type of irrigation system makes up to 35% of the total irrigated area followed by pump lift system (28%), small dam (24%), storage reservoir (9%) and water gate (3%) as shown below in the **Table 2**.

Table 2. Distribution of Irrigated Area by Type of System (MAF, 1997)

Type of system	Number of systems	Wet-season irrigated area (ha)	Percent of total irrigated area (%)
Small dam	521	38,957	24
Storage reservoir	263	16,304	9
Pump lift	292	46,157	28
Water gate / board	60	4,325	3
Traditional	14,331	57,374	35
Stone weir	33	1,156	1
Total	**15,500**	**164,273**	**100**

In 1995, the irrigated area in the uplands is predominating in the country and makes up about 123,000 ha or 83% of the total irrigated area in the wet season if compared with irrigated area in the lowlands which consists of just 27,000 ha or 17% of total irrigated area in the wet season as shown below in **Table 3**.

Table 3. Geographic Distribution of Irrigated Areas (MAF, 1995)

Geographic location	Size of area (ha)	Percent of total wet-season area (%)
Lowland irrigated area	27,000	17
Upland irrigated area	123,000	83
Total	**150,000**	**100**

Irrigation schemes in Lao PDR are small by international standards. Only six schemes have a service capacity of 1,000 ha or more, the largest of which services only 4,500 ha. Excluding the six largest irrigation schemes, the average service capacity is less than 500 ha. As of 1997, there were 15,500 irrigation schemes with a wet season service capacity of 164,273 ha, or about 20% of the country's 800,000 ha of annual cultivated land (MAF, 1999).

The total area equipped for irrigation was estimated at 155,394 ha in 1995. This area covers 123,917 ha designed for supplementary irrigation during the wet season and 31,477 ha designed for dry season irrigation and also used for supplementary irrigation during the wet season. While wet season irrigation is common throughout the country, dry season irrigation is mainly concentrated near the major cities: Vientiane (59% of total dry season irrigated areas), Savannakhet (11%) and Luang Prabang (6%). River diversion is the main source of water for irrigated schemes (83%) followed by pumping from rivers (15%) and reservoirs (2%). All areas are mainly irrigated by surface irrigation in Lao PDR (FAO, 1995).

The area equipped for irrigation almost doubled in the period 1995 - 2000. Most of the increase was based on the establishment of pumping schemes, which covered 46 150 ha in 1997 and 153 330 ha of agricultural land in 2000. Irrigated areas per province, totalled 295 535 ha in the wet season and 197 100 ha in the dry season (FAO, 2012).

More than 19,000 irrigation schemes had been installed in Lao PDR by 2000, servicing an area of 295,000 ha in the wet season and 197,000 ha in the dry season. The majority of schemes are of the traditional weir type in the mountainous northern and central regions, while pump irrigation is concentrated in the south. Overall, more than half of the irrigated area is pump irrigated (Nesbitt, 2005).

Most of the irrigation schemes located in the upland and mountainous area are of small size (less than 100 ha), and are not made in concrete, but with natural materials which are temporary (LNMC, 2004).

There are number of on-going irrigation developments in the LMB and the latest basin development plan predicts that dry season irrigation will increase significantly in Lao PDR. For example, in 2007, there was a total annual irrigated area of 270,677 hectares, of which 166,476 hectares are irrigable area for rice cultivation (166,476 hectares for the 1st season and 97,224 hectares for the 2nd season) and 6,977 hectares for non-rice crop area. A 20-year plan scenario analyzed by MRC predicts an increase of 239% for irrigated rice cultivation area in the dry season from 97,224 ha to 329,952 ha (MRC, 2010).

Lao PDR has 2,330 existing projects but the total irrigated area and the average irrigated area of each project (71 ha) are small relative to other countries in the Basin. This is largely due to the steep topography of the country and hence limited land area suitable for irrigation. The map here shows that existing projects are confined to narrow strips along major tributaries of the Mekong River and the Mekong River floodplain itself. Lao PDR has an ambitious plan for a further 2,768 irrigation projects in the future, focusing on irrigated non-rice crops in upland areas and dry-season rice, which under the 2030 Development Scenario are predicted to increase irrigated areas by 240% and 460% respectively (MRC, 2011).

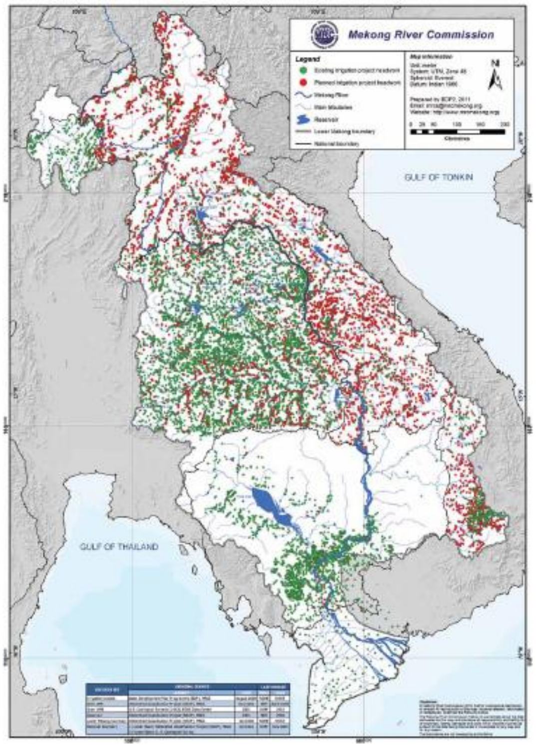

Figure 4. *Existing and Planned Irrigation Projects in the Lower Mekong Basin (MRC, 2011)*

The policy of the GOL[8] promotes the development of irrigated agriculture and has planned to increase its coverage to 60-70% of the cultivated land in the lowlands and uplands. The Seventh National Socio-Economic Development Plan (2011-2015) of Lao PDR has set the targets by 2015 to increase the irrigated area in the dry season to 500,000 hectares, including 300,000 hectares for dry season irrigated rice, and to expand wet season irrigated areas to 950,000 hectares. Consequently, many irrigation facilities will be further developed, especially irrigation reservoirs that will provide great potential for fisheries and aquaculture development in the future.

II. CROSS-RIVER OBSTACLES IN LAO PDR

The main cross-river obstacles in Lao PDR are hydropower dams on the Mekong tributaries and numerous irrigation dams and weirs scattered throughout the country as following:

[8] GOL - Government of Lao PDR

Name of dam/weir	Height *(in meter above downstream water surface)*	Purpose & Responsible agency	Geographical location, river system, and hydraulic condition of the river	Important fish species in the ecosystems, and impacts from dams/weir to fisheries	Fish passage construction
Existing cross-river obstacles					
Selabam (5MW)		Hydropower, EDL	Champasak province, Sedon river	No data available	No
Nam Dong (1MW)		Hydropower,EDL	Luangprabang province	No data available	No
Nam Ngum 1 (155MW)	75 m (wall height)	Multi-purpose / Hydropower, EDL	Vientiane province, Nam Ngum river.	54 fish species (Mattson et al, 2000)	No
Se Xet 1 (45MW)		Hydropower,EDL	Saravane province, Se Xet river	No data available	No
Nam Ko (1.5MW)		Hydropower, EDL	Oudomxay province	No data available	No
Theun-Hinboun (220MW)	38 m (wall height)	Hydropower, EDL	Bolikhamxay province, Theun and Hinboun rivers	No data available	No
Houay Ho (152 MW)	79.5 m (wall height)	Hydropower, EDL	Champasak / Attapeu provinces, Sekong river	No data available	No
Nam Leuk (60MW)	45.5 m (wall height)	Hydropower, EDL	Vientiane province, Nam Leuk river	No data available	No
Nam Mang 3 (40MW)		Hydropower, EDL	Vientiane province, Nam Gnong river	56 local fish species (survey report for ELD conducted by NUOL and Garry Thorncraft, 2004)	No
Se Xet 2 (76MW)	23 m (wall height)	Hydropower, EDL	Saravane province, Se Xet river	No data available	No
Nam Lik 1-2 (100MW)	103 m (wall height)	Hydropower, EDL	Vientiane province	No data available	No
Nam Theun 2 (1088MW)	45 m (wall height)	Hydropower, EDL	Khammouane province, Nam Theun and Xebangfai rivers	No data available	No
Nam Ngum 2 (615MW)	181.5 m (wall height)	Hydropower, EDL	Vientiane province, Nam Ngum river	No data available	No
Nam Nhone (6MW)		Hydropower, EDL	Bokeo province	No data available	No

Remarks: Future planned cross-river obstacles (dams and weirs) of Lao PDR can be found in the following websites: *http://www.poweringprogress.org and http://www.mrcmekong.org*

Cross-river obstacles in neighboring countries

The impacts from hydropower development in the Upper Mekong Basin (Lancang river) in China are so far not assessed. The MRC plans to conduct a regional study on "Sustainable Management and Development of the Mekong River including Mainstream Hydropower Development". This proposed study will also include study of upstream impacts (More info on the MRC website: http://www.mrcmekong.org).

III. FISH PASSAGES IN LAO PDR

3.1 Legal issues related to construction of fish passage in the country

So far there is no specific compulsory legislation that is related to the construction of fish passage for hydropower and irrigation facilities.

The main line agency responsible for hydropower development projects is the Ministry of Energy and Mines (MEM). While the responsibility for conducting environmental as well as social impact assessments (EIA and SIA), which includes fishery impact assessment, is the Division of Environmental and Social Impact Assessment (DESIA) of the Ministry of Natural Resources and Environment (MONRE). However, the Ministry of Agriculture and Forestry (MAF) has the mandate to supervise the management and development of fishery and irrigation work through its technical departments, namely, the Department of Livestock and Fisheries (DLF) and the Department of Irrigation (DOI) respectively.

The main legislations related to fish passages are:
- Law on Fishery (2009);
- Law on Water and Water Resources (2006);
- Law on Environmental Protection;
- Law on Protection of Wildlife and Aquatic Animals.

Beside these legislations, which serve as the principal legal instrument, Lao PDR is also a signatory to the International Convention on Biodiversity (CBD) since 1996.

Moreover, Lao PDR is a member of the Mekong River Commission (MRC) which consists of four riparian countries of the Lower Mekong Basin (LMB). The MRC is an inter-governmental organization established under the Mekong Agreement (1995). This agreement stipulates that all four Member Countries must follow the MRC rules and procedures which are serving as a technical framework for sustainable management and development of the Mekong river. Among the five MRC procedures the procedure on “Prior Notification, Prior Consultation and Agreement” (PNPCA) is the most relevant process related to the planning of water resources development on the Mekong mainstream especially with regard to hydropower and irrigation development projects and mitigation measures such as fish passages.

3.2 Existing fish passage

Location *(name of dam/weir)*	**Type/design of fish passage**	**Responsible agency** *(operation)*	**Data on effects of existing dams/weirs on fisheries before and after fish passage construction**
Pak Peung reservoir, Paksan district, Bolikhamxay province	Natural by- pass with cone or NAGA teeth for irrigation reservoir	Living Aquatic Resources Research Center (LARReC)	On-going project; supported by ACIAR.

3.3 Future fish passage

A fish passage is planned for the Xayaburi dam, which will be located on the Mekong mainstream in the Xayaburi province (on-going design and construction). More background information about the design of this fish passage can be found on the Lao Department of Energy Business’s website: http://www.poweringprogress.org and also on the MRC website: http://www.mrcmekong.org

LARReC is currently proposing a new project proposal for the uptake and application of fish passage technology (2014-2015) for support from potential donor agency (ACIAR). This project will test and apply fish passage technology for low-head irrigation structures in the northern mountainous area of Lao PDR.

3.4 Problems and constraints

The main problems and constraints related to the planning and construction of fish passages in Lao PDR can be tentatively summarized as following:
- Lack of knowledge on the basic technical information needed for the design of fish passages (*i.e.* biology and ecology of migratory fish species both in the Mekong mainstream and its tributaries);
- Lack of knowledge on the monitoring methodology to evaluate the effectiveness of fish passages;
- Lack of awareness and knowledge on this issue among the policy makers, decision-makers, researchers and managers;

- Institutional aspects: it is still not clear which line agency is responsible for the design, construction and management of fish passages; there is a need to also involve the concerned fishery line agencies (*i.e.* DLF[9], NAFRI[10], LARReC[11], etc.) and the local authorities as well as other key stakeholders (*i.e.* EDL[12], DOI[13], DEPP[14], LNMCS[15], DWR[16], DESIA[17], DEQP[18], etc.)
- Lack of specific legislation that is related to the construction of fish passage;
- Lack of human resources with technical background on fish passage design, construction and management;
- There is a need to involve the fishery line agencies in the planning and management process of future water resources development especially for hydropower and irrigation development projects.

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[9] DLF – Department of Livestock and Fisheries (under MAF)
[10] NAFRI – National Agriculture and Forestry Institute (under MAF)
[11] LARReC – Living Aquatic Resources Research Center (under NAFRI)
[12] EDL – Electricite Du Laos (Electricity Authority of Laos)
[13] DOI – Department of Irrigation (under MAF)
[14] DEPP – Department of Energy Policy and Planning (under MEM)
[15] LNMCS – Lao National Mekong Committee Secretariat (under MONRE)
[16] DWR – Department of Water Resources (under MONRE)
[17] DESIA – Division of Environmental and Social Impact Assessment (under MONRE)
[18] DEQP - Department of Environmental Quality Promotion (under MONRE)

Annex 9

FISH PASSAGE IN MALAYSIA

I. OVERVIEW

Malaysia with a land area of 329,847 square kilometers (127,355 square kilometers), it has land borders with Thailand in West Malaysia, and Indonesia and Brunei in East Malaysia. It is linked to Singapore by a narrow causeway, and also has maritime boundaries with Vietnam and the Philippines. The local climate is equatorial and characterized by the annual southwest (April to October) and northeast (October to February) monsoons. The temperature is moderated by the presence of the surrounding oceans. Humidity is usually high, and the average annual rainfall is 250 centimeters (98 in). The climates of the Peninsula and the East differ, as the climate on the peninsula is directly affected by wind from the mainland, as opposed to the more maritime weather of the East. Local climates can be divided into three regions, highland, lowland, and coastal. Climate change is likely to affect sea levels and rainfall, increasing flood risks and leading to droughts.

II. RESOURCES AND PRODUCTIVITY

In 2010, fisheries sub-sector showed an increase of 3.77% in production which is a total 1,777,366 mt compared to 1,710,301 mt in 2009. However at the same time it showed a decreased of 23% in value which is a total of RM 6,6579 million compared to RM8,546 million in 2009. Both capture fisheries and aquaculture contributed 1,415,211 mt and 362,155 mt to the country's fish production. Aquaculture showed a rise of 7.93% in production which is a total of 362,155 mt compared to 333,450 mt in 2009. The production value itself as well increased to RM 2.522 million out of RM 2.295 million in 2009. Brackishwater aquaculture stays as the main contributor of 205,931 mt compared to fresh water, 156,224 mt. This shows an upturn where in 2009 both brackishwater and freshwater aquaculture contributed 180,819 mt and 152,630 mt each. Brackishwater aquaculture contributed a total of RM 1.783 million in value compared to RM 1.589 million in 2009. On the other hand, freshwater aquaculture contributes a total of RM 738 million out of RM 704 million in 2009.

Conservation program on inland fishery resources is an initiative of the Department of Fisheries Malaysia to gather information on fresh water fishery resources in the country as well as to implement the fisheries management plan in order to sustain the fishery resources in Malaysia. In 2010, FRI Glami Lemi has conducted a few research activities and management of fresh water fishery resources to achieve those goals.

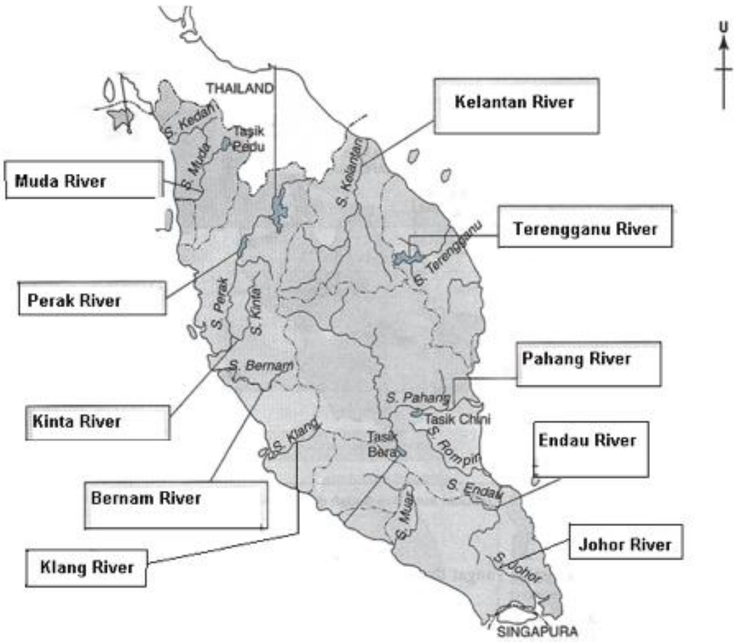

Fish fry release activities

Inventory study on fresh water fish species in river and lake systems in Peninsular Malaysia was also carried out. The lakes which were studies in 2010 includes Tasik Bera in Pahang and Putrajaya Lake, while river were Sungai Yong, Sungai Muar and Sungai Semberong in Johor, and Sungai Chiling in Selangor. In addition, a collaboration study with Kyushu University of Japan was conducted in the area of ecology and inventory of fresh water fish species in Jelebu Negeri Sembilan

III. CONSTRUCTION OF CROSS-RIVER OBSTACLES

Malaysia has a number of dams built for a specific purpose, namely to use hydroelectric, flood mitigation, drinking water and irrigation fields. Fish migration is a primary concern throughout this region. Fishes in Malaysian rivers utilized migration as an important adaptive tactic, and that migratory species were more common in the Kelantan River system, which has no large hydroelectric dams acting as barriers, than in the Perak River where there are four large hydroelectric dams acting as mainstream barriers. Dams, however, are not the only concerns with respect to riverine fisheries in the region. Tropical rivers in regions subject to deforestation and dams become increasingly simplified ecologically and unable to withstand additional impacts, the need to consider industrial development associated with the dam, and its impacts to river fisheries must be emphasized.

In Malaysia, there are 51 impoundments (46 in Peninsular Malaysia, 3 in Sabah, 2 in Sarawak) ranging in size from 10 ha (Mahang Dam) to 37 000 ha (Kenyir Dam) (Ho 1995) and 94 major river systems (49 in Peninsular Malaysia, 24 in Sabah, 21 in Sarawak).(Yap 1992). Yap (1992) reported yields for four principal rivers: Rajang (Sarawak, 100 kg/ha/year); Baram (Sarawak, 142-169kg/ha/year; Gombak (Selangor, 180 kg/ha/year), Perak (Perak, 11.64 kg/ha/year). Khoo *et al.* (1987) reported that inland capture fisheries in Malaysia are dominated by cyprinids and silurids in the country's larger river systems, and that there have been sharp declines in catches during recent decades. In the Selangor River, flows have been reduced from 5 482 000 m3/day to 300 000 m3/day and in Sabah, the release from the Babagon Reservoir dam has reduced streamflow to 5.5-21.0% of the natural river flow (Yap 1992).



Major River in Peninsula Malaysia

Reservoir systems along the Perak River in Malaysia have received considerable attention with respect to fisheries research. Along the Perak River, evaporation from the reservoirs may exceed streamflow. Chenderoh Dam blocked movements of *Probarbus julieni* and reduced breeding, spawning grounds and higher biodiversity in the Chenderoh Reservoir than in the river downstream from the dam but diversity in the reservoir has declined over time and fish standing stock is low. Yield from the reservoir fishery was estimated at 12.2 kg/ha/year which, while low, exceeded that of Bukit Merah Reservoir, a blackwater reservoir in the same region (3.7 kg/ha/year) (Ali and Lee, 1995). Limnological studies of impoundments along Malaysia's Perak River indicate that standing crop of phytoplankton and zooplankton is minimal, species are characteristic of oligotropohic fauna and production generally is low except for a brief period during the dry season (A.B. Ali, Universiti Sains Malaysia, Penang, pers. comm., 1999). Deep water reservoirs in Malaysia that have low retention times, and that are designed primarily for hydroelectric purposes, may have limited fishery potentials.

In Malaysian streams that have not been dammed (*e.g.* Tembling River, Pahang River system), demands for river fish have resulted in overfishing (Tan and Hamza, Universiti Sains, Penang, Malaysia: undated publication. Elsewhere in interior Malaysia, pollution and sedimentation impact riverine fisheries, especially during the rainy season when runoff is increased (Ho, 1995).

Lake Kenyir, the largest reservoir in Malaysia, has a surface area of approximately 36 000 ha, a maximum depth of 145 m, and a mean depth of 37 m (Yusoff *et al.*, 1995). The lake sustains a small-scale commercial fishery as well as popular recreational fisheries, with yields estimated at approximately 20 kg/ha/year (Yusoff *et al.*, 1995). These overall low yields are the result of an anoxic hypolimnion, lack of forage in the pelagic zone and few lacustrine fish species (Yusoff *et al.*, 1995). Historical fish migrations in the river were blocked by the dam, which does not have a fish ladder (Yusoff *et al.*, 1995).

Dam construction must have the approval of local authorities. Interested parties must go through the processes and specific regulations before a dam was built. Among the local authorities involved are the Department of Irrigation and Drainage, Land Office, Department of Environment, Department of Fisheries and others local authorities involved. Besides those benefits we derive from the construction of this dam, we are not free from disadvantages construction. Among the disadvantages is the loss of land and property, loss a job or source of income, water pollution, noise and air pollution, soil pollution and decrease fishery resources.

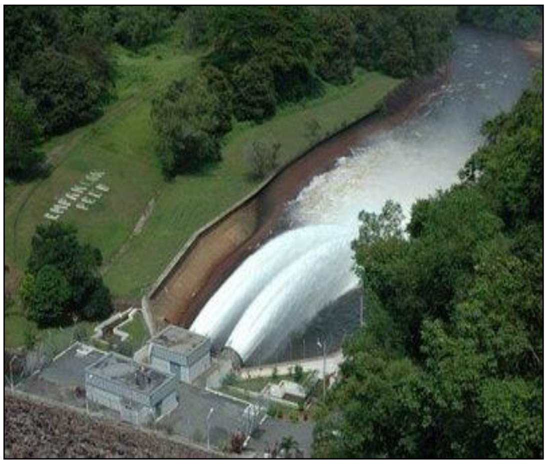
To reduce the adverse effects of the construction of dams, several measures have been taken by the Government, such as Preparation "Plan Land Acquisition and Relocation", appropriate compensation to those affected like one house one land, identify options for their source of income involved, cofferdam construction to enable work carried out on dry land, earthwork carried out during the dry season, dewatering and silty water from cofferdam channeled into silt traps before being discharged in to river, release of fish fry to the rivers and many more action was undertaken by Government to reduce impact.

Many species that are affected/reduced due to the construction of dams, as a measure to control the extinction / lack of fisheries resources, fisheries department has built a number of central inland fisheries and research center near the dam area for inland fisheries management as Inland Fisheries Center Banding, Perak near the Temanggor dam, and Fisheries Research Institut (FRI) Glami Lemi Jelebu, Negeri Sembilan

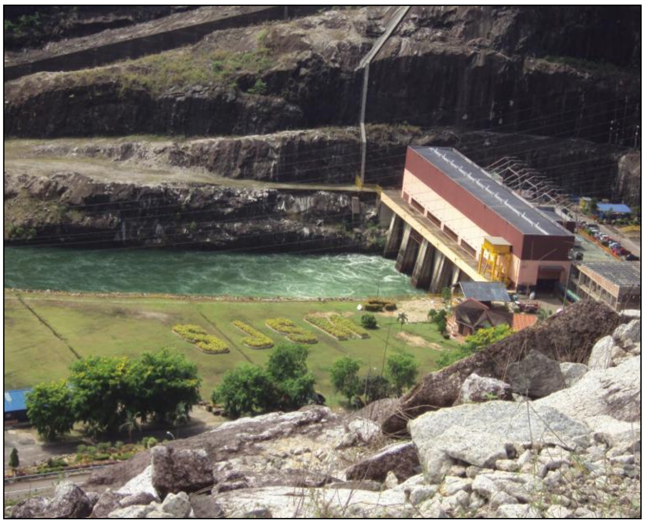
Cross-river obstacles in Malaysia

Name of dam/weir	Height	Purpose & responsible Agency	Geographic location	Important fish & impact from dam to fish	Fish passage construction
Kenyir dam	150 m	Hydro power Tenaga Nasional Berhad	Terengganu	Masheer/decrease population	No
Temmengor	127 m	Hydro power Tenaga Nasional Berhad	Perak	Masheer/decrease population	No
Bukit Merah	17.3 m	Irrigation Paddy Irrigation department	Perak	Arowana/decrease population	No
Bakun	205 m	Hydro power Tenaga nasional Berhad	Sarawak	Masheer/decrease population	No
Paya Peda	43 m	Domestic and paddy Irrigation Department	Terengganu	Masheer/decrease population	No

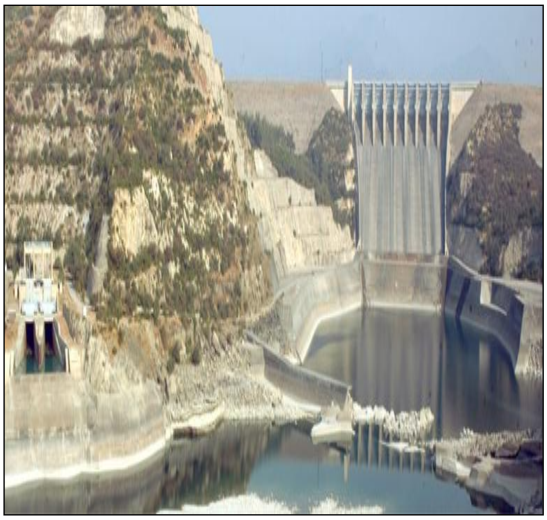
Bakun Dam



Temenggor Dam



Kenyir Dam



Paya Peda Dam

Bukit Merah Dam

Chenderoh Dam

Figure 1. *Biggest dams in Malaysia*

IV. FISH PASSAGE IN MALAYSIA

At the moment there are no fish passage construction projects in Malaysia. The reason being due to lack of knowledge In the designing of the fish passage and also lack of awareness regarding the important of to have fish passage facilities in weirs, barrage and dam construction in order to maintain the fish population and also the river ecosystem as a whole

V. CONCLUSION

Fish pass facilities is very important for the fish migration along the riverine and basin and also for the sustainability of the fish population .In the future constructions of barrage, weir and dam should be included with the facilities

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Annex 10

FISH PASSAGE IN MYANMAR

By Mr. Zaw Win Chit[1]*, Mr. Zaw Lwin Win*[2]

I. OVERVIEW

1.1 General Information

Myanmar is geographically located between 9° 32′ and 28° 31′ North Latitude and 92° 10′ and 101° 11′ East Longitude. Its land area is 676,553 sq-km and two thirds of the country is within the tropics. It has common international borders with five neighboring countries, namely, with China in the north and northeast, with Thailand and Laos in the southeast and east, with India and Bangladesh in the west and again with Thailand in the south. Land frontier, stretches with Thailand 2,099 km, Laos 235 km, China 2,227 km, Bangladesh 272 km and India 1,453 km. Total border length thus is 6,286 km (3,772 miles). Myanmar also has a fairly long coastline of 2,229 km (1,337 miles) and is facing Indian Ocean generally in the south. Sea frontier comprises Rakhine coastline 713 km, Delta coastline 438 km and Tanintharyi coastline 1,078 km.

1.2 Climate

Due to such geographical location, Myanmar Climatic and hydrologic conditions are much influenced by the Indian Ocean of the South and as such two-third of Myanmar falls within the tropic and the remaining one third enjoys temperate climate condition. And though Myanmar has a tropical monsoonal climate, climate conditions vary from extremely wet and humid to hot conditions due to its topography and thus paving the way to grow various crops and aquatic ecosystems.

II. OVERVIEW ON CONSTRUCTION OF CROSS-RIVER OBSTACLES

2.1 Water Potential in Myanmar

2.1.1 Surface Water Potential

The river basin characteristics in Myanmar are quite variable due to the differences in physiographic features. The principal water courses flowing in Myanmar comprise four major rivers, the Ayeyarwady, Chindwin, Sittaung and Thanlwin and other major tributaries such as Mu river, Myitnge river and Mone, Mann, Salin rivers. All rivers with the exception of the Thanlwin river which of trans-boundary nature can be considered national water assets. Their drainage area spreads rather extensively over the country, with some 876.73 million acre-ft (1,082 km^3) of water volume per annum from a drainage area of about 284,800 sq-miles (738,230 km^2).

The monthly distribution of river flow varies according to the pattern of rainfall, about 80 percent during the rainy season (May-October) and 20 percent in the dry season (November-April).

1. Irrigation Department, Myanmar
2. Department of Fisheries, Myanmar

Table 1. Annual Surface and Groundwater Potential in Myanmar

No.	River Basin Number	Name of Principal River Basin	Catchment area for each stretch (thousand sq.km)	Average estimated annual surface water (km^3)	Estimated groundwater potential (km^3)
1.	I	Chindwin River	115.30	227.920	57.578
2.	II	Upper Ayeyarwady River (up to its confluence with Chindwin River)	193.30	141.293	92.599
3.	III	Lower Ayeyarwady River (From confluence with Chindwin to its mouth)	95.60	85.800	153.249
4.	IV	Sittaung River	48.10	81.148	28.402
5.	V	Rivers in Rakhine State	58.30	139.245	41.774
6.	VI	Rivers in Tanintharyi Division	40.60	130.927	39.278
7.	VII	Thanlwin River (From Myanmar boundary to its mouth)	158.00	257.918	74.779
8.	VIII	Mekong River (Within Myanmar territory)	28.60	17.634	7.054
		TOTAL	**737.80**	**1080.885**	**494.713**

2.1.2 Groundwater Potential

In Myanmar, wherever a perennial supply of surface water is not available, groundwater is naturally utilized, and sometimes with higher costs. Groundwater has a greater advantage over surface water as it is usually free from pathogenic organisms and bacteria causing water related diseases.

The estimated groundwater potential in Myanmar is about 495 km^3 in eight principal basins in Myanmar. On the basis of stratigraphy, there are eleven different types of aquifers in Myanmar. Depending on their lithology and depositional environments ground water from those aquifers has disparities in quality and quantity. However, on the water scarcity regions, ground water from Peguan, Eocene, and Plateau Limestone aquifers are extracted for domestic use.

2.2 Socio-Economic Condition

Myanmar is an agricultural country and agriculture sector is the backbone of its economy. Agriculture sector contributes 30 % (2010 - 2011) of GDP, 13.7 % of total export earning and employs 61.2 % of the labour force and that is considerable measure for socio-economic condition of Myanmar people.

Moreover, 70 % of the Myanmar people reside in the rural area and most of them directly engage with agricultural works and thus their socio - economic condition is still relying on the agriculture. Furthermore, as the population grows and the demand for progress in economy for basic needs will rise and also the demand for consumer goods will rise as well. The increase in population will place greater demands on agricultural produce and products especially in rice products. And also, the growth in agriculture productivity has been recognized as having a direct role in raising the incomes of the rural poor and thus reducing poverty.

Therefore efforts for promotion and increasing of income for rural people is directly affecting not only for the financial situation of farmers but also for the economy of the country. For that reason Government of Myanmar made great effort for development of agriculture sector by means of increasing water and land productivity that could directly contribute for ensuring for food security.

2.3 Implementation of cross-river obstacles

Due to the importance of the agricultural sector, the Government has accorded high priority to its development, and numerous irrigation facilities have been implemented since last two decades for irrigation and water supply to monsoon and summer paddy crops. Furthermore, it is recognizing that adequate water supply is one of the basic requirements for boosting the production of crops, agricultural infrastructures including cross-river obstacles have been built throughout the country wherever necessary. In this scenario, Irrigation Department has accelerated the construction of cross-river obstacles such as dams, weirs and sluice-gates at feasible place. There are 239 numbers of irrigation facilities have been successfully established with the addition of 1.15 million hectare of productive irrigated land.

The projects are implemented especially for the purpose of irrigation, flood control and some are for hydropower generation. Although the huge amount of cross-river obstacles have being sited on the tributaries and streamlets of main river sources, it is still weak in monitoring and investigation of environmental impacts by those structures.

No.	Name of Dam/ Weir	Height *(in meter above downstream water surface) (m)*	Purpose & Responsible Agency	Geographical Location, River System, and Hydraulic Condition of the River	Important Fish Species in the Ecosystems, and Impacts from Dams/ Weir to Fisheries	Fish Passage Construction
Existing Cross-River Obstacles						
1.	Thaphanseik Multipurpose Dam	32.9	Irrigable, Hydropower / Irrigation Department	Kyunhla, Sagaing Region, Mu River	-	No
2.	Kyee-on Kyee-wa Multipurpose Dam	51.8	Irrigable, Hydropower / Irrigation Department	Pwintphyu, Magway Region, Mone River	-	No
3.	Paung Laung Multipurpose Dam	131.1	Irrigable, Hydropower / Irrigation Department	Pyinmana Township, Mandalay Region, Paung Laung River	-	No
4.	Ye Nwe Multipurpose Dam	76.5	Irrigable, Hydropower / Irrigation Department	Kyauktaka Township, Bago Region, Ye Nwe Creek	-	No
5.	Baingda Dam	37.2	Flood Control, Irrigable / Irrigation Department	Daikoo Township, Bago Region, Baingda Creek	-	No
6.	Kawliya Dam	39.6	Flood Control, Irrigable / Irrigation Department	Daikoo Township, Bago Region, Kawliya Creek	-	No
7.	Kabaung Dam	61.0	Irrigable, Hydropower / Irrigation Department	Oaktwin Township, Bago Region, Kabaung Creek	-	No
8.	Kabaung Weir	7.6	Irrigable / Irrigation Department	Oaktwin Township, Bago Region, Kabaung Creek	-	No
9.	Zawgyi Dam	44.2	Irrigable, Hydropower / Irrigation Department	Yatsauk Township, Shan State, Zawgyi River	-	No
10.	Yin Nyein Sluice Gate	1.8×4.9 (40) Nos.	Irrigable / Irrigation Department	Paung Township, Mon State, Yin Nyein Creek	-	No
11.	Thone Gwa Sluice Gate	1.8×3.6 (21) Nos.	Irrigable / Irrigation Department	East Dagon Township, Yangon Region, Thone Gwa Creek	-	No

No.	Name of Dam/ Weir	Height *(in meter above downstream water surface) (m)*	Purpose & Responsible Agency	Geographical Location, River System, and Hydraulic Condition of the River	Important Fish Species in the Ecosystems, and Impacts from Dams/ Weir to Fisheries	Fish Passage Construction
Future Plan Cross-River Obstacles						
1.	Buyoe Dam	48.8	Irrigable / Irrigation Department	Pantaung Township, Bago Region, Buyoe Creek	-	No
2.	Chi Chaung Dam	27.4	Irrigable / Irrigation Department	Pauk Township, Magway Region, Chi Creek	-	No
3.	Yebokegyi Dam	20.1	Irrigable / Irrigation Department	Pwintphyu Township, Magway Region, Yebokegyi Creek	-	No
4.	Kyaik Kaw Sluice Gate	1.8×2.4 (7) Nos	Irrigable / Irrigation Department	Mudon Township, Mon State, Kyaik Kaw Creek	-	No
5.	Thayee Dam	29.0	Irrigable / Irrigation Department	Kyauktaw Township, Rakhine State, Thayee Creek	-	No
6.	Gyat Chaung Dam	54.9	Irrigable / Irrigation Department	Laymyatnar Township, Ayeyarwaddy Region, Gyat Chaung Creek	-	No

III. FISH PASSAGE IN MYANMAR

Until now, there is no fish passage constructed in the country. The cause that hampers in fish passage construction:

- Lack of design knowledge
- Lack of awareness that fish passage facilities are needed

IV. CONCLUSION

Since the country is still developing with implementation of infrastructures including storage reservoirs, there is the adverse affect on the related environment and ecosystem, sometimes, in some cases involvement of undermining it up to certain extent. In the future, the Government Agencies would be recognized that for plan and formulating the development projects in line with environmentally viable.

Annex 11

FISH PASSAGE IN THE PHILIPPINES

By Enrique Marquez, Arnold Morales and Adan Diamante [1]

I. OVERVIEW

1.1 General geographical information of the country

The Philippines is an archipelago comprising 7,107 islands with a total land area of 300,000 km^2 at a geographic coordinates of 13 00 N, 122 00 E. The 11 largest islands contain 94% of the total land area. The largest of these islands is Luzon at about 105,000 km^2. The next largest island is Mindanao at about 95,000 km^2. The archipelago is around 800 km from the Asian mainland and is located between Taiwan and Borneo.

The islands are divided into three groups: Luzon, Visayas, and Mindanao. The Luzon islands include Luzon Island itself, Palawan, Mindoro, Marinduque, Masbate and Batanes Islands. The Visayas is the group of islands in the central Philippines, the largest of which are: Panay, Negros, Cebu, Bohol, Leyte and Samar. The Mindanao islands include Mindanao itself, plus the Sulu Archipelago.

The Philippines has a tropical wet climate dominated by a rainy season and a dry season. The summer monsoon brings heavy rains to most of the archipelago from May to October, whereas the winter monsoon brings cooler and drier air from December to February. Manila and most of the lowland areas are hot and dusty from March to May. Even at this time, however, temperatures rarely rise above 37 °C (98.6 °F). Mean annual sea-level temperatures rarely fall below 27 °C (80.6 °F). Annual rainfall measures as much as 5,000 millimeters (196.9 in) in the mountainous east coast section of the country, but less than 1,000 millimeters (39.4 in) in some of the sheltered valleys.

Monsoon rains, although hard and drenching, are not normally associated with high winds and waves. But the Philippines sit astride the typhoon belt, and it suffers an annual onslaught of dangerous storms from July through October. These are especially hazardous for northern and eastern Luzon and the Bicol and Eastern Visayas regions, but Manila gets devastated periodically as well.

1.2 Overview of inland aquatic system,resources/productivity, hydrological phenomenon, seasonal changes, stakeholders, involving utilization of inland aquatic resources.

The Bureau of Fisheries and Aquatic Resources or BFAR (1995) defined inland water resources in the country to include swamplands (fresh and brackish), fishponds (fresh and brackish) and other inland resources (lakes, rivers, and reservoirs).

The Philippines has about 200,000 ha of lakes and 30,000 ha of reservoirs. Lakes are traditionally a fishery resource and provide livelihood to small-scale fishermen in the surrounding communities. Reservoirs are mostly for power generation and irrigation purposes and fish production in them is considered to be of secondary importance.

Inland waters are home to a more than 316 fish species, some of which are endemic and confined to single lakes such as the *Sardinella tawilis* found only in Taal Lake. Fishbase records as of 2008 show

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[1] Bureau of Fisheries and Aquatic Resources, Philippines

that there are about 121 endemic and 76 threatened freshwater species. Other than fish, other species that depend on these habitats are waterbirds, semi-aquatic species like the highly endangered Philippine crocodile (*Crocodylus mindorensis*), plants, and a majority of amphibians.

Inland waters are also the most threatened of all ecosystem types. Globally, the main threats are: physical alteration, habitat degradation, water withdrawal, overexploitation, pollution, and introduction of invasive alien species. In the Philippines, the Environmental Management Bureau or EMB identified pollution from domestic (33%), industrial (27%), agricultural (29%) and non-point sources (11%) as the major reason for biodiversity loss in inland waters. Other threats include: (a) habitat loss and degradation; (b) resource use and exploitation; (c) climate change; and, (d) alien invasive species. Diversion of rivers for irrigation and dam construction has also affected movement of migratory fish species, changed the habitat of riverine flora and fauna, and dried rivers. Population pressure remains one of the biggest threats.

The NBSAP listed 78 lakes (DENR, 1977) while the Philippine Biodiversity Conservation Priorities (PBCP) included 211 lakes varying from 0.01 sq km to 900 sq km, 18 major rivers and 22 marshes, swamps and reservoirs (Ong *et al*, 2002). There are 10 major lakes that host aquaculture production and many other uses such as for household, recreation, and industry. There are also 421 principal river basins that provide various services for households, transportation, irrigation, and many others. These rivers drain in areas ranging from 41 sq km to 25,649 sq km, with about 20 of them considered as priority river basins. (DENR-RBCO, 2007). Lakes and rivers occupy 1,830 sq km or 0.61 percent of the total inland water area. The PBCP prioritized 34 inland water bodies for research and conservation.

Table 1. Some socio-economic features of natural lakes in the Philippines.

No	Name of Lake (Location)	Year of Reference	Area (HA)	Yield Annual (T)	KG/ HA	No. of Fishermen Total	No. of Fishermen Km^{-2}	Tons/ Fisherman	Source
1	Laguna de Bay (Laguna)	1961–63	90,000	82,881	921	9,756	10.5	8.40	Mercene, 1987; de Silva, 1991
		1968	90,000	39,055	434	8,700	9.7	4.48	Mercene, 1987; Moreau and de Silva, 1991
		1973	84,237	20,728	246	-	-	-	Mercene, 1987
		1978–79	78,000	30,940	397	4,646	6.0	6.70	Mercene, 1987
		1979–80	78,000	20,400	262	-	-	-	Mercene, 1987
2	Lanao (Mindanao)	1984	34,000	10,000	267	3,239	8.50	3.12	Montemayor, 1985; Moreau and de Silva, 1991
3	Taal (Batangas)	1984	33,432	11,800	485	8,429	34.5	1.40	Montemayor, 1985; Moreau and de Silva, 1991
4	Mainit (Surigao del Norte & Agusan del Norte)	1980–84	7,340	13,000	749	1,560	9.0	8.30	Montemayor, 1985
5	Naujan (Oriental Mindoro)	1984	8,000	5,000	633	1,209	15.8	4.00	Montemayor, 1985
6	Buluan (Maguindanao & Sultan Kudarat)	1984	6,134	11,200	1,827	4,544	74.2	2.50	Yap *et al*; 1983; Montemayor, 1985; Baluyut, 1987
7	Bato (Camarines Sur & Albay)	1984	3,800	2,200	579	1,110	29.2	2.00	Montemayor, 1985; Baluyut, 1987
8	Buhi (Camarines Sur)	1976	1,800	1,230	683	550	30.5	2.20	Montemayor, 1985; Moreau and de Silva, 1991
9	Wood (Zamboanga del Sur)	1976–85	720	80	114	40	5.7	2.00	Montemayor, 1985; Moreau and de Silva, 1991

No	Name of Lake (Location)	Year of Reference	Area (HA)	Yield Annual (T)	KG/HA	No. of Fishermen		Tons/Fisherman	Source
						Total	Km^{-2}		
10	Baao (Camarines Sur)	1980–82	400	600	894	500	74.1	1.20	Moreau and de Silva, 1991
11	Balut (Cotabato)	1984	206	180	873	140	68.0	1.30	Montemayor, 1985; Moreau and de Silva, 1991
12	Bito (Leyte)	1984	169	-	-	238	-	-	Montemayor, 1985;
13	Danao (Pacijan Is. Cebu)	1984	480	500	1,042	400	83.3	1.25	Montemayor, 1985; Moreau and de Silva, 1991
14	Dapao (Pualas, Mindanao)	1980–84	260	120	461	30	11.5	4.00	Montemayor, 1985
15	Sebu (South Cotabato)	1980–84	358	525	547	175	18.2	3.00	Moreau and de Silva, 1991
16	Paoay (Ilocos Norte)	1982–85	440	118	295	170	43.0	0.69	Moreau and de Silva, 1991
17	Pagusi (Santiago, Agusan del Norte)	1984	253	25	100	20	8.0	3.20	Montemayor, 1985
18	Butig (Butig, Maguindanao)	1980–82	50	250	486	100	19.5	2.50	Moreau and de Silva, 1991

Table 2. Annual catch landings (t) in some Philippines reservoirs. (Source: Balite, 1993; Cruz, 1993; Dela Cruz, 1993; Delos Trinos, 1990).

Year	Reservoir					
	Ambuklao	Angat	Binga	Magat	Pantabangan	Pulanguni IV
1982		68.00				
1983		76.86	7.73			
1984		98.31	10.10	393.47		
1985		71.85	4.84	298.94		
1986	0.96	88.01	1.60	183.95		
1987	0.89	97.05	0.95	135.34		2.40
				178.46		
1988	1.63	76.84	2.60	102.50		
				171.36		
1989	0.25	65.81	2.72	79.09		
1990		66.02	1.88	58.93		
1991		41.13	1.53	54.82		
1992		31.90	0.86		87.81	
1993						78.00[1]

[1] Catch from January-June (Cruz, 1993) multiplied by 2.

Fisheries productivity and enhancements in the country's inland waters were reviewed to determine the successes, the problems and to recommend further enhancements. The limited catch data indicated declining yields in lakes and reservoirs. The fish yields in 18 of the 70 lakes varied from 100–1827 kg/ha; while in four reservoirs, yields were 11–50 kg/ha. Lakes have a higher number of full-time fishermen (74–81%), yields/fisherman (0.7–8.3 t), density of fishermen (5.7–83.3 /km^2) and more kinds of fishing gears than reservoirs (33%, 0.4–2.6 t and 0.9–20.0/km^2, respectively). In some waters fish stock enhancement is done through fish stocking, establishment of fish sanctuaries and fish pen/cage culture. Improved fishing gears and boats; training, extension and credit support; and alternative sources of livelihood are seen as the means for improving living conditions of fishermen. Politics is seen as interfering in fisheries enhancement. The stocking of tilapia is accepted, because it easily establishes itself. The establishment of self-reproducing populations reduces the stocking cost. Further fish enhancements in inland waters may include adoption of techniques proven successful in other countries, which are suitable to the socio-economic and cultural setting of the country.

In reservoirs, the catch data also show a declining trend (Table 2). The decline in Ambuklao reservoir between 1988 and 1989 was 84.6% (1.63 to 0.25 t); in Binga, 52% (10.1 to 4.8 t) from 1984 to 1985;

Angat, 67.1% (97.0 to 31.9 t) in six years (1987-1992). Magat, the most productive among the reservoirs, declined by 86% (393.5 to 54.8 t) in eight years (1984–1992).The reasons behind the decline in catches were: 1) reduced fishing pressure as the number of fishermen decreased and engaged in other means of livelihood; 2) some fishermen or fish buyers were not reporting the high-priced catch or fish were smuggled out of the designated landing places; 3) spilling water carried downstream many fish; 4) unabated reservoir siltation; and 5) reduced fishing period due to inclement weather and unstable water level in reservoirs.

1.3 Overview on construction of cross-river obstacles, impact from such construction to different sectors (particularly to fisheries) and measures/action taken for the mitigation of such impacts including the construction of fish passages

Ambuklao Dam is a dam that supports a hydroelectric plant in the mountains of *Bokod, Benguet* province of the Philippines. The development of the Agno River for purposes of hydroelectric power generation, flood control, and irrigation had been conceived as early as the late 1940s. With maximum water storage capacity of 327,170,000 cubic metres (265,240 acre·ft), the dam, located 36 km (22 mi) from Baguio city, can produce 75 megawatts of electricity to Luzon grid. The main source of water comes from the Agno River which originates from Mt Data.

Binga Dam or **Binga Powerplant** is a hydroelectric plant situated at Barrio Binga, *Itogon, Benguet,* Philippines. The plant was constructed in 1956 and was opened in 1960, three years after Ambuklao Dam was opened. It is located 31 km southeast of Baguio City and 19 km downstream of Ambuklao Dam.[1] Improvement of the dam is ongoing for it had received heavy damage during the 1990 Luzon earthquake, and its installed capacity of 100 MW is being upgraded to 120 MW.

Angat Dam is a concrete water reservoir embankment hydroelectric dam that supplies the Manila metropolitan area water. It was a part of the Angat-Ipo-La Mesa water system. The reservoir supplies about 90 percent of raw water requirements for Metro Manila through the facilities of the Metropolitan Waterworks and Sewerage System and it irrigates about 28,000 hectares of farmland in the province of Bulacan and Pampanga.

The **Pantabangan Dam** is claimed to be the second largest dam in Asia, and supplies the irrigation requirements for about 77,000 hectares (190,000 acres) of agricultural lands in Central Luzon. Its power station generates 112 megawatts of hydroelectric power. The construction of the Dam had great economic and social impact on the lives of Pantabangeños. About 8,100 hectares (20,000 acres) of productive farmland and the town center (East and West *Poblacion*) along with seven outlying barangays (Villarica, Liberty, Cadaclan, San Juan, Napon-Napon, Marikit and Conversion) were submerged under the new lake. Residents were relocated to higher ground overlooking the vast reservoir, which became the new Pantabangan town center.

Magat Dam is a large rock-fill dam on the island of Luzon in the Philippines. The dam is located on Magat River, a major tributary of Cagayan River. Construction of the dam started in 1975 and completed in 1982. Magat Dam is one of the largest dams in the Philippines and has two primary purposes: as a source of irrigation water and as a provider of hydroelectric power. It was Southeast Asia's first large multipurpose dam.[3] The dam is part of the Magat River Multipurpose Project (MRMP) which was financed by the World Bank and whose purpose is to improve on the existing Magat River Irrigation System (MARIS) and to triple the production of rice in the Cagayan River basin.

The **Pulangi IV Hydroelectric Power Plant**, also known as the **Pulangi Dam**, is located on the Pulangi River near Maramag in Bukidnon province on the island of Mindanao in the Philippines. It uses two reservoirs, produced by damming the Pulangi River, to supply water to a run-off-the-river hydroelectric power plant; the power plant is capable of generating 255 megawatts (342,000 hp) of power. The upper (pondage) reservoir diverts water into a power channel which parallels the river until it reaches the lower reservoir (surge pool) 7.5 km (5 mi) to the south. At the lower reservoir, water is fed to each of the three 85 MW (114,000 hp) Francis turbine -generators via a penstock. The Pulangi IV power plant provides 23% of the hydroelectric power generated on Mindanao.

The **San Roque Dam**, operated under San Roque Multipurpose Project (SRMP) is a 200 m. tall, 1.2 km. long embankment dam on the Agno River. It spans the municipalities of San Manuel and San Nicolas, Pangasinan and is nearly 200 km north of Metro Manila. The dam impounds a reservoir with a surface area of about 12.8 km^2 extending North into the municipality of Itogon, Benguet. A gated spillway protects the dam from overtopping. Each wet season, the run-off is stored for later release via water turbines to generate power and irrigate crops.

Agno River is the third largest river in the Philippines with a total length of 221 kilometers and a drainage basin at the Project site of 1,225 square kilometers. The river originates in the Cordillera Mountains, initially flows from north to south, divides into several channels in the flat central plain of Luzon and meanders westerly through the provinces of Pangasinan and Tarlac before emptying into the Lingayen Gulf.

1.4 Impact from such construction

The constructions of these several dams (cross-river obstacles) affected the socio-economic condition of the people in the affected areas and the life cycle of some species of migratory fishes in the areas. Their lands were submerged, however they were relocated to the higher grounds by the government and were given livelihood. To mitigate the low yield of catch, stock enhancement were undertaken (communal stocking of tilapia and carps in the reservoirs). The government in order to sustain the management of the bodies of water created the National Fisheries and Agriculture Management Council. In general, the construction of these dams (for power and irrigation) has uplifted the economic condition of the country.

II. CROSS-RIVER OBSTACLE IN THE PHILIPPINES

2.1 Existing cross-river obstacle

Name of Dam/weir	Height (in meters above downstream water surface)	Purpose and responsible agency	Geographical location, river system, and hydraulic condition of the river	Important fish species in the ecosystem and impacts from dam/weir fisheries	Fish passage construction (yes/no)
Ambuklao Dam	129 meters	Power generation, flood mitigation SN Aboitiz Power-Benguet, Inc.	Located in Bokod, Benguet; Agno river system	Mudfish; catfish; eel; goby; tilapia; shrimp; carps; loach	no
Binga Dam	107.37 m	Power generation; National Power corporation	Itogon, Benguet; Agno River System	Mudfish; catfish; eel; goby; loach; tilapia; shrimp; carps;	no
Angat Dam	131m	Power generation; domestic water supply; irrigation; MWSS	Angat, Bulacan; Angat River	Mudfish; catfish; eel; gourami; goby; tilapia; shrimp; silver perch	no
Pantabangan Dam	230 m	Power generation; irrigation; flood control; NPC/NIA	Pantabangan, Nueva ecija; Upper Pampanga River	Mudfish; catfish; eel; gourami; goby; tilapia; shrimp; carps; large mouth bass; silver perch	no
Magat Dam	144 m	Power generation; irrigation / SN Aboitiz Power-Magat, Inc	Alfonso Lista, Ifugao/ Ramon Isabela; Magat River	Mudfish; catfish; eel; gourami; goby; tilapia; shrimp; carps; silver perch	no
Pulangui Dam		Power generation; irrigation / National Power Corporation/NIA	Bukidnon	Mudfish; catfish; eel; gourami; goby; tilapia; shrimp; carps	no
San Roque Dam	200 m	Power generation; irrigation / National Power Corporation, NIA	San Manuel and San Nicolas Pangasinan; Agno River	Mudfish; catfish; eel; silver perch goby; tilapia; shrimp; carps	no

2.2 Future plans cross-river obstacle

The area of reservoirs is expected to increase in the country as more small and large reservoirs are planned for development to satisfy the increasing demand for irrigation water, food production and the like purposes.

III. FISH PASSAGE IN THE PHILIPPINES

There is no fish passage constructed yet in the country. It is not being incorporated in the design and construction of any cross-river obstacles. This may be due to the fact that the government prioritized power generation and irrigation in the construction of dams. Policy makers of the country should consider “conservation of biodiversity (especially in fisheries)” as one criteria/incorporated in the design of any cross-river obstacle to achieve a balance and sustainable development. This workshop is very important to introduce and lay down the design and specification of the structures (fish passage) which will serve as a guide for the Southeast Asia.

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Annex 12

FISH PASSAGE IN THAILAND

I. OVERVIEW

1.1 General geographical information

Thailand's 514,000 square kilometers (198,000 sq mi) lie in the middle of mainland Southeast Asia. Area consists of 511,770 sq km (197,600 sq mi) of land and 2,230 cu km (540 cu mi) of water. There is land bordered to 4,863 km with border countries: Myanmar 1,800 km in North and West, Laos 1,754 km in Northeast, Cambodia 803 km in Southeast, and Malaysia 506 km in South. The coastline is 3,219 km along Gulf of Thailand and Andaman Sea. The National Research Council divides Thailand into six geographical regions, based on natural features including landforms and drainage, as well as human cultural patterns. They are, namely: the North Region, the Northeast Region, the Central Region, the East Region, the West Region and the South Region of Thailand. Bangkok, as the capital and largest city is part of the Central Region. Each of the six geographical regions differs from the others in population, basic resources, natural features, and level of social and economic development. The diversity of the regions is in fact the most pronounced attribute of Thailand's physical setting.

The North Region is a mountainous area. These high mountains are incised by steep river valleys and upland areas that border the central plain. Most rivers, including the River of Nan, Ping, Wang, and Yom, unite to form the Chao Phraya River in the lowlands of the Lower-North Region and the Upper-Central Region. Some rivers are drained, flowing into the Mekong River, like the Kok River and the Ing River. For the Salween River, there principal tributaries are the Moei River and the Pai River which drain into the Andaman Sea in Burma.

The Northeast Region consists mainly with its poor soils, which in some parts is extremely flat and a few low but rugged and rocky hills. Mountains ring the plateau on the west and the south, the amount of water in the river changes a lot seasonally. Most rivers, excepting the Pa Sak River, are flowing into ***the Mekong River System***. The Pa Sak River originates in the Phetchabun Mountains, and passes through as the backbone of the north and northeast regions. It then passes through The Central Region, until it runs into the Chao Phraya River in Ayutthaya Province. The other rivers, the Kok River and Ing River (from the North Region), the Song Kram River, the Mun River, the Chi River and the Lam Ta Klong River (joins the Mun River), are the principal tributaries of Mekong River, which flow through the Northeast Region. In terms of area drained, it is second only to the Chao Phraya River System.

The Central Region is dominated by the Chao Phraya and its tributaries. ***The Chao Phraya River System*** is the main river system of Thailand, covering approximately 35% of the nation's land and draining an area of 157,924 square kilometers (60,975 sq mi). It flows from north to south for 372 kilometers (231 mi). The principal tributaries of the Chao Phraya River are the Pa Sak River and the Sakae Krang River. In Chainat Province, the Tha Chin river splits into the main river course, which then flows parallel to the main river and exits to Gulf of Thailand at about 35 kilometers (22 mi) west of Bangkok in Samut Sakhon Province. In the low alluvial plain, many small canals split off from the main river. None of the tributaries of the Chao Phraya extend beyond the nation's borders.

The East Region lies between the Sankamphaeng Range, which forms the border of the Northeastern plateau to the north and the Gulf of Thailand to the south. The western end of the Cardamom Mountain extends into Eastern Thailand. The geography of the region is characterized by short mountain ranges alternating with small basins of short rivers which drain into the Gulf of Thailand. The rivers originating in the East Region are the Bang Pakong River. It principal tributaries are the Nakhon Nayok River and the Prachin Buri River.

The West Region hosts much of Thailand's less-disturbed forest areas. Thus, water is an important natural resource. The geography, like the North, is characterized by high mountains and steep river valleys. There are two main rivers which flow into the Gulf of Thailand. One is the Mae Klong River, begins at the confluence of the Khwae Noi River and the Khwae Yai River in Kanchanaburi Province. Another one is the Phetchaburi River. It originates and most of which is within the Phetchaburi Province.

The South Region, part of a narrow peninsula, is distinctive in climate, terrain, and resources. North-south mountain barriers and impenetrable tropical forest, rolling and mountainous terrain, and the absence of large rivers are conspicuous features of it. The following rivers are a number of rivers which drain into the Gulf of Thailand. The Pattani River is the longest of all rivers on the South Region with a total length of 214 kilometers (133 mi). The Tapi River with its main tributary the Phum Duang River drains the area of Surat Thani Province. The Pran Buri River and the Khlong Kui River are rivers in the Prachuap Khiri Khan Province.

In addition to the Chao Phraya River, a number of the Central Region rivers, the East Region rivers, the West Region rivers and the South Region rivers, which drain into the Gulf of Thailand, are the most significant ***the Gulf River System***.

1.2 Water resources information

For hydrological purposes, The National Committee on Hydrology separates surface water resources into 25 distinct hydrological units or river basins, as shown on **Fig. 1**.

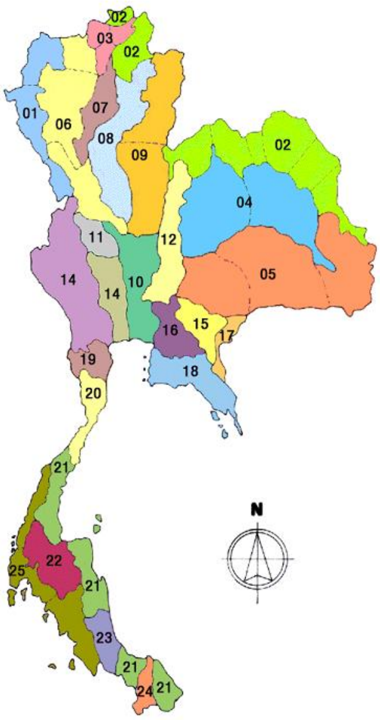


Figure 1. River basins of Thailand

Code	Name of river basin
01	Mae Nam Salawin
02	Mae Nam Khong
03	Mae Nam Kok
06	Mae Nam Ping
07	Mae Nam Wang
08	Mae Nam Yom
09	Mae Nam Nan
02	Mae Nam Khong
04	Mae Nam Chi
05	Mae Nam Mun
10	Mae Nam Chao Phraya
11	Mae Nam Sakae Krang
12	Mae Nam Pasak
13	Mae Nam Thachin
15	Mae Nam Prachin Buri
16	Mae Nam Bang Prakong
17	Thole Sap
18	East-Coast Gulf
14	Mae Nam Mae Klong
19	Mae Nam Petchaburi
20	West Coast Gulf
21	Peninsula-East coast
22	Mae Nam Tapi
23	Thale sap Songkhla
24	Mae Nam Pattani
25	Peninsula-West coast

1.3 Climate Variability

Most of Thailand has a Tropical wet and dry or savanna climate according to the Köppen climate classification, while the South Region and the eastern tip of the East Region have a tropical monsoon climate (**Fig. 2**); countrywide, temperatures normally range from an average annual high of 38 °C (100.4 °F) to a low of 19 °C (66.2 °F). Southwest monsoons that arrive between May and July (except in the South Region) signal the advent of the rainy season, which lasts into October. November and December mark the onset of the dry season. The Northeast Region experiences a long dry season from late November through mid March while the dry season

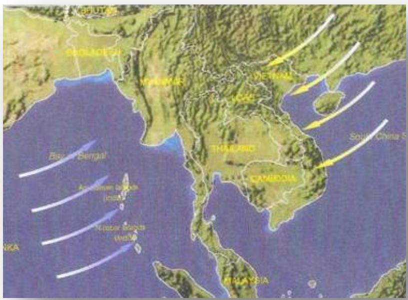


Figure 2. *Monsoons in Thailand*

is shortest in the South Region. With only minor exceptions, every area of Thailand receives adequate rainfall, but the duration of the rainy season and the amount of rain vary substantially from region to region and with altitude.

1.4 Rainfall and Runoff Water

The average annual rainfall countrywide is of about 1,700 mm. The total volume of water from rainfall in all the river basins in Thailand is estimated at 800,000 million m^3, 75 percent of which or about 600,000 million m^3 is lost through evaporation, evapo-transpiration and infiltration; the remaining 25 percent or 200,000 million m^3 constitutes the runoff that flows in rivers and streams. With a population of about 60 million, the availability of water resources is 3,300 m^3 per person per year, which is considered highly adequate in statistical terms. The data on surface water resources in Thailand are shown in **Table 1**.

Table 1 Thailand's surface water resources

Region	Catchment area (km^2)	Average annual rainfall (mm/year)	Amount of rainfall (million m^3)	Amount of runoff (million m^3)
North	169,640	1,280	217,140	65,140
Northeast	168,840	1,460	246,500	36,680
Central	30,130	1,270	38,270	7,650
East	34,280	2,140	73,360	22,000
West	39,840	1,520	60,560	18,170
South	70,140	2,340	164,130	49,240
Total	**512,870**	-	**799,960**	**198,880**

1.5 Floods and Droughts

Thailand is accustomed to dealing with large amounts of rain, an average annual rainfall of over 1,200 mm/year. However, some parts of the country continue to suffer drought problems due to the uneven distribution of rainfall. Thailand has frequently suffered from flood and drought. The floods often occur in the North Region and spread down the Chao Phraya River through the central plains, in the Northeast Region along the Chi River and Mun River flowing into the Mekong, or in the coastal hillsides of the East Region and the South Region. Remnants of tropical storms that strike Vietnam or the peninsular south commonly increase precipitation, resulting in further risk of flooding. Flooding usually occurs during the monsoon season (September - October) when there is intense precipitation. Drought (mainly water shortages for irrigation purposes) occurs in summer or when rainfall is delayed in the early part of the rainy season (July). Some particular areas experience both flooding and drought conditions in a single year, due to temporal and spatial uncertainties in the monthly rainfall or the poor management of the conveyance infrastructure.

1.6 Inland Water Bodies Classification

The main aquatic ecological pattern of inland typology in Thailand that classified by the Office of Environmental Policy and Planning can be divided into 3 main categories. There are; (1) rivers and floodplains water body, (2) large swamps and reservoirs water body, and (3) small inundated wetland. The total maximum water surface area of the country was estimated to be 16,410 km^2 which about 16.85 % of the total area was belonging to rivers and flood plains type, 51.86 % of swamps and reservoirs area, and the left of 31.29 % was occupy by small inundated wetland (**Table 2**).

Table 2 Total number and area of inland water bodies in Thailand (unit: km^2)

Typology	Northern Region		Northeastern Region		Central plain & Eastern region		Southern Region		Total	
	No.	Area	No.	Area	No.	Area	No.	Area	No.	Area
River & floodplain	5,461	1,116.7	8,053	1,091.5	8,380	163.5	3,114	393.0	25,008	2,765.7
Large swamp & reservoir	4,573	1,678.5	6,168	836.0	2,228	2,352.9	1,159	3,643.2	14,128	8,510.6
Small inundated wetland	539	26.1	368	49.8	750	142.2	336	4,916.1	1,993	5,134.2
Total	**10,573**	**2,821.3**	**14,589**	**1,977.3**	**11,358**	**2,659.6**	**4,609**	**8,952.3**	**41,129**	**16,410.5**

1.7 State of Inland Open Water Fisheries

Inland open water is the area's largest producer of free or cheap protein food for most Thais, from both capture fishery and aquaculture sectors. For capture fishery, inland fishing in Thailand usually operated in the major rivers, swamps, paddy field, lakes and reservoirs. In the past, floodplains were also important inland fisheries habitats but these have almost disappeared due to the construction of dams and other infrastructure developments. In overall figure inland capture fisheries are mainly for subsistence with very small numbers of commercial fishers. Generally, people who live near the water resources will regularly fish within these areas and catch is just adequate for home consumption while the occasional surplus is marketed. The commercial fishers were located only in the major reservoirs and floodplain area.

1.8 Thai Freshwater Fauna Resources

The inventory survey of freshwater fauna in Thailand has been relatively insufficient; approximately 570 of freshwater fish (Vidthayanon *et al*., 1997). The largest family is Cyprinidae, possesses 204 species. The second is Balitoridae 62 species known, and Cobitidae 31 species, respectively. The total number of economic species is in the order of 34 species plus 3 species of others, additionally 6 alien species was introduced and flourished in natural waters (**Table 3**).

Table 3 The economic species composition of freshwater fauna in Thailand

Scientific Name	Common Name	Thai Name
Oreochromis niloticus	Nile tilapia (Nile basin; Japan)	นิล
Cyprinus carpio	Common carp (China; China)	ไน
Barbodes gonionotus	Silver barb	ตะเพียน
Trichogaster pectoralis	Snake skin gourami	สลิด
Hypophthalmicthys sp.	Chinese carp (China; China)	จีน
Clarius spp.	Walking catfish	ดุก
Channa striata	Striped snake head	ช่อน
Pangaisanodon hypophthalamus	Striped catfish	สวาย
Oreochromis mossambicus	Java tilapia (Africa; Malaysia)	หมอเทศ
Oxyeleotris marmoratus	Sand gobi	บู่
Osphronemus gourami	Giant gourami	แรด
Lates calcarifer	Sea bass	กะพง
Labeo rohita	Rohu (Ganges basin; India)	ยี่สกเทศ
Notopterus notopterus	Grey feather back	สลาด
Pangasius larnaudii	Black ear catfish	เทโพ
Monopterus albus	Swamp eel	ไหล
Trichogaster trichopterus	Gourami	กระดี่
Anabas testudineus	Climbing perch	หมอไทย
Wallago attu	Great white sheatfish	เค้าขาว
Helostoma temmincki	Kissing gourami	หมอตาล
Hemibagrus spp.	Yellow mystus, Catfish	กด
Cyclocheilichthys enoplos	Soldier river barb	ตะโกก
Ompok bimaculatus	Butter catfish	ชะโอน
Morulius chrysophekadion	Black shark	กาดำ
Pristolepis fasciata	Striped tiger	หมอช้างเหยียบ
Hampala spp.	Carp	กระสูบ
Osteochilus spp.	Hard lipped barb	สร้อยนกเขา
Puntioplites proctozysron	Smith barb	กระมัง
Henicorhynchus siamensis	Jullien's mud carp	สร้อยขาว

Scientific Name	Common Name	Thai Name
Chitala ornate	Feather back clawn	กราย
Channa micropeltes	Red snake head	ชะโด
Clupeichthys aesarnensis	Thai river sprat	ซิวแก้ว
Kryptopterus spp.	Whisker sheatfish	เนื้ออ่อน
Wallago leerii	Great sheatfish	เค้าดำ
Channa lucius	Snake head	กระสง
Mystys spp.	Stripes mystus	แขยง
Macrognathus spp.	Eel	หลด
Cirrhinus migala	Migala (Ganges basin; Bangladesh)	นวลจันทร์เทศ
Acanthopsis choirorhynchos	Horse face loach	รากกล้วย
Botia spp.	Loach	หมู
Mystacoleucus spp.	Indian river barb	หนามหลัง
Macrobrachium rosenbergii	Giant freshwater prawn	กุ้งก้ามกราม
Rana spp.	Frog	กบ
Amydy cartilagenea	Soft-shelled turtle	ตะพาบน้ำ

1.9 Stakeholders involved in utilization of inland aquatic resources

Water is natural environment resource that characterizes climate condition, which could also have an impact on water resources and their availability. Southwest monsoon is the enormous hydrological cycle system and it fosters substantial water environment for food production, power generation, transportation, and so forth. Consequently millions of people are involved in utilization of inland aquatic resources such as rapid rural development, industrialization, tourism development and income growth have raised water demand for domestic usage, agriculture and other purposes drastically. Water provision and water demand in each river basin are as shown in **Table 4**.

Table 4 Description of water provision and water demand in the 25 river basins of Thailand

Code	Name of river basin	Catchment area	Average runoff (10^6 m^3)	Storage capacity (10^6 m^3)	Irrigation area (*rai*)	Water requirement (10^6 m^3/year)				
						Domestic consumption	Tourism industry	Ecological balance	Irrigation/ Agriculture	Hydro-power
1	Salawin	17,920	8,571	24.00	188,948.00	11.96	4.46	1,027.81	616.93	-
2	Mekong	57,422	19,362	1,551.00	1,692,333.00	132.57	1.98	1,145.69	4,323.33	-
3	Kok	7,895	5,279	30.00	520,767.00	14.90	0.43	680.00	401.39	-
4	Chi	49,477	8,752	4,246.00	1,863,173.00	195.17	49.62	573.33	3,052.82	2,156.00
5	Mun	69,700	26,655	4,255.00	1,819,785.00	337.88	94.30	956.63	2,628.85	591.30
6	Ping	33,898	7,965	14,107.00	1,942,927.00	75.26	1.00	457.27	2,428.20	3,623.00
7	Wang	10,791	1,104	197.00	472,350.00	20.21	1.00	48.00	487.42	45.00
8	Yom	23,616	3,117	98.00	994,205.00	53.87	0.08	315.36	859.13	-
9	Nan	34,330	9,158	9,619.00	1,780,637.00	66.29	0.32	315.36	2,870.80	2,583.00
10	Chao Phraya	20,125	22,015	33.00	5,731,375.00	1,594.40	646.05	1,250.00	8,768.59	-
11	Sakaekrang	5,191	1,297	162.00	436,410.00	8.62	-	3.35	878.75	-
12	Pasak	16,292	2,820	124.00	661,120.00	72.32	23.28	158.00	927.38	-
13	Tha Chin	13,682	22,300	416.00	2,385,259.00	94.94	310.25	1,000.00	4,292.11	-
14	Mae Klong	30,837	7,973	26,690.00	3,400,000.00	20.34	-	1,577.00	4,323.33	4,670.00
15	Prachinburi	10,481	5,192	57.00	733,862.00	8.08	2.78	377.00	838.32	-
16	Bang Pakong	7,978	3,713	74.00	1,353,263.00	14.18	9.05	946.00	2,243.60	1.94
17	Tonle Sap	4,150	6,266	96.00	123,720.00	12.60	-	9.80	197.00	-
18	Pen. East Coast	13,830	11,115	565.00	427,000.00	129.10	83.50	74.70	578.46	79.00
19	Phetchaburi	5,603	1,400	750.00	562,688.00	14.30	2.90	67.00	1,110.00	693.00
20	Pen.West Coast	6,745	1,420	537.00	327,015.00	18.00	2.97	39.10	1,383.00	-
21	Southeast Coast	26,353	23,270	5.00	1,780,481.00	56.40	8.70	161.70	1,129.10	2,577.00
22	Tapi	12,225	12,513	5,865.00	245,970.00	25.90	10.00	3,085.20	144.60	2,596.00

23	Songkhla Lake	8,495	4,896	28.00	905,550.00	56.45	37.50	312.00	2,994.70	-
24	Pattani	3,858	2,738	1,420.00	337,878.00	31.20	2.44	670.80	441.11	1,152.00
25	Southwest Coast	21,172	25,540	20.00	339,273.00	53.20	18.90	74.80	253.00	-
	TOTAL	**512,066**	**244,431**	**70,769.00**	**31,025,989.00**	**3,118.14**	**1,311.51**	**15,325.90**	**48,171.92**	**20,767.24**

NB: 6.25 *rai* = 1 ha

The North Region, all river basins suffer from water shortage, especially the Salawin basin and, to a minor extent, those of the Kok, Ping and Wang rivers. This area in the past was used as a source of raw water for the central area. However, the recent development of the area has increased local water consumption, thus reducing the contribution to the central area. Conflict is looming between this area and its downstream neighbor, the Central Region.

The Northeast Region, this is part of the Mekong river basin's catchment area. The area is geographically unsuitable for large-scale water storage, hence cannot respond adequately to local demand. The Mun river basin is the most seriously affected, followed by the Chi and Mekong river basins. The soil structure in the Northeast Region has low potential for water storage. It has to rely on medium-sized and small-scale water storage and on inter-basin transfer.

The Central Region is the most important area for Thailand's economy. It is also the most agriculturally productive area without its own large water sources. Demand for water in this area far exceeds locally available supply. The area therefore depends heavily on water from river basins upstream. The Central Region has faced the most serious water shortage problem. The high density of population and intense economic activity in the basin result in high water demand. The National Economic and Social Development Board (NESDB) study on a strategy for water resources management in the Chao Phraya river basin confirms the problem. The water shortage of the Lower Chao Phraya depends very much on the combined available water stored by the Bhumibol and Sirikit dams and on total rainfall in the North Region. The shortage of water will worsen in future, since water demand continues to increase both upstream and downstream while the total water supply remains the same or even decreases due to deforestation.

The East Region, This area is characterized by many short rivers, which are suitable only for medium-sized water storage projects. Due to other favorable conditions, the area is designated in the national development plan as a major industrial zone (the Eastern Seaboard) for the country. Accordingly, water shortage in the area is imminent.

The South Region, many short rivers and high annual rainfall characterize this area. There are a number of large water reservoirs. Water shortage is confined to a few places and is less severe than elsewhere.

1.10 Cross – River Obstacles

Historically, Thai governments have emphasized agriculture and rural development continuously by launching a rural development programme followed by agriculture – restructuring programme since the 1960s. Thailand has constructed more than forty major dams. Many Dams have been implemented in parallel with the development of irrigation. This approach has been successful in giving millions of Thai people access water to produce cheap and abundant rice, and to generate hydroelectricity for those industries. As such, Thailand has been one of the great development success stories, with sustained strong growth and impressive poverty reduction.

We all agree that the economic growth in Thailand and the associated increase in the demand for electricity have triggered the boom of the dam development in the North Region and the Northeast Region. However, benefits of Thailand's economic success have not been shared equally, with some regions particularly, the North Region and the Northeast Region, lagging behind the rest of the country in terms of poverty reduction. The different potential from dam to fulfill people's needs is both loss and gain. Therefore, the vision of dam construction had to include and reflect people's needs in every water basin.

Point to fish populations, inland capture fisheries are regarded as activities undertaken by poor in rural areas. This is mainly correct although there are some exceptions. They are important for food production, food security and have some economic importance for household incomes *etc*. It was clearly stated that inland fisheries in these terms were significantly more important than marine fisheries (which are regarded more as a source of revenue/exports). Those development programmes should complete the answers in fish population's questions: What will be lost and what will be gained by damming? How much of biodiversity and ecosystem services will be lost? What support the extremely high fish production in river? How much of fish migrations will be disrupted by the current configuration of planned dams? Where are the spawning grounds to be protected? Are pathways to the spawning grounds free of dam construction plan? What are the alternatives to the current configuration of the dams? Will reservoir fisheries be sustainable?

In case of the Chao Phraya River that the confluence of the Ping, Wang, Yom and Nan rivers is the beginning of the Chao Phraya River. Siltation of these four rivers has enriched this river basin making the Chao Phraya River System the most fertile plain of the country. Inhabitants of this river basin earn their living from agricultural production of rice, vegetables and other major economic crops. The life cycle of giant freshwater prawn takes place partly in fresh water and partly in brackish water. When the government started the rural development programme, the Chao Phraya Dam (the largest existing reservoir in this basin) was constructed in 1952 and completed in1957. The migration of giant freshwater prawn, whose the reproduction occurring in brackish water by migrate to the Chao Phraya river-mouth for breeding purposes and back to freshwater to the North Region (the Ping, Wang, Yom and Nan rivers) for trophic purposes was cut-off. The Chao Phraya Dam also prevented free upstream fish migration and thus contributes to the decline and even the extinction of species that depend on longitudinal movements along the stream continuum during certain phases of their life cycle. There has been a continuous and increasing decline in stocks of giant freshwater prawn and fish migration in the upper river. Reduced fluctuation of water levels the lower river, cause to shrinkage of floodplain, resulting to habitat loss or alteration, discharge modifications, are significant issues.

In case of the Mun River, the Northeast Region, even the effectiveness of a fish pass is a qualitative concept of its performance. The Pak Mun Dam was built on the Mun River, 5.5 km upstream from its confluence with the Mekong River. The Electricity Generating Authority of Thailand (EGAT) built and operates the dam as a run of the river hydropower plant. A fish ladder had been installed to help the migratory fish in the Northeast Region, but most fish species living in the Mun River are unable to swim upstream and downstream past the dam. This is far from the only impact. The real problem is not with the ladder. Rather Pak Mun Dam itself is ecologically unfriendly to fishes.

Thai government now faces a different and more complex set of challenges associated with a large increase in flooding impacts due to development within the floodplain environment leading to a decline in the flood retention areas, combined with the deforestation that has occurred on a large scale. Floods have been part of the natural order of Thailand since historical times that populations living within the urban and rural floodplains have found ways to adapted to. Now floods have become increasingly scarce. Following a mega flood event in 2011, a Master Plan for flooding was drafted in the construction of dykes and other flood control structures to protect the major urban centers and industrial areas. There is no master plan for such fish population’s management in any area. Dykes and other flood control structures block migration paths, shrinkage of floodplain as their natural breeding grounds. Thus, the alternatives to keep fish production in River Systems such a fish ladder must also be considered.

II. CROSS-RIVER OBSTACLES IN THAILAND

Name of dam/weir	Height	Purpose & Responsible agency	Geographical location river system	Important fish species	Fish passage construction
Existing cross-river obstacles					
Bhumibol	154.0	Power generation, Flood and drought	North Region Chao Phraya River System	Catfish	No
Sirikit	133.6	**Irrigation,** Power generation, Flood and drought	North Region Chao Phraya River System	Soldier river barb, Sand goby	No
Kio Lom	26.5	**Irrigation,** Power generation	North Region Chao Phraya River System	Grey feather back	No
Mae Ngat Somboon Chon	59.0	**Irrigation**	North Region Chao Phraya River System	Catfish, Striped catfish	No
Mae Kuang Udom Thara	68.0	**Irrigation,** Flood and drought, Drinking	North Region Chao Phraya River System	Striped snake head	No
Kio Kho Ma		**Irrigation,** Flood and drought	North Region Chao Phraya River System	Sand goby, Grey feather back	No
Khwaenoi Bamrungdaen	75.0	**Irrigation,** Flood and drought	North Region Chao Phraya River System	Great white sheatfish, Sand goby	No

Name of dam/weir	Height	Purpose & Responsible agency	Geographical location river system	Important fish species	Fish passage construction
Kra Siao	32.5	**Irrigation**	Central Region Chao Phraya River System	Jullien's mud carp	No
Thapsalao	26.8	Flood and drought	Central Region Chao Phraya River System	Jullien's mud carp	No
Pa Sak Jolasid	31.5	Flood and drought	Central Region Chao Phraya River System	Sheatfish, Catfish, Grey feather back	No
Nam Phung	41.0	**Irrigation,** Power generation, Flood and drought	Northeast Region Mekong River System	Black shark	No
Ubonrat	35.1	Power generation, **Irrigation**	Northeast Region Mekong River System	Striped catfish, Black shark	No
Lam Pao	33.0	**Irrigation**	Northeast Region Mekong River System	Catfish	No
Lam Ta Khong	40.3	**Irrigation**	Northeast Region Mekong River System	Red spiny eel, Soldier river barb	No
Lam Phra Phloeng	50.0	**Irrigation,** Flood and drought	Northeast Region Mekong River System	Striped snake head	No
Sirinthon	42.0	power generation	Northeast Region Mekong River System	Black shark	No
Chulabhorn	70.0	Power generation	Northeast Region Mekong River System		No
Nam Un	30.0	**Irrigation**	Northeast Region Mekong River System	Silver barb	No
Pak Mun	17.0	Power generation	Northeast Region Mekong River System	Black shark, Soldier river barb, Catfish	Yes
Lam Nang Rong	23.0	**Irrigation**	Northeast Region Mekong River System	Tire track eel, Catfish, Sand goby	No
Lam Chae		**Irrigation**	Northeast Region Mekong River System	Striped snake head	No
Kaeng Krachan	58.0	Power generation, **Irrigation,** Flood and drought	West Region Gulf River System	Walking catfish, Sand goby, Catfish	No
Pran Buri	42.0	**Irrigation** Flood and drought	South Region Gulf River System		No
Srinakarind	140.0	**Irrigation,** Flood and drought, Power generation	West Region Gulf River System	Feather back clawn, Greater brook carp, Catfish, Tire track eel	No
Vajiralongkorn	92.0	Power generation	West Region Gulf River System	Catfish	No
Bang Phra	24.0	**Irrigation**	East Region Gulf River System	Butter catfish, Grey feather back	No
Nong Phlalai	24.0	**Irrigation**	East Region Gulf River System		No
Khlong Si Yat	27.5	**Irrigation**	East Region Gulf River System	Sand goby	No
Khlong Tha	93.0	**Irrigation**	Central Region Gulf River System	Black shark, Striped catfish	No
Phra Sae	24.0	**Irrigation,** Prevent seawater intrusion	East Region Gulf River System	Striped snake head	No
Bang Lang	85.0	**Irrigation,** Power generation	South Region Gulf River System	ปลาพวงชมพู ปลาสลาด Catfish, Grey feather back	No
Ratchaphrapha	94.0	**Irrigation,** Power generation	South Region Gulf River System	Arowana	No
Naresuan	17.0	**Irrigation**	North Region Chao Phraya River System	Great white sheatfish	No
Chao Phraya	16.5	**Irrigation**	Central Region Chao Phraya River System	Chao Phraya giant catfish, Butter catfish, Striped catfish, Great white sheatfish, Giant freshwater prawn	No
Huai Luang	12.5	**Irrigation**	Northeast Region Mekong River System	Butter catfish, Catfish, Striped catfish, Butter catfish, Sand goby, Swamp eel	No

Name of dam/weir	Height	Purpose & Responsible agency	Geographical location river system	Important fish species	Fish passage construction
Future plan cross-river obstacles					
Mae Wong		Flood and drought	North Region		
Kang Suea Ten		Flood and drought	North Region		
Clong Chompu		Flood and drought	North Region		

III. FISH PASSAGES IN THAILAND

3.1 Legal issues related to construction of fish passage

Thailand has ***the Fisheries Act, B.E. 2490*** since 1947. The Act is implicated with 2 Chapters;

Chapter 1 Fisheries

Section 22

No person shall erect, set up or build dike, dam, screen fence, fishing nets or other fishing implement in fisheries obstructing the passage of aquatic animals, unless permission in the land owned by person.

The licensee must comply with the conditions imposed by the competent official such as those relating to the fish-ladders or other implements enabling aquatic animals to swim up and down.

Chapter 6 Penalties

Section 62

Whoever violates Section 9, Section 13, Section 17 to 19, Section 21, Section 22, Section 30, Section 54 or Section 55 shall be punished with fine not exceeding ten thousand Baht or with imprisonment not exceeding six months, or both.

3.2 Future fish passage

The fact that almost nothing is known about migrating species, in the absence of good knowledge on the species, the fish passes must be designed to be as versatile as possible and open to modifications. The fish passes for past obstacles can be provided for through several types of fishways: pool – type fish passes, Denil fish passes, nature – like bypass channels, fish lifts or locks, collection and transportation facilities. The most frequent causes of fish pass failure include lack of attraction flow, unsuitable location of the entrance, inadequate maintenance; hydraulic conditions (flow patterns, velocities, turbulence and aeration levels) in the fish pass not adapted to the target species. There is an urgent need for better biological information (*e.g.* migration period, swimming capacity, migratory behavior) and to do fish passage research (upstream and downstream) for other native species. Fish passage facilities must be systematically evaluated. It should be remembered that the fish pass technique is empirical in the original meaning of the term, *i.e.* based on feedback from experience. The most significant progress in fish passage technology has been made in countries, which systematically assessed the effectiveness of the passes and in which there was a duty to provide monitoring results.

One must never lose sight of the limits to the effectiveness of fish passes. In addition to problems relating to fish passage at obstacles, there are indirect effects of dams, which may prove of major significance such as changes in flow, water quality, the increase in predation and drastic changes to the habitat upstream or downstream. The protection of migratory species for a given dam must be studied in a much wider context than the strict respect of fish passage alone.

Annex 13

FISH PASSAGE IN VIETNAM

I. OVERVIEW

1.1 General Geographical Information of the Country

Location:	Southeastern Asia, bordering the Gulf of Thailand, Gulf of Tonkin, and South China Sea, alongside China, Laos, and Cambodia
Geographic coordinates:	16 00 N, 106 00 E
Map references:	Southeast Asia
Area:	total: 331,210 sq km (land: 310,070 sq km; water: 21,140 sq km)
Land boundaries:	total: 4,639 km (border countries: Cambodia 1,228 km, China 1,281 km, Laos 2,130 km).
Coastline:	3,444 km (excludes islands)
Maritime claims:	territorial sea: 12 nm
Contiguous zone:	12 nm
Exclusive economic zone:	200 nm
Continental shelf:	200 nm or to the edge of the continental margin
Terrain:	low, flat delta in south and north; central highlands; hilly, mountainous in far north and northwest
Elevation extremes:	lowest point: South China Sea 0 m; highest point: Fan Si Pan 3,144 m
Land use:	agriculture land: 20.14%; permanent crops: 6.93%; other: 72.93% (2005)
Irrigated land:	30,000 sq km (2005)
Natural hazards:	occasional typhoons (May to January) with extensive flooding, especially in the Mekong River delta
Geography - note:	extending 1,650 km north to south, the country is only 50 km across at its narrowest point.

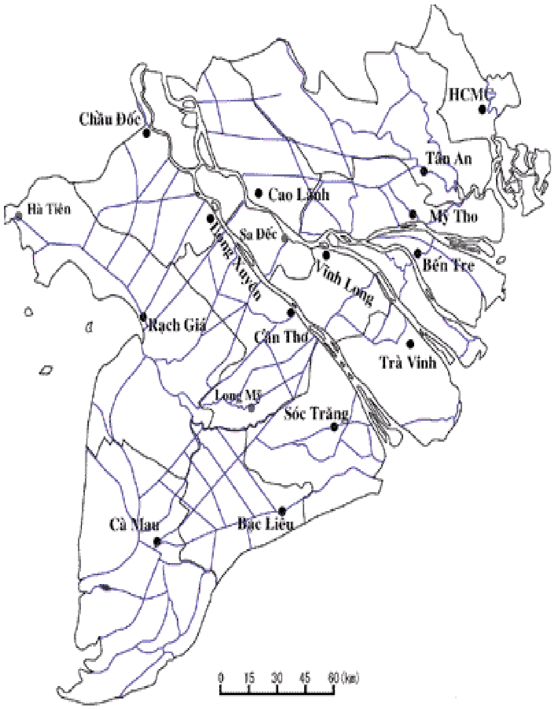
1.2 Overview on Inland Aquatic Ecosystems: Resources/Productivity, Hydrological Phenomenon, Seasonal Changes, Stakeholders Involving in Utilization of Inland Aquatic Resources

1.2.1 Inland Aquatic Resources

With 13 large river systems, which cover 10,000 km^2 in total, Vietnam is considered to have a complex and dense river network with most of the large river systems linked. Amongst those 13 main river systems, 9 have basins which contribute to 90% of total river basin area in the whole country. The 9 main river basins are Red, Thai Binh, Bang Giang-Ky Cung, Ma, Ca La, Thu Bon, Ba, Dong Nai, and Cuu Long river. The Red river and the Cuu Long river systems have the largest basin areas (155,000 and 795,000 km^2 respectively) as well as the highest total volume of water flow. Other than that, each river system has its own distinctive characteristics, thus environmental management approaches may vary greatly from one river basin to another, depending on socio-economic conditions, land use, environmental factors, and their economical and ecological values, etc.

The two rivers, the Bassac river to the south and the Mekong to the north, enter Vietnam. In Vietnam, the Bassac is called the Hậu River (Sông Hậu or Hậu Giang); the main, northern, branch of the Mekong is called the Sông Tiền or Tiền Giang. Some branches of Mekong River start in Vietnam's territory. These include Se San and Srepok river.

The Red River begins in China's Yunnan province. It flows generally southeastward, passing through Dai ethnic minority areas before leaving China through Yunnan's Honghe Autonomous Prefecture. It enters Vietnam at Lào Cai Province. It forms a portion of the international border between China and Vietnam. The river, known as Thao River for this upper stretch, continues its south-easterly course through north-western Vietnam before emerging from the mountains to reach the midlands. Its main tributaries, the Đà River and Lô River join in to form the very broad Hong near Viet Tri. Downstream from Viet Tri, the river and its many distributaries spread out to form the Red River Delta. The Red River flows past the Vietnamese capital Hanoi before emptying into the Gulf of Tonkin.



Dong Nai river system flows in the south Vietnam and passes through 11 provinces and cities in total. That includes HCM city, Lam Dong, Binh Phuoc, Binh Duong, Tay Ninh, Dong Nai, Dak Nong, Long An, Ba Ria-Vung Tau, Binh Thuan and Ninh Thuan provinces. The river basin covers an area of 14,800 km^2 and has 266 rivers and streams of over 10km each.

According to statistics of The Vietnam Fisheries Economics and Planning Institute (VIFEP), Vietnam has 632 freshwater fish species, out of which 243 and 134 and 255 species distributes in North and Central and South of Vietnam, respectively. The average inland exploitation yield is 200,000 tons/year but MRC estimate, this number is higher in reality, approximately 300,000-900,000 tons/year. Data we gathered from official record of Ministry of Fisheries (and now is Ministry of Agriculture and Rural Development), inland fisheries exploitation yield is 243,000 tons and 204,000 tons in 2001 and 2012, respectively.

1.2.2 Hydrological Phenomenon, Seasonal Changes

Tropical in North, monsoonal in South with hot, rainy season (mid-May to mid-September) and warm, dry season (mid-October to mid-March) so flood season will occur from May to September in Mekong river basin. In this season, migration fish species will start to swim upstream for breeding and larvae to be drifted by water flow to downstream area for catching out.

Tra (catfish), Basa (*Pangasius bocourti*), *Cyclocheilichthys enoplos*, *Cirrhinus microlepis*, *Catlocarpio siamensis*, *Probarbus jullieni* and some species belonging *Pangasiidae*, *Henicorhynchus* family are example for trans-border migration. They migrate to Tonle Sap lake or upper for breeding at the early of flood season and return to origination at the end of flood season. This characteristic will be changed in the case hydrological phenomenon change due to consequence of dam constructions in the main river at upstream.

1.2.3 Stakeholders Involving in Utilization of Inland Aquatic Resources

Have not got any research or survey or systematically statistics on how many stakeholders benefit from freshwater or brackish water fisheries resources on area of 34,6000 ha of 230 lake and lagoon, 400,000 ha of 2,500 hydraulic/hydropower reservoirs, 580.000 ha of paddy field (Red river account for 12%, Mekong river account for 88%) in nationwide. However, we understand that most of local people who are living along the river, surround the natural lake, lagoon are poor people. Their livelihood connects to these resources closely.
According to previous survey of RIA 2 in the year of 2002, around 200-800 millions fingerling in various species to be caught in Vietnam and nearly 165,000 millions fingerling to be caught in Cambodia by local people. At the present, Government of Vietnam and Cambodia agreed to put a ban on the fingerling exploitation in Mekong River.

The newest survey of Research Aquaculture Institute No 2 and MRC (Vietnam) indicated that freshwater fish exploitation yield that local people in An Giang province caught from Mekong river is 195,000 tons/year, out of which, 70% is migration fish (trans-boundary), equivalent to 92 million USD.

The life of approximately 1,500 local families who live in Phu Vang, Quang Dien, Phu Loc, Quang Phuoc districts, Thua Thien Hue province (central of Vietnam) depend on fisheries resources in Tam Giang lagoon (2,170 ha). Annually, they capture 2,500 -3,000 tons of various fisheries species and its enough to spend for their life.

1.3 Overview on Construction of Cross-river Obstacles, Impacts from Such Construction to Different Sectors (Particularly Fisheries) and Measures/Actions Undertaken for the Mitigation of Such Impacts Including the Construction of Fish Passage

1.3.1 Overview on Construction of Cross-river Obstacles in Vietnam

Up to November 2012, a total of 2,000 hydropower dams and hydraulic dams has been constructed in Vietnam, out of which, there are:

- 35 constructions with dam height is higher than 50m (32 hydropower constructions; 3 hydraulic constructions),
- 605 constructions with dam height's in range 15-50m (5 hydropower construction; 551 hydraulic constructions)
- 1,000 constructions with dam height is lower than 15m (no detail data because these constructions has been managing by Provincial People Committee).
- 360 hydraulic dams with height is lower than 1m (no detail data because these has been managing by community).

1.3.2 Impact to Fisheries Sector

China has launched a hydropower plan comprising eight large dams on the main stream river in the upper part of the catchment. Three dams have already been built and now also the countries in the lower basin, Laos, Cambodia and Vietnam have joined the pursuit with great visions. The hydropower expansion may well add to welfare and reduced poverty in especially Laos and Cambodia. However, it might also bring about negative consequences for the people living downstream. So far, a serious research on this issue did not carry out in Vietnam. But impact of dams to fisheries sector occurs in silent and invisible. The below is personal records, not represent for someone or any organization.

- The natural fisheries resources in general and Tra catfish resources in particular will be cut step by step until to be exhausted.
- Salt intrusion to inland with total estimated area is 1.2-1.6 million ha adjacent to the estuary in Mekong delta (25-40 km and salinity 4‰) (happening, in Ben tre province in specially).
- Lack of fresh water for agriculture/aquaculture producing and daily life in area of 2.1 million ha far from the river (happening).
- Some fish species (sticky eggs) in Thac ba lake give up the breeding function because the necessary water level for breeding in June lowers than needed (happened).
- In dry season, when upstream hydropower plants contain water, drought will be happened in a millions ha of Mekong delta.

Simple conclusion that the more dams there are, the better erosion and other environmental problems will be contained.

1.3.3 Action Undertaken for the Mitigation of Such Impacts Including the Construction of Fish Passage

- Release artificial fingerlings into reservoirs, lagoon, lake, hydropower reservoirs… so that reproduces fisheries resources, detail as below:
  Provincial Aquaculture Department has been releasing 2 millions fingerling each 2-3 years into Thac Ba lake (23,400 ha), Yen Bai province (North of Vietnam).
  Approximately, every year 1 million of big size fingerling to be released into Hoa Binh hydropower reservoir (208 km^2) by local authority (Hoa Binh province, in North of Vietnam).
  A comprehensive protection action has been implementing in Tam Giang lagoon, Thua Thien Hue province is to cultivate 5,000 local tree around the protective area, drop 50 artificial coral reef down

to the lagoon bottom, then release a hundred thousand shrimp post larvae and indigenous fingerlings.

- Protect the breeding-ground for fisheries species:
  Local authorities give a ban on exploitation fisheries during mature and breeding time in protective area.

- Community-based management:
  Set up a co-operative or cluster including the villager who share experience, life and long term benefit from common fisheries resources daily. They nominate a rotational leader by themselves and make a decision on how much kg of fish will be exploited a day, how many villager can involve in exploitation a day, and refund for reproductive, etc…together. By this way, fisheries resources are good managed.

- Utilization of water surface:
  For dam with height lower than 1 m, local people utilize water flow to set up a terraced ponds system for culturing fish.

II. CROSS-RIVER OBSTACLES IN VIETNAM

Some large dams from North to South of Vietnam to be described below:

Name of dam/weir	Height *(in meter above downstream water surface)*	Purpose & Responsible agency	Geographical location, river system, and hydraulic condition of the river	Important fish species in the ecosystems, and impacts from dams/weir to fisheries	Fish passage construction
Existing cross-river obstacles					
Son La	Dam height: 138 m Max water level: 215 m Water volume: 9.26 billion m3	Hydropower Government	In Northwestern of Vietnam (Son La province) On the Da river (upstream: China)	Native físh species. Haven't got any research on this issue due to this dam's going into operation at the end of 2012	No
Hoa Binh	Dam length: 734 m Dam height: 128 m Max water level: 120 m Water volume: 9 billion m3	Hydropower Government	In Northwestern of Vietnam (Hoa Binh province) On the Da river (upstream: China)	Native físh species. Haven't got any research on this issue due to this dam's going into operation at the end of 2012	No
Tri An	Dam length: 420 m Dam height: 40 m Max water level: 63.9 m Water volume: 2.76 billion m3	Hydropower EVN (Vietnam Electricity)	- In the South of Vietnam (Dong Nai province) - On Dong Nai river	Indigenous species	No

Name of dam/weir	Height *(in meter above downstream water surface)*	Purpose & Responsible agency	Geographical location, river system, and hydraulic condition of the river	Important fish species in the ecosystems, and impacts from dams/weir to fisheries	Fish passage construction
Tuyen Quang	Dam length: 717 m Dam height: 92 m Water level: 36 m Water volume: 2.2 billion m3	Hydropowe r EVN	- In Northeast of Vietnam (in Tuyen Quang province) - On	Indigenous species	No
Yaly	Dam length: 1,140 m Dam height: 71 m Water volume: 1 billion m3	Hydropowe r EVN	In the central highland of Vietnam (Gia Lai province)	Indigenous species	No
A Vương	Dam length: m Dam height: 384 m Water level: m Water volume: 0.343 billion m3	Hydropowe r EVN	In Quang Nam (central of VN)	Indigenous species	No
Song Tranh	Dam length: 717 m Dam height: 180 m Water level: 36 m Water volume: 2.2 billion m3	Hydropowe r EVN	In Quang Nam (central of VN)	Indigenous species	No
Dai Ninh	Dam length: 430 m Dam height: 56 m Water volume: 0.32 billion m3	Hydropowe r EVN	On Da Nhim river, 260 km far from HCM city	Indigenous species	
Future plan cross-river obstacles					
None of information					

III. FISH PASSAGES IN VIETNAM

3.1 Legal issues related to construction of fish passage in the country

Government Decree No 72/2007 dated 7th May 2007 on Dam safety management.

None of legal documents mentions about fish passage - a necessary facility in order to protect ecosystem, fisheries resources, the life of local people in downstream.

3.2 Existing fish passage

Up to now, none of fish passage has been constructed in Vietnam.

3.3 Cause that hampers/hinders fish pass planning construction

Lack of administrative support:

In Vietnam, Ministry of Industry & Trade (MIT) is the decision maker for the hydropower plants and hydraulic dams' construction. Ministry of Agriculture and Rural Development make a decision on constructing fish ports, irrigation channels and dikes.

So that why, Directorate of Fisheries (MARD) have not got a chance to give a suggestion on fish passage.

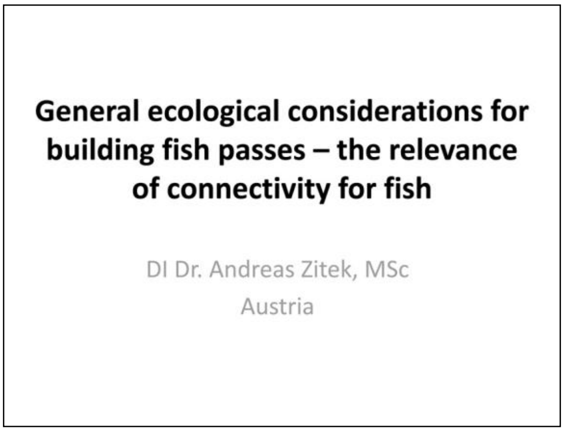
Lack of awareness:

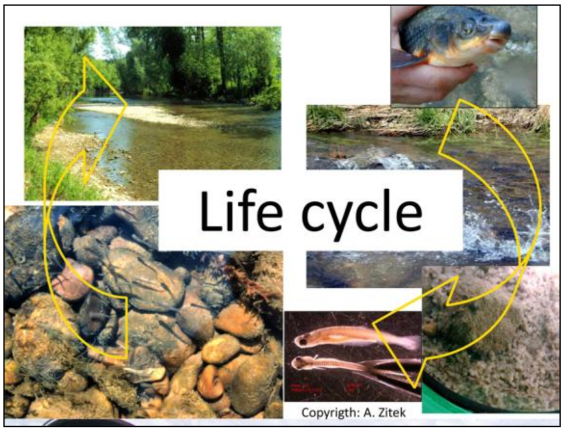
Fish passage is not a priority issue when MIT decide to construct any dam.

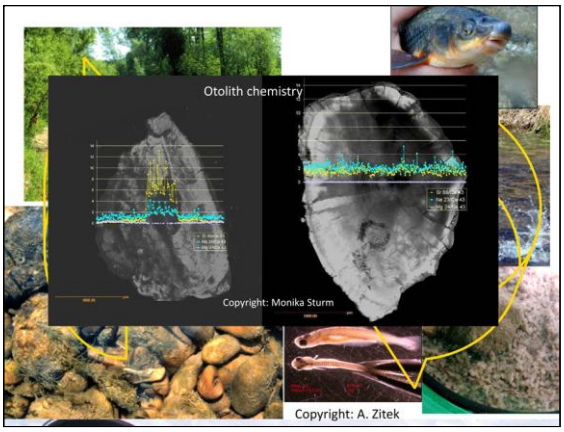
Annex 14

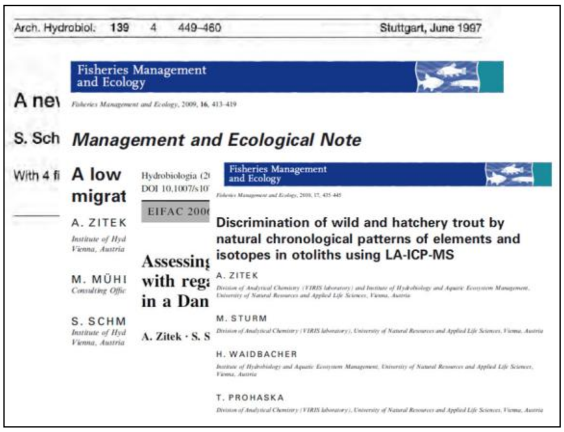
GENERAL ECOLOGICAL CONSIDERATIONS FOR BUILDING FISH PASSES

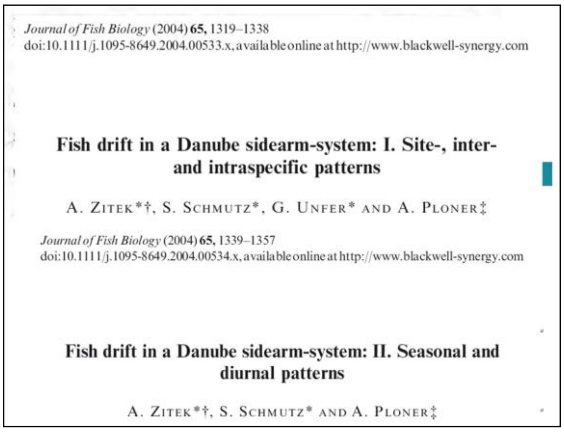
By Dr. Andreas Zitek











Content

- Global perspective
- General ecological considerations
- European perspective
- Conclusion

World wide perspective on freshwater fish diversity

- **Freshwater fishes** represent about **one quarter of the worlds vertebrates**.
- World wide total number of fish species **~29000** (Leveque et al. 2008)
  - **Freshwater: 13000** (40 %)
  - Marine: 16000
- Fishes exhibit **enormous diversity in size, shape, biology and in the habitats they occupy**

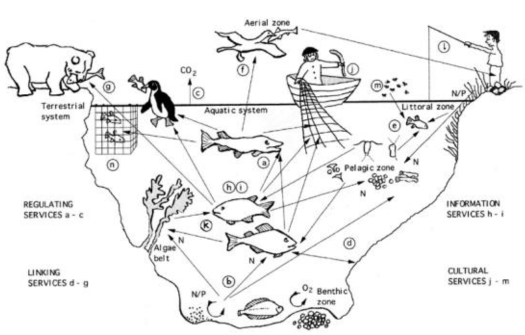
Global fresh and brackishwater fish species richnes by continents or large subcontinental units (FishBase 2005)

(Leveque et al. 2008)

	Freshwater		Brackish/salt		Total	
	Families	Species	Families	Species	Families	Species
Africa	48	2,945	66	295	89	3,240
Asia	85	3,553	104	858	126	4,411
Europe	23	330	36	151	43	481
Russia	28	206	28	175	40	381
Oceania	41	260	74	317	85	577
North America	74	1,411	66	330	95	1,741
South America	74	4,035	54	196	91	4,231
Total		12,740		2,322		15,062

Ecosystem services generated by fish

Holmlund (1999)



The Freshwater Fish Crisis

- **Freshwater represents the most threatened of all ecosystems.**
- **36 % of 5,685 fish species living at least part of their live in freshwater are threatened (IUCN).**
- ***"Large dams built for irrigation, flood control and power generation have had major impacts upon species in large rivers and have led to local extinction of numerous migratory species,"*** the Swiss-based IUCN said.
- **4 major threats:**
  1. pollution,
  2. **damming,**
  3. **wetland drainage and water abstraction,**
  4. Unsustainable fishery
  5. alien species

- **Critically endangered (examples):**
  - ***Atlantic sturgeon, the Beluga stugeon*** and the ***Mekong giant catfish***
  - and the ***European eel*** has declined **by 90 percent** since the early 1980s.

http://www.enn.com/top_stories/article/43015

http://www.zsl.org/conservation/regions/habitats/marine/fish-net/freshfishthreats,1763,AR.html

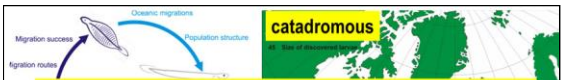
The Beluga sturgeon (*Huso huso*)

Damming

- **Damming of waterways** threatens 932 species worldwide. Many commercially important species are amongst the worst affected, such as salmonids and eels. There are over 50,000 large dams worldwide.

Oroville Dam, CA from the air, high water unknown date, California Department of Water Resources

http://www.zsl.org/conservation/regions/habitats/marine/fish-net/freshfishthreats,1763,AR.html

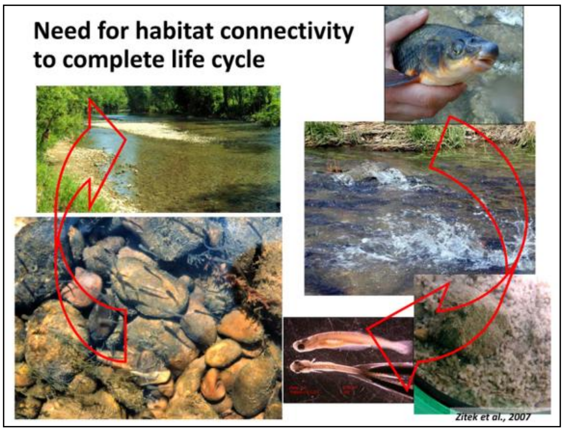


Fish Migrations take place to ensure and maximise reproduction, growth and survival (Northcote, 1978; 1984).

Major fish migrations are:
- Spawning migrations
- Post-spawning migrations
- Larval downstream drift
- Juvenile up- and downstream migration
- Feeding migrations
- Migrations for compensation after catatrophic drift
- Wintering/dry season migrations
- Exploration of settlement of new habitats
- Refuge migrations (flood, drought etc.)
- Migrations based on unknown reasons

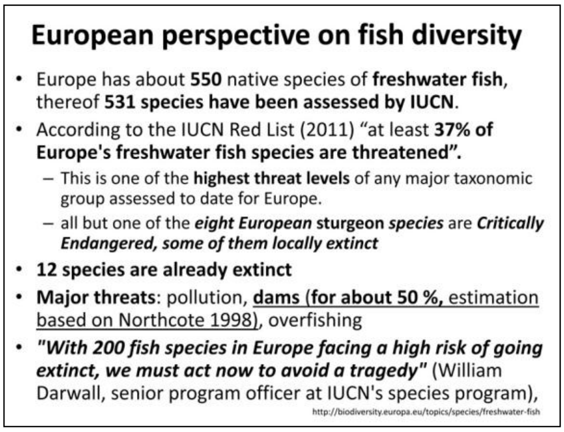
University of Washington, School of Fisheries Teaching and Research Fish Hatchery

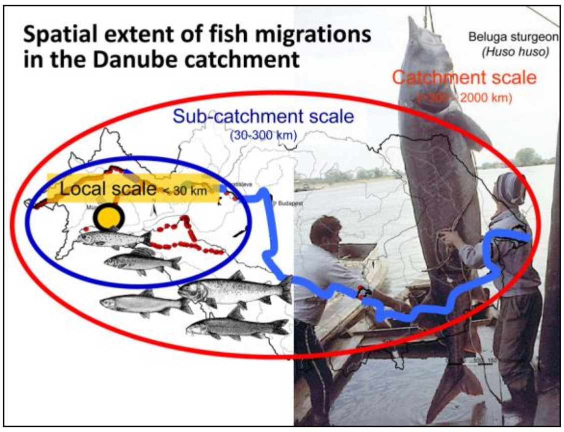
OCEAN

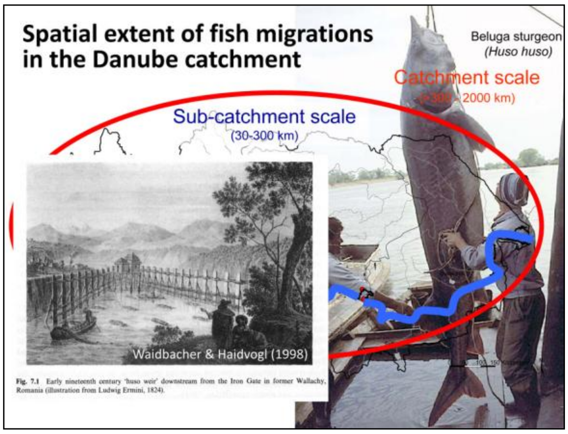

Need for habitat connectivity
to complete life cycle
Zitek et al., 2007

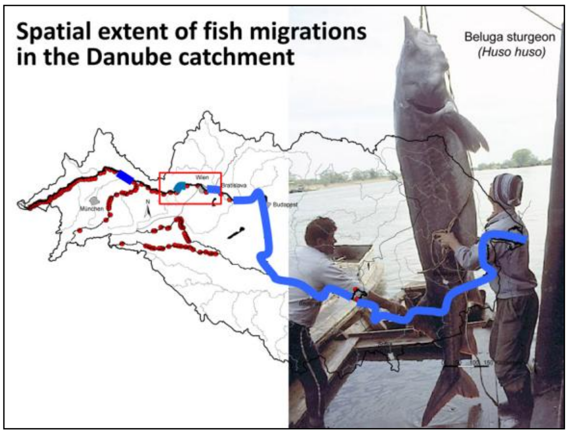

Wetland drainage and water abstraction
• Wetland drainage or water abstraction (for agriculture, domestic or commercial use) threatens 737 species worldwide. It is the greatest threat in the driest countries, often ones that have many endemic species. It is the single biggest threat to European fishes.
http://www.zsl.org/conservation/regions/habitats/marine/fish-net/freshfishthreats,1763,AR.html

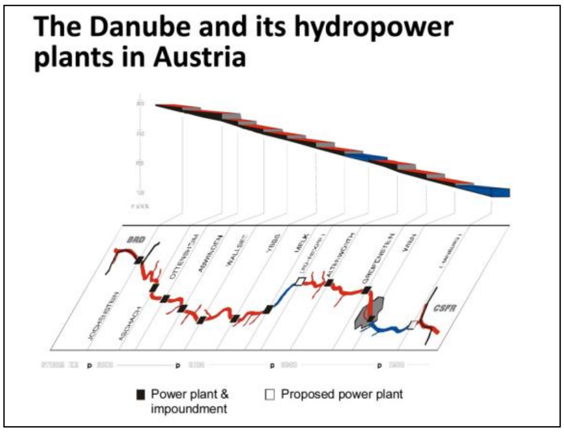

A final look to Europe and Austria...
>2000km to the Black sea

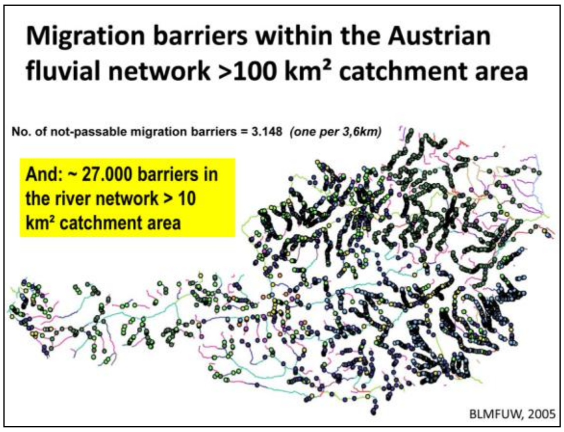

European perspective on fish diversity
• Europe has about 550 native species of freshwater fish, thereof 531 species have been assessed by IUCN.
• According to the IUCN Red List (2011) "at least 37% of Europe's freshwater fish species are threatened".
– This is one of the highest threat levels of any major taxonomic group assessed to date for Europe.
– all but one of the eight European sturgeon species are Critically Endangered, some of them locally extinct
• 12 species are already extinct
• Major threats: pollution, dams (for about 50 %, estimation based on Northcote 1998), overfishing
• "With 200 fish species in Europe facing a high risk of going extinct, we must act now to avoid a tragedy" (William Darwall, senior program officer at IUCN's species program),
http://biodiversity.europa.eu/topics/species/freshwater-fish

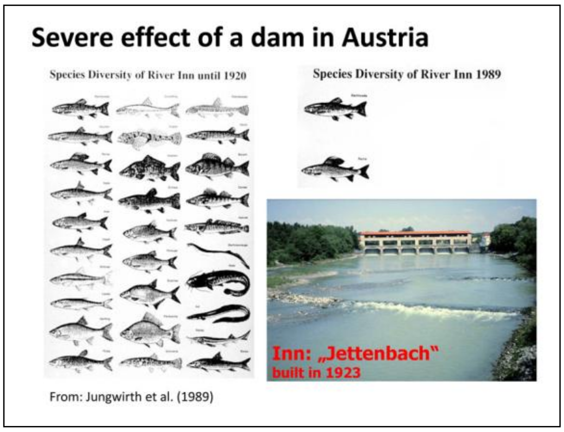

Spatial extent of fish migrations
in the Danube catchment
Beluga sturgeon
(Huso huso)
Catchment scale
(300-2000 km)
Sub-catchment scale
(30-300 km)
Local scale < 30 km

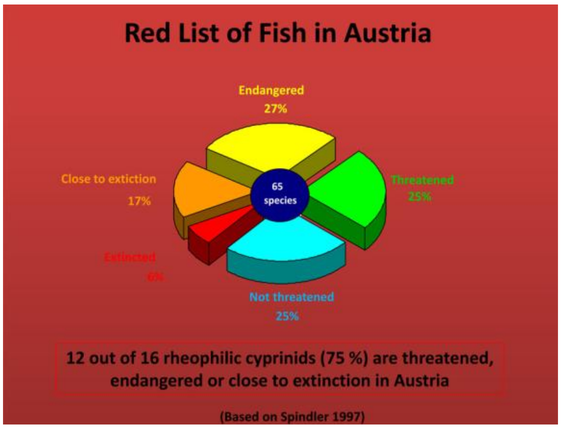

Spatial extent of fish migrations
in the Danube catchment
Beluga sturgeon
(Huso huso)
Catchment scale
(300-2000 km)
Sub-catchment scale
(30-300 km)
Waidbacher & Haidvogl (1998)
Fig. 7.1 Early nineteenth century 'huso weir' downstream from the Iron Gate in former Wallachy, Romania (illustration from Ludwig Ermini, 1824).


Spatial extent of fish migrations
in the Danube catchment
Beluga sturgeon
(Huso huso)
Wien
München


The Danube and its hydropower
plants in Austria
Power plant & impoundment
Proposed power plant







Building fish passes has become a priority in Europe – mainly triggered by the European legislation (EU-Water Framework Directive)!

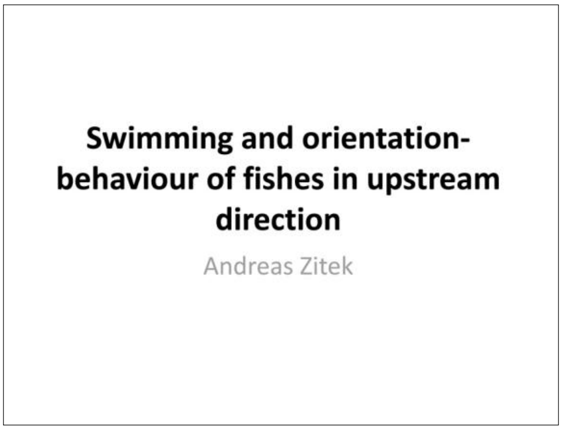
Guidelines for prioritization and for building effective fish passes had to be developed to support planners, managers and decision makers.

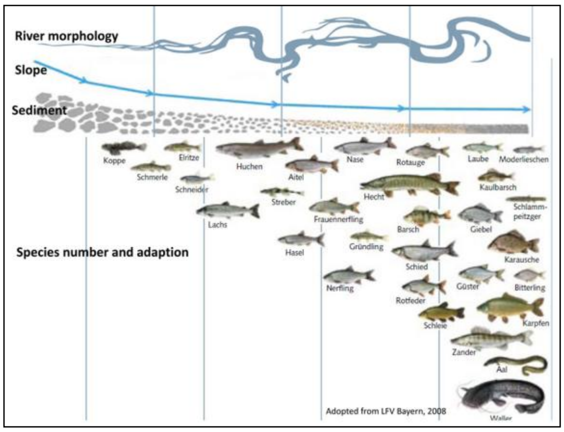
Summary

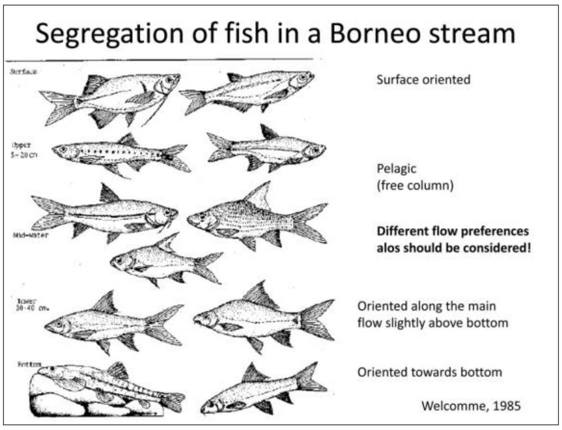
- **On a global and local level strategies** are needed to deal with **severe freshwater fish species loss** due to
  - Pollution, Damming, River regulation, Unsustainable fishery, Alien species
- Fish migrations **are adaptations to maximize survival, reproduction and growth**
- **Important to understand the full life cycle needs of a species (habitats, migrations - spatially/temporally)** for sustainable planning
- **Dams block different types of fish migrations**, why fish populations decrease and might get extinct
- **Building effective fish passes is an important effort to re-establish or maintain these migrations crucial for population maintenance**
- **Habitat availability** (also in form of floodplains, instream habitats) is crucial for the fulfillment of the life cycle of a species -> **Connectivity is always connectivity between habitats (lateral, longitudinal)**
- **Guidelines for planning effective fish passes** are helpful for planners

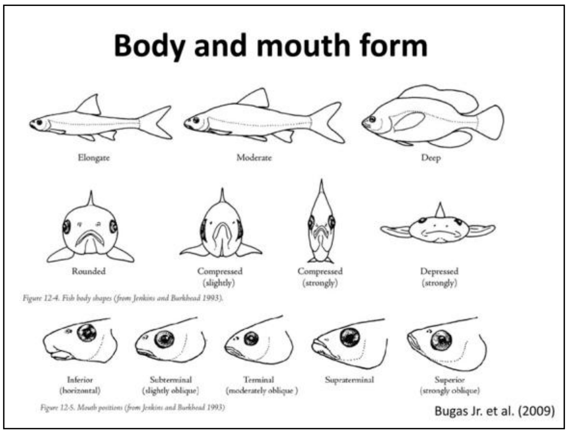
SWIMMING AND ORIENTATION BEHAVIOR OF FISHES IN UPSTREAM DIRECTION

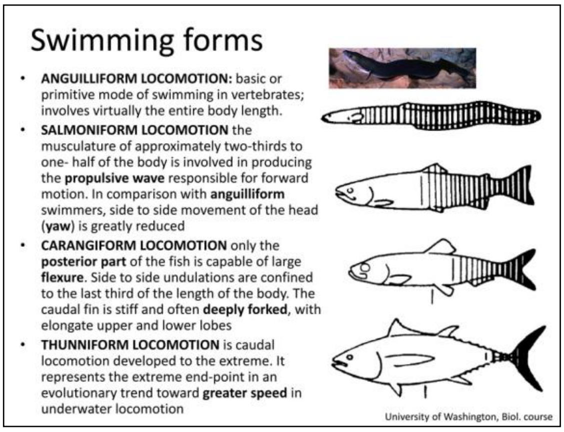
By Dr. Andreas Zitek

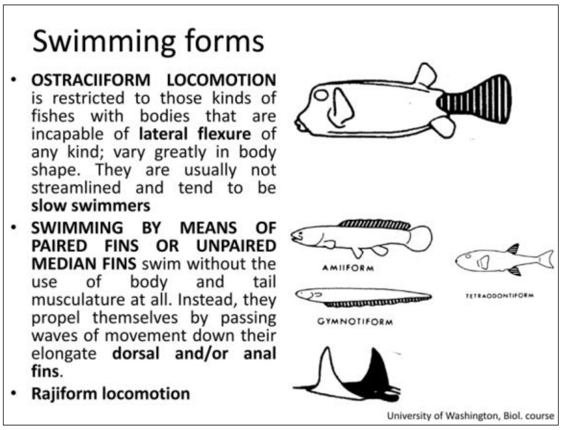


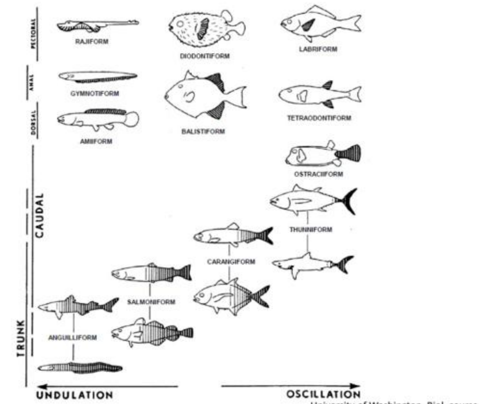








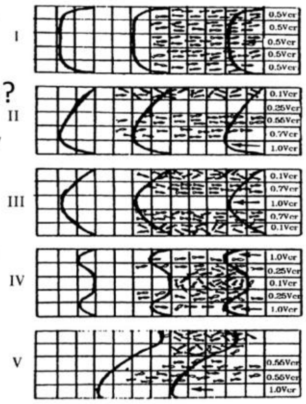




University of Washington, Biol. course

Critical velocity – when does rheoreaction begin?

Rheoreaction is influenced by
- flow velocity
- temperature,
- level of illumination,
- degree of turbulence, and
- the physiological condition of the fish.

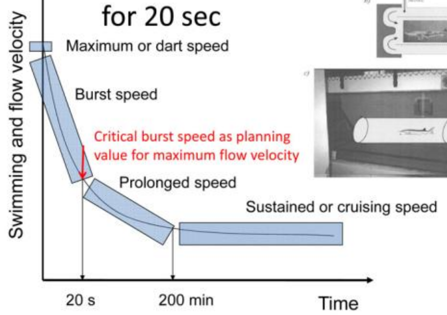


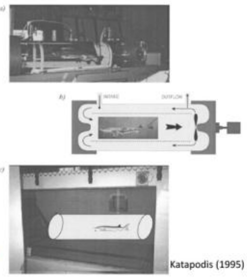
Pavlov (1989)

Muscle Power and Swimming

- Fast glycolytic (FG or white muscle) High power output, anaerobic but rapidly fatigues
- Slow oxidative (SO or red muscle) Relatively low power output but aerobic and non fatiguing
- Swimming performance of fish can fall into one of three general categories: sustained, prolonged, or burst.
  - **Sustained swimming** at relatively slow speeds, primarily red muscle fibers fueled by energy derived from aerobic metabolism are used; sustained swimming velocities for long periods (at least 200 minutes) without fatiguing
  - **Prolonged swimming** covers a spectrum of velocities between sustained and burst, using both red (aerobic) and white (anaerobic) muscle fibers.
  - **Burst swimming involves white muscle fibers which utilize energy from an anaerobic process to attain relatively high speeds for 15-20 seconds.**
  - **Critical burst – can be maintained ~ 20 sec – often used as maximum planning value**

Critical burst speed – a fish can maintain this for 20 sec





Katapodis (1995)

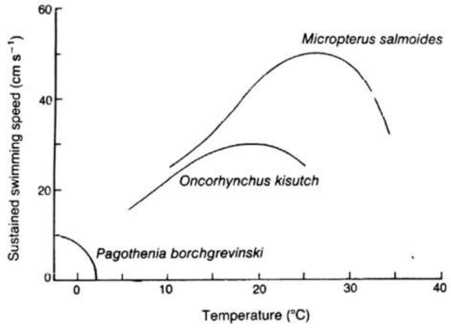


Fig. 1. Influence of temperature on the maximum sustainable swimming speed of fish (adapted from Beamish, 1978).

Johnston & Ball, 1996

Swimming performance of the freshwater neotropical fish: *Pimelodus maculatus* Lacepède, 1803

Santos, HA.[a,b,*], *Pompeu, PS.*[c], *Vicentini, GS.*[b], *and Martinez, CB.*[b]

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(With 11 figures)

Abstract

The present study used fixed and increasing velocity tests in an experimental apparatus based on Brett's respirome
examine prolonged and sustained speeds of the "mandi-amarelo", *Pimelodus maculatus*. When comparing the c
of critical speed versus total length between the mandi and the sockeye salmon *Oncorhynchus nerka*, it is obs
that for an equal total length, the mandi presents a greater speed, probably due to water temperature differences
sustained speed for the species was estimated in 5 lengths per second and the percentage of fatigued fish within ti
a certain velocity was established. The data raised for the mandi represents an important contribution to the imp
ment of the handling of the species, providing guidance and criteria for designing several structures, such as fish
fish screens and guidance systems.

Keywords: critical speed, prolonged speed, fish passages.

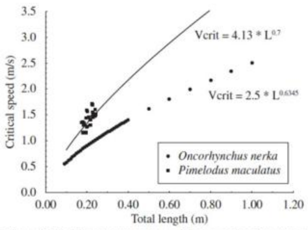


Figure 8. Relation between the critical speed and the total length for the mandi (*Pimelodus maculatus*) and the salmon (*Oncorhynchus nerka*).

Comparison of critical speeds between a salmonid and a neotropical species

Table 3. Absolute values of the mandi's and the salmon's critical speed.

Species	Vcrit (m/s) Length 19 cm	Vcrit (m/s) Length 26 cm
Mandi	1.291	1.61
Sockeye salmon	0.872	1.06
$\frac{Vcrit_{salmon} - Vcrit_{mandi}}{Vcrit_{salmon}}$ (%)	32.5	33.8

Santos et al., 2008

Summary of data for fish pass design

Fam	Spec	Swim. type	Type of migration (anadr., catadr., etc.)	Migratory guild (short, medium, long)	Body Form	Orientation type (bottom, shoreline, main current)	Life cycle description, short summary of existing literataure (up- and donstream migartions of at lest adults, juveniles, larvae)	Importance, management issues etc.

Target length	Body width	Body height	Critical burst swimming speed	Critical velocity for rheoreaction and attraction	Known behavioural issues

Turbulence

Turbulence reduces the swimming capacity of fish, leads to detoriation, exhaustion and may lead to injuries (Pavlov et al. 2008)

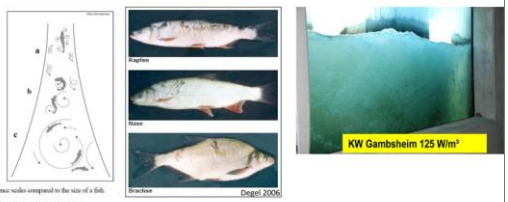
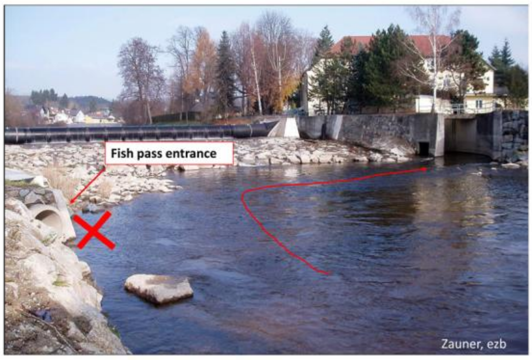


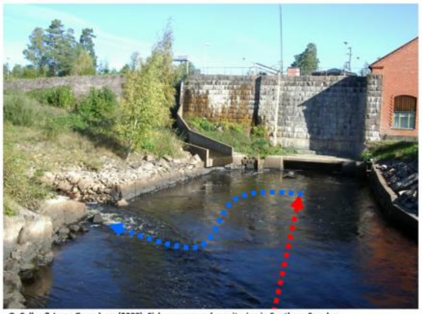
Figure 2. Turbulence scales compared to the size of a fish.

ODEH, M., NOREIKA, J. F., HARO, A., MAYNARD, A., CASTRO-SANTOS, T. und CADA, G. F. (2002).

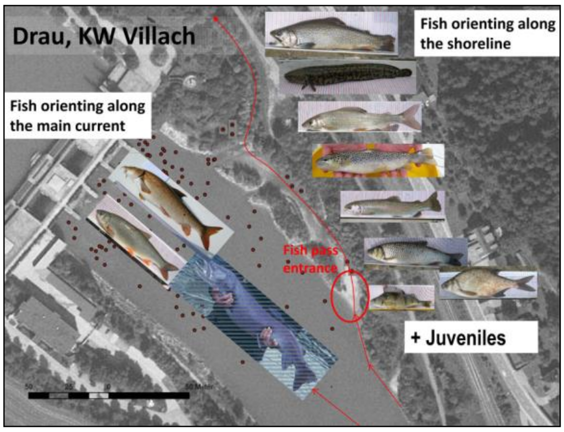
Orientation towards main water flow



Orientation towards main water flow



O. Calles & Larry Greenberg (2008). Fish passage and monitoring in Southern Sweden.
In: A. Zitek, M. Jelonek & G. Marmulla, Eds. Internal Proceedings of the 3rd MEETING of the EIFAC WORKING PARTY ON FISH PASSAGE BEST PRACTISES, KRAKOW 3 – 6 JUNE 2008.



Schooling behaviour or mass migration of fish – an important design issue

Adult fall Chinook salmon crowd the fish ladder on the Washington side of Bonneville Dam in September 2003. Photo: John Harrison
http://www.nwcouncil.org/history/fishpassage

Triggering factors of migration

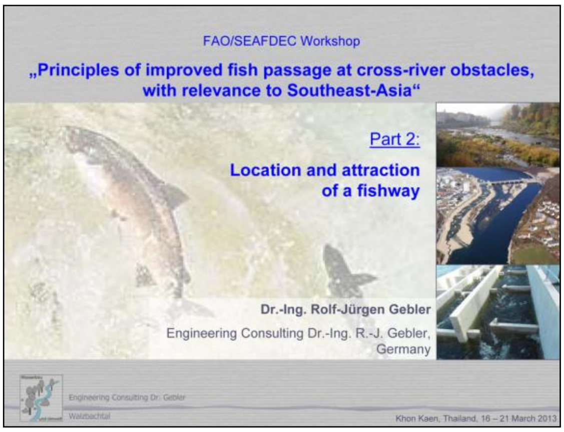
- Discharge
- Flow velocity
- Temperature
- Light
- Oxygen
- Water odour and quality
- Moon phase

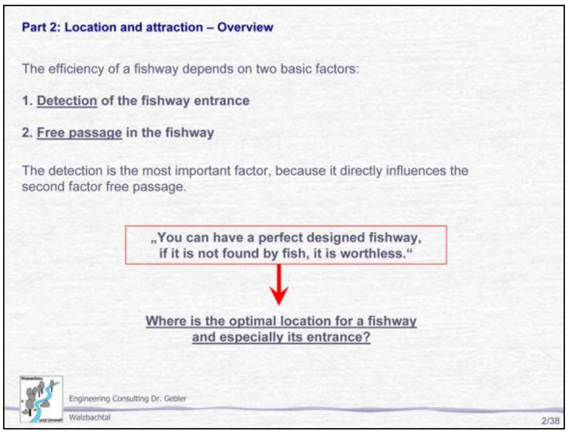
Parameters derived for fish pass building

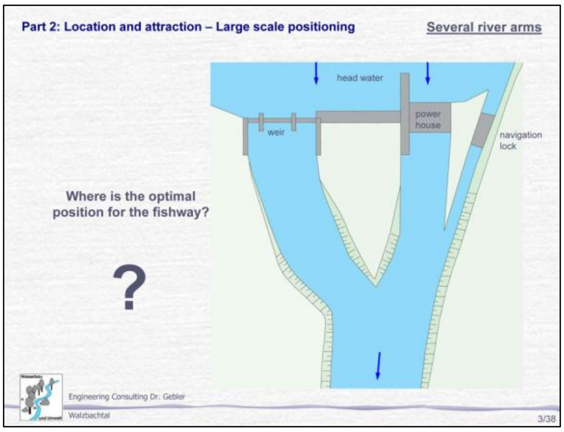
- **Design criteria** according to the **local species** taking into account **swimming type, body form, body dimension (weakest swimmer, swimming type, biggest fish)** and specific **behaviour** (schooling)
- **Adeuqate position** – at the **„natural migration corridor“** of the fish“, defined by their **form of orientation (bottom, shoreline, water current etc.)**
- **Connection** of the **fish pass** to the **river bottom**
- **Size** and **discharge** of **fish pass** big enough **to attract fish**
- **Flow velocities** adequate for **rheoreaction, attraction** and **maximum swimming speed** **(“critical burst speed”)**
- **Low turbulence values**, avoiding loss of orientation of fish
- **Duration of fish pass functionality depends on** different triggers of fish (low flow, high flow, temperature…) – **and river discharge**
  - Usually **all year round**, only at extreme events **reduced functionality** may occur – **from high flow to low flow**
  - **Important: fluctuating water levels** and discharges in rivers **need to be considered.**

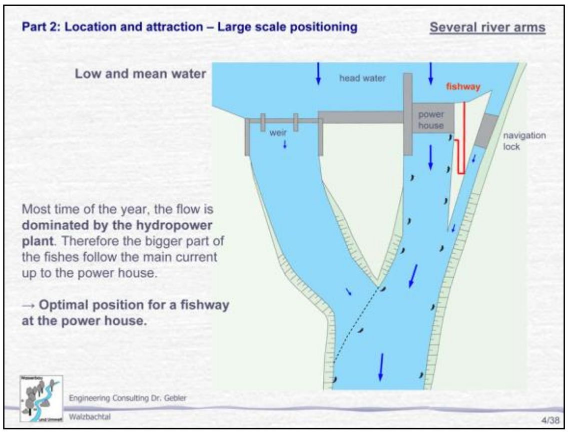
LOCATION AND ATTRACTION OF A FISHWAY

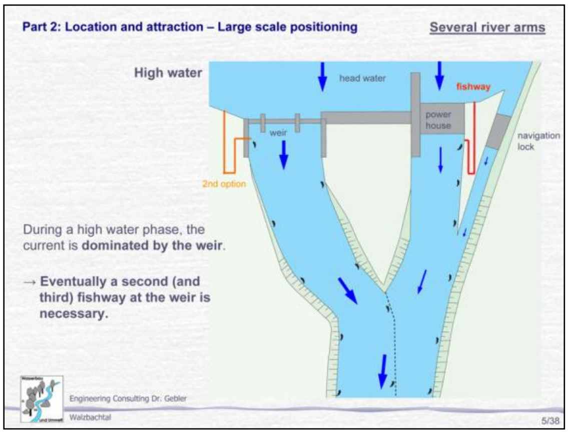
By Dr. -Ing Rolf-Jürgen Gebler

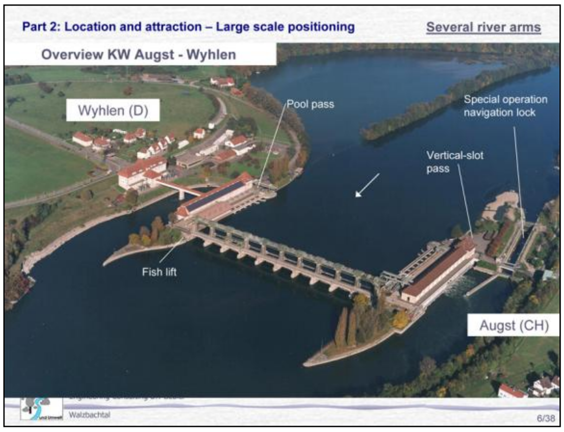




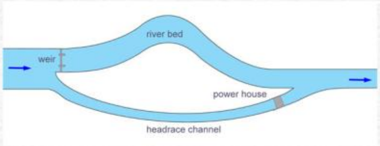








Part 2: Location and attraction – Large scale positioning Diversion plant

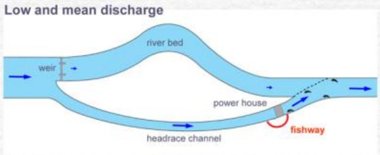


Where is the optimal position for the fishway?

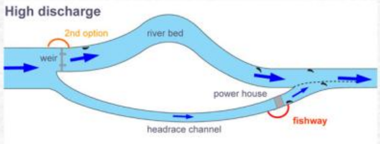
?

Part 2: Location and attraction – Large scale positioning Diversion plant

Low and mean discharge



High discharge



Part 2: Location and attraction – Large scale positioning Diversion plant

Part 2: Location and attraction – Attraction flow

The near range detection and attraction of a fishway depends on several aspects, which should be considered during the planning. Especially:

- **Exact location to the entrance** in consideration to the tailrace conditions below the power house (current and turbulences)
- Exit **angle** of flow
- **Velocity** of flow
- Need and arrangement of **additional entrances** (e.g. collection gallery)
- **Discharge ratio** of fish pass to competing discharge

The fish pass entrance should be designed to achieve a

- High momentum by the emergent flow (free passage must still be guaranteed)
- Good spreading of the emergent flow (perceptibility of the current by aquatic organisms over a wide area)

Part 2: Location and attraction – Attraction flow Location of the entrance

The **tailwater current** at a power house differs from site to site.

To identify the best position for the entrance of the fishway at the power house, the **local situation** must be well analysed.

Changes in tailwater level and operation mode of the hydropower plant according to the total discharge must be considered. Both aspects can have essential influence on the current.

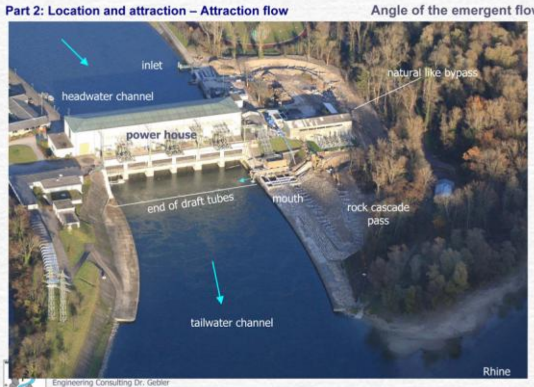
Part 2: Location and attraction – Attraction flow Location of the entrance

The bigger part of the fishes is **guided to the outlet of the power house** by the main current.

Especially species with high capability swim through the swelling current to the end of the draft tube. There they **search for an opportunity for further upstream migration** (lateral movements).

Part 2: Location and attraction – Attraction flow Angle of the emergent flow

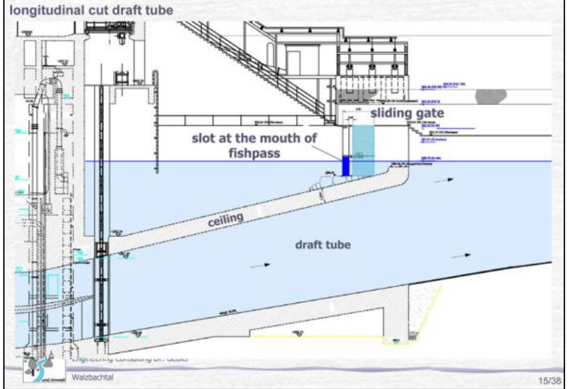
Part 2: Location and attraction – Attraction flow Angle of the emergent flow



Part 2: Location and attraction – Attraction flow

Angle of the emergent flow

longitudinal cut draft tube

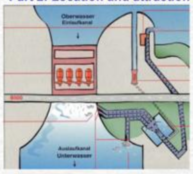


Part 2: Location and attraction – Attraction flow

Angle of the emergent flow

Part 2: Location and attraction – Attraction flow

Angle of the emergent flow

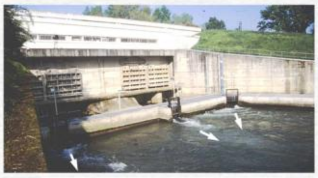


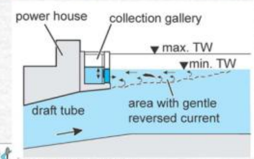
Mouth of fishpass downstream the power house.

The flow is directed above the ceiling of the draft tube and produces an efficient attraction current.

Part 2: Location and attraction – Attraction flow

Collection gallery





Principle a Collection gallery

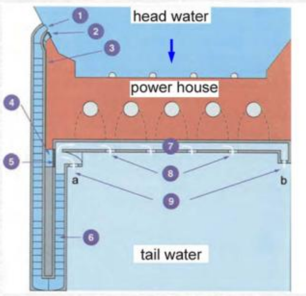
The Collection gallery is a widespread construction type in North America and France. It was developed especially for large hydropower plants.

In case of very wide power plants, a fishway entrance at the river bank is hard to find for migrating species in the middle or at the other side of the river arm.

To provide direct entrance for those fishes, in addition to the entrances at the river bank, a channel over the whole width of the power house is installed. It is located on top or in front of the draft tube ceiling. From this channel, several openings branch off, through which fishes can enter. Guided by the current in the channel, they reach the fishway at the river bank.

Part 2: Location and attraction – Attraction flow

Collection gallery



1:	Floating debris deflector
2:	Intake bypass discharge
3:	Bypass pipe/channel
4:	Addition bypass discharge
5:	Partition pool bypass discharge
6:	Fishway
7:	Collection gallery
8:	Entrances above the draft tube
9a/b:	Main entrances (on the side)

Part 2: Location and attraction – Attraction flow

Collection gallery

Collection gallery
hydropower station
Wettingen, Limmat (CH)

Collection gallery with 4 entrances (2 opened)

Part 2: Location and attraction – Attraction flow

Velocity of the emergent flow

Generally, the detection of the entrance gets better with increasing velocity of the attraction flow. However, to provide free passage for all relevant species, maximum theshold values should not be exceeded.

Usually the **velocity of the emergent flow** should not exceed **v_{max} = 2 m/s, depending on the local fish species**.

Part 2: Location and attraction – Attraction flow

Discharge ratio

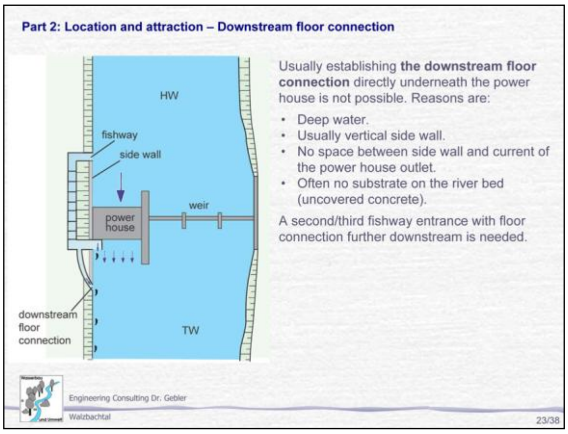
The tailrace current at a power house is dominated by the discharge of the power station. **The attraction flow of the fishway has to compete against this main flow.**

To increase the attraction of the fishway especial to achieve this at large facilities, it can be useful to increase the discharge at the fish pass entrance. For that, an additional pipe or channel can conduct the additional bypass discharge from headwater into the lowest pool (antechamber) of the fishway. The fishway is still designed for a smaller discharge to reduce the costs.

Recommended discharge at the entrance of the fishway (Larinier 2002):

1 – 5 % of the competing flow

Often an additional profitable **bypass turbine** can be installed to produce electricity.


Part 2: Location and attraction – Downstream floor connection
HW
fishway
side wall
weir
power house
TW
downstream floor connection
Usually establishing **the downstream floor connection** directly underneath the power house is not possible. Reasons are:
• Deep water.
• Usually vertical side wall.
• No space between side wall and current of the power house outlet.
• Often no substrate on the river bed (uncovered concrete).
A second/third fishway entrance with floor connection further downstream is needed.
Engineering Consulting Dr. Gebler
Walzbachtal
23/38


Part 2: Location and attraction – Downstream floor connection
Engineering Consulting Dr. Gebler
Walzbachtal
24/38

FISH SPECIES AND MIGRATION BEHAVIOR OF DIFFERENT SPECIES IN SOUTHEAST ASIA

By Dr. Andreas Zitek

Fish species and migration behaviour of different species in Southeast Asia

DI Dr. Andreas Zitek, MSc

Austria

Global fresh and brackishwater fish species richnes by continents or large subcontinental units (FishBase 2005)

(Leveque et al. 2008)

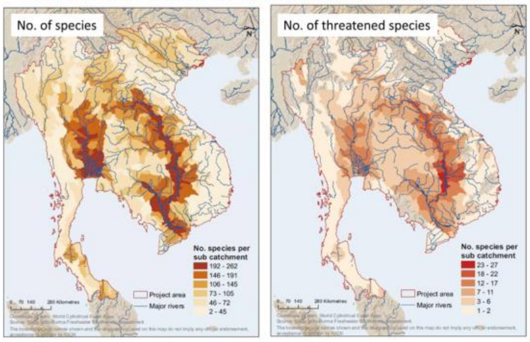
	Freshwater		Brackish/salt		Total	
	Families	Species	Families	Species	Families	Species
Africa	48	2,945	66	295	89	3,240
Asia	85	3,553	104	858	126	4,411
Europe	23	330	36	151	43	481
Russia	28	206	28	175	40	381
Oceania	41	260	74	317	85	577
North America	74	1,411	66	330	95	1,741
South America	74	4,035	54	196	91	4,231
Total		12,740		2,322		15,062

Kottelat, Maurice, Baird, Ian, Kullander, Sven, Ng, Hek Hee, Parenti, Lynne R., Rainboth, Walter and Vidthayanon, Chavalit. 2012. **The status and distribution of freshwater fishes of Indo-Burma**. In: Allen, David J., Smith, K. G. and Darwall, W. R. T., *The status and distribution of freshwater biodiversity in Indo-Burma.* Cambridge (UK) and Gland (Switzerland): IUCN, pp.38-64.

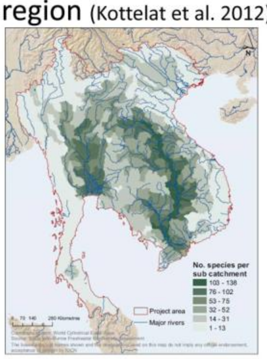
Table 3.1 The number of Indo-Burma freshwater fish species in each IUCN Red List Category.

Category	Number of fish species
Extinct	1
Extinct in the Wild	0
Critically Endangered	21
Endangered	39
Vulnerable	52
Near Threatened	33
Least Concern	518
Data Deficient	514
Total	1,178
% Threatened (excluding DD and EX spp.)	16.9

Patterns of freshwater fish species in the Indo-Burma region (Kottelat et al. 2012)



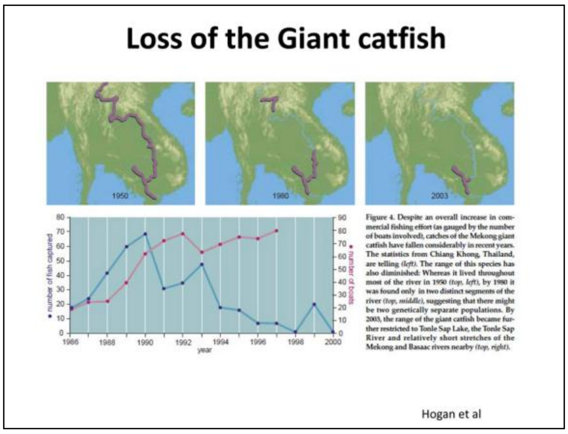
Endemic species in the Indo-Burma region (Kottelat et al. 2012)

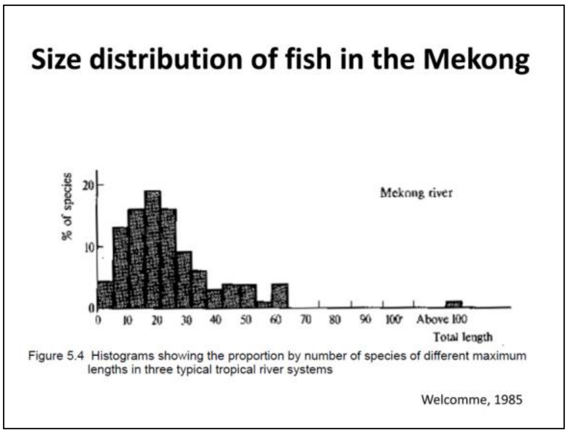


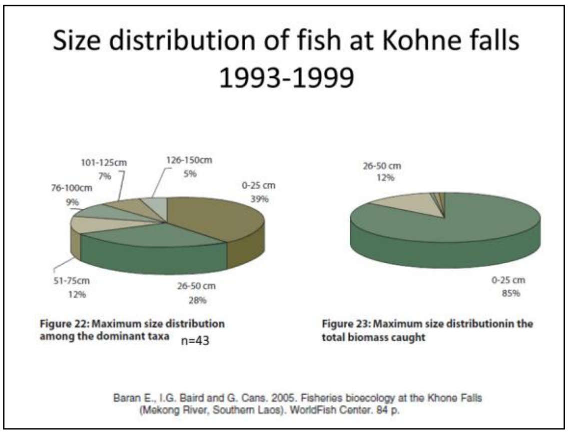
The fish fauna of the Mekong

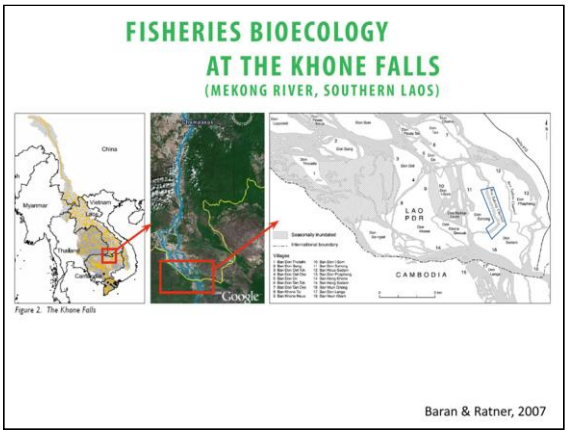
- The Mekong River - one of the m**ost biodiverse and productive rivers on Earth.**
- **Up to 1200 species** (different authors report different numbers) have been recorded from the Mekong, second only to the Amazon.
- The Mekong home to more species of giant freshwater fish than any river on Earth (Stone 2007) (at least 7). At least seven species of giant fish inhabit the Mekong: the Critically Endangered Mekong giant catfish *Pangasianodon gigas*, the Critically Endangered giant pangasius *Pangasius sanitwongsei*, the Endangered seven-striped barb *Probarbus jullieni*, and the Endangered giant barb *Catlocarpio siamensis*.
- **Over 100 species**, including the Mekong giant catfish, **have complex life cycles** involving long-distance migrations triggered by seasonal fluctuation of flows or the annual flood pulse.

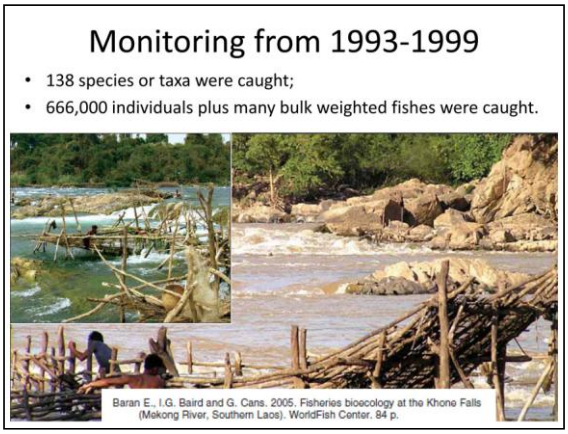
Hogan 2011, Sverdrup-Jensen, 2002

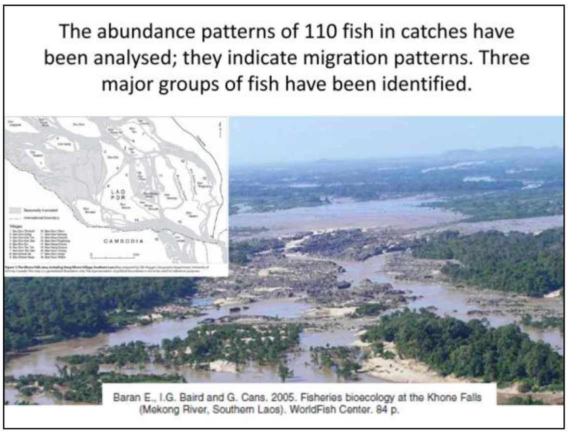

Loss of the Giant catfish
1950
1980
2003
year
Hogan et al

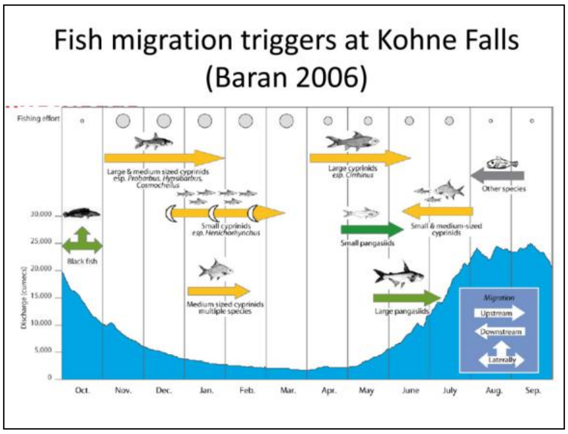

Size distribution of fish in the Mekong
% of species
Mekong river
Total length
Figure 5.4 Histograms showing the proportion by number of species of different maximum lengths in three typical tropical river systems
Welcomme, 1985

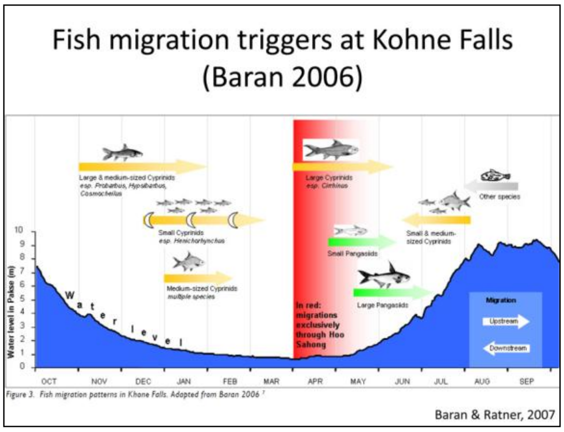

Size distribution of fish at Kohne falls 1993-1999
101-125cm 7%
126-150cm 5%
76-100cm 9%
0-25 cm 39%
51-75cm 12%
26-50 cm 28%
26-50 cm 12%
0-25 cm 85%
Figure 22: Maximum size distribution among the dominant taxa
n=43
Figure 23: Maximum size distributionin the total biomass caught
Baran E., I.G. Baird and G. Cans. 2005. Fisheries bioecology at the Khone Falls (Mekong River, Southern Laos). WorldFish Center. 84 p.


FISHERIES BIOECOLOGY
AT THE KHONE FALLS
(MEKONG RIVER, SOUTHERN LAOS)
LAO PDR
CAMBODIA
Figure 2. The Khone Falls
Baran & Ratner, 2007


Monitoring from 1993-1999
138 species or taxa were caught;
666,000 individuals plus many bulk weighted fishes were caught.
Baran E., I.G. Baird and G. Cans. 2005. Fisheries bioecology at the Khone Falls (Mekong River, Southern Laos). WorldFish Center. 84 p.


The abundance patterns of 110 fish in catches have been analysed; they indicate migration patterns. Three major groups of fish have been identified.
Baran E., I.G. Baird and G. Cans. 2005. Fisheries bioecology at the Khone Falls (Mekong River, Southern Laos). WorldFish Center. 84 p.


Fish migration triggers at Kohne Falls (Baran 2006)
Fishing effort
Large & medium sized cyprinids
Large cyprinids
Other species
Small cyprinids
Small & medium-sized cyprinids
Small pangasiids
Black fish
Medium sized cyprinids multiple species
Large pangasiids
Migration
Upstream
Downstream
Laterally
Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sep.


Fish migration triggers at Kohne Falls (Baran 2006)
Large & medium-sized Cyprinids
Large Cyprinids
Other species
Small Cyprinids
Small & medium-sized Cyprinids
Small Pangasiids
Medium-sized Cyprinids multiple species
Large Pangasiids
In red: migrations exclusively through Hoo Sahong
Water level
Water level in Pakse (m)
Migration
Upstream
Downstream
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP
Figure 3. Fish migration patterns in Khone Falls. Adapted from Baran 2006
Baran & Ratner, 2007

Sensitivity of taxa to discharge variations at Khone falls (Baran et al. 2005)

These results of the 47 dominant taxa show:

1) The high percentage of taxa sensitive to discharge among the dominant taxa of the Khone Falls

2) The extremely high percentage of species highly sensitive to discharge in the overall catch of the Khone Falls fisheries.

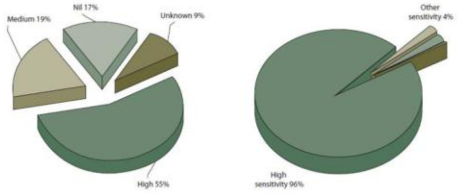
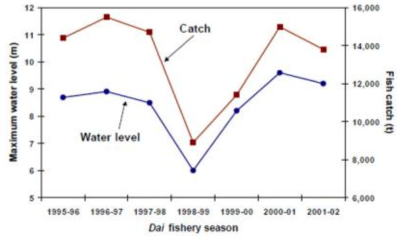


Figure 26: Percentage of each class of sensitivity to discharge among the dominant taxa.

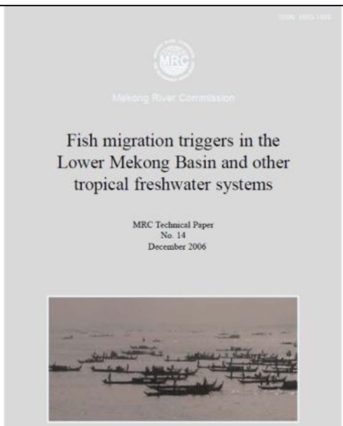
Figure 27: Percentage of taxa sensitive to discharge in the total biomass caught

Dependence of fish production in the Tonle Sap Great Lake from water level



Catch and Culture

Update on the status of the Cambodian inland capture fisheries sector with special reference to the Tonle Sap Great Lake
by N.P. van Zalinge



Mekong River Commission

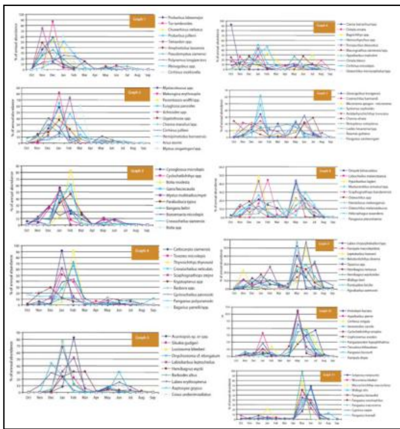
Fish migration triggers in the Lower Mekong Basin and other tropical freshwater systems

MRC Technical Paper
No. 14
December 2006

Detailed analysis of migration patterns

- i) species **present during the dry season (peak in January)**, some of them exhibiting a small secondary peak in catches at the beginning of the rainy season (May-June);
- ii) species **present during two equivalent periods (dry and wet season respectively)** or **being regularly distributed all year long (no evident migrations);** and
- iii) species showing a **dominant or exclusive abundance at the beginning of the rainy season** (May-June).
- Among the 110 taxa studied, **90 exhibit strong patterns of sudden abundance in catches.** Most of these species are migrating.

Baran E., I.G. Baird and G. Cans. 2005. Fisheries bioecology at the Khone Falls (Mekong River, Southern Laos). WorldFish Center. 84 p.



Migration patterns at Khone falls

Baran et al. (2005)

Information on some selected species: *Probarbus jullieni*

Figure 8: *Probarbus jullieni*

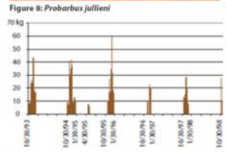
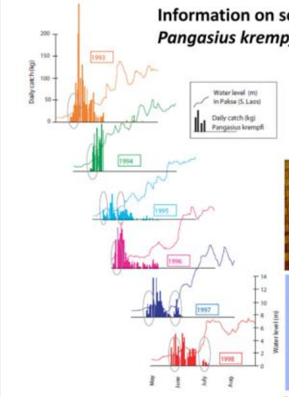


Figure 9: temporal pattern of *Probarbus jullieni* catche

- A large cyprinid found in the mainstream of a number of large rivers in mainland Southeast Asia
- This excellent tasting and high-priced food fish can reach 150 cm and is mainly caught in large-meshed gill nets during its spawning season.
- Sudden high abundance levels beginning in **November-December** every year.
- Short distance migrations supposed

Baran E., I.G. Baird and G. Cans. 2005. Fisheries bioecology at the Khone Falls (Mekong River, Southern Laos). WorldFish Center. 84 p.

Information on some selected species: *Pangasius krempfi*

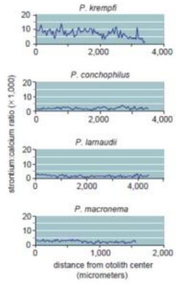


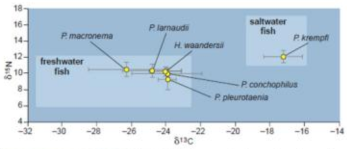
Relationships between water level increases and *Pangasius krempfi* catches in Kh

- The catfish *Pangasius krempfi* is a highly migratory species sensitive to water level rises, triggered by the first seasonal increase in flow and current speed.
- The migration occurs suddenly at Khone, and lasts around 40-50 days.

Baran E., I.G. Baird and G. Cans. 2005. Fisheries bioecology at the Khone Falls (Mekong River, Southern Laos). WorldFish Center. 84 p.

Otolith element and isotope ratios reveal migration patterns of Silver-toned catfish (*P. krempfi*) (Hogan et al., 2004)





Rings in a fish's ear bone record its Mekong travels.
M. Fukushima

The first documented case of anadromy in a Mekong River species - a Mekong "salmon". It starts life in the higher reaches of the Mekong, then drifts down to the coastal flood plains during the monsoon season. Adult fish live in the brackish waters of the delta and the South China Sea, but they fight their way back upstream to spawn at the beginning of the rainy season every year.

The life history of *Pangasius krempfi*

(Hogan et al., 2007)

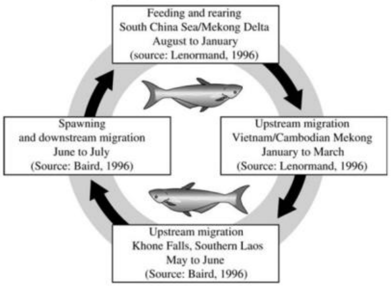
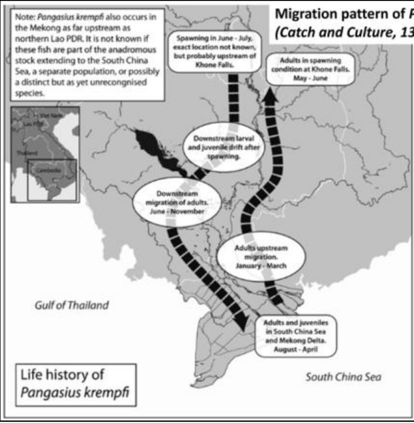


FIG. 1. The life history of *Pangasius krempfi* based on Baird (1996) and Lenormand (1996).

Migration pattern of *Pangasius krempfi* *(Catch and Culture, 13, 2 (Sept. 2007)*



Focus: distribution **and** ecology **of the** small-scale **river carp,** *Cirrhinus microlepis*

Before it matures and spawns, this omnivorous species of carp migrates between feeding and refuge habitats over several seasons. As it swims upstream in the dry season from January to March, it emerges as one of the most important species for local fisheries. The species is also important for the dai fishery on the Tonle Sap between December and February

Scientific name: *Cirrhinus microlepis*
Family: *Cyprinidae* (minnows and carps)
Khmer: *trey pruol, trey kralang*
Lao: *pa phon, pa phon mak kok*
Thai: *pla nuan chan, pla pon*
Vietnamese: *ca duong*
Size: up to 65 cm

Distribution
Mekong (throughout lower basin) and Thailand's Chao Phraya system.

Population
At least two populations occur in the Mekong. One stretches from Bolikhamxay province near Vientiane down to the delta in Viet Nam (Figure 1). Another has been recorded from the area around the Loei River, upstream from Vientaine, to as far north as the port of Chiang Saen near the Thai-Lao border with Myanmar. The populations may overlap.

Critical habitats
As of 2004, research had identified one spawning habitat in the Lao village of Phatomphone about 50 km south of Pakse. This wide stretch of the river near the Lao-Cambodian border has sandy bottoms and shallow beaches alternating with rapids. For many years, the site has supplied broodstock for an artificial breeding programme. Feeding habitats for larvae and juveniles are in the floodplains, particularly in the Tonle Sap and the delta in Viet Nam, and include flooded forest areas where young fish feed on leaves. Dry-season refuge habitats are found in deep pools along the Mekong mainstream north of Kratie.

Life cycle
After spawning in June and July, eggs and larvae drift downstream to nursery habitats in the extensive flood plains of the Mekong River. Juveniles and adults also move downstream during the flood season, especially to flood plains in southern Cambodia and Viet Nam, and up into the Tonle Sap as the river reverses its flow every year.

As the floodwaters recede with the onset of the dry season in October and November, the young start moving out of the flood plains. Once back in the Mekong, they start migrating upstream in large numbers to seek refuge in dry-season habitats in deep pools. When the next flood season arrives, the younger fish return to the flood plains to feed as the mature adults head for their spawning grounds. The species is sexually mature at 17 cm and a female of two to three kilogrammes can produce between 130,000 and 275,000 eggs.

Migration patterns are less clear for the population further north. In Ubon Ratchathani province in Thailand, research shows that the species migrates upstream from Khong Chiam district in February and from Khemarat district in March or April. At Mukdahan, it starts migrating upstream in May. But in June and July, it migrates back downstream to Khong Chiam, some in a reproductive condition.

Upstream from Vientiane, the species is found all year around near the Loei River in Thailand. Between the Lao province of Xayaboury and the Chiang Saen district of Thailand, younger fish of 15

Migration of *Cirrhinus microlepis*

Upstream migration in dry season from January to March after leaving the floodplains beginning with the onset of the dry season (Oct-Nov) (Catch and Culture, Aug. 2006)

Experience with fish ladders

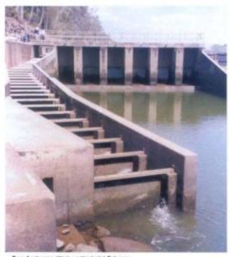
- In the Mekong basin because of the high species diversity and and the intensity (biomass) of fish migrations it is hard to find a good solution for a fish ladder.
- Available data show that fish migration can reach a density of 30 tons per hour in some areas of the basin. This is too much for fish passes to cope with.
- At the Pak Mun Dam in Thailand, despite construction of a fish pass, fishing communities both upstream and downstream of the dam reported a 50 to 100 percent decline in fish catch.
- Many fish species disappeared, especially migratory and rapid-dependent species.
- Several fishways have been constructed in the Lower Mekong Basin, but none demonstrate evidence of attempting to incorporate knowledge of local species and hydrology into fishway design.
- Building fish passes requires flexibility and adaptation of existing approaches!

Pak Mun fish ladder

The Pak Mun fish ladder in north-eastern Thailand, pictured at low flow.

Vertical Slot - a solution for tropical species? Examples from Australia (Jensen, 2010)

- A "Vertical Slot" fishway installed at the 4 metre high Ben Anderson Barrage (Australia) has proven efficient for passage of tropical fish over weirs from 1.5 to 7 metres.
- Slope of 1: 15 or less steep (1:20), and water velocities at the inlet to the fishway of between 0.8 and 1.0 meter per second. Enough to attract the fish, but not more than also the smaller fish can negotiate the current
- Chambers of 1.50 metre length and around 2.00 metres wide, connected through 20 cm vertical slots, "lift" the fish 10 cm each. To pass a 6-metre high weir the fish- way may have 60 chambers and must be at least 90 metres long.
- The Pak Mun Dam is 17 metres high and the pool-and-weir fish ladder constructed at the dam is 15 metres high and 92 metres long with a slope of 1:6.
- It has 54 "steps" requiring a vertical "jump" of 28 cm between each step, a construction which does not allow many Mekong fish species to pass in any significant quantity.
- Pak Mun fish pass originally designed by the biologists like the earlier pool-and- weir fishways in Australia with a slope of 1: 10, but cost considerations by the builders led to a reduction in its length and a steeper slope.



Ben Anderson Weir vertical slot fishway.

Upstream passage of fish through a vertical-slot fishway in an Australian subtropical river

I. G. STUART & A. P. BERGHUIS

Risk of failure for diff. species at a proposed fish ladder at the Xayaburi dam

The risks can be viewed as links in a chain for upstream and downstream migration – attraction into, passage through and exit of a fish pass are all essential to complete fish passage, as are the components for downstream passage. All risks in a horizontal block need to be addressed to enable the full migration of that group to be completed. Downstream issues hard to address. Habitat availability is pre-condition.

Table 5. Reassessment of risk of Proposed Design after applying recommendations and mitigations outlined in the present report.

	Upstream Migration			Downstream Migration			
	Limited attraction and entry into fish passage facilities	Limited ascent of fish pass	Ineffective exit	Limited passage through impoundment	Limited attraction and entry into fish passage facilities	Limited passage and low survival at dam	Poor exit; risk of predation downstream
Life Stage							
Larvae & fry	N/A	N/A	N/A	Very High	Very High	Very High	High
Small-bodied species (15 -30 cm)	Moderate	Moderate	Moderate	High	High	High	Moderate
Medium-bodied species (30-150 cm)	Moderate	Moderate	Moderate	Moderate	Very High	High	Moderate
Large-bodied species (150-300 cm)	High	High	Moderate	Moderate	Very High	High	Moderate
Behaviour							
Surface	Moderate	Moderate	Moderate	N/A	Moderate	Moderate	Moderate
Mid-water	Moderate	Moderate	Moderate	N/A	High	High	Moderate
Benthic (including thalweg)	High	Moderate	Moderate	N/A	High	Very High	Moderate
High Biomass							
Powerhouse Operating	Moderate	High	Moderate	Very High	High	Very High	High
Powerhouse and Spillway Operating	Moderate	High	Moderate	Moderate	Moderate	Moderate	Moderate

Annex 4 of the Prior Consultation Project Review Report– Fisheries Expert Group Report (Xayaburi dam)

Australian Government
Australian Centre for International Agricultural Research

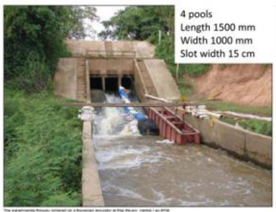
Final report

Small research and development activity

project	**Development of fish passage criteria for floodplain species of Central Laos**
project number	FIS/2007/076 & FIS/2006/183
date published	March 2010
prepared by	Lee Baumgartner Research Scientist, Freshwater Ecology Industry and Investment NSW
co-authors/ contributors/ collaborators	Garry Thorncraft, Tim Marsden, Oudom Phonekhampeng, Douangkham Singhanouvong, Ivor Stuart, Ubolratana Suntornratana

Developing fish-passage criteria for floodplain species in central Lao PDR

Catch and Culture
Fisheries Research and Development in the Mekong Region



4 pools
Length 1500 mm
Width 1000 mm
Slot width 15 cm

Experimental: Different slopes, moderate (1:15 or 6%) or steep (1:8 or 12%), quantifying the number of fish successfully ascending

The present study sought to determine whether a vertical slot fishway can be designed to provide passage for Lower Mekong fish species attempting to access floodplain habitat. Experimental manipulations of flow and turbulence were used, under field conditions, to determine the optimal design criteria to guide potential application at other sites in the Lower Mekong Basin. Cues to migration and the influence of changing water levels were also investigated.

Results – Vertical slot fishway for floodplain species (Baumgartner 2010)

- Wide size range (19 – 285 mm) but the greatest proportion of captured fish were relatively small (< 100 mm) in all experimental treatments.
- Some smaller species were almost virtually absent from catches during steep slope experiments. In contrast, catches of larger fish increased with steeper slope.
- The most number of fish were collected during moderate slope treatments (1:15; n = 7,666) but the most species (n = 52) were collected from control samples (fish just trying to ascend the fish ways).
- Species appeared to fall within three main groupings based on passage success within the experimental unit.
  - Firstly, there were species which only migrated when the fishway was established on a steep slope. These species (n = 20) were either absent, or collected in extremely low abundances during control and moderate slope treatments.
  - Another group of fish which were collected only from control groups (n = 14) and were absent from treatments.
  - The final group of fish (n = 39) were collected from both control and treatment groups irrespective of fishway slope.

Results – Vertical slot fishway for floodplain species (Baumgartner 2010)

- Vertical slot fishways can provide passage for Lower Mekong fish species at low head weirs.
- Results suggested that a vertical slot fishway constructed on a 1:15 (6%) slope with small slot widths (150mm) and moderately sized cells (1000 mm X 1500 mm) was suitable for the majority of migratory species and size classes in Central Laos.
- However, some species which prefer fast flowing water may not ascend a fishway on this slope.
- Migration rates were substantially influenced by river flow which suggests that the design of permanent fishway installations must make careful consideration of local hydrology to perform efficiently.
- Fishway efficiency must be optimised at times of water level increases to ensure maximum fish passage rates. Careful consideration of these design aspects will provide functional fishways that have potential for widespread application.
- But also other alternative low-cost designs should be considered to increase the potential for wider application at other wetlands throughout the Lower Mekong Basin.

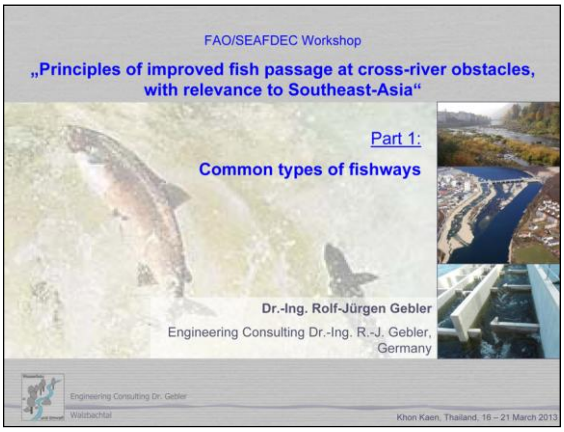
Summary

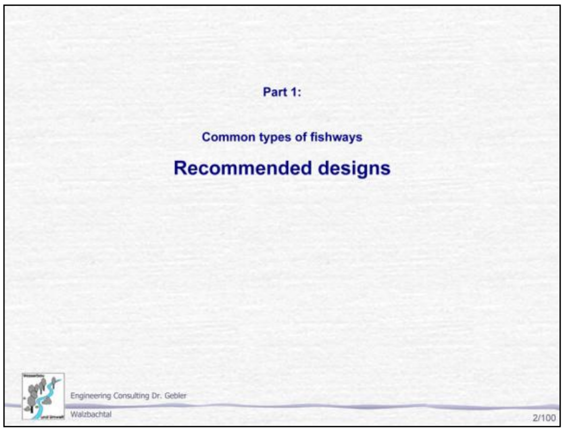
- Fish migration **during wet AND dry season**
  - Upstream
  - Downstream
- Main trigger is **discharge change** (for upstream migration, for leaving or entering floodplains etc.)
- It is important o learn more on **swimming and behaviour** of fish species in Southeast Asia
- **At least 1 diadromous fish species with long distance migrations** („The salmon of the Mekong")
- **Fish ladders are questioned in their mitigation effect for high abundant and species rich fish fauna**
- **Vertical slot fish passes might work**
  - Consideration of different discharge situations
  - Consideration of flow preferences of different fish species
  - Consideration of maximum size of fish (slot width, pool dimensions)
- **Structured approach for collecting the information** as proposed in the earlier talk would provide an important basis for further action and studies (might be existing already in acertain form)
- **Future studies on swimming, behaviour and life cycles needed**

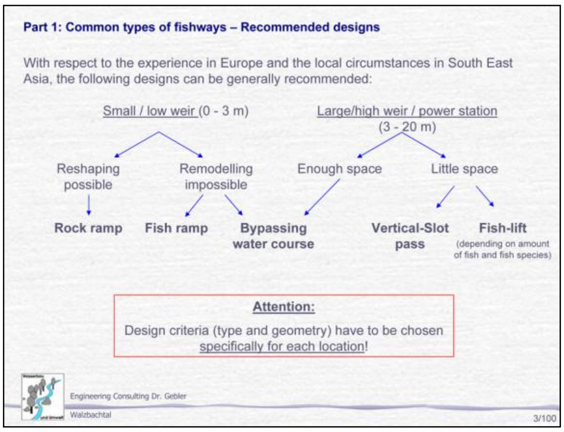
Annex 18

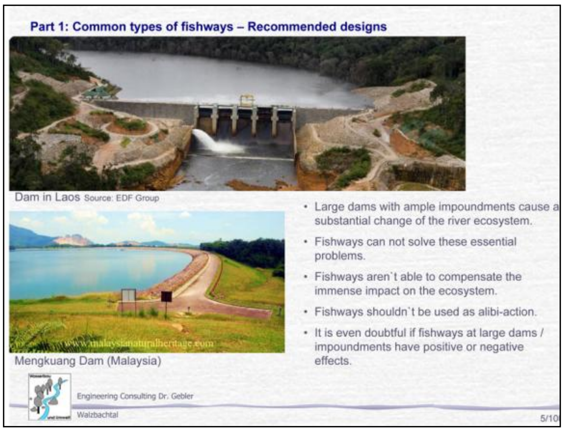
COMMON TYPES OF FISHWAY

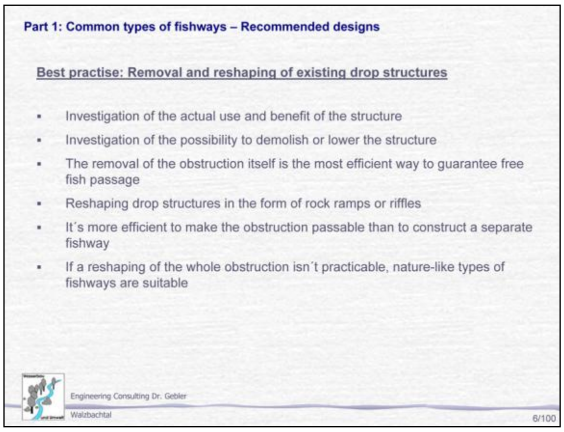
By Dr. -Ing Rolf-Jürgen Gebler

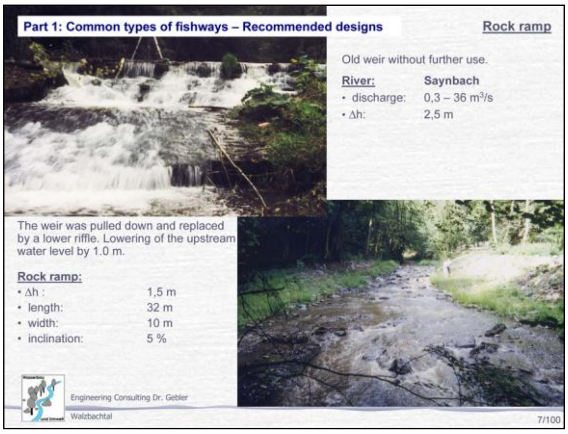


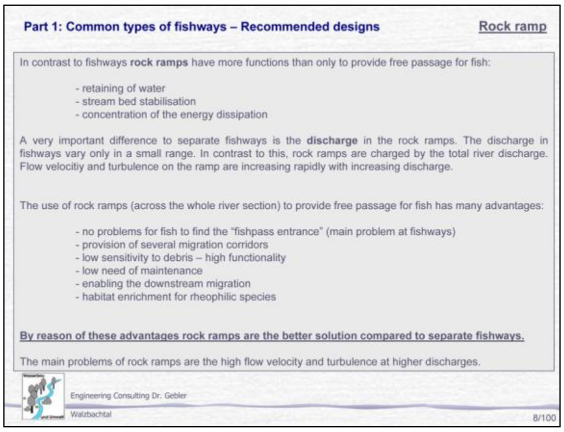


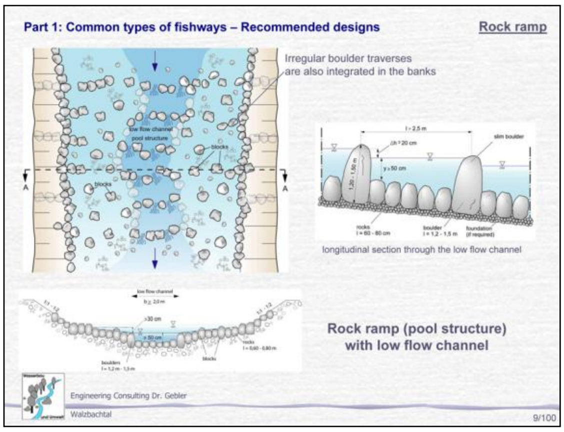


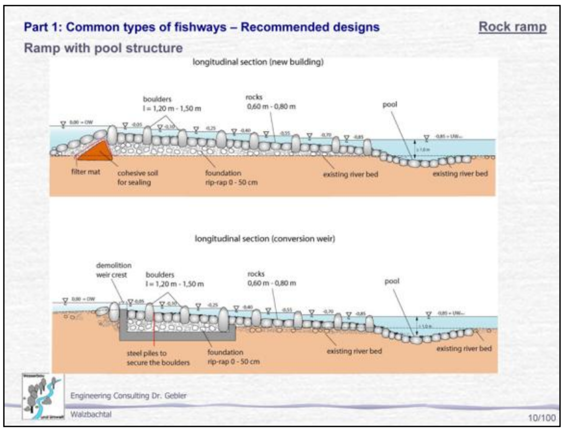


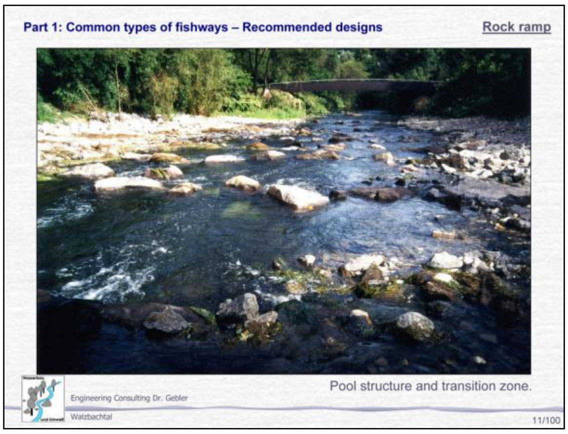


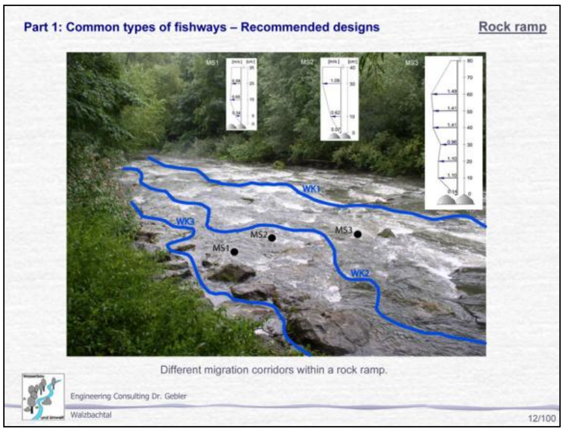

Part 1: Common types of fishways – Recommended designs
Rock ramp
Old weir without further use.
River: Saynbach
• discharge: 0,3 – 36 m³/s
• Δh: 2,5 m
The weir was pulled down and replaced by a lower riffle. Lowering of the upstream water level by 1.0 m.
Rock ramp:
• Δh : 1,5 m
• length: 32 m
• width: 10 m
• inclination: 5 %
Engineering Consulting Dr. Gebler
Walzbachtal
7/100

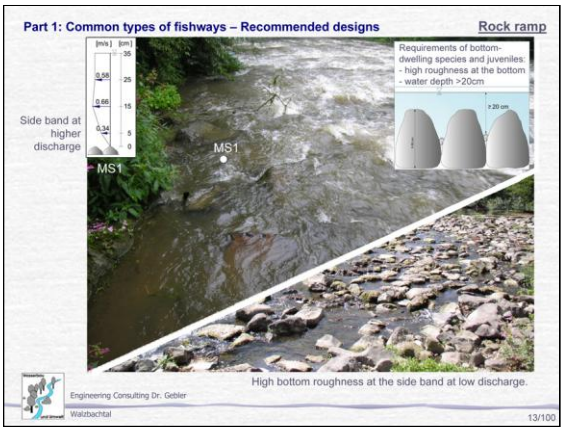

Part 1: Common types of fishways – Recommended designs
Rock ramp
In contrast to fishways rock ramps have more functions than only to provide free passage for fish:
- retaining of water
- stream bed stabilisation
- concentration of the energy dissipation
A very important difference to separate fishways is the discharge in the rock ramps. The discharge in fishways vary only in a small range. In contrast to this, rock ramps are charged by the total river discharge. Flow velocitiy and turbulence on the ramp are increasing rapidly with increasing discharge.
The use of rock ramps (across the whole river section) to provide free passage for fish has many advantages:
- no problems for fish to find the "fishpass entrance" (main problem at fishways)
- provision of several migration corridors
- low sensitivity to debris – high functionality
- low need of maintenance
- enabling the downstream migration
- habitat enrichment for rheophilic species
By reason of these advantages rock ramps are the better solution compared to separate fishways.
The main problems of rock ramps are the high flow velocity and turbulence at higher discharges.
Engineering Consulting Dr. Gebler
Walzbachtal
8/100

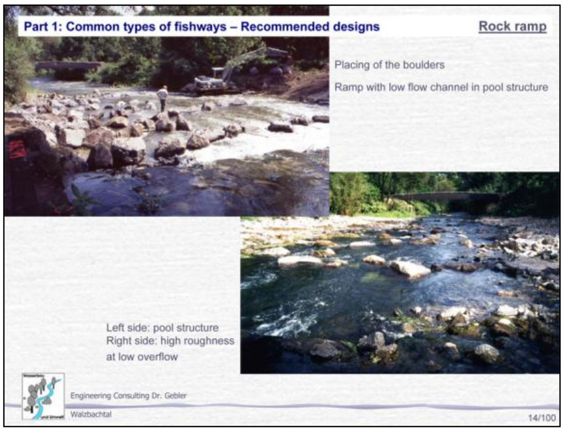

Part 1: Common types of fishways – Recommended designs
Rock ramp
Irregular boulder traverses are also integrated in the banks
longitudinal section through the low flow channel
Rock ramp (pool structure) with low flow channel
Engineering Consulting Dr. Gebler
Walzbachtal
9/100

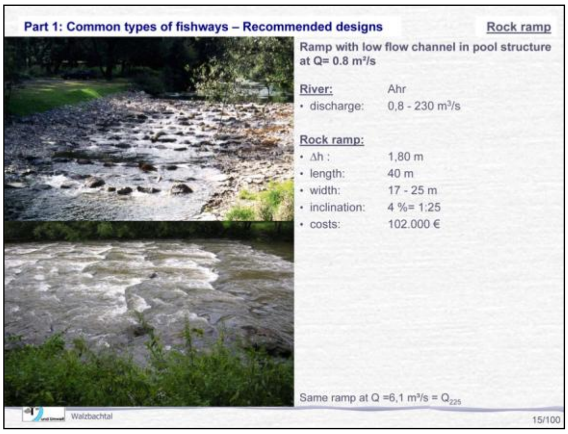

Part 1: Common types of fishways – Recommended designs
Rock ramp
Ramp with pool structure
longitudinal section (new building)
boulders
l = 1,20 m - 1,50 m
rocks
0,60 m - 0,80 m
pool
filter mat
cohesive soil for sealing
foundation rip-rap 0 - 50 cm
existing river bed
longitudinal section (conversion weir)
demolition weir crest
steel piles to secure the boulders
Engineering Consulting Dr. Gebler
Walzbachtal
10/100


Part 1: Common types of fishways – Recommended designs
Rock ramp
Pool structure and transition zone.
Engineering Consulting Dr. Gebler
Walzbachtal
11/100

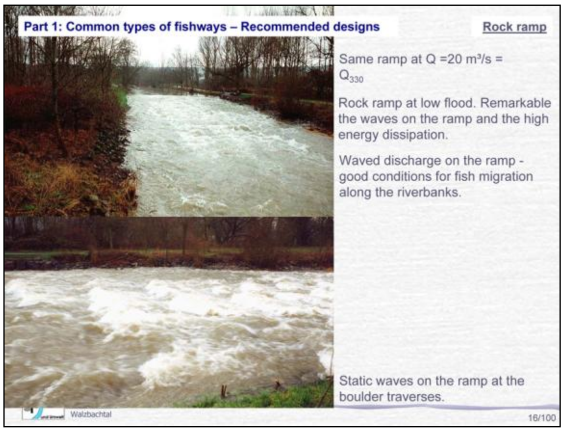

Part 1: Common types of fishways – Recommended designs
Rock ramp
MS1
MS2
MS3
WK1
WK2
WK3
Different migration corridors within a rock ramp.
Engineering Consulting Dr. Gebler
Walzbachtal
12/100


Part 1: Common types of fishways – Recommended designs
Rock ramp
Side band at higher discharge
MS1
Requirements of bottom-dwelling species and juveniles:
- high roughness at the bottom
- water depth >20cm
High bottom roughness at the side band at low discharge.
Engineering Consulting Dr. Gebler
Walzbachtal
13/100

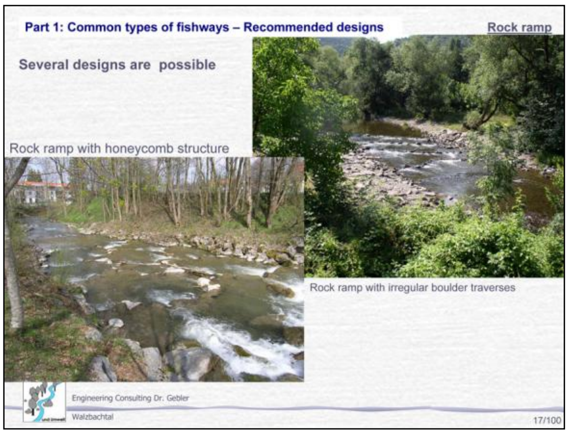

Part 1: Common types of fishways – Recommended designs
Rock ramp
Placing of the boulders
Ramp with low flow channel in pool structure
Left side: pool structure
Right side: high roughness at low overflow
Engineering Consulting Dr. Gebler
Walzbachtal
14/100



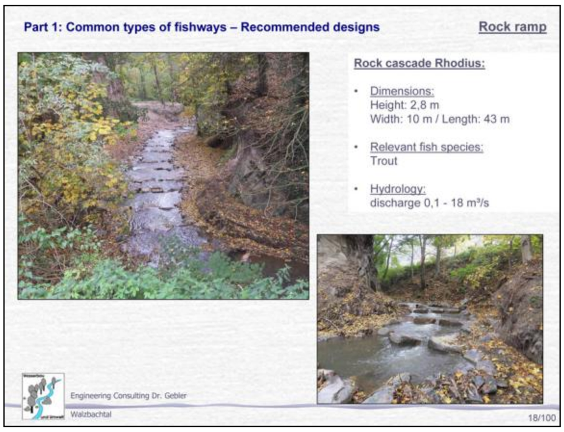
Part 1: Common types of fishways – Recommended designs
Rock ramp
Ramp with low flow channel in pool structure at Q= 0.8 m³/s
River: Ahr
• discharge: 0,8 - 230 m³/s
Rock ramp:
• Δh : 1,80 m
• length: 40 m
• width: 17 - 25 m
• inclination: 4 %= 1:25
• costs: 102.000 €
Same ramp at Q =6,1 m³/s = Q225
Walzbachtal
15/100



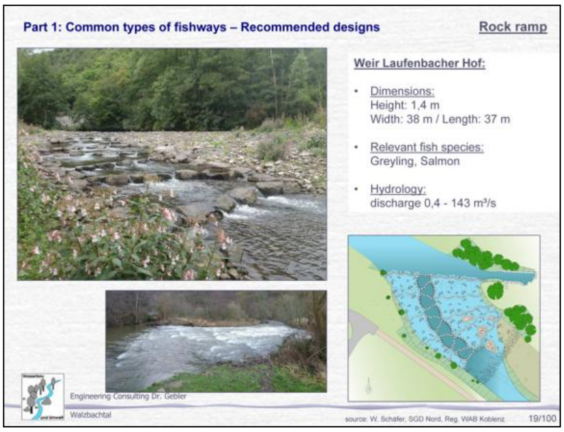
Part 1: Common types of fishways – Recommended designs
Rock ramp
Same ramp at Q =20 m³/s = Q330
Rock ramp at low flood. Remarkable the waves on the ramp and the high energy dissipation.
Waved discharge on the ramp - good conditions for fish migration along the riverbanks.
Static waves on the ramp at the boulder traverses.
Walzbachtal
16/100



Part 1: Common types of fishways – Recommended designs
Rock ramp
Several designs are possible
Rock ramp with honeycomb structure
Rock ramp with irregular boulder traverses
Engineering Consulting Dr. Gebler
Walzbachtal
17/100

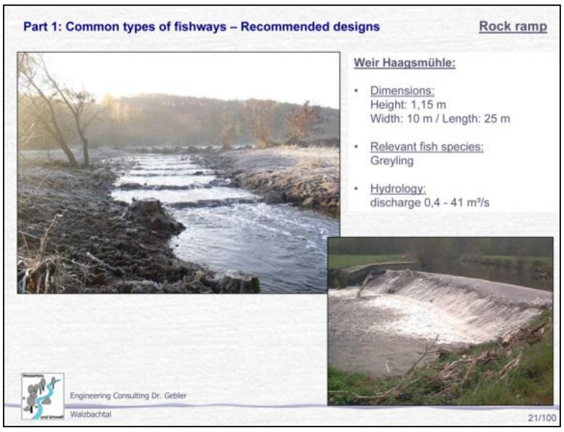


Part 1: Common types of fishways – Recommended designs
Rock ramp
Rock cascade Rhodius:
• Dimensions:
Height: 2,8 m
Width: 10 m / Length: 43 m
• Relevant fish species:
Trout
• Hydrology:
discharge 0,1 - 18 m³/s
Engineering Consulting Dr. Gebler
Walzbachtal
18/100

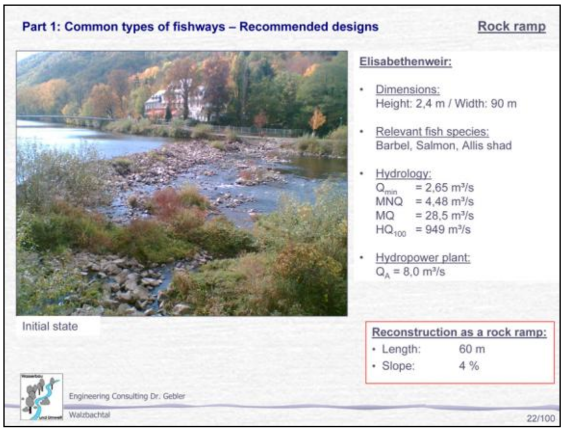


Part 1: Common types of fishways – Recommended designs
Rock ramp
Weir Laufenbacher Hof:
• Dimensions:
Height: 1,4 m
Width: 38 m / Length: 37 m
• Relevant fish species:
Greyling, Salmon
• Hydrology:
discharge 0,4 - 143 m³/s
Engineering Consulting Dr. Gebler
Walzbachtal
source: W. Schäfer, SGD Nord, Reg. WAB Koblenz
19/100

Part 1: Common types of fishways – Recommended designs
Rock ramp
Casinoweir,
Bad Neuenahr-Ahrweiler, Ahr (D):
• Dimensions:
Height: 1,8 m
Width: 20 m / Length: 50 m
• Relevant fish species:
Greyling, Salmon
• Hydrology:
discharge 0,5 – 230 m³/s
Engineering Consulting Dr. Gebler
Walzbachtal
20/100

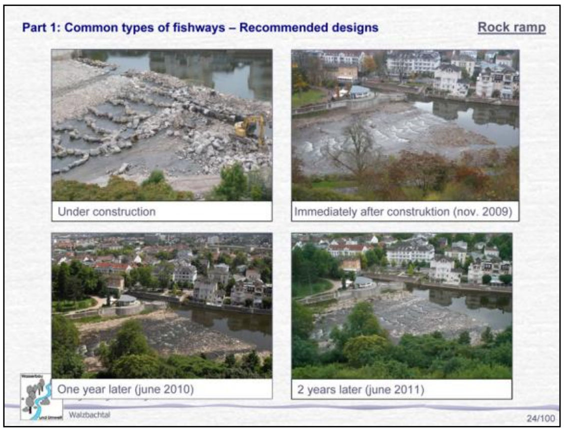


Part 1: Common types of fishways – Recommended designs
Rock ramp
Weir Haagsmühle:
• Dimensions:
Height: 1,15 m
Width: 10 m / Length: 25 m
• Relevant fish species:
Greyling
• Hydrology:
discharge 0,4 - 41 m³/s
Engineering Consulting Dr. Gebler
Walzbachtal
21/100

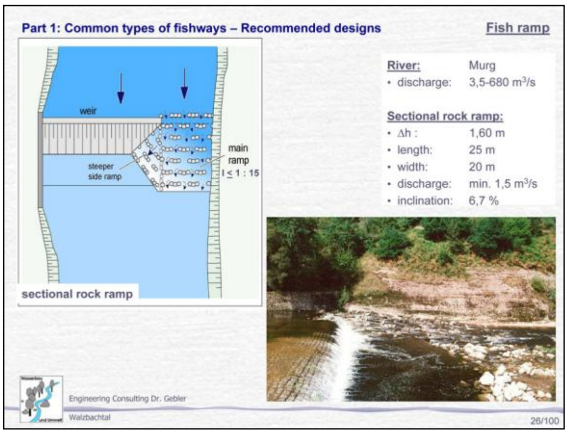


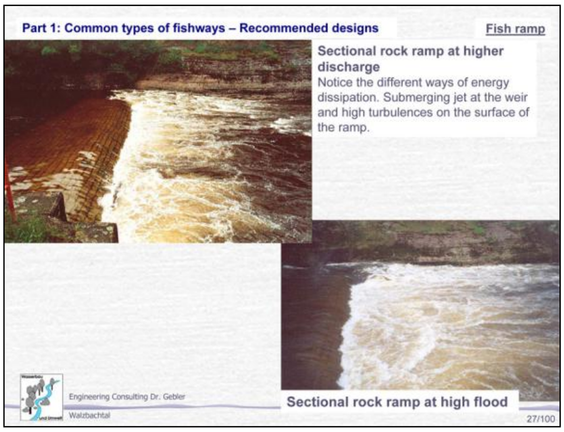
Part 1: Common types of fishways – Recommended designs
Rock ramp
Elisabethenweir:
• Dimensions:
Height: 2,4 m / Width: 90 m
• Relevant fish species:
Barbel, Salmon, Allis shad
• Hydrology:
Qmin = 2,65 m³/s
MNQ = 4,48 m³/s
MQ = 28,5 m³/s
HQ100 = 949 m³/s
• Hydropower plant:
QA = 8,0 m³/s
Initial state
Reconstruction as a rock ramp:
• Length: 60 m
• Slope: 4 %
Engineering Consulting Dr. Gebler
Walzbachtal
22/100

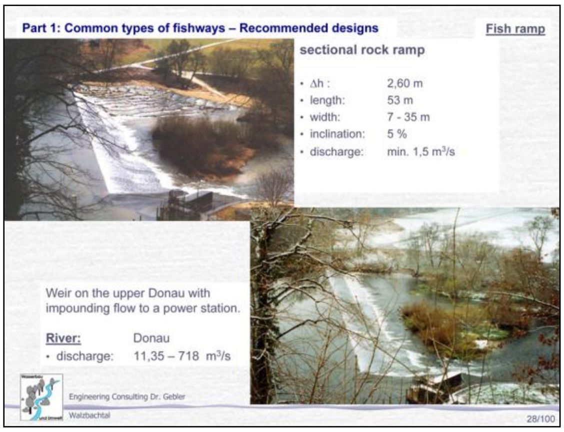

Part 1: Common types of fishways – Recommended designs
Rock ramp
Source: www.chiangmai-thai.com
Tha Wangtan weir, Ping River
in Tambon Pa Daed, Chiang Mai (T)
(Local details about the structure, use and fish migration unknown!)
Engineering Consulting Dr. Gebler
Walzbachtal
23/100

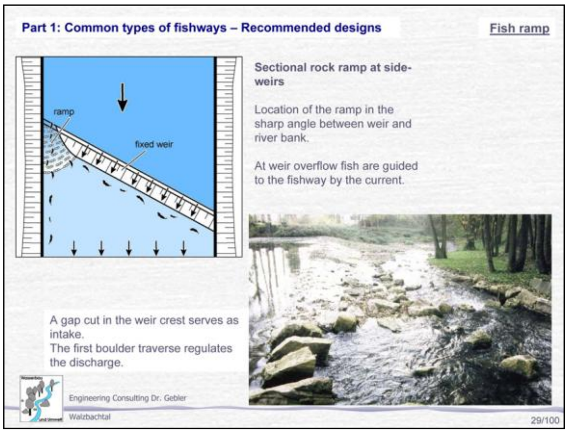

Part 1: Common types of fishways – Recommended designs
Rock ramp
Under construction
Immediately after construktion (nov. 2009)
One year later (june 2010)
2 years later (june 2011)
Engineering Consulting Dr. Gebler
Walzbachtal
24/100

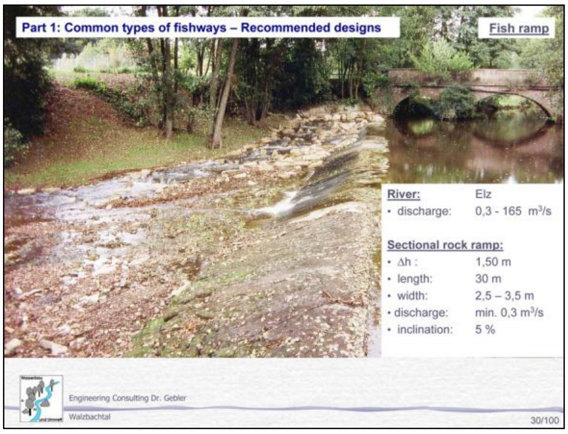

Part 1: Common types of fishways – Recommended designs
Rock ramp
Q = 2,65 m³/s
Q = 20 m³/s
Q = 130 m³/s
Q = 250 m³/s
Engineering Consulting Dr. Gebler
Walzbachtal
25/100

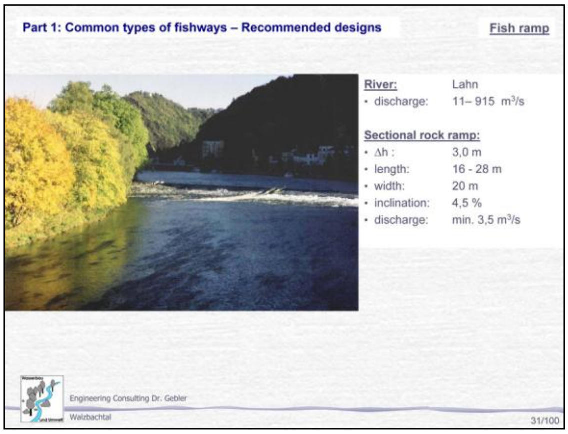

Part 1: Common types of fishways – Recommended designs
Fish ramp
weir
steeper side ramp
main ramp
I ≤ 1 : 15
sectional rock ramp
River: Murg
• discharge: 3,5-680 m³/s
Sectional rock ramp:
• Δh : 1,60 m
• length: 25 m
• width: 20 m
• discharge: min. 1,5 m³/s
• inclination: 6,7 %
Engineering Consulting Dr. Gebler
Walzbachtal
26/100

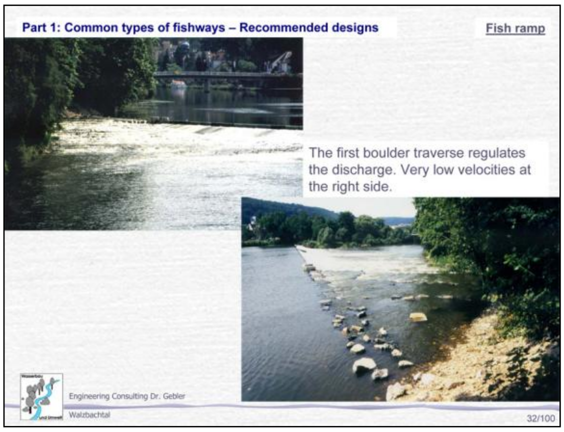

Part 1: Common types of fishways – Recommended designs
Fish ramp
Sectional rock ramp at higher discharge
Notice the different ways of energy dissipation. Submerging jet at the weir and high turbulences on the surface of the ramp.
Sectional rock ramp at high flood
Engineering Consulting Dr. Gebler
Walzbachtal
27/100

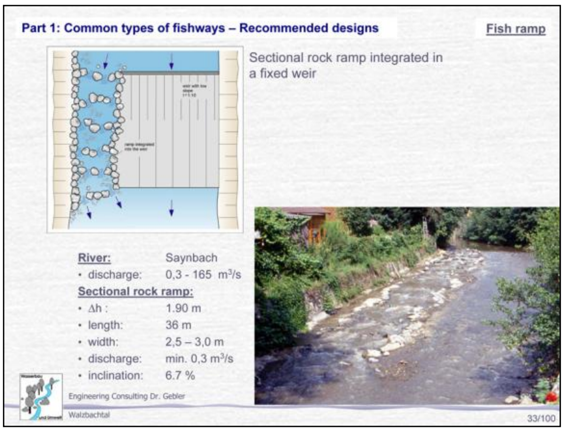

Part 1: Common types of fishways – Recommended designs
Fish ramp
sectional rock ramp
• Δh : 2,60 m
• length: 53 m
• width: 7 - 35 m
• inclination: 5 %
• discharge: min. 1,5 m³/s
Weir on the upper Donau with impounding flow to a power station.
River: Donau
• discharge: 11,35 – 718 m³/s
Engineering Consulting Dr. Gebler
Walzbachtal
28/100

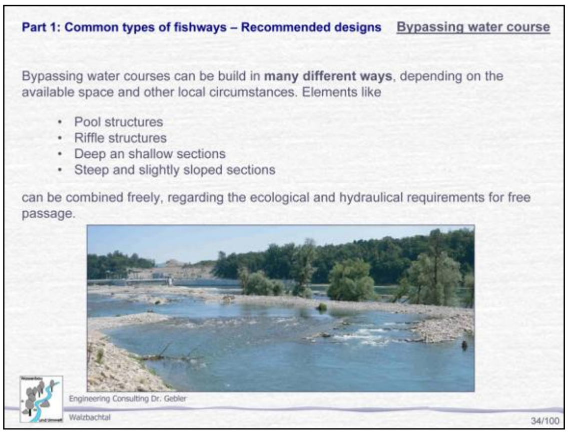

Part 1: Common types of fishways – Recommended designs
Fish ramp
ramp
fixed weir
Sectional rock ramp at side-weirs
Location of the ramp in the sharp angle between weir and river bank.
At weir overflow fish are guided to the fishway by the current.
A gap cut in the weir crest serves as intake.
The first boulder traverse regulates the discharge.
Engineering Consulting Dr. Gebler
Walzbachtal
29/100

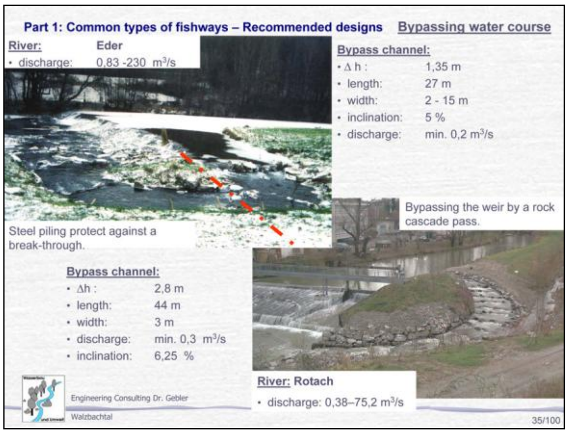

Part 1: Common types of fishways – Recommended designs
Fish ramp
River: Elz
• discharge: 0,3 - 165 m³/s
Sectional rock ramp:
• Δh : 1,50 m
• length: 30 m
• width: 2,5 – 3,5 m
• discharge: min. 0,3 m³/s
• inclination: 5 %
Engineering Consulting Dr. Gebler
Walzbachtal
30/100

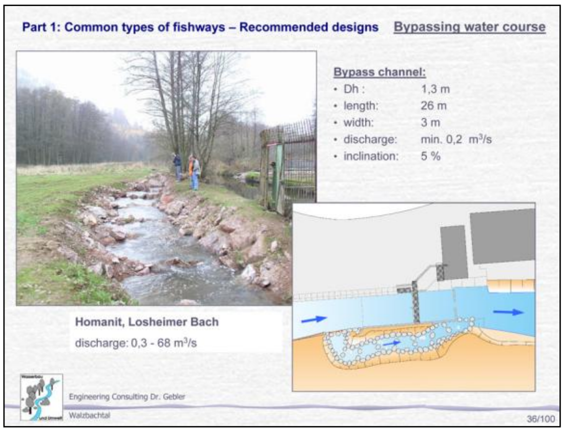

Part 1: Common types of fishways – Recommended designs
Fish ramp
River: Lahn
• discharge: 11– 915 m³/s
Sectional rock ramp:
• Δh : 3,0 m
• length: 16 - 28 m
• width: 20 m
• inclination: 4,5 %
• discharge: min. 3,5 m³/s
Engineering Consulting Dr. Gebler
Walzbachtal
31/100

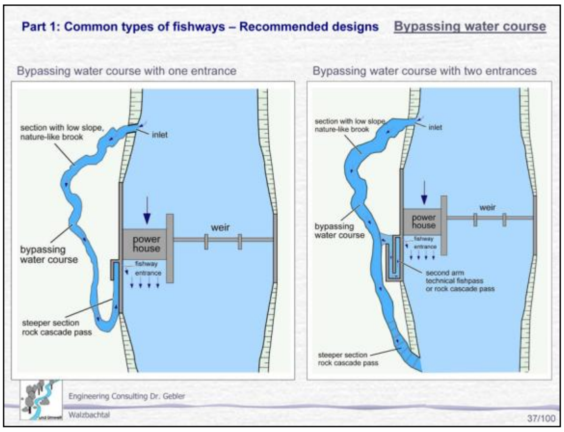

Part 1: Common types of fishways – Recommended designs
Fish ramp
The first boulder traverse regulates the discharge. Very low velocities at the right side.
Engineering Consulting Dr. Gebler
Walzbachtal
32/100

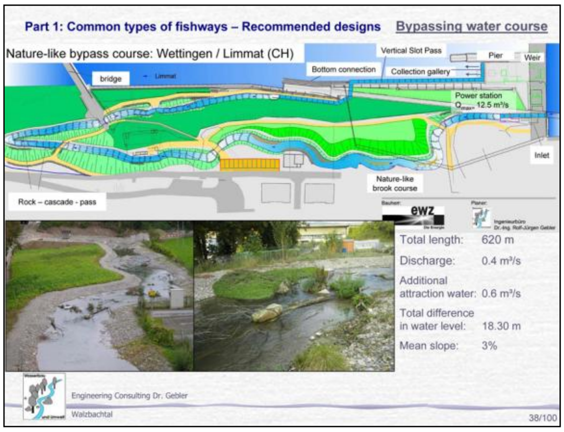

Part 1: Common types of fishways – Recommended designs
Fish ramp
Sectional rock ramp integrated in a fixed weir
River: Saynbach
• discharge: 0,3 - 165 m³/s
Sectional rock ramp:
• Δh : 1.90 m
• length: 36 m
• width: 2,5 – 3,0 m
• discharge: min. 0,3 m³/s
• inclination: 6.7 %
Engineering Consulting Dr. Gebler
Walzbachtal
33/100

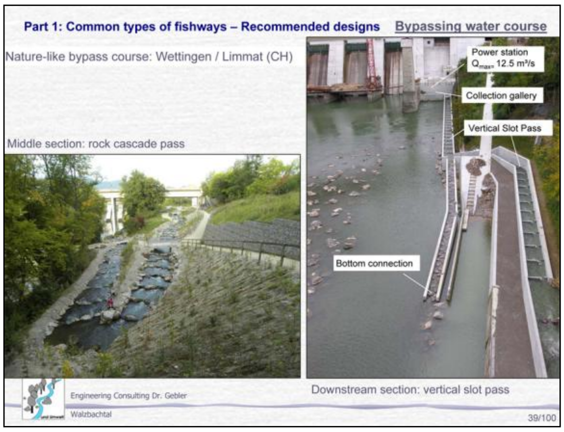

Part 1: Common types of fishways – Recommended designs
Bypassing water course
Bypassing water courses can be build in many different ways, depending on the available space and other local circumstances. Elements like
• Pool structures
• Riffle structures
• Deep an shallow sections
• Steep and slightly sloped sections
can be combined freely, regarding the ecological and hydraulical requirements for free passage.
Engineering Consulting Dr. Gebler
Walzbachtal
34/100

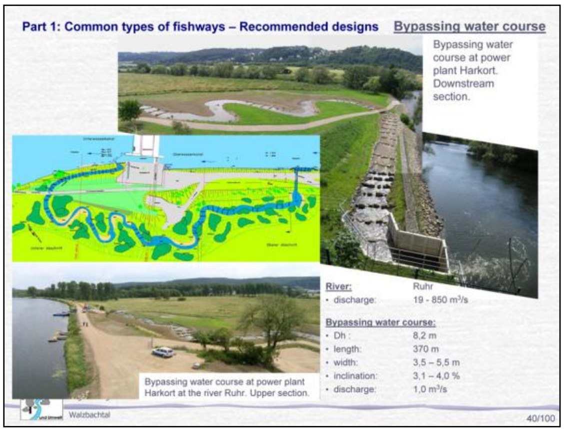

Part 1: Common types of fishways – Recommended designs
Bypassing water course
River: Eder
• discharge: 0,83 -230 m³/s
Bypass channel:
• Δ h : 1,35 m
• length: 27 m
• width: 2 - 15 m
• inclination: 5 %
• discharge: min. 0,2 m³/s
Bypassing the weir by a rock cascade pass.
Steel piling protect against a break-through.
Bypass channel:
• Δh : 2,8 m
• length: 44 m
• width: 3 m
• discharge: min. 0,3 m³/s
• inclination: 6,25 %
River: Rotach
• discharge: 0,38–75,2 m³/s
Engineering Consulting Dr. Gebler
Walzbachtal
35/100

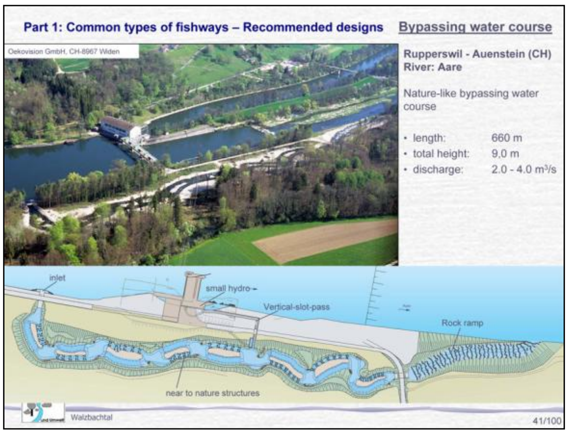

Part 1: Common types of fishways – Recommended designs
Bypassing water course
Bypass channel:
• Dh : 1,3 m
• length: 26 m
• width: 3 m
• discharge: min. 0,2 m³/s
• inclination: 5 %
Homanit, Losheimer Bach
discharge: 0,3 - 68 m³/s
Engineering Consulting Dr. Gebler
Walzbachtal
36/100

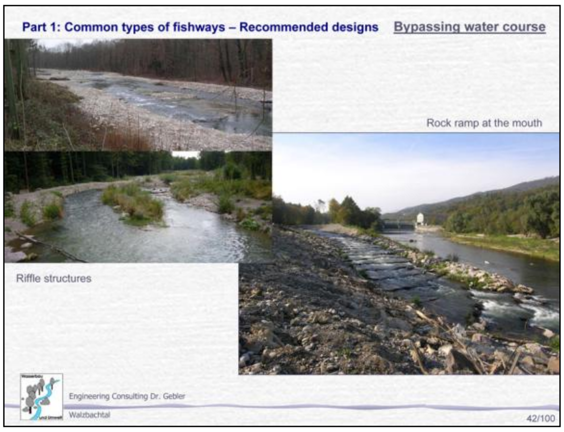

Part 1: Common types of fishways – Recommended designs
Bypassing water course
Bypassing water course with one entrance
Bypassing water course with two entrances
section with low slope, nature-like brook
inlet
power house
weir
fishway entrance
bypassing water course
steeper section rock cascade pass
second arm technical fishpass or rock cascade pass
Engineering Consulting Dr. Gebler
Walzbachtal
37/100

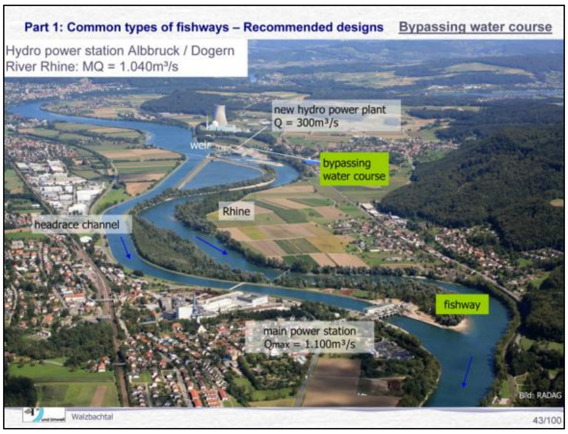

Part 1: Common types of fishways – Recommended designs
Bypassing water course
Nature-like bypass course: Wettingen / Limmat (CH)
Vertical Slot Pass
Pier
Weir
bridge
Limmat
Bottom connection
Collection gallery
Power station
Inlet
Nature-like brook course
Rock – cascade - pass
ewz
Total length: 620 m
Discharge: 0.4 m³/s
Additional attraction water: 0.6 m³/s
Total difference in water level: 18.30 m
Mean slope: 3%
Engineering Consulting Dr. Gebler
Walzbachtal
38/100

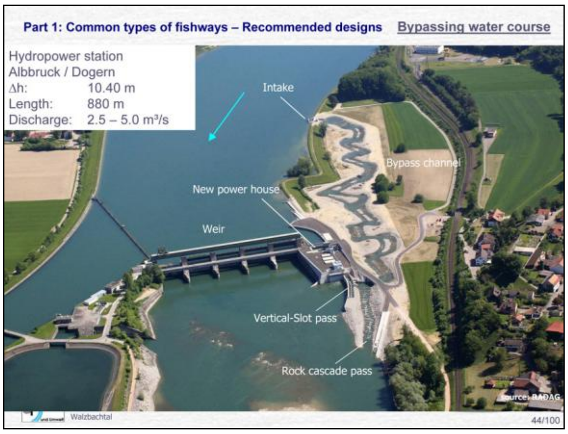

Part 1: Common types of fishways – Recommended designs
Bypassing water course
Nature-like bypass course: Wettingen / Limmat (CH)
Power station
Q_{max}: 12.5 m³/s
Collection gallery
Vertical Slot Pass
Middle section: rock cascade pass
Bottom connection
Engineering Consulting Dr. Gebler
Downstream section: vertical slot pass
Walzbachtal
39/100

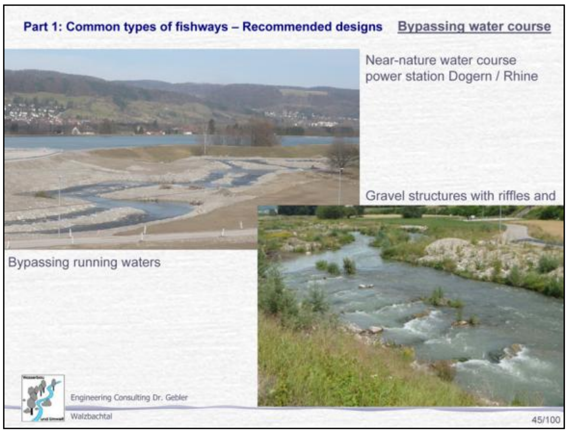

Part 1: Common types of fishways – Recommended designs
Bypassing water course
Bypassing water course at power plant Harkort. Downstream section.
River: Ruhr
• discharge: 19 - 850 m³/s
Bypassing water course:
• Dh : 8,2 m
• length: 370 m
• width: 3,5 – 5,5 m
• inclination: 3,1 – 4,0 %
• discharge: 1,0 m³/s
Bypassing water course at power plant Harkort at the river Ruhr. Upper section.
Walzbachtal
40/100

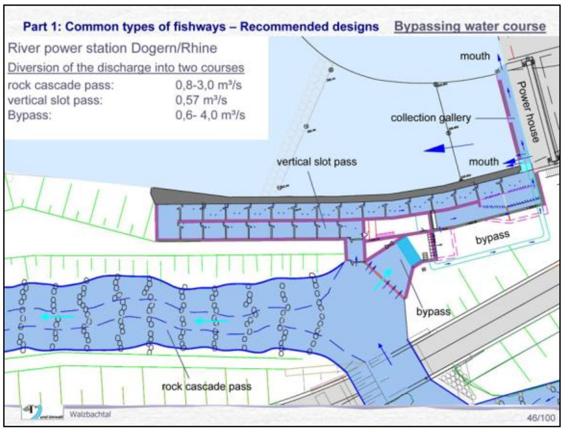

Part 1: Common types of fishways – Recommended designs
Bypassing water course
Oekovision GmbH, CH-8967 Widen
Rupperswil - Auenstein (CH)
River: Aare
Nature-like bypassing water course
• length: 660 m
• total height: 9,0 m
• discharge: 2.0 - 4.0 m³/s
inlet
small hydro
Vertical-slot-pass
Rock ramp
near to nature structures
Walzbachtal
41/100


Part 1: Common types of fishways – Recommended designs
Bypassing water course
Rock ramp at the mouth
Riffle structures
Engineering Consulting Dr. Gebler
Walzbachtal
42/100

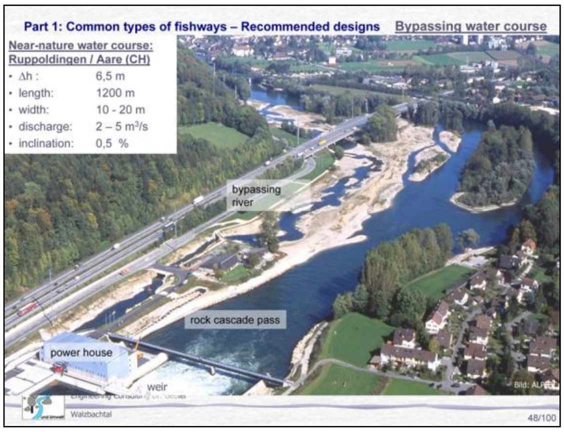

Part 1: Common types of fishways – Recommended designs
Bypassing water course
Hydro power station Albbruck / Dogern
River Rhine: MQ = 1.040m³/s
new hydro power plant
Q = 300m³/s
weir
bypassing water course
Rhine
headrace channel
fishway
main power station
Qmax = 1.100m³/s
Bild: RADAG
Walzbachtal
43/100

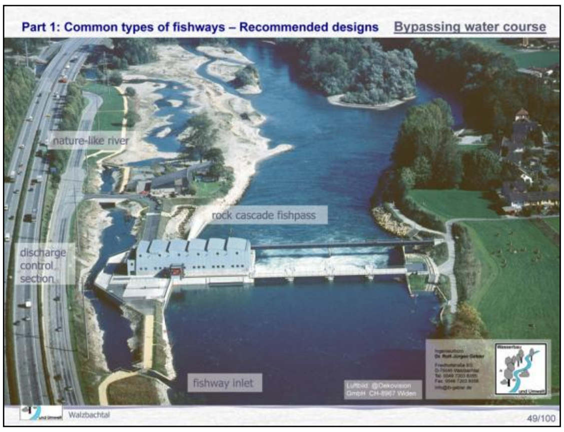

Part 1: Common types of fishways – Recommended designs
Bypassing water course
Hydropower station
Albbruck / Dogern
Δh: 10.40 m
Length: 880 m
Discharge: 2.5 – 5.0 m³/s
Intake
Bypass channel
New power house
Weir
Vertical-Slot pass
Rock cascade pass
Source: RADAG
Walzbachtal
44/100

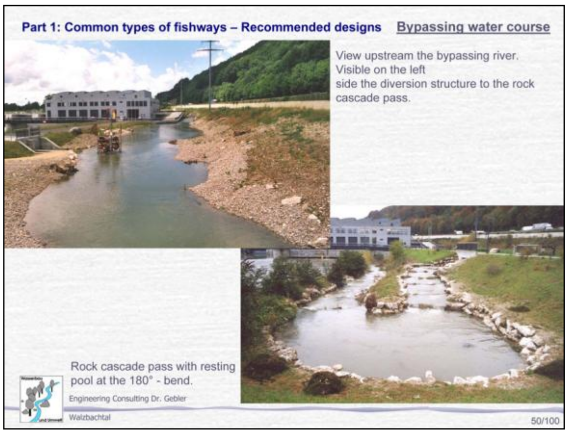

Part 1: Common types of fishways – Recommended designs
Bypassing water course
Near-nature water course
power station Dogern / Rhine
Gravel structures with riffles and
Bypassing running waters
Engineering Consulting Dr. Gebler
Walzbachtal
45/100

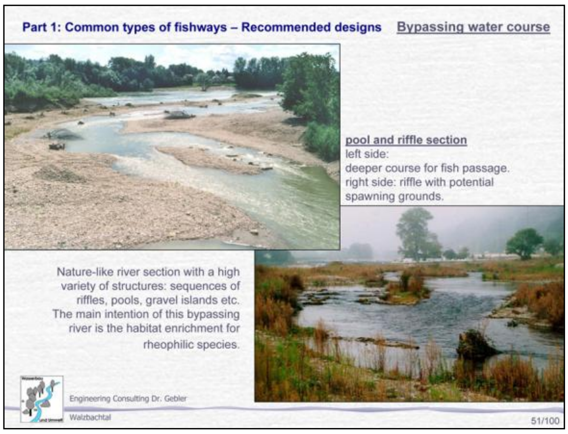

Part 1: Common types of fishways – Recommended designs
Bypassing water course
River power station Dogern/Rhine
Diversion of the discharge into two courses
rock cascade pass: 0,8-3,0 m³/s
vertical slot pass: 0,57 m³/s
Bypass: 0,6- 4,0 m³/s
mouth
Power house
collection gallery
vertical slot pass
mouth
bypass
bypass
rock cascade pass
Walzbachtal
46/100

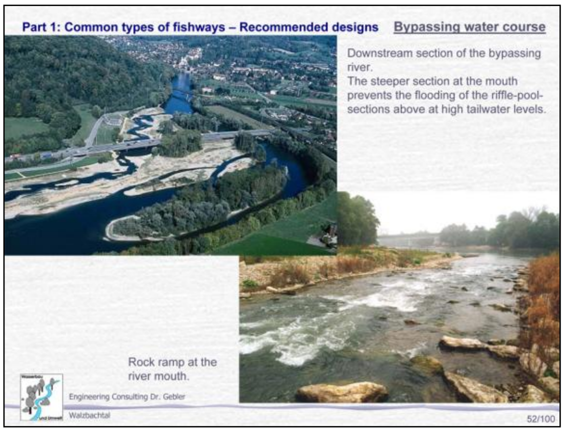

Part 1: Common types of fishways – Recommended designs Bypassing water course
Old hydroelectric power-station Ruppoldingen (CH) designed as diversion type.
River: Aare
discharge: 127 - 900 m³/s
New hydroelectric power-station designed as run-of-river type. The headrace channel was filled up and a nature-like river was installed.
Engineering Consulting Dr. Gebler
Walzbachtal
47/100

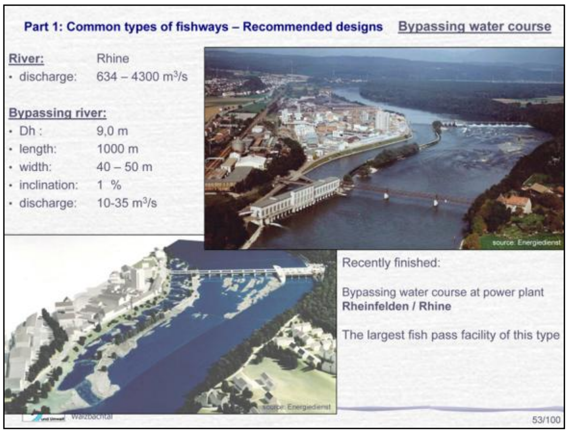

Part 1: Common types of fishways – Recommended designs Bypassing water course
Near-nature water course:
Ruppoldingen / Aare (CH)
• Δh : 6,5 m
• length: 1200 m
• width: 10 - 20 m
• discharge: 2 – 5 m³/s
• inclination: 0,5 %
bypassing river
rock cascade pass
power house
weir
Walzbachtal
48/100


Part 1: Common types of fishways – Recommended designs Bypassing water course
nature-like river
rock cascade fishpass
discharge control section
fishway inlet
Walzbachtal
49/100

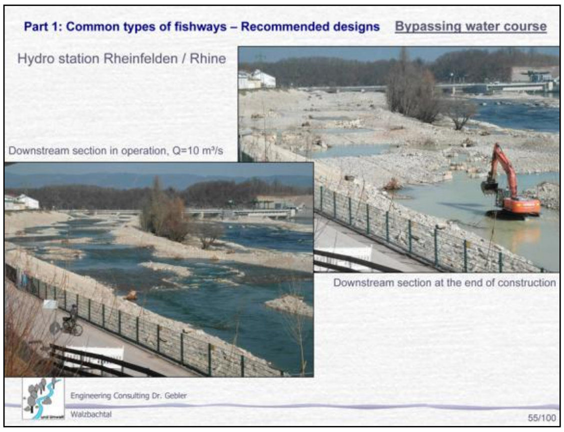

Part 1: Common types of fishways – Recommended designs Bypassing water course
View upstream the bypassing river. Visible on the left side the diversion structure to the rock cascade pass.
Rock cascade pass with resting pool at the 180° - bend.
Engineering Consulting Dr. Gebler
Walzbachtal
50/100

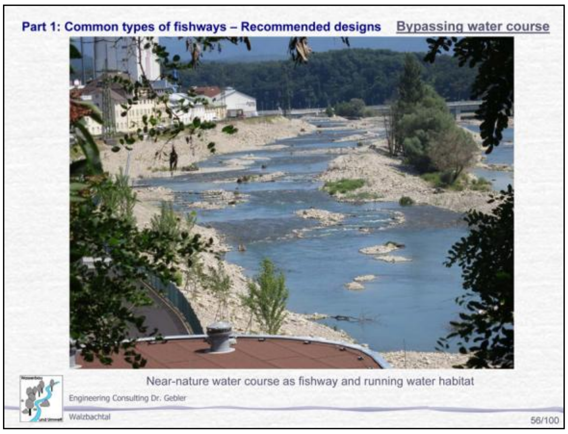

Part 1: Common types of fishways – Recommended designs Bypassing water course
pool and riffle section
left side:
deeper course for fish passage.
right side: riffle with potential spawning grounds.
Nature-like river section with a high variety of structures: sequences of riffles, pools, gravel islands etc. The main intention of this bypassing river is the habitat enrichment for rheophilic species.
Engineering Consulting Dr. Gebler
Walzbachtal
51/100

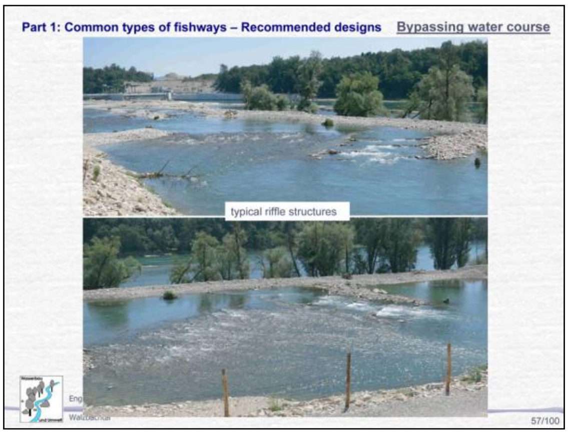

Part 1: Common types of fishways – Recommended designs Bypassing water course
Downstream section of the bypassing river.
The steeper section at the mouth prevents the flooding of the riffle-pool-sections above at high tailwater levels.
Rock ramp at the river mouth.
Engineering Consulting Dr. Gebler
Walzbachtal
52/100

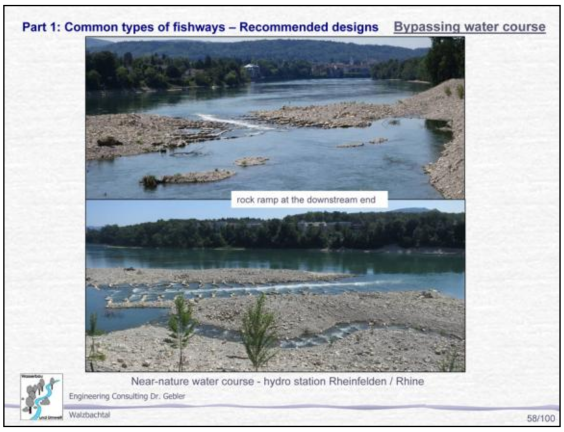

Part 1: Common types of fishways – Recommended designs Bypassing water course
River: Rhine
• discharge: 634 – 4300 m³/s
Bypassing river:
• Dh : 9,0 m
• length: 1000 m
• width: 40 – 50 m
• inclination: 1 %
• discharge: 10-35 m³/s
source: Energiedienst
Recently finished:
Bypassing water course at power plant Rheinfelden / Rhine
The largest fish pass facility of this type
source: Energiedienst
Walzbachtal
53/100

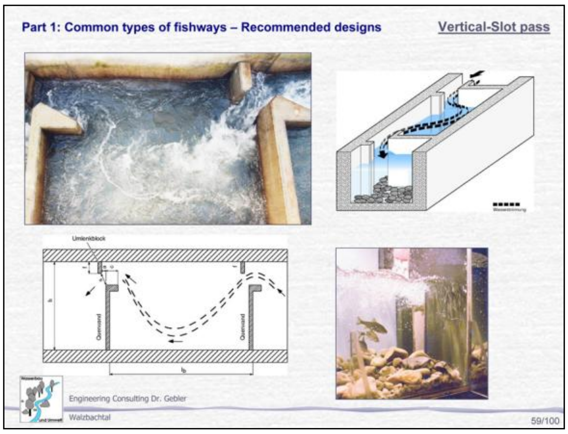

Part 1: Common types of fishways – Recommended designs Bypassing water course
Rock cascade pass
Vertical slot pass
Near-nature water course
Rock ramp
Hydro power station
Rheinfelden / Rhine
Bild: Luftaufnahmen Meyer, Hasel
Walzbachtal
54/100

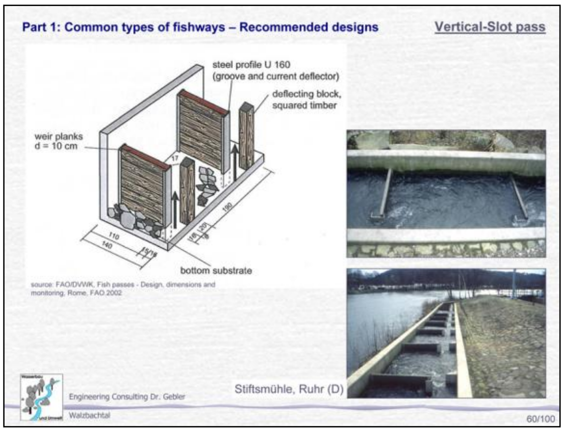

Part 1: Common types of fishways – Recommended designs
Bypassing water course
Hydro station Rheinfelden / Rhine
Downstream section in operation, Q=10 m³/s
Downstream section at the end of construction
Engineering Consulting Dr. Gebler
Walzbachtal
55/100

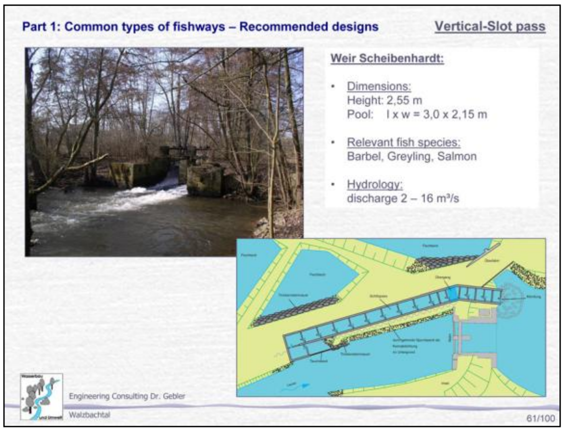

Part 1: Common types of fishways – Recommended designs
Bypassing water course
Near-nature water course as fishway and running water habitat
Engineering Consulting Dr. Gebler
Walzbachtal
56/100

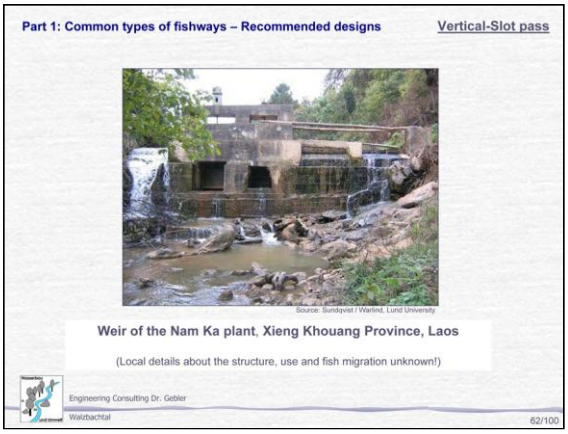

Part 1: Common types of fishways – Recommended designs
Bypassing water course
typical riffle structures
57/100


Part 1: Common types of fishways – Recommended designs
Bypassing water course
rock ramp at the downstream end
Near-nature water course - hydro station Rheinfelden / Rhine
Engineering Consulting Dr. Gebler
Walzbachtal
58/100


Part 1: Common types of fishways – Recommended designs
Vertical-Slot pass
Engineering Consulting Dr. Gebler
Walzbachtal
59/100

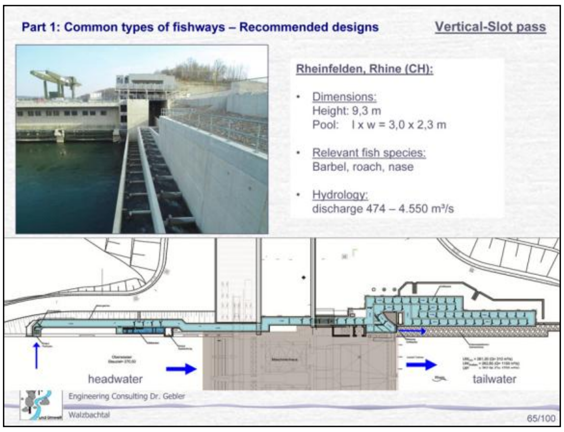

Part 1: Common types of fishways – Recommended designs
Vertical-Slot pass
steel profile U 160
(groove and current deflector)
deflecting block,
squared timber
weir planks
d = 10 cm
bottom substrate
source: FAO/DVWK, Fish passes - Design, dimensions and monitoring, Rome, FAO 2002
Stiftsmühle, Ruhr (D)
Engineering Consulting Dr. Gebler
Walzbachtal
60/100


Part 1: Common types of fishways – Recommended designs
Vertical-Slot pass
Weir Scheibenhardt:
• Dimensions:
Height: 2,55 m
Pool: l x w = 3,0 x 2,15 m
• Relevant fish species:
Barbel, Greyling, Salmon
• Hydrology:
discharge 2 – 16 m³/s
Engineering Consulting Dr. Gebler
Walzbachtal
61/100


Part 1: Common types of fishways – Recommended designs
Vertical-Slot pass
Source: Sundqvist / Warlind, Lund University
Weir of the Nam Ka plant, Xieng Khouang Province, Laos
(Local details about the structure, use and fish migration unknown!)
Engineering Consulting Dr. Gebler
Walzbachtal
62/100


Part 1: Common types of fishways – Recommended designs
Vertical-Slot pass
Engineering Consulting Dr. Gebler
Walzbachtal
63/100


Part 1: Common types of fishways – Recommended designs
Vertical-Slot pass
Engineering Consulting Dr. Gebler
Walzbachtal
64/100

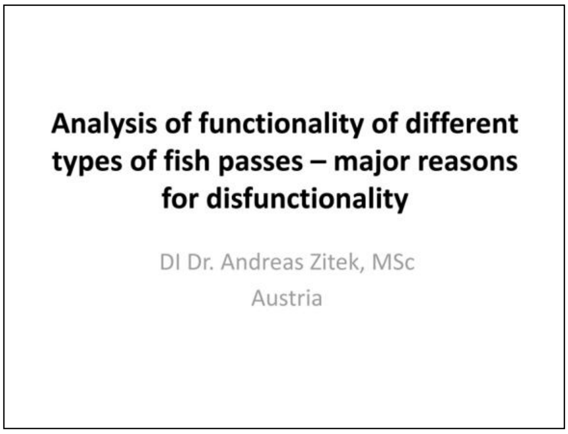

Part 1: Common types of fishways – Recommended designs
Vertical-Slot pass
Rheinfelden, Rhine (CH):
Dimensions:
Height: 9,3 m
Pool: l x w = 3,0 x 2,3 m
Relevant fish species:
Barbel, roach, nase
Hydrology:
discharge 474 – 4.550 m³/s
headwater
tailwater
Engineering Consulting Dr. Gebler
Walzbachtal
65/100

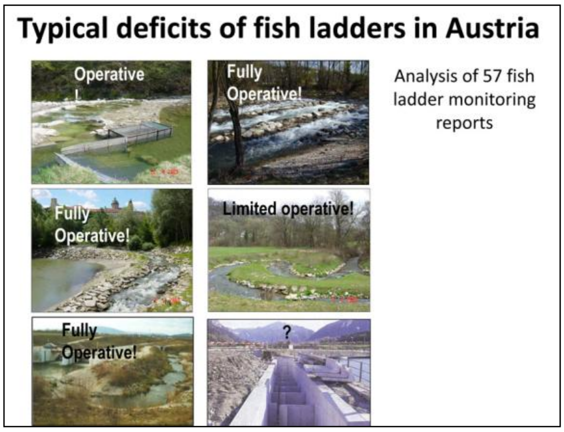

Part 1: Common types of fishways – Recommended designs
Vertical-Slot pass
Engineering Consulting Dr. Gebler
Walzbachtal
66/100

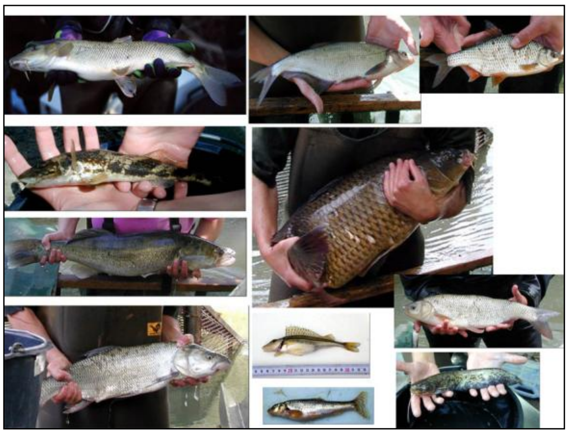
Annex 19

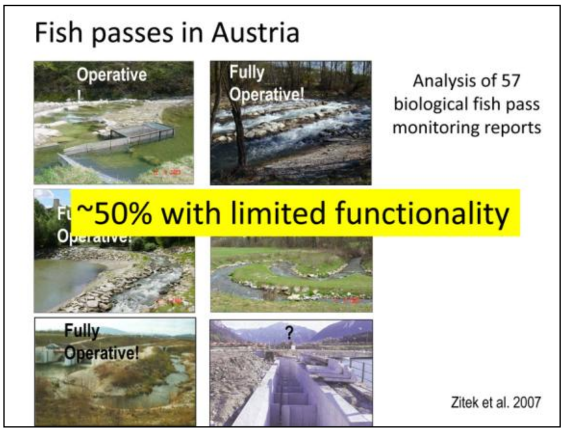
ANALYSIS OF FUNCTIONALITY OF DIFFERENT TYPES OF FISH PASSES

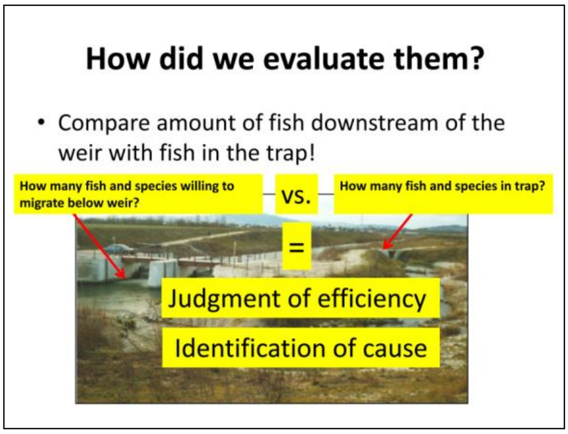
By Dr. Andreas Zitek

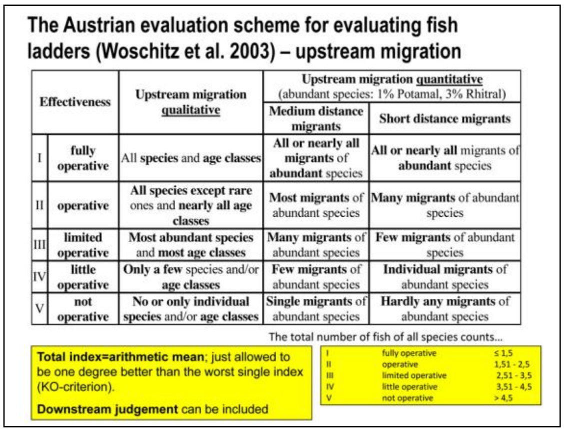












Effectiveness		Upstream migration qualitative	Upstream migration quantitative (abundant species: 1% Potamal, 3% Rhitral)	
			Medium distance migrants	Short distance migrants
I	fully operative	All species and age classes	All or nearly all migrants of abundant species	All or nearly all migrants of abundant species
II	operative	All species except rare ones and nearly all age classes	Most migrants of abundant species	Many migrants of abundant species
III	limited operative	Most abundant species and most age classes	Many migrants of abundant species	Few migrants of abundant species
IV	little operative	Only a few species and/or age classes	Few migrants of abundant species	Individual migrants of abundant species
V	not operative	No or only individual species and/or age classes	Single migrants of abundant species	Hardly any migrants of abundant species

The total number of fish of all species counts...

Total index=arithmetic mean; just allowed to be one degree better than the worst single index (KO-criterion).

Downstream judgement can be included

I	fully operative	≤ 1,5
II	operative	1,51 - 2,5
III	limited operative	2,51 - 3,5
IV	little operative	3,51 - 4,5
V	not operative	> 4,5

Fish pass type and deficits

Type of fish ladder	Efficiency evaluated	Operative		Limited or not operative	
Number (N) / Percentage (%)	**N**	**N**	**%**	**N**	**%**
Nature-like pool and weir pass	10	4	*40*	6	*60*
Nature-like bypass channel	9	6	*67*	3	*33*
Nature-like bypass channel with nature-like pool and weir pass	2	1	*50*	1	*50*
Nature-like bypass channel with technical pool and weir pass	1	0	*0*	1	*100*
Nature-like rock ramp	6	6	*100*	0	*0*
Vertical slot fish pass	2	2	*100*	0	*0*
Vertical slot with nature-like pool and weir pass	1	0	*0*	1	*100*
Vertical slot with natur-like bypass channel	1	1	*100*	0	*0*
Vertical slot fish pass with technical pool and weir pass	1	0	*0*	1	*100*
Technical pool and weir pass	19	8	*42*	11	*58*
Total	**52**	**28**	**54**	**24**	**46**

Known funcionality deficits of fish passes (Zitek et al. 2007)

Entrance situation

Too far from weir or not at migration route (12)
Too little minimum flow below the weir (5)
Entrance sill to high (4)
Missing attraction flow (3)
Disconnected waterjet (1)
High flow velocities and turbulence (1)

Fish pass

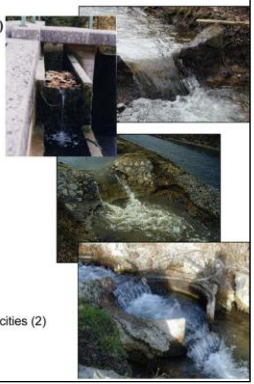
High flow velocities and slope (18)
Pool drops too high (16)
Discharge too low (5)
Water depth too low (5)
Flow velocities too low (3)
Too much water (2)
High turbulence (1)
Gravel sedimentation (1)
Gravel mobilisation (1)
Disconnected waterjet (1)

Exit

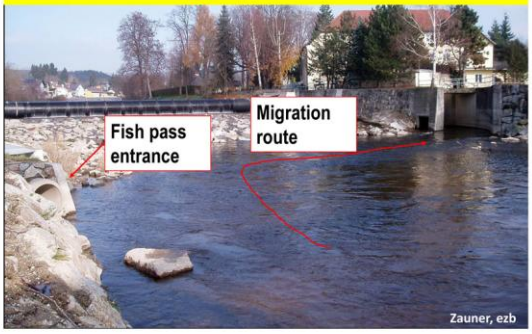
Sills to high, high turbulence and jet-like flow velocities (2)
Situated too neir at weir (1)

Service

Missing service (2)



Entrance too far from weir or not at migration route



Drop heigths to high

Final conclusion: Functionality of a fish pass depends on…

Entrance efficiency

Passage efficiency

+

Consideration of sediment and woody debris transport and extreme events

JÄGER et al. 2009

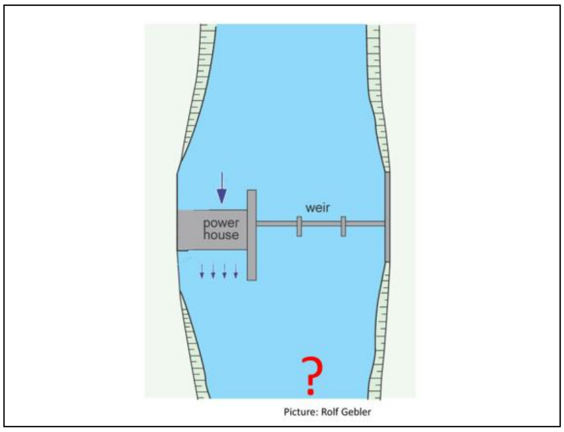
ECOLOGICAL REQUIREMENTS FOR THE CONSTRUCTION OF FISH PASSES

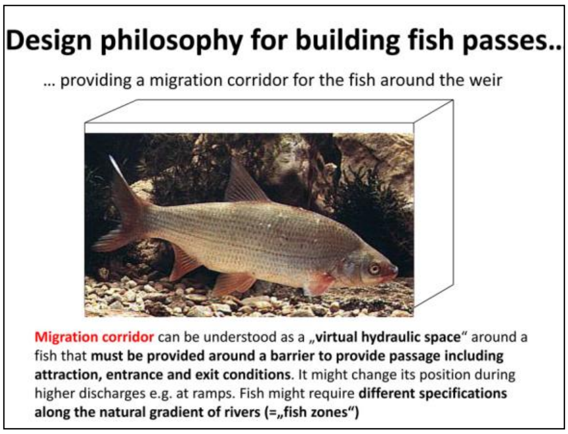
By Dr. Andreas Zitek

Ecological requirements for the construction of fish passes

How to establish/select the main parameters important for passage

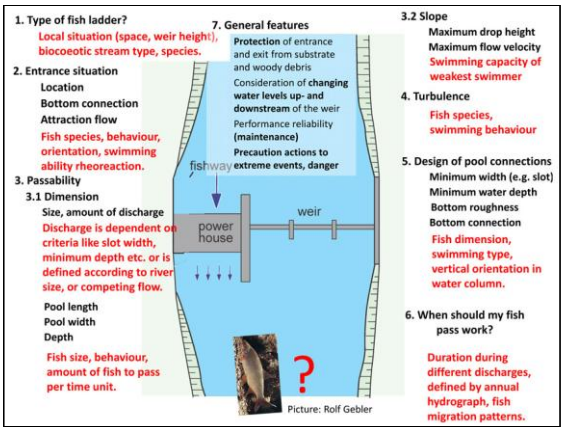
DI Dr. Andreas Zitek, MSc
Austria

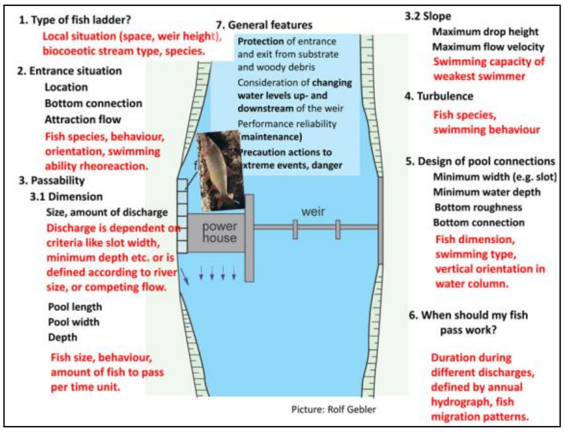




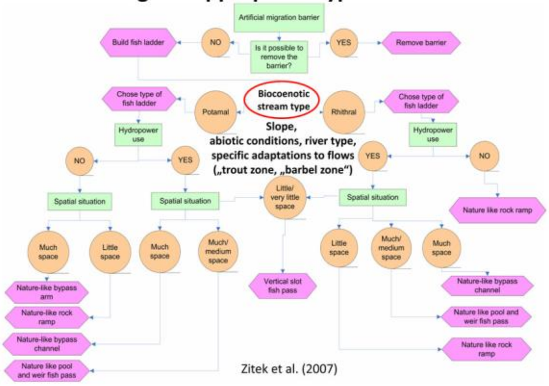
Design philosophy

- The **geometric and hydraulic design values** for the **minimum dimension** the fish passes are determined by the **requirements of the dominant and subdominant species** (**swimming capability, body length, body width and height, behavior like schooling**) of the **river type specific fish communities**.
- But **secondly**, the **overall size of fish pass** and its **attraction flow** is calculated with regard to **river size** and **competing flow**
  - **Usually for Europe the attraction is 1-5% in relation to the competing flow – but I could imagine that this could be significantly higher in large river systems with high diversity and biomasses (5-10 %)**





Selecting the appropriate type of fish ladder



Zitek et al. (2007)

Design considerations - entrance

- **Situation** with regard **to the weir**, the **turbine** and **extreme turbulences** and **flow velocities** and **natural migration routes of fish**
  – Most influencial parameter
- **Attraction flow**
  – Amount of water
  – Flow velocity

1-5 % of river discharge, dynamically maintained over a range of river discharges (up to the turbine capacity of the power plant)

- **Connection to river bottom**

Picture: Paul Jäger

General geometric design criteria – pool dimensions

- **Pool length = 3 x body length of the size-determining fish species**
- **Pool width = 2 x body length of the size-determining fish species**
- **At nature like bypass channels** these dimensions cannot be determined exactly.
- Minimum depth 5 x body height or e.g. at vertical slot pools **minimum pool depth = 60 cm**
  – **According to fish regions increase of depths in pools**
- **For nature-like pool passes minimum depths = 70-120 cm (exception Danube: 170 cm)**
- **Minimum depth at pool connections = 2,5 x body height or minimum 20 cm**
- **Turbulence** is naturally **increasing from down to upstream depending on fish region - 30-50 W/m³ for lowland tropical rivers ?** (33 W/m³ Stuart & Berghuis 2002)

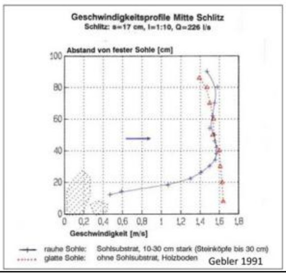
General geometric design criteria – slot width

- **Minimum slot width = 3 x body width**
- **Recommended: minimum slot width = 20 cm** to reduce probability of log jams

Both pictures: A. Lunardon (AG-FAH, 2011)

Bottom roughness

- **Bottom** in fish passes without sediment transport is composed of a **10-20 cm thick layer of sediment with single stones sticking out for e.g. 15 cm in rhithral fish zone („trout zone“) and 20 cm in potamal rivers „barbel zone“.**



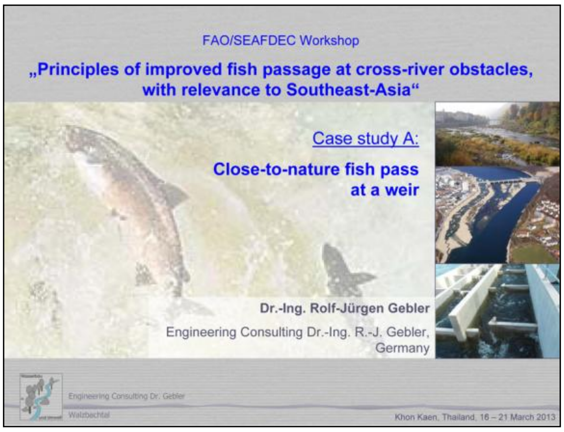
Gebler 1991

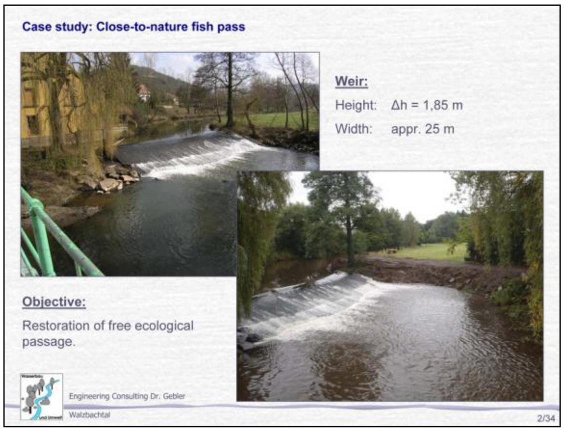
(Foto: Rücker) (Jäger and Zitek 2009)

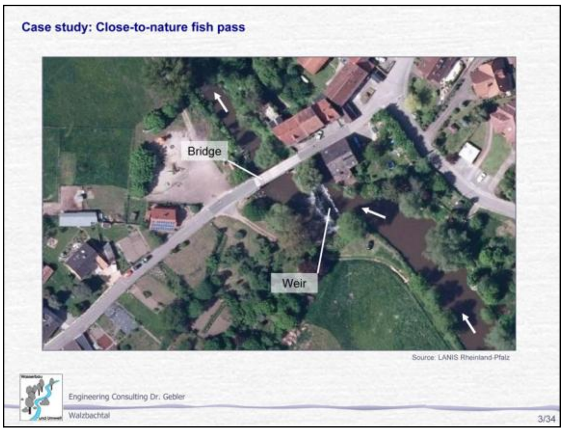
Annex 21

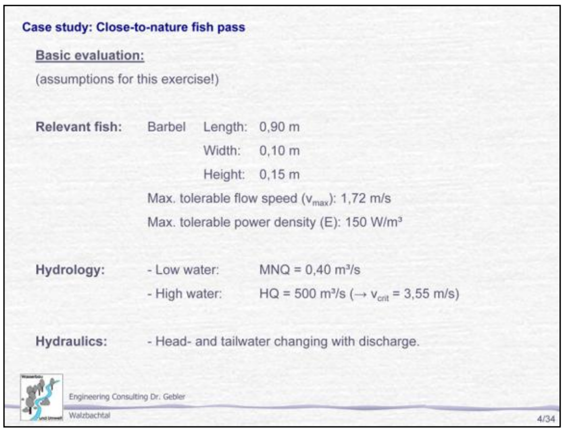
CLOSE-TO-NATURE FISH PASS AT A WEIR

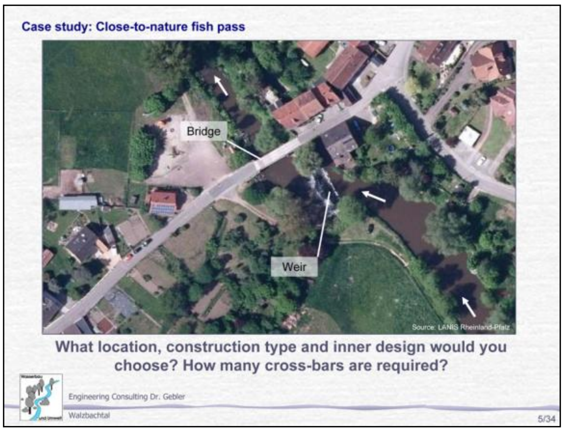
By Dr. -Ing Rolf-Jürgen Gebler

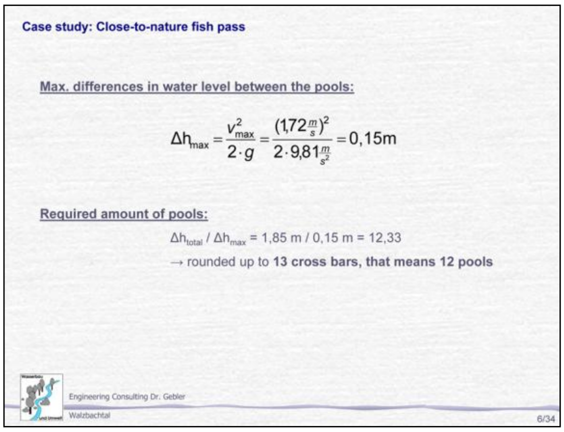


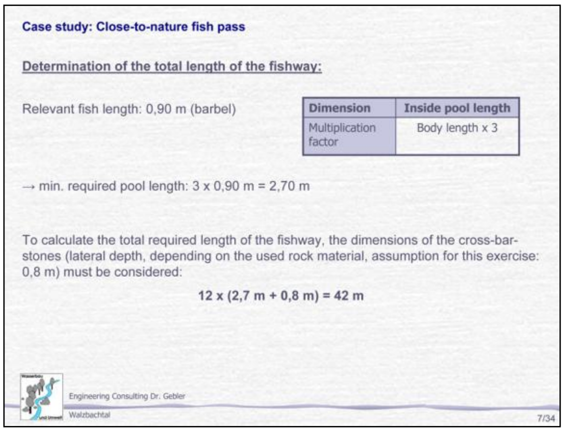


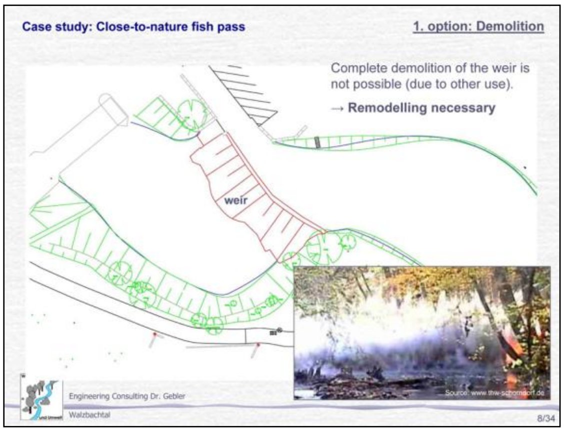


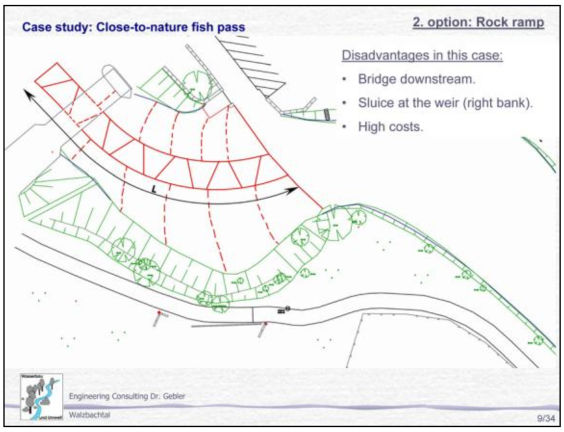


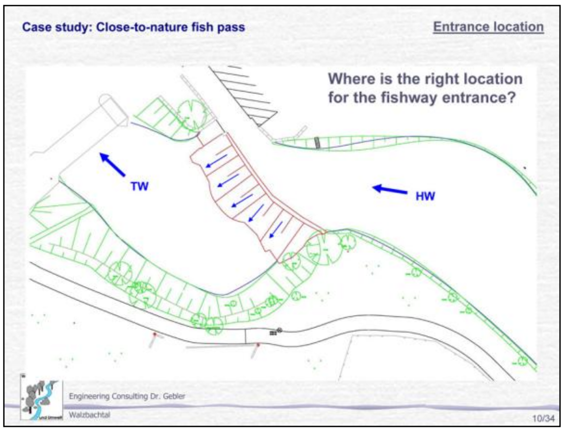


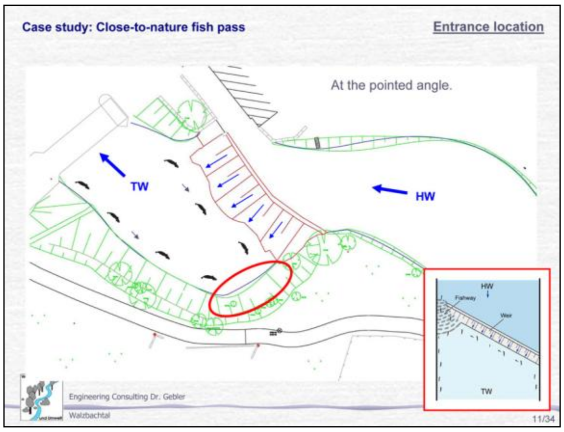


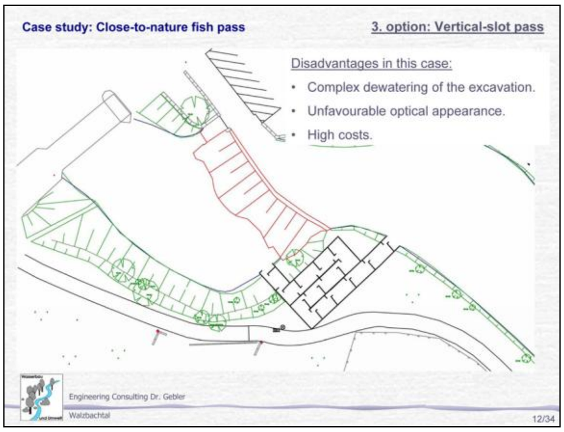

Case study: Close-to-nature fish pass
Determination of the total length of the fishway:
Relevant fish length: 0,90 m (barbel)
Dimension | Inside pool length
Multiplication factor | Body length x 3
→ min. required pool length: 3 x 0,90 m = 2,70 m
To calculate the total required length of the fishway, the dimensions of the cross-bar-stones (lateral depth, depending on the used rock material, assumption for this exercise: 0,8 m) must be considered:
12 x (2,7 m + 0,8 m) = 42 m
Engineering Consulting Dr. Gebler
Walzbachtal
7/34

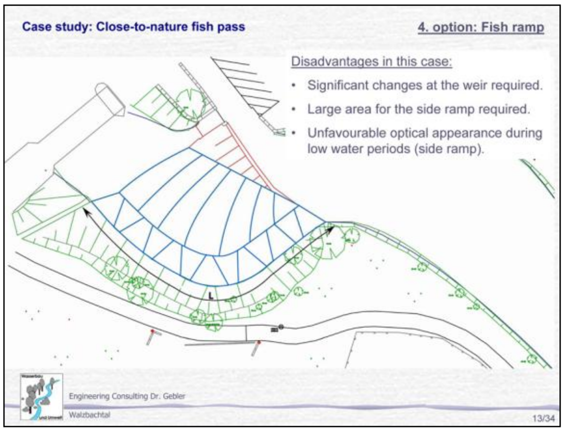

Case study: Close-to-nature fish pass
1. option: Demolition
Complete demolition of the weir is not possible (due to other use).
→ Remodelling necessary
weir
Engineering Consulting Dr. Gebler
Walzbachtal
8/34

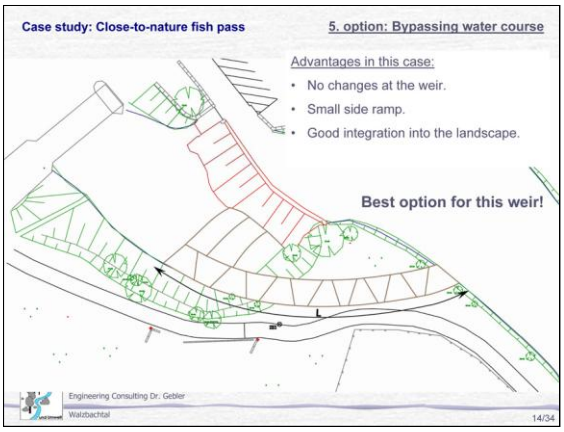

Case study: Close-to-nature fish pass
2. option: Rock ramp
Disadvantages in this case:
• Bridge downstream.
• Sluice at the weir (right bank).
• High costs.
L
Engineering Consulting Dr. Gebler
Walzbachtal
9/34


Case study: Close-to-nature fish pass
Entrance location
Where is the right location for the fishway entrance?
TW
HW
Engineering Consulting Dr. Gebler
Walzbachtal
10/34


Case study: Close-to-nature fish pass
Entrance location
At the pointed angle.
TW
HW
HW
Fishway
Weir
TW
Engineering Consulting Dr. Gebler
Walzbachtal
11/34

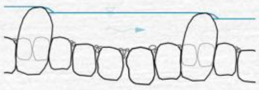

Case study: Close-to-nature fish pass
3. option: Vertical-slot pass
Disadvantages in this case:
• Complex dewatering of the excavation.
• Unfavourable optical appearance.
• High costs.
Engineering Consulting Dr. Gebler
Walzbachtal
12/34


Case study: Close-to-nature fish pass
4. option: Fish ramp
Disadvantages in this case:
• Significant changes at the weir required.
• Large area for the side ramp required.
• Unfavourable optical appearance during low water periods (side ramp).
L
Engineering Consulting Dr. Gebler
Walzbachtal
13/34


Case study: Close-to-nature fish pass
5. option: Bypassing water course
Advantages in this case:
• No changes at the weir.
• Small side ramp.
• Good integration into the landscape.
Best option for this weir!
L
Engineering Consulting Dr. Gebler
Walzbachtal
14/34

Case study: Close-to-nature fish pass

Pool structure (longitudinal section):



In the main points, the design-proceeding for a bottom ramp, fish ramp or rough-channel pool pass is the same (similar pool structure).

Case study: Close-to-nature fish pass

What are the minimal required pool and opening dimensions?

Case study: Close-to-nature fish pass

Determination of the minimal pool and opening dimensions by body dimensions of relevant fish species:

Dimension	Min. inside pool length	Min. inside pool width	Min. pool depth
Multiplication factor	Body length x 3	Body length x 2	Body height x 5

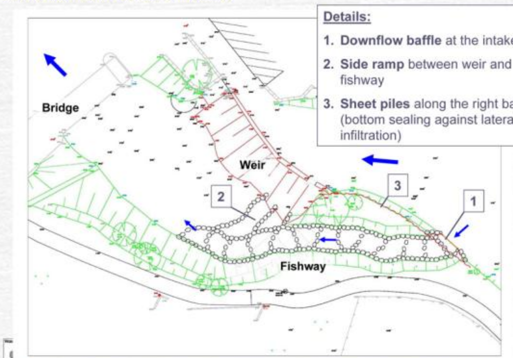
Dimension	Min. opening depth	Min. opening inside width
Multiplication factor	Body height x 2	Body width x 3

Case study: Close-to-nature fish pass

Required pool-dimensions based on largest relevant fish-species (barbel):

Minimal pool-length:	2,70 m	(fish-length x 3 = 0,90 m x 3)
Minimal pool-width:	1,80 m	(fish-length x 2 = 0,90 m x 2)
Minimal pool-depth:	0,75 m	(fish-height x 5 = 0,15 m x 5)
Minimal opening-depth:	0,30 m	(fish-height x 2 = 0,15 m x 2)
	Better choose: 0,60 m!	
Minimal opening-width:	0,30 m	(fish-width x 3 = 0,10 m x 3)

Case study: Close-to-nature fish pass



Details:

1. **Downflow baffle** at the intake
2. **Side ramp** between weir and fishway
3. **Sheet piles** along the right bank (bottom sealing against lateral infiltration)

Case study: Close-to-nature fish pass

Needed discharge to achieve the aspired hydraulic conditions?

and

What is the resulting power density in the pools?

Case study: Close-to-nature fish pass

Required discharge: $Q = v_{max} \cdot A_{total}$ (continuation equation)

With $v = \sqrt{2 \cdot g \cdot \Delta h} = \sqrt{2 \cdot 9{,}81\frac{m}{s^2} \cdot 0{,}15m} = 1{,}72\frac{m}{s}$

And A = opening-depth x opening-height = 0,60 m x 0,30 m = 0,18 m²

$Q_{opening}$ = 1,72 m/s x 0,18 m² = 0,310 m³/s (+ losses through small holes!)

$\boxed{Q_{FP} = \text{appr. } 0{,}40\ m^3/s}$

If possible, choose 2 openings!

(Here not advisable due to MNQ = 0,40 m³/s)

Case study: Close-to-nature fish pass

Proof of low turbulent flow in the pools:

$$E = \frac{\rho \cdot g \cdot \Delta h \cdot Q}{poolvolume}$$

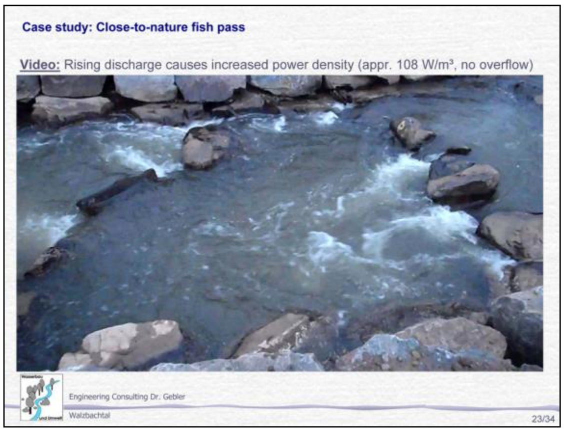
With:

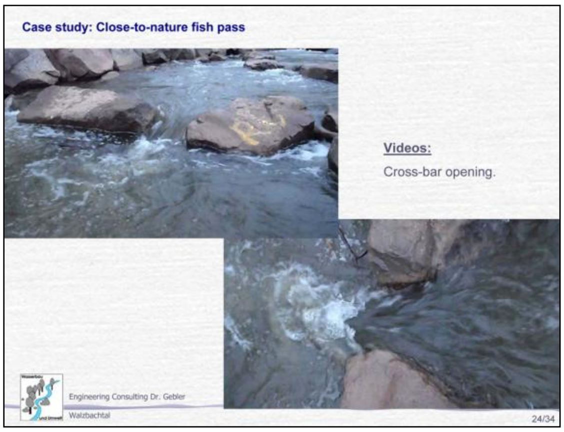
ρ	= density of water	= 1.000 kg/m³
g	= acceleration due to gravity	= 9,81 m/s²
Δh	= water level difference	= 0,15 m
V_{pool}	= pool volume	

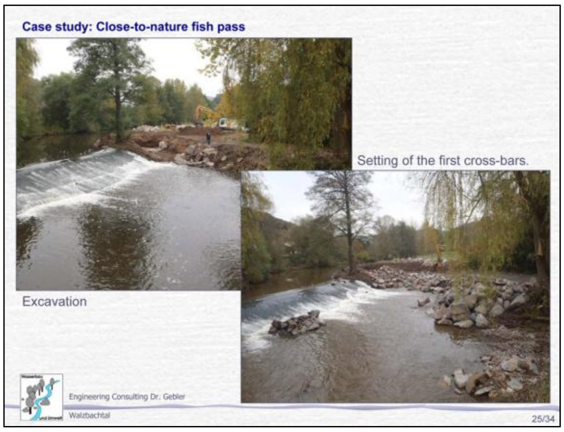
Mean pool depth: 0,75 m
Mean pool width: 3,50 m
Mean pool length: 2,70 m

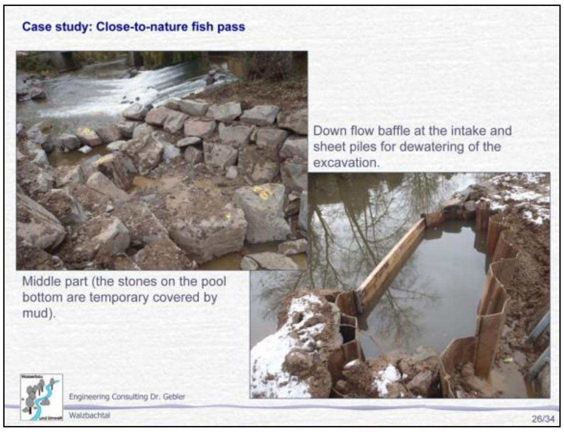
$$V_{pool} = 0{,}75\,m \cdot 3{,}50\,m \cdot 2{,}70\,m = 7{,}09\,m^3$$

$$E = \frac{1000\frac{kg}{m^3} \cdot 9{,}81\frac{m}{s^2} \cdot 0{,}15\ m \cdot 0{,}40\frac{m^3}{s}}{7{,}09\ m^3} = 83\ W/m^3 < 150 W/m^3\ ✓$$


Case study: Close-to-nature fish pass
Video: Rising discharge causes increased power density (appr. 108 W/m³, no overflow)
Engineering Consulting Dr. Gebler
Walzbachtal
23/34


Case study: Close-to-nature fish pass
Videos:
Cross-bar opening.
Engineering Consulting Dr. Gebler
Walzbachtal
24/34


Case study: Close-to-nature fish pass
Setting of the first cross-bars.
Excavation
Engineering Consulting Dr. Gebler
Walzbachtal
25/34


Case study: Close-to-nature fish pass
Down flow baffle at the intake and sheet piles for dewatering of the excavation.
Middle part (the stones on the pool bottom are temporary covered by mud).
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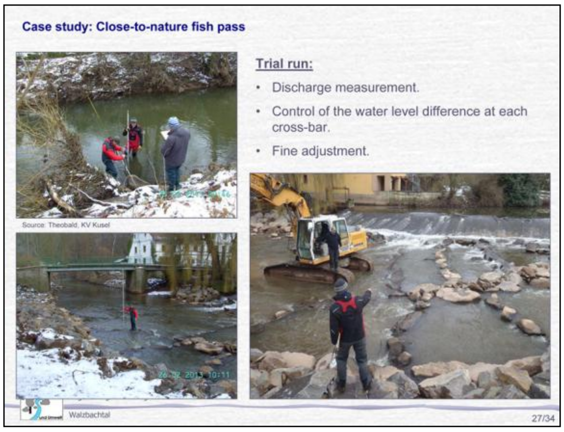
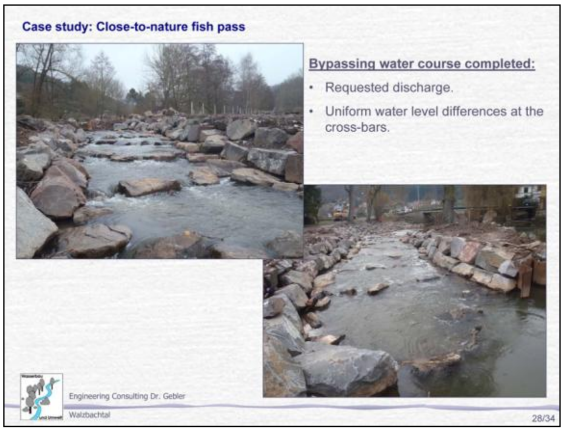

Case study: Close-to-nature fish pass
Trial run:
• Discharge measurement.
• Control of the water level difference at each cross-bar.
• Fine adjustment.
Source: Theobald, KV Kusel
Walzbachtal
27/34


Case study: Close-to-nature fish pass
Bypassing water course completed:
• Requested discharge.
• Uniform water level differences at the cross-bars.
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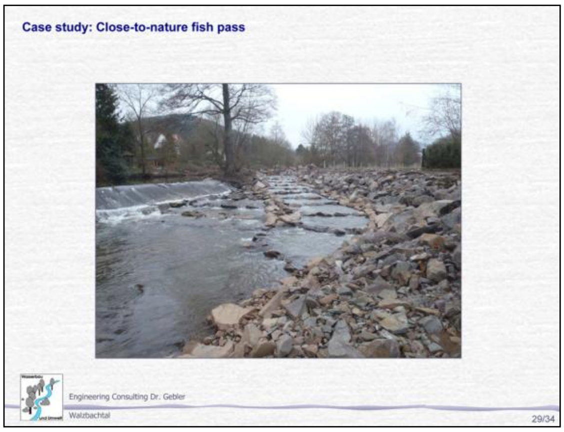
Case study: Close-to-nature fish pass
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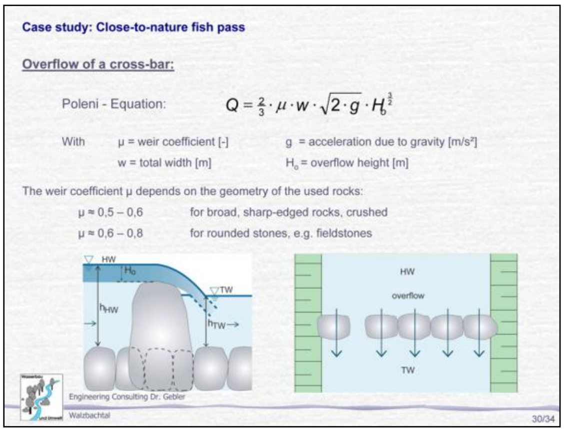
Case study: Close-to-nature fish pass
Overflow of a cross-bar:
Poleni - Equation: $Q = \frac{2}{3} \cdot \mu \cdot w \cdot \sqrt{2 \cdot g} \cdot H_0^{\frac{3}{2}}$
With μ = weir coefficient [-]   g = acceleration due to gravity [m/s²]
w = total width [m] H_0 = overflow height [m]
The weir coefficient μ depends on the geometry of the used rocks:
μ ≈ 0,5 – 0,6   for broad, sharp-edged rocks, crushed
μ ≈ 0,6 – 0,8   for rounded stones, e.g. fieldstones
HW
H_0
TW
h_{HW}
h_{TW}
HW
overflow
TW
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Case study: Close-to-nature fish pass

Example: Influence of cross-bar overflow on the pool current

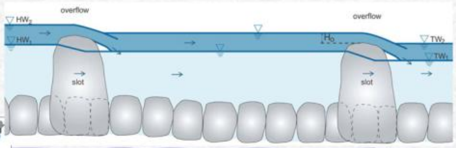
Input: $H_o = 0.15$ m w = 3.5 m μ = 0.6 (sharp edged rocks)

Asked: 1. Additional discharge Q_{over} due to overflow?

2. Resulting power density in the pool?

$$Q_{over} = \frac{2}{3}\cdot\mu\cdot w\cdot\sqrt{2\cdot g}\cdot H_o^{\frac{3}{2}} = \frac{2}{3}\cdot 0.6\cdot 3.5m\cdot\sqrt{2\cdot 9.81\tfrac{m}{s^2}}\cdot(0.15m)^{\frac{3}{2}} = 0.36\,\tfrac{m^3}{s}$$

→ Total discharge: $Q_{total} = Q_{openings} + Q_{over} = 0.40\ m^3/s + 0.36\ m^3/s = 0.76\ m^3/s$



Case study: Close-to-nature fish pass

Resulting power density in the pool:

$$E = \frac{\rho\cdot g\cdot\Delta h\cdot Q}{poolvolume}$$

With:	ρ	= density of water	= 1.000 kg/m³
	g	= acceleration due to gravity	= 9,81 m/s²
	Δh	= water level difference	= 0,15 m
	V_{pool}	= pool volume	

Mean pool depth: 0,75 + 0,15 m = 0,90 m
Mean pool width: 3,50 m
Mean pool length: 2,70 m

$V_{pool} = 0{,}90\,m\cdot 3{,}50\,m\cdot 2{,}70\,m = 8{,}51\,m^3$

Case study: Close-to-nature fish pass

Resulting power density in the pool (H_o = 0,15 m):

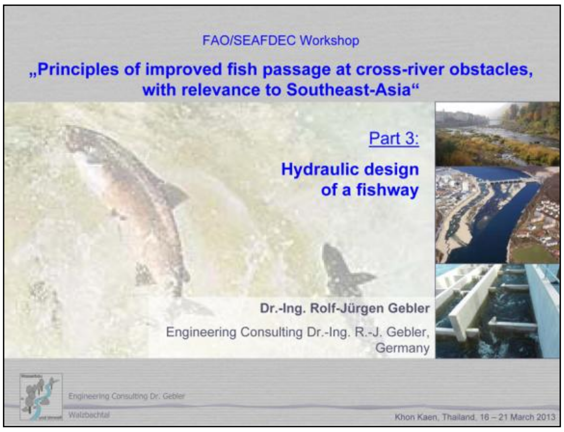
$$E = \frac{1000\tfrac{kg}{m^3}\cdot 9{,}81\tfrac{m}{s^2}\cdot 0{,}15\ m\cdot 0{,}76\tfrac{m^3}{s}}{8{,}51\ m^3} = 131 W/m^3 < 150 W/m^3 \checkmark$$

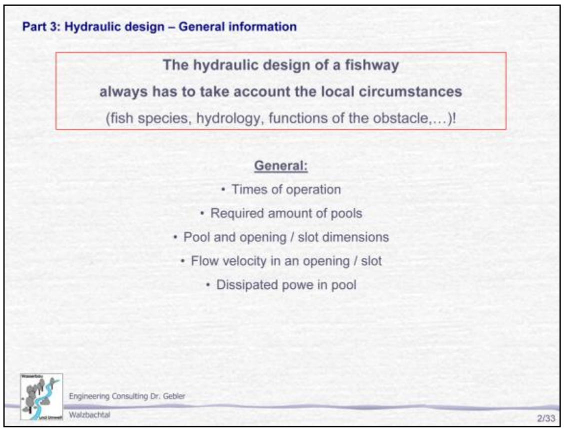
In comparison: H_o = 0,20 m
→ E = 156 W/m³
→ Threshold value exceeded!

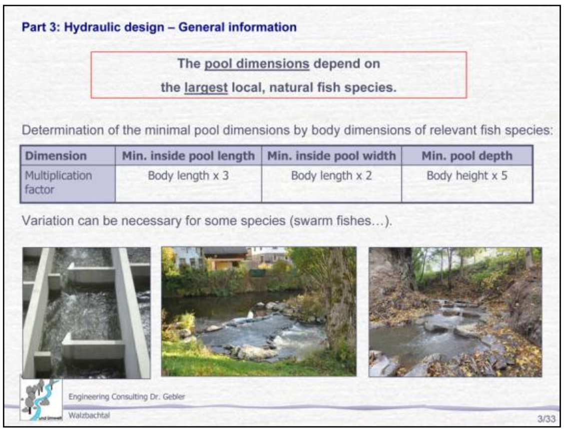
Annex 22

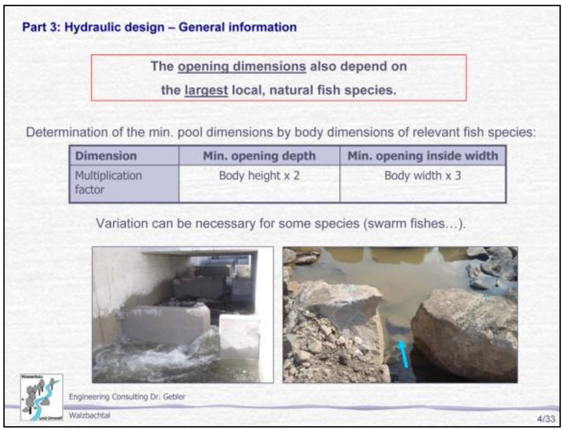
HYDRAULIC DESIGN OF A FISHWAY

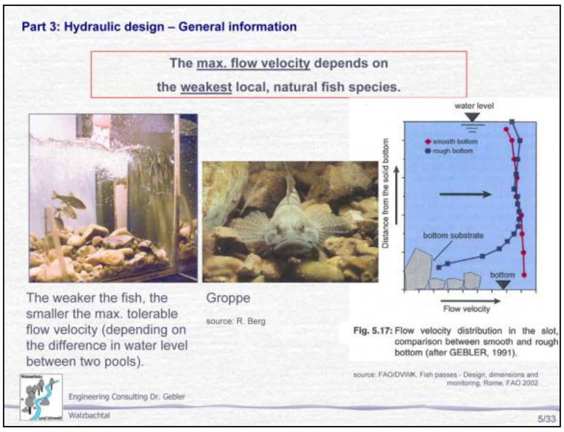
By Dr. -Ing Rolf-Jürgen Gebler

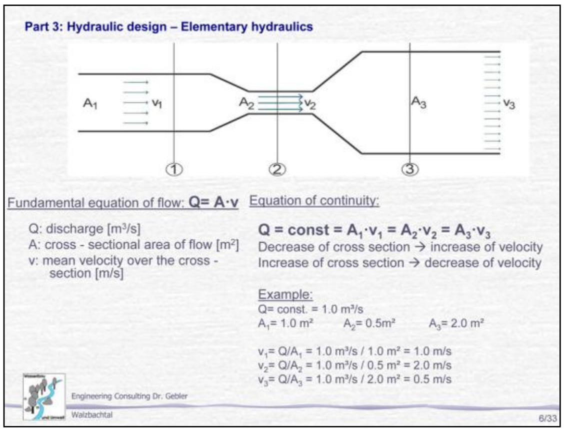


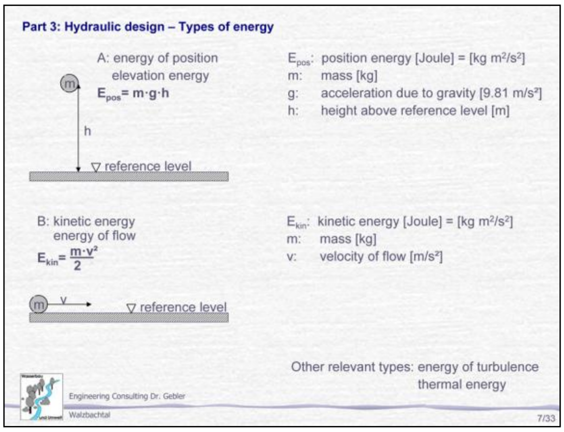











Part 3: Hydraulic design – Types of energy
A: energy of position
elevation energy
$E_{pos} = m \cdot g \cdot h$
m
h
▽ reference level
E_{pos}: position energy [Joule] = [kg m²/s²]
m: mass [kg]
g: acceleration due to gravity [9.81 m/s²]
h: height above reference level [m]
B: kinetic energy
energy of flow
$E_{kin} = \frac{m \cdot v^2}{2}$
E_{kin}: kinetic energy [Joule] = [kg m²/s²]
m: mass [kg]
v: velocity of flow [m/s²]
m
v
▽ reference level
Other relevant types: energy of turbulence
thermal energy
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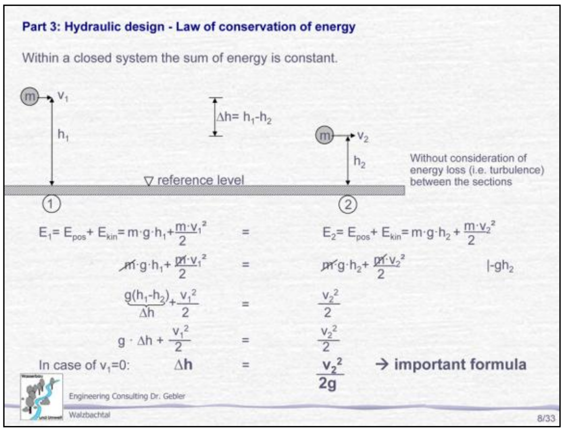
Part 3: Hydraulic design - Law of conservation of energy
Within a closed system the sum of energy is constant.
m
v_1
h_1
$\Delta h = h_1 - h_2$
m
v_2
h_2
Without consideration of energy loss (i.e. turbulence) between the sections
▽ reference level
1
2
$E_1 = E_{pos} + E_{kin} = m \cdot g \cdot h_1 + \frac{m \cdot v_1^2}{2} = E_2 = E_{pos} + E_{kin} = m \cdot g \cdot h_2 + \frac{m \cdot v_2^2}{2}$
$\cancel{m} \cdot g \cdot h_1 + \frac{\cancel{m} \cdot v_1^2}{2} = \cancel{m} \cdot g \cdot h_2 + \frac{\cancel{m} \cdot v_2^2}{2}$ |$-gh_2$
$\underbrace{g(h_1 - h_2)}_{\Delta h} + \frac{v_1^2}{2} = \frac{v_2^2}{2}$
$g \cdot \Delta h + \frac{v_1^2}{2} = \frac{v_2^2}{2}$
In case of $v_1 = 0$: $\Delta h = \frac{v_2^2}{2g}$ → important formula
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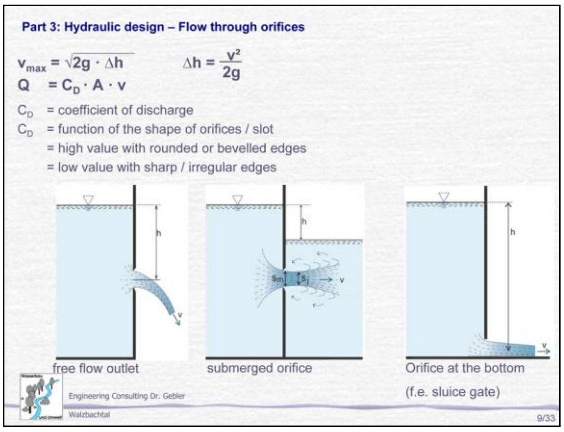
Part 3: Hydraulic design – Flow through orifices
$v_{max} = \sqrt{2g \cdot \Delta h}$ $\Delta h = \frac{v^2}{2g}$
$Q = C_D \cdot A \cdot v$
C_D = coefficient of discharge
C_D = function of the shape of orifices / slot
= high value with rounded or bevelled edges
= low value with sharp / irregular edges
h
v
h
sm
sj
v
h
v
free flow outlet
submerged orifice
Orifice at the bottom
(f.e. sluice gate)
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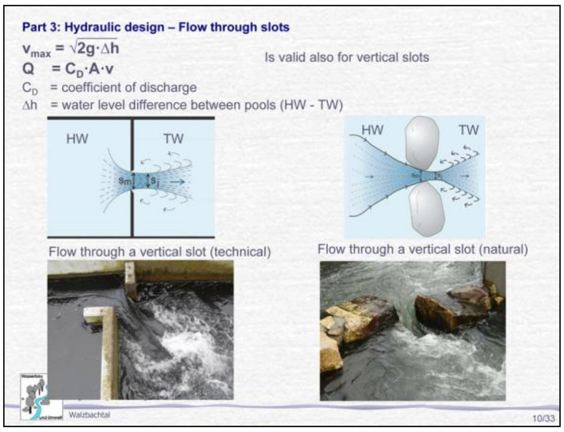
Part 3: Hydraulic design – Flow through slots
$v_{max} = \sqrt{2g \cdot \Delta h}$
$Q = C_D \cdot A \cdot v$
Is valid also for vertical slots
C_D = coefficient of discharge
Δh = water level difference between pools (HW - TW)
HW
TW
HW
TW
Flow through a vertical slot (technical)
Flow through a vertical slot (natural)
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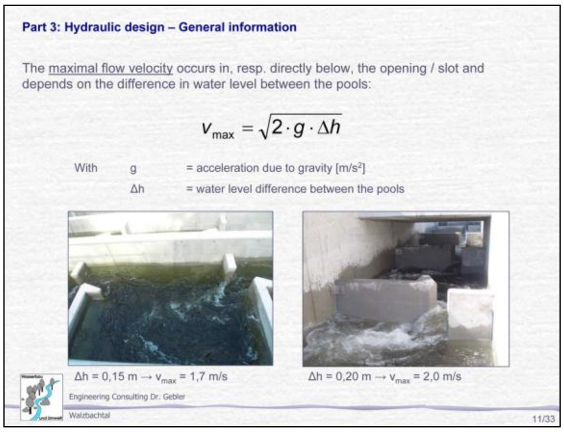
Part 3: Hydraulic design – General information
The maximal flow velocity occurs in, resp. directly below, the opening / slot and depends on the difference in water level between the pools:
$v_{max} = \sqrt{2 \cdot g \cdot \Delta h}$
With g = acceleration due to gravity [m/s²]
Δh = water level difference between the pools
Δh = 0,15 m → v_{max} = 1,7 m/s
Δh = 0,20 m → v_{max} = 2,0 m/s
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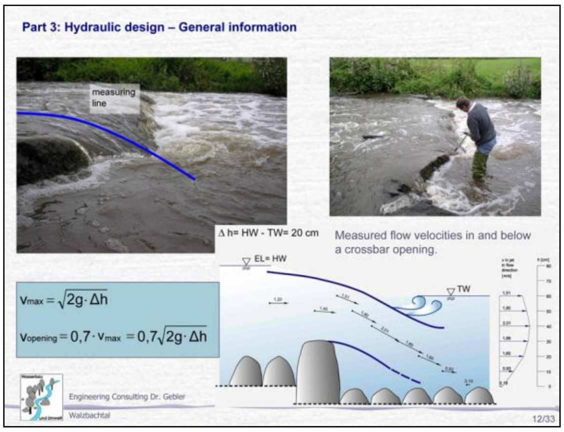
Part 3: Hydraulic design – General information
measuring line
Δ h= HW - TW= 20 cm
Measured flow velocities in and below a crossbar opening.
EL= HW
TW
$V_{max} = \sqrt{2g \cdot \Delta h}$
$V_{opening} = 0{,}7 \cdot V_{max} = 0{,}7\sqrt{2g \cdot \Delta h}$
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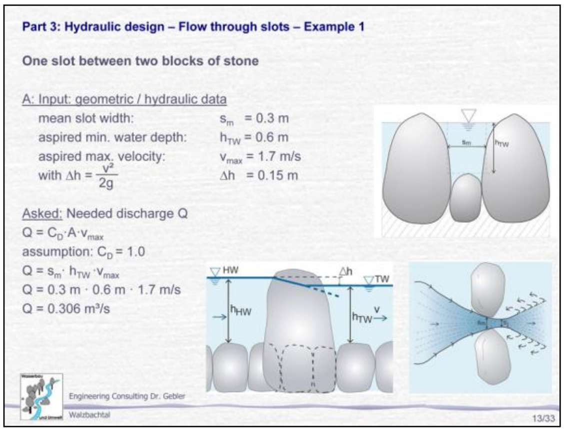
Part 3: Hydraulic design – Flow through slots – Example 1
One slot between two blocks of stone
A: Input: geometric / hydraulic data
mean slot width: s_m = 0.3 m
aspired min. water depth: h_{TW} = 0.6 m
aspired max. velocity: v_{max} = 1.7 m/s
with $\Delta h = \frac{v^2}{2g}$ Δh = 0.15 m
Asked: Needed discharge Q
$Q = C_D \cdot A \cdot v_{max}$
assumption: C_D = 1.0
$Q = s_m \cdot h_{TW} \cdot v_{max}$
Q = 0.3 m · 0.6 m · 1.7 m/s
Q = 0.306 m³/s
sm
hTW
HW
Δh
TW
hHW
hTW
v
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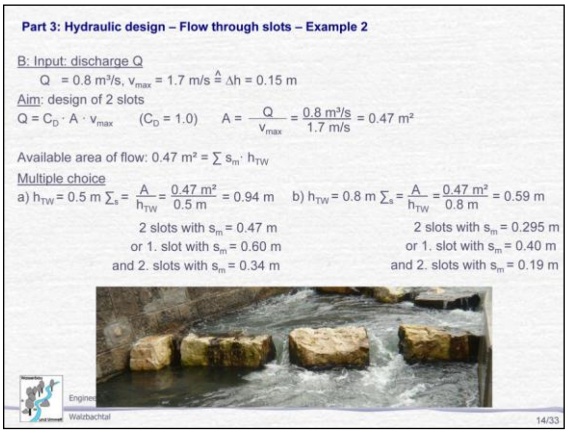
Part 3: Hydraulic design – Flow through slots – Example 2
B: Input: discharge Q
Q = 0.8 m³/s, v_{max} = 1.7 m/s ≙ Δh = 0.15 m
Aim: design of 2 slots
$Q = C_D \cdot A \cdot v_{max}$ (C_D = 1.0) $A = \frac{Q}{v_{max}} = \frac{0.8\ m^3/s}{1.7\ m/s} = 0.47\ m^2$
Available area of flow: 0.47 m² = $\sum s_m \cdot h_{TW}$
Multiple choice
a) h_{TW} = 0.5 m $\sum_s = \frac{A}{h_{TW}} = \frac{0.47\ m^2}{0.5\ m}$ = 0.94 m
b) h_{TW} = 0.8 m $\sum_s = \frac{A}{h_{TW}} = \frac{0.47\ m^2}{0.8\ m}$ = 0.59 m
2 slots with s_m = 0.47 m
or 1. slot with s_m = 0.60 m
and 2. slots with s_m = 0.34 m
2 slots with s_m = 0.295 m
or 1. slot with s_m = 0.40 m
and 2. slots with s_m = 0.19 m
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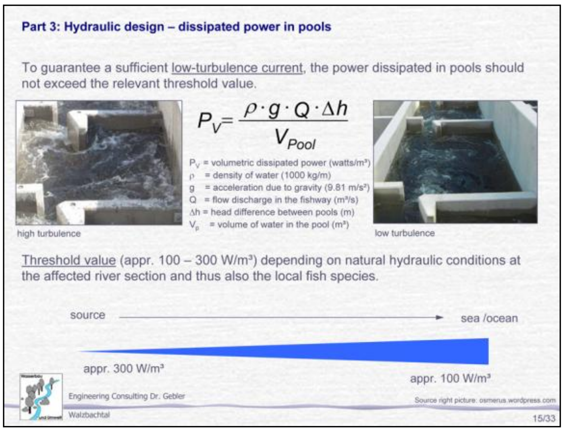
Part 3: Hydraulic design – dissipated power in pools
To guarantee a sufficient low-turbulence current, the power dissipated in pools should not exceed the relevant threshold value.
$P_V = \frac{\rho \cdot g \cdot Q \cdot \Delta h}{V_{Pool}}$
P_V = volumetric dissipated power (watts/m³)
ρ = density of water (1000 kg/m)
g = acceleration due to gravity (9.81 m/s²)
Q = flow discharge in the fishway (m³/s)
Δh = head difference between pools (m)
V_p = volume of water in the pool (m³)
high turbulence
low turbulence
Threshold value (appr. 100 – 300 W/m³) depending on natural hydraulic conditions at the affected river section and thus also the local fish species.
source
sea /ocean
appr. 300 W/m³
appr. 100 W/m³
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Walzbachtal
Source right picture: osmerus.wordpress.com
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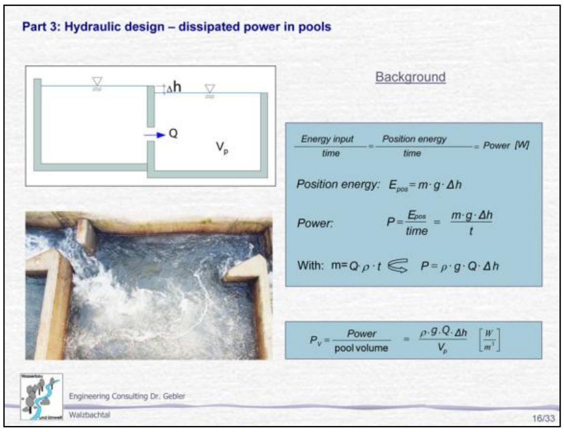
Part 3: Hydraulic design – dissipated power in pools
Δh
Q
V_p
Background
Energy input / time = Position energy / time = Power [W]
Position energy: $E_{pos} = m \cdot g \cdot \Delta h$
Power: $P = \frac{E_{pos}}{time} = \frac{m \cdot g \cdot \Delta h}{t}$
With: $m = Q \cdot \rho \cdot t$ $P = \rho \cdot g \cdot Q \cdot \Delta h$
$P_V = \frac{Power}{pool\ volume} = \frac{\rho \cdot g \cdot Q \cdot \Delta h}{V_p}$ $\left[\frac{W}{m^3}\right]$
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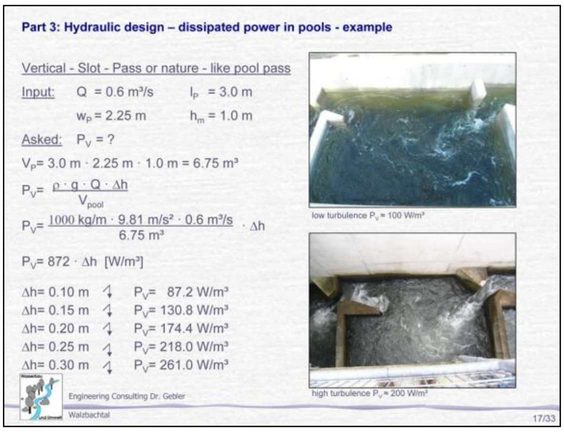
Part 3: Hydraulic design – dissipated power in pools - example
Vertical - Slot - Pass or nature - like pool pass
Input: Q = 0.6 m³/s l_p = 3.0 m
w_P = 2.25 m h_m = 1.0 m
Asked: P_V = ?
V_P = 3.0 m · 2.25 m · 1.0 m = 6.75 m³
$P_V = \frac{\rho \cdot g \cdot Q \cdot \Delta h}{V_{pool}}$
$P_V = \frac{1000\ kg/m \cdot 9.81\ m/s^2 \cdot 0.6\ m^3/s}{6.75\ m^3} \cdot \Delta h$
P_V = 872 · Δh [W/m³]
Δh= 0.10 m P_V= 87.2 W/m³
Δh= 0.15 m P_V= 130.8 W/m³
Δh= 0.20 m P_V= 174.4 W/m³
Δh= 0.25 m P_V= 218.0 W/m³
Δh= 0.30 m P_V= 261.0 W/m³
low turbulence P_V ≈ 100 W/m³
high turbulence P_V ≈ 200 W/m³
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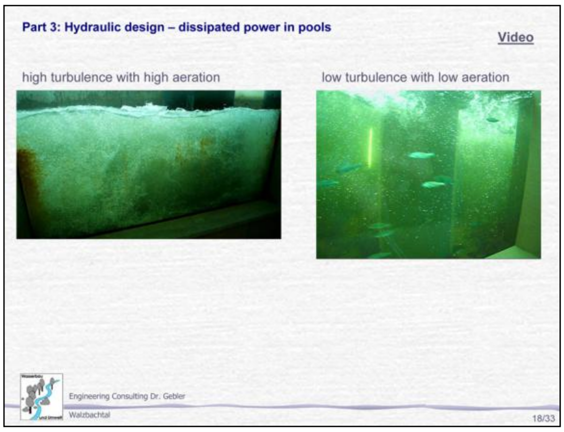
Part 3: Hydraulic design – dissipated power in pools
Video
high turbulence with high aeration
low turbulence with low aeration
Engineering Consulting Dr. Gebler
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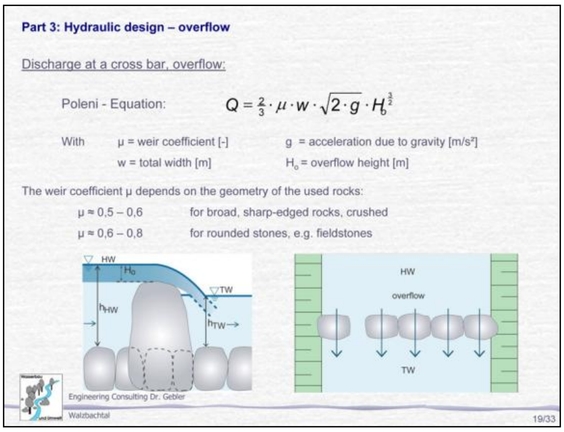
Part 3: Hydraulic design – overflow
Discharge at a cross bar, overflow:
Poleni - Equation: $Q = \frac{2}{3} \cdot \mu \cdot w \cdot \sqrt{2 \cdot g} \cdot H_o^{\frac{3}{2}}$
With μ = weir coefficient [-] g = acceleration due to gravity [m/s²]
w = total width [m] H_o = overflow height [m]
The weir coefficient μ depends on the geometry of the used rocks:
μ ≈ 0,5 – 0,6 for broad, sharp-edged rocks, crushed
μ ≈ 0,6 – 0,8 for rounded stones, e.g. fieldstones
HW
H_o
TW
h_{HW}
h_{TW}
HW
overflow
TW
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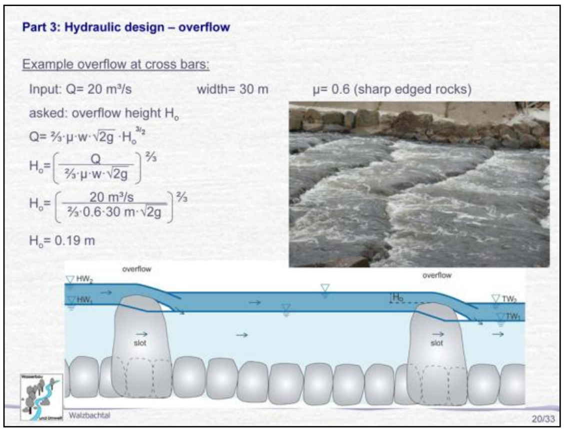
Part 3: Hydraulic design – overflow
Example overflow at cross bars:
Input: Q= 20 m³/s width= 30 m μ= 0.6 (sharp edged rocks)
asked: overflow height H_o
$Q = ⅔ \cdot \mu \cdot w \cdot \sqrt{2g} \cdot H_o^{3/2}$
$H_o = \left(\frac{Q}{⅔ \cdot \mu \cdot w \cdot \sqrt{2g}}\right)^{⅔}$
$H_o = \left(\frac{20\ m^3/s}{⅔ \cdot 0.6 \cdot 30\ m \cdot \sqrt{2g}}\right)^{⅔}$
H_o= 0.19 m
overflow
overflow
HW_2
HW_1
H_o
TW_2
TW_1
slot
slot
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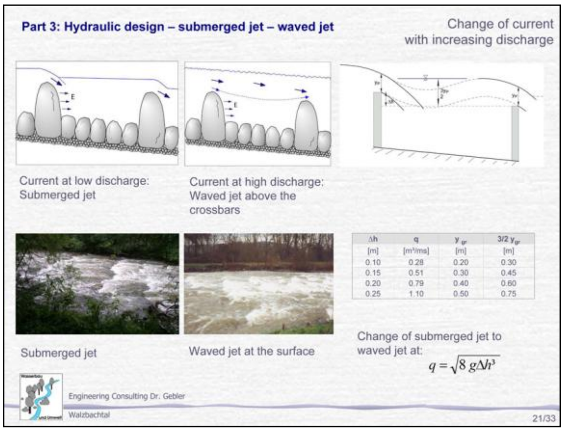
Part 3: Hydraulic design – submerged jet – waved jet
Change of current with increasing discharge
Current at low discharge: Submerged jet
Current at high discharge: Waved jet above the crossbars
Submerged jet
Waved jet at the surface

Δh	q	y_{gr}	3/2 y_{gr}
[m]	[m³/ms]	[m]	[m]
0.10	0.28	0.20	0.30
0.15	0.51	0.30	0.45
0.20	0.79	0.40	0.60
0.25	1.10	0.50	0.75

Change of submerged jet to waved jet at:
$q = \sqrt{8\, g \Delta h^3}$
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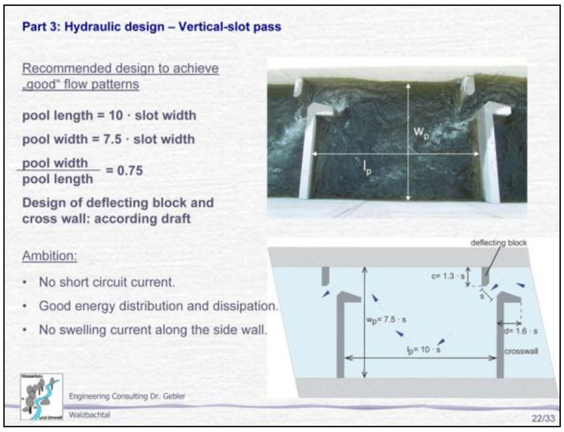
Part 3: Hydraulic design – Vertical-slot pass
Recommended design to achieve „good“ flow patterns
pool length = 10 · slot width
pool width = 7.5 · slot width
pool width / pool length = 0.75
Design of deflecting block and cross wall: according draft
w_p
l_p
Ambition:
• No short circuit current.
• Good energy distribution and dissipation.
• No swelling current along the side wall.
deflecting block
c= 1.3 · s
s
w_p= 7.5 · s
l_p= 10 · s
d= 1.6 · s
crosswall
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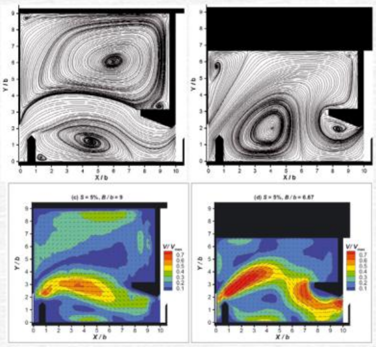
Part 3: Hydraulic design – Vertical-slot pass

The flow patterns in the pool are characterised by the jet and recirculation zones at the sides.

The unsteady flow reacts very sensible to the geometric layout of the pool and the baffle.

It is important to avoid a short-circuit of the jet through the pool.



Source: Wang; David; Larinier (2010)

Part 3: Hydraulic design – Vertical-slot pass

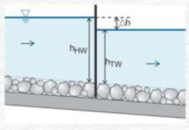
Discharge through a slot:

Equation: $Q = \frac{2}{3} \cdot \mu_r \cdot s \cdot \sqrt{2 \cdot g} \cdot h_{HW}^{3/2}$

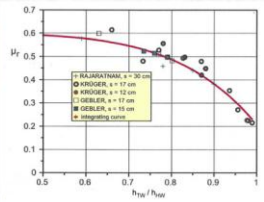
With μ_r = weir coefficient [-]   g = acceleration due to gravity [m/s²]

s = slot width [m] h_{HW} = water depth upstream the cross wall [m]

The weir coefficient μ_r depends on the ratio h_{TW} / h_{HW}:

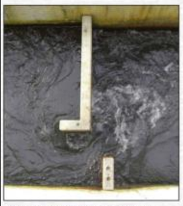


Source: FAO/DVWK, Fish passes - Design, dimensions and monitoring, Rome, FAO 2002



Part 3: Hydraulic design – Vertical-slot pass

Different types of forming the cross wall and the hook are possible



Cross wall with rectangular hook

Cross wall with v-shaped hook and rounded edges

Wooden Cross wall and hook formed by a steel profile

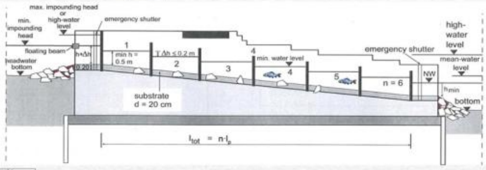
Part 3: Hydraulic design – General information

Determination of the amount of required cross walls and pools:

$n_{\text{cross walls}} = \frac{\Delta H_{total}}{\Delta h_{\text{cross wall}}}$ $n_{Pool} = n_{\text{cross wall}} - 1$

With ΔH_{total} = (max.) headwater – min. tailwater ("worst-case scenario")

$\Delta h_{\text{cross wall}}$ = water level difference between two pools (depending on relevant species)



Part 3: Hydraulic design – General information

Times of operation:

Providing free passage through a fishway all-the-year is very difficult and expensive, due to peaks of low and high water. Thus, the following **limitations in relation to the total discharge** can be accepted:

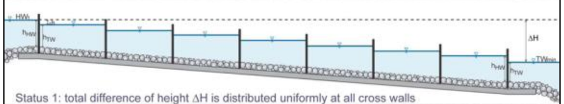
$Q < Q_{30}$ = Discharge, which is deceeded 30 days per year

$Q > Q_{330}$ = Discharge, which is exceeded appr. 35 days per year (deceeded 330 days per year).

During these periods of low and high water, the **migration activity** of most of the species is very low.

Part 3: Hydraulic design – different headwater and tailwater levels

Status 1:
uniform flow



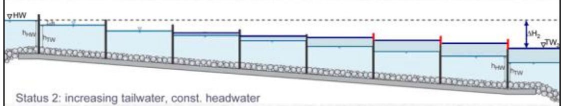
Status 1: total difference of height ΔH is distributed uniformly at all cross walls

ΔH = n ·Δh n= number of cross walls

Δh = difference of water levels in pools

Part 3: Hydraulic design – different headwater and tailwater levels

Status 2:
increasing tailwater and const. headwater



Status 2: increasing tailwater, const. headwater

↳ impounding of the downstream part of fish pass

Δ H decreasing: non uniform (asymptotic) distributed at the cross walls

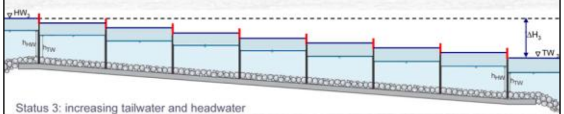
Q remains constant until the impounding arrives at the first cross wall

downstream section: increasing water depth ↳ decreasing velocity and turbulence ↳ no problem

cross walls must be raised

Part 3: Hydraulic design – different headwater and tailwater levels

Status 3:
increasing tailwater and headwater



Status 3: increasing tailwater and headwater

supposed: Δ HW = Δ TW

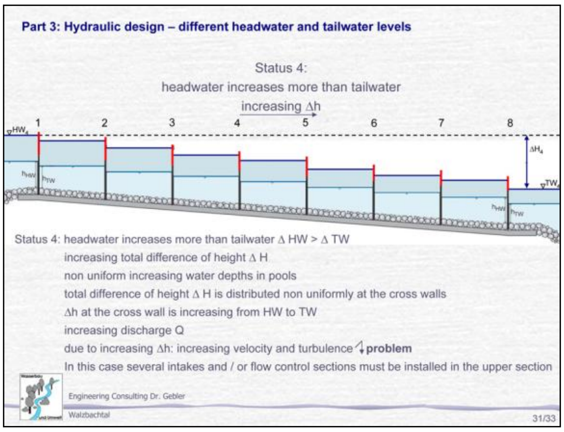
↳ uniform increasing water depths in all pools

total difference of height Δ H remains constant and is distributed uniformly at all cross walls

increasing discharge Q

velocity and flow patterns remain constant ↳ no problem

cross walls must be raised


Part 3: Hydraulic design – different headwater and tailwater levels
Status 4:
headwater increases more than tailwater
increasing Δh
1
2
3
4
5
6
7
8
ΔH4
Status 4: headwater increases more than tailwater Δ HW > Δ TW
increasing total difference of height Δ H
non uniform increasing water depths in pools
total difference of height Δ H is distributed non uniformly at the cross walls
Δh at the cross wall is increasing from HW to TW
increasing discharge Q
due to increasing Δh: increasing velocity and turbulence problem
In this case several intakes and / or flow control sections must be installed in the upper section
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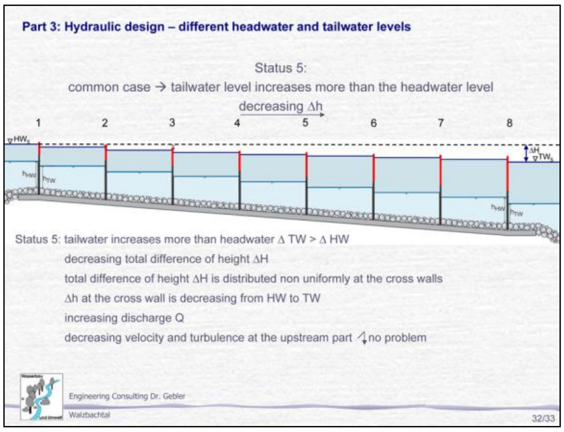
Part 3: Hydraulic design – different headwater and tailwater levels
Status 5:
common case → tailwater level increases more than the headwater level
decreasing Δh
1
2
3
4
5
6
7
8
Status 5: tailwater increases more than headwater Δ TW > Δ HW
decreasing total difference of height ΔH
total difference of height ΔH is distributed non uniformly at the cross walls
Δh at the cross wall is decreasing from HW to TW
increasing discharge Q
decreasing velocity and turbulence at the upstream part no problem
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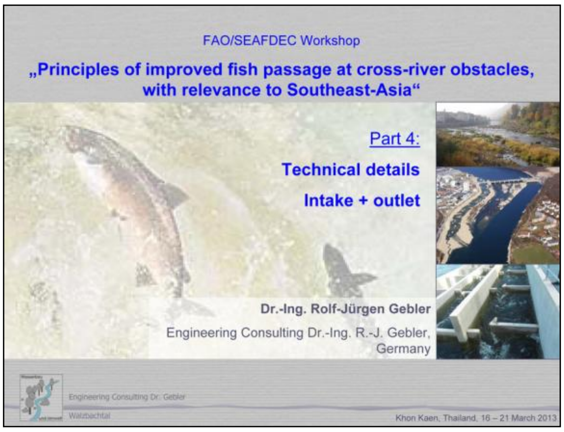
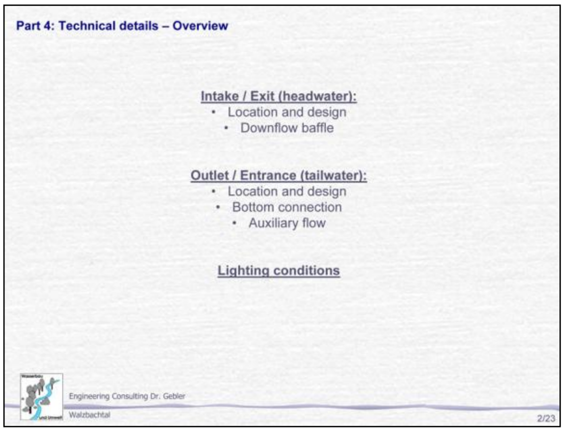
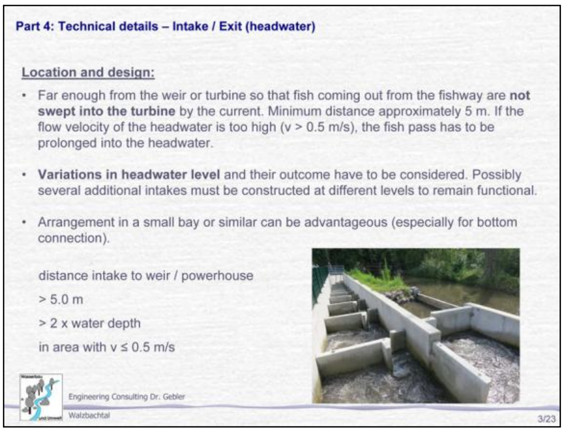
Annex 23

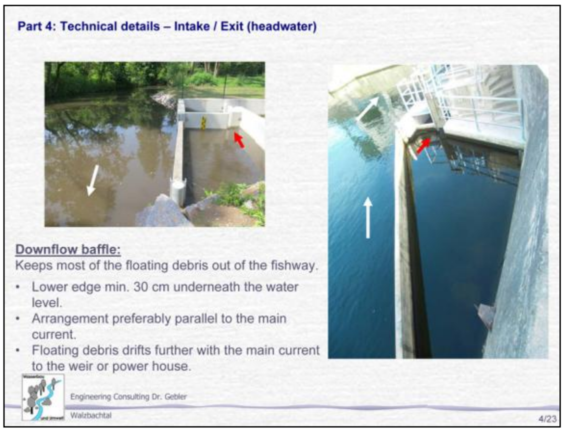
TECHNICAL DETAILS: INTAKE + OUTLET

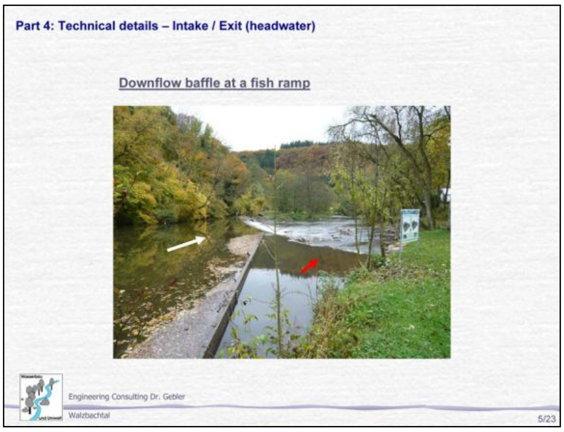
By Dr. -Ing Rolf-Jürgen Gebler

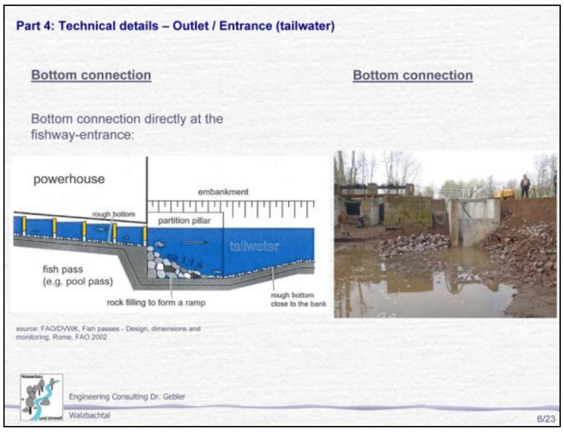


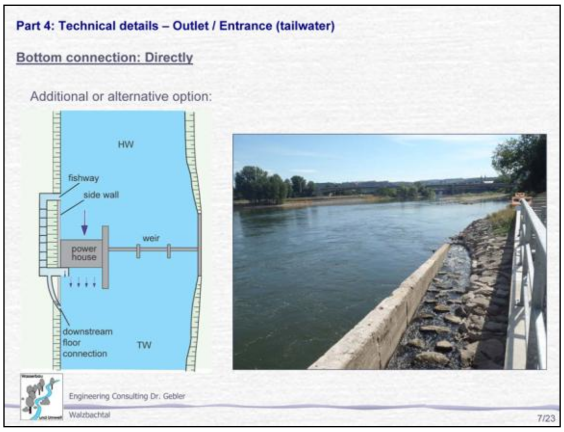











Part 4: Technical details – Outlet / Entrance (tailwater)
Bottom connection: Directly
Additional or alternative option:
HW
fishway
side wall
weir
power house
downstream floor connection
TW
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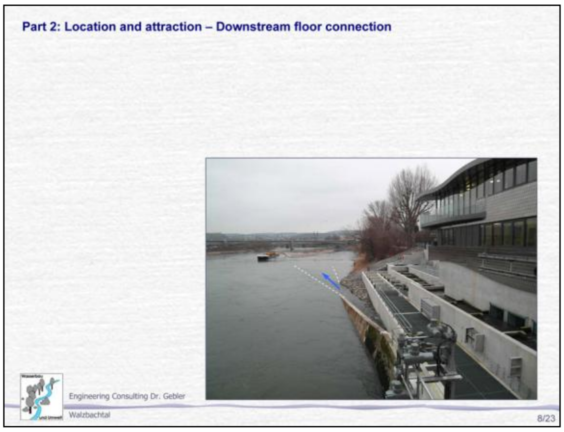
Part 2: Location and attraction – Downstream floor connection
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Part 4: Technical details – Outlet / Entrance (tailwater)
Bottom connection: Artificial bench
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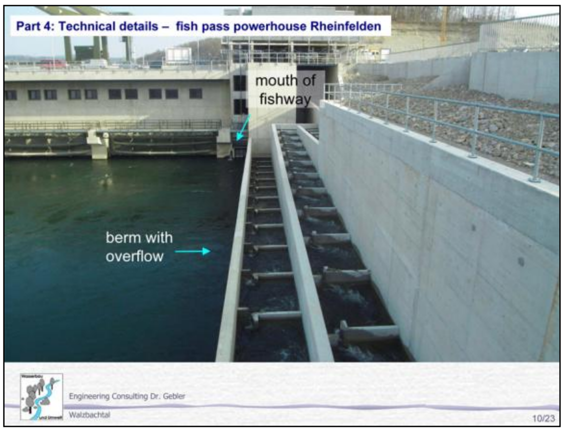
Part 4: Technical details – fish pass powerhouse Rheinfelden
mouth of fishway
berm with overflow
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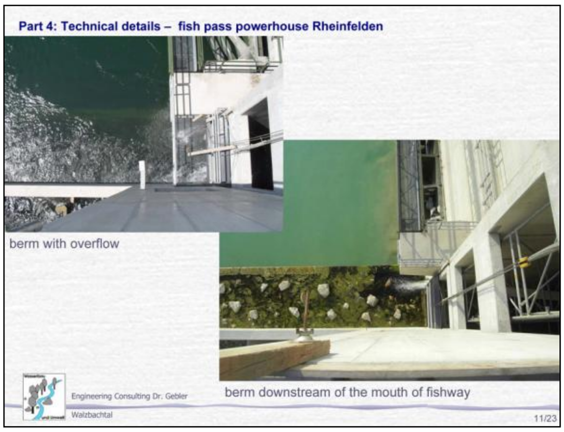
Part 4: Technical details – fish pass powerhouse Rheinfelden
berm with overflow
berm downstream of the mouth of fishway
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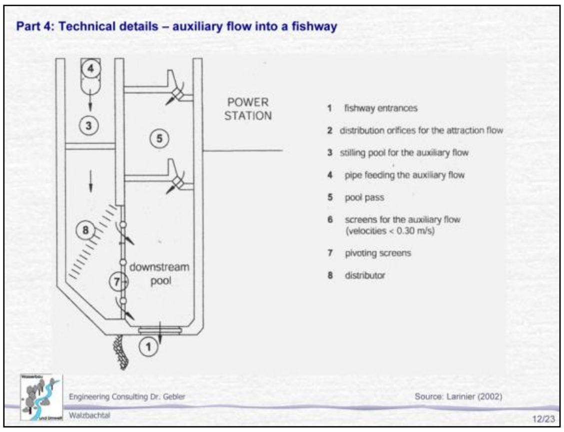
Walzbachtal
11/23


Part 4: Technical details – auxiliary flow into a fishway
POWER STATION
downstream pool
1 fishway entrances
2 distribution orifices for the attraction flow
3 stilling pool for the auxiliary flow
4 pipe feeding the auxiliary flow
5 pool pass
6 screens for the auxiliary flow (velocities < 0.30 m/s)
7 pivoting screens
8 distributor
Source: Larinier (2002)
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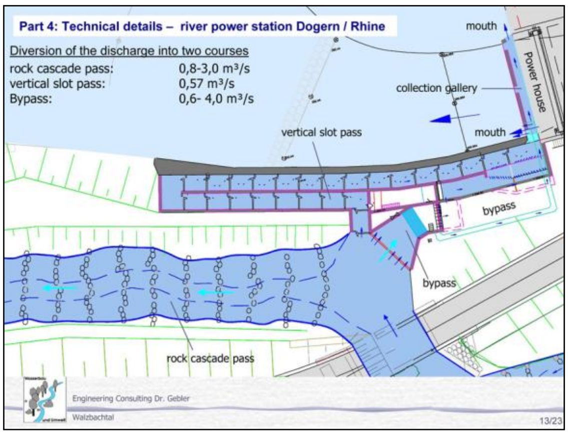
Part 4: Technical details – river power station Dogern / Rhine
Diversion of the discharge into two courses
rock cascade pass: 0,8-3,0 m³/s
vertical slot pass: 0,57 m³/s
Bypass: 0,6- 4,0 m³/s
mouth
Power house
collection gallery
vertical slot pass
mouth
bypass
bypass
rock cascade pass
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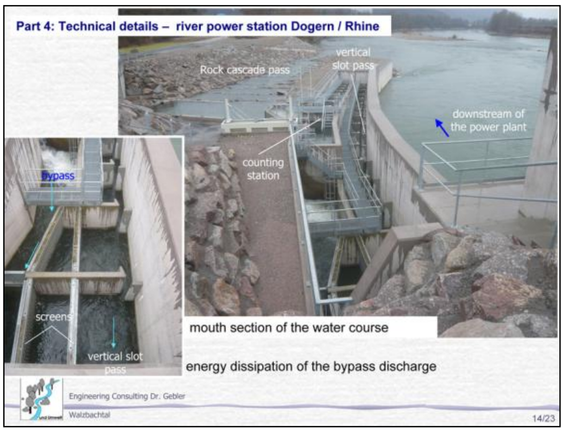
Part 4: Technical details – river power station Dogern / Rhine
Rock cascade pass
vertical slot pass
downstream of the power plant
Bypass
counting station
screens
vertical slot pass
mouth section of the water course
energy dissipation of the bypass discharge
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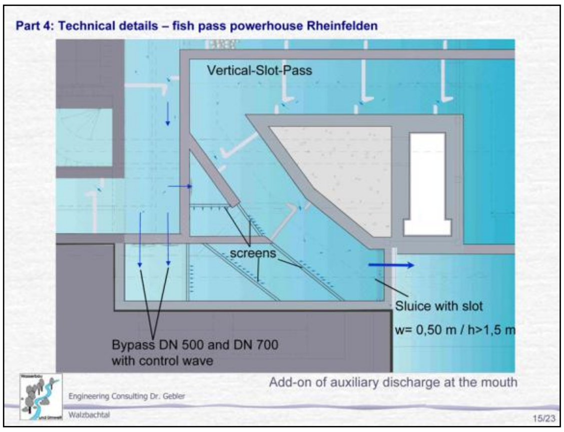
Part 4: Technical details – fish pass powerhouse Rheinfelden
Vertical-Slot-Pass
screens
Sluice with slot
w= 0,50 m / h>1,5 m
Bypass DN 500 and DN 700
with control wave
Add-on of auxiliary discharge at the mouth
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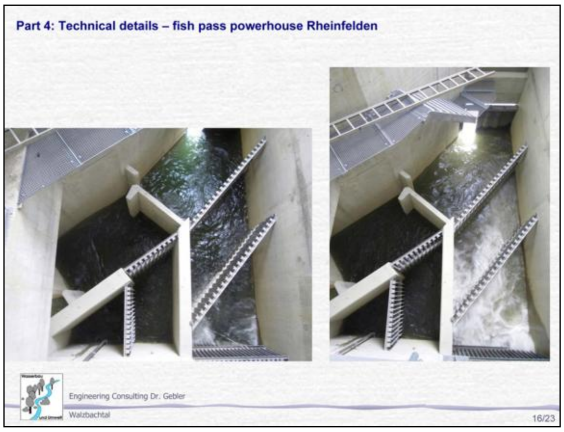
Part 4: Technical details – fish pass powerhouse Rheinfelden
Engineering Consulting Dr. Gebler
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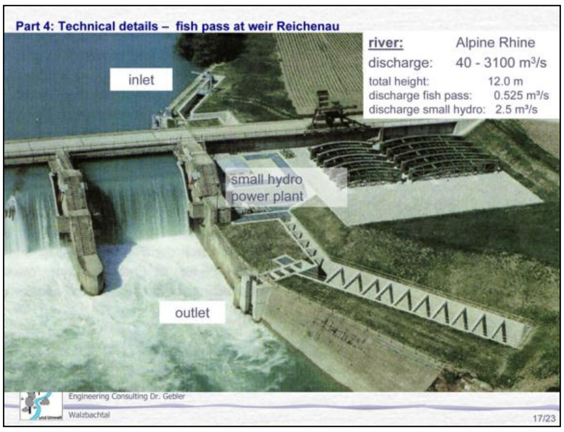
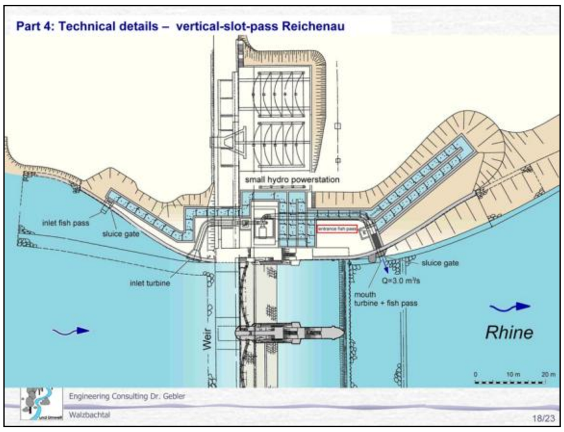
16/23


Part 4: Technical details – fish pass at weir Reichenau
inlet
river: Alpine Rhine
discharge: 40 - 3100 m³/s
total height: 12.0 m
discharge fish pass: 0.525 m³/s
discharge small hydro: 2.5 m³/s
small hydro power plant
outlet
Engineering Consulting Dr. Gebler
Walzbachtal
17/23


Part 4: Technical details – vertical-slot-pass Reichenau
small hydro powerstation
inlet fish pass
sluice gate
inlet turbine
sluice gate
Q=3.0 m³/s
mouth turbine + fish pass
Weir
Rhine
Engineering Consulting Dr. Gebler
Walzbachtal
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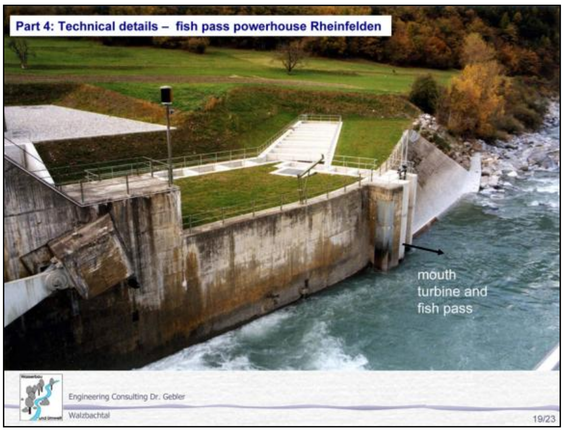
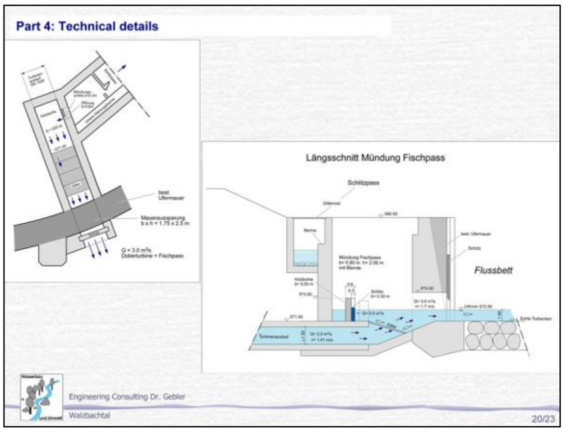
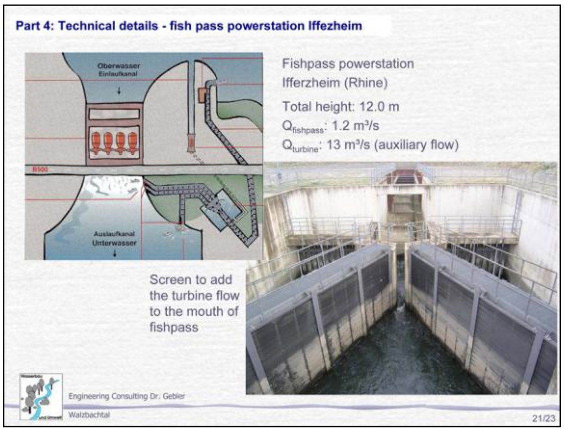

Part 4: Technical details – fish pass powerhouse Rheinfelden
mouth
turbine and
fish pass
Engineering Consulting Dr. Gebler
Walzbachtal
19/23


Part 4: Technical details
Längsschnitt Mündung Fischpass
Schlitzpass
Flussbett
Engineering Consulting Dr. Gebler
Walzbachtal
20/23


Part 4: Technical details - fish pass powerstation Iffezheim
Oberwasser
Einlaufkanal
Auslaufkanal
Unterwasser
Fishpass powerstation
Ifferzheim (Rhine)
Total height: 12.0 m
Q fishpass: 1.2 m³/s
Q turbine: 13 m³/s (auxiliary flow)
Screen to add
the turbine flow
to the mouth of
fishpass
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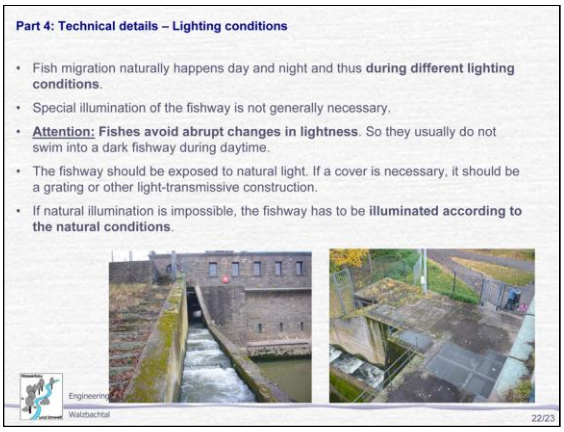
Walzbachtal
21/23


Part 4: Technical details – Lighting conditions
Fish migration naturally happens day and night and thus during different lighting conditions.
Special illumination of the fishway is not generally necessary.
Attention: Fishes avoid abrupt changes in lightness. So they usually do not swim into a dark fishway during daytime.
The fishway should be exposed to natural light. If a cover is necessary, it should be a grating or other light-transmissive construction.
If natural illumination is impossible, the fishway has to be illuminated according to the natural conditions.
Walzbachtal
22/23

Annex 24

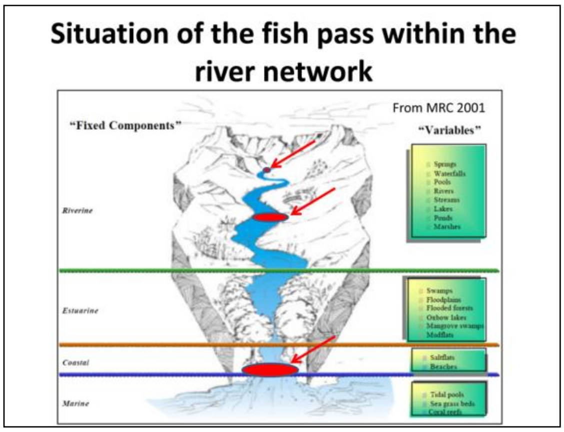
CLASSIFICATION SYSTEM FOR RIVER TYPES AND TYPICAL FISH FAUNA

By Dr. Andreas Zitek

Classification system for river types and typical fish fauna

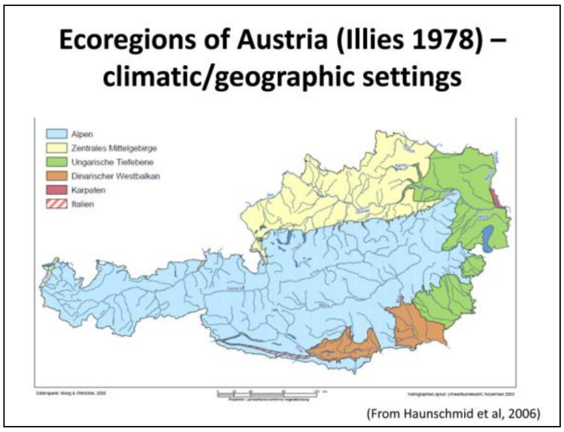
DI Dr. Andreas Zitek, MSc

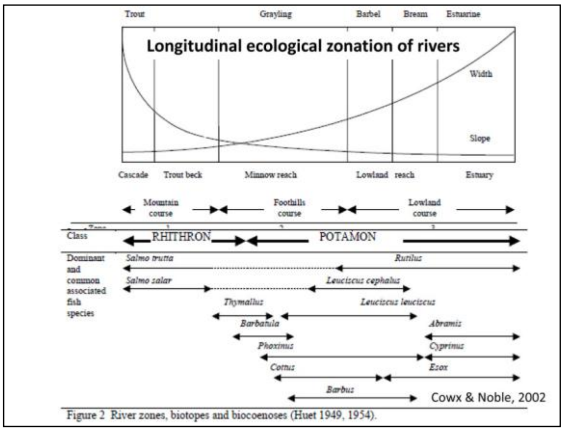
Austria

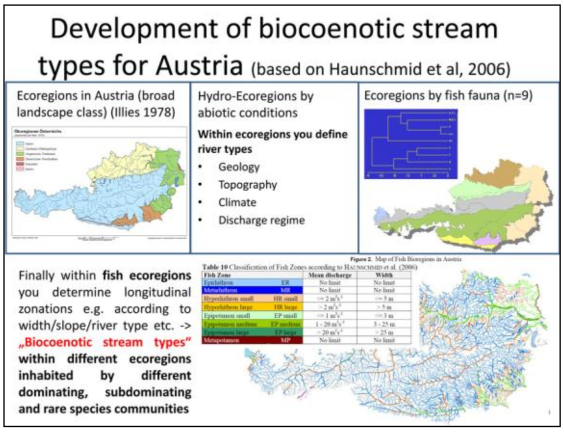


Target

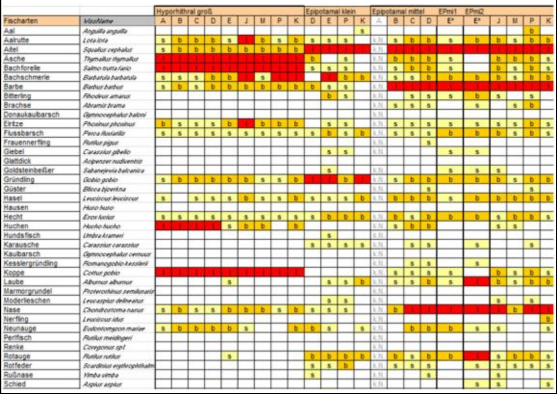
- **Simplifying** the decision of fish pass construction **by**
  - **defining biocoenotic stream types combining**
    - **ecoregions,**
    - **abiotic settings,**
    - and the **typical longitudinal ecological zonations of rivers (in Europe** based on **Huet, „trout", „grayling", „barbel", „bream", „flounder" zone)**
- **„Biocoentoic stream types"** within different ecoregions are inhabited **by different dominating, subdominating and rare species communities.**
- **You can the define individual species or species groups relevant for the planning of hydraulic and geometric dimensions of the fish pass for regions with similar conditions!**
- **These biocoenotic stream types might exist with low and high discharge.**



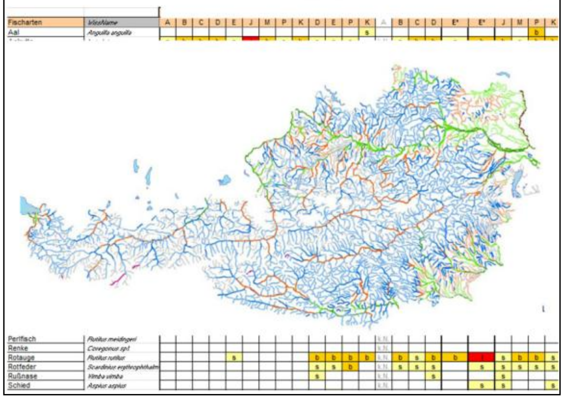




Biocoenotic stream types (based on Haunschmid et al, 2006)



Biocoenotic stream types (based on Haunschmid et al, 2006)



Ecoregion

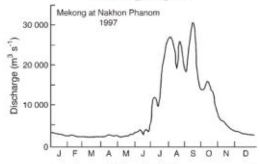
- **Ecoregions** cover relatively **large areas of land or water**, and **contain characteristic, geographically distinct assemblages of natural communities and species**.
- In theory, biodiversity or conservation ecoregions are relatively large areas of land or water where the probability **of encounter of different species and communities at any given point remain relatively constant**, within an acceptable range of variation (largely undefined at this point).

Freshwater Ecoregions of the World: A New Map of Biogeographic Units for Freshwater Biodiversity Conservation

(Abell et al. 2008)

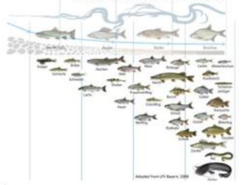
Combine the ecoregions with hydrograph, river morphology and/or position in river network

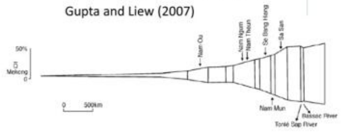
Discharge regime



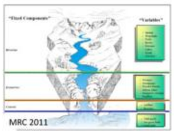
Gupta and Liew (2007)

Natural zonation of rivers



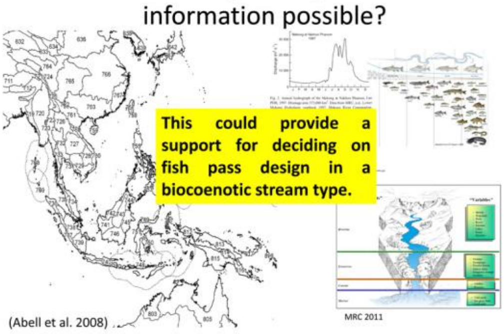


Downstream cumulative annual mean flow of the Mekong



MRC 2011

Definition of „biocoenotic stream types" based on existing ecoregions and other information possible?



This could provide a support for deciding on fish pass design in a biocoenotic stream type.

(Abell et al. 2008)

MRC 2011

Considerations on fish pass design related to the position in the river network

River

Freshwater ecoregion

- River type
- Hydrology
- Morphology

Copyright: A. Zitek

- Species composition
- Fish abundance
- Migratory guilds
- Swimming types
- Swimming capacities

Biocoenotic stream regions

Species relevant for design criteria

Fish pass

Copyright: A. Zitek

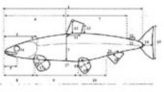
- Fish pass type
- Slope
- Flow velocities
- Width, depth, turbulence
- Attraction flow
- Size in relation to river

Copyright: A. Zitek

- Discharge needed
- Length of construction

Biocoenotic stream type	Relevant fish species and size
Epirhithral < 2 m³/s MQ	30 cm Bachforelle
Epirhithral > 2 m³/s MQ	40 cm Bachforelle
Metarhithral	
Metarhithral, < 2 m³/s MQ	40 cm Bachforelle
Metarhithral, > 2 m³/s MQ	50 cm Bachforelle, Äsche
Hyporhithral	
Hyporhithral, klein (< 2 m³/s MQ)	50 cm Bachforelle, Aitel, Äsche, 60 cm Aalrutte
Hyporhithral, mittel (> 2 m³/s MQ)	60 cm Aalrutte, Barbe
Hyporhithral, mittel (> 2 m³/s und < 20 m³/s MQ) mit Huchen	80 cm Huchen
Hyporhithral, groß (> 20 m³/s MQ), mit Huchen	100 cm Huchen
Epipotamal	
Epipotamal, klein (< 1 m³/s MQ)	60 cm Barbe, 50 cm Aitel, 50 cm Äsche
Epipotamal, mittel ohne Hecht ohne Huchen	60 cm Barbe
Epipotamal, mittel mit Hecht ohne Huchen	90 cm Hecht, 50 cm Brachse
Epipotamal, mittel mit Huchen	90 cm Huchen, 50 cm Brachse
Epipotamal, groß mit Huchen	100 cm Huchen
Epipotamal, groß ohne Huchen mit Wels	120 cm Wels
Epipotamal, groß ohne Huchen ohne Wels	90 cm Hecht, 50 cm Brachse
Schmerlen- und Gründlingsbach	
Schmerlenbach (östl. Flach- und Hügelländer)	40 cm Aitel
Grosse Flüsse	
Donau	150 cm Wels
Alpenrhein	90 cm Seeforelle, Hecht
Drau	100 cm Huchen, 120 cm Wels
Inn	100 cm Huchen, 120 cm Wels (unterer Inn, Oberösterreich)
Salzach	100 cm Huchen (flussab Salzburg, Oberösterreich), 120 cm Wels (Oberösterreich)
Mur	100 cm Huchen, 120 cm Wels (untere Mur)
Enns	100 cm Huchen
Seezubringer und Seeausrinne	
Seezubringer und Seeausrinne	90 cm Seeforelle, 90 cm Hecht, 70 cm Perlfisch, 60 cm Barbe, 50 cm Brachse

Relevant fish species and **size** were determined for each biocoenotic stream region according to **river size** (smaller rivers might host smaller individuals of the same species); **body heigth and width** were also estimated for these species and sizes.



(Jäger et al. 2010)

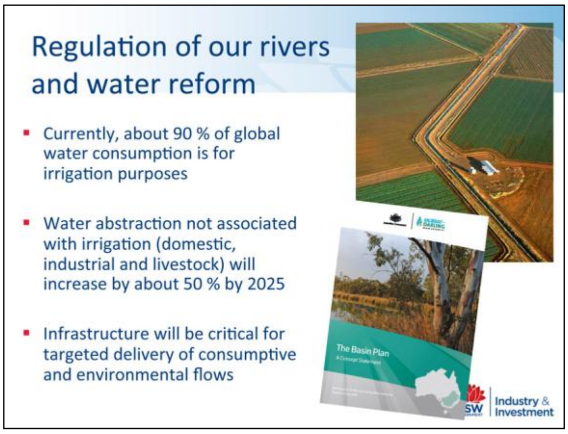
Important

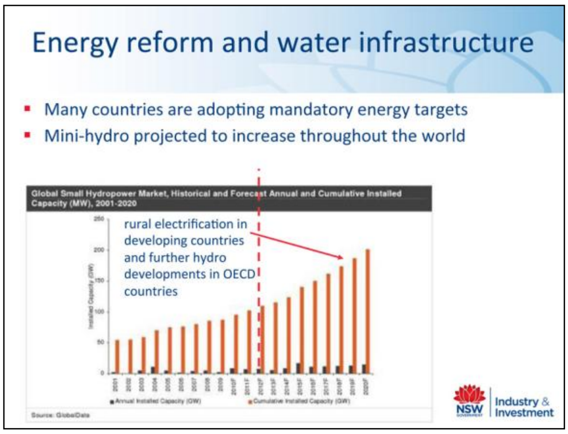
- You might define **special unique biocoenotic stream types** – e.g. the main channel of the Mekong up to a certain point (*in Austria: Danube*) – with the *Giant catfish* or the pure amount of migrating fish is relevant for planning
- However, **you might be able to define longer river areas or group zones in tributaries**, which simplifies your life on decision making with regard to fish pass design.

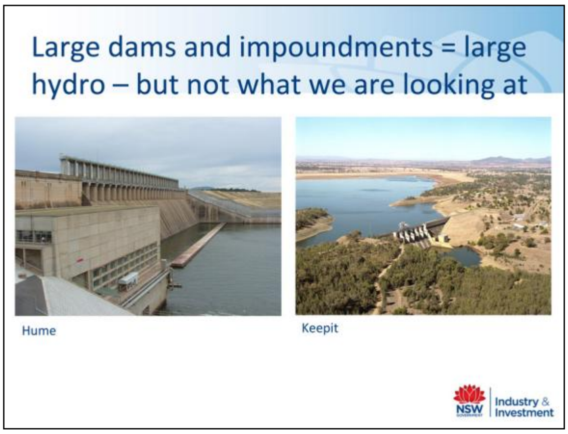
Annex 25

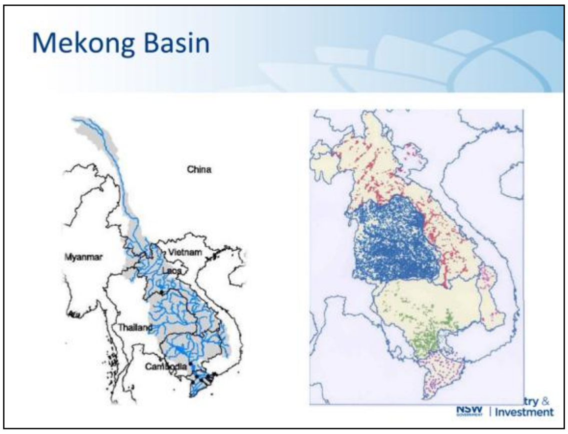
SUSTAINABLE IRRIGATION AND MINI HYDRO DEVELOPMENT IN THE ASIA-PACIFIC

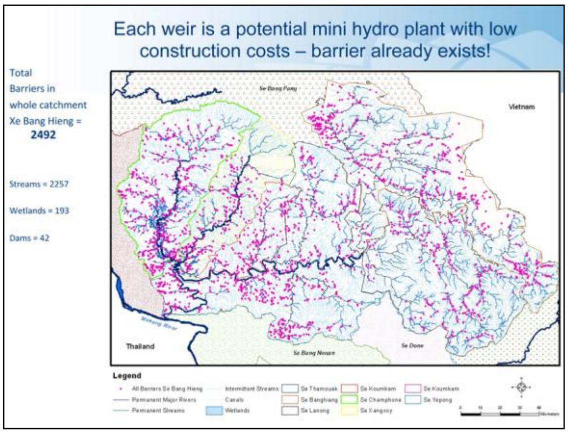
Presented by Garry Thorncraft

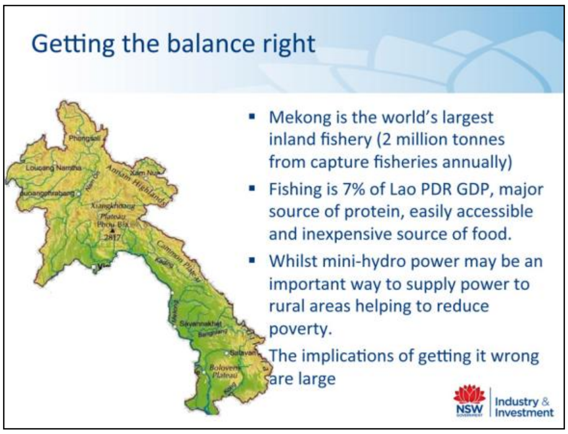


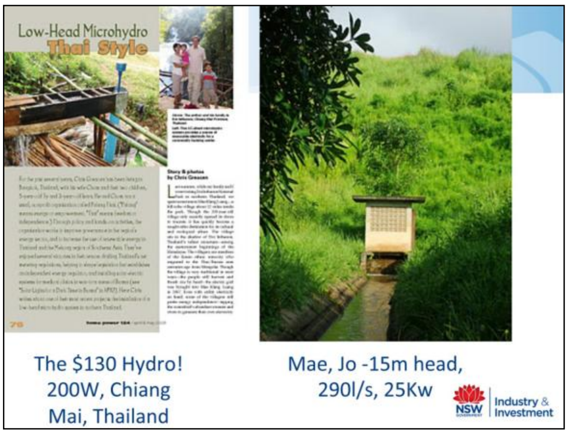




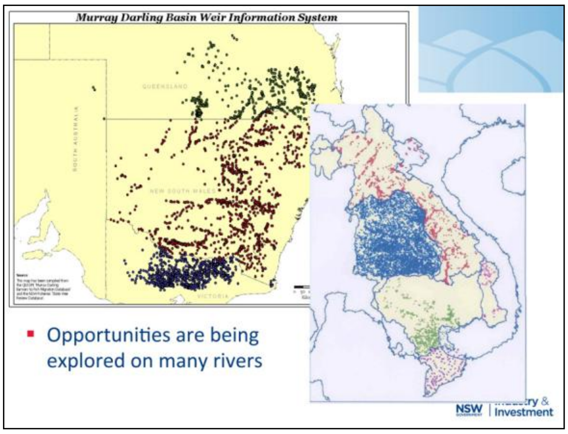

Mekong Basin
China
Myanmar
Vietnam
Laos
Thailand
Cambodia
Industry & Investment

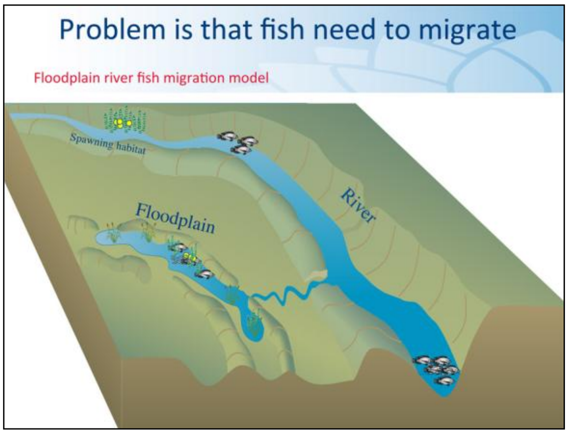

Each weir is a potential mini hydro plant with low construction costs – barrier already exists!
Total Barriers in whole catchment Xe Bang Hieng = 2492
Streams = 2257
Wetlands = 193
Dams = 42
Vietnam
Thailand
Legend

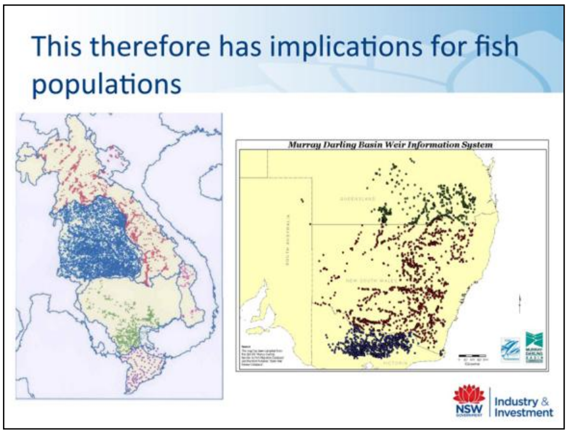

Getting the balance right
Mekong is the world's largest inland fishery (2 million tonnes from capture fisheries annually)
Fishing is 7% of Lao PDR GDP, major source of protein, easily accessible and inexpensive source of food.
Whilst mini-hydro power may be an important way to supply power to rural areas helping to reduce poverty.
The implications of getting it wrong are large
NSW Industry & Investment

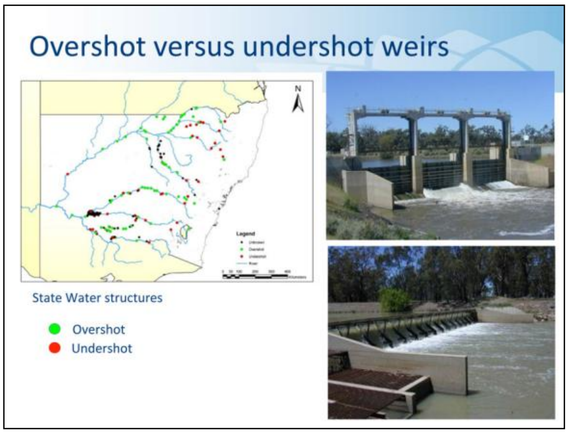

Low-Head Microhydro Thai Style
The $130 Hydro! 200W, Chiang Mai, Thailand
Mae, Jo -15m head, 290l/s, 25Kw
NSW Industry & Investment

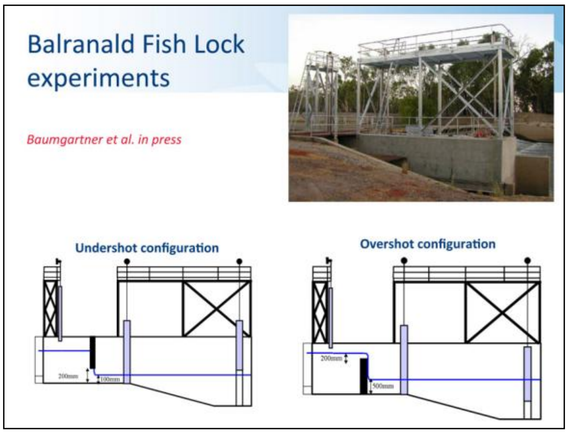

Village-scale project, Vietnam
1kW
Village-scale project, Thailand, 3Kw
NSW Industry & Investment


Murray Darling Basin Weir Information System
Opportunities are being explored on many rivers
NSW Industry & Investment

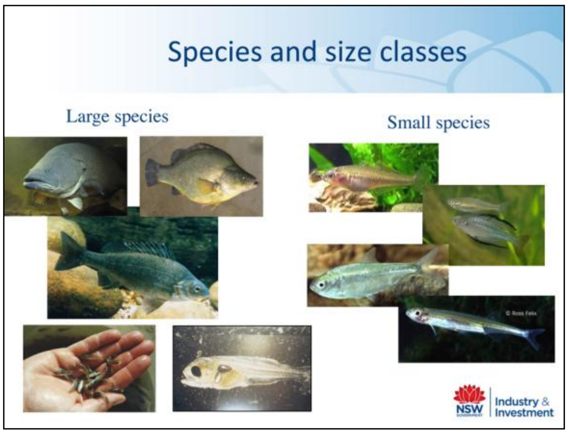

Problem is that fish need to migrate
Floodplain river fish migration model
Spawning habitat
Floodplain
River

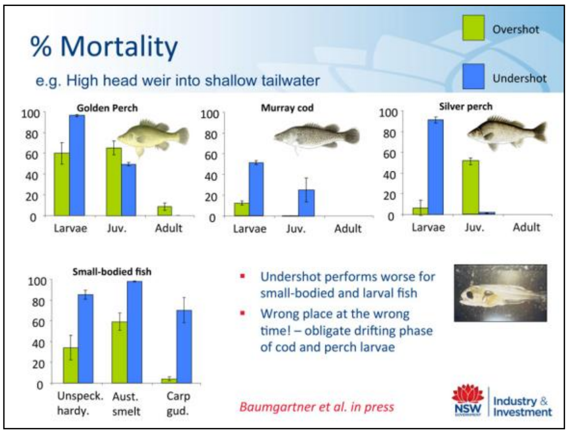

This therefore has implications for fish populations
Murray Darling Basin Weir Information System
NSW Industry & Investment


Overshot versus undershot weirs
State Water structures
Overshot
Undershot

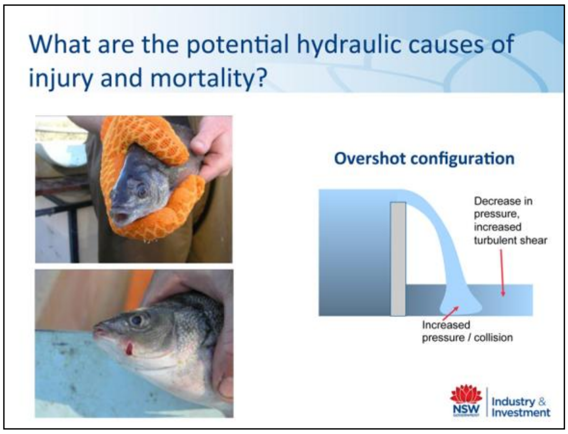

Balranald Fish Lock experiments
Baumgartner et al. in press
Undershot configuration
Overshot configuration

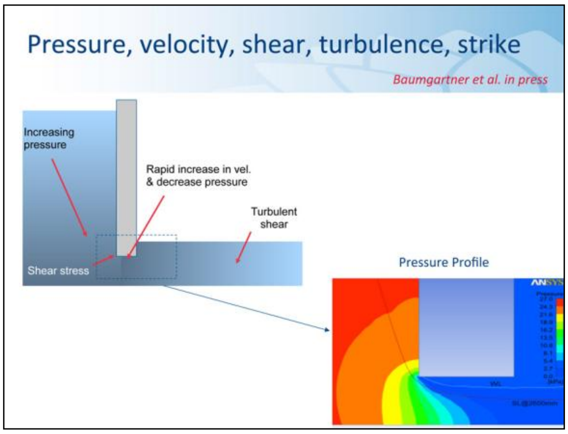

Fish scientists throughout the world come in different shapes and sizes…so do the fish
Investment

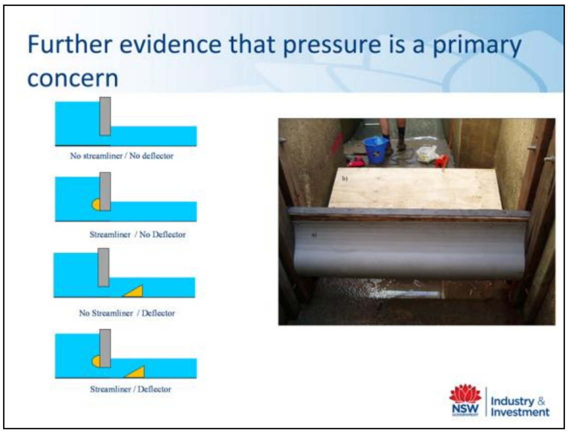

Species and size classes
Large species
Small species
Industry & Investment

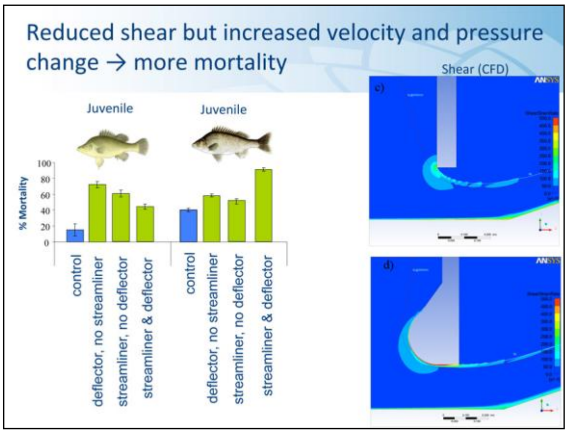

% Mortality
e.g. High head weir into shallow tailwater
Overshot
Undershot
Golden Perch
Murray cod
Silver perch
Larvae
Juv.
Adult
Small-bodied fish
Unspeck. hardy.
Aust. smelt
Carp gud.
Undershot performs worse for small-bodied and larval fish
Wrong place at the wrong time! – obligate drifting phase of cod and perch larvae
Baumgartner et al. in press
Industry & Investment

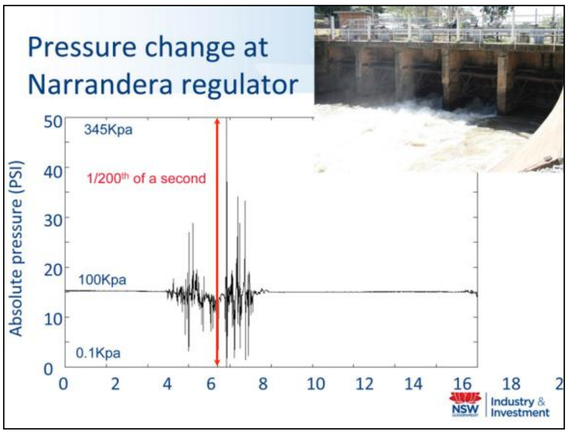

What could be causing this?
Pushing water past a structure significantly changes its hydraulics
River
Weir pool
Industry & Investment

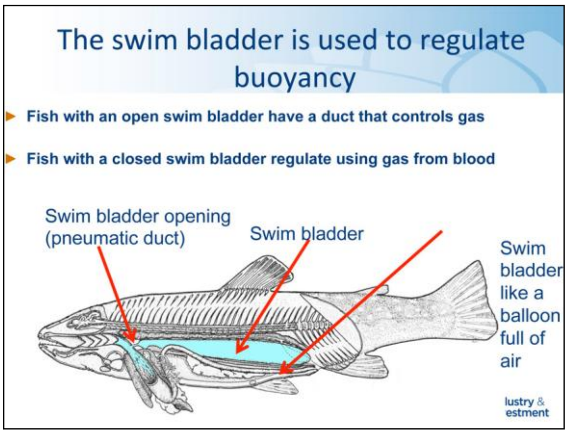

What are the potential hydraulic causes of injury and mortality?
Overshot configuration
Decrease in pressure, increased turbulent shear
Increased pressure / collision
Industry & Investment

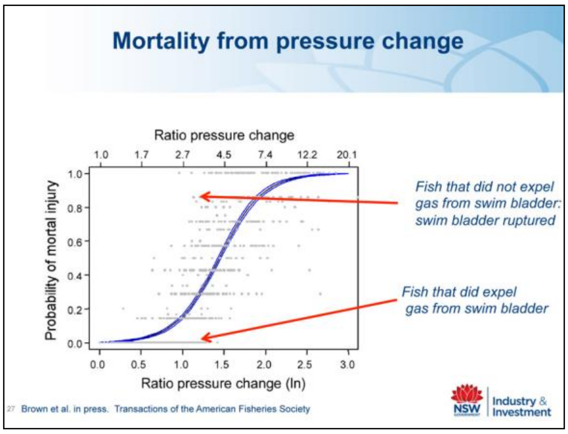

Pressure, velocity, shear, turbulence, strike
Baumgartner et al. in press
Increasing pressure
Rapid increase in vel. & decrease pressure
Turbulent shear
Shear stress
Pressure Profile

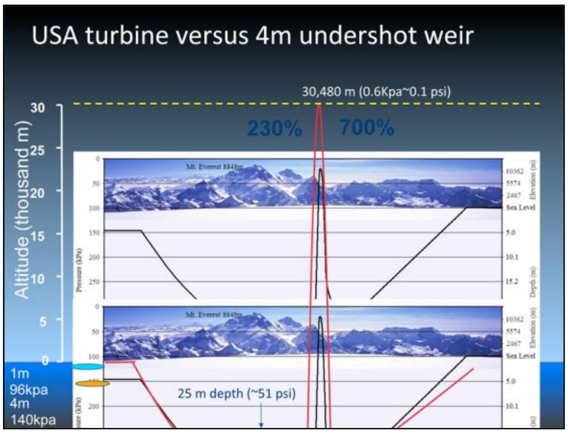

Further evidence that pressure is a primary concern
No streamliner / No deflector
Streamliner / No Deflector
No Streamliner / Deflector
Streamliner / Deflector
NSW Industry & Investment


Reduced shear but increased velocity and pressure change → more mortality
Shear (CFD)
Juvenile
Juvenile
% Mortality
100
80
60
40
20
0
control
deflector, no streamliner
streamliner, no deflector
streamliner & deflector
control
deflector, no streamliner
streamliner, no deflector
streamliner & deflector

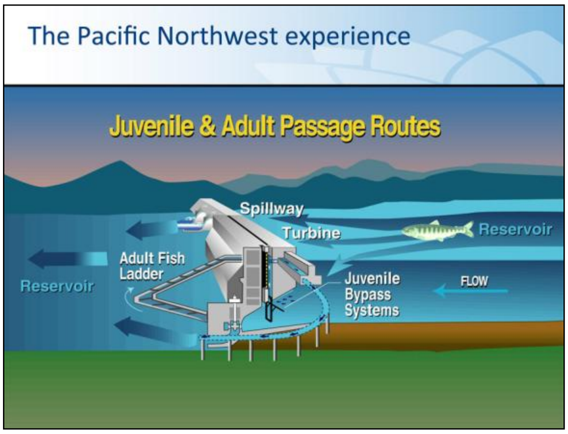

Pressure change at Narrandera regulator
Absolute pressure (PSI)
345Kpa
1/200th of a second
100Kpa
0.1Kpa
50
40
30
20
10
0
0 2 4 6 8 10 12 14 16 18
NSW Industry & Investment

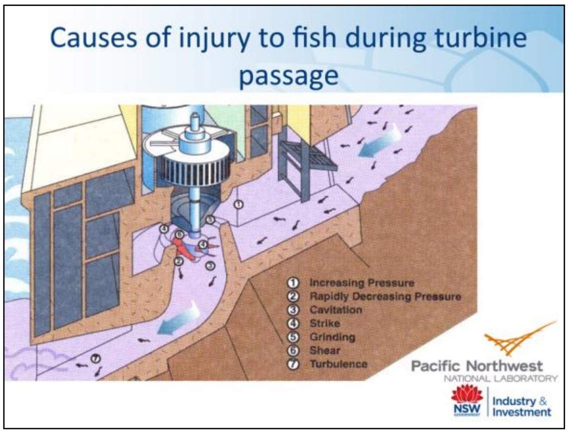

The swim bladder is used to regulate buoyancy
Fish with an open swim bladder have a duct that controls gas
Fish with a closed swim bladder regulate using gas from blood
Swim bladder opening (pneumatic duct)
Swim bladder
Swim bladder like a balloon full of air

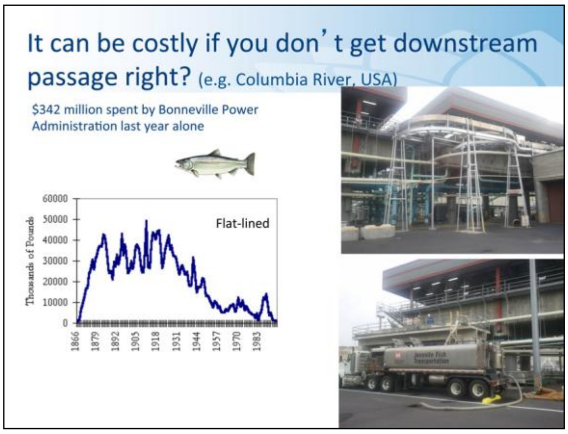

Mortality from pressure change
Ratio pressure change
1.0 1.7 2.7 4.5 7.4 12.2 20.1
Probability of mortal injury
Fish that did not expel gas from swim bladder: swim bladder ruptured
Fish that did expel gas from swim bladder
Ratio pressure change (ln)
0.0 0.5 1.0 1.5 2.0 2.5 3.0
27 Brown et al. in press. Transactions of the American Fisheries Society
NSW Industry & Investment

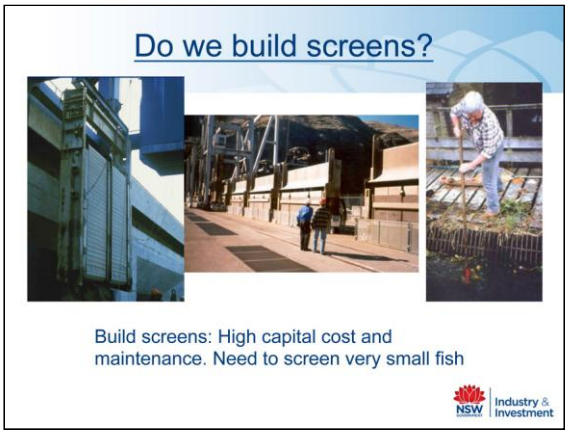

USA turbine versus 4m undershot weir
30,480 m (0.6Kpa~0.1 psi)
230%
700%
Altitude (thousand m)
Mt. Everest 8848m
1m
96kpa
4m
140kpa
25 m depth (~51 psi)


The Pacific Northwest experience
Canada
U.S.
Seattle
Portland
Washington
Oregon
Idaho
Montana
Bonneville
The Dalles
John Day
McNary
Ice Harbor
Lower Monumental
Little Goose
Lower Granite
Dworshak
Grand Coulee
Chief Joseph
Mica
Revelstoke


The Pacific Northwest experience
Juvenile & Adult Passage Routes
Spillway
Turbine
Reservoir
Adult Fish Ladder
Reservoir
Juvenile Bypass Systems
FLOW


Causes of injury to fish during turbine passage
① Increasing Pressure
② Rapidly Decreasing Pressure
③ Cavitation
④ Strike
⑤ Grinding
⑥ Shear
⑦ Turbulence
Pacific Northwest
NATIONAL LABORATORY
NSW Industry & Investment


It can be costly if you don't get downstream passage right? (e.g. Columbia River, USA)
$342 million spent by Bonneville Power Administration last year alone
Flat-lined
Thousands of Pounds
60000
50000
40000
30000
20000
10000
0
1866
1879
1892
1905
1918
1931
1944
1957
1970
1983


Do we build screens?
Build screens: High capital cost and maintenance. Need to screen very small fish
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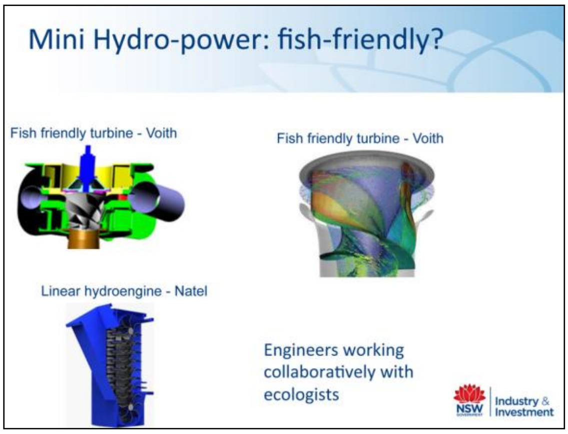
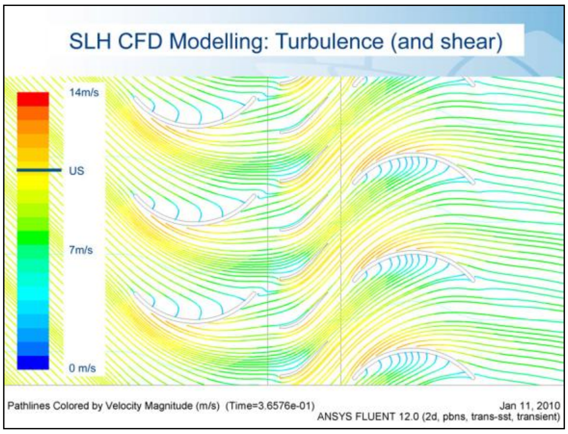
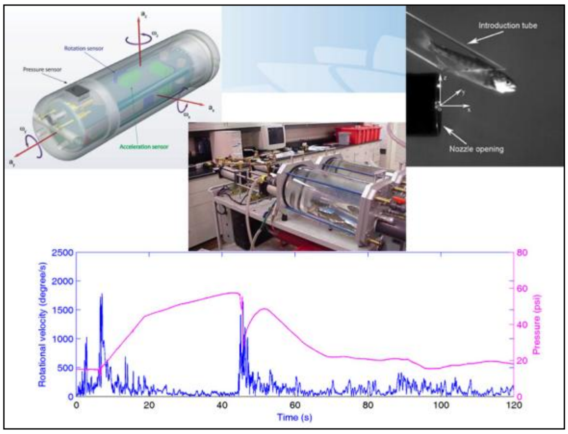
Trashrack with fouling issues


Mini Hydro-power: fish-friendly?
Fish friendly turbine - Voith
Fish friendly turbine - Voith
Linear hydroengine - Natel
Engineers working collaboratively with ecologists
NSW Industry & Investment


SLH CFD Modelling: Turbulence (and shear)
14m/s
US
7m/s
0 m/s
Pathlines Colored by Velocity Magnitude (m/s) (Time=3.6576e-01)
Jan 11, 2010
ANSYS FLUENT 12.0 (2d, pbns, trans-sst, transient)


Rotation sensor
Pressure sensor
Acceleration sensor
Introduction tube
Nozzle opening
Rotational velocity (degree/s)
Pressure (psi)
Time (s)
2500
2000
1500
1000
500
0
80
60
40
20
0
20
40
60
80
100
120


A truly collaborative approach
International Research partners:
– NSW DPI
– National University of Laos
– Charles Sturt University
– Pacific Northwest National Laboratory
– Water Research Laboratory (UNSW)
– Living Aquatic Resource Research Centre (Laos)
Industry partners:
– Waratah Power
Funding Partners:
– NSW Government (OEH, NSW DPI)
– Australian Centre for Renewable Energy (Federal)
– Australian Centre for International Agricultural Research (ACIAR)
Supporting partners (needed to be successful):
– Electricity du Laos
– Department of Irrigation (Ministry of Agriculture and Forestry)
– Mekong River Commission
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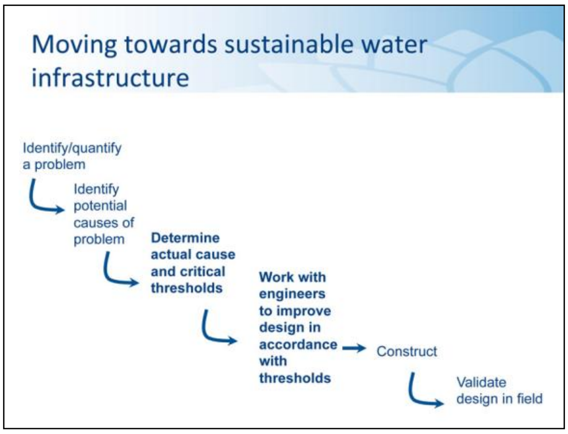
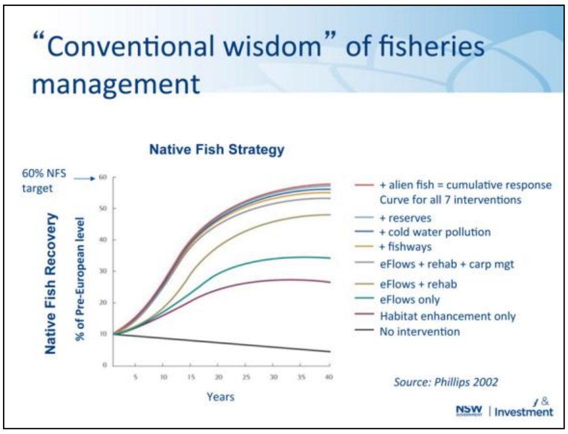
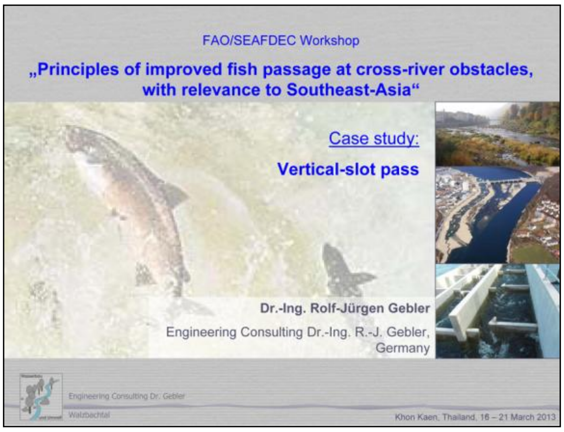
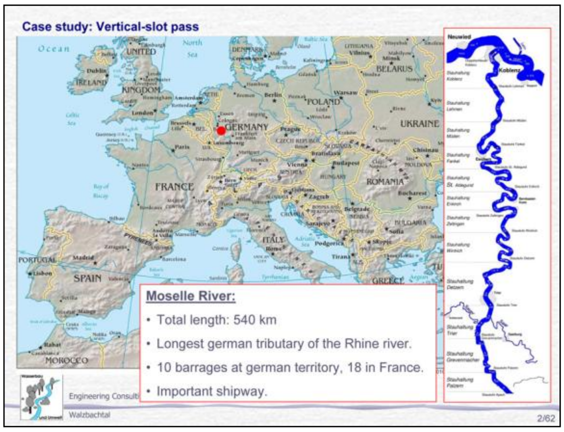

Moving towards sustainable water infrastructure
Identify/quantify a problem
Identify potential causes of problem
Determine actual cause and critical thresholds
Work with engineers to improve design in accordance with thresholds
Construct
Validate design in field

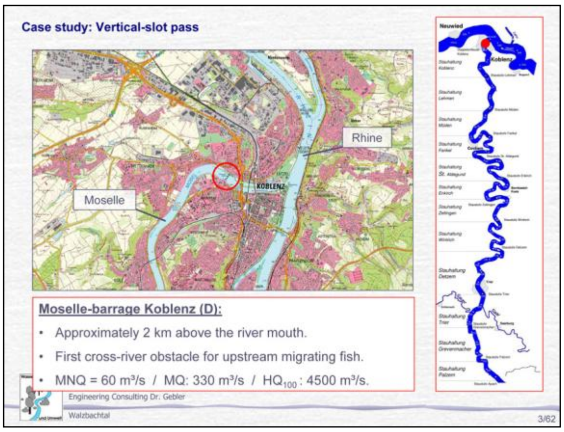

“Conventional wisdom” of fisheries management
Native Fish Strategy
60% NFS target
Native Fish Recovery
% of Pre-European level
Years
+ alien fish = cumulative response Curve for all 7 interventions
+ reserves
+ cold water pollution
+ fishways
eFlows + rehab + carp mgt
eFlows + rehab
eFlows only
Habitat enhancement only
No intervention
Source: Phillips 2002
NSW | Investment

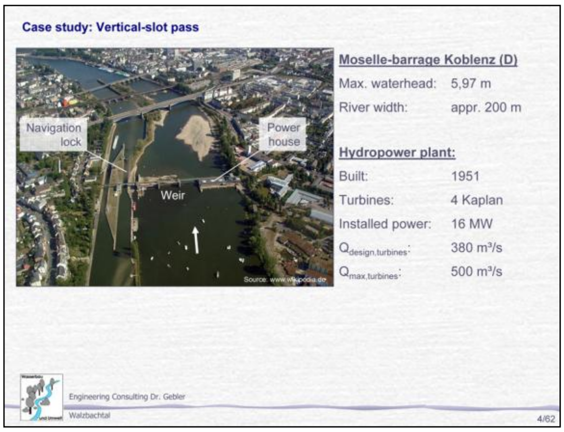
VERTICAL SLOT PASSES AT THE POWER STATION

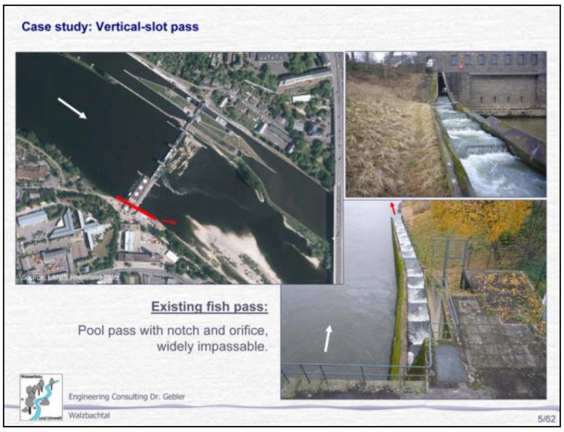
By Dr. -Ing Rolf-Jürgen Gebler











Case study: Vertical-slot pass

Right bank, next to the power house.

Case study: Vertical-slot pass

The whole area is intensely used!

What **construction type** and **inner design** would you choose?

Where is the **optimal location** for the fishway, especially entrance and exit?

Case study: Vertical-slot pass

Due to the local lack of space: **Technical fishway (Vertical-slot pass).**

To find the right position for the entrances, an **Examination of the local flow conditions** downstream of the power house at different discharges and operating conditions is necessary.

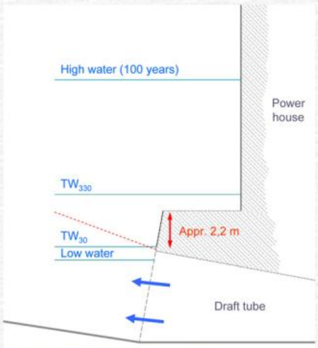
→ **Field studies!**

Case study: Vertical-slot pass

Longitudinal section through the draft tube:

Due to the 2,2 m thick draft tube ceiling, an area with low turbulent flow along the end of the ceiling can be expected.

→ **To be verified with field studies!**



Case study: Vertical-slot pass

Situation 1:

$Q_{Moselle}$ = appr. 900 m³/s TW = appr. 62,30 m+NN Appr. 340 shortfall days/year

Video: Turbine 1 full load (appr. 110 m³/s)

Case study: Vertical-slot pass

Situation 1:

$Q_{Moselle}$ = appr. 900 m³/s TW = appr. 62,30 m+NN Appr. 340 shortfall days/year

Turbine 1 full load (appr. 110 m³/s)

Case study: Vertical-slot pass

Situation 2:

$Q_{Moselle}$ = 232 m³/s TW = appr. 60,20 m+NN Appr. 200 shortfall days/year

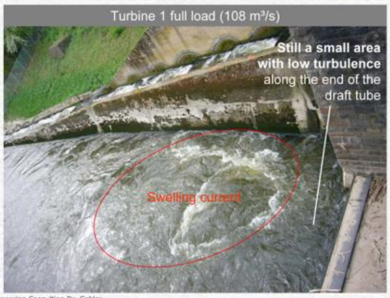
Video: Turbine 1 full load (108 m³/s)

Case study: Vertical-slot pass

Situation 2:

$Q_{Moselle}$ = 232 m³/s TW = appr. 60,20 m+NN Appr. 200 shortfall days/year

Turbine 1 full load (108 m³/s)

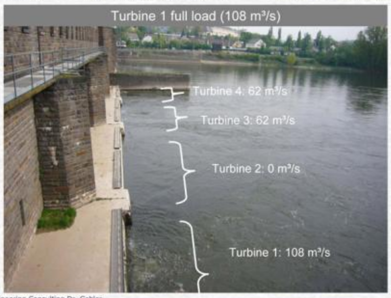


Case study: Vertical-slot pass

Situation 2:

$Q_{Moselle}$ = 232 m³/s   TW = appr. 60,20 m+NN   Appr. 200 shortfall days/year

Turbine 1 full load (108 m³/s)



Case study: Vertical-slot pass

Situation 2:

$Q_{Moselle}$ = 232 m³/s   TW = appr. 60,20 m+NN   Appr. 200 shortfall days/year

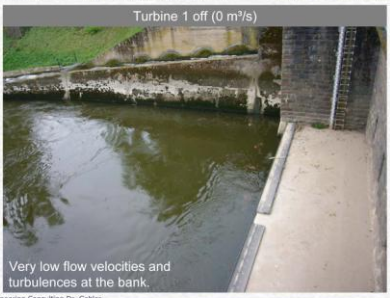
Turbine 1 partial load (78 m³/s)

Case study: Vertical-slot pass

Situation 2:

$Q_{Moselle}$ = 232 m³/s   TW = appr. 60,20 m+NN   Appr. 200 shortfall days/year

Turbine 1 off (0 m³/s)



Case study: Vertical-slot pass

Situation 3:

$Q_{Moselle}$ = 86 m³/s   TW = appr. 59,00 m+NN   Appr. 25 shortfall days/year

Video: Whole discharge through turbine 1 (86 m³/s)

Case study: Vertical-slot pass

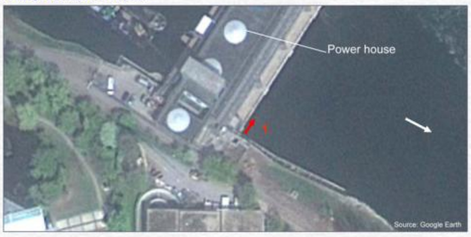
Situation 3:

$Q_{Moselle}$ = 86 m³/s   TW = appr. 59,00 m+NN   Appr. 25 shortfall days/year

Case study: Vertical-slot pass

Based on the showed results of the field studies, where is the **optimal location for the entrance**?

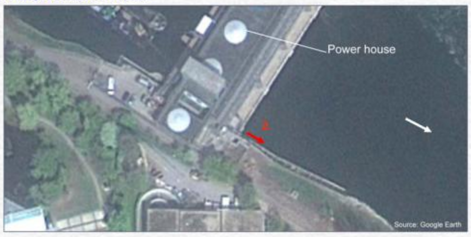
Case study: Vertical-slot pass



Entrance Nr. 1: Directly underneath the power house at the end of the draft tube, parallel to the power house.

Purpose: Generate an **attraction flow along the end of the draft tube**. Thus, also fish in the middle or even at the other side of the power house can be reached.

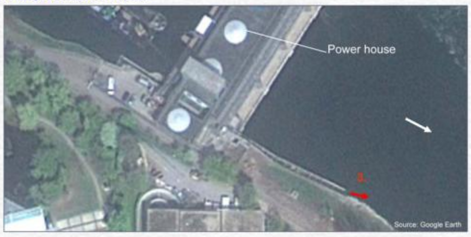
Case study: Vertical-slot pass



Entrance Nr. 2: Directly underneath the power house at the end of the draft tube, parallel to the main flow.

Purpose: Generate an **attraction flow along the river bank**. Thus, fish on the expected main migration corridor are guided into the fishway.

Case study: Vertical-slot pass



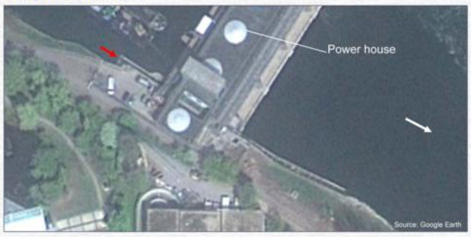
Entrance Nr. 3: Approximately 50 m downstream of the power house.

Purpose: **Bottom connection** and additional entrance, especially for species with low capability.

Case study: Vertical-slot pass

Where is the **optimal location for the exit**?

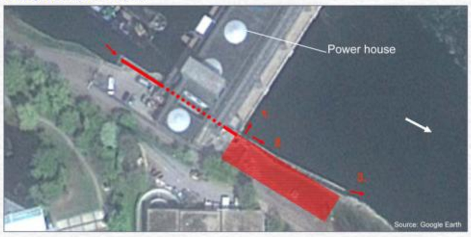
Case study: Vertical-slot pass



Exit of the fish pass:

- Use of the old fish pass exit, appr. 17 m upstream of the turbine intake.
- Sufficient low flow velocities, due to sufficient distance to the intake.
- Small bay to realize the upstream bottom connection.

Case study: Vertical-slot pass



Upper part: Use of the old fish pass channel, new inner design.

Main part: Downstream bank slope.

Case study: Vertical-slot pass

To determine the right **design for the entrances**, the changes in tail- and headwater level as a function of time have to be regarded.

The tailwater of the barrage is influenced by the water level of the rhine (distance only 2 km).

Relevant tailwater range:

59,08 - 61,94 m+NN (2,86 m)

Between these water levels, the functionality of the fishway must be garanteed.

Constant headwater level:

65,05 m+NN

Deceeding period in days	Deceeded water level in m+NN
(365)	---
364	65.16
363	64.69
362	64.48
361	64.23
360	64.04
359	63.86
358	63.74
357	63.57
356	63.48
350	62.88
340	62.30
330	**61.94**
320	61.64
300	61.21
270	60.80
240	60.50
210	60.25
183	60.07
150	59.83
130	59.71
120	59.66

Deceeding period in days	Deceeded water level in m+NN
110	59.61
100	59.55
90	59.50
80	59.45
70	59.40
60	59.34
50	59.27
40	59.18
30	**59.08**
25	59.00
20	58.91
15	58.84
10	58.78
9	58.76
8	58.73
7	58.70
6	58.69
5	58.66
4	58.62
3	58.55
2	58.48
1	58.46
0	58.35

Case study: Vertical-slot pass

Entrances 1 and 2:

- Generation of a **good perceptible attraction flow**, even during periods with high tailwater levels. Therefore a preferably constant opening extend is needed.
- Design primary for free swimming species. Thus, entrances should be **positioned near to the water surface**.

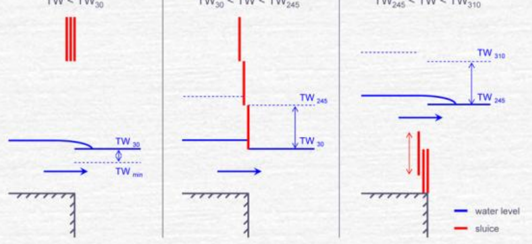
→ Three-part sluices with regulation depending on tailwater level.

Case study: Vertical-slot pass Sluice regulation

Situation 1: $TW < TW_{30}$

Situation 2: $TW_{30} < TW < TW_{245}$

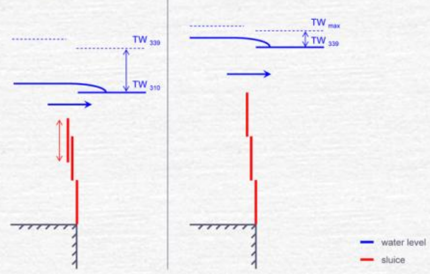
Situation 3: $TW_{245} < TW < TW_{310}$



Case study: Vertical-slot pass

Situation 4: $TW_{310} < TW < TW_{339}$

Situation 5: $TW > TW_{339}$



Case study: Vertical-slot pass

Entrance 3:
- Rough channel with low flow velocities.
- Gradient: 1:25
- Discharge: 100 l/s
- Waterdepth: > 30 cm


Case study: Vertical-slot pass

Fish fauna:

Salmon	Length:	1,10 m	
	Width:	0,11 m	
	Height:	0,22 m	
Allis shad	(swarm fish and thus special requirements!)		
Max. tolerable flow speed (v_{max}):		1,72 m/s	
Max. tolerable power density (E):		150 W/m³	

Allis shad

Salmon

Case study: Vertical-slot pass

Max. differences in water level between the pools:

$$\Delta h_{max} = \frac{v_{max}^2}{2 \cdot g} = \frac{(1{,}72\frac{m}{s})^2}{2 \cdot 9{,}81\frac{m}{s^2}} = 0{,}15m$$

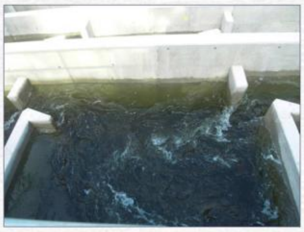
Required amount of pools:

$\Delta h_{total} / \Delta h_{max}$ = 5,97 m / 0,15 m = 39,8

→ Rounded up to **40 cross-walls, that means 39 pools.**

Case study: Vertical-slot pass

What are the minimal required pool and opening dimensions (for salmon)?



Case study: Vertical-slot pass

Determination of the minimal pool and opening dimensions by body dimensions of relevant fish species:

Dimension	Inside pool length	Inside pool width	Pool depth
Multiplication factor	Body length x 3	Body length x 2	Body hight x 5

Dimension	Opening depth	Opening inside width
Multiplication factor	Body hight x 2	Body width x 3

Case study: Vertical-slot pass

Required pool-dimensions based on largest relevant fish-species (assumption salmon):

Minimal pool-length:	3,30 m	(fish-length x 3 = 1,10 m x 3)
Minimal pool-width:	2,20 m	(fish-length x 2 = 1,10 m x 2)
Minimal pool-depth:	1,10 m	(fish-height x 5 = 0,22 m x 5)
Minimal opening-depth:	0,44 m	(fish-height x 2 = 0,22 m x 2)
	Better choose the whole pool depth!	
Minimal opening-width:	0,33 m	(fish-width x 3 = 0,11 m x 3)



Case study: Vertical-slot pass

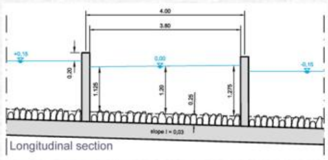
Special requirements to respect the needs of **allis shad** (swarm fish):

Dimensioning allis shad	
Opening width:	0,45 m
Pool length:	3,80 m
Pool width:	2,70 m
Mean pool depth:	≥ 1,20 m

Length / width - ratio:

2,7 m / 3,8 m = 0,71 ≈ 3/4 ✓

Case study: Vertical-slot pass



Longitudinal section

h_{TW} = 1,125 m / h_{HW} = 1,275 m

Bottom substrate with high roughness in the whole fishway for better energy dissipation and free passage for substrate oriented species.

Total length of the fishway:

To calculate the total required length of the fishway, the thickness of the cross-walls must be considered (assumption: 0,2 m):

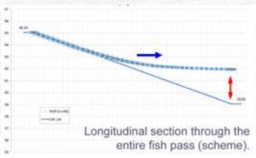
40 x (3,8 m + 0,2 m) = 160 m

This is only the minimal length of the pool section!

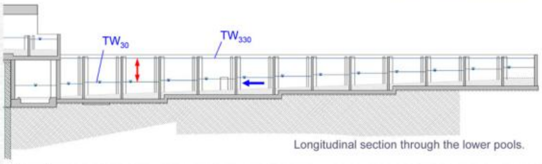
Case study: Vertical-slot pass

At rising tailwater, also the water depth in the lower pools increases.

To keep a sufficient high attraction flow through the entire fish pass, the top of the lower cross-walls lays above the highest relevant water level (no cross-wall overflow).



Longitudinal section through the entire fish pass (scheme).



Longitudinal section through the lower pools.

Case study: Vertical-slot pass

Needed discharge to achieve the aspired hydraulic conditions?

and

What is the resulting power density in the pools?

Case study: Vertical-slot pass

Discharge through a slot:

Equation: $Q = \frac{2}{3} \cdot \mu_r \cdot s \cdot \sqrt{2 \cdot g} \cdot h_{HW}^{\frac{3}{2}}$

With μ_r = coefficient [-] g = acceleration due to gravity [m/s²]

s = slot width [m] h_{HW} = water depth upstream of the crosswall [m]

In our case:

μ_r = 0,41 (h_{TW}/h_{HW} = 1,125m/1,275m = 0,88)

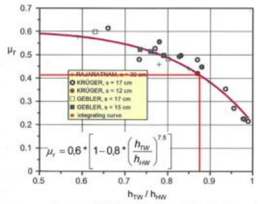
s = 0,45 m

g = 9,81 m/s²

h_{HW} = 1,275 m

$Q = \frac{2}{3} \cdot 0{,}41 \cdot 0{,}45m \cdot \sqrt{2 \cdot 9{,}81\frac{m}{s^2}} \cdot (1{,}275m)^{\frac{3}{2}}$

→ **Q = 0,78 m³/s**



source: FAO/DVWK, Fish passes - Design, dimensions and monitoring, Rome, FAO 2002

Case study: Vertical-slot pass

Proof of low turbulent flow in the pools:

$$E = \frac{\rho \cdot g \cdot \Delta h \cdot Q}{poolvolume}$$

With:

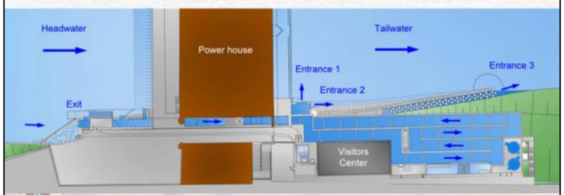
ρ = density of water = 1.000 kg/m³
g = acceleration due to gravity = 9,81 m/s²
Δh = water level difference = 0,15 m
V_{pool} = pool volume

Mean pool depth: 1,20 m
Mean pool width: 2,70 m
Mean pool length: 3,80 m

$V_{pool} = 1{,}20\,m \cdot 2{,}70\,m \cdot 3{,}80\,m = 12{,}312\,m^3$

$$E = \frac{1000\frac{kg}{m^3} \cdot 9{,}81\frac{m}{s^2} \cdot 0{,}15\,m \cdot 0{,}78\frac{m^3}{s}}{12{,}312\,m^3} = 93\,W/m^3 < 150\,W/m^3$$ ✓

Case study: Vertical-slot pass



Case study: Vertical-slot pass

Case study: Vertical-slot pass — Discharge ratio

The tailrace current at a power house is dominated by the discharge of the power station. **The attraction flow of the fishway has to compete against this main flow.**

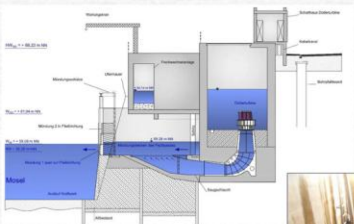
Recommended discharge at the entrance of the fishway to **increase the attraction flow** (Larinier 2002):

1 – 5 % of the competing flow

In this case:

- Discharge through the fish pass ($Q_{fish\ pass}$ = 0,78 m³/s) does not provide sufficient attraction flow.
- **Additional discharge: Q_{bypass} = 4,0 m³/s.**
- $Q_{attraction} = Q_{fish\ pass} + Q_{bypass}$ = 0,78 m³/s + 4,0 m³/s = 4,78 m³/s.
- Approximately 1 % of the maximal competing flow.
- **Bypass turbine.**

Case study: Vertical-slot pass



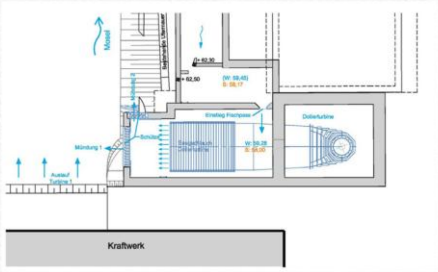
Turbine bypass-discharge:

Q = 4,0 m³/s

(approximately 1% of the max. discharge of the hydropower station)

Case study: Vertical-slot pass

Top view entrance 1 und 2

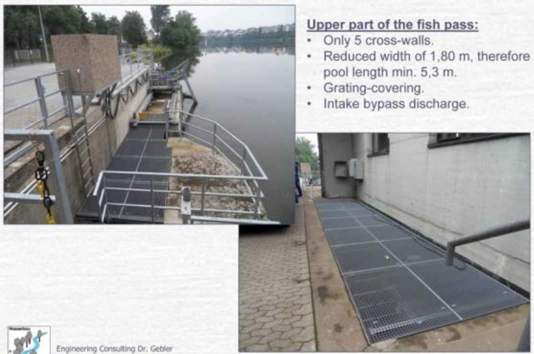


Case study: Vertical-slot pass

Case study: Vertical-slot pass

Video

Case study: Vertical-slot pass

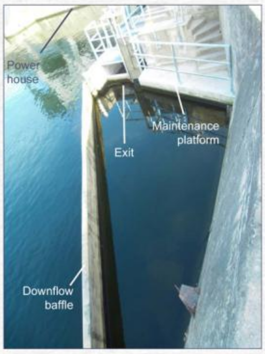


Upper part of the fish pass:
- Only 5 cross-walls.
- Reduced width of 1,80 m, therefore pool length min. 5,3 m.
- Grating-covering.
- Intake bypass discharge.

Case study: Vertical-slot pass

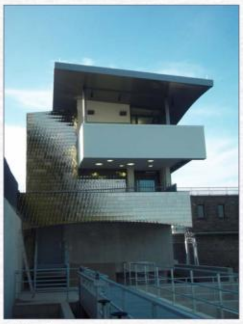
Exit (headwater):
- Use of the existing fish pass channel and exit.
- Floating debris is passed down to the power house.

Initial state.



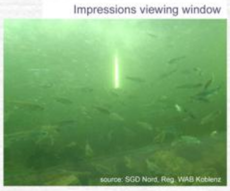
Case study: Vertical-slot pass

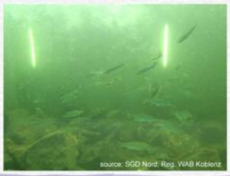
Visitors Center „Mosellum“



Case study: Vertical-slot pass

Impressions viewing window

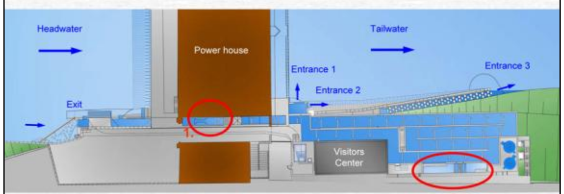




Case study: Vertical-slot pass

At the fish pass Koblenz, two counting-systems are installed:

1. Vaki-Counter
2. Catchment basin



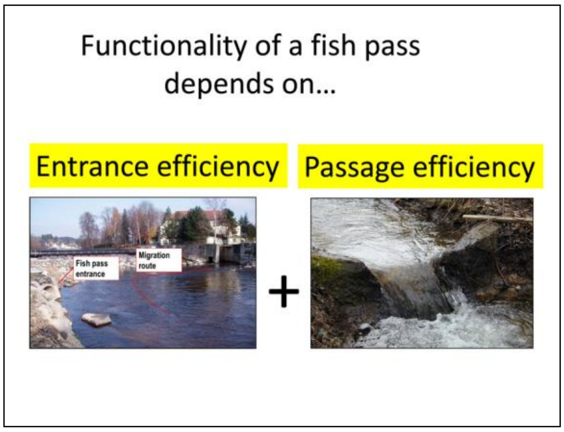

Case study: Vertical-slot pass
Vaki-Counter
Walzbachtal
59/62

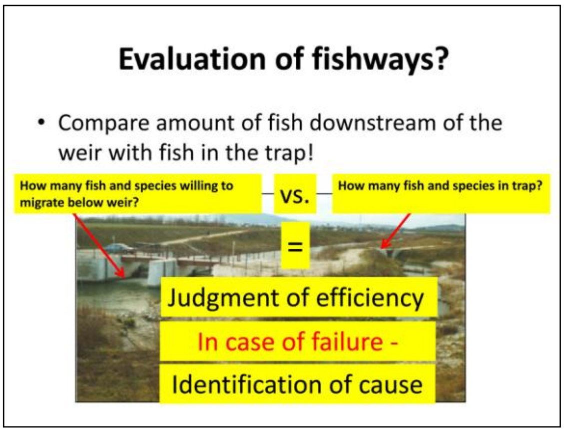

Case study: Vertical-slot pass
Catchment basin
Catchment basin
Fish basins
• Bypassing chamber to catch fish.
• In addition two fish basins for temporary storage.
More detailed information later!
Engineering Consulting Dr. Gebler
Walzbachtal
61/62

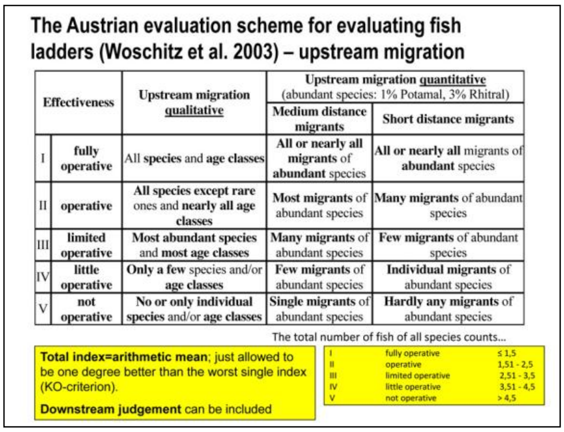
Annex 27

MONITORING – UPSTREAM MIGRATION

By Dr. Andreas Zitek






The Austrian evaluation scheme for evaluating fish ladders (Woschitz et al. 2003) – upstream migration

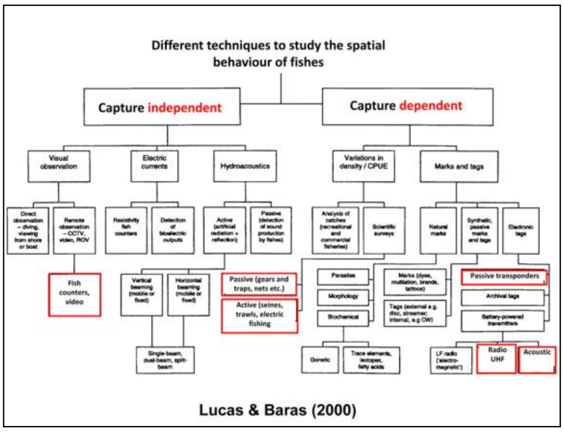
Effectiveness		Upstream migration qualitative	Upstream migration quantitative (abundant species: 1% Potamal, 3% Rhitral)	
			Medium distance migrants	Short distance migrants
I	fully operative	All species and age classes	All or nearly all migrants of abundant species	All or nearly all migrants of abundant species
II	operative	All species except rare ones and nearly all age classes	Most migrants of abundant species	Many migrants of abundant species
III	limited operative	Most abundant species and most age classes	Many migrants of abundant species	Few migrants of abundant species
IV	little operative	Only a few species and/or age classes	Few migrants of abundant species	Individual migrants of abundant species
V	not operative	No or only individual species and/or age classes	Single migrants of abundant species	Hardly any migrants of abundant species

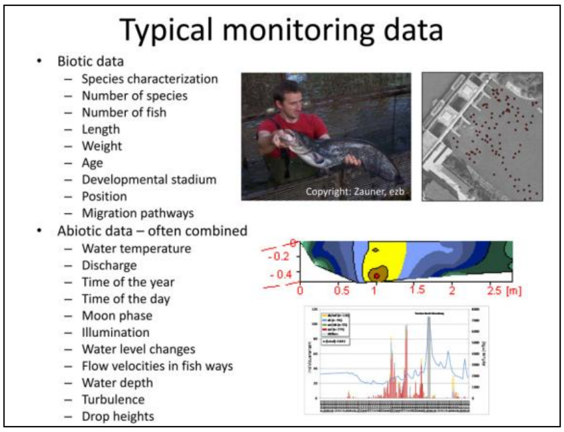
The total number of fish of all species counts…

Total index=arithmetic mean; just allowed to be one degree better than the worst single index (KO-criterion).

Downstream judgement can be included

I	fully operative	≤ 1,5
II	operative	1,51 - 2,5
III	limited operative	2,51 - 3,5
IV	little operative	3,51 - 4,5
V	not operative	> 4,5





Assessing the efficiency of fish ladders – upstream direction

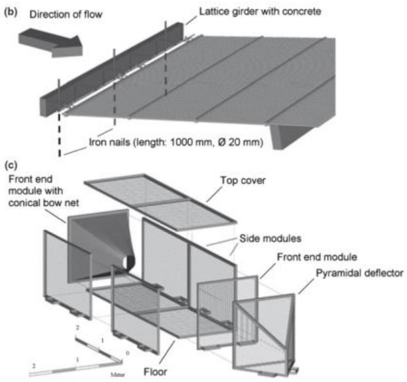
- **Fish counts at fish ladders or specific sites**
  - amount of successful migrants as proportion of all migrants or delay
    - Tagging experiments, or by a combination of other methods (visual observations, electric fishing, expert judgement)
- **Efficiency of multiple fish ladders on a catchment level**
  - number of fish show up at the next fish ladder or
  - at spawning grounds given efficiencies of individual fish passes
- **Effect of connectivity measures on fish populations**
  - Counting upstream spawning places and/or recruitment
  - Quant. the number of downstream migrating smolts/larvae
  - Long-term studies of migrants – also in relation to other management measures
  - Application of standardized biotic assessment methods

A method for assessing fish migration: using traps and a flood resistant weir

(Zitek et al. 2009)

Advantages
- Flood resistant
- Self cleaning ability
- flexibility
- Low cost

Construction details (Zitek et al. 2009)



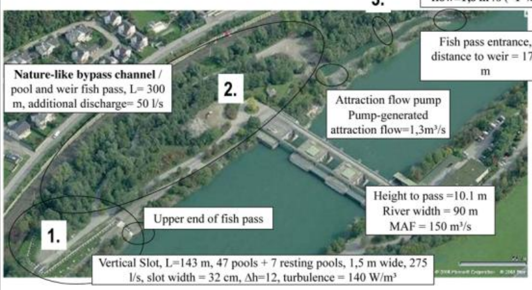
The Original: The Alaskian Fish Weir

http://www.fishtraps.com/

Tobin, J. h. (1994). Construction and Performance of a Portable Resistance Board Weir for Counting Migrating Salmon in Rivers. Kenai. U. S. Fish and Wildlife Service, Kenai Fishery Resource Office. 27.

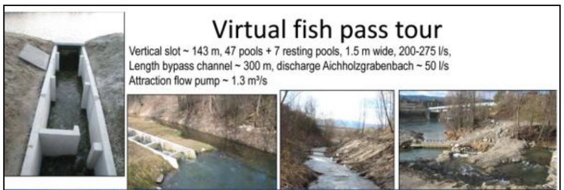
Monitoring of a fish pass at the river Drau, Villach

Fish pass entrance, **total generated attraction flow=1,6 m³/s (~1 %)**



Virtual fish pass tour

Vertical slot ~ 143 m, 47 pools + 7 resting pools, 1.5 m wide, 200-275 l/s,
Length bypass channel ~ 300 m, discharge Aichholzgrabenbach ~ 50 l/s
Attraction flow pump ~ 1.3 m³/s



Monitoring design

a) **Electro fishing** in fish pass and in the downstream section of the weir, marking of all fish according to region of capture

Marked fish (with panjet injector); quick and lasts for up to 1 year)

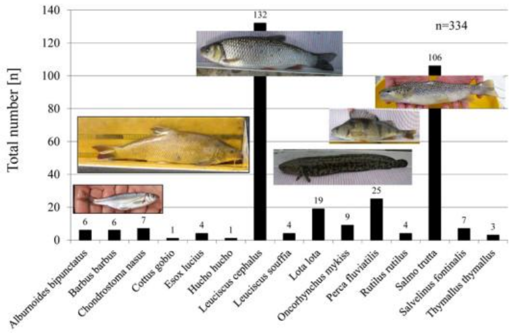
b) **Traps at lower and upper end of fish pass, marking of all fish; duration** 3 months in autumn/winter and 3 months in spring/summer season

c) **Radiotelemetry** of 50 nase for about 4 months

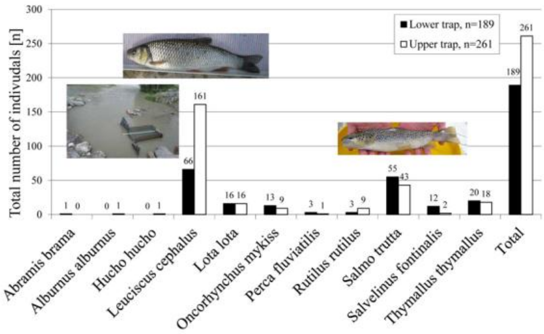
Electrofishing

Trap locations

Electro-fishing data impoundment



Trap monitoring data 20.03.2008 to 30.06.2008



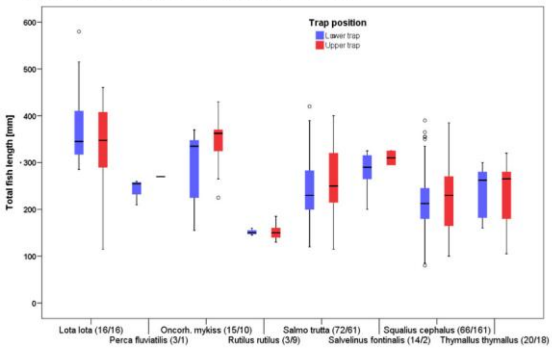
Efficiency in relation to downstream fish stock

Species	Flow preference	Migration distance	Electrofishing Total n	%	Trap Total n	%
Abramis brama (bream)	Indifferent euryopar	middle	0	0	1	0.3
Alburnoides bipunctatus (schneider, spirlin)	Rheophil rheopar	short	6	1.8	0	0.0
Alburnus alburnus (bleak)	Indifferent euryopar	short	0	0.0	1	0.3
Barbus barbus (barbel)	Rheophil rheopar	middle	6	1.8	0	0.0
Chondrostoma nasus (nase)	Rheophil rheopar	middle	7	2.1	0	0.0
Cottus gobio (bullhead)	Rheophil rheopar	short	1	0.3	0	0.0
Esox lucius (pike)	Indifferent limnopar	short	4	1.2	0	0.0
Hucho hucho (Danube salmon)	Rheophil rheopar	middle	1	0.3	1	0.3
Leuciscus souffia agassizi (vairone)	Rheophil rheopar	short	4	1.2	0	0.0
Lota lota (burbot)	**Indifferent euryopar**	**middle**	**19**	**5.7**	**22**	**6.5**
Oncorhynchus mykiss (rainbow trout)	**Indifferent rheopar**	**not native**	**9**	**2.7**	**19**	**5.6**
Perca fluviatilis (E. perch)	Indifferent euryopar	short	25	7.5	4	1.2
Rutilus rutilus (roach)	**Indifferent euryopar**	**short**	**4**	**1.2**	**12**	**3.6**

Efficiency in relation to downstream fish stock

Species	Flow preference	Migration distance	Electrofishing Total n	%	Trap Total n	%
Abramis brama (bream)	Indifferent euryopar	middle	0	0	1	0.3
Alburnoides bipunctatus (schneider, spirlin)	Rheophil rheopar	short	6	1.8	0	0.0
Alburnus alburnus (bleak)	Indifferent euryopar	short	0	0.0	1	0.3
Barbus barbus (barbel)	**Rheophil rheopar**	**middle**	**6**	**1.8**	**0**	**0.0**
Chondrostoma nasus (nase)	**Rheophil rheopar**	**middle**	**7**	**2.1**	**0**	**0.0**
Cottus gobio (bullhead)	Rheophil rheopar	short	1	0.3	0	0.0
Esox lucius (pike)	Indifferent limnopar	short	4	1.2	0	0.0
Hucho hucho (Danube salmon)	Rheophil rheopar	middle	1	0.3	1	0.3
Leuciscus souffia agassizi (vairone)	Rheophil rheopar	short	4	1.2	0	0.0
Lota lota (burbot)	Indifferent euryopar	middle	19	5.7	22	6.5
Oncorhynchus mykiss (rainbow trout)	Indifferent rheopar	not native	9	2.7	19	5.6
Perca fluviatilis (E. perch)	Indifferent euryopar	short	25	7.5	4	1.2
Rutilus rutilus (roach)	Indifferent euryopar	short	4	1.2	12	3.6
Salmo trutta (brown trout)	Rheophil rheopar	short	106	31.7	88	26.0

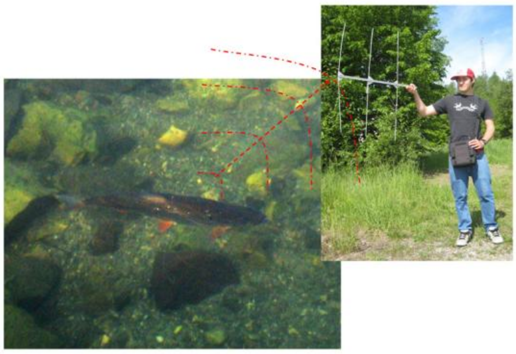
Size selectivity of fish pass – comparing fish sizes of lower ad upper trap

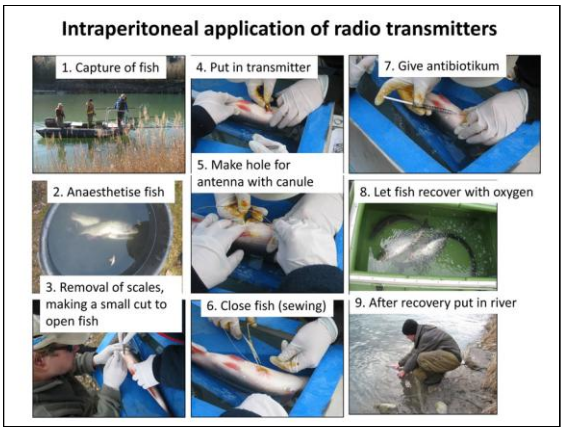


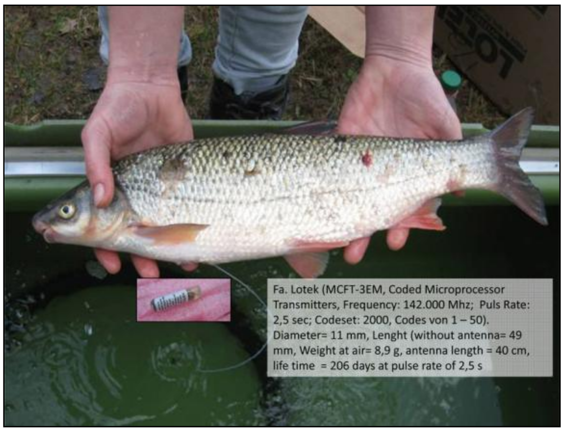
Correlation between migration data and abiotic data (Spearman rank correlation)

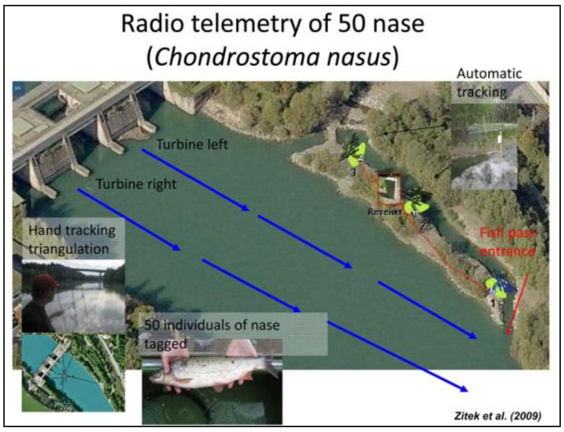
Spearman-Rho Korrelation		Burbot	Chub	Grayling	Brook charr	Roach	Total upper trap
Water level changes upstream (cm)	Correlation coeff.	,034	**,277(**)**	-,124	,022	**,207(*)**	**,197(*)**
	Sig.	,729	,004	,206	,827	,033	,043
Daily mean water level dowstream	Correlation coeff	**,399(**)**	**,288(**)**	-,076	,045	,064	**,299(**)**
	Sig.	,000	,003	,438	,645	,517	,003
Water level changes downstream (cm)	Correlation coeff	-,033	,188	-,072	**-,213(*)**	**,241(*)**	,132
	Sig.	,738	,053	,461	,028	,013	,177
Water temperature upper trap	Correlation coeff	,197(*)	**,380(**)**	**-,203(*)**	,020	,133	**,326(**)**
	Sig.	,043	,000	,037	,836	,175	,001
Water temperature lower trap	Correlation coeff	,184	**,400(**)**	**-,196(*)**	,026	,176	**,351(**)**
	Sig.	,059	,000	,044	,791	,070	,000

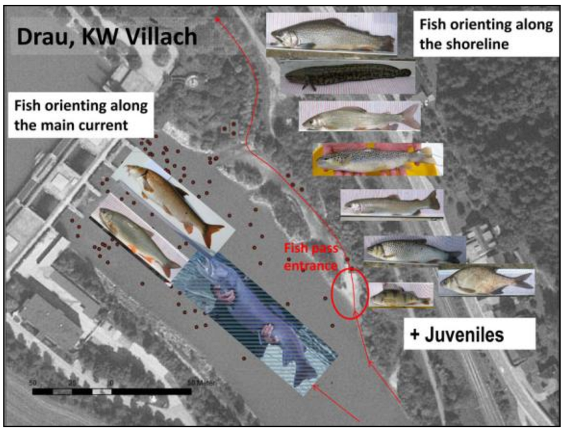
Radio telemetry

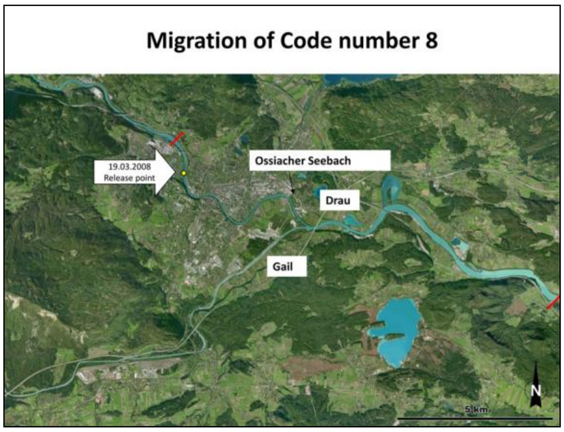


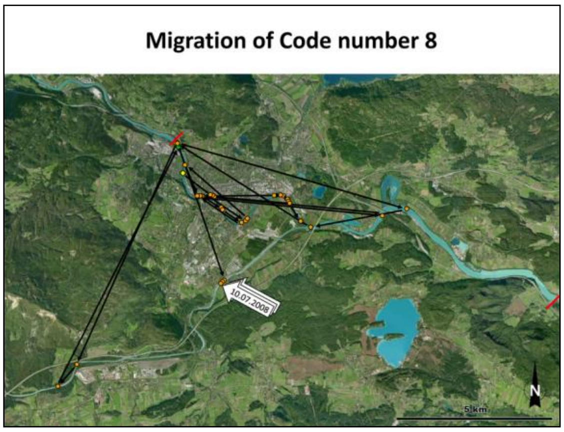

Intraperitoneal application of radio transmitters
1. Capture of fish
2. Anaesthetise fish
3. Removal of scales, making a small cut to open fish
4. Put in transmitter
5. Make hole for antenna with canule
6. Close fish (sewing)
7. Give antibiotikum
8. Let fish recover with oxygen
9. After recovery put in river

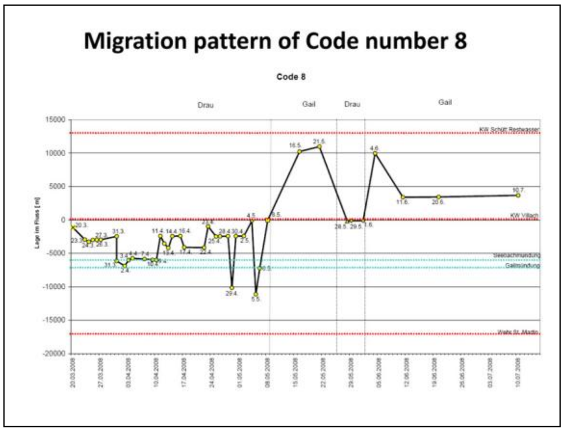

Fa. Lotek (MCFT-3EM, Coded Microprocessor Transmitters, Frequency: 142.000 Mhz; Puls Rate: 2,5 sec; Codeset: 2000, Codes von 1 – 50). Diameter= 11 mm, Lenght (without antenna= 49 mm, Weight at air= 8,9 g, antenna length = 40 cm, life time = 206 days at pulse rate of 2,5 s

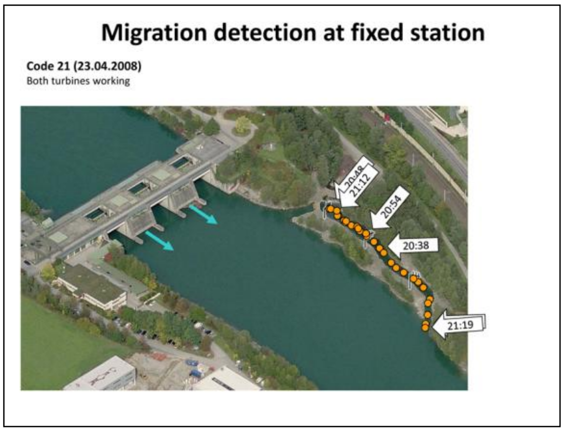

Radio telemetry of 50 nase (*Chondrostoma nasus*)
Automatic tracking
Turbine left
Turbine right
Hand tracking triangulation
Fish pass entrance
50 individuals of nase tagged
Zitek et al. (2009)

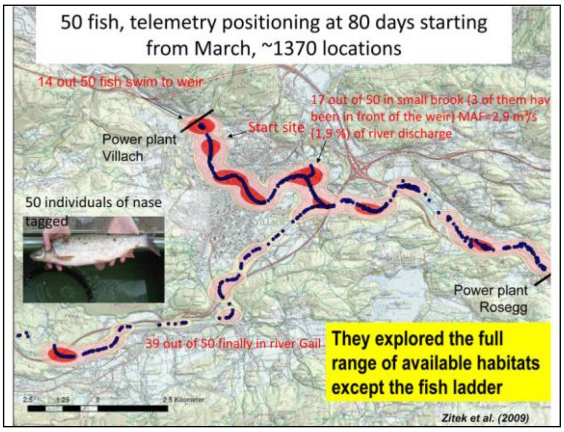

Drau, KW Villach
Fish orienting along the shoreline
Fish orienting along the main current
Fish pass entrance
+ Juveniles

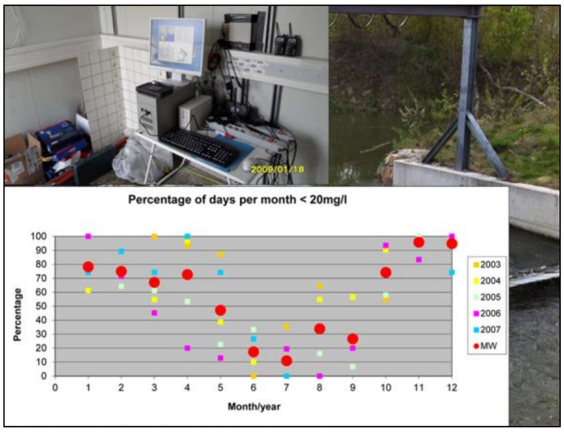

Migration of Code number 8
19.03.2008
Release point
Ossiacher Seebach
Drau
Gail
5 km

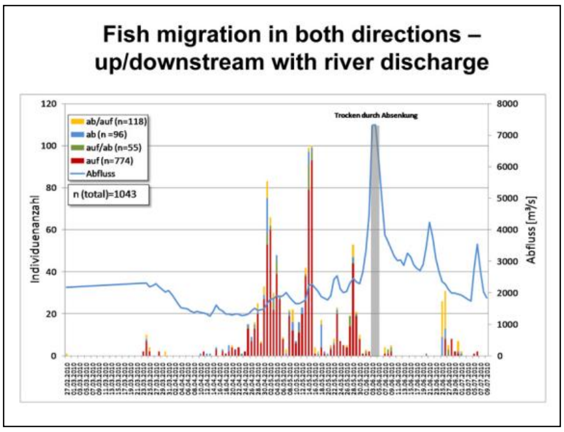

Migration of Code number 8
10.07.2008
5 km

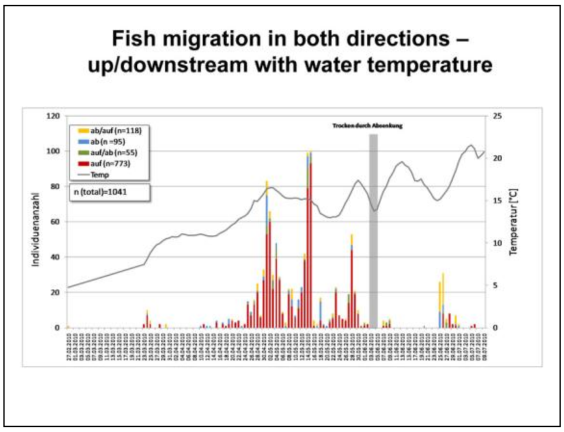

Migration pattern of Code number 8
Code 8
Drau
Gail
Drau
Gail
KW Villach

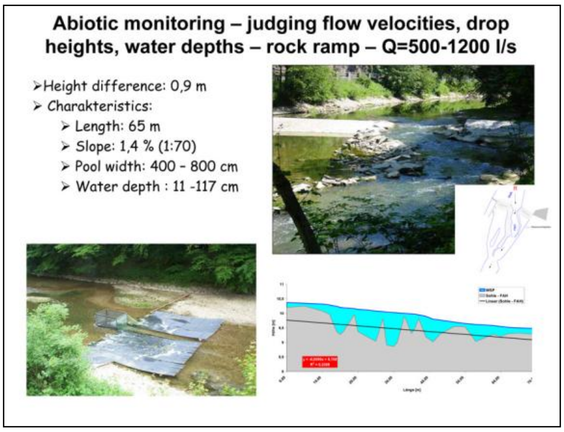

Migration detection at fixed station
Code 21 (23.04.2008)
Both turbines working
20:49
21:12
20:54
20:38
21:19

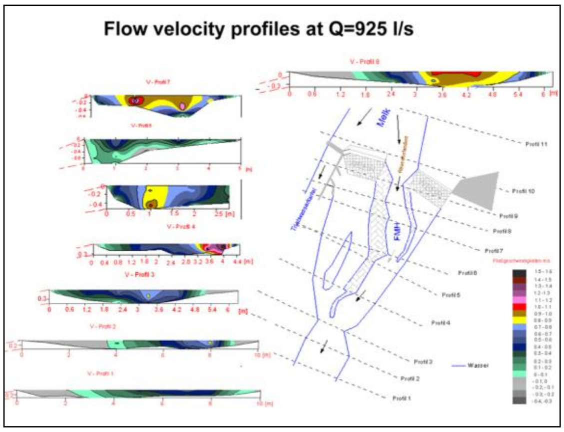

50 fish, telemetry positioning at 80 days starting from March, ~1370 locations
14 out 50 fish swim to weir
Power plant Villach
Start site
17 out of 50 in small brook (3 of them hav been in front of the weir) MAF=2,9 m³/s (1,9 %) of river discharge
50 individuals of nase tagged
Power plant Rosegg
39 out of 50 finally in river Gail
They explored the full range of available habitats except the fish ladder
Zitek et al. (2009)

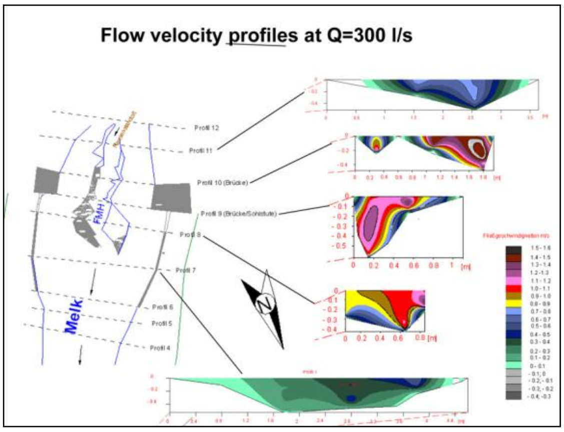

2009/01/18
Percentage of days per month < 20mg/l
Percentage
Month/year
2003
2004
2005
2006
2007
MW

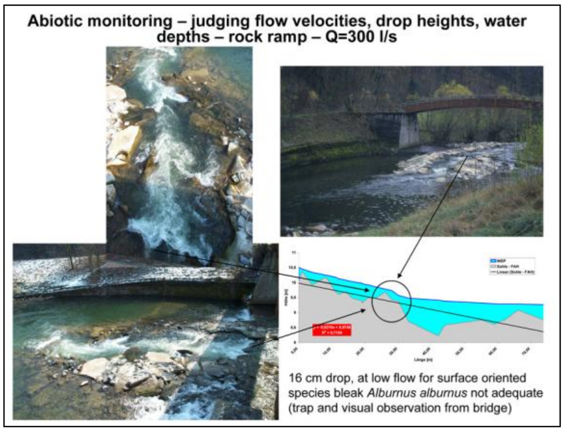

Fish migration in both directions – up/downstream with river discharge
ab/auf (n=118)
ab (n =96)
auf/ab (n=55)
auf (n=774)
Abfluss
n (total)=1043
Trocken durch Absenkung
Individuenanzahl
Abfluss [m³/s]


Fish migration in both directions – up/downstream with water temperature
ab/auf (n=118)
ab (n =95)
auf/ab (n=55)
auf (n=773)
Temp
n (total)=1041
Trocken durch Absenkung
Individuenanzahl
Temperatur [°C]


Abiotic monitoring – judging flow velocities, drop heights, water depths – rock ramp – Q=500-1200 l/s
➢Height difference: 0,9 m
➢ Charakteristics:
➢ Length: 65 m
➢ Slope: 1,4 % (1:70)
➢ Pool width: 400 - 800 cm
➢ Water depth : 11 -117 cm

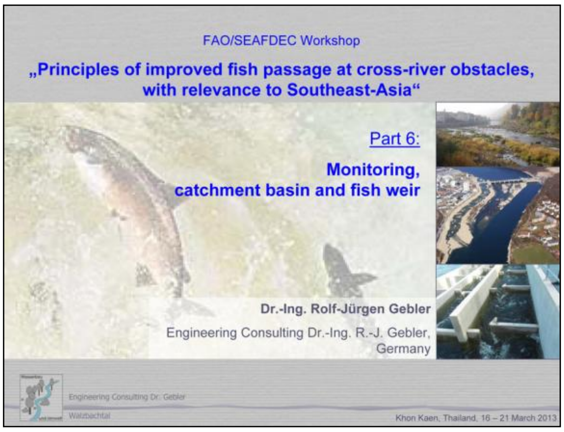

Flow velocity profiles at Q=925 l/s
Melk
FMH
Profil 11
Profil 10
Profil 9
Profil 8
Profil 7
Profil 6
Profil 5
Profil 4
Profil 3
Profil 2
Profil 1
Wasser

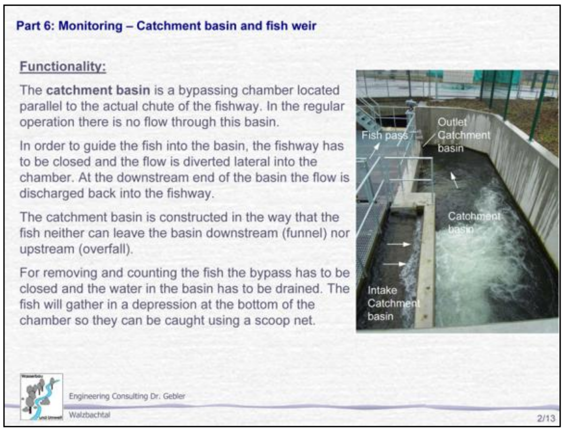

Flow velocity profiles at Q=300 l/s
Profil 12
Profil 11
Profil 10 (Brücke)
Profil 9 (Brücke/Sohlstufe)
Profil 8
Profil 7
Profil 6
Profil 5
Profil 4
FMH
Melk
Fließgeschwindigkeiten m/s

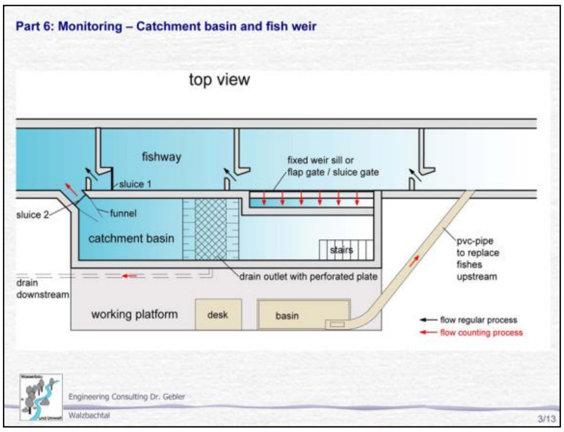

Abiotic monitoring – judging flow velocities, drop heights, water depths – rock ramp – Q=300 l/s
16 cm drop, at low flow for surface oriented species bleak Alburnus alburnus not adequate (trap and visual observation from bridge)

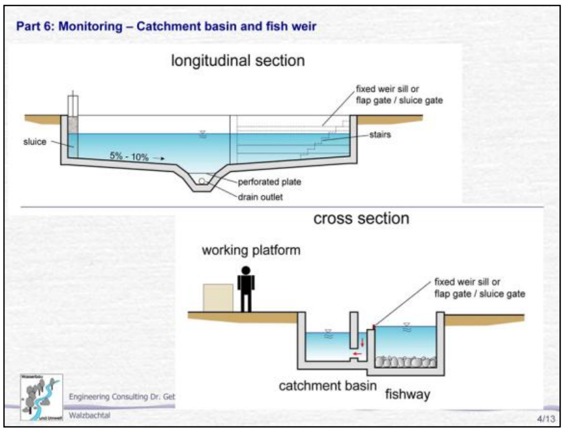
MONITORING, CATCHMENT BASIN AND FISH WEIR

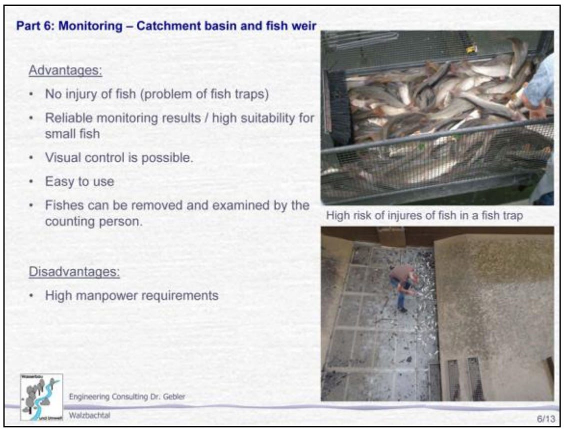
By Dr. -Ing Rolf-Jürgen Gebler

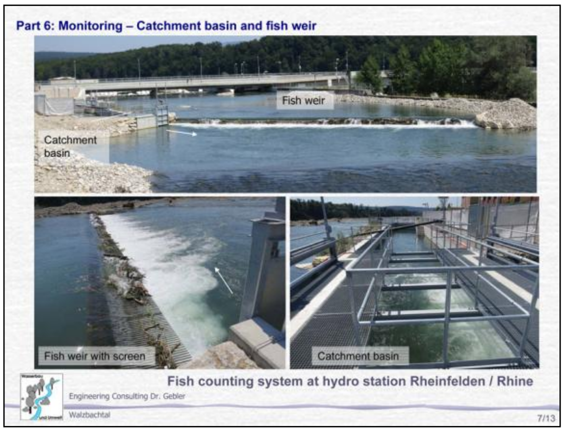


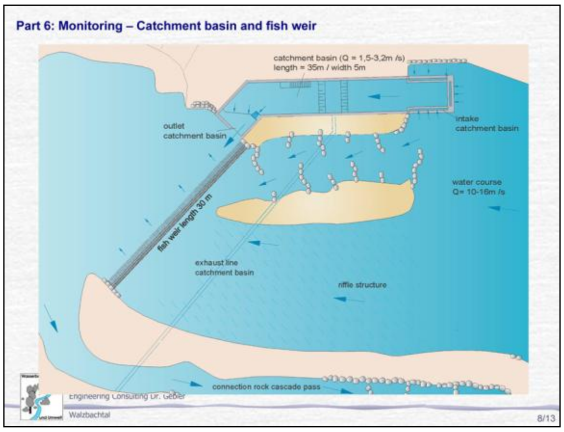


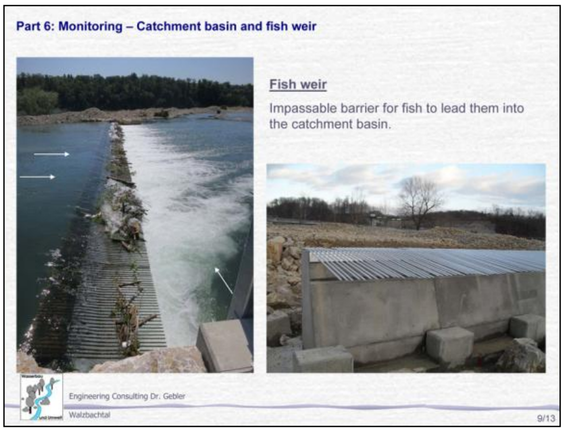







Part 6: Monitoring – Catchment basin and fish weir
Fish weir
Catchment basin
Fish weir with screen
Catchment basin
Fish counting system at hydro station Rheinfelden / Rhine
Engineering Consulting Dr. Gebler
Walzbachtal
7/13


Part 6: Monitoring – Catchment basin and fish weir
catchment basin (Q = 1,5-3,2m³/s)
length = 35m / width 5m
outlet catchment basin
intake catchment basin
water course Q= 10-16m³/s
fish weir length 30 m
exhaust line catchment basin
riffle structure
connection rock cascade pass
Walzbachtal
8/13


Part 6: Monitoring – Catchment basin and fish weir
Fish weir
Impassable barrier for fish to lead them into the catchment basin.
Engineering Consulting Dr. Gebler
Walzbachtal
9/13

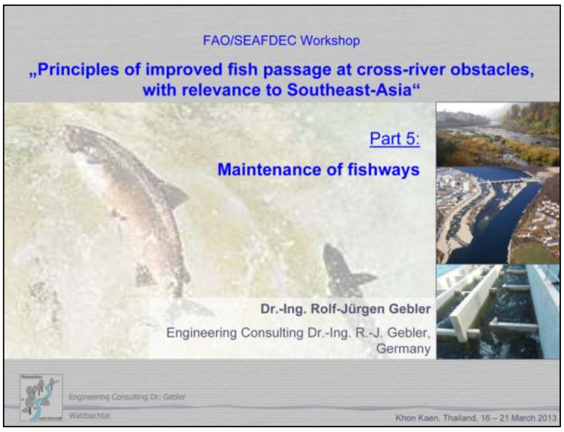

Part 6: Monitoring – Catchment basin and fish weir
Engineering Consulting Dr. Gebler
Walzbachtal
10/13

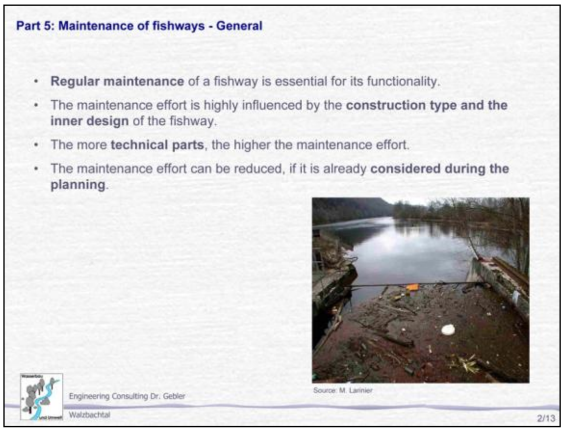

Part 6: Monitoring – Catchment basin and fish weir
Left: Sluice gate at the inlet
Below: Funnel at the outlet/fish entrance
Engineering Consulting Dr. Gebler
Walzbachtal
11/13

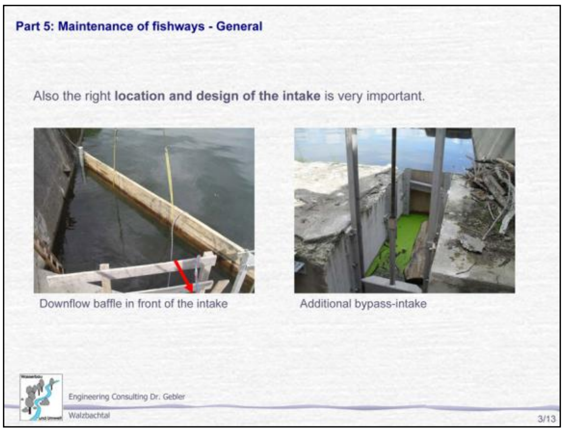

Part 6: Monitoring – Catchment basin and fish weir
source: Energiedienst
Engineering Consulting Dr. Gebler
Walzbachtal
12/13

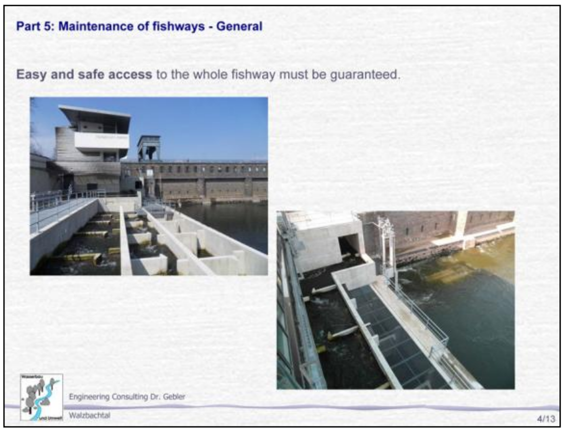
MAINTENANCE OF FISHWAYS

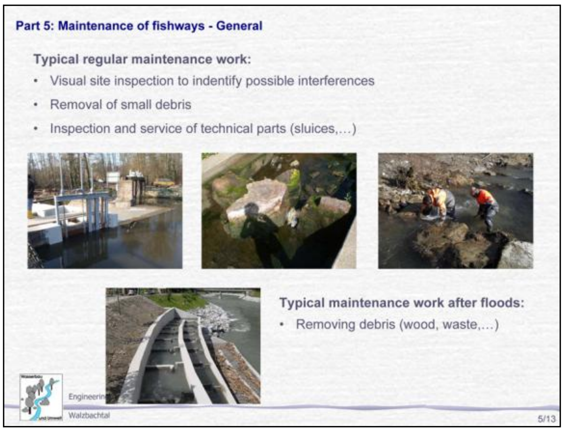
By Dr. -Ing Rolf-Jürgen Gebler

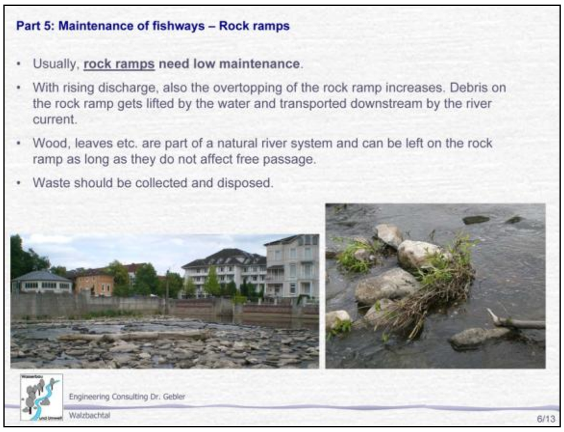


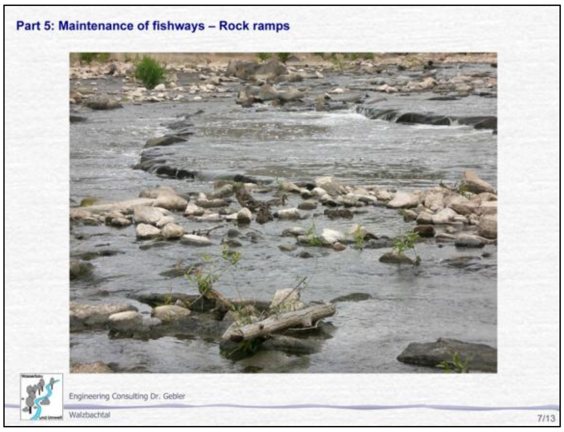


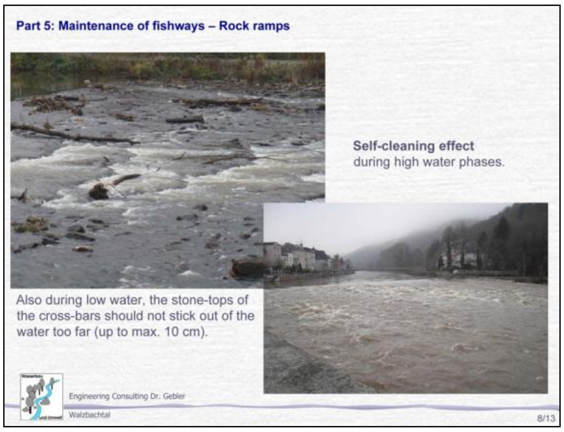


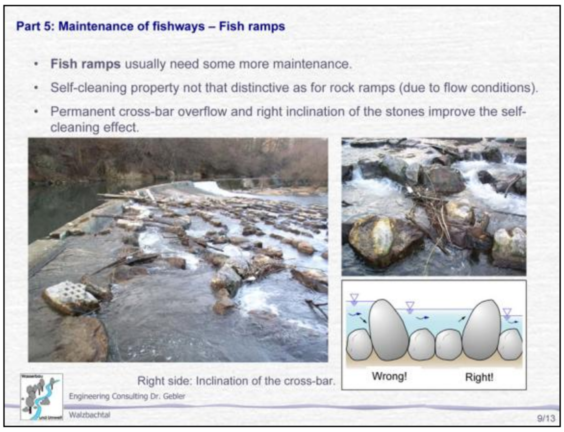


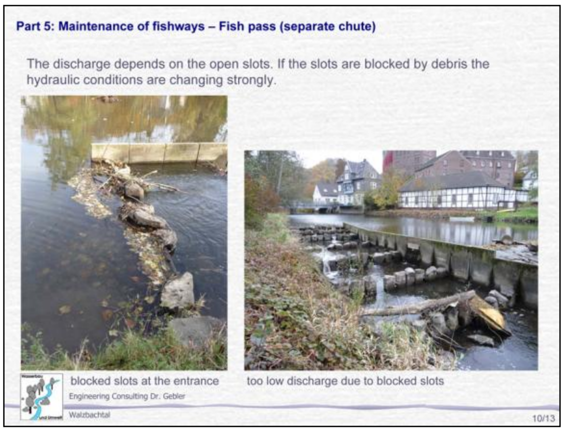


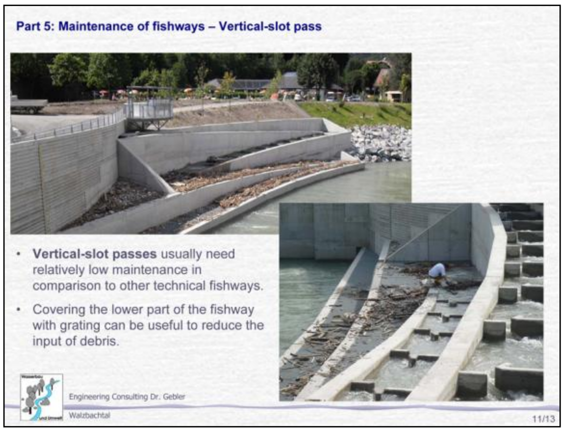


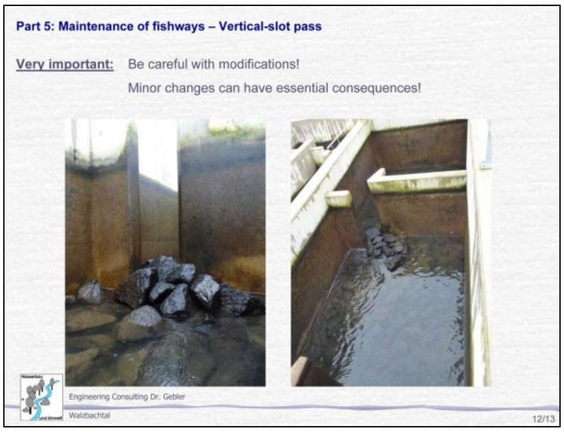

Part 5: Maintenance of fishways – Rock ramps
Engineering Consulting Dr. Gebler
Walzbachtal
7/13


Part 5: Maintenance of fishways – Rock ramps
Self-cleaning effect
during high water phases.
Also during low water, the stone-tops of the cross-bars should not stick out of the water too far (up to max. 10 cm).
Engineering Consulting Dr. Gebler
Walzbachtal
8/13


Part 5: Maintenance of fishways – Fish ramps
• Fish ramps usually need some more maintenance.
• Self-cleaning property not that distinctive as for rock ramps (due to flow conditions).
• Permanent cross-bar overflow and right inclination of the stones improve the self-cleaning effect.
Right side: Inclination of the cross-bar.
Wrong!
Right!
Engineering Consulting Dr. Gebler
Walzbachtal
9/13


Part 5: Maintenance of fishways – Fish pass (separate chute)
The discharge depends on the open slots. If the slots are blocked by debris the hydraulic conditions are changing strongly.
blocked slots at the entrance
too low discharge due to blocked slots
Engineering Consulting Dr. Gebler
Walzbachtal
10/13


Part 5: Maintenance of fishways – Vertical-slot pass
• Vertical-slot passes usually need relatively low maintenance in comparison to other technical fishways.
• Covering the lower part of the fishway with grating can be useful to reduce the input of debris.
Engineering Consulting Dr. Gebler
Walzbachtal
11/13


Part 5: Maintenance of fishways – Vertical-slot pass
Very important: Be careful with modifications!
Minor changes can have essential consequences!
Engineering Consulting Dr. Gebler
Walzbachtal
12/13

Annex 30

ECOLOGICAL REQUIREMENTS OF DOWNSTREAM MIGRATION

By Dr. Andreas Zitek

Ecological requirements downstream migration

DI Dr. Andreas Zitek, MSc
Austria

Known types of downstream migration

- Post spawning migrations
- Larval drift
- Juvenile drift or downstream migration
- Wintering migrations
- Catastrophic drift

Documented post spawning migrations of potamodromous fish

Pike				
Ovidio & Philippart (2005)	15,7	↑	Gesamt	L
	20	↓	Gesamt	NL
Asp				
Fredrich (2003)	166	↑	Gesamt	L
	166	↓	Gesamt	NL
Dace				
Clough et al. (1998)	≤ 0,2	↑	Gesamt	NL
	3,5-14	↓	Gesamt	NL
Chub				
Fredrich et al. (2003)	25	↑	Gesamt	L
	15	↓	Gesamt	NL
Roach				
Geeraerts et al. (2007)	6,5	↑	Gesamt	L
Geeraerts et al. (2007)	6,5	↓	Gesamt	NL

Own radio telemetry study for nase

Various forms of downstream migration

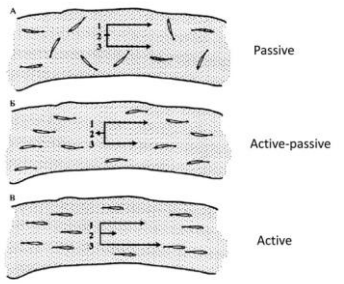
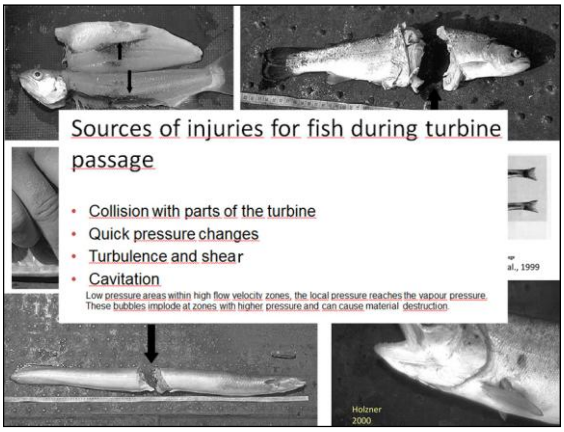


Figure 4.7 Orientation and velocity of various forms of downstream migration

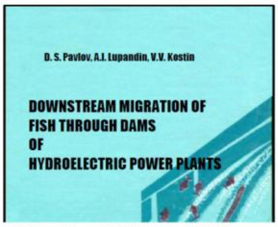
Forms: A – passive, Б – active – passive, B – active; 1 – current velocity; 2 – velocity of fish movements, 3 – fish downstream migration velocity (total)

Pavlov et al. 2002



Assessing the efficiency of fish ladders - Downstream migration

- Experimental studies
- Field type monitoring studies
  - Marking experiments and/or downstream nets
    - percentage of successful downstream migrants
    - analyzing injuries
- Some studies available, more studies needed (each power plant an individual, behaviour of most fish species during downstream migration unknown)
- Niels Jepsen:
  - –The **only way to insure good fish passage seems to be to spill or divert a lot of water!**
  - –Despite using hundreds of millions of dollars on the screening facilities in Columbia river (for helping downstream migrating smolts through the hydro-powerstations), **the most effective way is to spill a lot of water** and let the smolts pass over the spillways…



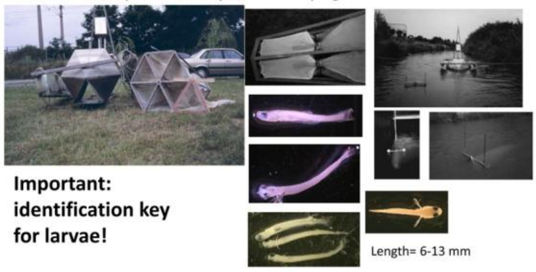
Pavlov, D. S., A. I. Lupandin, and V. V. Kostin. 2002. Downstream Migration of Fish Through Dams of Hydroelectric Power Plants. Trans. T. Albert, trans. ed. G. F. Cada. ORNL/TR-02/02. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Available on-line from the U.S. Department of Energy Hydropower Program [http://hydropower.id.doe.gov/] and on CD from:

Glenn F. Cada, Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6036, U.S.A.

Sampling drifting larvae

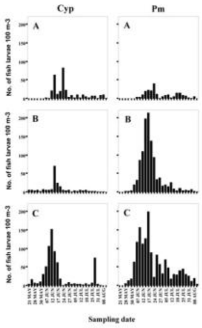
Automatic drift sampler for 24 hour permanent sampling



Important: identification key for larvae!

Length= 6-13 mm

Spring/summer – seasonal larval drift results for Cyprinids and *Proterorhinus marmoratus*

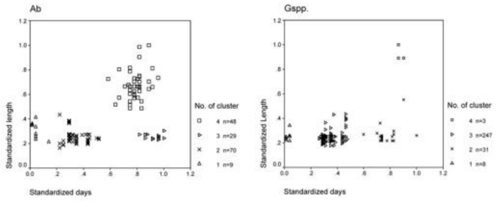


Simultaneous measurement of larval drift at 3 different sites at 28 days between 21 May and 14 August.

Number of fish larvae 100 m-3 captured at site A, B and C by drift nets divided into Cyp Cyprinidae and Pm *Proterorhinus marmoratus* (Pallas), on each sampling date during 21 May and 14 August 1996; six sampling dates are lacking at site A.

Zitek et. al 2004

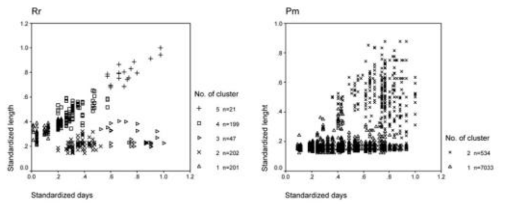
Seasonal drift patterns for different species



Seasonal patterns of larval drift by cluster analyses for.

Zitek et al. 2004

Seasonal larval drift patterns for different species



Seasonal patterns of larval drift by cluster analyses for Rr – *Rutilus rutilus* and Pm – *Proterorhinus marmoratus*

Zitek et al. 2004

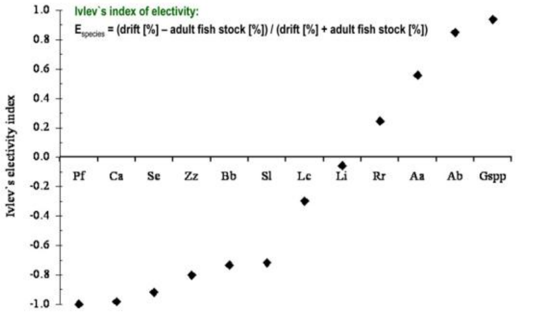
Classification of drifting larval fish according to developmental stages in drift and numer of occurrence of early developmental stages (=number of spawning events)

Dominant larval stages in drift (x: > 5%, -: < 5% of total catch per species) and number of spawning events determined by the repeated occurrence of early larval stages in drift.

Species	L1-L2	L3-L6	J1-J2	No. of spawning events or continuous spawning activity
Abramis brama (L.)	x	x	x	3
Alburnus alburnus (L.)	x	x	-	3
Aspius aspius (L.)	-	x	x	2
Barbus barbus (L.)	x	x	-	continuous
Gobio spp.	x	-	-	3
Leuciscus cephalus (L.)	x	x	-	3
Leuciscus idus (L.)	x	-	-	2
Proterorhinus marmoratus (Pallas)				continuous
Rutilus rutilus (L.)	x	x	x	>3 to continuous

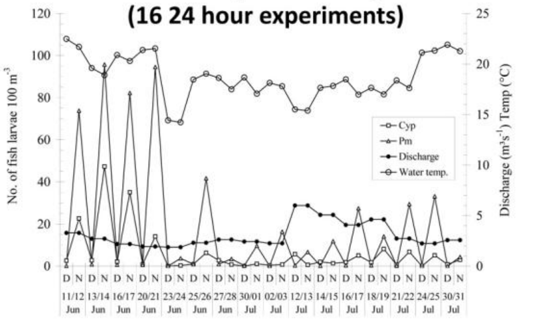
Zitek et. al. 2004

Drift index of different fish species – Ivlev`s index of electivity



Zitek et al. 2004

Spring summer larval drift – diurnal differences between 21. May und 14. August 1996 (16 24 hour experiments)



Zitek et al. 2004

Spring/summer larval drift – diurnal differences

	Day		Dusk		Night		Dawn		Total n
Species	%	n	%	n	%	n	%	n	
Abramis brama (L.)	47	22	5	2	45	16	3	1	41
Alburnus alburnus (L.)	29	80	4	11	63	153	5	13	257
Aspius aspius (L.)	38	3	0	0	40	5	22	2	10
Barbus barbus (L.)	0	0	0	0	100	12	0	0	12
Cyprinidae	18	133	5	39	67	448	10	58	678
Gobio spp.	8	10	5	5	83	86	4	4	105
Leuciscus cephalus (L.)	0	0	33	6	56	10	11	2	18
Leuciscus idus (L.)	9	9	5	7	64	70	22	19	105
Proterorhinus marmoratus (Pallas)	2	39	2	46	95	1612	1	23	1720
Rutilus rutilus (L.)	7	9	5	8	72	96	16	17	130
Total	7	305	3	124	86	2508	4	139	3076

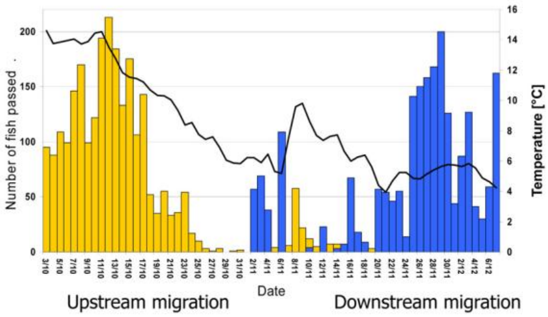
Day (0600-0800) and (1000-1800)

Dusk (2000-2200) Night (2200-0400)

Dawn (0400-0600).

Zitek et al. al 2004

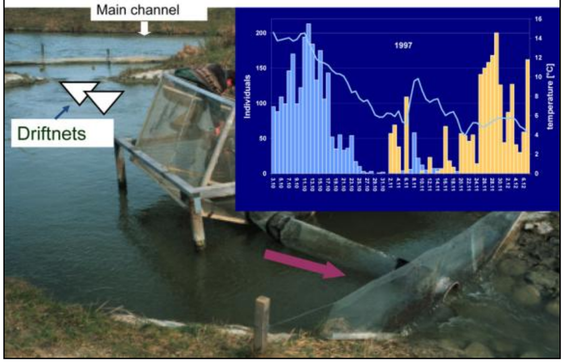
Autumn/winter drift, up- and downstream migration of juveniles (03.10. - 06.12.1997)



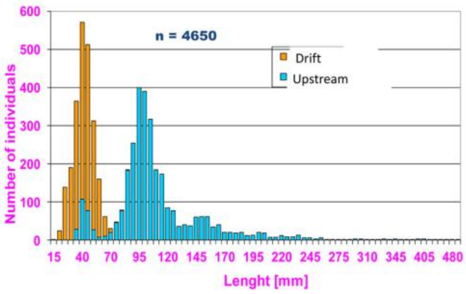
Classification of species with regard to their occurrence in drift (Lit. Review, Zitek in prep.)

- **"Accidental" – 10 species single individuals**
  A. ballerus (L.), *A. sapa* (L.), *Carassius carassius* (L.), *Cobitis taenia* (L.), *Cottus gobio* (L.), *Gymnocephalus baloni* (L.), *Gymnocephalus schrätzer* (L.), *Sander volgensis* (Gmelin), *Silurus glanis* (L.), *Vimba vimba* (L.)
- **"Facultative/never abunda**nt (<5%)" – 10 species
  Cyprinus carpio (L.), *Gasterosteus aculeatus* (L.), *Leucaspius delineatus* (L.), *Neogobius kessleri* (Günther), *Pelecus cultratus* (L.), *Tinca tinca* (L.), *Zingel streber* (Siebold), *Zingel zingel* (L.).
- **"Obligatory, sometimes with very high abundances" - 15 species**
  A. bjoerkna (L.), *A. brama* (L.), *A. alburnus* (L.), *A. aspius* (L.), *B. barbus* (L.), *C. auratus gibelio* (Bloch), *C. nasus* (L.), *Gobio spp.*, *L. cephalus* (L.), *L. idus* (L.), *L. leuciscus* (L.), *Rhodeus sericeus* (Pallas), *R. rutilus* (L.), *Sander lucioperca* (L.), *Scardinius erythrophthalmus* (L.).
- **"Facultative present/sometimes with high abundances dependent on different factors** (e.g. habitat, timing and location of drift sampling, general occurrence, spawning success, drift period limited to early stages)" – 8 species
  Barbatula barbatula (L.), *Lepomis gibbosus* (L.), *Neogobius fluviatilis* (L.), *Neogobius melanostomus* (Pallas), *Perca fluviatilis* (L.), *Phoxinus phoxinus* (L.), *Proterorhinus marmoratus* (Pallas), *Pseudorasbora parva* (Temminck & Schlegel),

1997 *Trap at the bypass - October*

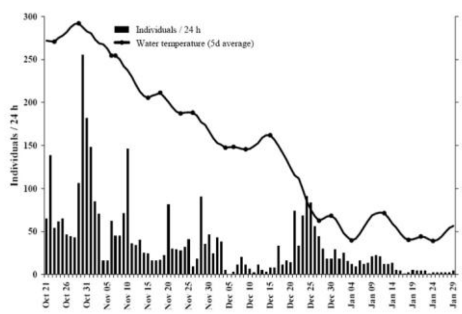


Length frequency distribution, Juveniles autumn up- and downstream migration 1997

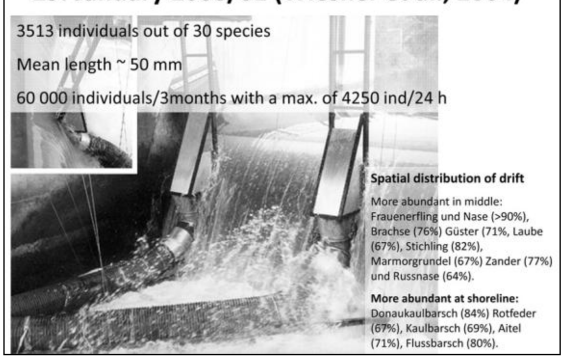


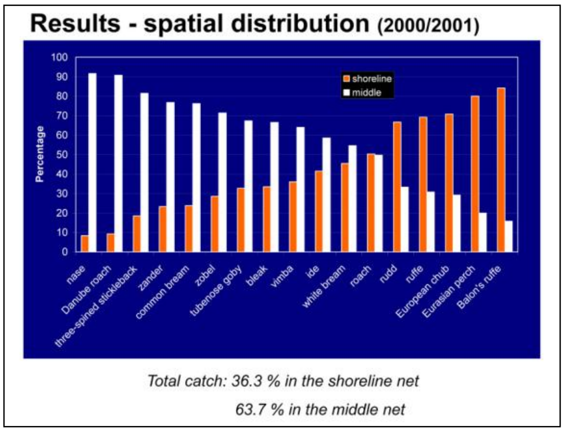
Sampling drifting juvenile fish at a weir

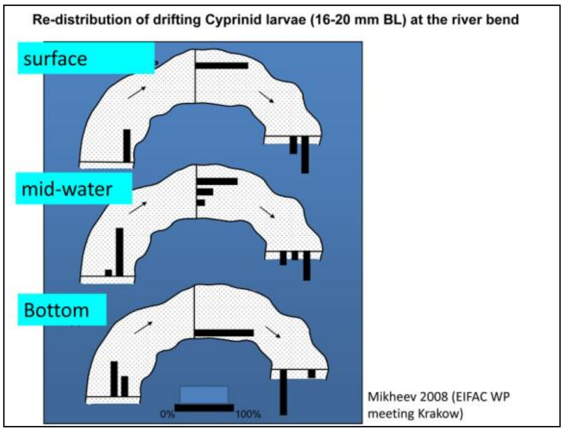
Juvenile autumn/winter drift, 20. October – 29. January 2000/01 (Wiesner et al., 2004)

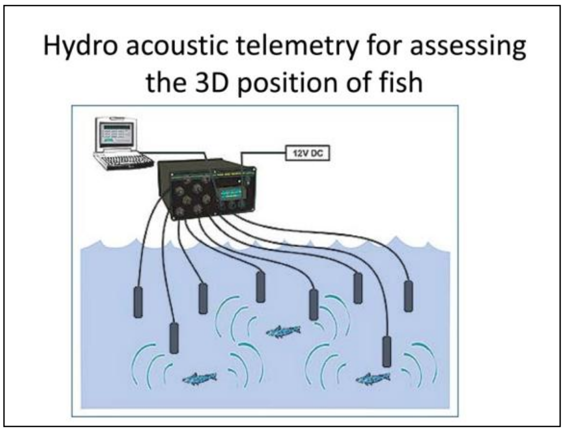


Juvenile autumn/winter drift, 20. October – 29. January 2000/01 (Wiesner et al., 2004)

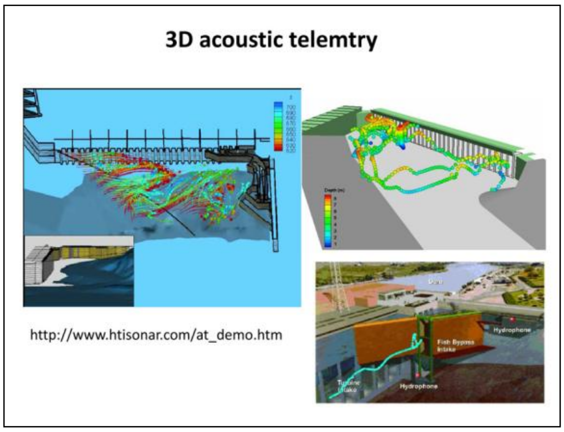


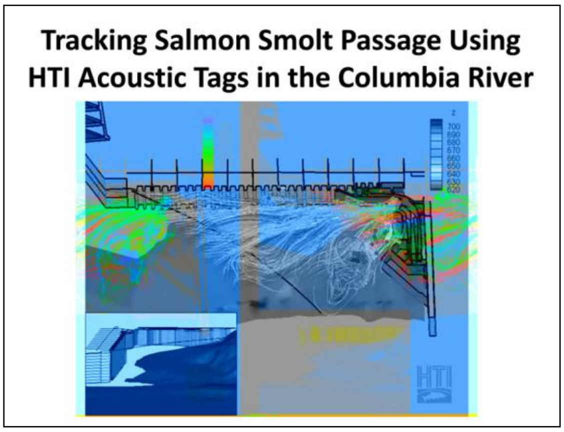

Results - spatial distribution (2000/2001)
Percentage
shoreline
middle
nase
Danube roach
three-spined stickleback
zander
common bream
zobel
tubenose goby
bleak
vimba
ide
white bream
roach
rudd
ruffe
European chub
Eurasian perch
Balon's ruffe
Total catch: 36.3 % in the shoreline net
63.7 % in the middle net


Re-distribution of drifting Cyprinid larvae (16-20 mm BL) at the river bend
surface
mid-water
Bottom
0%
100%
Mikheev 2008 (EIFAC WP meeting Krakow)

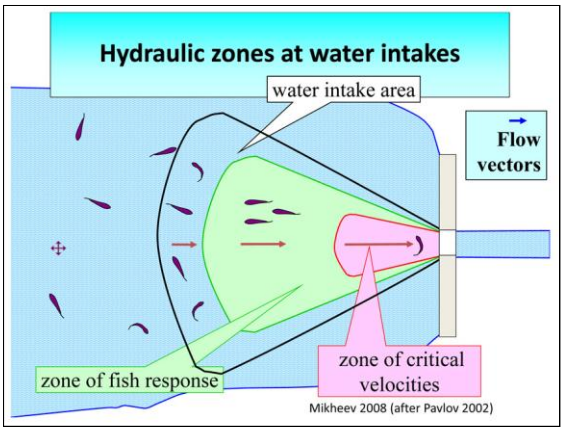

Hydro acoustic telemetry for assessing the 3D position of fish
12V DC


3D acoustic telemtry
HTI
Acoustic Tag Demos
http://www.htisonar.com/at_demo.htm

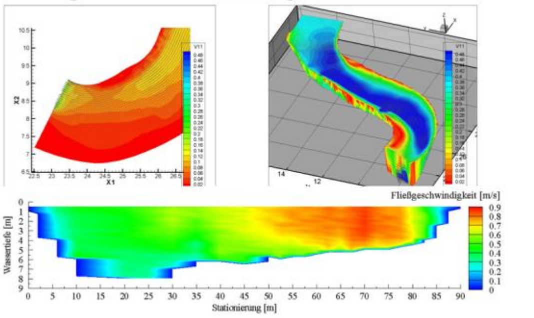

3D acoustic telemtry
http://www.htisonar.com/at_demo.htm


Tracking Salmon Smolt Passage Using HTI Acoustic Tags in the Columbia River
HTI


PIT Tag (Passive Integrated Transponder)
Copyright: Olle Calles

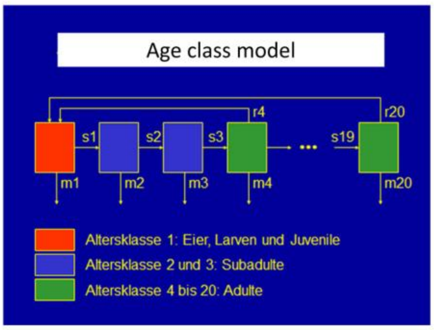

Hydraulic zones at water intakes
water intake area
Flow vectors
zone of fish response
zone of critical velocities
Mikheev 2008 (after Pavlov 2002)

Flow velocity distrubution in impoundment during different discharges

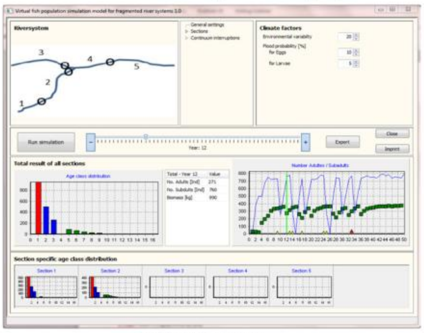


Schneider, TU Graz

Individual based model of fish populations



Simulation tool to assess the potential effects of turbine mortality on fish populations



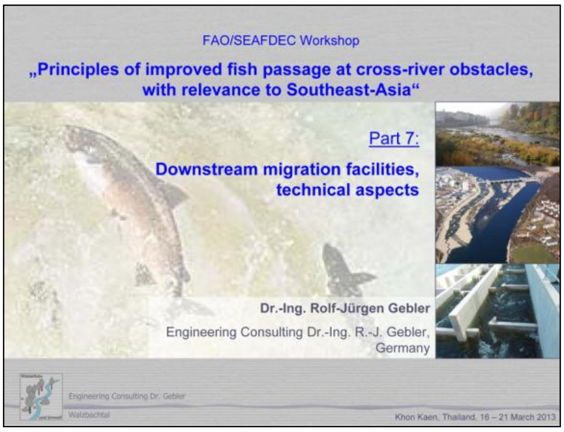
Zitek and Vogl (2013)

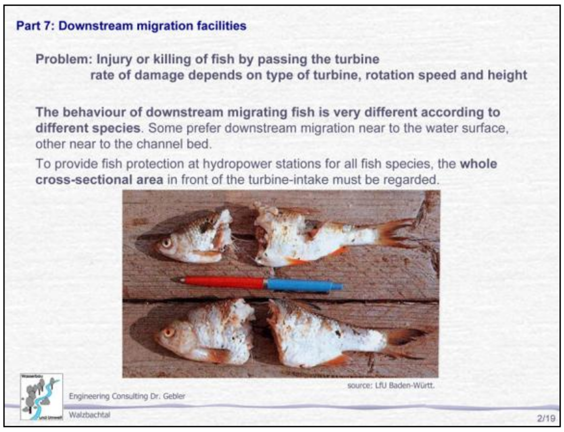
Summary

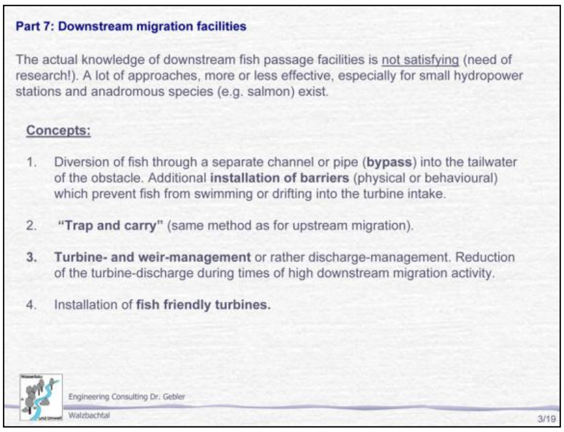
- Different types of downstream migrations (Adults, Juveniles, Larvae)
- Seasonal and diurnal rhythm of migration
- Distinct spatial distribution of fish
- Migration in very in high numbers
- Severe injuries of fish might occur during tubine passage due to
  - Collision with parts of the turbine
  - Quick pressure changes
  - Turbulence and shear
  - Cavitation
- Lack of knowledge for individual situations
- Methods include netting of downstream migrants, Pit tagging and acoustic telemetry
- Biological data related to abiotic conditions (temperature etc., and flow velocity distrbutions in rivers and dams, pressure changes, turbine passage etc.) might yield the most relevant insight in the potential management of downstream migration
- Simulations might help better understand of different degrees of larval mortality on fish populations
  - Multiple dams have to be considered

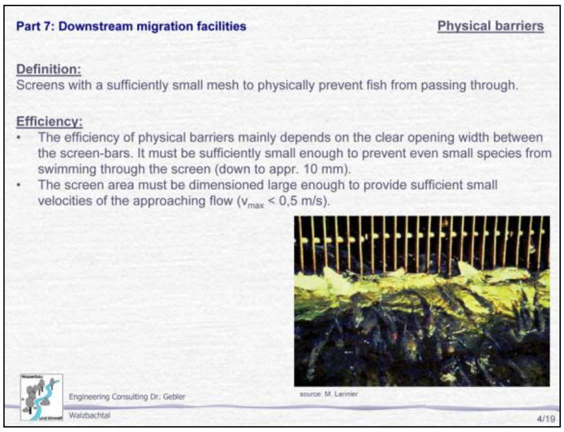
TECHNICAL ASPECT OF DOWNSTREAM MIGRATION FACILITIES

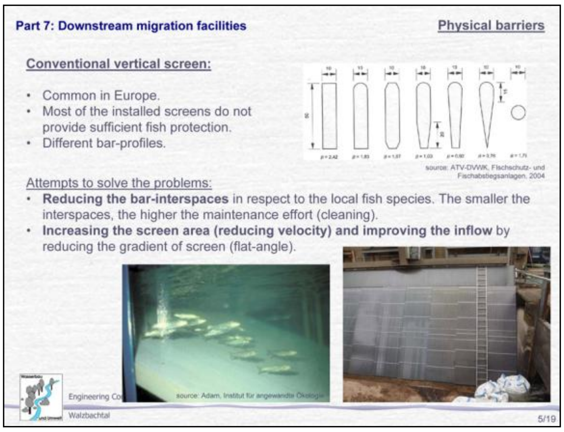
By Dr. -Ing Rolf-Jürgen Gebler







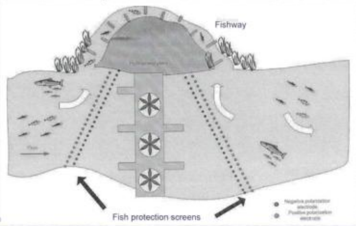




Part 7: Downstream migration facilities — Behavioral barriers

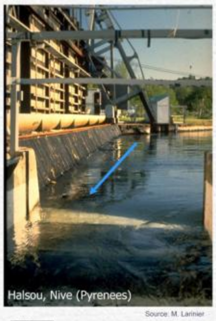
Definition:
Visual, acoustic, electrical or hydrodynamic stimuli, either to scare fishes away or to guide them.

Efficiency:
- Some types are more or less efficient for special cases, but **in general low reliability**.
- Behavior barriers are **still experimental** and thus handled with care.



Source: Doc. Dr. hab. W. Wisniewolski

Part 7: Downstream migration facilities — Bypass



Source: M. Larinier

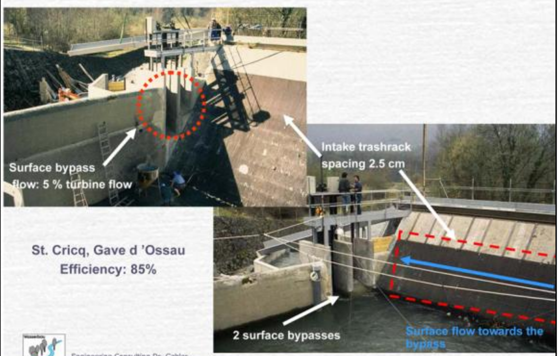
In France, several **facilities for downstream migration of Salmon Smolts** were built and tested for its efficiency.

The following pictures and results are extracted from "Upstream an downstream fish passage facilities - design criteria, selection and monitoring" (M. Larinier, France).

The efficiency of bypasses is determined by:
- Spacing of the bars.
- Location of the bypass entrance (close to the trash rack).
- existence of a tangential (surface) velocity guiding fish towards the bypass entrance.
- Bypass discharge: 2-5 % of the turbine discharge.

Efficiency as a function of the clear opening width of the bars:
- 5-6 cm: 10-20 %
- 3-4 cm: 60-70 %
- 2,5 cm: 80-90 %

Part 7: Downstream migration facilities — Bypass



St. Cricq, Gave d 'Ossau
Efficiency: 85%

Part 7: Downstream migration facilities — Examples

Hydropower station Glatfelter, Murg (D)

- Funnel next to the trash rack (near the water surface) with additional flume into the tailwater.
- Q_{Bypass} = 0,5 m³/s (4 % of the turbine discharge)
- Vertical screen (s = 15 mm)



Part 7: Downstream migration facilities — Examples


WWF Aueninstitut Rastatt, Murg (D)

- Constantly overflowed trash rack with attached chute and bypass on one side.
- Vertical screen (s = 10 mm)

Sea lamprey in chute.

Part 7: Downstream migration facilities — Downstream surface Bypasses

- Surface bypasses installed at a new powerplant (Castetarbe, Gave de Pau). Efficiency > 95% (fish pass + bypasses + spilling)

Source Slide: M. Larinier

Part 7: Downstream migration facilities — Physical barriers

Horizontal screen:

- New design, several facilities were built in Germany during the last years.
- Very positive feedback from plant operators and ecologists.
- Very efficient combination with bypasses possible.

source: Hydro-Energie Roth GmbH

Part 7: Downstream migration facilities — Examples

Hydropower station Planea, Saale (D)

- Horizontal screen (s = 20 mm)
- Q_{Bypass} = 3,0 m³/s (6 % of the turbine discharge)

Part 7: Downstream migration facilities — Examples

Hydropower station Planea, Saale (D)

Trashrack cleaning-machine

Hydraulic bypass gate

Part 7: Downstream migration facilities — Turbine-management

The following possibilities should be considered:

1. **Temporary reducing the turbine discharge** and thus the flow velocities in front of the intake/screen.
2. **Optimization of the turbine blade-angle** for safe downstream fish passage.
3. **Temporary decommissioning of several machines** and specific weir-opening to provide save passage for fish.
4. **Temporary decommissioning of the whole power station.**

Part 7: Downstream migration facilities — Fish friendly turbines

Source: Hydrowatt, Karlsruhe (D)

Water wheel

Suitable for small hydro stations, low efficiency compared to other turbines.

Hydrodynamic screw with low rotational frequency

Part 7: Downstream migration facilities — Fish friendly turbines new design in progress

Alden turbine

Source: Voith

Minimum Gap Runner

Source: Voith

Annex 32

SUMMARY OF THE WORKSHOP EVALUATION

At the end of the Workshop, participants were requested to provide ***feedback on different evaluation criteria***, of which the results could be summarized as follows:

Criteria	Percentage of respondents (%)					Average score
	Very good (5)	Good (4)	Moderate (3)	Poor (2)	Very poor (1)	
1. Content (topics, presentations, and time allocation)	**81.8**	12.1	6.1	0	0	4.76
2. Resource persons	**75.8**	21.2	3.0	0	0	4.73
3. Documentations and materials	37.5	**43.8**	18.8	0	0	4.19
4. Interaction/inputs from participants	37.5	**50.0**	12.5	0	0	4.25
5. Excursion programs	**45.5**	36.4	18.2	0	0	4.27
6. Administrative/logistics arrangements and other services	**59.4**	37.5	3.1	0	0	4.56

(Summarized from a total of 33 respondents)

The results showed that majority of participants found that the content of the workshop, the resource persons, the administrative/logistics arrangement, and the excursion programs are very good; while the interaction/inputs from participants and documentations and materials are good.

On the question ***whether the Workshop met participants' expectation***, 87.8 % of respondents indicated that the workshop met their expectation, 6.1% indicated that the workshop partly met their expectation, while another 6.1% did not give expression on this.

On the inquiry on ***the aspects that participants found most useful in this Workshop***, followings were areas identified as the most useful:
- Knowledge on fish passage including its design (66.7%)
- Knowledge on fish behavior in relation to fish passage (15.2%)
- Ecological aspects relevant to fish passage (9.1%)
- Information from country reports (3%)
- Sharing of experiences among participants (3%)
- Future adoption of policy on fish passage (3%)

On ***the way that participants could apply knowledge gain from the workshop in their future work***, followings are the possible areas of application as indicated by participants:
- Possible application of fish passage as practical and applicable in the country (42.4%)
- Development of fish passage design that are suitable for the country/region (12.1%)
- Use of knowledge and information to support relevant policy/decision-making (9.1%)
- Further sharing of knowledge from the workshop to relevant officers in the country (9.1%)
- Development of guidelines on fish passage (3%)

Participants also provided ***suggestion for improvement of future workshops*** as follows:
- There should be more case studies/expertise that are relevant to the region (18.2%)
- Materials should be provided in advance to the workshop (12.1%)
- Excursion should allow participants to visit fish passage facility that shows good results (12.1%)
- More workshops on fish passage (incl. follow-up workshop) should be conducted in the future (9.1%)
- Field practical works should be included in the workshop (6.1%)
- Workshop topics should also include management and governance aspects (3%)
- Other countries (*e.g.* China, Japan) and organizations (*e.g.* APFIC) should be involved in the Workshop. (3%)