Report of the Expert Workshop on Fishway Design Principles to Enhance the Sustainability of Inland Fishery in the Southeast Asian Region

6-10 March 2016, Thailand and Lao PDR

The Workshop was organized by
the Southeast Asian Fisheries Development Center (SEAFDEC)

With support from
the Australian Centre for Agricultural Research (ACIAR)

SEAFDEC

Australian Government
Australian Centre for International Agricultural Research

REPORT OF

THE EXPERT WORKSHOP ON FISHWAY DESIGN PRINCIPLES TO ENHANCE SUSTAINBILITY OF INLAND FISHERY IN THE SOUTHEAST ASIAN REGION

6-10 March 2016
Thailand and Lao PDR

The Workshop was organized by
the Southeast Asian Fisheries Development Center (SEAFDEC)

with support from
the Australian Centre for Agricultural Research (ACIAR)

SEAFDEC

Australian Government
Australian Centre for International Agricultural Research

EXECUTIVE SUMMARY

The Expert Workshop on "Fishway Design Principles to Enhance Sustainability of Inland Fishery in the Southeast Asian Region" was organized by the Southeast Asian Fisheries Development Center (SEAFDEC) on 6-10 March 2016 in Thailand and Lao PDR under the project on "Application of fish passage design principles to enhance sustainability of inland fishery resources in the Southeast Asian region" with financial support from the Australian Centre for International Agricultural Research (ACIAR).

The Expert Workshop was participated in by the participants, which include international and regional experts, officers and experts of Department of Fisheries and the Royal Irrigation Department of Thailand, as well as SEAFDEC Secretary-General, concerned officers of the SEAFDEC Secretariat, Training Department (TD), and Inland Fishery Resources Development and Management Department (IFRDMD).

During the Expert Workshop, participants noted the biological information and requirements of different species group is very important for development of appropriate design of fishway. Although, the existing fishway design could facilitate migration of fish, but not all species could migrate up to lake. There is therefore a need for identification of target species, which should focus on those that require long-distance migration. From the Experts' presentation on the works related to fishways design development in Cambodia, Lao PDR, and Thailand, it was noted that there are several types of fishways could be used to facilitate either upstream or downstream migration of fish, the choosing of particular design need to compare their advantages and disadvantages, and take consideration the concerned species. It was emphasized that one of the factors to facilitate effective migration of fish at fishway is the operational management of water inflow to fishway facilities in particular fish passing to culvert.

The experiment fishway model which was developed by SEAFDEC/TD under the ACIAR-supported project on "Application of fish passage design principles to enhance sustainability of inland fishery resources in the Southeast Asian region," was presented and discussion particularly on criteria for fishway design towards enhancing the sustainability of inland fishery resources in the Southeast Asian region. Moreover, the future actions were also discussed. It was recommended that the fishway experiment at TD should be continued, funding support also should be further sought for conduct of field experiment and validation, and assessment be made on new design of fishway in comparison with existing design(s). In this connection, the Workshop also suggested to conduct experiments using fishway model developed by TD to come up with biological information on various fish species/species group.

CONTENTS

ANNEXES

Page

REPORT OF THE EXPERTS WORKSHOP ON FISHWAY DESIGN PRINCIPLES TO ENHANCE SUSTAINABILITY OF INLAND FISHERY IN THE SOUTHEAST ASIAN REGION

6-10 March 2016, Thailand and Lao PDR

I. INTRODUCTION

1. The Experts Workshop on Fishway Design Principles to Enhance Sustainability of Inland Fishery in the Southeast Asian Region was organized by the Southeast Asian Fisheries Development Center (SEAFDEC) on 6-10 March 2016, Thailand and Lao PDR under the project on "Application of fish passage design principles to enhance sustainability of inland fishery resources in the Southeast Asian region" with financial support from the Australian Centre for International Agricultural Research (ACIAR).

2. The Workshop was attended by regional and international experts, officers and experts of the Department of Fisheries and the Royal Irrigation Department of Thailand, as well as SEAFDEC Secretary-General, concerned officers of the SEAFDEC Secretariat, TD, and IFRDMD. The List of Participants appears as **Annex 1**.

3. The Workshop has objectives to obtain information from experts on works related to biology and ecology in relation to fish migration and fishway designs, as well as their recommendations for undertaking of activities under the ACIAR-supported project on "Application of fish passage design principles to enhance sustainability of inland fishery resources in the Southeast Asian region," particularly on criteria for fishway design towards enhancing the sustainability of inland fishery resources in the Southeast Asian region.

II. PRE-WORKSHOP EXCURSION

4. Excursion program was arranged for participants to visit fish passage at Sui Reservoir in Cham Phone District; and fish friendly floodgates in Huay Papak, Huay Kae and Huay Phin in Xayburi District, Savanakhet Province in Lao PDR on 6 March 2016. Participants also observed fishway facilities at Thoranit-naruemit Watergate, and Na Koo Watergate in Nakhon Phanom Province; and Suraswadi Watergate in Sakon Nakhon Province in Thailand on 7 March 2016.

III. WORKSHOP SESSION

3.1 Opening of the Workshop

5. SEAFDEC Secretary-General, *Dr. Kom Silapajarn*, welcomed participants, and expressed the utmost appreciation of SEAFDEC for the participation of experts from various countries to this Workshop. He briefly reiterated the importance of this Workshop in developing recommendations, particularly on criteria for fishway designs and for further activities to be undertaken under the fishway project that is being implemented by SEAFDEC with support from ACIAR. He subsequently expressed the appreciation to ACIAR for extending financial support to this project and to Dr. Chumnarn Pongsri for leading the implementation of this project; and declared the Workshop open. His Opening Remarks appears as **Annex 2**.

3.2 Introduction of the Workshop

6. The Workshop took note of the overview of the project on "Application of fish passage design principles to enhance sustainability of inland fishery resources in the Southeast Asian region," including the agenda and arrangements as well as the expected results of the Workshop. The Prospectus of the Workshop appears as **Annex 3**.

3.3 Review of Works Related to Fish Migration Biology and Ecology in Southeast Asia

- **Overview on Biological and Ecological Aspects in Relation to Fishway**

7. As basis for further discussion on development and operation of fishways to mitigate impacts from cross-river obstacles in the Southeast Asian region, *Dr. Chumnarn Pongsri* emphasized the need to give due consideration on three important aspects, namely: 1) engineering aspect; 2) biological aspect; and 3) social aspect. Specifically, the engineering and biological aspects should be integrated to come up with appropriate fishway designs. He further reiterated that different catchments comprise different groups of aquatic species, and thus development of single fishway design that could facilitate migration for all catchments/species would not be possible.

8. It was noted that biological information and requirements of different species group is very important for development of appropriate designs of fishway. There is therefore a need for identification of target species, which should focus on those that require long-distance (longitudinal) migration and provide significant contribution to long-term food security of people; and collection of necessary biological information of such species.

9. The Meeting further noted that under this Project, SEAFDEC intended to develop on-station experimental fishway design, aiming to come up with model construction of fishway that could be managed and used for the conduct of further scientific experiment; as well as to facilitate understanding of public on the importance of fishways. Specifically, such fishway model could also be used to obtain additional information on biological aspect of different groups of fish, *e.g.* dimension of fish, ability to swim against water, migration behavior, migration time, etc. This information should be pooled with other available information to facilitate the development of most effective engineering designs to facilitate migration of fish in the future.

- **Fish Passages in Nam Kam River, Thailand**

10. Presentation on “Fish Passages in Nam Kam River, Thailand” (**Annex 4**) was made by *Mr. Boonsong Sricharoentham* from the DOF Thailand. He provided an overview of Nam Kham River, a tributary of the Mekong River, which is equipped with a series of fish ladders, from Suraswadi (uppermost watergate next to Nong Han Lake) to Thoranit-Naruemit (lowermost watergate before Mekong River). Different fish ladders were constructed using different designs (varied pool dimension, number of pool, length of fish ladder, number of water gate, etc.).

11. *Mr. Boonsong* subsequently informed results from the study conducted during 2012-2015 with support of MRC to evaluate fish migration through fish ladders, migration pattern of economically important aquatic species, impact of hydrology on fish migration, and undertake DNA marker study. In particular, information was collected on species, number, length and weight of fish, at the second uppermost pool of the ladder at 2-hour interval during different diurnal period (day/night time) and seasons. The study showed that out of 83 species of fish found at Thoranit-Naruemit Watergate, only 43 species could be recorded at Suraswadi Watergate. Tagging experiment was also conducted, with fish being released at Thoranit-Naruemit Watergate to monitor recapture in the upstream river.

12. Observation was made that although the existing fishway design could facilitate migration of fish, but not all species could migrate upto Nong Han Lake. This could be due to the fact that fish migration occurs mainly during the early rainy season, when rainfall would be reserved in Nong Han Lake and not discharged through the watergate, resulting in less water flow through Nam Kam River than the amount that could trigger fish migration (comparing with the flow from other nearby tributary).

13. It was noted that Suraswadi Watergate is used to control water level and prevent flooding in Sakon Nakhon Province, and this is the primary factor to be considered in discharging of water through the watergate. Furthermore, while the operation of fishway should be undertaken during migration season, currently no one is in charge in regulating the fishway based on the actual water level and migratory requirement.

14. While noting that the operation of fishway in Nam Kam River was made by partial opening of the inlet, observation was made that this kind of fishway is designed to be fully opened or fully closed, and water would be automatically regulated at the opening of the pool slot.

3.4 Review of Works Related to Fishway Designs

- **Principle of Fishway Design on Low-level Dams and Weirs**

15. "Principle of Fishway Design on Low-level Dams and Weirs" (**Annex 5**) was presented by *Dr. Martin Mallen-Cooper.* He elaborated the fishway design principles, which include the need to: 1) address upstream/downstream migration; 2) integrate biology/ecology and hydraulics; 3) locate and design fishway entrance to attract fish; 4) determine appropriate size of fishway to meet the biomass and flows of the river system; and 5) document assumption and use adaptive management.

16. Several types of fishway designs, *e.g.* cone fishways, vertical-slot, rock-ramp fishways, etc., were explained with advantages and disadvantages of each design, which should be taken into consideration in choosing of appropriate design for different situation. It was further noted that each site for construction of fishway is unique, and thus the design need to take into consideration the actual situation to ensure that fishway could perform as expected. Construction of fishway model (small size) or computer modeling to imitate actual situation and operation could be considered for fishway entrance design, as this is much cheaper than changing the entrance after actual construction and could help identifying/solving problems that may occur before the construction.

- **Fish Passage Evaluation and Monitoring Technologies**

17. *Dr. Daniel Deng* shared information on "Fish Passage Evaluation and Monitoring Technologies" (**Annex 6**), with particular emphasis on: 1) Acoustic Telemetry; and 2) Sensor Fish Device, as options that have been used extensively in the United States and around the world for monitoring of fish passage. It was noted that "acoustic telemetry" (with tag attached to individual fish, receiver, and information processing device) could be used to provide information on fish behavior and passage routes, *e.g.* how fish approach the fishway, and the migrating behavior after passing fishway; but the equipment could be costly and required high labor (although cost is recently significantly declined). For "sensor fish device," this is useful for monitoring of physical condition that the fish experience, *e.g*. pressure, strike and turbulence in fishway and other structures that can cause fish injury and mortality.

- **Fish Trap and Haul System for High Dam in China**

18. *Dr. Xiaotao Shi* made presentation on "Fish Trap and Haul (T&H) System for High Dam in China" (**Annex 7**). Although fishway is also used to facilitate fish migration across cross-river obstacles in China, construction of fishway could be too costly for high dams, *e.g*. those with the height of over 100 meters, and thus T&H could be an alternative system that is cheaper and could be used to mitigate both upstream and downstream migration requirement. It was noted that in designing the appropriate T&H System, consideration should be given to appropriate site for putting trap, taking into consideration water current, convenience of work; appropriate timing (season) based on migratory season of fish; and release point where fish can find familiar environment, etc.

19. The advantages of T&H System were elaborated, particularly the ability to change location of the trap in response to different conditions; ability to regulate trapping flow rate according to different fish species in a larger scope; ability to release fish into the river course with no effect from discharge flow; while there is no need to draw water from upstream reservoir for the operation of fishway. The application of behavior guidance methods including attraction flow, light, air bubble curtain, guiding net, etc. should be further studied. Challenges faced in the operation of T&H System and counter-measures toward them were also explained in the presentation.

- **Fish and Fishway in Cambodia**

20. *Mr. Chan Sokheng* presented the "Fish and Fishway in Cambodia" (**Annex 8**), outlining the importance of inland capture fisheries for Cambodia, and the nature of fish migration in Tonle Sap which occurs during the wet season when fish enter into the tributaries, and during the dry season when fish gets back to deeper water in Mekong River.

21. While noting that there are several types of fishways that could be used to facilitate either upstream or downstream migration of fish, the choosing of particular design need to compare their advantages and disadvantages, and take into consideration the concerned species. The result of study at Stung Chinit showed that 41 out of 55 species could pass through fishway. It was also noted that proper design of fishway for Cambodia still requires further studies, *e.g.* on swimming capabilities of target species to make sure that these passes will be efficient.

- **Fish Passage Development in Lao PDR**

22. *Mr. Douangkham Singhanouvong* presented on "Fish Passage Development in Lao PDR" (**Annex 9**). He outlined rational on the need of fish passage as an option to preserve biodiversity of fish species in response to construction of cross-river obstacles, *e.g.* large number of floodplain regulators in Lao PDR. In 2008, pilot study on fish passage was undertaken in the country with support from ACIAR, covering both upstream and downstream migration. Specifically for upstream migration, three types of fish passes, *i.e.* vertical slot, submerge orifice, and rock ramp were used; while for downstream migration, migrations through overshot and undershot gates were experimented. Specifically for downstream migration, it was noted that undershot gate could cause higher injury or mortality than overshot gate. A new gate design which operate as overshot will therefore be installed and tested in Pak Peung wetland in 2016-2017. Economic modeling would also be undertaken to evaluate the feasibility of fish pass.

- **Lao Fish Passage Research-Results, Outcomes and Future Works**

23. *Mr. Garry Thorncraft* made the presentation on "Lao Fish Passage Research-Results, Outcomes and Future Works" (**Annex 10**). He elaborated steps required for establishment of fish passage facilities, which include: 1) Scoping (prioritizing the barriers, considering that there are very large number of barriers in Lao PDR); 2) Research (on different types/designs of fishway, and undertaking experiments to compare different types of design); 3) Construct; and 4) Assess (the ability of fish that can pass fishway through data collection on species and size distribution at the top, bottom and culvert of fishway).

24. While noting the results from the fishway assessment showed the design pass almost all of the species observed downstream of the site. It was emphasized that one of the factors to facilitate effective migration of fish at fishway is the operational management of water inflow to fishway facilities in particular fish passing to culvert, which is an important area and need more research/consideration for future fishway design. Future works to be undertaken in Lao PDR were also noted, which include projects on: 1) Improving the design of irrigation infrastructure to increase fisheries production in floodplain wetlands of the Lower Mekong and Murray-Darling Basins 2014-2017 (supported by ACIAR); 2) Quantifying biophysical and community impacts of improved fish passage in Lao PDR 2016 – 2021 (supported by ACIAR); and 3) Development of fish-friendly sustainable hydropower technology guidelines 2016 (Supported by USAID). It was further noted that involvement of stakeholders at different level is the key for success of the project implementation.

3.5 Experimental Flumes for Fishway Design

25. *Dr. Martin Mallen-Cooper* informed the Workshop on "Experimental Flumes for Fishway Design" (**Annex 11**). His presentation outlined different types of flume designs: namely: Straight flume in laboratory; 2) Experimental fishway in laboratory or field station; and 3) Experimental fishways on site in river/wetland, including advantages and disadvantages for each type of flume design. Cautions for the use of flumes were however noted, *i.e.*: 1) flume could not be scaled-up to come up with full-scale construction; data from laboratory experiment may underestimate swimming ability of fish in actual

situation and mislead fish behavior; and experimental fishway constructed for laboratory use is much shorter (in length) than the real construction.

3.6 Experimental Fishway Model at SEAFDEC/TD

26. *Mr. Suthipong Tanasarnsakorn* presented on "Fishway Experiment" (**Annex 12**) which was undertaken at the SEAFDEC/TD. It was noted that the initial model (*i.e.* pool dimension, pool opening, etc.) was designed based on recommendations made during the Workshop on Principle of Improved Fish Passage at Cross-river Obstacles, with Relevance to Southeast Asia convened by SEAFDEC in 2013; and was experimented to observe the possibility of several indigenous fish species to pass through the model.

27. The Workshop was informed that this initial model of vertical slot fishways was targeted at fingerling size cyprinids (white fish) that require longitudinal migration. While it is anticipated that the model would be further improved and used for experiment on various fish species to come up with relevant data and information on fish biology and behavior; SEAFDEC also plans to construct smaller model that could be demonstrated, *e.g.* during exhibitions, to enhance public understanding on fishway concept and the utilization of fishway to mitigate impacts from cross-river obstacles.

3.7 Discussion

28. The Workshop discussed and came up with following recommendations:

Component and Criteria for Fishway Design

a) Designing and construction of fishways need to consider both biological aspect of aquatic species (*e.g.* fish species, size, etc.), as well as hydrological aspect of the fishway (*e.g.* water discharge volume of the river, water head, etc.). Although standard criteria for fishways (*e.g.* pool dimension, entrance size) is already available, but this should be tailored to fit with the specificity of different locality and also make use of available indigenous knowledge.

b) Steps for prioritization of sites for fishways could include: 1) **Use of satellite data**: to mark water barriers, observe physical characteristics, position/size of catchment and aquatic habitat; 2) **Field survey** to the site to see the actual barrier, condition of habitat/species, fishing activities, local/indigenous knowledge; and 3) **Evaluation/assessment** to determine the potential benefit from fishways (based on social-economic and biological dimensions), give score/rank and prioritize the site; 4) allocate fund to **develop preliminary design, and formulate proposal** for donor support. Criteria for prioritizing sites for fishway could be found at *http://aciar.gov.au/project/fis/2009/041.* Priority should be given not only to fishways for upstream migration, but also downstream migration, as if fish can migrate into downstream part of the river, they can further migrate upward later on.

c) Attraction of fish to the entrance is important to facilitate migration:
   - Based on the expert's experience, the need of ~10% of total discharge through fishway (including auxiliary flow) to attract fish was noted, and the structure of fishway should be able to accommodate this.
   - Requirement of discharge to attract fish is only during fish migration period, *e.g.* early period of rainy season and not all-year-round (water flow during fish migration peak is not as much as during water flow peak)
   - Entrance position and design are also very important to facilitate/attract fish to find the entrance (should be placed near the bank where fish usually swim).

d) Designing of fishways should also take into consideration migratory requirements of species under international concerns *e.g.* eels (*Anguilla* spp). In this regard, *Dr. Daniel Deng* was requested to share further information on fishway design to facilitate eel migration to SEAFDEC/IFRDMD. In addition, migration of other important species, such as giant freshwater prawn should also be considered.

Improving Preliminary Fishway Model of SEAFDEC/TD

e) The initial design of on-station fishway model of SEAFDEC/TD should be improved by increasing the depth as much as possible. It was noted that the existing model still have ~ 30 cm freeboard, and thus water depth could be increased by adding more water pump.

f) TD may consider varying the shape of slot opening (*e.g.* using straight slot, wide at the bottom and/or top, blocked at the middle). However, different opening shape should be designed based on various factors, *e.g*. fish species/size/behavior, amount of water discharge. The shape has to be carefully chosen for specific site/situation.

g) Based on research (by *Dr. Martin Mallen-Cooper*): i) baffle deflector (small baffle) should be increased to 1.6 times of slot width; ii) large baffle return should be increased to 2.0 times of slot width; iii) sill in the base of the slot should be used and should be equal or greater than the height of the head loss; and iv) pool proportions should be closer to 3:2 (length: width).

h) Experiment should be conducted making use of the on-station fishway model, using different species and size of fish, different water flow rate and fishway slope, etc. Data should be recorded on:
   - Water depth, pool depth, head loss between each pool, etc.
   - Fish species/groups, fish size that could pass through the fishway (DOF Thailand may help identifying priority species/groups to be experimented)
   - Migration during different time of the day (day/night time)
   - Flow measurement details, including spatial and temporal, and equipment used for measurement

i) Experts as well as staff of DOF Thailand, Cambodia and Lao PDR are invited to make use of the experimental model at TD to conduct relevant study.

j) In the future, TD should transfer the fishway model laboratory data to undertake field experiments before publishing design criteria.

Way Forward

<u>Information Collection and Exchange</u>

k) Activities should be pursued to collect addition biological information of fish, *e.g*.:
   - **Fish swimming performance in different turbulences and water velocities (high priority)**
   - Fish behavior in the river, approaching the weirs and below the weirs (*e.g*. using acoustic telemetry, radio telemetry, camera). However, consideration should be made that fish in the Southeast Asian region are small-size, large in number and high species diversity.
   - Influence of lunar cycle should also be considered in data collection

l) Harmonized methodology for data collection should be developed and used for collection of data/information on migratory fish by various agencies/institution, *e.g*. along Mekong up to upstream river in China, as this could affiliate sharing/exchange of information in the future. Existing methodologies developed by MRC should also be considered (see *www.mrcmekong.org*).

m) Data should also be collected on performance indicator of fishway, such as:
   - Whether fish population upstream could be maintained;
   - Proportion of fish that can pass into fishway (entrance attraction); and
   - Whether fish migrate from bottom to top of the fishway itself.

n) Regular exchange of relevant information should be considered. This should include not only the success case, but also the failure.

o) Establishment of e-group by SEAFDEC, comprising experts attending in this Workshop, to facilitate communication and sharing/exchange of information (high priority)

Enhancing Cooperation with Royal Irrigation Department

p) Cooperation with RID should be enhanced in the future to ensure that appropriate fishway designs would be taken into consideration in designing of new construction project.

q) It was noted that clear standard/criteria for design of fishways (both for upstream and downstream migration) is necessary to facilitate communication with decision makers to understand specific criteria/requirements for fishways. Information on benefit of fishway to biodiversity and contribution to nutritional requirement of people should also be included.

r) Watergate operator/manager should be involved in designing of the fishways in order to know the basic principle (*e.g.* water demand for fishways, discharge time, etc.), considering that the effectiveness of fish migration also relies on watergate operation.

s) In seeking approval for engineering design of fishways, working group should be established, comprising engineer, scientist, biologist, etc., to review the construction plan and minimize the chance of mistake.

t) In addition to criteria that should be considered in construction of new fishway, modification of the existing fishway structure or its operation to facilitate fish migration should also be considered.

3.8 Future Actions

29. The Workshop recommended that: 1) fishway experiment at TD be continued; 2) funding be further sought for conduct of field experiment and validation (particularly on turbulence and baffle design); and 3) Assessment be made on new design of fishway in comparison with existing design(s).

30. The Workshop suggested that as the conduct of experiments using fishway model developed by TD to come up with biological information on various fish species/species group may take some time; SEAFDEC, DOF and RID could consider developing a proposal for funding support from donors, *e.g.* ACIAR or USAID, for field experiment using the fishway model. Thus, the field experiment could proceed shortly after obtaining the required biological information.

31. *Mr. Douangkham Singhanuwong* informed the Workshop that Lao PDR is planning to host the "Regional Workshop on Fish Passage and Hydropower" in September 2016; and encouraged all experts to also attend in this Workshop. It was noted that participants of the Workshop would not only be from the region but worldwide to share relevant knowledge and information.

3.9 Closing of the Workshop

32. *Dr. Kom Silapajarn* expressed his appreciation to the participants for their inputs and contribution that paved the way toward facilitating the future activities of SEAFDEC in improving the design of fishway model and conducting on-station experiments making use of the model. He expressed the willingness of SEAFDEC to continue cooperation with all experts in the future works, as well a in sharing of information on works in relation to fishways in the future; and declared the Meeting closed.

Annex 1

LIST OF PARTICIPANTS

REGIONAL AND INTERNATIONAL EXPERTS

Martin Mallen-Cooper (Dr.) Director	Fishway Consulting Services 8 Tudor, St.Ives Chase, NSW, 2075 Australia Tel: +61 2 94499638 Mobile: +61 417 612267 E-mail: mallencooper@optusnet.com.au
Xiatao Shi (Dr.) Fishway Scientist	China Three Gorges University University Ave.8, Yichang, China Tel: +86 150 71730399 E-mail: sxtshanghai@163.com
Garry Thorncraft Research Associate	National University of Laos P.O. Box 10864 Vientiane Lao PDR Tel: +856 20 55646370 E-mail: garrythorncraft@yahoo.com.au
Douangkham Singhanouvong Deputy Director	Living Aquatic Resources Research Center (LARReC) Ban Chansavang, Sikhotabang District, Vientiane Lao PDR Tel: +856 21 612039 Fax: +856 21 612437 E-mail: douangkham_s@yahoo.co.uk, douangkhams@gmail.com
Daniel Deng (Dr.) Fish Passage expert	Pacific Northwest National Laboratory Richland WA 99354, USA Tel: +1 509 372 6120 E-mail: zhiqun.deng@pnnl.gov
Chan Sokheng Acting Chief of Fisheries Technology Research Division	Fisheries Administration #186, Preah Norodom Blvd. Chamcarmon, P.O. Box: 582 Phnom Penh, Cambodia Tel: +855 12 883228 E-mail: chan_sokheng@yahoo.com

DEPARTMENT OF FISHERIES OF THAILAND

Chumnarn Pongsri (Dr.) Director	Department of Fisheries Fisheries Foreign Affairs Division Kaset Klang, Phaholyotin Rd., Chatuchak Bangkok 10900, Thailand Tel/Fax: +66 25798215 E-mail: chumnarnp@gmail.com

Oopatham Pawaputanon (Dr.)
Advisor

Department of Fisheries
Kaset Klang, Phaholyotin Rd., Chatuchak
Bangkok 10900, Thailand
Tel/Fax: +66 25798215
Mobile: +66 89 9615333
Email: Oopatham@yahoo.com

Anand Tunsutapanich
Advisor

Department of Fisheries
Kaset Klang, Phaholyotin Rd., Chatuchak
Bangkok 10900, Thailand
Tel/Fax: +66 25798215
Mobile: +66 81 3055668

Noppadol Puwapanich
Project Adviser

Department of Fisheries
Kaset Klang, Phaholyotin Rd., Chatuchak
Bangkok 10900, Thailand
Tel/Fax: +66 25798215
Mobile: +66 81 9831377
E-mail: p_nopadol@hotmail.com

Boonsong Srichroentham
Senior Expert in Ecology

Department of Fisheries
Kaset Klang, Phaholyotin Rd., Chatuchak
Bangkok 10900, Thailand
Tel/Fax: +66 25798215
Mobile: +66 82 4864768
E-mail: boonsosr@yahoo.com

Sontipan Pasugdee
Director

Department of Fisheries
Inland Fisheries Research and Development Division
Kaset Klang, Phaholyotin Rd., Chatuchak
Bangkok 10900, Thailand
Tel/Fax: +66 25798215
E-mail: ffishpp@ku.ac.th

Suttichai Rittitum
Director

Department of Fisheries
Coastal Fisheries Research and Development Division
Kaset Klang, Phaholyotin Rd., Chatuchak
Bangkok 10900, Thailand
Tel/Fax: +66 25798215
E-mail: suttichairittitum@gmail.com,
rittitum@yahoo.com

Winai Juntubtim
Dirctor

Department of Fisheries
Inland Aquaculture Research Institute
Ayutthaya Province
Mobile: +66 81 6493777
Fax: +660 35 704170
E-mail: winaipotang@gmail.com

Kuankit Rattanarak
Civil Engineer

Department of Fisheries
Kaset Klang, Phaholyotin Rd., Chatuchak
Bangkok 10900, Thailand
Tel: +662 558 0234
Fax: +662 558 0200
E-mail: kuankit9352@gmail.com

Pramook Ruekaema
Fisheries Biologist

Department of Fisheries
Sakon Nakhon Inland Fisheries Research and Development Center
1535 Saisawang Road, Thadchuengchum Sub-district, Sakon Nakhon
Tel: +660 42 711447
Fax: +660 42 716220
E-mail: prukaewma@hotmail.com

ROYAL IRRIGATION DEPARTMENT OF THAILAND

Somkiat Prajamwong (Dr.)
Director,
Bureau of Project Management

Royal Irrigation Department
811 Samsen Road, Khaug Tanoonnakorn Chaisri, Dusit District Bangkok 10300, Thailand
Phone: +66 2 241 0068, 092 2549966
Fax: +66 2 243 7870
Email: prajamwong@yahoo.com

Chakkrapong Taewwichit (Dr.)
Engineer

Royal Irrigation Department
Office of Engineering and Architectural Design
811 Samsen Road, Khaug Tanoonnakorn Chaisri, Dusit District Bangkok 10300, Thailand
Tel/Fax: +662 6693587
Mobile: +668 1 6842111
E-mail: chakkrappong@hotmail.com

SEAFDEC
SECRETARIAT

Kom Silapajarn (Dr.)
Secretary-General and Acting Chief of SEAFDEC/TD

P.O. Box 1046, Kasetsart Post Office
Bangkok 10903, Thailand
Tel: + 66 2940 5682
Fax: +66 2940 6336
E-mail: sg@seafdec.org

Nualanong Tongdee (Ms.)
Information Program Coordinator, *a.i.*

P.O. Box 1046, Kasetsart Post Office
Bangkok 10903, Thailand
Tel: + 66 2940 6326
Fax: +66 2940 6336
E -mail: nual@seafdec.org

Saivason Klinsukhon (Ms.)
Information Officer I

P.O. Box 1046, Kasetsart Post Office
Bangkok 10903, Thailand
Tel: + 66 2940 6326
Fax: +66 2940 6336
E -mail: saivason@seafdec.org

Julasak Markawat
General Service Office
P.O. Box 1046, Kasetsart Post Office
Bangkok 10903, Thailand
Tel: + 66 2940 6326
Fax: +66 2940 6336
E -mail: julasak@seafdec.org

TRAINING DEPARTMENT (TD)

Yuttana Theparoonrat
Coastal and Small-scale Fisheries Management Division Head/
Information and Training Division Head
P.O. Box 97, Phrasamutchedi Post Office
Samut Prakan 10290 Thailand
Tel: + 66 2425 6100 Ext. 169
Fax: +66 2425 6110
E -mail: yuttana@seafdec.org
Website: http://www.seafdec.or.th

Suthipong Thanasarnsakorn
Fisheries Engineer Section Head
P.O. Box 97, Phrasamutchedi Post Office
Samut Prakan 10290 Thailand
Tel: + 66 2425 6100
Fax: +66 2425 6110
E -mail: suthipong@seafdec.org

Thaweesak Thimkrub
Fishery Engineer
P.O. Box 97, Phrasamutchedi Post Office
Samut Prakan 10290 Thailand
Tel: + 66 2425 6100
Fax: +66 2425 6110
E -mail: thaweesakt@seafdec.org

Nopporn Manajit
Fisheries Resources Enhancement Scientist
P.O. Box 97, Phrasamutchedi Post Office
Samut Prakan 10290 Thailand
Tel: + 66 2425 6100
Fax: +66 2425 6110
E -mail: nopporn@seafdec.org

INLAND FISHERY RESOURCES DEVELOPMENT AND MANAGEMENT DEPARTMENT (IFRDMD)

Dina Muthmainah (Dr.)
Special Departmental Coordinator and Researcher
Inland Fisheries Resources Development and Management Department (IFRDMD)
Jalan Beringin No. 8
Mariana, Palembang, Indonesia
Tel: +62 711 7537194
Fax: +62 711 7537205
E-mail: dina.gofar@yahoo.co.id;
dina.mth@seafdec.or.id

Sevi Sawestri (Ms.)
Inland Fisheries Resources Development and Management Department (IFRDMD)
Jalan Beringin No. 8
Mariana, Palembang, Indonesia
Tel: +62 711 7537194
Fax: +62 711 7537205
E-mail: sawestri@seafdec.or.id

Annex 2

OPENING REMARKS

By Dr. Kom Silapajarn
SEAFDEC Secretary-General

Dr. Chumnarn Pongsri, Leader of the project on Fishway Design Principles to Enhance Sustainability of Inland Fishery in the Southeast Asian Region,
Delegates from the Royal Irrigation Department and Department of Fisheries of Thailand,
Officials of SEAFDEC Secretariat, TD and IFRDMD,
Ladies and Gentlemen,

Good morning,

First of all, please let me welcome all of you once again to the Meeting Session of the "Experts Workshop on Fishway Design Principles to Enhance Sustainability of Inland Fishery in the Southeast Asian Region," although today is already the third day of the Expert Workshop. I would like to also take this opportunity to express the gratitude of SEAFDEC for all of you in sparing your valuable time to attend in this Workshop, and share with us your knowledge and experiences on wide aspects of fishway designs.

During the past two days, we have visited several fishway designs both in Lao PDR and Thailand, to equip us with some background on the nature of cross-river construction in the Southeast Asian region, as well as some fishway designs that had been constructed and operated in the area. I hope that this should provide a good basis for the discussion that we are about to make today and tomorrow to come up with recommendations towards improving the fishway designs that could be suitable for the specificity of the Southeast Asian region.

To give you some more background on what we are doing now, SEAFDEC recently received a small research grant from the Australian Centre for International Agricultural Research or ACIAR to implement the project entitled "Application of fish passage design principles to enhance sustainability of inland fishery resources in the Southeast Asian region", with a view of developing a regional collaborative approach on fish passage; and coming up with design and construction of experimental fishway model in Thailand. And it is expected that the experimental fishway models prepared through this project would provide a pathway for further research to improve knowledge on appropriate designs that could facilitate upstream migration of indigenous fish in the Southeast Asian region.

For SEAFDEC, our works on fishway started very recently, only in 2013, when we convened the "Workshop on Principles of Improved Fish Passage at Cross-rive Obstacles, with Relevance to Southeast Asia," supported by FAO, also with partial support from ACIAR. And based on the information obtained from the 2013 Workshop, SEAFDEC started some works in designing and construction of initial models of fishway at our Training Department in Thailand. Thus, we could also have some time at this Workshop to also look into our initial designs in order to improve them, and see how this could be applicable on-site in the future.

On behalf of SEAFDEC and our Member countries, I am thankful to ACIAR for extending financial support to this new fishway project; and to Dr. Chumnarn Pongsri, the former Secretary-General of SEAFDEC and leader of this project, for continue leading the implementation of this project, including the conduct of this very important Workshop, even after he already transferred back from SEAFDEC to the Department of Fisheries of Thailand.

I also wish this Workshop to come up with fruitful recommendations, particularly on recommendations on criteria designing of fishway models that would be applicable for mitigating problems of cross-river construction and enhance the sustainability of inland fishery in the Southeast Asian region in the future.

With that, I would like to declare this Expert Workshop open.
Thank you very much and have a good day.

Annex 3

PROSPECTUS OF THE WORKSHOP

1. Background

Inland capture fisheries in the Southeast Asian region including Mekong River Basin deliver food security and income for rural households and also serve as a valuable source of protein and important micro-nutrients. However, inland fisheries are becoming increasingly threatened by riverine development projects. Construction of cross-river obstacles such as dams, weirs, roads, etc. as means for rapid development in response to increasing population and demand for agriculture products, hydropower generation or urbanization, are major threats to the long term sustainability of inland capture fisheries as any changes in migration, reproduction and biodiversity of aquatic populations has the potential to decrease capture fisheries productivity. Appropriate mitigation measures to alleviate possible impacts from such migration barrier are therefore necessary.

Fishways have been constructed worldwide and have proved to help mitigate many fisheries globally. Nevertheless, in order to assure the effectiveness of the fishways, it is important that fishway design criteria are established for local species and conditions of the specific region, and not adapted from studies conducted elsewhere.

SEAFDEC in collaboration with the Department of Fisheries of Thailand therefore implement the project on “Application of fish passage design principles to enhance sustainability of inland fishery resources in the Southeast Asian region” with funding support from the Australian Centre for International Agricultural Research (ACIAR). The project would be implemented for the period of 16 months starting from May 2015 to September 2016, with objectives to:

1) Develop a regional collaborative approach on fish passage through the conduct of an expert workshop;
2) Design and construct experimental fishway facilities in Thailand; and
3) Provide a pathway for further research to improve knowledge on appropriate designs that could facilitate upstream migration of indigenous fish.

In June 2015, SEAFDEC and the DOF Thailand convened an informal discussion and came up with initial recommendations for designing fishway model to be experimented under the project. Initial experimental fishway model was also put-up at SEAFDEC Training Department in Samut Prakan, Thailand. SEAFDEC therefore plans to convene an “Expert Workshop on Fishway Design” to seek views from regional/international experts on issues/factors to be considered in designing fishways that are effective for the Southeast Asian region, and for improving of initial model of experimental fishway, as well as to identify way forward to be undertaken, making use of the fishway designs developed under this project.

2. Objectives of the Workshop

The Workshop has objective to obtain information from experts on works related to biology and ecology related to fish migration and fishways, as well as their recommendations for undertaking of activities under the ACIAR-supported project on “Application of fish passage design principles to enhance sustainability of inland fishery resources in the Southeast Asian region”, particularly on criteria for fishway design towards enhancing the sustainability of inland fishery resources in the Southeast Asian region.

3. Expected Outputs

It is expected that the Workshop would come up with:

1) Review of information on fish migration biology and ecology in Southeast Asia, as well as on fishway designs worldwide;
2) Recommendations on criteria for fishway designs for the Southeast Asian region, as well as specific comment(s) for improving of initial model of experimental fishway; and
3) Recommendations on way forward for application of the fishway designs developed under this project.

4. Date and Venue

The Workshop would be organized on 6-10 March 2016.

Excursion session would be arranged on 6-7 March 2016 for site visits in Savannakhet, Lao PDR; Nakhon Phanom and Sakon Nakhon, Thailand. ***Workshop session*** would be conducted on 8-10 March 2016 in Sakon Nakhon Province, Thailand.

5. Participants

The Workshop would be attended by:

1) Regional and international experts* on relevant subjects, *e.g.* fish biology, ecology, fishway designs, etc.;
2) Relevant officers and experts* of the Department of Fisheries and the Royal Irrigation Department of Thailand; and
3) SEAFDEC Secretary-General, concerned officers of the SEAFDEC Secretariat, TD, and IFRDMD.

* Experts attending in the Workshop would be requested to make presentation either under the sub-agenda on: a) Review of works related to fish migration biology and ecology in Southeast Asia; or b) Review of works related to fishway designs. Experts are also requested to submit corresponding working paper(s) prior to the Workshop.

6. Workshop Program

Saturday, 5 March 2016

- Arrival of Participants to Nakhon Phanom, Thailand *(transportation will be provided to Mukdahan Province)*
- Stay overnight in Mukdahan Province

Excursion Session

Sunday, 6 March 2016 (8.00 – 17.00 hrs)

Excursion program in Lao PDR
- Visit Fish Passage at Sui Reservoir, Cham Phone District, Savannakhet Province
- Visit Huy Papak Fish Passage, Xebangfai District, Khammoun Province

Back to stay overnight in Mukdahan Province

Monday, 7 March 2016 (8.00 – 17.00 hrs)

Check-out and leave Mukdahan Province
Excursion program in Nakhon Phanom and Sakon Nakhon, Thailand
- Visit fishway at Site 1: Thoranit-naruemit Watergate, That Phanom, Nakhon Phanom
- Visit fishway at Site 2: Na Koo Watergate, Na Kae, Nakhon Phanom
- Visit fishway at Site 3: Suraswadi Watergate, Phon Na Kaew, Sakon Nakhon

Check-in and stay overnight in Sakon Nakhon Province, Thailand

Workshop Session

Tuesday, 8 March 2016 (9.00-16.30 hrs.)

1. Opening of the Workshop

   SEAFDEC Secretary-General welcomes all experts to the Workshop and delivers his Opening Remarks.

2. Introduction of the Workshop

The organizer presents an overview of the project on "Application of fish passage design principles to enhance sustainability of inland fishery resources in the Southeast Asian region". The agenda and arrangements of the Workshop, as well as the expected results are also presented to the Workshop.

3. Review of Related Works

   a) Review of works related to fish migration biology and ecology in Southeast Asia *(topics to be identified by experts)*
   Experts present on fish migration biology and ecology, with particular focus on the Southeast Asian specificity.

   b) Review of works related to fishway designs *(topics to be identified by experts)*
   Experts present on works related to fishway design. These also include the initiatives undertaken in other regions that may be applicable for Southeast Asia.

<u>Wednesday, 9 March 2016 (9.00-16.30 hrs.)</u>

3. Review of Related Works (Continued)

4. Discussion

   a) Component and criteria for fishway design
   Based on the previous presentations on review of related works, experts are requested to provide further recommendations on components and criteria for fishway design, as well as on factors and other issues to be considered in designing fishways with a view to enhance its effectiveness for the Southeast Asian region.

   b) Experimental fishway model
   SEAFDEC/TD presents the initial models of experimental fishway, and seeks views from Experts for improvement of the model. Experts are also requested to provide comment on commissioning of the experimental fishway design, to ensure it performs hydraulically and also ecologically.

   c) Way forward
   The Workshop discusses way forward on future activities to be undertaken using the experimental fishway design. These include future studies, e.g. experiment on important fish species to ensure its applicability in the region, possibility for on-site application of fishway design in the future, etc.

<u>Thursday, 10 March 2016 (9.00-12.00 hrs.)</u>

5. Summary of the Results from the Workshop

Summary of the recommendations and future plan will be presented for consideration by the Experts.

6. Closing of the Workshop

SEAFDEC Secretary-General expressed his appreciation to all experts and declares the Workshop closed.

<u>Thursday, 10 March 2016 (13.00-16.30 hrs.)</u>

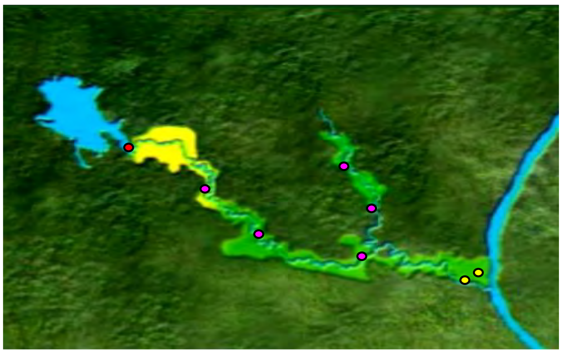
Work Planning Session – to be attended only by participants from SEAFDEC Secretariat, TD and DOF Thailand to discuss implementation of the project

Annex 4

FISH PASSAGES IN NAM KHAM RIVER, THAILAND

1. Introduction

The Nam Kam River is a tributary of the Mekong River. Along its 123 kilometres, there are 5 Watergates between the Nong Han Swamp (12,320 ha.) in the head waters and the confluence into the Mekong River. All Watergates are equipped with fish passages. The study from 2010-2012 indicated that many fishes can migrate from the Mekong River through the most downstream passage, but only few species were found passing through the other four passages. There was evidence that several species that pass through the most downstream passages were different from those being able to pass the more upstream passages. This present study is designed to implement research activities in the Nam Kam River at Thoranit Naruemit Watergate, the most downstream passages closest to the Mekong River and Suraswadee Watergate, the most upstream passage connected to the Nong Han Swamp, because many fishes can migrate through these two fish ways and the water management systems in these locations are well maintained.



Suraswadee Watergate

Thoranit Naruemit Watergate

Connecting to biodiversity survey study in the Nam Kam River found over 103 species of 24 families of which sampling from fish passages for 92 species of 21 families, and from gillnets for 66 species of 20 families. At the Toranit Naruemit Watergate, sampling fishes that migrated through the passages for 60 days found 440,015 individuals, from 83 species of 21 families. At the Surassawadee Watergate, sampling fishes that migrated through the passages of for 40 days found 413,471 individuals, from 56 species from 15 families.

At Toranit Naruemit Watergate, many fishes migrated in early rainy season, and a lot of rainfall period. There were a few fishes migrated in ending rainy season, because fishes moved upstream from Mekong River to Nam Kam River for spawning. At Surassawadee Watergate, a few fishes migrated in early rainy season, while many fishes migrated during ending rainy season. Due to low the floodgate that causing the water level in the Nam Kam River low, fishes would find a new habitat

At Thoranit Naruemit Watergate, there were 70 species (95.80% of the total observed fishes) migrated during the daytime. The most abundance species were *Sikukia gudgeri* , *Dangila lineatus, Hypsibarbus malcolmi,* and *Barbodes altus*, respectively. During the night time, there were 68 species (4.19% of the total observed fishes) migrated through the fish ladder. The most abundance species were *Hemibagrus nemurus, Laides longibarbis, Kryptopterus cheveyi, Mystus singaringan,* and *Hypsibarbus lageri,* respectively. At Surassawadee water gate, there were 35 species (6.97% of the total observed fishes) migrated through the fish ladder. The most abundance species were *Hemibagrus nemurus, Rasbora argyrotaenia, Mastacembelus armatus, Dangila lineatus,* respective. During the daytime, there were 35 species (93.03% of the total observed fishes) migrated. The most abundance species were *Dangila lineatus, Rasbora argyrotaenia, Osteochilus lini, and Osteochilus hasselti, Cyclocheilichthys apogon, Parambassis siamensia, Systomus orphoides, Monotrete turgidus*, respectively.

Fishes that migrated through fish passages at the Toranit Naruemit Watergate were in adult and maturation states, like *Morulius chrysophekadion*(Bleeker,)0581*Barbodes altus*(Gunther,)0585, *Hemibagrus nemurus* (Valenciennes,)0581, *Kryptopterus cheveyi*(Durand,)0191, *Osteochilus hasselti*(Valenciennes,)0591, *Yasuhikotakia modesta* Bleeker, 0588, *Crossocheilus siamensis* (Smith,)0180, and *Puntioplites proctozystron*(Bleeker,)0588; and sub-adult species, like *Morulius chrysophekadion*(Bleeker,)0581, *Barbodes altus*(Gunther,)0585, *Hypsibarbus malcolmi* (Smith,)0198, *Hypsibarbus wetmorei* (Smith,)0198, *Scaphognathops bandanensis* Boonyaratpalin & Srirungroj,0190, and *Puntioplites proctozystron* (Bleeker, 1865). At the Surassawadee Watergate, fishes that migrated through fish passages were in adult and maturation states, like *Osteochilus hasselti*(Valenciennes,)0591, *Dangila lineatus*(Sauvage,)0595, *Hampala dispar* Smith,0189, *Henicorhynchus siamensis*(de Beaufort,)0119, and *Rasbora argyrotaenia* (Bleeker,)0581; and sub-adult species, like *Osteochilus hasselti*(Valenciennes,)0591, *Dangila lineatus* (

Sauvage,)0595, *Osteochilus lini* Fowler, 0188, *Pristolepis fasciata* (Bleeker,)0580, And *Hemibagrus nemurus* (Valenciennes, 1839).

PRINCIPLES OF FISHWAY DESIGN ON LOW-LEVEEL DAMS AND WEIRS

EXECUTIVE SUMMARY

Fishways or fishpasses are a valuable method to restore fish migrations along rivers and into wetlands. The following paper provides background on principles of fishway design, common fishway types and the design process.

There are five design principles for fish passage that have general application but specific importance for tropical rivers:

1. Address upstream and downstream migration.
2. Integrate biology, hydrology and hydraulics.
3. Locate and design the fishway entrance to attract fish.
4. Size the fishway to meet the biomass and flows of the river system.
5. Document assumptions and use adaptive management.

It is important to consider all these, even on small projects.

The common fishway types include: cone fishways, vertical-slot fishways, trapezoidal fishways, rock-ramp fishways and Denil fishways. They all have advantages and disadvantages, relating to the size of fish that they pass, water level range and flexibility of design; a summary of these is included in the paper.

To achieve an effective design at a site it is important to start with a concept design that includes:

i) Collating background information (e.g. biology and hydrology)

ii) Determining ecological and social objectives

iii) Site inspection

iv) Engineering

Following the concept design and obtaining funds for capital, it is important to: commission the fishway; implement a maintenance plan; and do biological assessment.

Because each site or weir in a river is unique, all fishways are a unique application, even if design elements (e.g. baffles) are common between fishways. Hence, it is important to consider each design and its application separately, and assess them to ensure they are performing as expected and to inform future fishways.

1 INTRODUCTION

The lower Mekong Basin supports high aquatic biodiversity, particularly fish, providing sustainable and often irreplaceable sources of food and livelihoods for people. All of these fish move and migrate among habitats at different life history stages. 'Blackfish' species may move within or between wetland habitats while 'greyfish' and 'whitefish' species move along rivers and between rivers and floodplain habitats. These fish are moving to spawn, feed, seek nursery areas, or seek dry season refuges. Providing for these movements is essential for these fish to complete their life cycles. When these migrations are blocked by dams, weirs, regulators, or road culverts, total fish production declines.

To address these issues SEAFDEC in collaboration with the Department of Fisheries of Thailand, with funding support from the Australian Centre for International Agricultural Research (ACIAR), has implemented a project on "Application of fish passage design principles to enhance sustainability of inland fishery resources in the Southeast Asian region". Part of the project is the present workshop on fish passage on 5-10th March 2016. The present paper concerns fish passage at low-level barriers to fish migration such as weirs and floodplain regulators, and is intended to provide general background on fishways and the design process.

The paper is divided up into the following sections:

- Principles of fishway design
- Fishway types
- Design process and implementation.

2 PRINCIPLES OF FISHWAY DESIGN

Principle 1: address upstream and downstream migration

Fish passage at dams and weirs often concentrates on upstream migration, but without safe downstream passage the life cycle is not completed and the function of upstream passage facilities - to maintain or rehabilitate fish populations - is severely or completely compromised.

Principle 2: Integrate biology, hydrology and hydraulics

Developing fish passage solutions is a combination of three disciplines: *biology*, *hydrology* and *hydraulics*. The relationship between these disciplines is shown in Figure 1, along with some key design parameters.

In biology it is important to know the:

- *smallest fish* that are migrating (not the smallest fish in the river or wetland) as these usually have the weakest swimming ability and this determines the maximum water velocity, turbulence and gradient of upstream fishways.
- largest fish, which determines the depth and space required in the fishway, and
- migratory biomass, which determines the size of the fishway and flow required.
- expected species, which can influence operation based on seasonality.

Fish behaviour is a key biological characteristic defining fishway design, although many aspects of migratory fish behaviour are universal. **Hydrological data**, specifically the variation of upstream levels (headwater) and downstream (tailwater) levels, when fish are migrating; are essential in any fishway design. **Hydrological data** is combined with **biological data** to set depths, operating range and determine the length and gradient of fishways.

A critical aspect is integrating biology and hydrology to examine the migration ecology and specifically the flows in which fish are migrating. This analysis influences the:

- Location of the fishway entrance, or entrances. For example,
  - Fish migrating at high flows would need an entrance a distance away from high turbulence of the spillway, whereas fish migrating at low flows would need an entrance close to the spillway.
  - At low-level weirs usually one entrance is sufficient, along with design of weir crests, abutment training walls or operation of gates.
- Operational range of headwater and tailwater. For example,
  - If fish are migrating at high flows, a fishway entrance with high walls would be required, otherwise flows from the fishway are submerged by high tailwater and attraction is diffuse.

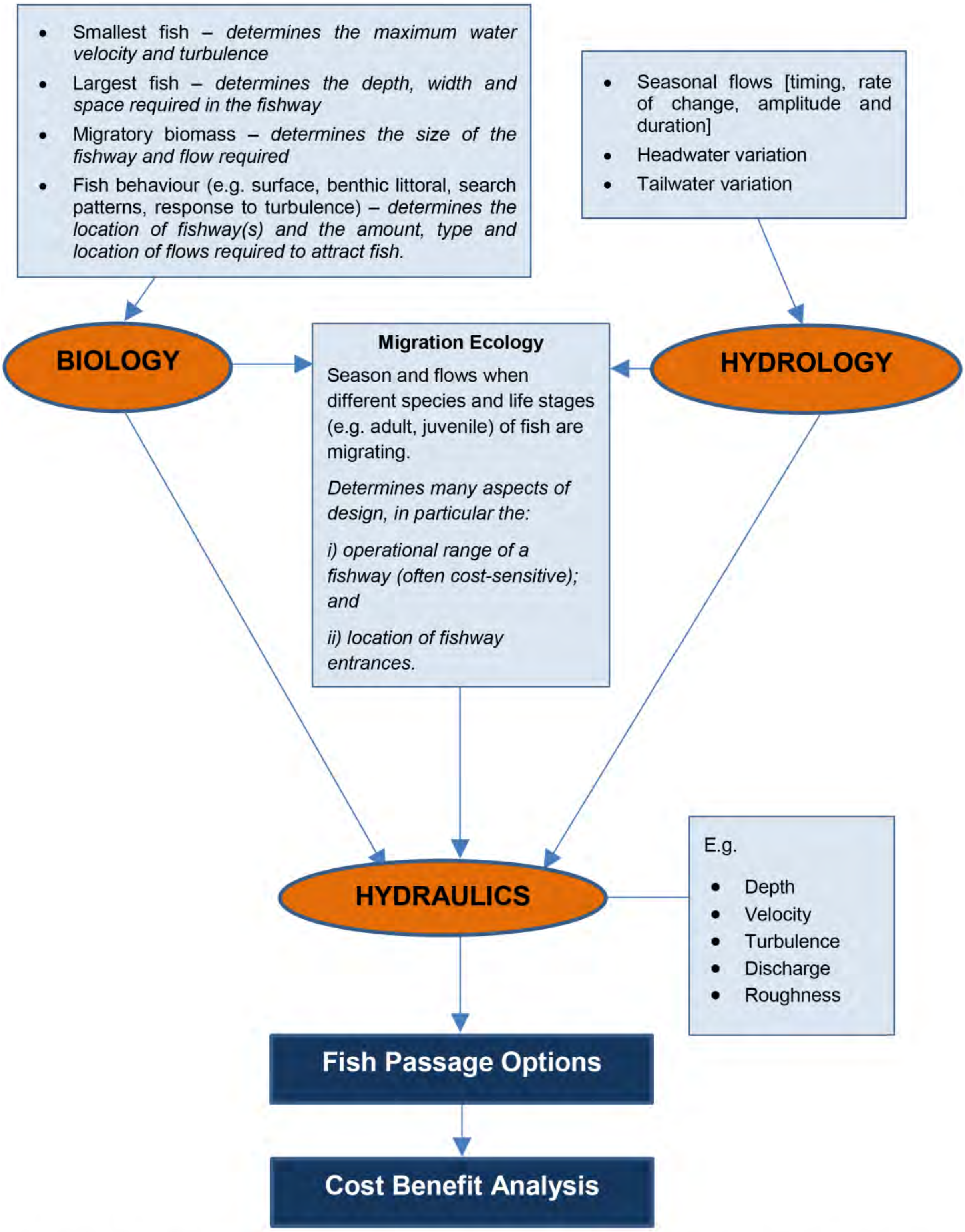


Figure 1. Diagram showing the interaction of three disciplines – biology, hydrology and hydraulics – in developing fish passage options. Key parameters are show in light blue boxes.

- If fish are migrating at different periods of the year when the headwater is likely to vary, then the upstream exit needs to have sufficient depth to accommodate this variation.

- Type or application of fishway design. Some limited examples include,
    - If fish are migrating at high river flows then the fishway type will need to have the capacity to pass high flows to provide attraction
    - If small fish are migrating at low flows, then the fishway will need to have low velocities and turbulence at these flows.
    - If fish are migrating only in the day or night (diel) they may need to complete their ascent in one diel period; hence, fishways on a gradient would need large resting pools.

All these characteristics, and many more, form a set of hydraulic criteria for fish passage design, which can be directly used to develop fish passage options (Figure 1). The cost-benefits of each option can then be evaluated; the final design is often driven by the economic viability of the fish passage solution and the net benefit likely to be achieved in terms of fishery production and community values.

Principle 3: Locate and design the fishway entrance to attract fish

There are two components of effective fish passage:

attraction, which involves ensuring the hydraulic conditions (flow paths and turbulence) near the barrier *guide fish to the fishway entrance*; and

passage, which involves the hydraulic and physical design of the fishway itself.

A common and fundamental flaw of poor upstream fishways is locating the entrance away from attracting flows such as a spillway or regulator gates; often this is done to reduce cost by reducing design and construction complexity. If fish cannot find the entrance, then they will not ascend the fishway.

A fishway itself can have outstanding engineering and hydraulics that are suitable for all migratory fish in the river, but its effectiveness is completely dependent on fish finding the entrance. If fish cannot locate the fishway then fish populations decline and the fishway has not fulfilled its function.

Designing for fish attraction is mostly independent of the choice of fishway design; at low-level weirs it involves the design of the spillway, gates and abutments to guide fish to the entrance. At existing structures it may involve modifying these to direct flows.

There are some universal characteristics of migratory fish behaviour that can be integrated into design principles for optimising fish attraction:

i) Fish are attracted to flow.

Fish that are migrating upstream will be attracted to the spillway or gates. Fish that are migrating downstream will also follow the flow, so they can also be expected to be attracted to the greatest flow which will be the spillway or gates.

ii) Locate the fishway entrance at the *upstream limit of migration*.

This applies to upstream fishways, where fish that are migrating upstream will swim until they reach the limit of their swimming ability, which may be a physical barrier (e.g. dam wall), high water velocities or high turbulence. The key implication for design is that the fishway entrance needs to be at that *upstream limit of migration*, otherwise fish will bypass the fishway.

iii) Avoid recirculating flows or eddies.

Migrating fish orient and swim against, or with (for downstream migrants), the direction of the current. At large dams, recirculation flows can occur near spillway abutments (Figure 2), regulating gates that have asymmetrical operating regimes (Figure 3), or powerhouses. Recirculating flows cause migrating fish to orient to these circular directions and swim past fishways. These recirculating flow patterns need to be minimized and ideally flow direction should not differ by more than 90^{O} from the stream centreline. The main method of predicting these flow patterns and minimising them is physical modelling. Reducing recirculating flows is also a key design objective of water engineers as it reduces the likelihood of erosion near the abutments.

iv) Ensure fishway flow is not masked by competing flows.

The fishway entrance needs to not only be at the *limit of migration*, as described earlier, but also have *integrity of flow* so that the flow is easily distinguished by fish and not masked by other flows and turbulence. This is particularly important at sites with high discharge. As for the principles and design objectives above, the main method of ensuring *integrity of fishway flow* is using physical modelling. It is important to note that the limit of migration may change locations under different discharges or tailwater levels

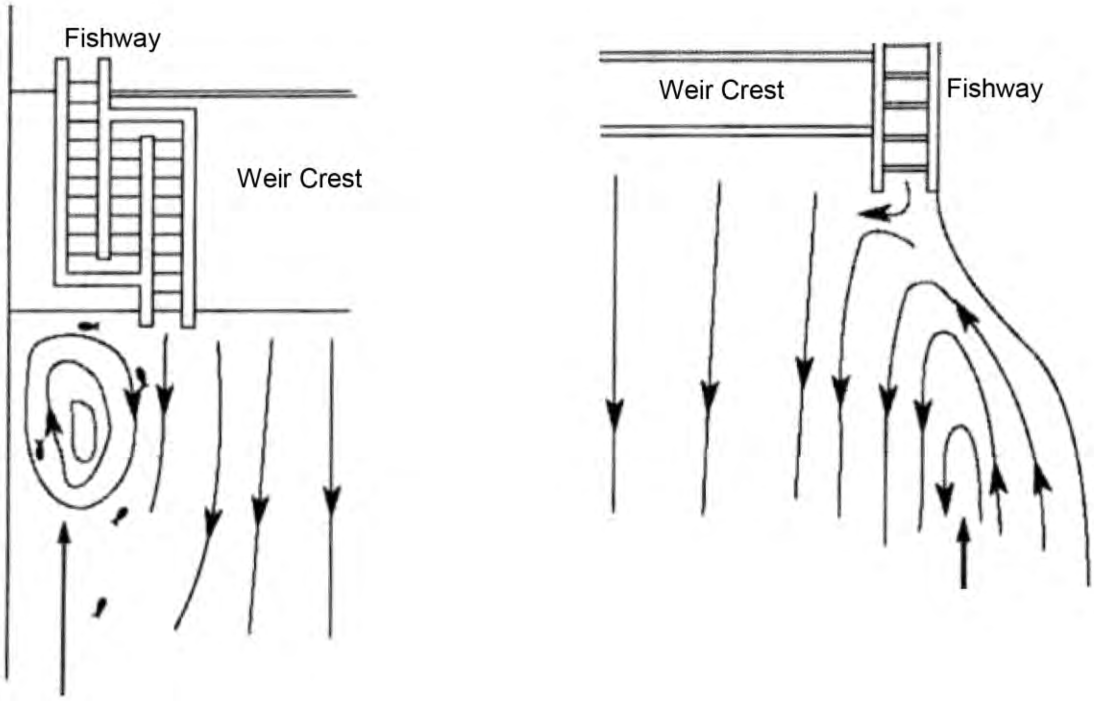


Figure 2. Examples of recirculation eddies that mask fishway flow and direct fish away from a fishway (Larinier 2002).

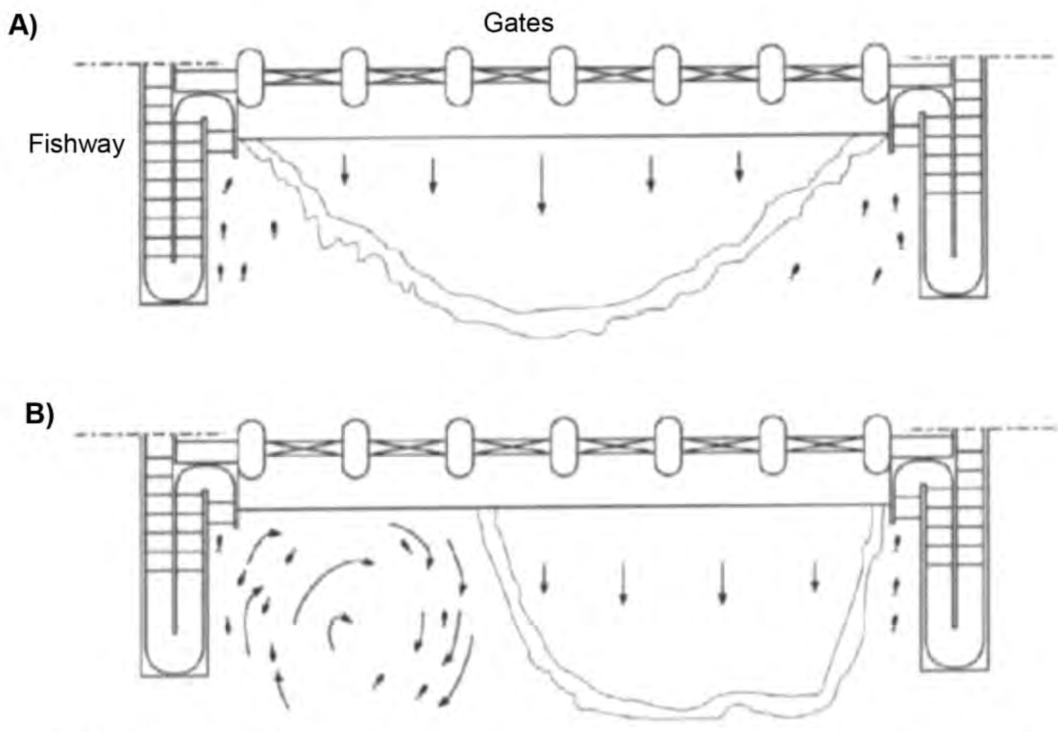


Figure 3. Diagram of spillway gates showing a) optimised for fish attraction, and b) a recirculation eddy caused by asymmetric gate operation. (Larinier 2002).

Physical models in hydraulics laboratories have often been used at large dams (Figure 4) to model flow patterns for fish attraction and these are becoming increasing used for low–level weirs. The models are specific for each site and at a scale of 1:10 to 1:20.

The objective of physical modelling is to create flows that guide fish to specific locations, rather than have migratory fish attracted to numerous locations across a weir face.

Figure 4. Example of a physical model of a 32 m high dam and fishway in Australia that was used to determine entrance location and hydraulic conditions for the fishway. Scale is 1:20 but 1:10 is preferred.

Principle 4: Size the fishway to meet the biomass and flows of the river system

Fishways need to be sized to suit the river system. Small rivers can have small fishways if there are small fish and little biomass. In larger rivers, fishways need to be suitably sized to accommodate larger fish, larger biomass and higher flows. Essentially, fishway size will be dictated by the fish that will need to use it.

To attract fish into a fishway sufficient flow is needed. The design principle is that flows for fish passage need to be maximised. As a rule a fishway should use at least 10% of total flow but higher flows provide better attraction.

Principle 5: Document Assumptions and Use Adaptive Management

At any dam or weir site it is not possible to have all the specific biological data. The method to overcome this in fishway design is to:

i) Produce a model of fish migration, using expert elicitation methods, that includes the key design characteristics, such as migration flows, based on any available data including nearby river systems, the same or similar species elsewhere, or anecdotal information.

ii) Document the assumptions and use this to develop a targeted monitoring program.

iii) Assess the design criteria that are based on available biological knowledge and that also have the most influence on the design, and build <u>flexibility into the design</u> to enable adaptive management, whereby the design can be modified in response to the monitoring programme.

Box 1. CASE STUDY: DEVELOPING FISHWAY DESIGN IN LAOS PDR

The most suitable case study for this workshop is the development of fishway design in Laos PDR over the last 10 years in a joint program with LAAReC, the University of Laos, and independent researchers from Australia and Laos. In this program a model of fish migration was developed, based on available data, and experimental fishway flumes were used to test different fishway designs in the field (Baumgartner *et al.* 2012). From those experiments a prototype was developed and built to pass fish from the Mekong into a wetland at Pak Peung. Fish passage through the prototype has been assessed and further investigations are underway to assess downstream passage and the economic benefits to communities of increased fish abundance and production.

Mr.Douangkham Singhanouvong from Living Aquatic Resources Research Center (LARReC), Lao PDR will be presenting detail of this project at the workshop.

3 FISHWAY TYPES

The following is a brief overview of the five main categories of fishway design that are suitable for low-level weirs: i) cone fishways ii) vertical-slot fishways, iii) rock-ramp fishways, iv) Denil fishways, and v) culvert fishways. Within each of these there is considerable variation and each individual site results in a unique configuration and application.

i) Cone fishways

Description

Cone fishways (Figure 5) are a pool-type design with a channel divided into pools by evenly spaced baffles. The channel is usually rectangular in cross-section but can be trapezoidal or have irregular walls. The baffles are characterised by a series of faceted (5-6 sided) cones on the top of each baffle which can be designed with different heights or widths, so that some overtop at high flows, but have a consistent area between baffles. The baffles are usually pre-cast concrete. The slope of the channel varies from 1:20 to 1:40.

Figure 5. Example of a cone fishway (Photo Courtesy of Tim Marsden).

Advantages

- Headwater range can be extended to the height of the cones.
- Can be adapted to streams with differing minimum flows to maximise operating time. This is achieved by modifying the slope, head loss, number of cones and the depth between the cones.
- It can provide high depth, including at minimal streamflow.
- Can be designed with low water velocities and turbulence for small fish.
- Has the capacity to pass a high biomass of fish in wide designs.
- The internal hydraulics are consistent and predictable so that maintenance needs are easily detectable.

Disadvantages

- Operational range of upstream (headwater) levels limited by height of cones.
- May be susceptible to high sediment loads.
- Maintenance is dependent on the site and is mainly removal of debris (mostly vegetation) which can block the gaps between the cones. In narrow applications the hydraulics are sensitive to blockage because there are few cones and gaps, but the hydraulics are more robust (i.e. keeping the same water velocities) if the fishway is wide and has numerous cones.
- Potentially poor passage of crustaceans and other invertebrates, and other non-fish aquatic fauna (e.g. turtles).
- At sites with high tailwater there is low water velocity as the entrance is submerged, which provides less efficient attraction of fish.
- Passage of large fish and bottom-dwelling fish is unknown.
- Typically a shallow depth

ii) Vertical-slot fishways

Description

The vertical-slot fishway (Figure 6) is a pool-type design with a channel divided into pools by evenly spaced baffles. The channel is usually rectangular in cross-section, although the walls can be irregular (e.g. sheet pile or cut into rock), and the baffle has a vertical slot that runs the full water depth. The baffle is designed to angle the jet of water across the pool to dissipate the energy of the water evenly (Figure 7). Vertical-slot fishways can be pre-cast concrete units or concrete poured on-site. Baffles can be pre-cast concrete, or in smaller fishways they have also been compressed fibre sheet or aluminium. Some simpler designs have used timber baffles although these often need annual maintenance.

In Australia the gradients or slopes vary from 1-on-32 to 1-on-15 (i.e. the channel rising 1 m vertically for 15 m of horizontal length) and the pool sizes vary from 3 m long by 2 m wide to 1.5 m long by 1.0 m wide. There is a minimum depth in the channel of one metre but the channel is usually deeper at the downstream (tailwater) side to accommodate rises in river levels during higher flows.

Figure 6. A vertical-slot fishway

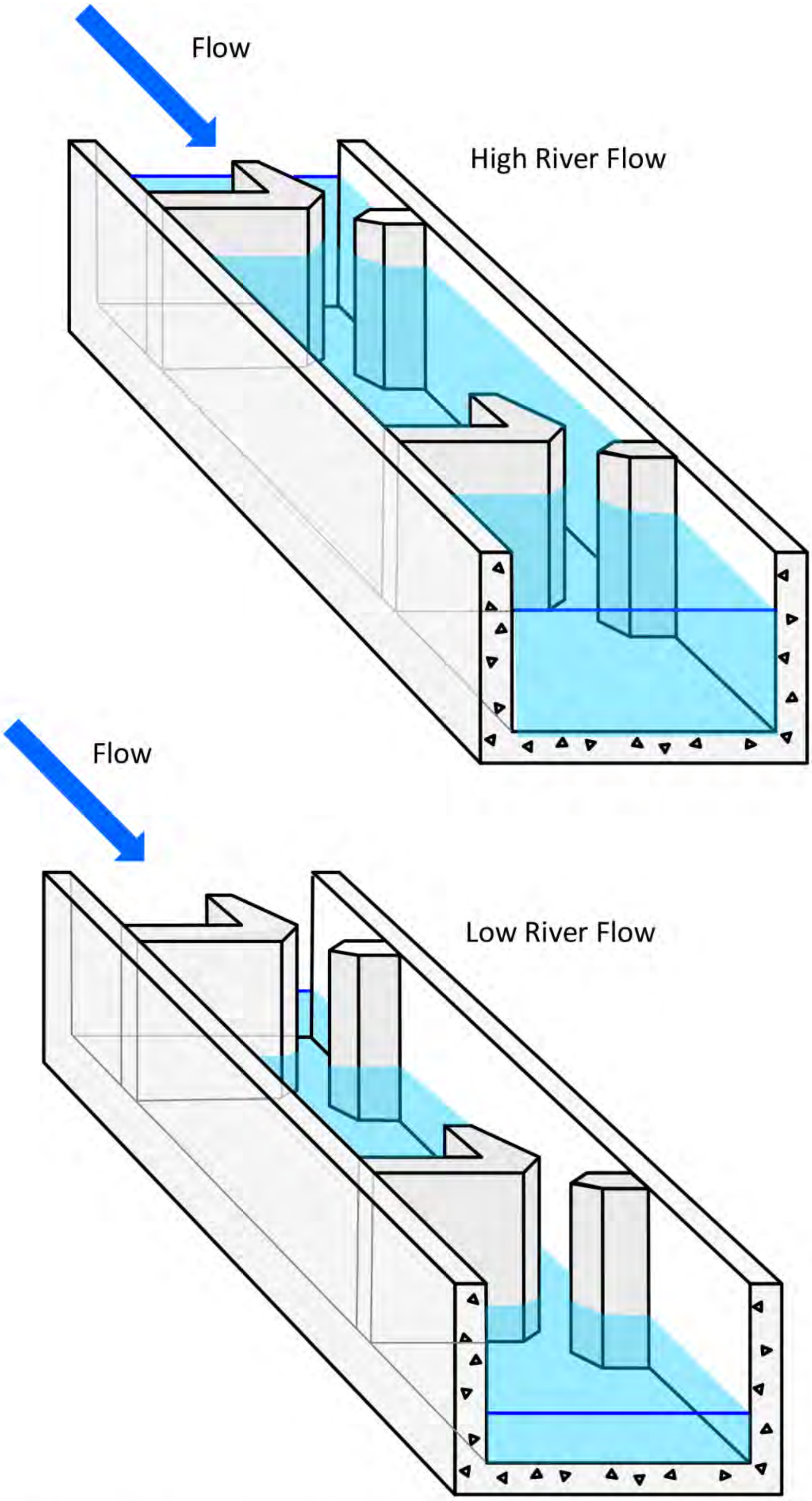


Figure 7. Diagram of a vertical-slot fishway.

Advantages

- Can operate over a very wide range of upstream (headwater) levels and downstream (tailwater) levels, so that if fish are migrating during rises in river levels they can locate and use the fishway.
- Can be adapted to streams with differing minimum flows to maximise operating time. This is achieved by modifying the slope, head loss, slot width and slot depth.
- The full depth slot in the baffle enables the passage of bottom- and surface-dwelling species.
- It provides a high depth, including at minimal streamflow, for the passage of large fish if designed appropriately.
- Can be designed with low water velocities and turbulence for small fish.
- Has the capacity to pass a high biomass of fish and a wide size range.
- Maintenance is generally low with well-designed trash racks.
- The flow pattern in each pool tends to be self-scouring.
- The internal hydraulics are consistent and predictable so that maintenance needs are easily detectable.

Disadvantages

- Can have a high capital cost compared with other fishways (depends on design parameters e.g. pool size and gradient).
- Can require maintenance at sites with sandy sediment loads and low turbulent designs.
- Poor passage of crustaceans and other invertebrates (may be improved by lining the fishway with rocks), and other non-fish aquatic fauna (e.g. turtles).
- At high tailwater in some designs there can be low water velocity at the entrance and less efficient attraction of fish.
- Risk of entrapment of children and livestock if uncovered and small slot widths are used.

iii) Trapezoidal weirs

Description

These fishways are a series of trapezoidal weirs with slots on each side (Figure 8). The hydraulics are close to a continuous roughened channel in the middle with pool-type hydraulics on the side. The design was developed with computer and physical modelling to: integrate attraction flow; pass small fish in low turbulence along the sides; pass large fish at high discharge in the middle flow; provide stream gauging; and pass floating debris through the central flow.

Figure 8. A trapezoidal weir fishway.

Advantages

- Provides suitable hydraulics for passage of small fish, particularly at low flows, and large fish at higher flows
- Integrated attraction flow.
- Very low maintenance, although may collect sandy sediments.
- Flat pre-fabricated baffles for construction.
- The internal hydraulics are consistent and predictable so that maintenance needs are easily detectable.

Disadvantages

- Narrow headwater range (e.g. 0.75 m)
- Can require maintenance at sites with sandy sediment loads and low turbulent designs.
- Poor passage of crustaceans and other invertebrates, and other non-fish aquatic fauna (e.g. turtles).
- Large fish passage success unknown.

- Very difficult to have bends in the fishway and suits locations where the channel is straight. Thus, it has limited options for locating the entrance.

iv) Rock-ramp fishways

Description

Rock-ramp fishways simulate the structure of a riffle or rocky creek. In Europe these are often referred to as 'nature-like fishways'. There are two main groups of rock-ramp fishways: they either occupy the *full width* of the stream (Figure 9), or a *partial width* of the stream (Figure 10). Full-width rock-ramp fishways, which occupy the full width of the stream, are often used in narrow streams as they are generally not cost-effective at wide streams. Partial-width rock-ramp fishways commonly have the downstream entrance at the base of the weir, most of the fishway channel downstream of the weir and the exit near the weir abutment. If the channel passes around the weir these fishways are sometimes referred to as *bypass channels*.

Rock-ramp fishways need to be well-engineered and are not simply rock dumped in the river. Some significant design points are: the rock needs to be sized to withstand storm events and high water velocities at the site; the preferred building technique is to have keyed-in boulders, where the friction and stability of the boulders increases with high velocity flooding; the rock-ramp channel needs to be lined with geotextile and 100 mm diameter gravel to protect the geotextile during construction; and at low streamflow sites (uncommon in SE Asia) a layer of impermeable membrane is needed to prevent percolation of water directly through the rock-ramp.

The rocks in a rock-ramp fishway provide roughness that creates zones of low water velocity. Roughness is decreased when the large rocks in the fishway become submerged – the effective operating range is considered to be when the rocks are breaking the surface of the water and there is a gradual decrease in fish passage with increasing depth over the rocks.

Advantages

- *Full-width* designs operate over the full range of headwater and tailwater
- Can have a relatively low capital cost compared with other fishways but this depends on the design criteria, especially depth and width, and a nearby supply of large angular rock.
- Can be built on a relatively poor foundation.
- Provide good passage of climbing fish species and non-fish fauna such as crustaceans, invertebrates, and turtles.
- Depending on the depth and width, rock-ramp fishways have the potential to pass a high biomass.
- Full-width rock-ramp fishways in streams which do not have low minimum flows are almost free from maintenance.

Figure 9. A full-width rock-ramp fishway with central low-flow channel.

Figure 10. A partial-width rock-ramp fishway with arrow showing direction of flow.

Disadvantages

- *Partial-width* designs operate over a narrow range of upstream water levels; typically a variation in upstream water levels (headwater or weirpool) of 0.2 m can be accommodated in the design.
- *Partial-width* designs have a narrow tailwater range.

  In most rock-ramp configurations the fishway channel rises in elevation from the base of the weir by heading downstream before heading upstream. As the lower part of the channel becoming submerged during rising river levels the entrance of the fishway effectively moves downstream, away from the weir, and away from aggregating fish. There are, however, sites where a narrow tailwater range is appropriate.

  The partial-width rock-ramp configurations that are exceptions to this are where the fishway is: i) recessed into the weirpool, or ii) parallel with the weir crest. In these cases the entrance is always at the base of the weir.

- In streams with very low flows or periods of no flow there is often encroachment of vegetation.

  Reducing the area of the rock-ramp fishway disrupts the hydraulics, reduces fish passage efficiency and increases maintenance.

- At low streamflow sites rock-ramp fishways have shallow depths that reduce passage of medium- and large-bodied fish, and can increase the risk of predation.
- Has a larger construction footprint compared with other fishways. The extent of this issue depends on land tenure and the topography of the surrounding land.
- Sedimentation after flooding

  This depends on the bedload of the stream and the deposition patterns near the weir and fishway.

- Detecting when maintenance is needed can be more difficult than other fishway designs.

  The hydraulics are more complex and more difficult to measure than other fishways. A detailed maintenance manual can address this aspect.

- There is a perception that these are cheap and easy to construct. But there are complex technical aspects of design which are commonly overlooked.

v) *Denil fishways*

Description

Denil fishways are systematically-roughened channels. Rather than separate pools, like pool-type fishways, they have closely-spaced 'U'-shaped baffles (Figure 11, Figure 12). The flow turns upon itself at the base of the baffle and this creates a low velocity zone that fish use to ascend. If a Denil fishway is over a certain length then resting pools are provided. The main advantage of Denil fishways is that they can be built on steeper slopes (e.g. 1-on-12 to 1-on-7) compared with pool-type fishways like the vertical-slot design.

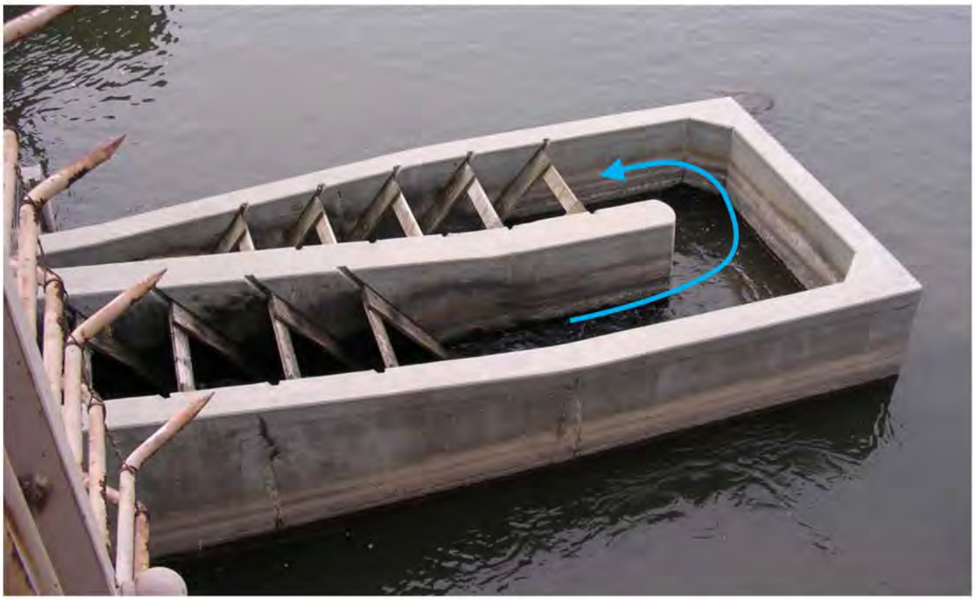


Figure 11. A Denil fishway with arrow showing direction of flow.

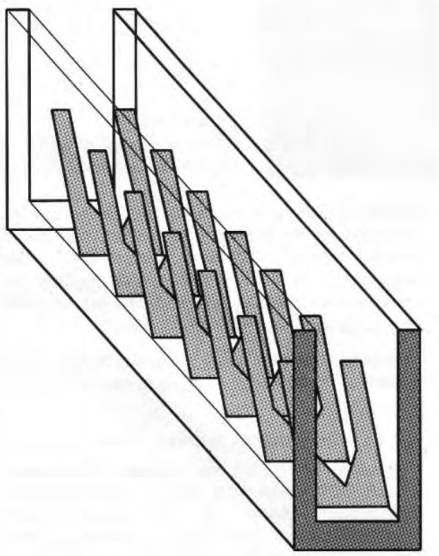


Figure 12. Drawing of a Denil fishway showing the baffles.

Denil fishways are widely used in North America (Clay 1995) and Europe (Larinier *et al.* 2002) for the passage of adult herring and salmon. In Australia research has indicated the potential of Denil fishways for native fish. They are still being assessed and have been applied to a few sites.

The design tends to favour the passage of bottom- and midwater–dwelling fish species and poor passage has been reported of some surface-dwelling species.

Advantages

- Low capital cost.
- Small construction footprint.
- Can be pre-cast off-site, in fibreglass, aluminium or steel.
- Design parameters and hydraulics well known and documented.

Disadvantages

- Very limited headwater range.

  Denil fishways operate over a headwater variation of approximately 0.4 m for small fish and 0.8 m for large fish, which is wider than partial-width rock-ramp fishways but narrower than vertical-slot fishways. Upstream gates or removable baffles can extend the headwater range.
- Biological assessment indicates passage of small fish (< 100 mm) is much poorer than other fishways.
- Very poor passage of crustaceans and other invertebrates, and other non-fish aquatic fauna (e.g. turtles).
- Very poor passage of elvers (juvenile eels) and other eel-like species.
- Susceptible to blockage from floating debris and requires well-designed trash racks.

v) Culvert fishways

Culverts generally present a different hydraulic situation to weirs, where the intent is to pass water rather than impound water. Hence, a culvert can often have very little difference in water level upstream and downstream and the issue for fish passage is high water velocities through the culvert that exceed the swimming ability of fish and also darkness, which can provide a behavioural barrier.

If a culvert impounds water and causes a difference in water level of more than 0.3 metres then it can be considered a weir. A fishway would then need to be applied or the downstream water can be raised up to the culverts through the use of one or more rock weirs (i.e. full-width rock-ramp fishways) downstream.

For the situation where there is little or no impounded water there are various guidelines for designing culverts. Some general approaches include: maximising the cross-sectional area of the culverts to approach or exceed the cross-sectional area of the stream, setting some culverts below the bed level of the stream to ensure depth for fish passage at low flows, maximising natural light, setting culverts at different levels for different flows and using roughened culverts to provide zones of low velocity for fish passage. As with fishways, management of debris needs to be considered in design and maintenance.

vi) Other designs

Other fishway designs include fish locks, fish lifts and trap-and-transport systems which generally apply to high dams, although fish locks have also been used on low weirs. All of these fishways are mechanically complex and need high maintenance.

vii) Comparison of fishways

Table 1 provides a summary of the characteristics of the fishways discussed here. Culvert fishways are not included as they are a special case where water is generally not impounded. The scoring for each characteristic is indicative only as these can vary in the application of each design and at each site.

Table 1. Comparison of common fishway designs.

Scoring

- ●●●●● **Excellent**
- ●●●● **Very Good**
- ●●● **Good**
- ●● **Fair**
- ● **Poor**

	Cone fishways	Vertical-slot	Trapezoidal weirs	Rock-ramp: Full-width	Rock-ramp: Partial-width	Denil
Biology						
Passage of small fish	●●●●●	●●●●●	●●●●*[1]	●●●●●	●●●●●	●
Passage of large fish	●●●*[1]	●●●●●	●●●*[1]	●●●	●●	●●●
Passage of non-fish fauna	●	●*[2]	●	●●●●●	●●●●	●
Operating conditions						
Headwater range	●●●	●●●●●	●●●	●●●●●	●	●●*[3]
Tailwater range	●●●	●●●●	●●●	●●●●●	●●	●●●●
Operation at low streamflow	●●●●●	●●●●●	●●●●●	●●●*[4]	●●●*[4]	●●●
Operation at high streamflow	●●●[5*]	●●●	●●●	●●●●●	●	●●●
Constructability	●●●	●	●●●	●●●*[6]	●●●●	●●●●●

*[1] Yet to be assessed.

*[2] Passage of invertebrates can be improved by lining the fishway channel with rocks.

*[3] Can be designed for variable headwater with upstream sections or baffles that lift out manually.

*[4] Shallow depth of low streamflow.

*[5] Wide designs have greater operation at high streamflow.

*[6] Depends on the width of the stream.

4 DESIGN PROCESS AND IMPLEMENTATION

Six steps can be identified in developing and implementing a fishway design:

1. Concept design with cost estimate
2. Obtain funding for capital
3. Detailed design and construction
4. Commissioning
5. Implementation of maintenance plan
6. Biological assessment

It can appear more logical to obtain funding first and estimate the fishway cost based on other projects. However, fishway costs are highly variable and site specific. Variations in one fishway design to suit different fish species can vary the cost by 100%. Site-specific variables, such as foundation, extent of dewatering, remoteness of the site and the intensity of flooding have a major influence on cost.

Obtaining funds for construction without an accurate estimate of cost can lead to significant risk to the project. It is preferable to seek funding in two stages: one for concept design and one for construction. The concept design stage is done primarily to enable an accurate estimate of construction costs which includes detailed design. On small projects detailed design can be part of the concept stage and on large projects it would be a separate stage. Investigating different fish passage options is usually part of the concept design stage. Even on small projects, such as installing a new culvert, a brief concept report with a cost estimate should be done first.

Step 1. Concept design with cost estimate

In developing a concept design it is essential to use both engineering and biological expertise and involve stakeholders. There are four major components in developing a concept design:

i) Collating background information

Obtaining information on the biology and hydrology of the site is the first step. A catchment model of species distribution and fish movements enables the biological parameters for the fishway to be identified, such as the size range and species composition (including fauna other than fish) that the fishway needs to pass. Describing the seasons and flows over which fish are expected to move are important for the fishway design as these are integrated with the hydrology of the site to determine the operating range for the fishway. If there is no specific data for the site, a list of expected species and expected migrations can be used.

The important aspects of hydrology include: the water levels (upstream and downstream) and how these vary with streamflow; the lowest flows (if fish migrating at these flows), and drown-out flows. In the Mekong, hydrology must account for seasonal variation (rainy and dry seasons).

Engineering plans and survey of the site are useful background information. A survey is usually required to develop a concept design with an accurate cost estimate.

ii) Determine ecological and social objectives

Prior to choosing a fishway design for a site it is useful to determine the ecological and social objectives with all stakeholders. These objectives need to relate to the value of fish at the site and will help develop the design criteria and fishway design, rather than the fishway design driving the ecological outcomes. Ecological objectives are also useful in developing performance standards to evaluate the fishway and, if compromises in design and intended function are necessary to reduce cost, then these can be strategic. Biologists and engineers must both be included in this step.

iii) Site inspection

A site inspection is always necessary to evaluate different fish passage options and develop the most suitable and cost-effective design. At the site inspection it is useful to have the stakeholders present, particularly the owner/operator of the structure.

If a fishway is considered the most likely fish passage solution then the first objective of the site inspection is to determine the entrance location and the second is to evaluate fishway options and layouts. The guiding principle for the design of fishway entrances is that 'fish will move to the upstream limit of migration', which can be the physical obstruction, such a weir crest, or it can be high turbulence and high water velocity.

Considering fishway entrance conditions during the site inspection provides a snapshot of flow conditions on the day. It is important to consider what happens to the flow patterns at different flows and where fish are likely to aggregate. Any photographs or video taken of the site at different flows can be very useful. In fact, once a high priority fish passage site has been identified it is useful to notify locally-based staff so that they can take video at infrequent flow conditions, which are usually high flows, when these occur.

It is worth noting that there are two approaches to considering fishway entrance design: i) using the hydraulic conditions that are present and ii) changing the hydraulic conditions through modification to the structure or its operation. The latter might involve raising or lowering a weir crest near the fishway or changing the operation of stoplogs or gates on a weir.

iv) Engineering design

Generally in developing a fishway design or fish passage solution a few options will be considered along with a few applications or configurations of these options. At this early stage it is often useful to consult with key stakeholders to discuss the pros and cons of each option, including how well each option meets the objectives of the project. In achieving the most effective cost-benefit some compromises in function may be needed and involving stakeholders in this process provides transparency.

Step 2. Obtain Funding

With a concept design and a detailed cost estimate the project will have greater credibility with funding agencies as it provides greater confidence of completion. Submissions for funding should also include:

- The anticipated benefits to fish abundance and distribution, preferably with distribution maps of the major species before and after restoration of fish passage.
- The logic for selecting the barrier as a high priority.
- How the project will integrate with other habitat restoration measures.
- Performance indicators of the project, which should be linked with
- A biological assessment program.
- Who will be the owner of the structure and who will maintain it, preferably with a supporting letter from the future owner.

Step 3. Detailed Design and Construction

There are a few important project management items that need to be included in this stage. During detailed design there should be a review of the plans midway and at completion, and during construction there should be a site inspection midway and near completion. Occasionally there are small decisions made during these stages that unintentionally affect the function of the fishway which are often easy to correct at the time.

Included in detailed design should be trash racks which need to meet the debris load of the stream. Trash racks are needed for most fishways except full-width rock-ramps. A maintenance plan should be part of the detailed design phase.

Detailed design is also the stage to consider assessment needs. These can include fish-traps and microchip (PIT) tag readers which need to be appropriate for the site.

Step 4. Commissioning

Fishway designers (both biologists and engineers) and other stakeholders need to inspect the fishway once it is completed, preferably with construction equipment still on site in case minor modifications are needed. In commissioning all the hydraulic parameters, such as depth, water velocity, step heights (head losses) between pools should are checked as well as the fishway entrance conditions. The latter will need to be checked at a range of flows. Generally there are minor modifications needed to optimise the fishway.

Step 5. Implementation of Maintenance Plan

Ownership of the fishway and responsibility for regular inspections and maintenance should be clarified at the beginning of the project and can formally begin with successful commissioning.

Step 6. Biological assessment

Although there are generic designs of fishways each application is unique and therefore needs some level of assessment to ensure it is functioning as intended. These assessments can range from surveys over one season for small projects to large projects spanning years.

It is worth noting that fish migration can be highly variable between days, seasons and years and that brief surveys may not manage the sample the fishway when fish are migrating.

In general, biological assessment is aimed at quantifying the fish community that approaches, passes through, and exits the fishway. Various techniques can used such as traps at the top and bottom of the fishway, radiotags, PIT tags and electrofishing sites upstream and downstream to assess broad-scale changes in the fish community.

Biological assessment can detect where and when the fishway is not performing as intended, which helps refine and optimise fishway function. Biological assessment helps the design of future fishways.

5 CONCLUSION

Fishways are a valuable method of improving fisheries that have declined due to migration barriers. To be effective, however, they need to be selected to meet the requirements of the fish and hydrology of the site and the design needs to include *attraction* as well as *passage*, so the entrance is well located and fish can easily locate it.

Because each site or weir in a river is unique, all fishways are a unique application, even if design elements (e.g. baffles) are common between fishways, so it important to assess them to ensure they are performing as expected and to inform future fishways. Finally, it is important for local communities to have ownership of fishways, so that simple maintenance is done and the fishway is a considered valuable asset to the community that contributes to restoring fisheries over a wide area.

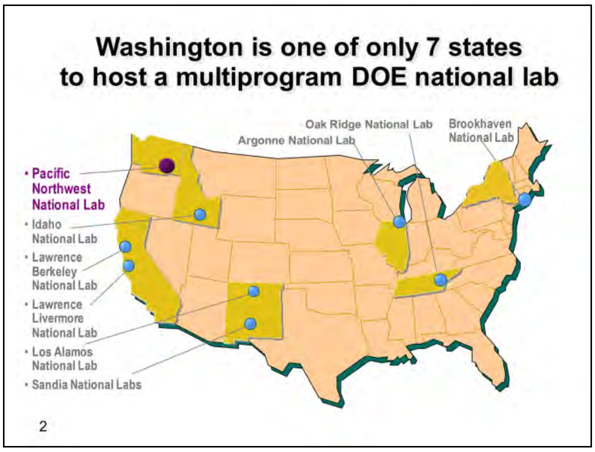
References

Baumgartner, L.J., Marsden, T., Singhanouvong, D., Phonekhampheng, O., Stuart, I.G., and Thorncraft, G. (2012) Using an experimental *in situ* fishway to provide key design criteria for lateral fish passage in tropical rivers: a case study from the Mekong River, central Lao PDR. *River Research and Applications* **28**(8), 1217-1229.

Larinier, M. (2002) Biological factors to be taken into account in the design of fishways, the concept of obstructions to upstream migration. *Bulletin Français de la Pêche et de la Pisciculture*(364 supplément), 28-38.

Annex 6

FISH PASSAGE EVALUATION AND MONITORING TECHNOLOGIES: ACOUSTIC TELEMETRY AND SENSOR FISH



Background

- Safe passage of fish through hydro dams has been a topic of interest for decades
- Fish passage is still a challenge, despite advances in fish friendly turbine design
- Innovations across a broad range of technologies for fish passage monitoring over the last two decades

4 Pacific Northwest NATIONAL LABORATORY *Proudly Operated by Battelle Since 1965*

Selected Monitoring Technologies

- Modeling
  - Physical models
  - Numerical models
  - Blade-strike models
- Hydroacoustics Technology (Acoustic Imaging)
  - Fixed-Aspect Hydroacoustics Technique
  - Imaging sonar
- Biotelemetry
  - Passive Integrated Transponder
  - Radio Telemetry
  - Acoustics Telemetry
- Direct biological testing
  - Field: balloon-tag
  - Lab: pressure testing, shear/strike testing
- Direct physical measurements
  - Sensor Fish device

5 Pacific Northwest NATIONAL LABORATORY *Proudly Operated by Battelle Since 1965*

Acoustic Telemetry

- Sound source transmitting a signal containing information
- A receiver receiving the signal and decoding it to recover the transmitted information
- Encoding strategies
  - amplitude
  - frequency
  - phase of individual pulses
  - time between pulses

6 Pacific Northwest NATIONAL LABORATORY *Proudly Operated by Battelle Since 1965*

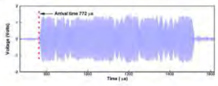
Acoustic Telemetry - continued

- Operating frequency
  - higher frequencies attenuated more rapidly than lower frequency signals
  - lower frequency signals have longer physical length -> more echoes around dams, bottom or surface -> Lower detection rates
  - Dam background noise affects lower frequency signal more
- Detailed fish behavior and passage routes
- Relative high equipment and labor cost but declining quickly
  - Competitive procurement
  - Injectable tag

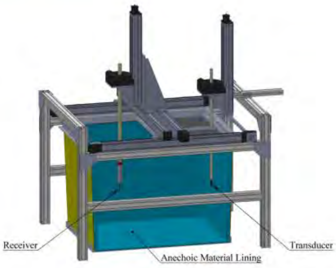
7 Pacific Northwest NATIONAL LABORATORY *Proudly Operated by Battelle Since 1965*

An example: Juvenile Salmon Acoustic Telemetry System (JSATS)

- The JSATS consists of acoustic microtransmitters, receivers, and data management and processing software.



PNNL Bioacoustics and Flow Lab (http://bfl.pnnl.gov), accredited by A2LA to ISO/IEC 17025:2005



Deng ZD, et al. 2010. "Design and Instrumentation of a Measurement and Calibration System for an Acoustic Telemetry System." Sensors 10(4):3090-3099.

ACCREDITED

Cabled Receivers – 3D Behavior and Passage Routes

Detection range in fresh water = 75 – 250 m dependent on ambient noise


Baffled hydrophone on trolley


Trolley pipe, cable tray


Server rack, amps


Star array for 3D tracking away from structure

Weiland MA, et al. 2011. "A cabled acoustic telemetry system for detecting and tracking juvenile salmon: Part 1. Engineering design and instrumentation." Sensors 11(6):5645-5660.

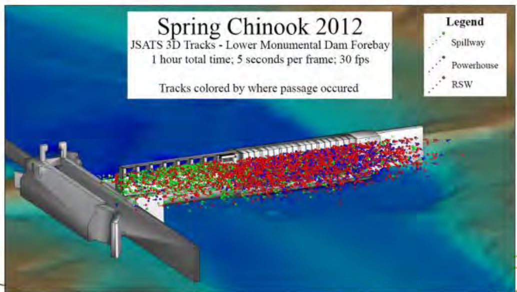
Deng ZD, et al. 2011. "A Cabled Acoustic Telemetry System for Detecting and Tracking Juvenile Salmon: Part 2. Three-Dimensional Tracking and Passage Outcomes." Sensors 11(6):5661-5676.

10

Autonomous nodes – Presence/Absence

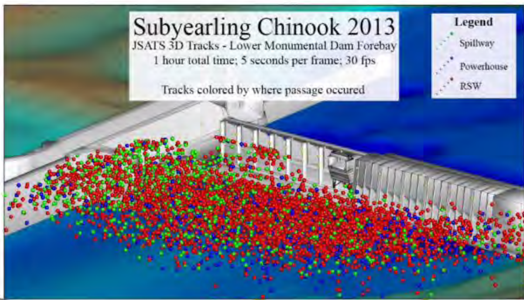
11

3D tracks of fish tagged with acoustic transmitter (50,000 tagged fish in 2012)



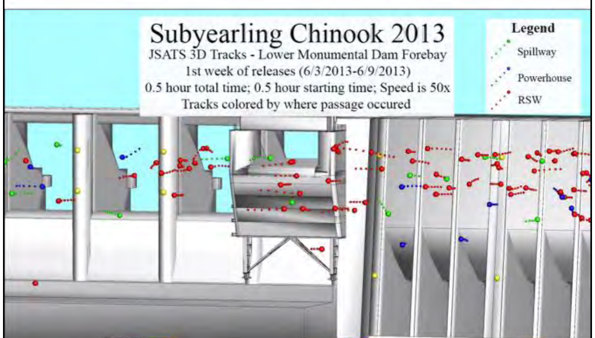
Pacific Northwest NATIONAL LABORATORY

12 *Proudly Operated by* Battelle *Since 1965*



Pacific Northwest NATIONAL LABORATORY

13 *Proudly Operated by* Battelle *Since 1965*

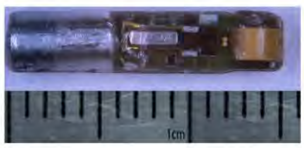


Pacific Northwest NATIONAL LABORATORY

14 *Proudly Operated by* Battelle *Since 1965*

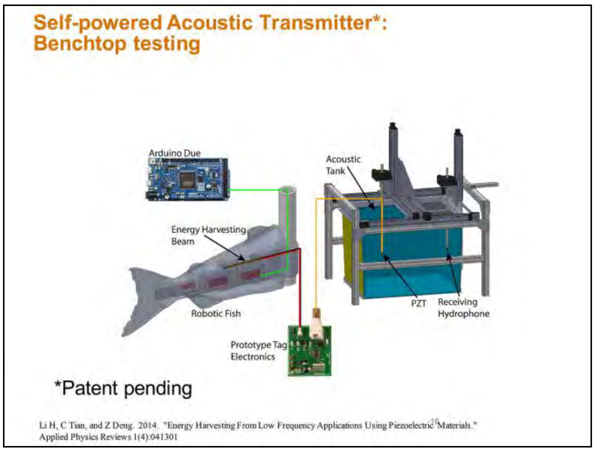
2014 prototype

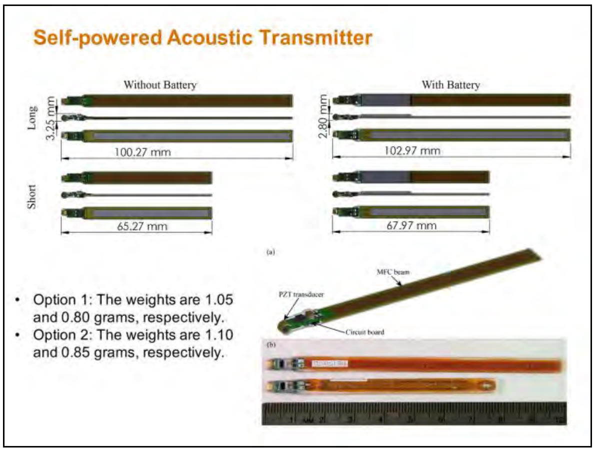
- Dimension: 15 mm x 3.3 mm
- Dry Weight: 217 mg
- Wet weight: 106 mg
- Volume: 0.111 mL
- Source Level:
  - 156 dB at zero deg
  - 155 dB average -90 to 90 deg
- Configurable pulse rate interval & tag code.
- Optional temperature, alternating, and hibernation mode.
- Tag life: > 100 days at 3-s pulse rate interval

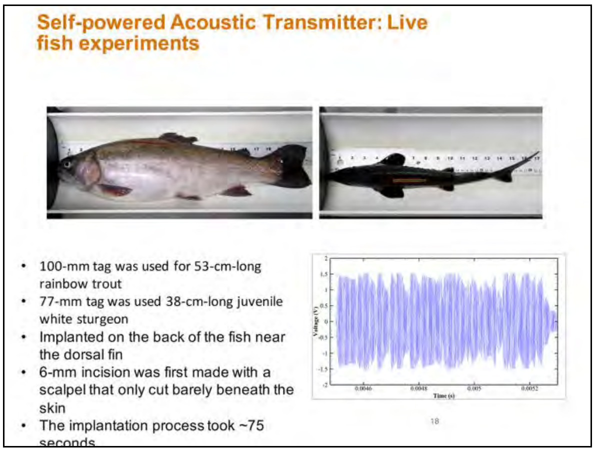


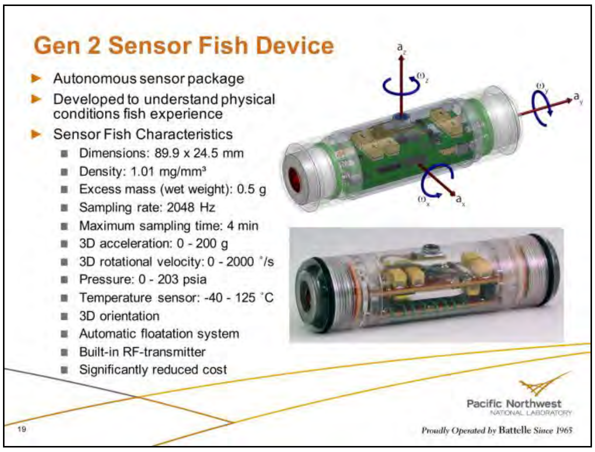
Pacific Northwest NATIONAL LABORATORY

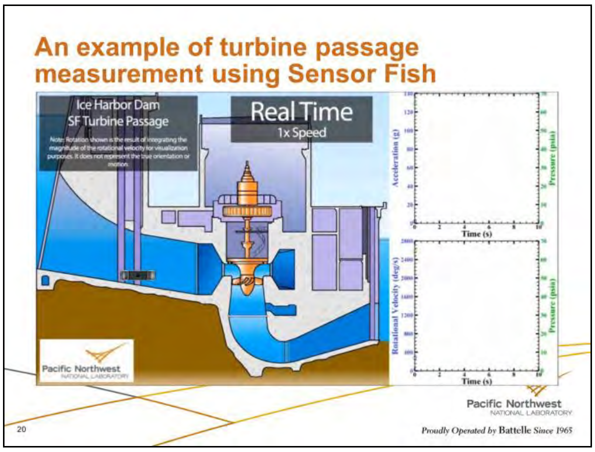
15 *Proudly Operated by* Battelle *Since 1965*

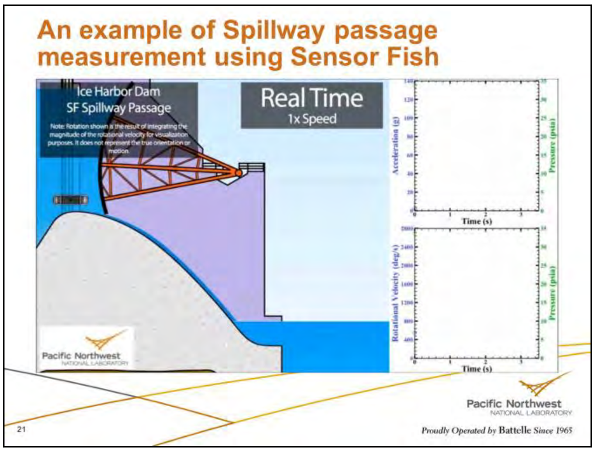

Self-powered Acoustic Transmitter*: Benchtop testing
Arduino Due
Acoustic Tank
Energy Harvesting Beam
Robotic Fish
PZT
Receiving Hydrophone
Prototype Tag Electronics
*Patent pending
Li H, C Tian, and Z Deng. 2014. "Energy Harvesting From Low Frequency Applications Using Piezoelectric Materials." Applied Physics Reviews 1(4):041301

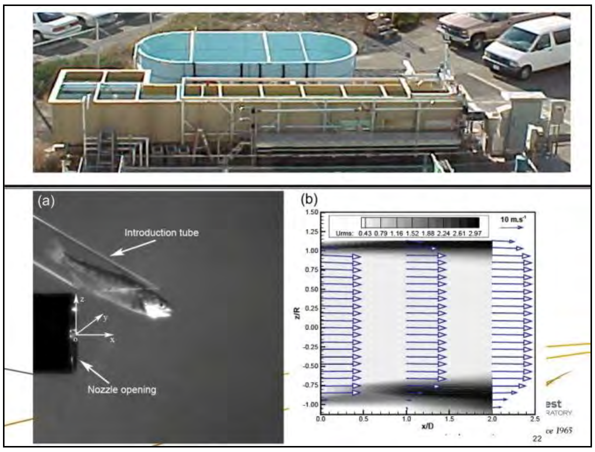

Self-powered Acoustic Transmitter
Without Battery
With Battery
Long
Short
3.25 mm
2.80 mm
100.27 mm
102.97 mm
65.27 mm
67.97 mm
(a)
MFC beam
PZT transducer
Circuit board
(b)
• Option 1: The weights are 1.05 and 0.80 grams, respectively.
• Option 2: The weights are 1.10 and 0.85 grams, respectively.

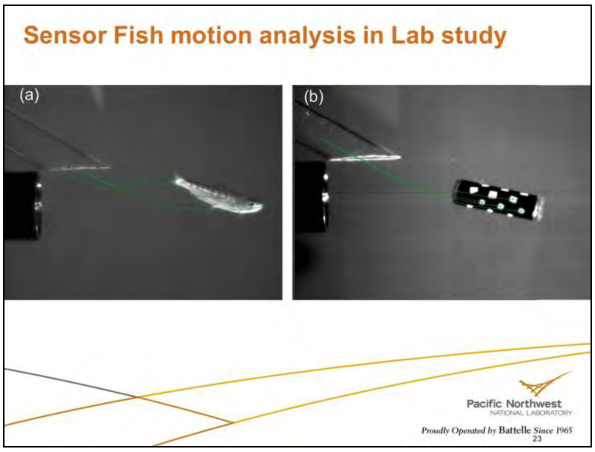

Self-powered Acoustic Transmitter: Live fish experiments
• 100-mm tag was used for 53-cm-long rainbow trout
• 77-mm tag was used 38-cm-long juvenile white sturgeon
• Implanted on the back of the fish near the dorsal fin
• 6-mm incision was first made with a scalpel that only cut barely beneath the skin
• The implantation process took ~75 seconds
Voltage (V)
Time (s)
18


Gen 2 Sensor Fish Device
Autonomous sensor package
Developed to understand physical conditions fish experience
Sensor Fish Characteristics
Dimensions: 89.9 x 24.5 mm
Density: 1.01 mg/mm³
Excess mass (wet weight): 0.5 g
Sampling rate: 2048 Hz
Maximum sampling time: 4 min
3D acceleration: 0 - 200 g
3D rotational velocity: 0 - 2000 °/s
Pressure: 0 - 203 psia
Temperature sensor: -40 - 125 °C
3D orientation
Automatic floatation system
Built-in RF-transmitter
Significantly reduced cost
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965
19


An example of turbine passage measurement using Sensor Fish
Ice Harbor Dam
SF Turbine Passage
Real Time
1x Speed
Acceleration (g)
Pressure (psia)
Time (s)
Rotational Velocity (deg/s)
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965
20


An example of Spillway passage measurement using Sensor Fish
Ice Harbor Dam
SF Spillway Passage
Real Time
1x Speed
Acceleration (g)
Pressure (psia)
Time (s)
Rotational Velocity (deg/s)
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965
21


(a)
Introduction tube
Nozzle opening
(b)
10 m.s⁻¹
z/R
x/D
22


Sensor Fish motion analysis in Lab study
(a)
(b)
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965
23

Summary

- Major advances on monitoring and evaluation technologies.
- Each technology has advantages and disadvantages.
- Different technologies for different applications.
- Complex issues require multiple technologies working together.
- Both Acoustic Telemetry and Sensor Fish have been used extensively for fish passage evaluation around the world.

Pacific Northwest
NATIONAL LABORATORY

References

- Deng Z, et al. 2014. "Design and Implementation of a new Autonomous Sensor Fish to Support Advanced Hydropower Development." Review of Scientific Instruments 85(11):115001
- Richmond MC, et al. 2009. "Response Relationship Between Juvenile Salmon and an Autonomous Sensor in Turbulent Flows." Fisheries Research 97(1-2):134-139.
- Deng ZD, TJ Carlson, H Li, J Xiao, MJ Myjak, J Lu, JJ Martinez, CM Woodley, MA Weiland, and MB Eppard. 2015. "An injectable acoustic transmitter for juvenile salmon." Scientific Reports 5:8111
- Deng Z, MA Weiland, TJ Carlson, and MB Eppard. 2010. "Design and Instrumentation of a Measurement and Calibration System for an Acoustic Telemetry System." Sensors 10(4):3090-3099.
- Deng Z, MA Weiland, T Fu, TA Seim, BL Lamarche, EY Choi, TJ Carlson, and MB Eppard. 2011. "A Cabled Acoustic Telemetry System for Detecting and Tracking Juvenile Salmon: Part 2. Three-Dimensional Tracking and Passage Outcomes." Sensors 11(6):5661-5676.
- Jung KW, Z Deng, JJ Martinez, DR Geist, JR Stephenson, GA Mcmichael, and P Graf. 2015. "Performance of an Acoustic Telemetry System in a Fishway." Animal Biotelemetry 3:Article No. 17.
- Li H, C Tian, and Z Deng. 2014. "Energy Harvesting From Low Frequency Applications Using Piezoelectric Materials." Applied Physics Reviews 1(4):041301
- Li X, Z Deng, Y Sun, JJ Martinez, T Fu, GA McMichael, and TJ Carlson. 2014. "A 3D approximate maximum likelihood solver for localization of fish implanted with acoustic transmitters." Scientific Reports 4:Article number: 7215
- Li X, ZD Deng, JJ Martinez, T Fu, PS Titzler, JS Hughes, MA Weiland, RS Brown, BA Trumbo, ML Ahmann, and JF Renholods. 2015. "Three-Dimensional Tracking of Juvenile Salmon at Mid-Reach Location between Dams." Fisheries Research. 167:216–224
- Liss SA, RS Brown, NK Ashton, RW Walker, P Bates, C Klassen, S Backhouse, RL Townsend, M Howell, Z Deng, H Li, and AHA Colotelo. 2015. "Evaluation of surgical tagging techniques and guidelines for implantation of acoustic transmitters into small juvenile white sturgeon." Fisheries Research (in review).
- Lu J, Z Deng, H Li, MJ Myjak, JJ Martinez, J Xiao, RS Brown, and SS Cartmell. 2015. "A Small Long-Life Acoustic Transmitter for Environmental Monitoring. Submitted to IEEE Sensors.
- McMichael GA, MB Eppard, TJ Carlson, JA Carter, BD Ebberts, RS Brown, MA Weiland, GR Ploskey, RA Harnish, and Z Deng. 2010. "The Juvenile Salmon Acoustic Telemetry System; A New Tool." Fisheries 35(1):9-22.
- Walker RW, NK Ashton, RS Brown, SA Liss, AHA Colotelo, B Do Vale Beirao, RL Townsend, ZD Deng, and MB Eppard. 2016. "Effects of a Novel Acoustic Transmitter on Swimming Performance and Predator Avoidance of Juvenile Chinook Salmon: Determination of a Size Threshold." Fisheries Research 176:48–54.
- Weiland MA, Z Deng, TA Seim, BL Lamarche, EY Choi, T Fu, TJ Carlson, AI Thronas, and MB Eppard. 2011. "A cabled acoustic telemetry system for detecting and tracking juvenile salmon: Part 1. Engineering design and instrumentation." Sensors 11(6):5645-5660.

Pacific Northwest
NATIONAL LABORATORY

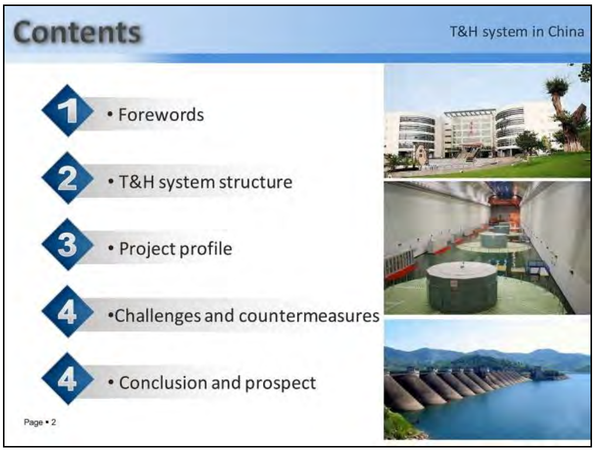
Acknowledgements

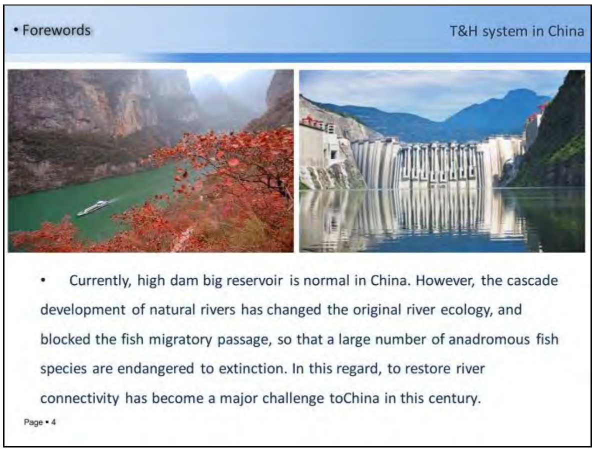
- U.S. Department of Energy Waterpower Program
- Electric Power Research Institute
- U.S. Army Corps of Engineers
- Grant County Public Utilities District

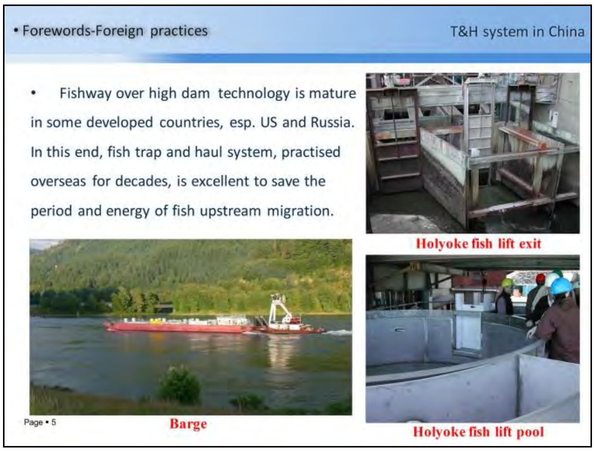
Pacific Northwest
NATIONAL LABORATORY

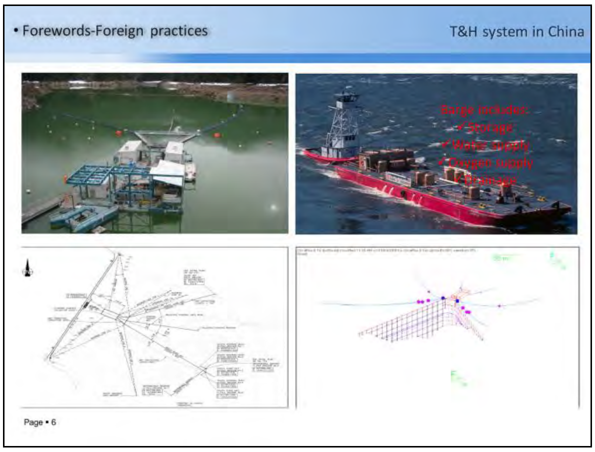
Annex 7

FISH TRAP AND HAUL (T&H) SYSTEM FOR HIGH DAM IN CHINA









• Forewords-Chinese practices

• Now, as China pays more attention to fishway over high dam projects, fish trap and haul system is inevitably favored.


Barges in Pengshui, Chongqing

Barge– "Tanghuan No.1" fish haul platform of Pengshui Hydropower Station, on Wu River

• Forewords

• This study will take examples of three T&H systems substantially completed or prepared for construction in West China since 2013, to explain the development and construction of T&H system in China.

T&H system of Mamaya Level-1 Hydropower Station, on Beipan River, Guizhou

T&H system of Guoduo Hydropower Station, on Zhaqu River, Tibet

T&H system of Longkaikou Hydropower Station, on Jinsha River, Yunnan

• T&H system structure

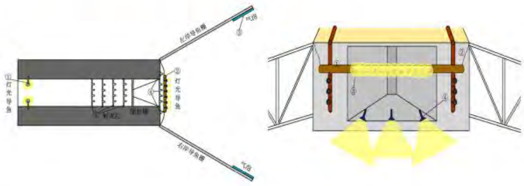
T&H system structure

T&H system

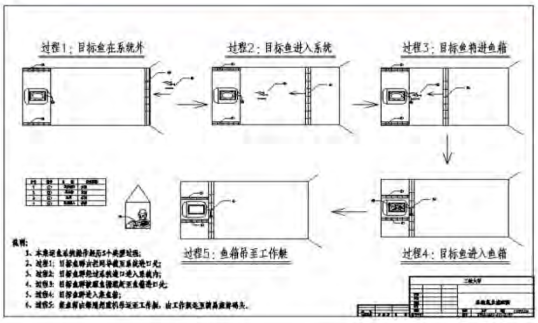
- trap system: Movable platform on river, to trap fish in the fishway or passage .
- haul system: By land or by water. In some cases, as required, by water and land mixed transport.
- supporting facilities: Approach, terminal, security, and monitoring facilities that is also used for surveillance and research.

• T&H system structure-trap system

• A trap system can be a ship or boat, or other floating structure, which trap target fish in the fishway or passage, by sound, light, electricity, gas or other non-structural approach. Later, fish will be gathered through the guide fence of passage, into the cage at the end of system.



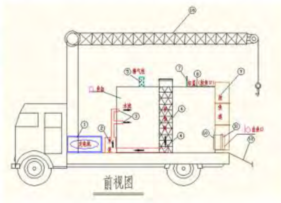
• T&H system structure-trap system



• T&H system structure-haul system

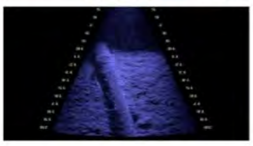
• When the trap system gathers target fish into designated zone or cage, the fish will be transported to the other side of the dam, by vehicle.


Truck


Truck drawing

• T&H system structure-supporting facilities

• In supporting facilities, the most important is monitoring facility that can be an optical camera, fish finder or sonar, to capture real-time changes in fish, and get accurate data.

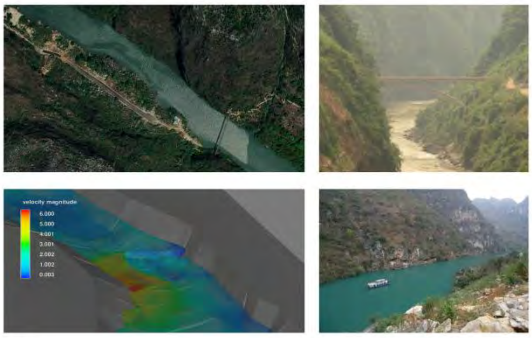


• Project profile-Mamaya project

Project profile

• The T&H system of Mamaya Level-1 Hydropower Station on Beipan River (Mamaya project) is a ecological protection project supporting the hydropower station, which is also the first scientific experiment-oriented project of fish ecological protection in cascade hydropower development of Beipan river, located in Zhenfeng County, Guizhou Province. It is downstream Mamaya Level-1 Hydropower Station, 150m upstream the building of Beipan River Maritime Office of Zhenfeng County Maritime Bureau, in the reservoir area of Dongjing Hydropower Station (subsidiary of Mamaya station)

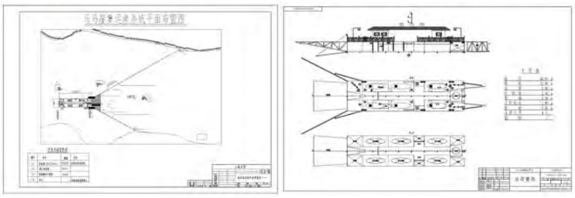
Project profile-Mamaya project



Project profile-Mamaya project

Project profile-Mamaya project

- This project is composed of trap system, haul facility, supporting facility etc. to realise fishway upstream over dam. The trap system includes 22.8m*6.6m floating steel platform and trapping facility. The haul facility includes barge and truck. The supporting facility includes riverside road, platform, pier and the like. The platform is 70m away from the left bank, and 25m from the right bank.

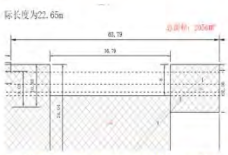


Project profile-Mamaya project

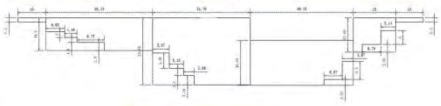
Project profile-Mamaya project

- The trapping measures include guide nets, light, bubble curtain and water flow.

Guide structure

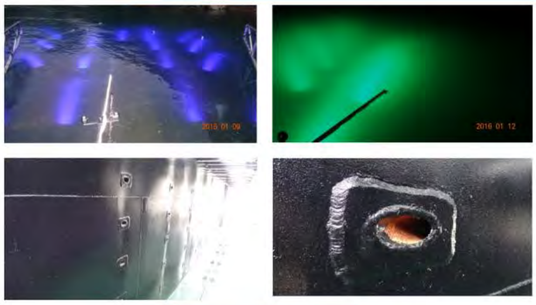


Bubble curtain navigable section



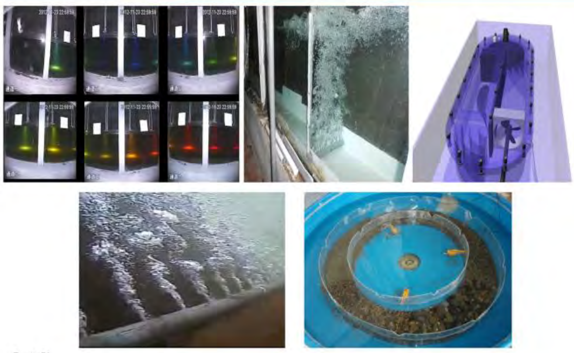
Seamless connection

Project profile-Mamaya project



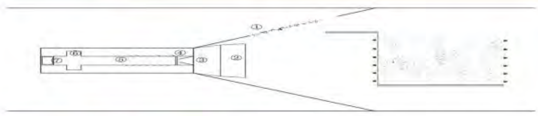
Light, flow trap

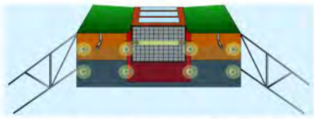
Project profile-Mamaya project

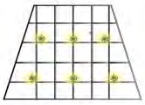


Project profile-Mamaya project

• Project profile-Mamaya project T&H system in China







- 30 underwater cameras are set on the left side of guide net bubble curtain part, on bottom guide fence, passage entrance part, inside anti-escape net, upstream jet hole curtain, rest zone and in the cage.

Page • 23

• Project profile-Mamaya project T&H system in China

Automatic counting system

Page • 24

• Project profile-Mamaya project T&H system in China

Work Schedule

序号	工程项目	2014 年					2015 年				
		8 月	9 月	10 月	11 月	12 月	1 月	2 月	3 月	4 月	5 月
1	施工准备工作									5	
2	集鱼平台建造										
3	导鱼网基础工程施工										
4	集鱼平台安装锚固										
5	附属设施施工安装										

Page • 25

• Project profile-Mamaya project T&H system in China

- Now, the project is under 1-year commissioning.

Realtime monitoring

Trap platform

Page • 26

• Project profile-Guoduo project T&H system in China

- Guoduo Hydropower Station is located in Changdu, Tibet. It is on the second cascade of Zhaqu river. This course of river is mainly to conserve or improve fish species and population. After careful research, this project allows following species to pass the dam, namely, two kinds of Pareuchiloglanis sinensis, as well as Schizopygopsis anteroventris, Schizothorax lissolabiatus, Ptychobarbus kaznakovi, Triplophysa stenura.

Page • 27

• Project profile-Guoduo project T&H system in China

Schizopygopsis anteroventris	Schizothorax lantsangensis	Schizothorax lissolabiatus	Ptychobarbus kaznakovi	Triplophysa stenura	Pareuchiloglanis gracilicaudata
TL=27cm	TL=29cm	TL=20cm	TL=240±10cm	TL=13cm	TL=11cm
BW=280±15g	BW=260±15g	BW=40g	BW=260±15g	BW=23±5g	BW=26g

Page • 28

• Project profile-Guoduo project T&H system in China

Site visits

• Project profile-Guoduo project T&H system in China

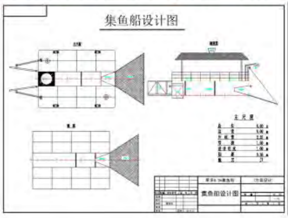
表 2—5 主要过鱼对象过鱼季节选择表

主要过鱼对象	月份											
	1	2	3	4	5	6	7	8	9	10	11	12
前腹裸裂尻鱼												
裸腹叶须鱼												
澜沧裂腹鱼												
光唇裂腹鱼												
细尾高原鳅												
细尾鮡												
上行过鱼季节			3	4	5	6	7	8	9	10	11	12

注：其中 → 主要过鱼季节 → 繁殖期 → 兼顾过鱼季节

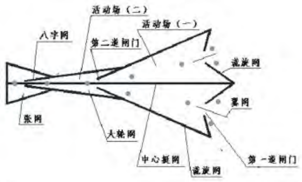
Page • 30

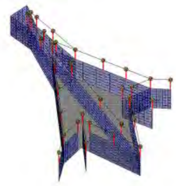
- The project equip the trap platform with bottom flow trap device, deep water net foil, transport fish by truck on land, and release fish by chute in reservoir area, based on local condition and demand. Trap facility starts work by opening the water flow trap. When there is enough fish in the trap device, the truck will lift the cage on a whole and transport it timely to upstream release pier.



Deep water net coil

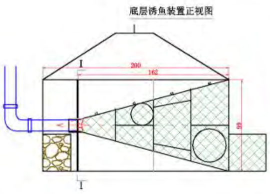
- This project for the first time traps fish with support of deep water net coil and bottom trap device, as effective supplement to trap platform.
- **Simple, low cost, able to trap both pelagic fish and demersal fish.**

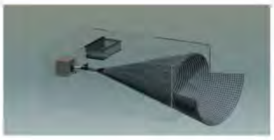




demersal fish trap device

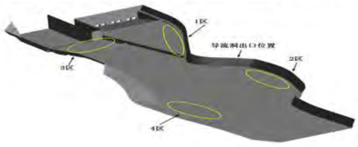
- **A flow trap device for demersal fish.**





Trap point selection

集鱼区	优点	缺点
1 区	贴近尾水洞，可在鱼上溯途中集到大部分鱼；左上方是公路，提供良好的运行管理环境。	在不同工况下，此处水流速度变化较大，要根据不同工况来调整集鱼装置
2 区	是导流隧洞周边，区域宽阔，交通方便，水深较稳定，且存在一定的缓流区域。	部分趋流性较强的鱼类可能会沿河道中间上溯
3 区	鱼类上溯的最前沿，部分鱼会聚集在此	位于泄流洞下，丰水期水期造成危险，枯水期近似静水，并且装置运行维修极不方便。
4 区	导流隧洞出口对面，区域开阔，部分鱼上溯会经过这里	水深变化大，不利于布置集鱼船；交通不便。



Release point selection

Low maintenance cost
Clear upstream migration direction
Easy for fish to find familiar condition
Define as release point

- Longkaikou Hydropower Station is located in Yunnan. It is a level-6 power station developed in plan of "one reservoir + eight levels of power stations" in the middle course of Jinsha river.
- The T&H system here is composed of trap, haul, release and supporting facilities. Currently, the up/downstream haul piers are completed, and the rest facilities will be completed and put into commissioning in 2016.

- The T&H system at Longkaikou station is the first project involving downstream operation among similar projects in China.

• Challenges and countermeasures — T&H system in China

- T&H system with downstream passage shall:
  1. Try to avoid the turbine water inlet;
  2. Form a smooth surface flow field to downstream trap device, before the dam;
  3. Shorten the lag time, in migrating downstream;
  4. Try to use less water discharge to pass more young fish over the dam safe, during downstream migration
- T&H system as a mobile fishway facility has following advantages:

1. Change trap location according to different work conditions;
2. Regulate trapping flow rate according to different fish species in a larger scope;
3. Can release fish into the river course not affected by discharge flow, when the directional velocity is determined;
4. No need to draw water from upstream reservoir.

Page • 39

• Challenges and countermeasures-Challenges — T&H system in China

1. Life history, distribution rules, environmental factors preference and other information of fish are always unknown.
2. Chinese T&H systems are mainly placed in West China. Given the topography in West China, the water level, velocity, flow and other parameters in the course of river where the project is located is changing at all times, esp. in flood season. The design becomes more difficult as it has to consider facilities and managers security under different hydrological conditions, as well as the effect of facilities.

Page • 40

• Challenges and countermeasures-Challenges — T&H system in China

3. Extensive trap scope, so it requires strict selection and setting of trap points
4. T&H system of certain station in the cascade development of river courses will encounter water level overlap during up/downstream reservoir dispatch. This is a new challenge to trap system.
5. Trap facilities are mostly set underwater, so it is unable to directly know the setup conditions, including fixation, stability, functionality.
6. In annual fish migration peak, target fishes will concentrate on the trap platform, which will increase the difficulty of fish collection.

Page • 41

• Challenges and countermeasures-Countermeasures — T&H system in China

Countermeasure 1: Based on local consultation, carry out scientific experiment before work, to obtain the latest fish resource information and other specific fish behaviour information.

Countermeasure 2: In different work conditions, carry out hydraulics simulation based on observations, to ensure prediction in dry season and flood season, draw up possible scenarios, esp. plan the commissioning, the make prejudgment.

Countermeasure 3: Select suitable trap device and location according to different work conditions, different landforms and flow field features, upon field survey, considering the overall layout of hydropower station. Equip the trap device with light, flow and physical guide. In addition, further optimise the trap facility plan in the process of commissioning.

Page • 42

• Challenges and countermeasures-Countermeasures — T&H system in China

Countermeasure 4: Fully understand the dispatch of cascade power stations before work, and on this basis flexibly design the type and setup of trap facility. In commissioning stage, keep in close contact with cascade reservoir dispatch center, and grasp local flow real time, to flexibly adjust the T&H system plan.

Countermeasure 5: Use underwater monitoring equipment, for bottom intelligent monitoring, to timely take responsive or remedial measures.

Countermeasure 6: Take anti-escape measures in the trap platform approach, to ensure trap quantity, increase collection efficiency. In addition, preserve enough running equipment in design stage, for busy work in trap peak.

Page • 43

• Conclusion and Prospect — T&H system in China

- Scientific researches to be made in the future:
  1. Tendency of target fish toward certain environmental factor;
  2. Target fish circadian rhythm and distribution;
  3. Fish response to different trapping flows;
  4. Bubble curtain blocking effect and mechanism ;
  5. Energy consumption in upstream migration and passage structure optimization

Page • 44

Annex 8

FISH AND FISHWAY IN CAMBODIA

1. Fishery in Cambodia

Cambodia's fisheries play a very important role in contributing to employment opportunities to about 6 million people working full- and part-time in fisheries and fisheries related activities, providing people's livelihoods, national food security and adding approximately US$1.5 Billion per year to the economy, corresponding to around 8-12% of total Gross Domestic Product (GDP).

At present, multiple factors, including population growth, the impacts of dams, climate change, overfishing etc. are likely to have potential impacts on fisheries resources. Recently, the massive acceleration in plans for hydropower development in the Mekong has led to growing concern over the potential environmental, economic and social costs; in particular, there is acute concern over the impact on the basin's fisheries.

Today, about 500 inland fish species and 520 marine fish species are known in Cambodia, and the total annual freshwater and marine capture fisheries production is estimated at about 700-800 thousand tons, of which the annual yield of inland fish amounts to 500-600 thousand tons, ranking 4th worldwide in inland fish production after China, India and Bangladesh. The annual marine capture fish production is estimated at 100-150 thousand tons, and the annual aquaculture production adds some 90-100 thousand tons. Cambodian fish consumption is 63kg/person/year and fish provides 81.5% of Cambodian people's animal protein intake.

2. Fish migrations and life cycles in Cambodia

In rivers, fishes have adapted to life in running water and to seasonal changes in habitat availability. The need to migrate is part of this adaptation. Fish movements take place at all stages of life, even the earliest stages. In rivers, movements of fish eggs and larvae, in the form of downstream passive drift are common, and are integrated events of the overall movement patterns of migrating fishes. Often, migration routes and the spatial position of spawning areas are finely tuned to hydrological and environmental circumstances, ensuring that eggs and/or larvae drift back downstream to their rearing habitats with the flowing water.

In an ecological context, fish migrations cannot be described without at the same time describing essential fish habitats and the environment within which these habitats are embedded. Therefore, impacts of development scenarios on fish migrations are not confined to the blocking of migration routes caused by damming of rivers. Impacts on the environment, and there by on fish habitats, and changes in hydrological patterns are equally important.

In a multi-species fisheries environment such as the Mekong system, it is useful to distinguish different species groups based on different life history strategies. The broadest classification of fishes in the Mekong fisheries context is the classification of fishes into black-fishes, whitefishes, and grayfish.

Fish migration pattern in the Mekong River and it tributaries of Cambodia are markedly different in dry season and flooded season. An upstream migration from Phnom Penh capital to the Khone Falls occurs between November and February. During this period, most of all whitefishes, and grayfish move out into the Tonle Sap from flooded areas along the river and Great Lake. When in the Tonle Sap, they migrate down to the Mekong River. Fish migrate upstream from Tonle Sap into the Mekong River just before full moon and Sambor (near Kratie city) during full moon and after full moon near Khone Falls.

From May to July, fish migrate the opposite direction, from Khone Falls and migrated downstream.

3. Dams and Fish Migration

In view of these concerns and the special importance of migratory fish in the Mekong River in Cambodia, we conducted an assessment of the potential impact of mainstream dams on fish migration and recruitment in the Mekong and on the fisheries that depend upon migratory species. We reviewed available information on ecological and population characteristics for important fish species in the Mekong operating hydroelectric dams to minimize impacts on migratory fish populations.

We concluded that the dams currently planned for the Mekong will have a major impact on the fisheries of the basin. In particular, we concluded that the barriers created by the dams will disrupt upstream spawning migration of economically and biologically important species. In addition, the downstream drift of fish eggs and larval stages that sustain fisheries recruitment will be compromised, mainly because juvenile life stages will be trapped in the impoundments. Dams in the tributaries and stream round Great Lake, will stop the longest migrations and disrupt recruitment to the lower reaches of the river. Although the impacts of dams higher in the basin and on individual tributaries will be restricted to the fish populations that use these reaches, these populations contribute substantially to fish production along large stretches of the river.

In the Cambodia, a suite of fish passage technologies has been developed to partially mitigate the impacts of dams. However, our assessment concluded that existing mitigation technology in the form of fishways, locks and lifts cannot cope with the scale of fish migration on the Mekong River in Cambodia. In addition, fish passage mitigation measures for dams in Stung Chinit necessitated research and development conducted over decades, and relied on teams of experienced biologists and fish passage engineers. Similar investments would be needed in the Mekong before any level of certainty on their effectiveness could be determined. Furthermore, specific mitigation measures adapted to the species and hydrological conditions of the Mekong would need to be designed from the start and integrated into dam engineering and operation. Given the lack of investment so far, it is unlikely that any substantial mitigation measures will be available in the foreseeable future.

4. Stung Chinit's Fishway

The main purposes of this paper were reviewed the monitoring fish pass after fish ladder built on Stung Chinit diversion weir to allow fish migration . The fish ladder was the first structure in Kompong Thom province, Cambodia. It was built in 2005 to allow fish migrate from downstream to upstream. Fish ladder has 43 pools. Fish migration in fish ladder was monitored one year through fish cage checked everyday in front of the structure, and 8 fishermen were selected to make logbook to study about fish productivity.

Fishway in Stung Chinit

During one year of fish ladder monitoring (Sep-2006 to Aug-2007), 41,980 fish individuals for 850 kilograms migrated throw fish ladder. There were only 4 orders with 10 families and 55 fish species which migrated from downstream to upstream and only 5 orders with 11 family and 40 fish species from upstream to downstream throw spill way structure. Only 18 of 55 fish species was occurrence in fish ladder. Most fish species migrated were in Cypriniformes orders, especially in September and October 2006. Fish prefer migration at day to night time which Cipriniformes at day time and Siluriformes at night time. Fish species migrated to find new habitat than spawning. Fish migration had not relationship with rainfall factor, but it had relationship with water level in reservoir and in downstream, especially fish migration had relationship with lunar calendar (waxing moon). For fish catch estimation by fishermen logbook (6 fishermen in reservoir and 2 fishermen in downstream), there were 8 orders with 18 families and 69 fish species was recorded in Chinit reservoir and 44 fish species recorded in Chinit downstream. The total catch in the both sites were around 11 tons per year which the figure was higher than in 2002-2003. But for the total catch was estimated 653 tons per year in Chinit reservoir that meant 0.9 kilograms/family/day and 74 tons per year in Chinit River that meant 0.6 kilograms/family/day. The abundant of fish was caught by gill net and seine net.

After Chinit reservoir rehabilitation, fish stock in Chinit reservoir has increased from 141 tons to 151 tons. It meant that the fish stock high potential to support in local consumption, because just after dam construction, fish stock increased 10 tons, and moreover, fish ladder structure has attracted fish to migrate from downstream to reservoir, which fish around 40,000 with 750 kilograms a year. But high fish yield was caught by fishermen using Brush Park during December 2006 to April 2007, which this fishing gear is prohibited by fishery law. If this fishing gear is reduced or eliminated from Chinit downstream, the fish stock in Chinit reservoir will be high potential.

5. Conclusion

The economic and social transformation of the twentieth century saw a dramatic increase in human population, economic activity and demand for natural resources.

Choice the type of fishway, in many cases the final decision will be a compromise. Several types of facilities may be suitable, each of which will have its own advantages and disadvantages.

The species concerned. Some fishways are very specific as White-fishes, black-fish and greyfishes . This is clearly the fish migration and spawning.

Dams will bring a range of changes to the river and its fish habitats.
In a nutshell, fish passes can help mitigate the impact of dams but they are not a magic bullet. Fish passes must be considered for all dams on tributaries, but a proper design requires studies of swimming capabilities of target species to make sure that these passes will be efficient. On the mainstream and in the lower part of the Mekong, the intensity of migrations is such that no fish pass can provide a realistic mitigation measure.

References

Soel Schouten(1999):Rehabilitation of Stung Chinit Diversion Weir in Cambodia and Impacts on Fish Migration and Fisheries

Anders et al (2000): Fish Migration and Spawning Habits in the Mekong Mainstream.

SOK Seyha (2007): Migration and Productivity of Wild Fish in Stung Chinit Reservoir, Kampong Thom Province, Cambodia

Fisheries Administration (2014) : Cambodia Fishers at a glance

Fisheries Administration (2013) : Food and Nutrition Security Vulnerability to Mainstream Hydropower Dam Development in Cambodia.

Annex 9

FISH PASSAGE DEVELOPMENT IN LAO PDR

1. Background

Rice production is important for Lao people. Approximately 50% of poor people in Lao PDR live in rural areas reliant on irrigation-assisted agriculture, mostly rice production, which comprises 12–15% of the gross domestic product and 73% of total employment (David and Huang, 1996). Most rice production occurs on floodplains, which contain the most fertile and productive soil. The Lower Mekong Basin has large annual water-level fluctuations that lead to floodplain inundation, which drives productivity and increased rice yields. However, uncontrolled inundation can limit rice production, because high water levels can drown and destroy crops. A common way to protect crops is to build regulators that protect crops by controlling the amount of water spilling onto the floodplain; however, these can block important migration pathways for fish.

Fish are an equally important commodity in Laos(Baird 2006). The average Lao citizen consumes 29 kg fish/year, which is 48% of total animal protein intake (Hortle 2007). Between 40 and 70% of the overall capture fishery depends on species that are considered migratory (Barlow *et al*. 2008). Developing wetlands for irrigation or crop protection can lead to substantial capture-fishery decline because fish cannot access spawning or nursery habitat; thus impacting river communities by reducing available protein and income.

The Mekong is one of the world's major catchment systems, and is generally recognized as the 10th largest in the world in both discharge and length(Bouakhamvongsa and Poulsen 2001). It drains a total area of 795,000km^{2}and is approximately 4,000km in length. Over 60 million people reside within the catchment in the six countries it flows through. The river has immense importance in terms of benefits and ecosystem services (fisheries, soil fertility, navigation, irrigation, ground water recharge) and cultural values for the people of the region. It also contains some of the world's most unique aquatic communities, which include freshwater dolphins, giant catfish, stingrays, and approximately 850 freshwater fish species(Campbell et al. 2006, Valbo-Jorgensen et al. 2009).

There are more than 1,200 fish species was found in lower Mekong Basin, of which about 500 to 600 species are habited in the Mekong River of Laos. The Mekong River and its tributaries plays very important role in term of water resources and fisheries source for rural Lao Peoples. About 60 million people in the Lower Mekong Basin are rely on fisheries and fish production from the Mekong River.

Fisheries are immensely important throughout the lower Mekong basin (the LMB, which is the Mekong drainage within Lao P.D.R., Thailand, Cambodia and Vietnam). In food security terms, fish and other aquatic animals provide on average 48% and 79% of the animal protein intake in Lao P.D.R. and Cambodia respectively (see Table 1). From a livelihood perspective, more than 80% of rural households in the Mekong basin in Thailand, Lao P.D.R. and Cambodia are involved in capture fisheries, and up to 95% of the rural households in the Viet Nam delta (Hortle 2009). In economic terms, the capture fishery has a first-sale value of between US$2,000-4,000 million per year (Hortle 2009). The annual yield from the capture fishery in the LMB is about two million tonnes, which is approximately 2% of the total world marine and freshwater catch, and about 11 times the total yield of all of Australia's capture fisheries(Allan et al. 2005).

Table 1. Consumption of fish and other aquatic animals (OAAs) and selected meats in Lao P.D.R. and Cambodia. (Information derived from Hortle, 2007).

Country	Fish and OAAs Kg/person/year	% animal protein	Beef Kg/person/year	Pork Kg/person/year	Chicken Kg/person/year
Lao P.D.R.	29	48	5	6	5
Cambodia	37	79	2	3	2

2. The Impact of Water Management Structures on Fisheries Production

The Mekong supports a large population of subsistence farmers and fishermen who rely heavily on regular flooding of floodplain areas to increase productivity. Increased irrigation development in the four LMB countries has led to construction of numerous (in excess of 10,000 in Thailand alone) low-level (generally less than 6 m) water regulation devices which limit the movement of migratory fish(Daming and Kung 1997). Weirs were installed for water management purposes to improve water security/irrigation, but had a negative impact on fish migration(Le et al. 2007). Consequently, the fish cannot move between rivers and floodplains, which is essential for completion of their lifecycles. The proliferation of structures such as roads and irrigation weirs can cost anywhere between several thousand to several million dollars per site depending on size of the structure.

Unfortunately, construction of these structures can individually (and cumulatively) delay or prevent fish passage onto the floodplain at the onset of the wet-season, thus reducing the habitat area available for fish reproduction and growth(Baumgartner 2005). In addition, they create artificial aggregations of pre-spawning fish below these barriers which are extremely vulnerable to overexploitation and disease. These fish either spawn at the wrong time in the wrong place or do not spawn at all. Over time, these impacts reduce the diversity and productivity of the fishery and the benefits of development projects (such as improved road transport and more secure water supplies) are thus negatively offset by lost fisheries productivity.

Many fish species within the region are highly migratory, and require connectivity among river reaches to maintain access to feeding areas, spawning grounds and refuge habitats(Jensen 2001). The creation of barriers on these important pathways can interrupt important life-cycle stages and can result in large-scale population collapses. For instance, following construction of the Pak Mun Dam (Mun River, Thailand) daily fish catches in upstream reaches had declined by 60-80%(Roberts 2001). Overall, the construction of the dam led to the disappearance of 169 fish species from upstream reaches. This can be particularly damaging to rural communities as their livelihood strategies are generally reliant on wild fisheries productivity.

3. Opportunity to Use Fish Passage Technology to Reconnect Wetlands

In other areas of the world, fishways are effectively used to maintain pathways for migratory fish in order to prevent large-scale fish community declines(Clay 1995). Fishways are simply channels around or through an obstruction that permit fish to pass with undue stress. Fish swim through these channels and are able to complete their migrations. In particular, the development of upstream fish-passage facilities has advanced considerably in Australia over recent years(Stuart and Berghuis 2002, Mallen-Cooper and Stuart 2007, Barrett et al. 2008, Baumgartner et al. 2008). Work underway in Australia is directly relevant to the Lower Mekong Basin. Developing a formal collaboration on fishway development issues is important to ensure the long-term sustainability of these economically and socially important and ecologically unique fish community assemblages.

There is strong evidence to suggest that advancing fish passage work in the Lower Mekong could have substantial fisheries productivity returns. A fish yield of 67-137 kg/ha/year has been estimated for wetlands in the LMB, and a first sale value of AUD1.20-2.00/kg (Hortle and Suntornratana 2008, Hortle 2009). Using these data, restoration of a hypothetical wetland of 1,500-2,000 ha to full fisheries productivity would return a value greater than the cost of the project within 5-10 years. Such a target is feasible, given the potential involvement of large donor agencies (*e.g*., ADB and World Bank) in implementing the results of the proposed project in separate interventions.

The estimated economic benefit is based on first sale price only, so it does not include multiplier effects from trade, nor any estimate of the associated livelihood benefits (nutrition/health and employment) from the increased fish supply. It is also important to appreciate that the fish are produced by the functioning ecological system requiring little or no human input, unlike an aquaculture or other animal husbandry operation.

Our project sought to determine whether a fishway could be applied as a technology to rehabilitate degraded floodplain fisheries in the Lower Mekong Basin. There were three major focus areas that were required to develop multiple lines of evidence supporting fishways as a tool to rehabilitate fisheries, firstly:

(1) To understand the scale of wetland development in several key catchments;
(2) To determine if engineering solutions can help fish recover from the effects of floodplain development;
(3) To understand the social and economic issues of impacted, and rehabilitated, floodplain fisheries.

The focus of our project was to determine if an integrated approach could be used to document the overall impact, solution and benefits of obstructed fish passage at a demonstration site in the Lower Mekong Basin.

Since 2008 to present the fish passage technology research for both upstream fish migration and downstream fish migration has been conducted in Savanakhet and Bolikhamxay Province (Paksan district). Three type of fish passage has been tested *e.g.* Vertical-slot, Sub Orifice and Rock Ram.

4. Downstream Fish passage- Improving Irrigation Infrastructure to Increase Fisheries Production in the Mekong and Murray-Darling River Basins

4.1. The Importance of the Mekong Fishery:

The Lower Mekong Basin (LMB) sustains the largest freshwater fishery in the world (~18% world production), more than 80% of rural households are involved in capture fisheries. People of the LMB consume 6-8 times more freshwater fish than anywhere else in the world 70% of species in the LMB Fishery need to migrate. There are three group of fish migration:

- Feeding migrations – *fish may migrate into rich feeding grounds of floodplain wetlands during floods and often return to river when flood recedes.*
- Breeding migrations – *fish may migrate large distances (usually upstream) to spawn.*
- Dispersal migrations – *fish may move actively upstream or downstream between habitats or passively drift downstream (as with eggs and larvae)*

Floodplain wetlands are rich in habitat and food and are important breeding and feeding sites for fish. "Black fish" species are floodplain specialists and typically remain in off-channel habitats. "Grey fish" species move into wetlands on floods and return to main channel when flood recedes

4.2. Floodplain Regulators are Barriers to Fish Accessing Wetlands

The wetland regulators are important for irrigated agriculture and flood protection, however, the regulators restrict fish access to most of the 200,000 km^2 of wetland in the LMB, by improving fish passage at wetland regulators we can improve the Fishery. It has been estimated* that by improving the productivity of wetlands, annual wetland capture fisheries production could increase from:

- Across Laos PDR: ~20,000 to ~82,000 tonnes
- Across the LMB: ~581,000 tonnes to ~2.3 million tonnes

So far over then 100 different species have been trapped moving through fishway into wetland, however, to return to the Mekong fish must leave the wetland through undershot gates, the pilot experiments in Australia and Laos PDR show that more fish are injured or killed by undershot weirs than overshot weirs. Therefore, the aims of this project are:

- *To assist farming communities and management authorities to adapt irrigation structures in ways that increase fishery value.*

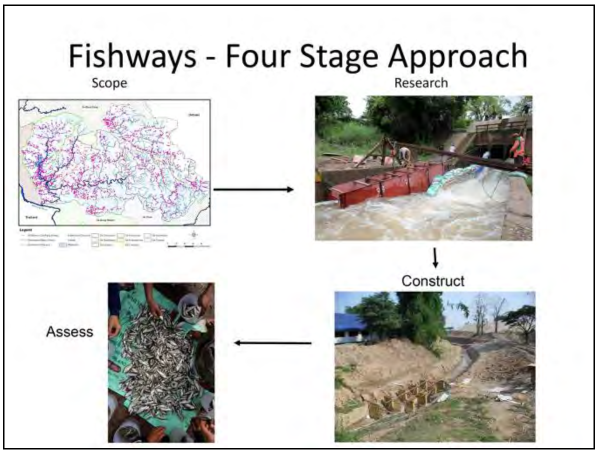
The main objectives of the project are to:

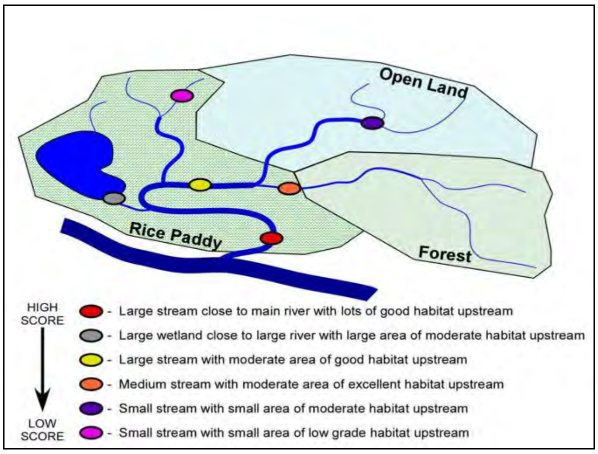
- Understand the impact of irrigation infrastructure on the passage of fish from wetlands and rivers;
- Install and assess the effectiveness of a fish-friendly regulator; and
- Determine how improved fish passage at irrigation structures can increase the value of capture fisheries.

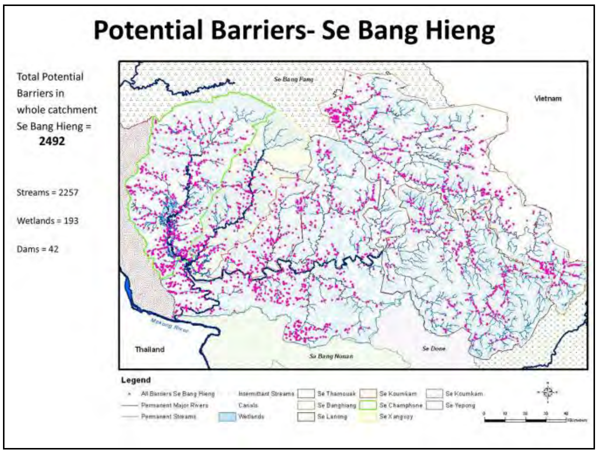
The project activities are:

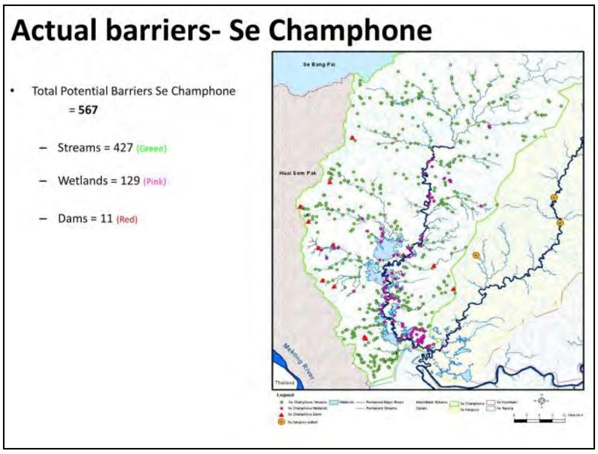
1. *Fish passage surveys*: This survey is to determine what species, life stages and biomass of fish are passing through Pak Peung regulator; by Capture fish moving out of Pak Peung wetland used the fyke and larval netting; Record species, abundance, length and weight.
2. *Hydraulic surveys of irrigation structures in the LMB and MDB*: The Sensor Fish will be used to measure hydraulic stresses (e.g. shear and pressure)faced by fish at different regulators
3. *Installation and testing of a fish-friendly regulator at Pak Peung*: Fish-friendly' overshot Layflat gates have successfully replaced undershot gates at over 50 sites in Australia; therefore, in Lao PDR these type of gates will be retro-fitted upstream of existing gates at Pak Peung. The prototype flap gates will be designed by the AWMA company (Australia) for Pak Peung. After installation, the experiments will test difference in fish mortality between old undershot and new layflat gates. The Pak Peung will become the first ever demonstration site for both upstream and downstream fish passage at a wetland in the LMB. It is Important teaching and promotional tool for application at more sites throughout the LMB
4. *Economic modelling of improvements in fisheries value*: The resulting from regulator upgrades from fish passage and mortality estimates we will be able to compare the cost of upgrading a regulator to the returned value to the capture fishery.

LAO FISH PASSAGE RESEARCH-RESULTS, OUTCOMES AND FUTURE WORKS

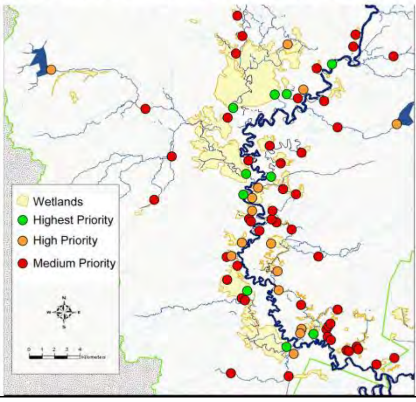






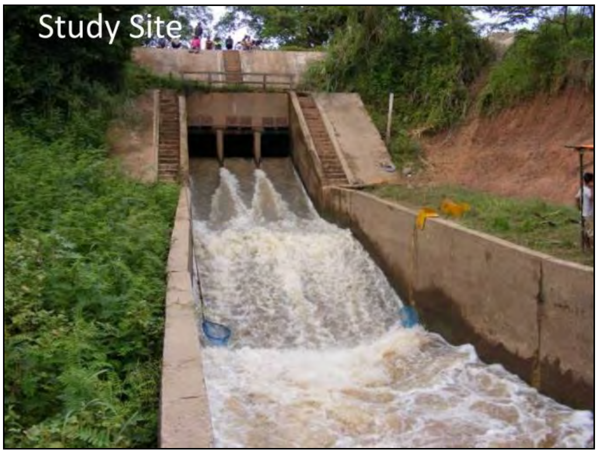


Prioritisation - Se Champhone



Research – Fishway Criteria

Study Site



Summary

Four experiments completed:

1. Fishway designs (V-slot, Sub Orifice, Rock ramp)
2. Fishway effectiveness (top/bottom)
3. Fishway optimisation (top/bottom/culvert)
4. Fishway innovation (lock vs denil)

1. Fishway designs (V-slot, Sub Orifice, Rock ramp)

Two locations:

Savannahkhet; Huai Xai regulator

Pak San; Pak Peung regulator

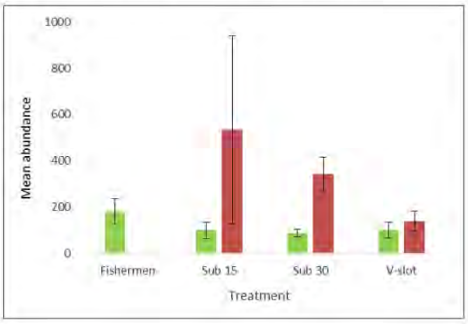
Vertical slot and Submerged Orifice fishway

Experimental Design

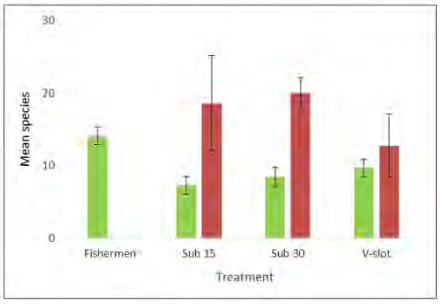
- Three treatments: v-slot, sub o (15), sub o (30)
- Fisherman control
- Latin-square design (two days to complete)
- Three hour trap sets
- All fish captured were weighed, measured and identified

Compared v-slot, sub 0 (15) and sub o (30)

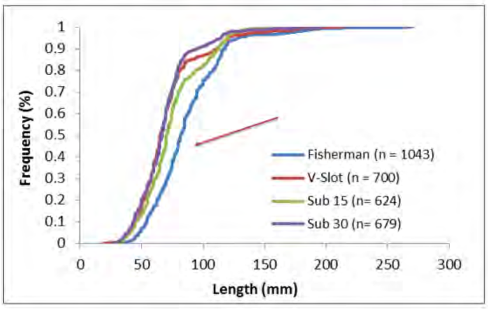
Total Abundance (day vs night)



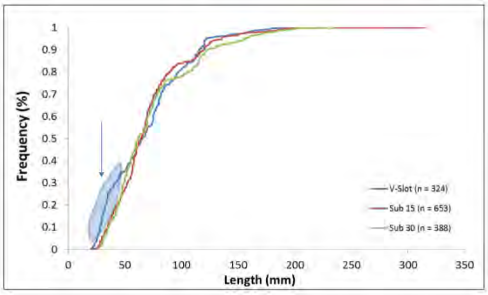
Species richness (day vs night)



Length frequency (day)

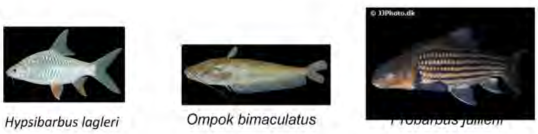


Length frequency (all species, night)



IUCN listed species

Species	IUCN Listing	Sub 15	Sub 30	V-Slot	Grand Total
Hypsibarbus lagleri	Vulnerable	2 (0.005)	7 (0.021)	0	9 (0.026)
Ompok bimaculatus	Near Threatened	1 (0.018)	0	0	1 (0.018)
Probarbus jullieni	Endangered	6 (0.049)	0	1 (0.011)	7 (0.060)
Total		9 (0.072)	7 (0.021)	1 (0.011)	17 (0.104)



Hypsibarbus lagleri *Ompok bimaculatus* *Probarbus jullieni*

Attempt at Savannahkhet

Only two days............

Rock ramp fishway

- Two treatments: top / bottom
- Paired randomised block design
- Four hour trap sets
- All fish captured were weighed, measured and identified

Rock ramp fishway – Huay Xai

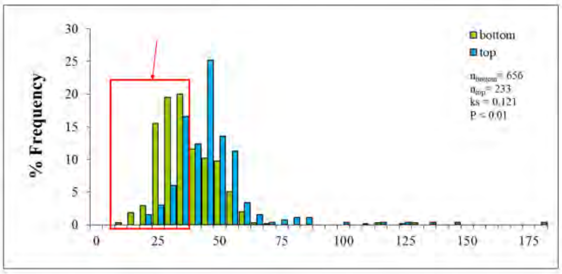
Rock ramp fishway – Huay Xai

Preliminary data – Rock ramp

Species name	Bottom	Top	Grand Total
Rasbora borapetensis	104	112	216
Parambassis siamensis	143	6	149
Unidentified (1)	129	3	132
Esomus longimanus	52	76	128
Dermogenys siamensis	106	0	106
Esomus metallicus	68	24	92
Rasbora rubrodorsalis	51	19	70
Unidentified (2)	52	2	54
Unidentified (3)	4	25	29
Macrognathus siamensis	7	3	10

Total catch = 1037 fish from 28 species collected in 144 hours sampling (16 days)

Length differences



Assessment- Cone Fishway

Trap location experiments

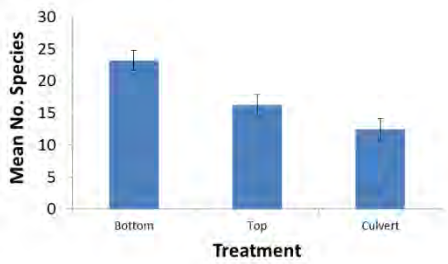
Experimental Design

- Three treatments: bottom, top, culvert
- Latin-square design (two days to complete)
- Three hour trap sets
- All fish captured were weighed, measured and identified
- 24 latin square 'blocks' completed overall

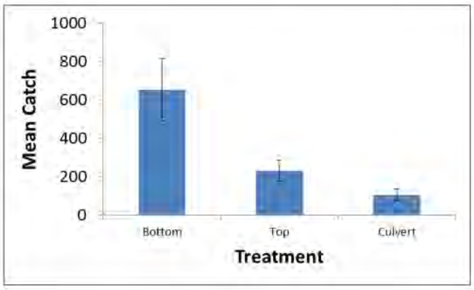
Total catch

Species	Bottom	Top	Culvert	Grand Total
Parambassis siamensis	5188 (5.3150)	2154 (3.3901)	454 (0.7453)	7796 (9.4504)
Clupeichthys aesarnensis	4300 (3.0128)	68 (0.0844)	0	4368 (3.0972)
Sikukia gudgeri	791 (3.0553)	738 (3.4044)	324 (1.8135)	1853 (8.2732)
Xenentodon sp.	677 (2.2012)	400 (3.2388)	129 (1.4930)	1206 (6.9330)
Rasbora borapetensis	785 (0.7149)	256 (0.2138)	49 (0.0393)	1090 (0.9680)
Parachela sp.	452 (0.6133)	260 (0.3454)	138 (0.2390)	850 (1.1977)
Rasbora aurotaenia	166 (0.9899)	171 (1.7697)	222 (1.7488)	559 (4.5084)
Puntius brevis	289 (0.6809)	72 (0.3343)	59 (0.2501)	420 (1.2653)
Puntioplites falcifer	240 (0.5536)	61 (0.3290)	65 (0.5025)	366 (1.3851)
Amblyrhynchichthys micracanthus	91 (0.9604)	203 (2.0152)	45 (0.6097)	339 (3.5853)
Total	12979 (18.0973)	4383 (15.1251)	1485 (7.4412)	18847 (40.6636)

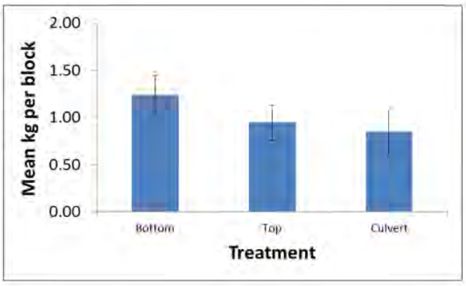
Species Richness (per block)



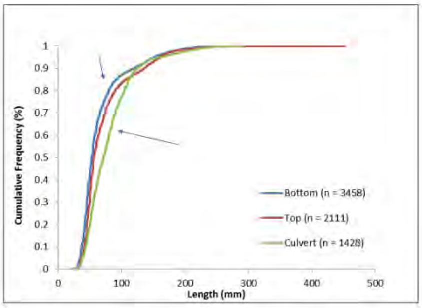
Average catch (per block)



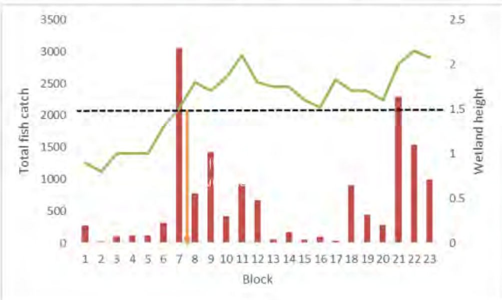
Average biomass (per block)



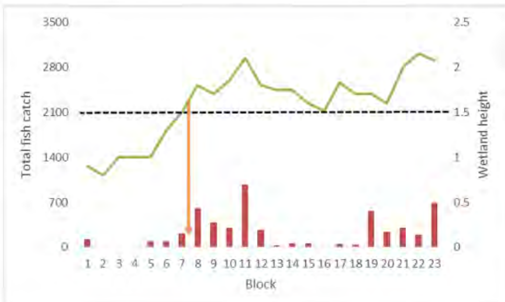
Length comparisons



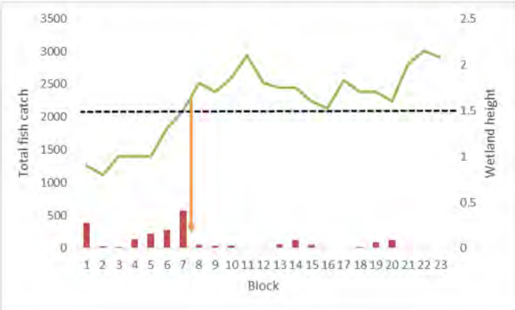
Influence of wetland height



Influence of wetland height



Influence of wetland height



Key statistics

No. Species:

171 to date (inc fishermen; 20% of total in LMB)

Covered two geographical areas:

Savannahkhet and Bolikhamsay

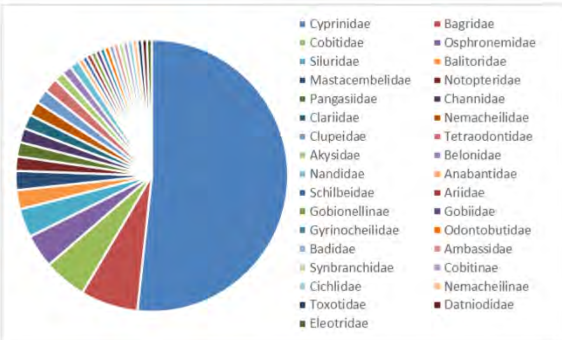
Fishways investigated:

Vertical slot, rock ramp, cone, submerged orifice

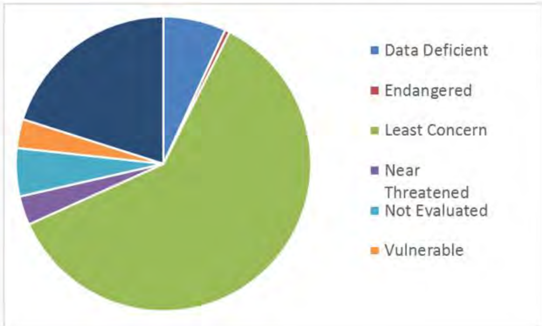
Size Range through fishway:

19-300mm

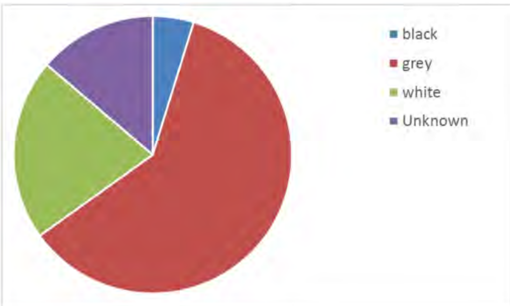
Family breakdown



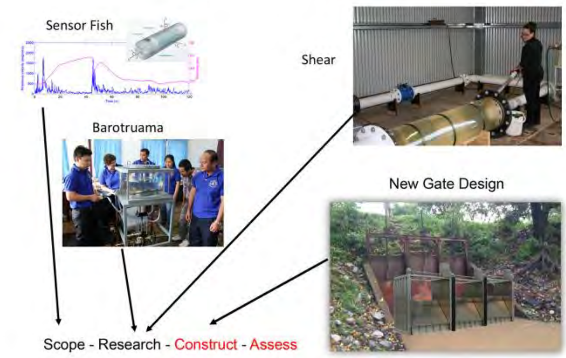
IUCN Status



Ecology



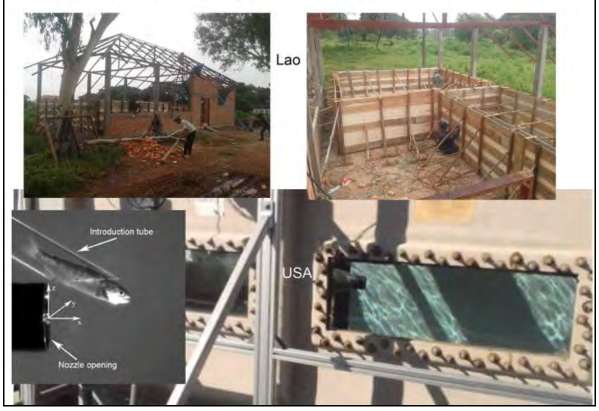
Downstream Passage



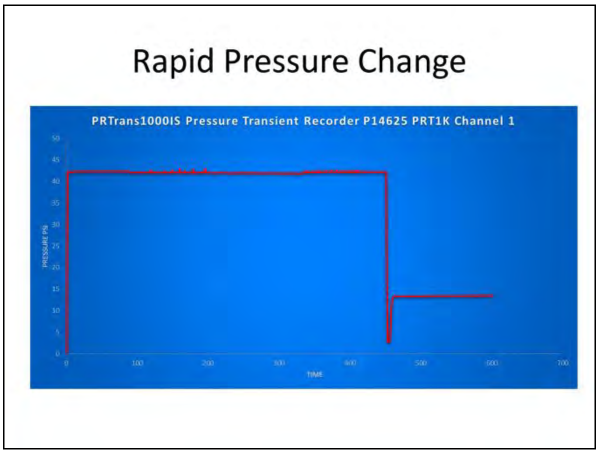
Undershot fish mortality

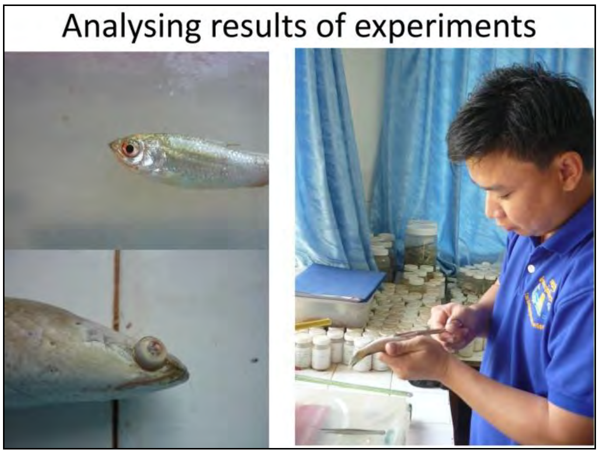
- Nongteng pilot experiments 2012

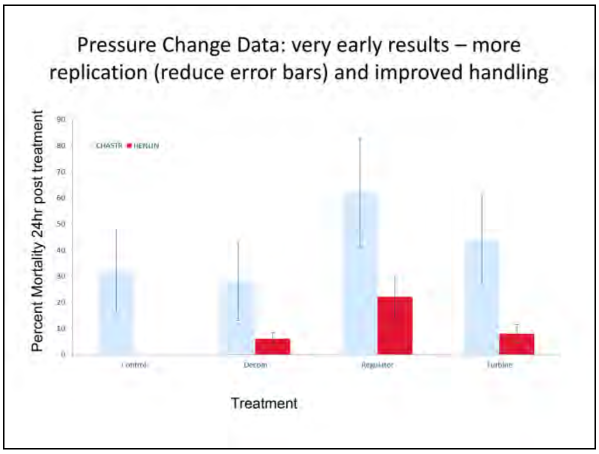

Shear Lab at Don Dok Campus Vientiane, National University of Lao

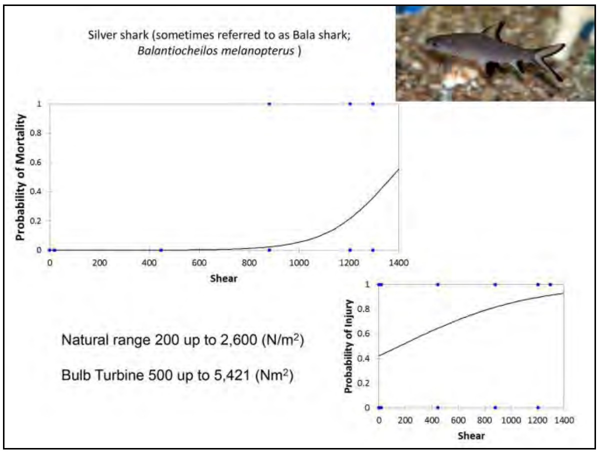



Barotrauma Chambers at Don Dok Campus Vientiane, National University of Lao

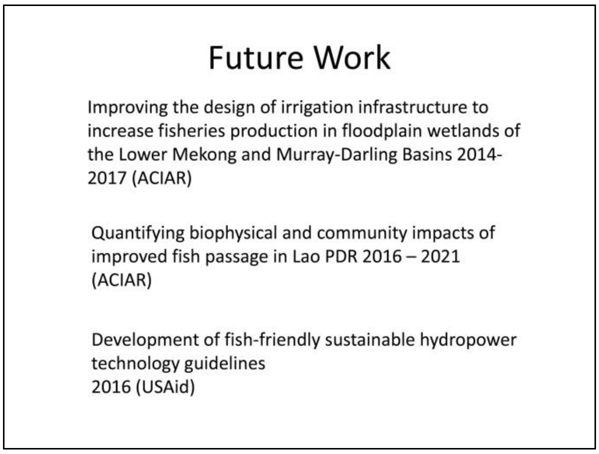

Rapid Pressure Change
PRTrans1000IS Pressure Transient Recorder P14625 PRT1K Channel 1

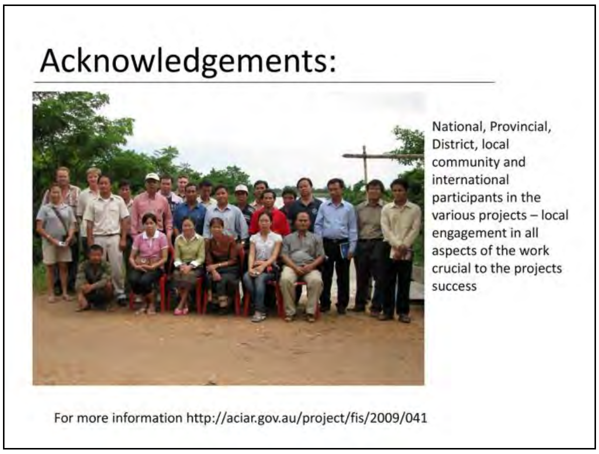

Analysing results of experiments


Pressure Change Data: very early results – more replication (reduce error bars) and improved handling
Percent Mortality 24hr post treatment
Treatment


Silver shark (sometimes referred to as Bala shark; *Balantiocheilos melanopterus*)
Probability of Mortality
Shear
Natural range 200 up to 2,600 (N/m2)
Bulb Turbine 500 up to 5,421 (Nm2)
Probability of Injury
Shear


Outcomes – World Bank Funded Construction in XE Bang Fai and Xe Champone
2 Fishways
9 Fish-friendly Gates


Future Work
Improving the design of irrigation infrastructure to increase fisheries production in floodplain wetlands of the Lower Mekong and Murray-Darling Basins 2014-2017 (ACIAR)
Quantifying biophysical and community impacts of improved fish passage in Lao PDR 2016 – 2021 (ACIAR)
Development of fish-friendly sustainable hydropower technology guidelines
2016 (USAid)


Acknowledgements:
National, Provincial, District, local community and international participants in the various projects – local engagement in all aspects of the work crucial to the projects success
For more information http://aciar.gov.au/project/fis/2009/041

OVERVIEW OF EXPERIMENT FLUMES TO DEVELOP FISHWAY DESIGN CRITERIA

1 INTRODUCTION

SEAFDEC, in collaboration with the Department of Fisheries of Thailand, with major funding support from the Australian Centre for International Agricultural Research (ACIAR), is implementing a project on "Application of fish passage design principles to enhance sustainability of inland fishery resources in the Southeast Asian region". Part of the project is the present workshop on fish passage on 5-10th March 2016 seeking to design a laboratory-based fishway flume.

Developing fishway design in a region with diverse fish and diverse rivers requires an experimental approach to develop design criteria. The alternative is to use very conservative design criteria to ensure the fishway is effective and this becomes very costly.

The present paper concerns the use of experimental flumes in fishway design and is intended as an overview for the workshop to stimulate discussion. The paper is divided up into the following sections:

- Types of experimental flumes.
- Design of experimental flumes.
- Operating experimental flumes.
- Interpreting data from experimental flumes.

2 Types of Experimental Flumes used for Fishway Design

Experimental flumes used for fishway design can be applied in the laboratory/field station or on-site at a river or wetland (Figure 1). There are two types of flumes: straight channels which are used in the laboratory (Figure 2) or flumes with fishway baffles (i.e. experimental fishways) that can be used in the laboratory/field station or on-site (Figure 3).

There is a fundamental difference between these two in their application to fishway design. In straight flumes the *swimming speed* of fish (e.g. burst, prolonged and cruising speed) is measured, which is often applied to research on physiology and sometimes to road culvert design. In these studies fish are non-volitionally or manually introduced into the flume and forced to swim, so there is no information about natural (unforced) behaviour. There is also no information on swimming ability in a complex hydraulic environment with turbulence, and other interacting factors, such as a fishway. There is, however, substantial control over hydraulics conditions.

In experimental fishways fish are not forced to swim and the full range of swimming ability is tested in the fishway. For fishway design this is particularly important as fish need to negotiate: i) water velocity and ii) turbulence; both of which are directly transferable to design criteria. Turbulence in a pool-type fishway is the amount of energy entering the pool (i.e. mass and velocity of water) and the pool volume available to dissipate that energy. Turbulence is measured in Watts per cubic metre but this is an average measure and does not consider the distribution of turbulence within a pool. In practice, the measure is transferable between fishways that use the same design with minor variations.

Experimental fishways also test the behaviour of fish. This may be the reaction to different baffle designs, floor gradients, discharges or different depths.

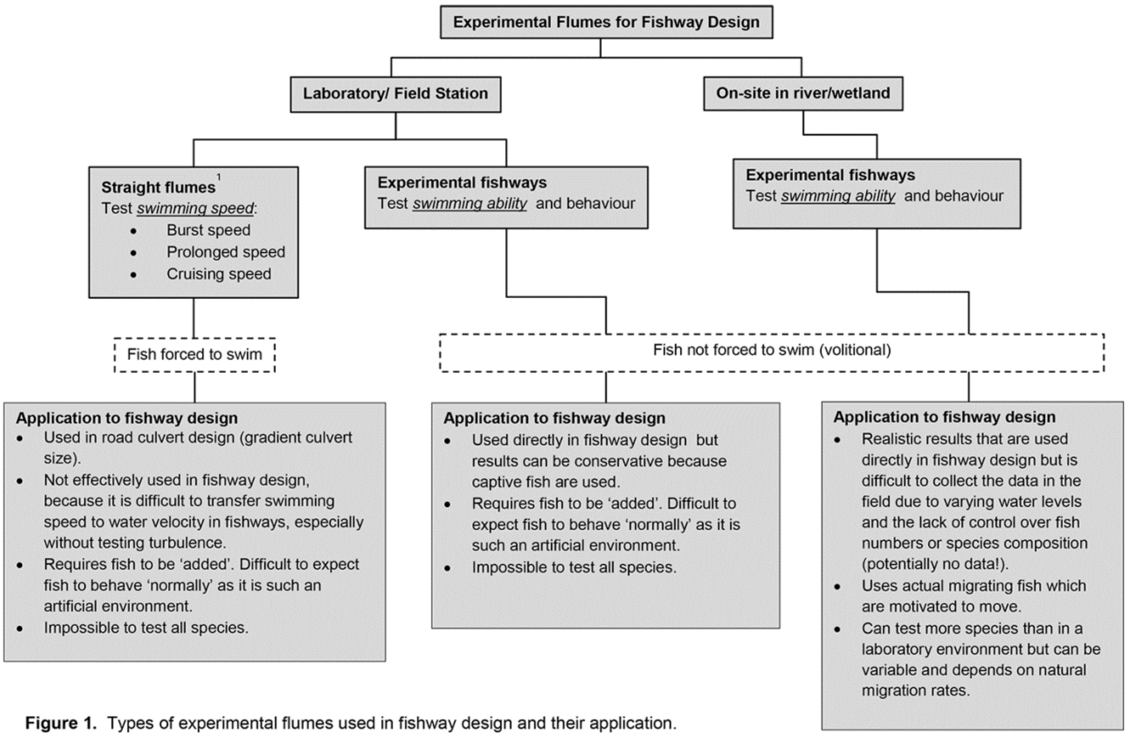


Figure 1. Types of experimental flumes used in fishway design and their application.

---
[1] Flumes are usually straight but can be annular (circular track).

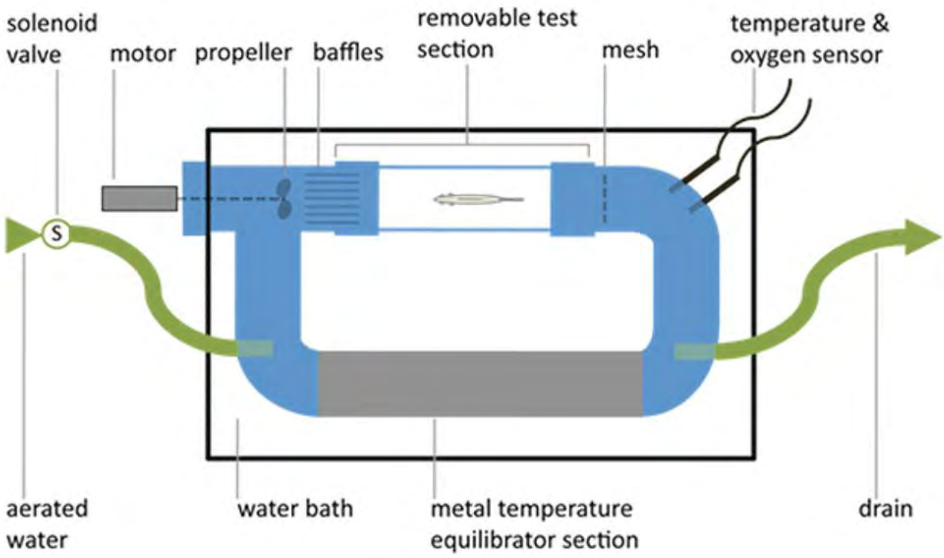


Figure 2. Examples of straight flumes for testing swimming speed (From: http://www.microcosmofscience.com/the-energetic-rhythm-of-mexican-cavefish/ and http://pages.towson.edu/nelson/dace/dace.html) .

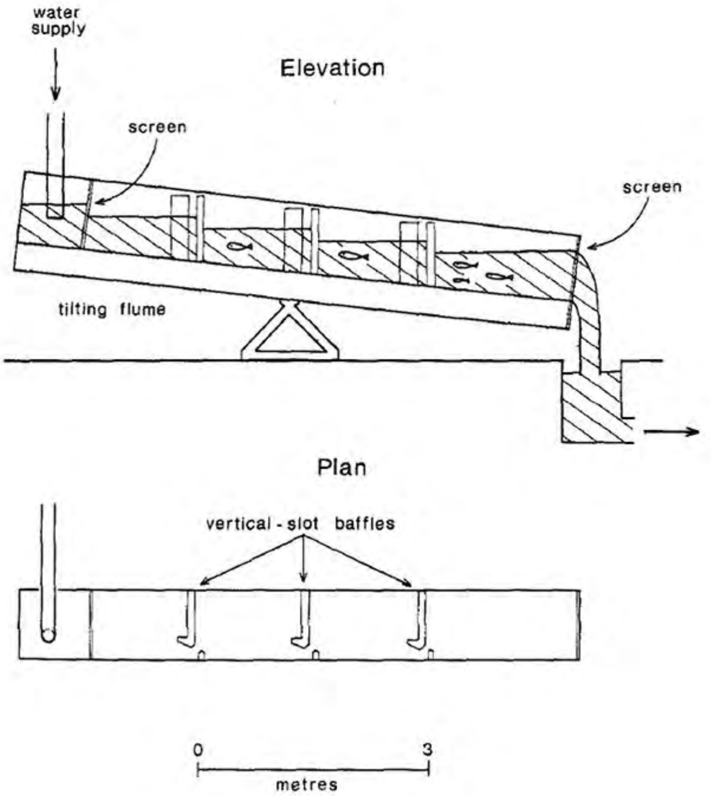


Figure 3. Example of an tilting experimental fishway in a laboratory (Mallen-Cooper 1992).

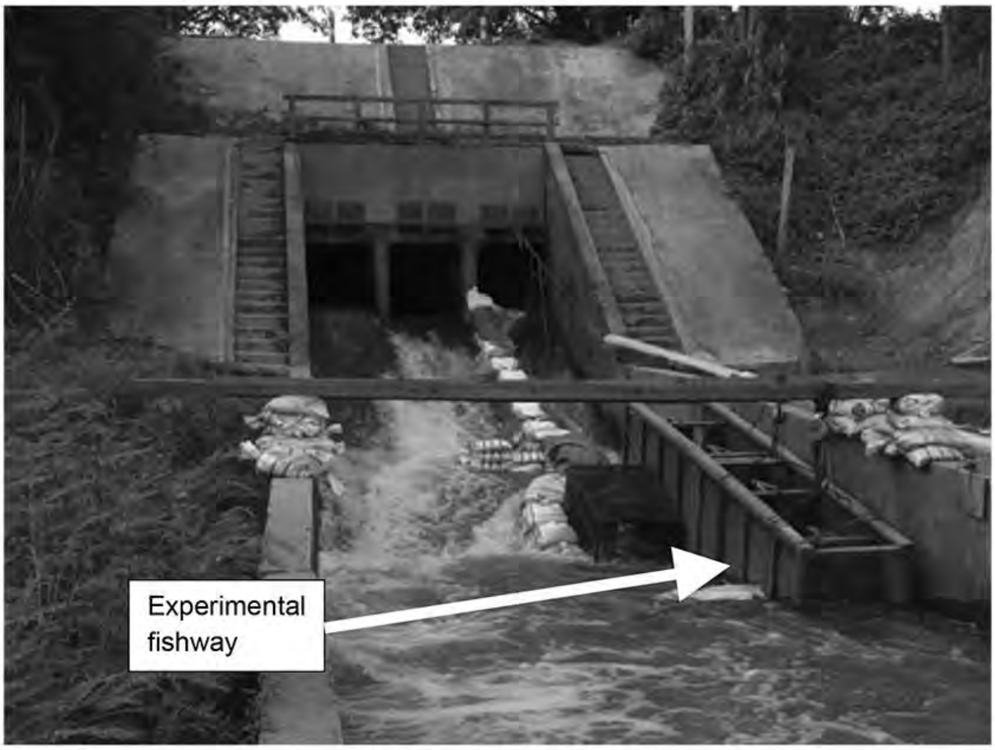


Figure 4. Example of an experimental fishway used on-site (Baumgartner *et al.* 2012)

Straight flumes

Advantages

- Guaranteed to get data.
- Highly controlled hydraulic environment.

Disadvantages

- Fish are forced to swim so the results may not reflect natural ability.
- Required "ground speed" unknown (i.e. how much faster than the ground do fish need to swim to make sufficient forward progress)
- Proportion of *burst*, *prolonged*, *cruising* velocities that are required in a fishway are unknown.
- Does not measure the ability of fish to negotiate turbulence.
- Fish are usually captive, not wild fish, although this type of work could be done with wild fish and reduced handling.
- Impossible to test all species.

Experimental fishway in laboratory/field station

Advantages

- Fish are not forced to swim.
- Can test swimming ability in different water velocities and turbulence.
- Can test behaviour of fish to diferrent baffle design (i.e. will the fish use the fishway even at very low water velocity and turbulence).
- For experimental design the species and number of fish can be controlled.
- The hydraulic environmental is more easily controlled compared to sites in the river.

Disadvantages

- Fish that are held in captivity may not swim as well as wild fish or be motivated to migrate (i.e. they do not use fishway although physically capable).
- Some handling of fish may be required.
- Swimming results can be conservative (Note: large fish are often more stressed than smaller or juvenile fish).
- Fish behaviour may not be 'normal' given the highly unnatural environment

Experimental fishway on-site in river/wetland

Advantages

- Fish are not forced to swim and enter the fishway naturally
- Fish are not handled so that any results are very realistic.
- Can observe fish migration immediately in response to altered design parameters

Disadvantages

- No control of species or number of fish.
- Water levels largely cannot be controlled, so experimental fishway needs to be moveable to adjust to changing flows.

These three approaches vary in the ease of getting data and the value of the data. The straight flume is easy to get data on swimming speed but the data is not valuable for fishway design while the experimental fishway in the field is very difficult to get the data but the data has high value and can be directly applied to fishway design, while the experimental fishway in laboratory or field station is between the two.

3 Design of Experimental Flumes

The following comments refer to experimental fishways as these are likely to be used if the project objective is to develop fishway design criteria. Experimental fishways have seven specific characteristics:

i) Control the flow or discharge of water.

- This is important as it controls water velocity, depth and turbulence, which needs to be consistent during an experiment.
- In the laboratory this can be done with pipes and valves but needs a reliable water supply; in a field station it can be done with stoplogs; or in the field it can be done with valves, pipes or sandbags; but requires a water source will considerable head.

ii) Measure the discharge of water.

- It is important to know discharge because it contributes to turbulence; which is known to be a major limiting factor influencing passage success.
- Discharge is usually measured indirectly using a current meter to measure velocity and combined with a known area (e.g. cross-sectional area of a pipe).
- Another indirect measure of discharge is using *head loss* (difference in upstream and upstream water level) in a baffled fishway. *Head loss* provides an estimate of water velocity which can be combined with cross-sectional area to estimate discharge.

iii) Diffuse the energy of the water before entering the fishway, so that turbulence is within the test parameters.

- Experimental fishways can use gravity-fed water or pumped water and both require that the turbulent energy entering the upstream end of the fishway is diffused before entering the fishway channel. The most upstream pool of the fishway (i.e. the exit pool for upstream migrants) needs to resemble a stable non-turbulent weirpool, which is the typical exit for a fishway. This pool also serves to hold fish once they have ascended the fishway.
- Diffusion of the energy of water in the inlet of experimental fishways is simply done with nylon mesh (geotextile), a vertical layer of gravel between coarse mesh, or multiple baffles specifically designed to absorb energy.

iv) Physical gradient needs to be adjustable, as this controls the hydraulic gradient (slope of water surface).

- On small models the fishway can have an adjustable gradient, while on larger models the weight of water (e.g. 6 tonne) restricts adjustability, so false floors are used to simulate different gradients.
- In the field, a rope and pulley (or similar arrangement) can be used to adjust the floor slope

v) The tailwater level needs to be controlled, as this also controls the hydraulic gradient.

- The tailwater can be controlled with a gate or stoplogs at the downstream end; or in the field the model needs to be moved to match the river level.
- To maintain the hydraulic gradient, the upstream depth of water entering the fishway needs to be the same as the downstream depth leaving the fishway.
- In field sites this is impossible to do, so it is important that the fishway can be physically raised or lowered

vi) Fish need to be contained within the experimental facility.

- Screens are usually used at the upstream and downstream ends of the facility to contain fish.

vii) A fish holding bay needs to be included to ensure fish are acclimated to the facility and handling is minimal.

- The holding bay needs to have fresh water entering or recirculating with very low turbulence and water velocity.
- Handling needs to be minimal because fish are stressed by handling which affects their behaviour. Migratory behaviour is usually the first behaviour to suffer because of stress. It is also important to note that fish take longer to recover from stress than mammals; in fish it can take up to 24 hours to metabolise lactate caused by stress.
- Fish are also stressed by movement. The experimental facilities therefore need to provide sufficient cover and protection

Selecting the size and design of the experimental fishway depends on the fish size to be tested, the intended range of sites of final application and the availability and quantity of source water.

4 Operating Experimental Flumes

There are two general approaches to using experimental fishway/flumes: i) using a fixed, short period of time (e.g. 20 minutes, 2 hours, or 24 hours) or ii) allowing a long time and assessing behaviour over that time. In the first approach fish are allowed to enter the fishway facility and the size and proportion of fish that ascend is compared with those fish that do not ascend. In the second approach fish are observed over long periods, which is most effectively done with PIT tags or through other electronic methods.

The experimental method needs to minimise handling of fish or allow for a long post-handling period (e.g. 24 hours or longer). Important variables to measure, both before and after experimentation, are:

i) discharge,
ii) head loss at baffles,
iii) pool depths (to help calculate turbulence),
iv) pool volumes, and
v) fishway gradient.

Note that measuring water velocity would appear important to assess swimming ability, but the direct criteria that engineers use to design fishways are the five criteria listed above. Water velocity can also be misinterpreted in fishway design as it is not constant. So it is more direct and useful to use the above criteria to report the results of experimental fishways. Nonetheless, velocity can be calculated using the above criteria.

Many have attempted to use small-scale models of fishways with test fish as they are cheaper and simpler, but the results cannot be scaled up to physically larger fishways. This is a very important point. The results of small-scale models are completely misleading for larger physical dimensions. The reason for this is that the viscosity of water is constant and cannot be scaled with the smaller model; so fish can ascend a steeper fishway on a small scale but cannot ascend the same slope in a larger fishway. Hence, the results of experimental fishways only apply to the specific size tested.

Sometimes in laboratory or field station experiments fish do not respond in an experimental fishway even when the velocities and turbulence are low. Four variables that are worth changing to encourage fish to migrate are diel period (day/night) of testing, colour (bright surfaces or 'natural' colours of green or brown have sometimes inhibited fish where black has been more effective), depth (shallow depth can inhibit fish), and altering water temperature if possible. Hatchery fish or fish held in captivity for some time are often not motivated to migrate, so freshly transported wild fish can be tried, allowing time to recover from capture and handling. But even then, such a transition from wild to unnatural can yield sub-optimal results.

5 Interpreting Data from Experimental Flumes

1) Straight flumes and data on *swimming speeds.*

- Where fish are forced to swim and the data is only *swimming speed*, it is difficult to use it for fishway design.
- The data does include the extent that fish need to swim faster (i.e. ground speed) than the water velocity in a fishway to make progress.
- These experiments do not include data on fish behaviour, particularly whether a fish will use a particular type of fishway baffle or not.
- The data can be applied to similar situations in the field, such as culverts or road crossings

2) Experimental fishways in the laboratory /field station.

- These provide useful data for fishway design.
- It can be difficult to obtain data if fish are not motivated to migrate.
- Data on *swimming ability* may be underestimated because fish are handled more than wild fish and may be stressed. However, applying underestimates to fishway design in the field will ensure that fish will have a high probability of ascending the fishway.
- Experimental fishways are short and extrapolating to long fishways in the field requires resting pools and a conservative interpretation of the data.
- Data on fish behaviour through baffles is generally accurate and can be directly extrapolated.
- Experience has shown that data on fish behaviour and depth can be misleading in the laboratory and greater water depth is needed in the field. This appears largely because fish are captive with little choice, compared to the river environment where fish can choose deep or shallow water. The same observations have been made regarding the colour of a fishway; light colours (green or metal) which were effective in the laboratory were not effective in the field and darker colours or more depth were required.

3) Experimental fishways on site in river/wetland

- Data from these experiments, which use wild fish that are migrating in the river, and have no handling of fish until after each experiment, are realistic and can be used directly for fishway design.
- It can be difficult to obtain data if fish are not migrating or river levels vary.
- These experimental fishways are also short in length and extrapolating to long fishways in the field requires resting pools and a conservative interpretation of the data.
- Data on fish behaviour (baffle design, depth, fishway colour) is accurate and can be directly extrapolated.
- Water needs to be deep to optimise fish passage

Of the two experimental fishway methods, it is important to test, report and extrapolate depth directly. This is often overlooked as baffle head loss, gradient and sometimes water velocity are often reported. Low depth in a fishway increases the effects of roughness and enables small fish to ascend more easily. A steep shallow fishway in the laboratory may not work as well for small fish in the field if a greater depth is used. As mentioned above a shallow depth may also not work in the field because larger fish are reluctant to use it. Hence, test a realistic and not-shallow depth in the experiments.

One more important context of experimental fishways is that the first few prototype fishways that use the data should err on the conservative side (i.e. use slightly lower water velocities and turbulence) and use field verification to then refine the design criteria.

5 Conclusion

Experimental flumes for fishways are a useful and essential tool to develop design criteria to build fishways. Specific swimming speed data is difficult to apply to fishway design, but data from experimental fishways in the laboratory and field have been effectively used. Data using wild fish that are not handled is more realistic but much more difficult to obtain, whilst data using captive fish is useful but requires more interpretation.

References

Baumgartner, L.J., Marsden, T., Singhanouvong, D., Phonekhampheng, O., Stuart, I.G., and Thorncraft, G. (2012) Using an experimental *in situ* fishway to provide key design criteria for lateral fish passage in tropical rivers: a case study from the Mekong River, central Lao PDR. *River Research and Applications* **28**(8), 1217-1229.

Mallen-Cooper, M. (1992) Swimming ability of juvenile Australian bass, *Macquaria novemaculeata* (Steindachner), and juvenile barramundi, Lates calcarifer (Bloch), in an experimental vertical-slot fishway. *Marine and Freshwater Research* **43**(4), 823-833.

FISHWAY EXPERIMENT

Fishway Experiment

SEAFDEC Training Department

Hydraulic design –General information

The hydraulic design of a fish way experiment by SEAFDEC/TD

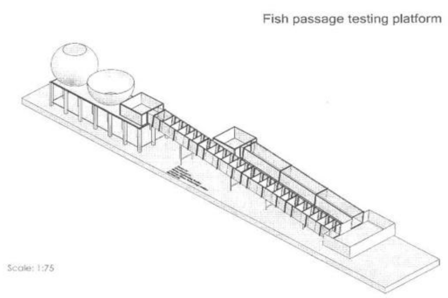
General:

- Target fish
- Overall dimension
- Required amount of pools
- Pool and opening / slot dimensions
- Flow velocity in an opening / slot
- Dissipated power in pool
- Deflecting block
- Result

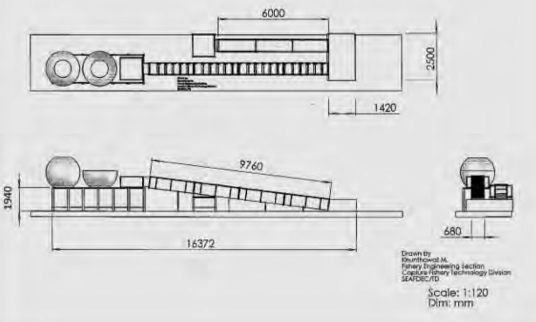
Target fish

Fish species	Dimension		
	Body length	Body width	Body height
xxx	10 cm	1.3 cm	4 cm

Overall dimension



Fish passage testing platform with overall dimension



Type of fishway experiment

1. Vertical slot
2. Rock ramp

Required amount of pools

Determination of the amount of pools

Number of pools = ΔH/Δh

Design factor	Δ H = 2.2 m	Δh = 10
∴ Number of pool	22 pools	

Pool and opening / slot dimensions

Dimension	Min. opening depth = Body height x2	Min. opening inside width = Body width x 3
Model	20 cm	1.3 x 3 ≅ 4 cm

Flow velocity in an opening / slot

$$v_{max} = \sqrt{2 \cdot g \cdot \Delta h}$$

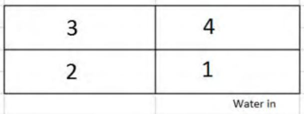
Δh = 0.1 m

V max = 1.40 (Design)

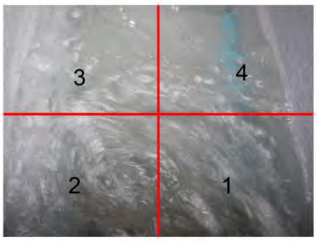
Dissipated power in pool

$$P_V = \frac{Power}{pool\ volume} = \frac{\rho \cdot g \cdot Q \cdot \Delta h}{V_p} \left[\frac{W}{m^3}\right]$$

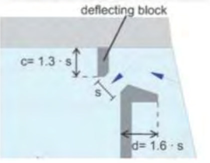
Dissipated power (Pv)	((1000 x 9.81 x 0.015)/0.072)x 0.1
	204.37 W/cu.m.

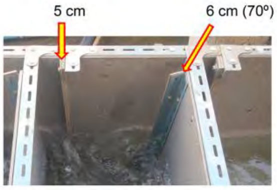


	speed(m/s)
1	0.72
2	0.41
3	0.04
4	0.08



Deflecting block

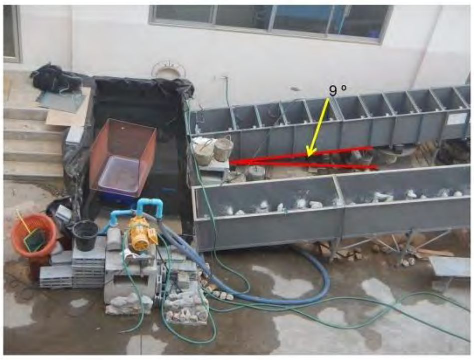


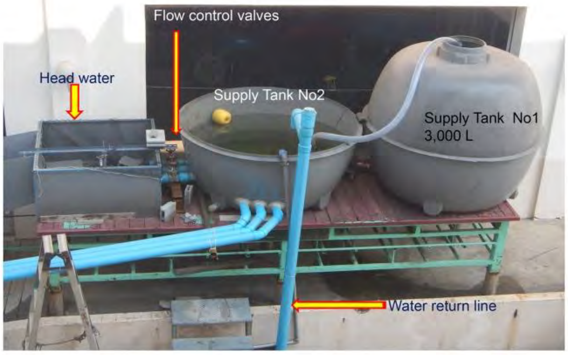


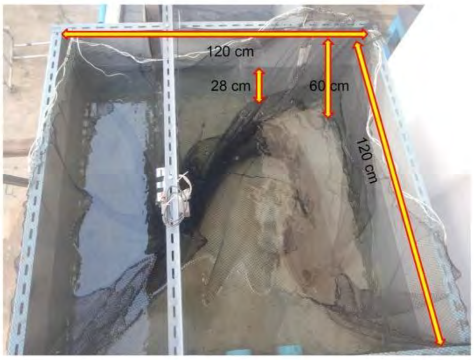
Results

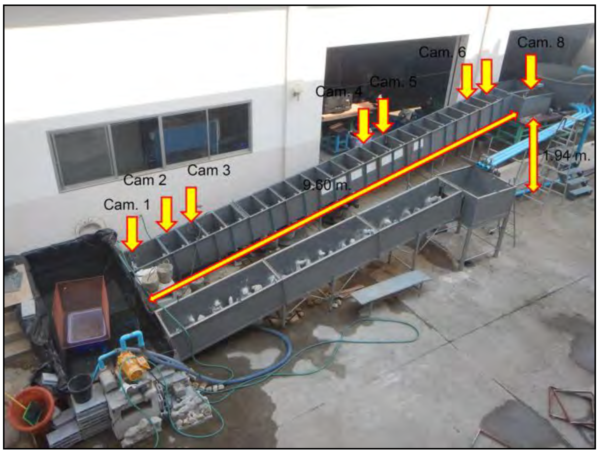
Items	Min. inside pool length	Min. inside pool width	Min. pool depth	Number of pool	Min. opening inside	Free board
Design factor	Fish body length x3	Fish body length x2	Fish body height x5		Fish body width x3	
Target fish	10 cm					-
Model	40 cm	60 cm	20 cm	22 pools	4 cm	30 cm
Total length	9.60 m					
Slope degree	0°					
Head water	220 cm					
Tail water	30 cm					
Δ h Water pool	8 - 10 cm					
Flow velocity	0.7 m/s					
v opening	1.40 m/s					
Water quantity	900 ℓ /minute					
	204.37 W/cu.m.					

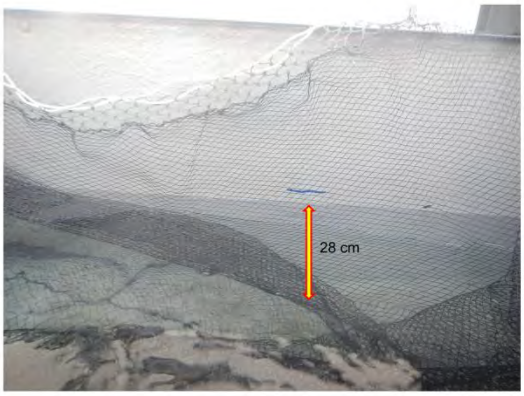
Experiment of the fish way

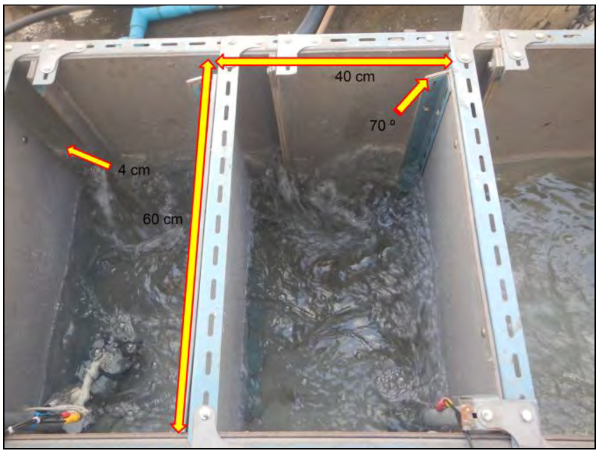

9 °


Flow control valves
Head water
Supply Tank No2
Supply Tank No1
3,000 L
Water return line


120 cm
28 cm
60 cm
120 cm


Cam. 6
Cam. 8
Cam. 5
Cam. 4
1.94 m.
Cam 2
Cam 3
9.60 m.
Cam. 1


28 cm


40 cm
70 °
4 cm
60 cm

Results

Flow velocity (m/s)	
C1 (Top chamber)	0.54
C2	0.63
C3	0.60
C4	0.69
C5	0.68
C6	0.63
C7	0.68
C8	0.72
C9	0.66
C10	0.78
C11	0.86
C12	0.38
C13	0.73
C14	0.75
C15	0.76
C16	0.75
C17	0.84
C18	0.76
C19	0.74
C20	0.67
C21	0.61
C22 (Bottom chamber)	0.57

Results

Period of experiment	Amount of fish (Tail water)	Amount of fish (Upstream)
10 Min.	55 fish	13 fish