IMPROVING HABITAT OF FORMOSAN LANDLOCKED SALMON BY DAM REMOVAL

Chao-Hsien Yeh[1] and Hui-Pang Lien[2]

[1]Associate Professor & Correspondence Author, Department of Water Resources Engineering, Feng Chia University, P.O. Box. 25-123, Taichung 400, Taiwan
PH (8864) 2451-0824; FAX (8864) 2451-5827 (e-mail: chyeh@fcu.edu.tw)
[2]Professor, Department of Water Resources Engineering, Feng Chia University, Taiwan

Abstract: With increasing recognition on conservation of endangered species in Taiwan, one of the major conservation projects is the habitat restoration of Formosan Landlocked Salmon which is major threatened by check dams in the channel for their blockading pathway to upstream and causing the problems of population isolation and close-blood mating. By creating an opening in the central dam body appropriately, partial removal dams can provide pathway for the fish for the better upstream channel habitat. Four check dams at Gau-Shan Creek were remodeled between April of 1999 and September of 2002 with information supported from model experiments under certain hydraulic condition of field environment. Based on the follow-up investigation, the channel morphology of observation sections is in stable condition and the total number of Formosan Landlocked Salmon in this creek increased promptly at the reach containing partial-removed dams.

Keywords: oncorhynchus masu formo sanum, dam removal, model experiment, follow-up investigation

1. INTRODUCTION

Located at south-east Asia (Figure 1), Taiwan receives bountiful rainfall of tropical storms from Pacific Ocean during summer seasons. Even with average annual precipitation of 2510 mm (i.e., 988 inches), the usable precipitation per capital in Taiwan is only about one sixth of that for the entire world due to extreme distribution of rainfall in space and time (Ouyang 1997). Hence, there were 87 reservoirs constructed during the past half-century to supply all kinds of water uses in Taiwan. For example, four reservoirs are allocated along the 140-kilometer long Ta-chia River for water and electricity supplies. However, combination of ill geological condition, 69% area of the island with slope over 5%, storms and typhoons in summer, and human activities in upstream basins promotes the sediment yield due to soil erosion and landslide. To prevent the sedimentation in reservoirs, various approaches and structures of soil conservation were then applied to the channels of upstream rivers and slopes of their watersheds. Among various structural techniques, check dam is often utilized as erosion control facility for channel sedimentation and also becomes an impossible-to-conquer barrier for mitigation fishes. Among them, Formosan Landlocked Salmon (Oncorhynchus masu formo sanum, Figure 2) is the most famous victim under this circumstance.

Identified as land-locked salmon, Formosan Landlocked Salmon had been recognized as natural monument for its biological importance

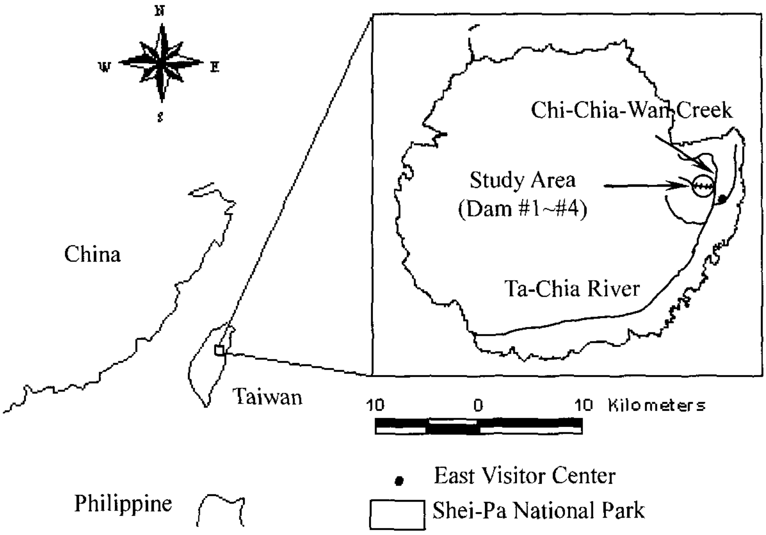


Figure 1. Study area

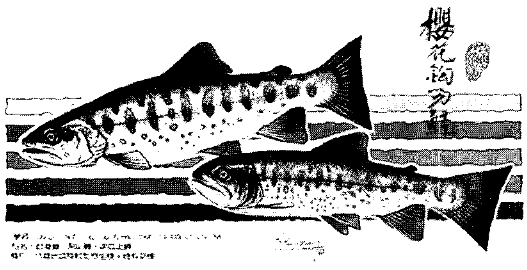


Figure 2. Formosan Landlocked Salmon

at 1938 by Japan government during its colonization of Taiwan. At 1940s, several high altitude streams in central Taiwan, including Chi-Chia-Wan Creek, were their main habitat regions (Shei-Pa National Park 1996). However, Formosan Landlocked Salmon right now can only be found in the Chi-Chia-Wan Creek and its tributary channels (Figure 1). According to the research by Lin & Liang (1990), appropriate habitat condition for salmon and trout should include several key environmental elements. In Taiwan, these elements include low water temperature (below 16°C), high dissolved oxygen in the water (above 6 ppm), sufficient flow discharge, well cover of plantation shade over channel, adequate food source from invertebrate, and non-polluted channel bed for eggs' spawn, hatch, and protection. However, increasing human activities (i.e., wild fire, deforestation, over-cultivation, pollution, mining, flood and drought, and changes in channel formation and characteristics) around their habitat often affect these key elements and become a threat for their survival. Chang (1990) further classified the changes of habitation environmental factors into physical, chemical and biological changes. In his definition, construction of dams or weirs across channel, development activities, and deforestation of watershed or channel banks are the major physical changes for channel habitat. For Formosan Landlocked Salmon, major changes in habitat result from physical changes, especially from increase of water temperature and isolation of population. While climate irregular alteration, channel development, deforestation, and reservoirs are the causes for temperature increasing (Lin & Liang 1990), check dams in the channel separate entire population in to groups without gateway for exchange for this special salmon. According to the field investigation of Tzeng et al (2000) since 1997, check dams in Chi-Chia-Wan Creek not only increase water temperature in the downstream channel (below Dam No. 2) and cause high fatal rate of zygote during mating periods, but also lead to the situation of gene homogeneity for each population within one section. With high concentration of sedimentation during flood periods, fish ladders over- passing check dams were found infeasible by blocking sediments particles. Therefore, searching for appropriate approaches to enhance or restore channel habitat of Formosan Landlocked Salmon has been the major objective for Shei-Pa National Park since 1990s.

Designed for flood mitigation by its central opening at dam body, detention dam is slightly different from traditional check dam (Yeh & Tuan, 1994). This structure will causes morphological change at the dam site soon after its construction like the other channel improvement structures do (Figure 3). With its structure formation and changes on channel morphology, detention dam can be recognized as partial-width weir by Hey's (1996) definitions on structural techniques and contributes its effect on creating pools. Therefore, the remodeling of check dams by partial removal can provide both gateway and various habitats of low temperature for Formosan Landlocked Salmon. In this paper, the authors illustrate the procedures and the results of this habitat improvement by dam removal, including flume experiments, field implementation, and follow-up monitoring on all the four check dams at Gau-Shan Creek (tributary of Chi-Chia-Wan Creek).

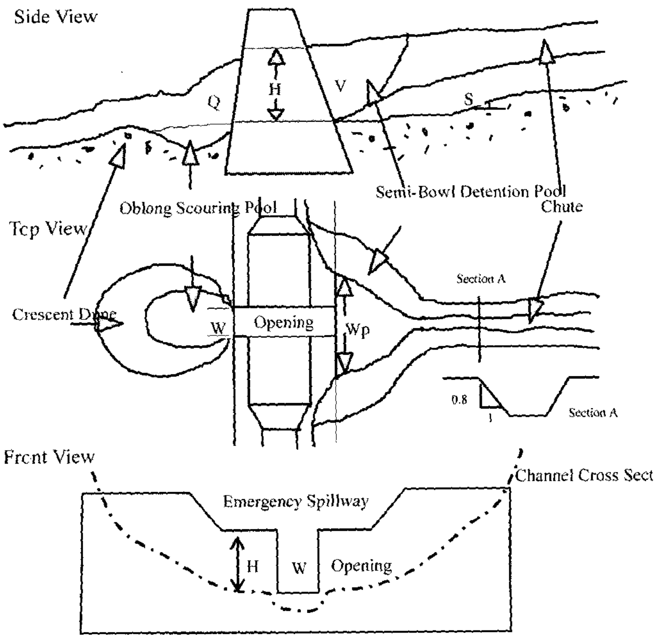


Figure 3. Channel morphology after construction of detention dam

2. FLUME EXPERIMENT

Without any previous experience on dam removal/remodeling for ecological conservation purpose in Taiwan, this study first confirmed the idea of dam-removal based on the results of related research and literature mentioned previously. Field investigation, channel survey, and hydrological analysis were then processed before conducting model experiments. The main objective of flume experiment is to observe the channel reactions regarding to various combinations of opening shapes and dam partial-removal procedures. Suggestions on channel habitat enhancement for Formosan Landlocked Salmon were then made from experimental findings. After necessary administration procedures in several related management agencies, implementation of dam removal was finally taken into action while follow-up investigations on the change of channel morphology were scheduled to monitor and record the whole process of habitat restoration. Consequently, the operation flowchart of this habitat improvement is assembled by these components and illustrated as Figure 4. (Yeh et al., 2001)

In order to simulate the channel reactions responding to partial dam-removal under experimental condition, study reaches around dam sites (i.e., Gau-Shan Creek Dam No. 4 & No. 3) were modeled using the two-dimensional flume. Appropriate similitude (i.e., scale between experimental model and prototype) was carefully selected to reach balance between simulations of hydraulics and sedimentation based on the similarity criteria for gravitation of flow, resistance of flow, distribution of suspended sediment, sediment transporting capacity, and time of channel bed deformation. Because the flow depth of Gau-Shan Creek is very shallow compared to the width of creek channel, a distorted model was conducted. The horizontal similitude of the model was selected as 1 to 70 in order to suit the experimental facility in Feng Chia University while vertical similitude was 1 to 50. With these two scales and designating scale of unit dry weight of deposit as 1, several key experimental conditions and their similitude of models were then analyzed. Table 1 shows the result for Dam No.4.

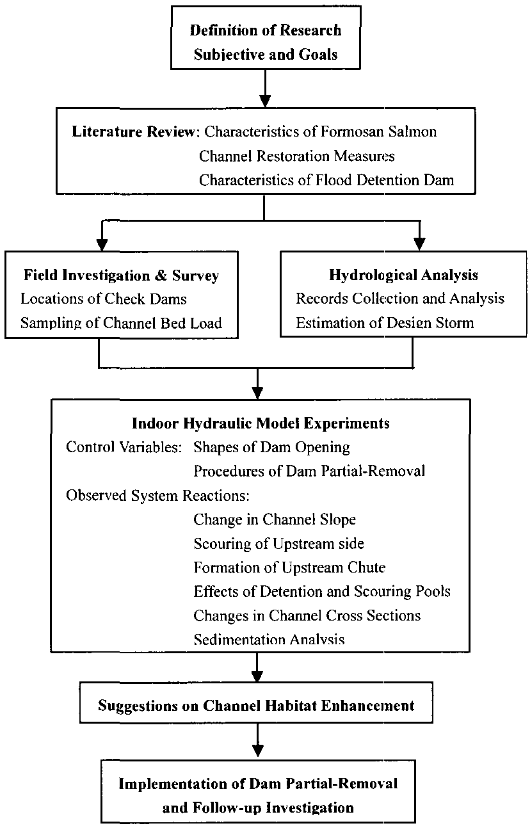


Figure 4. Flowchart of operation procedures

For the upstream reaches of mountain creeks in Taiwan, the changes in channel morphology occur during the extreme storm events. Therefore, three design storms with recurrence periods of ten, twenty-five, and fifty years were

Table 1. Experimental conditions of indoor hydraulic model for dam No.4 of Gaushan creek

Experimental Condition	Prototype	Model Similitude
Flow Discharge	Estimated Storm of 50 Years of Return Period	1:24750
Channel Slope	2.79%	1.4:1 (3.906%)
Sedimentation	Distribution from Study Reach	1:30
Flood Duration	24 Hours	1:16 (90 Minutes)

calculated separately by the unit hydrograph, the rainfall mass curves (Figure 5), and design 24-hour rainfall based on the analytic results from the storm events and frequency analysis of the study area. Shown as Figure 6, these three 24-hour design storms have diverse forms because of the essential differences in the rainfall mass curves, i.e. the total rainfall of the 10-year design storm is 290mm and those of the other two storms are 340mm and 400mm. The control variables of model experiments are opening shapes (i.e. rectangular and trapezoid) and removal procedures (gradually and simultaneously) under selected design hydrographs which are adjusted every five minutes.

For better simulation results, sediment collected from study area was mixed with sediment of same grain distribution from other sources to fill the model channel and supply as sediment source during simulating storm period. Observed responses of channel system include change in channel slope, scouring of upstream side, formation of upstream chute, effects of de-

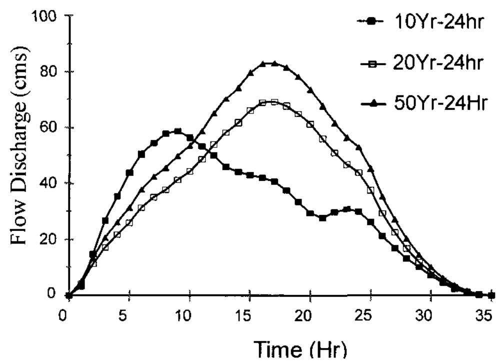


Figure 6. Hydrogaphs of 24-hour storms under different return periods

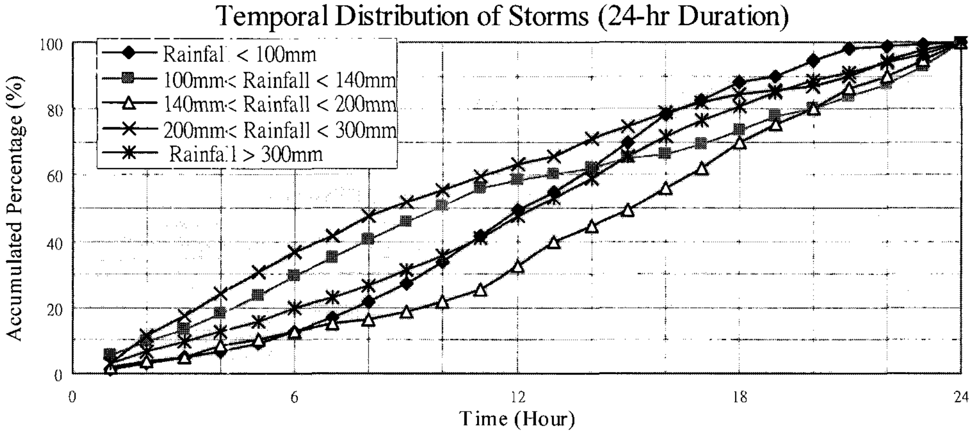


Figure 5. Mass curves of different total rainfall were analyzed from the storm events

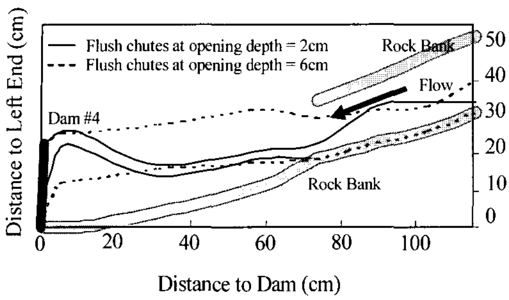


Figure 7. Flush chutes under different experiment conditions

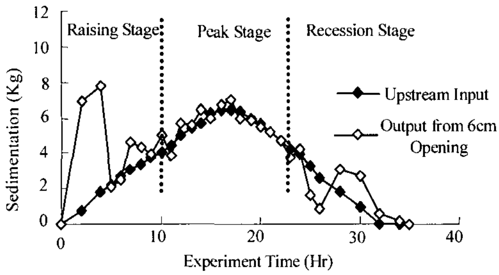


Figure 8. Sedimentation under experimental condition of rectangular opening remodeled simultaneously

tention and scouring pools, changes in channel cross sections, and sedimentation analysis. Shown in Figure 7, because the whole left bank of the upstream channel of Dam #4 is hard rock and there is about 70 cm fluvial bank at right bank, a wider flush chute appeared for the model setting of open depth set to 6 cm compared to that for the experiment with 2 cm opening depth. However, both experimental results indicated that potential scouring may occur at right upstream stream bank near dam site and deeper opening could causes larger erosion. For the sedimentation process at dam site (Figure 8), the sediment discharge inflow changed with the hydrograph to reach its peak at the 18^{th} hour while the two peaks of sediment output occurred at first 4 hours and at the 18^{th} hour contributed by the sediment from the detention pond and flush chute, respectively. With the considerations of morphological changes and habitat environment, remodeling of dams at Gau-Shan Creek were suggested to be implemented gradually into detention dam with trapezoid opening such that less impact on channel and sedimentation can be accepted (Table 2).

3. IMPLEMENTATION OF PARTIAL DAM REMOVAL

The implementation of the dam removal for all four dams involved several management agents and lasted for three years to complete (Table 3). However, the configurations of openings were modified to extend maximum width of opening (Figure 9 and Picture 1 ~ 8).

Table 2. Comparisons on the experimental results of dam-remodeling for dam No. 4

Opening Type		Rectangular		Trapezoid	
Disassembling Procedures		Simultaneously	Gradually	Simultaneously	Gradually
Upstream Morphology	Scouring Depth	2.5 m	2.5 m	2.7 m	2.7 m
	Flush Chute	Yes	Yes	Yes	Yes
	Slope Ratio*	2.57	2.48	2.32	2.32
Downstream Morphology	Sediment Discharge Ratio	1.28	1.15	1.29	1.17
	Sediment Concentration Ratio	1.27	1.15	1.29	1.17
Suggested Priority		4	2	3	1

* Ratios were calculated from the observed values of original condition and specific experimental combination.

Table 3. Implementation time table of dam partial-removal applied at Gaushan Creek

Dam	No.4	No.3	No. 1 & 2
Time	April, 2000	October, 2001	September, 2002

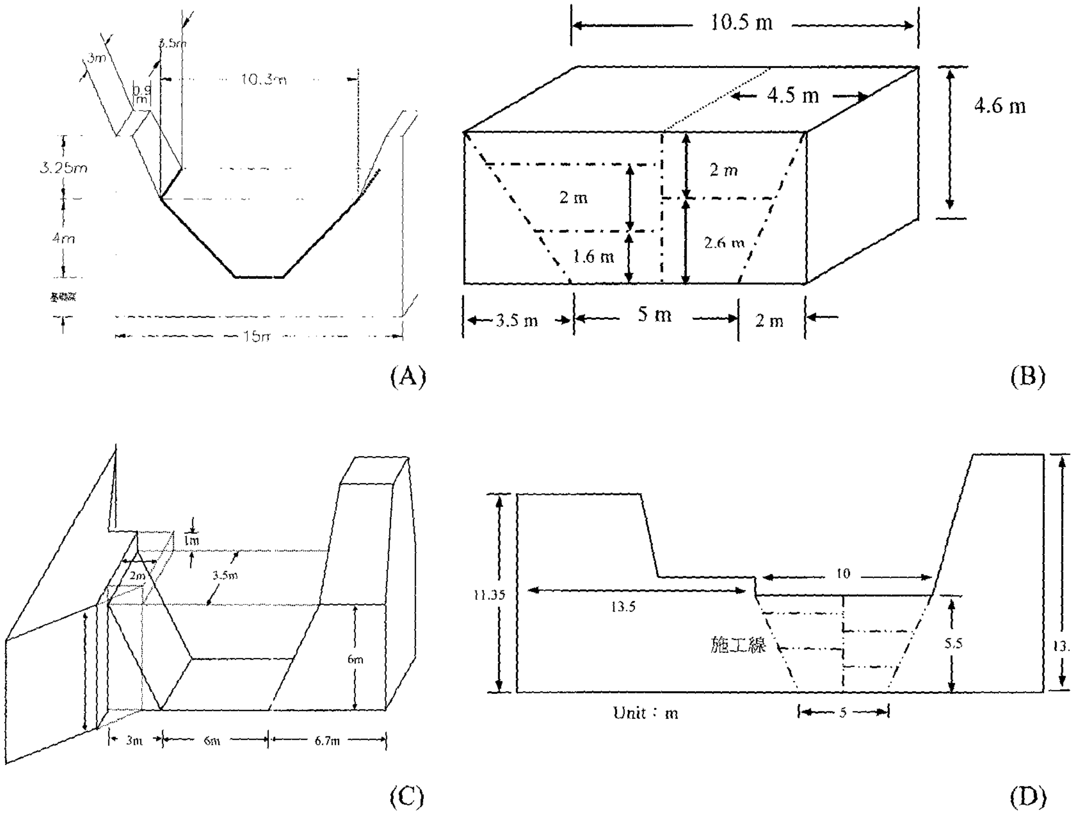
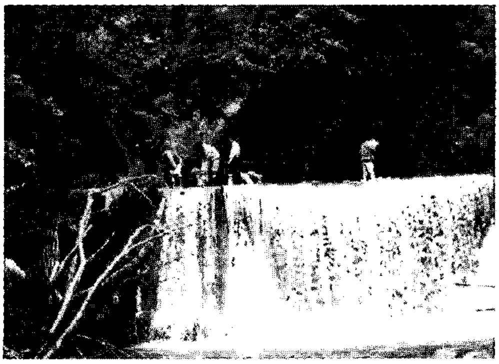


Figure 9. Illustration graphs of partial removal for dam (A) No.4, (B) No.3, (C) No.2, and (D) No.1

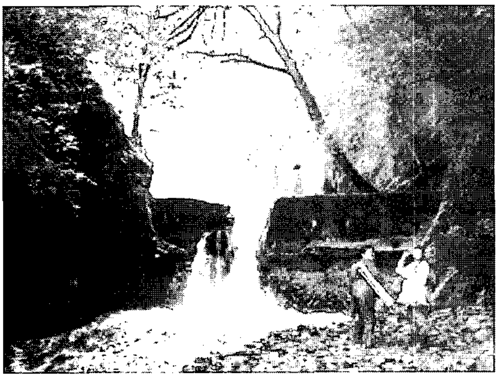


Picture 1. Dam No.4 (April, 1999)

Picture 2. Dam No.4 (October, 2001)

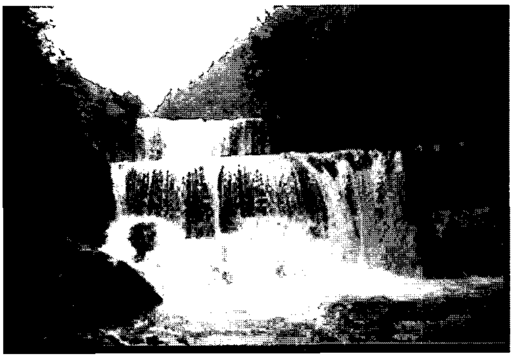
Picture 3. Dam No.3 (October, 1997)

Picture 4. Dam No.3 (November, 2000)



Picture 5. Dam No.2 (October, 1997)

Picture 6. Dam No.2 (October, 2001)

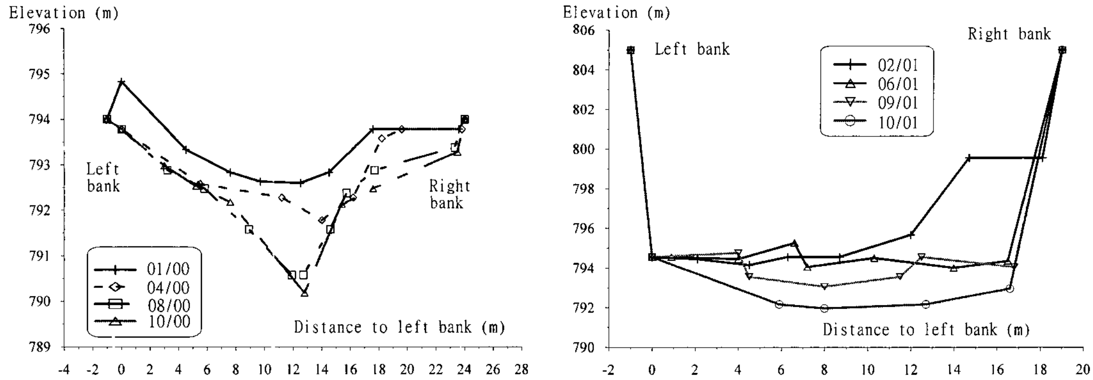


Picture 7. Dam No.1 (April, 2000)

Picture 8. Dam No.1 (December, 2001)

4. FOLLOW-UP MONITORING

To record the process of morphological change at study sections, various follow-up surveys for longitude section and cross sections were applied since January of 2000 (Yeh & Lian, 2001). Compared to original condition, not only the transitions of cross sections at detention pools and scouring pools can be defined, Figure 10, the distance and channel slope between the end point of flush chute and dam site also can be estimated through the survey results on the longitude cross section of upstream channels. For example, shown in Figure 11, the slope of the



(A) (B)

Figure 10. Transitions of scouring pool (A) and detention pool (B) for Dam No. 4

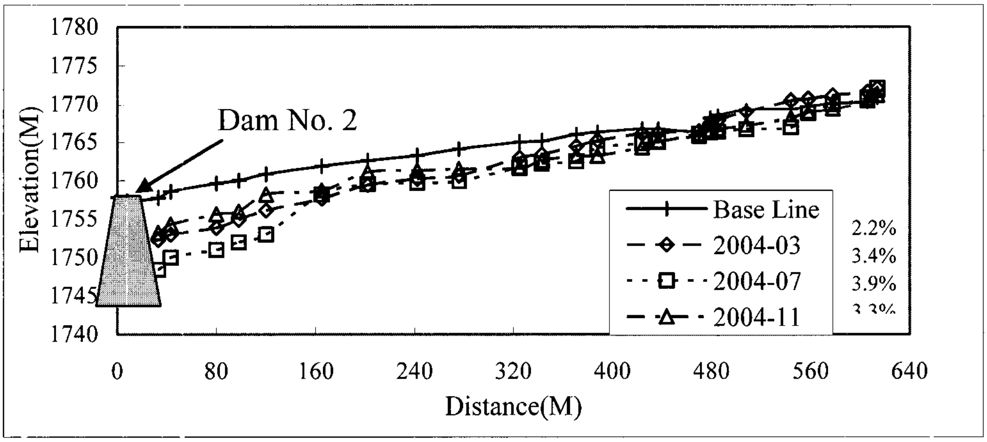


Figure 11. Transition of upstream longitude cross section of Dam No. 2 in 2004

channel between Dams No. 2 and No. 3 changed from original 2.2% to above 3.3% in Year of 2004.

Originally, the management agent have released human-hatched Formosan Landlocked Salmon at the upstream reach of Dam #4 between 1994 and 2000, however, the salmons were often carried to downstream by the storm flow and failed to return to upstream for these dams in channel (Tzen, 2001). To understand the effect of check dam partial removal, semi-annual population survey Formosa Landlocked Salmon in these reaches has been conducted since 1997. The investigation results (Tzen, 2003) not only show spatial distribution of the population in the creek and also displays the effect of dam removal on channel continuity. The total numbers of salmon found within each reach are tabulated as Table 4, which indicates that the number of Formosan Landlocked Salmon increased promptly at the reach containing partial-removed dam(s) even though the human-hatched salmons are not released since 2001. Disappointedly, the analysis results on the compositions of channel habitats, i.e., riffles, runs, deep runs, and pools, indicated that there is no statistical difference for the conditions before and after partial dam removals in the reach between Dam No.3 and No.4 (Lin et. al, 2001).

5. CONCLUSIONS

For Formosan Landlocked Salmon, alterations of habitat environmental factors are resulted mainly from physical changes, especially from increase of water temperature and isolation of population. Check dams in Chi-Chia-Wan Creek and Gau-Shan Creek not only increase water temperature in the downstream channel and cause high fatal rate of zygote during mating periods, but also lead to the situation of gene homogeneity for each population within one channel section separated by those dams. Identified as partial-width weir in river restoration structure, flood detention dam can be remodeled from original check dam by partial removal to provide pathway and create pools. With findings from model experiments, all four dams of Gau-Shan Creek were remodeled gradually by partial-removal into detention dam with trapezoid opening. According to the follow-up investigation results, the morphological change of channel will become stable after two to three years after removal. The numbers of salmon at each reach indicate the effectiveness of dam removal for fish passage, however, diversity of habitat does not improve as expect.

REFERENCES

Chang, K.S. 1990. Fish Ecology. pp. 15-22. In: *Proceedings of Aquatic Fishes Conservation in Forest Rivers*, National Taiwan University, Taipei, Taiwan. (In Chinese)

Chiou, G.G. 1990. Habitat Investigation and Improvement for the Aquatic Fishes in Forest Rivers. pp. 139-188. In: *Proceedings of Aquatic Fishes Conservation in Forest Rivers*, National Taiwan University, Taipei, Taiwan. (In Chinese)

Hey, R.D. 1996. Environmentally Sensitive River Engineering. pp. 80-105. In: Petts, G. et al (ed.), *River Restoration: Selected Extracts from the Rivers Handbook*, , Blackwell Science Ltd. Oxford, UK.

Lin, Y.S. & S.S. Liang. 1990. Ecology of Salmon and Trout. pp. 33-52. In: *Proceedings of Aquatic Fishes Conservation in Forest Rivers*, National Taiwan University, Taipei, Taiwan. (In Chinese)

Lin, U.F., U.L. Chen, L.I. Liau, 2001, Investigation of Change in Stream Habitat After Dam Removal at Gau-Shan Creek. Research Report No. 9006, Shei-Pa National Park, Taiwan. (In Chinese)

Ouyang, C. F. et al, 1997, Chapter 2: Hydrologic Cycle. pp. 13-26. In: *Use and Conservation of Water Resources*, National Open University, Taipei, Taiwan. (In Chinese)

Shei-Pa National Park. 1996. *Shei-Pa National Park*, pp. 37-38, Taichung, Taiwan.

Tzeng, C.S., C.M. Yu & C.H. Yang. 2000. Studies on Population Ecology of the Formosan Landlocked Salmon. pp.115-135. In: *Proceedings of The Workshop on Conservation of the Taiwan Masou Salmon,* Taiwan Endemic Species Research Institute, Nantou, Taiwan. (In Chinese)

Tzeng, C.S. 2001. Studies on population ecology of the Formosan landlocked salmon *Oncorhynchus masu formosanus* (IV). Research Report No. 9001, Shei-Pa National Park, Taiwan. (In Chinese)

Tzeng, C.S. 2003. Studies on population ecology of the Formosan landlocked salmon *Oncorhynchus masu formosanus* (VI). Research Report No. 9208, Shei-Pa National Park, Taiwan. (In Chinese)

Yeh, C.H. & C.H. Tuan. 1994. Hydrological and Hydraulic Characteristics of Flood-Detention Dam. *Journal of Chinese Soil and Water Conservation*, **25**(4), pp.181-189. (In Chinese)

Yeh, C.H., P.H. Ling, & C.H. Tuan. 2001. A Study of Effects of Check Dam Remodeling on the Changes of Channel Morphology and Habitat Formations for Gau-Shan Creek, *Journal of National Park*, 11(1) pp. 71-85. (In Chinese)

Yeh, C.H. & H.P. Lien. 2001. An Experimental Study of Channel Habitat Improvement for Formosan Landlocked Salmon. pp. 255-263. In: *Proceedings of 21st Annual American Geophysical Union "HYDROLOGY DAYS"*, Colorado State University, Fort Collins, USA.

Associate Professor & Correspondence Author, Department of Water Resources Engineering, Feng Chia University, P.O. Box. 25-123, Taichung 400, Taiwan; PH (8864) 2451-0824; FAX (8864) 2451-5827

(e-mail: chyeh@fcu.edu.tw)

Professor, Department of Water Resources Engineering, Feng Chia University, Taiwan