RESTORATION OF FORMOSAN LANDLOCKED SALMON HABITAT AS REFUGE DURING HIGH FLOWS

Jen-Yang LIN[1], Yen-Chang CHEN[2], Eric Hsienshao TSAO[3] and Han-Chung YANG[4]

[1]Professor, Dept. of Civil Eng. and Water Enrironment Research Center, National Taipei University of Technology
(1 Sec. 3, Chung-Hsiao E. Rd., Taipei 106, Taiwan)
E-mail:jylin@ntut.edu.tw
[2]Associate Professor, Dept. of Civil Eng., National Taipei University of Technology
(1 Sec. 3, Chung-Hsiao E. Rd., Taipei 106, Taiwan)
E-mail:yenchen@ntut.edu.tw
[3] Curator, Animal Department, Taipei Zoo
(30 Sec. 2 Hsin Kuang Rd., Taipei 106. Taiwan)
E-mail:dwx07@zoo.gov.tw
[4]Assistant Professor, Dept. of Leisure, Recreation and Tourism Management, Shu-Te University
(59 Hun Shan Rd, Yen Chau, Kaohsiung County 824, Taiwan)
E-mail:hcyang@mail.stu.edu.tw

Owing to the characteristics of Taiwan's watersheds includes erodible solid, uneven rainfall, steep slopes and high mountains, only 30 percent of terrestrial surface is not occupied by mountains. Traditional river engineering work has always emphasized safe and practical, but not necessarily ecologically or environmentally sound designs. In recent years, however, environmental awareness and the demands of outdoor recreation have risen dramatically. Large scaled river "beautification" projects have received considerable attentions and many have been implemented. On the other hand, still relatively few engineering projects are designed for maintaining ecological functions or habitat protection and restoration. The lack of close communication among biologists, ecologists, and civil and environmental engineers has been recognized as an important factor. Another significant factor is the scarcity of data on the quantitative relationship between hydraulic patterns, streamflow structure and habitat requirement for specific target species. In this paper, a brief description of the status of activities regarding "ecological engineering methods" in Taiwan is given. A case example of recent collaborative efforts including the hatchery center, streambank treatment, and backwater area made for saving the Formosan landlocked salmon population is described, with emphasis on the quantification of the relationship between refuges and habitat requirements of the endangered fish. A two-dimensional computational fluid dynamic model is used to help the design of backwater area. It shows that the hydraulic model can be considered as a suitable technique for habitat restoration.

Key Words : *computational fluid dynamic model, ecological engineering, Formosan landlocked salmon, habitat, refuge, restoration*

1. INTRODUCTION

Streams and rivers are fundamental to the existence of human populations and histories. The water resources development projects by means of manipulating flows are to fulfill a wide variety of beneficial purposes such as water supply, irrigation, and hydroelectric power. However, many hydraulic structures may be contributed to the long term degradation of ecosystem and the endanger status of native fish fauna. Over the pass decades, understanding of stream ecosystem structures and functions has improved rapidly. Recently, the opposition to the construction of hydraulic structures in streams by heightened desire for environmental protection has gained much attention in Taiwan. In addition, the inclusion of ecological considerations in water resource planning has become widely adopted, especially in developed countries.

In Taiwan, the hydraulic engineering works have mainly dealt with soil and water conservation, flood mitigation, and storm drainage. However, since the mid-1990's, planning for many river projects has begun to include the consideration of ecological conservation. The adoption of "ecologically friendly" engineering methods in water resources projects is still at its preliminary stages in Taiwan. Several hindering factors to the progresses of ecological engineering practices in Taiwan have been identified such as the loose regulatory framework, the shortage of quantified information of the relationship between habitat requirement and stream physical parameters, and the lack of public education especially on the long-term benefits of ecological engineering methods.

One of the early concepts of ecological engineering methods was introduced in 1938 by Seifert of Germany (Kao, 1999)[1] pointing out that using near natural processes in plan river engineering work would be less costly and could preserve the natural landscape. Over the years similar concepts have evolved in many parts of the world. In Germany these methods are called river ecology natural engineering methods; in Japan they are entitled naturally diverse river development; in Australia they are green vegetative engineering methods; in United States they are ecological engineering, and in Taiwan ecological engineering methods. Now the ecological engineering is spawned and its time has come (Mitsch and Jorgensen, 2003)[2].

The aim of stream restoration is basically to generate healthy, living streams with diverse types of habitats. Without considerations of hydraulic properties of the target stream, the habitat restorations are usually fraught with unexpected and often disastrous consequences. The natural patterns and processes in streams are the basis for effective stream restoration (Ward et al., 2001)[3]. The abundance, growth, and many other population characteristics of target species depend heavily on the available amount of suitable habitats (Shirvell and Dungey, 1983)[4]. Habitat attributes can include physical features such as flow, water quality, and biological components (Marcus et al., 1990)[5]. To protect a designated species, engineers can design and construct certain features that biologists requested. Therefore, the hydraulic analysis of the designing works can at least adopt an understanding of the ecological nature of the streams, especially during the high flows. Hydraulic models using mathematical equations are developed extremely well. As computers become powerful, the complex hydraulic issues such as the hydraulic patterns of fish habitat in urban river (Booker, 2003)[6], flow structures in a natural pool and riffle (Booker et al., 2001)[7] and velocity, sediment in constructed wetland ponds (Koskiaho, 2003)[8], assessing stream habitat conditions (Crowder and Diplas, 2000)[9] and the effects of discharge on habitat quality (Korman et al., 2004)[10] can be solved. Based on computing results, the ecological engineers can thus select the locations of shelters and determine the techniques to control the riverbed, stabilize channel alignment, protect stream banks and rebuild suitable habitat.

In Taiwan, the most well known stream restoration project is the Formosan Landlocked Salmon Protection and Habitat Restoration that is designed in conjunction with its recovery plan. The project includes creation of shelter habitats for the salmon population as refuge during the floods and stabilization of stream bank to prevent erosion caused by peak flows in the Chichiawan Creek. In this paper modeled hydraulic patterns of habitats before and after improved have been compared to assess the quantity of physical habitats available during high flow. A two-dimensional computational fluid model is used to simulate the flow pattern of peak discharges in the study area to show that the salmon can hide in the shelters to against the strong current during the high flows. The results suggest that the project can successfully restore the habitat of the Formosan Landlocked Salmon.

2. FORMOSAN LANDLOCKED SALMON AND SITE DESCRIPTION

Species of Salmonidae are coldwater fishes inhabiting the waters of the northern hemisphere. The Formosan landlocked salmon, Oncorhynchus masou formosanus, was discovered in 1916. It is one of the southernmost natural salmon populations in the world. Moreover, the Formosan landlocked salmon is considered an endangered species and the population was once dropped to less than 2000 (Lin et al., 1999)[11]. Occurrence of the Formosan landlocked salmon is the result of uplift of the mountain range, deglaciation, and subsequent evolution of a freshwater form from anadromous ancestors. The historical ranges of the Formosan landlocked salmon were distributed only at the upstream of the Tachia River, and the salmon were abundant in all six tributaries of the upper Tachia River basin above Lishan, with elevations between 1,450 to 2,500 m above sea level, as shown in **Fig. 1**.

The Tachia River with a stream length of 124 km, located in central Taiwan, extends from the mountains (elevation 3,470 m) to the sea level and drains an area of 1,236 km^2 to the Taiwan Strait. The catchment of upstream of the Tachia River is covered by the densely mature forests. The mean discharge of the Tachia River is 80 m^3/s near the Techi Reservoir, which is located 90 km from the river mouth. Because of the abrupt elevation changes downstream the Techi Reservoir, the Tachia River has the greatest potential for hydropower development among all rivers in Taiwan. Five hydropower plants all the Tachia River contribute electricity production. The Tachia River is unique in Taiwan because of his relatively flat longitudinal profile above 1,500 m from sea level. This gentle stream gradient at high elevation may be the primary reason of the existence of the Formosan landlocked salmon in the upstream reaches of the Tachia River (Taso, 1995)[12).

Owing to the reclamations of agricultural lands and constructions of check dams for sediment control, the suitable habitats and population sizes of the salmon had declined sharply after 1960s. The Formosan landlocked salmon was declared as an endangered species in 1989 when the salmon population had declined to only about 200. Since then, the refuge was established to protect the national treasure fish and ensure the survival of the species, and the salmon population began to recover. The size of the population was estimated at 700 in 1985, and grew to about 2,000 by 1987. However, the total number has been decreasing ever since, despite significant artificial productions and other restoration efforts.

At the present time, the remaining salmon population is located in short reaches of the Chichiawan and Hsuehshan Creeks. (**Fig. 1**) Sixty percent of the salmon were distributed along the Chichiawan Creek, between check dams No. 3 and No. 1. Recruitment of young-of-the-year mainly occurred between the check dams No. 2 and No. 4. During the last decade, however, the total number of the salmon has been declining due to the gradual decreasing of young-of-the-year salmon. Both floods and human activities have contributed to the endangered status of the salmon. Recent investigations showed that the salmon population in 1999 has declined to less than 800 individuals. It was evidenced that in the Chichiawan Creek system, those sections that previously had the highest density of salmon showed the greatest declines (Day et al., 1993)[13)]. After the constructions of check dams, the Chichiawan Creek dominated by sediment became wider, shallower, and slower. The decrease in depth was considered to be the major factor affecting adult salmon density. In addition, high sediment deposition in streambed has reduced survival rates of the salmon eggs (Lin et al., 1989)[14)].

Temperature is another important variable for the salmon survival. A temperature of 16 ^{0}C or lower was found to be best. Recent study also indicated that a high percentage of the salmon has been forced to inhabit areas with maximum summer water temperature exceeding 18 ^{0}C (Lin et al, 1989)[14)]. **Table 1** (Day et al., 1993)[13)] and **Fig. 2** show the habitat conditions for the salmon during different life stages.

The construction of a series of check dams for

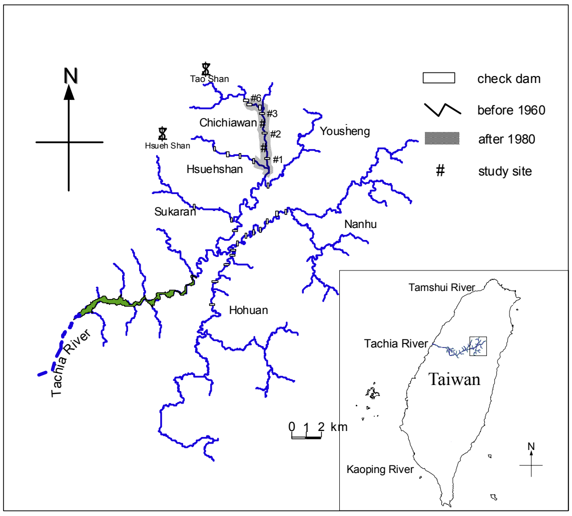


Fig.1 Location of habitat range of the Formosan landlocked salmon.

Table 1 Habitat conditions for the Formosan landlocked salmon during different life stages.

Life stage	Time of year (month)	Habitat Conditions: Water temp. (^{o}C)	Current velocity (m/s)	Bottom material (cm)	Depth (cm)
Egg	10-11	10-12	0.15	0.2 - 6.4	5-52
Sac Fry	11-12	7-15	Slow moving bank sides	-	-
Fry	12-2	5-14	Still water bank sides	-	8-25
Parr	3-4	8-16	Slow moving areas	Stone and gravel	30
Young adult	5-9	9-16	Habitat condition variable		
Adult	9-10	10-16	Habitat condition variable		

instream erosion and flood control has severely destroyed the habitats of the salmon. Except a small portion of the Chichiawan Creek, spawning habitats are relatively restricted to the small sections divided by consecutive check dams of the other five tributaries of the upper Tachia River. The lack of adequate spawning habitats in these streams has contributed to the absence of the salmon recruitments. In addition, floods have resulted in the downstream transport of fish away from their original habitats. Check dams have further contributed to water warming and have interfered with the natural hydraulic processes (Wang, 1989)[15]. The distances between consecutive check dams also have influences to the declines of the salmon population. This is particularly true where steep gradients exist between the dams. These areas provide little refuge from high velocities and consequently the salmon populations in these areas have declined. Reclamation of riparian area that causes stream canopy losses; stream channelization, and agriculture practices have resulted in more extreme peak flows and degraded water quality, specifically warmer water temperatures, increased sediment load, and eutrophication. These factors may be responsible for the failure of salmon recruitment in the downstream sections of the Chichiawan Creek where suitable spawning habitats still remain (Tsao, 1995)[12].

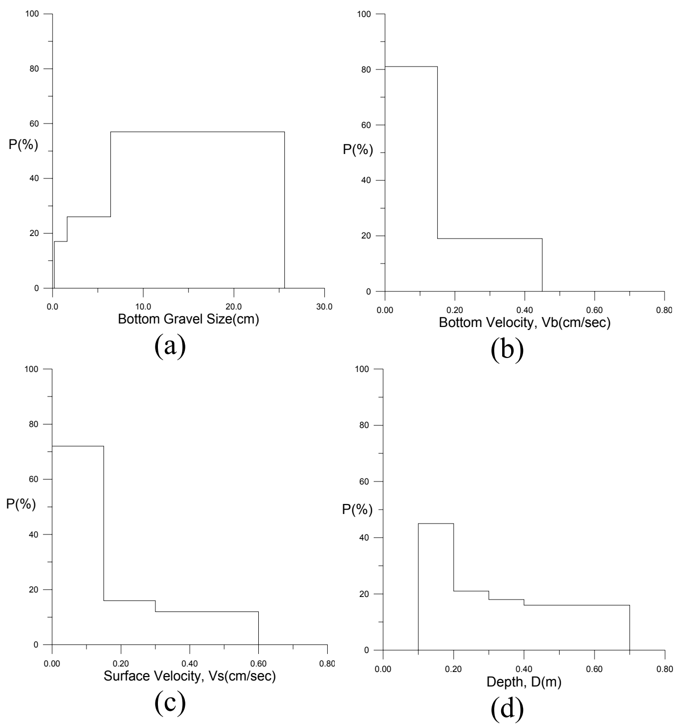


Fig. 2 Relation of relative frequency of observations and stream physical parameter; (a) bottom gravel size; (b) bottom velocity; (c) surface velocity; (d) depth.

3. SAVE THE SALMON

(1) Chichiawan Creek Restoration Project

To save the salmon from the risk of extinction, governmental agencies have collaboratively undertaken a great deal of efforts to restore habitats since the mid - 1990's. The most significant efforts have been lunched by the Shi-Pa National Park Administration (SPNA), which include the establishment of riparian corridors; alignment stabilization; bank protection; the maintenance of salmon refuges and spawning sites; the construction of shelters, and the restoration of fish passage over check dams (Lin, 2000)[16].

An engineering project, the Chichiawan Creek Restoration Project (CCRP) was designed to create a more desirable habitat for the salmon. The CCRP was conceived as a result of intensive discussions among governmental agencies, ecologists, hydrologists, and hydraulic and environmental engineers. After reviewing all the natural and man made factors that had contributed to the gradual demise of the salmon, the working group developed the CCRP on the Chichawan Creek in 1999. It included the following action plan:

- Invest the complex nature of ecological patterns and hydrological processes in the Chichiawan Creek.
- Remove the check dams on the Chichiawan and the Hsuehshan Creeks to provide easier access for the salmon to reach its spawning areas.
- Imply the numerical model to simulate the flow patterns of flood for selecting the locations of shelter.
- Implement bank protection techniques at selected sections on the Chichiawan Creek to prevented the erosion of the banks and landslides that increase the sediment load to destroy the salmon habitat.
- Construct shelters for the salmon to seek the refuge during high flows and hide from specific threats.

(2) The numerical model

The two dimensional computational fluid dynamic (CFD) code used for this investigation was RAM2 that was originally developed by Norton, King, and Orlob of Water Resources Engineers in 1977 (Norton and Ring, 1977)[17] and subsequent enhanced by the Waterways Experiment Station (WES) Hydraulics Laboratory, U.S. Army Corps of Engineers. RMA2 is a two dimensional depth averaged finite element hydrodynamic numerical model. It computes water surface elevations and horizontal velocity components for subcritical, free surface flow in two dimensional flow fields. RAM2 has been successfully applied to a number of engineering situations such as simulation of flow dynamics in a creek, simulation of water levels, flow patterns and flow distribution in streams, reservoirs and estuaries, simulation of contracting and expanding reaches basing on the assumptions of non-compressible and constant-density flow, RMA2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations

$$F_x = \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial y} + v\frac{\partial u}{\partial y} + g(\frac{\partial h}{\partial x} + \frac{\partial z_o}{\partial x}) - \frac{\varepsilon_{xx}}{\rho}\frac{\partial^2 u}{\partial x^2} - \frac{\varepsilon_{xy}}{\rho}\frac{\partial^2 u}{\partial y^2} + \frac{gu}{c^2 h}\sqrt{u^2+v^2} \quad (1)$$

$$F_y = \frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g(\frac{\partial h}{\partial y} + \frac{\partial z_o}{\partial y}) - \frac{\varepsilon_{yx}}{\rho}\frac{\partial^2 v}{\partial x^2} - \frac{\varepsilon_{yy}}{\rho}\frac{\partial^2 v}{\partial y^2} + \frac{gv}{c^2 h}\sqrt{u^2+v^2} \quad (2)$$

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(hu) + \frac{\partial}{\partial y}(hv) = 0 \quad (3)$$

(1) and (2) are the equations for conservation of momentum in the horizontal direction and (3) is an equation for conservation of mass. The shear stress terms in (1) and (2) are defined as

$$F_x = \frac{gu}{\dfrac{(1.486h^{1/6})^2}{n}}\sqrt{u^2+v^2} - \frac{\zeta}{h}{}_a V_a^2 \cos\psi - 2wv\sin\phi \quad (4)$$

$$F_y = \frac{gv}{\dfrac{(1.486h^{1/6})^2}{n}}\sqrt{u^2+v^2} - \frac{\zeta}{h}{}_a V_a^2 \cos\psi - 2wv\sin\phi \quad (5)$$

The symbol notation is given in **Table 2**. Friction is calculated with the Manning's equation, and eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady state (dynamic) problems can be analyzed.

It is difficult to obtain the analytical solution of (1) and (2). However the velocity in (1) and (2) can be approached by finite element method. In order to apply the finite element method, (1) and (2) are multiplied by h as

$$f_u = h\frac{\partial u}{\partial t} + hu\frac{\partial u}{\partial x} + hv\frac{\partial u}{\partial y} - \frac{h}{\rho}\left(\varepsilon_{xx}\frac{\partial^2 u}{\partial x^2} + \varepsilon_{xy}\frac{\partial^2 u}{\partial y^2}\right) + gy\left(\frac{\partial a}{\partial x} + \frac{\partial h}{\partial x}\right) + F_x h = 0 \quad (6)$$

Table 2 Notation for the symbols of RAM2.

u v = velocities in x and y direction
h = water depth
n = Manning's roughness coefficient
z_o = Channel bottom elevation
x y = Coordinate in x and y direction
t = Time
ρ = Density
g = Gravitational acceleration
a = Elevation of bottom
Σ = Eddy viscosity coefficient
for xx = normal direction on x axis surface
for yy = normal direction on y axis surface
for xy and yx = shear direction on each surface
ζ = Empirical wind shear coefficient
V = Wind velocity
ψ = Wind direction
ϕ = Local latitude
ω = rate of earth's angular rotation

$$f_v = h\frac{\partial v}{\partial t} + hu\frac{\partial v}{\partial x} + hv\frac{\partial u}{\partial y} - \frac{h}{\rho}\left(\varepsilon_{yx}\frac{\partial^2 u}{\partial x^2} + \varepsilon_{yy}\frac{\partial^2 u}{\partial y^2}\right) + gy\left(\frac{\partial a}{\partial x} + \frac{\partial h}{\partial x}\right) + F_y h = 0 \quad (7)$$

(6) and (7) can be solved by the finite element method with Galerkin method of weighted residuals as

$$\begin{bmatrix} \int N^T \frac{\partial f_u}{\partial u} dA & \int N^T \frac{\partial f_u}{\partial v} dA & \int N^T \frac{\partial f_u}{\partial h} dA \\ \int N^T \frac{\partial f_v}{\partial u} dA & \int N^T \frac{\partial f_v}{\partial v} dA & \int N^T \frac{\partial f_v}{\partial h} dA \\ \int M^T \frac{\partial f_c}{\partial u} dA & \int M^T \frac{\partial f_c}{\partial v} dA & \int M^T \frac{\partial f_c}{\partial h} dA \end{bmatrix} \begin{Bmatrix} u \\ v \\ h \end{Bmatrix} = \begin{Bmatrix} N^T f_u dA \\ N^T f_v dA \\ M^T f_c dA \end{Bmatrix} \quad (8)$$

in which M and N are shape functions for velocity and depth. The Newton-Raphson nonlinear iteration is used to obtain u, v and h at each node within a finite element mesh.

The inputs of RAM2 include bathymetry data, boundary conditions, Manning's roughness coefficients, and eddy viscosity values. Bathymetry data describing the channel geometry can be collected in the form of XYZ coordinates. Boundary conditions are required to drive RMA2 throughout a simulation. They are constraints, which are applied along the flow boundaries of the solution domain, and required to eliminate the constants of integration. Manning's roughness coefficients are assigned to a particular element based on the material properties within the study reaches. Eddy viscosity values that are characteristic of each bed material within the study reaches.

(3) Restoration in the Chichiawan Creek

The CCRP was completed in fall of 2001. The constructions in the artificial restoration areas included streambank protection, shelters, salmon hatchery center, intake, and water storage tank, as shown in **Fig. 3**. The width of the restored reach is between 10 and 21 m and the length is about 150 m. The process of bank failure was examined to determine the bank protection treatment technique. Since undercutting caused the bank erosion in the CCRP area, combinations of rock riprap and gabions were selected as the appropriate treatment in the study reach. Rock riprap consisted of a layer of rock placed on a steam back to protect it from erosion. However the rock piles were expected to resist the dragging force during the floods. The rock size can be determined from

$$D_m = \frac{1}{\varepsilon^2 \times 2g(\frac{\rho_s}{\rho} - 1)} \times V_0^2 \quad (9)$$

where D_m is the diameter of rock; V_0 is the velocity; ρ_s is the rock density. It shows if rock riprap was applied, at least the rock diameter had to be greater than 1.5 m. Unfortunately, the rock with D_m>1.5 m is difficult to obtain in the CCRP area. Therefore the rock gabions with vegetation were applied to protect the stream bank, as shown in **Fig. 4**.

Fig. 5 concludes a recent survey on the relationship between hydraulic conditions and the microhabitat use of the age I+ and older salmon with total length of larger than 18 cm. Microhabitat variables such as focal point depth and velocity were measured only after the activity of an individual fish was identified (at least 3-5 mins). It shows that the salmon prefers current velocities less than 0.4 m/s, which are not generally found along the Chichiawan Creek. A study on the microhabitat used by the Formosan landlocked salmon showed that gravel from 0.2 to 1.6 cm, pebbles from 1.6 to 6.4 cm, and cobbles from 6.4 to 25.6 cm dominated the substrate composition of the redds (Tsao et al., 1998)[18]. Similar type of substrate composition was applied for the shelter channel on top of a relatively impervious layer of fabric or compacted clay soil. Gravel piles and wood stacks were placed at shallow water areas along the banks to provide hiding and resting places for the salmon. The designs of substrate, water depth and velocity were all possibly based on habitat requirements of the salmon.

The restoration of salmon shelters in the study reach included creating a backwater area and excavating three pools in the stream. **Fig. 6** shows the flow patterns before and after the creations of shelters during high flow that is simulated by the CFD model. Basing on the hydrological statistics, the return period flood of 50 years of the Chichiawan Creek is 920 m^3/s. The highest simulated velocity in the stream is 6.8 m/s that is very close to the observed velocity, 6.4 m/s. After the creation of backwater, the velocity in backwater area will reduce from 1.98 to 0.5 cm/s and the velocities in pools also reduce. The CFD model simulation indicates that the

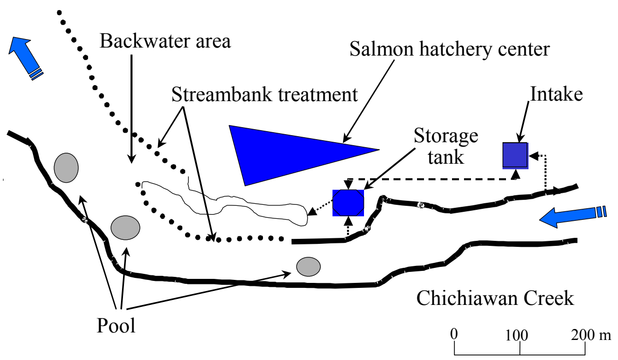


Fig.3 Schematic of Habitat Restoration Project on the Chichiawan Creek.

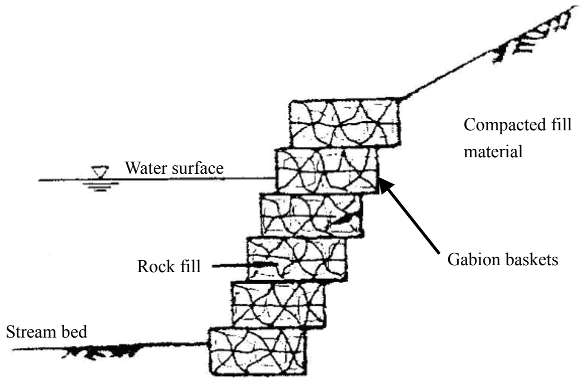


Fig. 4 Scheme of rock gabion used in the CCRP.

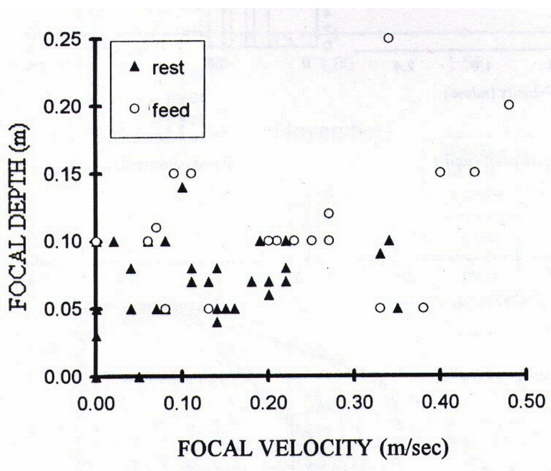
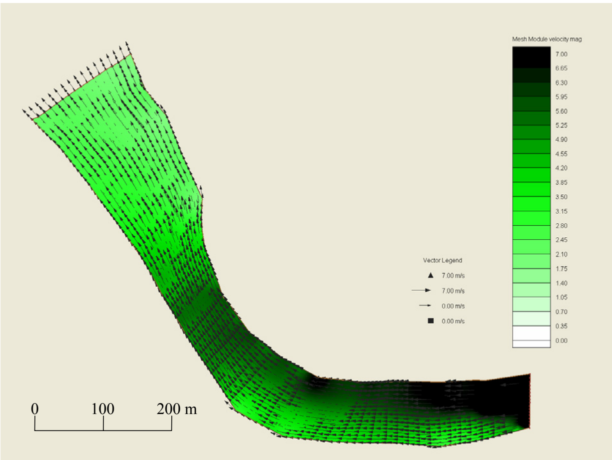
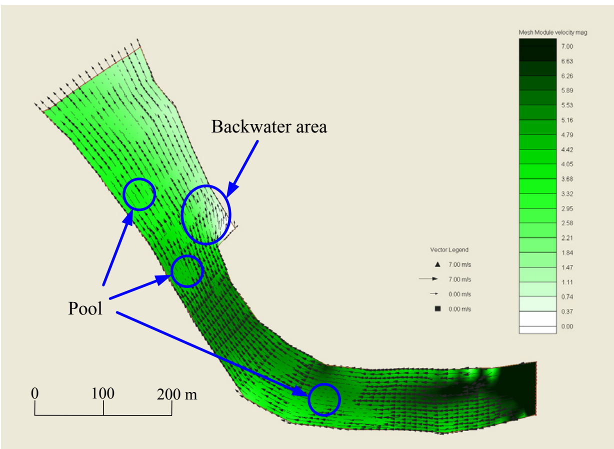


Fig. 5 Current velocity and depth of focal points used by age I+ and older (total length of large than 18 cm) Formosan landlocked salmon for feeding and resting behaviors.

hydraulic design ensures progressive submergence of the backwater during the floods. The complex currents during the floods will also affect the patterns of sediment deposition at the junction of the backwater with the stream. Floods swept over the stream and the complex currents affected the patterns of sediment deposition at the backwater area. Large eddies inevitably arise and these can easily cause sediments to settle down in the backwater area. Compared with the high currents in the stream, backwater area was thus a quiet refuge of still water in high flows and would provide some shelter suitable for fish fry and invertebrates. The flow patterns simulations within the CCRP area during the floods suggest that better survival of the salmon will be attributed to better opportunities to escape from the strong currents and to find themselves suitable refuge habitats to gain a longer response time. The shelters, moreover, can enlarge the habitat area by excavating additional pools.



(a)



(b)

Fig.6 Flow patterns simulation during flood; (a) before restoration; (b) after restoration.

Due to the endangered status of the Formosan landlocked salmon, it has been difficult to build the temporal and spatial relationships between the salmon distribution and the habitat changes. However, to better evaluate the effectiveness of the project based on the information routinely collected from the salmon monitoring program, analysis of salmon population dynamics near the CCRP area was initiated. Both **Fig. 7** and **Table 3** show the results from surveys conducted between 1999 and 2002 at the CCRP area. The adult, sub-adult, and juvenile salmon sizes are above 25 cm, between 15 and 20 cm, and below 15 cm, respectively. During the surveys, macro- environment variables such as water temperature, sunlight power and the precipitation were considered similar along the Chichiawan Creek. Therefore, the quantitative changes of the salmon population, which only occurred near the CCPR area, may reflect the availability of suitable microhabitats within the area. In addition, the habitat variables in the backwater area are similar to the ones measured in the resting microhabitat of the adult Formosan landlocked salmon (Tsao, 1995)[12]. Although salmon observed from different stream sections might be accumulated for different analysis purposes, all the results indicate that the number of salmon observed in winter of 2002 after the completion of the CCRP increase drastically. Especially the number of juvenile salmon increased from zero in spring 2002 to 90 in winter 2002 that was found to be statistically significant (Lin et al., 2003)[19]. However the increases in young adult and adult salmon were less significant. The significant increase in the number of juvenile fish observed in the backwater area indicates that younger and fragile individuals could benefit more from the protection provided by the shelters.

Recently Typhoon Aere ruined not only natural habitats but also artificial restoration areas of the salmon population. The storage tank, intake facility, hatchery center and other equipments were destroyed. About 3,000 members of the unique salmon population in the Chichiawan Creek had been imperiled by the heavy rainfall. Fortunately, the refuge shelters were not damaged and a portion of the salmon population could have hidden themselves in the backwater area during the peak flow.

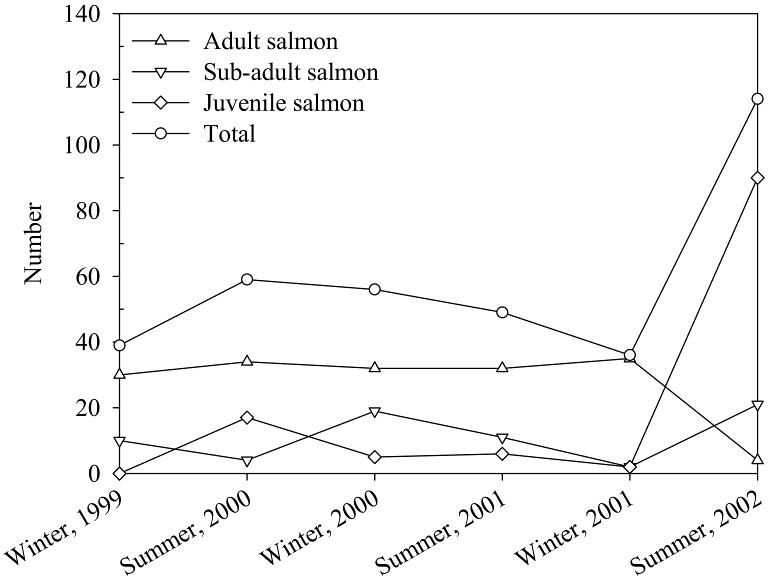


Fig. 7 Number of salmon observed near the CCRP site.

Table 3 Numbers of Formosan Salmon Observed in Different Stream Sections near the CCRP Project Site along the Hsueshan and the Chichiawan Creeks.

	Adult				**YOY**			
Salmon count	2001 Summer	2001 Winter	2002 Summer	2002 Winter	2001 Summer	2001 Winter	2002 Summer	2002 Winter
Total	257	352	573	1288	89	56	3415	2933
Hsueshan Creek	18	46	68	150	21	11	509	425
CCRP & downstream	**0**	**1**	**8**	**37**	**0**	**0**	**25**	**46**
CCRP upstream to dam 1	9	34	17	75	5	1	64	74
Upstream from dam 1	230	269	480	1026	63	40	2817	2388
N_1/N_0	2001 Summer	2001 Winter	2002 Summer	2002 Winter	2001 Summer	2001 Winter	2002 Summer	2002 Winter
Total		1.37	1.63	2.25		0.63	60.98	0.86
Hsueshan Creek		2.56	1.48	2.21		0.52	46.27	0.83
CCRP & downstream		**	**8.00**	**4.63**		**---**	**	**1.84**
CCRP upstream to dam 1		3.78	0.50	4.41		0.20	64.00	1.16
Upstream from dam 1		1.17	1.78	2.14		0.63	70.43	0.85

Note: N1/N0 is the comparison between the current and the previous observations of Formosan landlocked salmon; ** indicates the N1/N0 comparison is not available due to the zero value in the previous observation; Adult includes all the salmon with total length equal and above 15 cm; YOY includes all the salmon with total length below 15 cm.

4. CONCLUSIONS

The Formosan landlocked salmon is a genetically unique species that is a component of the global biodiversity (Berman, 1995)[20]. The Formosan landlocked salmon recovery program is an important milestone in Taiwan. It sets the stage for a new relationship with natural resources upon which the future welfare of the country depends. During the past 14 years, almost all the studies have documented that the decline of the salmon population is mainly due to habitat deterioration. Natural disturbances combining with anthropogenic factors have contributed to the spatial and temporal variability of habitats. In most recent times, human impacts are related to the failure of the Chichiawan Creek management program. Without conservation measures, the decline in the salmon population and even its extinction can be expected.

The application of ecological engineering in Taiwan is still at its preliminary stages. It is recognized that ecological engineering can be adopted to restore the habitat of the salmon. The CFD models can be used to simulate the hydraulics in the restoration area to help stream restoration. The results of the CFD model presented herein reasonably simulate the flow pattern of the CCRP area during flood. More over it can provide useful hydroinformatics of high flow for the hydraulic engineers and ecologists to win public confidence in ecological engineering.

The objective of the CCRP that established the salmon conservation hatchery, build the intake and storage tank, excavated the pools, created the backwater and protect the streambank was to restore the salmon habitat and increase the number of the salmon. Understanding functional processes in the Chichiawan Creek is essential in this regard, however, few data are available. Much more information is still needed to be collected. Although the hatchery center was destroyed by the typhoon, the backwater and bank protection are strikingly successful features of the project. It does not only provide refuge habitats for better survival of the salmon during the floods, but also attracts diverse forms of aquatic life.

ACKNOWLEDGEMENTS : This paper is based on work supported by the Water Resources Agency of Taiwan.

REFERENCES

1) Kao, C.-Y.: Near-nature management -stream engineering work based on landscape and ecological considerations, J. Peking Forestry Uni., Vol. 21, No. 1, pp. 80-85, 1999 (in Chinese).
2) Mitsch, W.J. and Jorgensen, S.E.: Ecological engineering: a field whose time has come. Ecological Engineering, Vol. 20, No. 5, pp. 363-377, 2003.
3) Ward, J.V., Tockner, K., Uehlinger, U. and Malard, F.: Understanding natural patterns and processes in river corridors as the basis for effective river restoration, Regul. Rivers: Res. Mgmt., Vol. 17, pp. 311-323, 2001.
4) Shirvell, C.S. and Dungey, R.G.: Microhabitats chosen by Brown Trout for feeding and spawning in rivers, Trans. Amer. Fish Soc., Vol. 112, pp. 355-367, 1983.
5) Marcus, M.D., Young, M.K., Noel, L.E. and Mullan, B.A.: Salmonid-habitat Relationships in the Western United States. Tech. Rep. RM-188, Forest Service, Rocky Mountain Forest and Range Experiment Station, USDA, Fort Collins, CO, 1990.
6) Booker, D.J.: Hydraulic modelling of fish habitat in urban rivers during high flows, Hydrol. Process., Vol. 17, No. 3, pp. 577-599, 2003.
7) Booker, D.J., Sear, D.A. and Payne, A.J.: Modelling three-dimensional flow structures and patterns of boundary shear stress in a natural pool-riffle sequence, Earth Surf. Process. Landforms, Vol. 26, pp. 553-576, 2001.
8) Koskiaho, J.: Flow velocity retardation and sediment retention in two constructed wetland-ponds, Ecol. Engrg., Vol. 19, No. 5, pp. 325-337, 2003.
9) Crowder, D.W. and Diplas, P.: Using two-dimensional hydrodynamic models at scales f ecological importance, J. Hydrol., Vol. 230, pp. 172-191, 2000.
10) Korman, J., Wiele, S.M. and Torizzo, M.: Modelling effects of discharge on habitat quality and dispersal of juvenile humpback chub (Gila Cypha) in the Colorado River, Grand Canyon. River Res. Applic., Vol. 20, pp. 379-400, 2004.
11) Lin, Y.S., Tsao, E.H.S. and Chang, K.H.: Population and distribution of the Formosan landlocked salmon (Oncorhynchus masou formosanus) in Chihciawan Stream, Bulletin of the Institute of Zoology, Academia Sinica, Vol. 29, No. 3, pp. 73-86, 1990.
12) Tsao, E.H.S.: An Ecological Study of the Requirements of the Formosan Landlocked Salmon (Oncorhynchus masou formosanus), Ph.D. Dissertation, Colorado State Univ., Fort Collins, Colorado, 1995.
13) Day Y.T., Tsao, H.S., Chang, K.H. and Lin, Y.S.: Spatial and temporal changes of Formosan landlocked salmon, (Oncorhynchus masou formosanus), in Chichiawan Stream, Bull. Inst. Zool. Acad. Sinica., Vol. 32, No. 2, pp. 87-99, 1993.
14) Lin, Y.S., Tsao, E.H.S. and Chang, K.H.: Breeding behavior of Formosan landlocked salmon. Ecol. Res., Council of Agr. of Taiwan, 1988, No. 8., 1989 (in Chinese).
15) Wang, C.M.J.: Environmental quality and fish community ecology in an agricultural mountain stream system of Taiwan. Ph. D. Dissertation, Iowa State Univ., Iowa, 1989.
16) Lin, Y.S.: Contribution of Formosan landlocked salmon conservation on studies of freshwater ecology, Proceeding of Workshop on Conservation of the Taiwan Masu Salmon, Oncorhynchus Masou Formosanus, Taiwan Endemic Species Research Institute, pp. 17-27, 2000.
17) Norton, W.R. and Ring, I.P.: Operating Instructions for the Computer Program MA2-2V, Resource Management Associates, Lafayette, CA, 1977.
18) Tsao, E.H.S., Lin, Y.T., Behnke, R. and Bergersen, E. P.:

Microhabitat use of Formosan Lanlocked Salmon - Oncorhynchus Masou Formosanus, Zoological Studies, Academic Sinica, Vol. 37, No. 4, pp. 269-281, 1998.
19) Lin, Y.F., Chen, Y.L. and Liao, L.Y.: Investigation on the Habitat Changes of the Formosan Salmon after the Completion of the Shelter Channel and Other Engineering Projects, Technical Report, Shi-Pa National Park Administration, Taichung, Taiwan, 2003 (in Chinese).
20) Berman, C.: Recommendations: Formosan Salmon Recovery Effort, Unpublished Manuscript, US Environmental Protection Agency, Region 10, Seattle, Washington, 1995.

(Received August 11, 2005)