A Case Study of the Temporal and Spatial Distribution of River Hydraulics and Habitat in the Wu-chi river, Taiwan

[1]Po-Wen, Wen. [2]Ray-Shyan, Wu and [2]Chen-Tai, Mao

[1]**Ecosystem Solutions,** [2]**Hydraulic Engineering, E-Mail:** pwwen@cc.ncu.edu.tw

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EXTENDED ABSTRACT

Based on the premise of flood management, administration of rivers in Taiwan consists of building many water structures to protect the lives and properties of people. But the ecological equilibrium of the area may possibly be damaged. Thus, how to maintain the ecological instream flow and how to lessen the negative impact of human development on river ecology are topics that have to be further investigated. The relationships between hydraulic conditions and ecological habitats are discussed and compared with quantified assessment technology in this study. *Acrossocheilus paradoxus* was selected as the target species, and a hydraulic model HES-RAS 3.0 along with the habitat model RHABSIM 2.2 was employed to estimate the ecological instream flow of the habitat. The Wu-chi river in Taiwan was chosen for the case study.

This study finds some results. First, when flow increases, the habitat spaces increase while the combined suitability factor (CSF) also increase in a relatively lower rate. And by this reason, the majority of habitat spaces are of the “run” type while a few “pool” types also existed. When flow rate is more than 200cms, the “pool” type diminished. Second, In the river ecology, pool type is an important refuge and perch for fishes. For flows which are too fast in the run areas (such as section 66), *Acrossocheilus paradoxus* may possibly be unable to cross, resulting in habitat cut offs, and which may hamper survival of this fish species given the habitat conditions. Third, Local and international results indicate that ecological flows are described as single values but for the animals, there should be a range which changes can occur. Thus, this study considers the effect of variety of habitats and habitat to set the ecological base flow limits of the section under study and to maintain the ecological habitat diversity required. In addition, we have set the ecological base flow limits for the research section between 10–40 cms as most suitable for *Acrossocheilus paradoxus* survival.

Finally, table 1 indicates that in 1997, a total of 288 days failed to meet the ecological base flow standard while the longest number of days which did not meet the ecological base flow standard is 125 days during 1994. These two years should be the worst years for the ecology; if the year where the most number of days meeting the ecological base flow limits are seen as the best year for the ecology, then 1991 is the best (250 days) and then followed by 2000 (245 days). Moreover, Table 1 shows that 1991 has the lowest longest number of days which does not meet the ecological base flow limits (26 days). Thus, 1991 is the best year for the ecology.

Table 1 Number of days meeting and failing to meet the ecological base flow limits over the years

Year	(1)*	(2)*	(3)*
1987	209	102	156
1988	181	30	185
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*p.s.(1)Total number of days not meeting the ecological base flow limits
(2)The longest number of continuous days not meeting the ecological base flow limits
(3)The number of days meeting the base flow limits

1. INTRODUCTION

In recent years, interest in ecological concerns regarding river hydraulic engineering has been on the rise resulting in development of many ecological protection evaluation techniques in Taiwan. This paper studies two factors, flow and depth. Using HEC-RAS hydraulic model combined with RHABSIM hydraulic model and the habitat model, we calculate the relationship of target fish species flow with the usable area of the habitat. Based on the case study, we investigate water environment habitat distribution patterns located at the upstream area of the Wu-chi river, finding the link between fish habitat changes and time factors. Through this, we determine which flow can offer fish better habitat and can allow wildlife to multiply in equilibrium. Finally, we use weighted usable area (WUA) and consider the effects of habitat diversity and pool to determine the basic ecological flow ranges and to evaluate the proper ecological base flows.

Because of the different factors which have to be considered in ecological base assessment methods, runly several methods have already been developed and can be generally classified into historical flow method, hydraulic assessment method, habitat assessment method, and experiential rules. Tennant (1976) used mean annual flow (MAF) as the most representative. When investigating the various flow percentages using MAF, the representative character of the water ecology environment is used to determine different preservation standards for river ecology base flow. Forlong (1994), using flow duration curve, suggests the use of time percentage of 96% as corresponding to flow duration Q_{96} which is the research sample's river ecological base flow. For Taiwan, Q_{95} is frequently used as a river ecological base flow. Bartschi (1976) suggests that when flow only maintains yearly average flow and the corresponding wet perimeter length is 80%, this is possibly the lowest limit that the ecosystem can take. Tennant (1976) suggests the turning point in a wet boundary-flow curve as the corresponding flow of the ecological base flow. U.S. Fish and Wildlife Service (USWFS) developed the Instream Flow Incremental Methodology (IFIM), using the concept of the lowest flow demanded by fishes and transformed into a relationship between flow and habitat. Bovee (1982) thinks that by combining this continuous concept and method with channels, flow characteristics, and index wildlife, different flow simulations can be used to predict the increase or decrease of habitat area.

2. METHODS

This study uses HEC-RAS hydraulic method by analyzing for the water level data of each section at varying flow simulation from the known section flow data; through RHABSIM hydraulics and habitat model, the flow velocity and weight can make use of the habitat area and the ecological base flow. The following further discusses the HEC-RAS hydraulic model, RHABSIM hydraulic and habitat model, and the fish type index suitability curve from this study.

2.1. HEC-RAS and RHABSIM Model

The HEC-RAS software was developed by the Hydrologic Engineering Center, US Amry Corps of Engineers (1998). This study uses its calculation for the section's average water level as RHABSIM input value. Velocity estimation makes use of the RHABSIM model mainly because during analysis of the habitat, if the average water depth and average velocity are used from each section, then it is impossible to fully express the habitat conditions of the section. Thus, the RHABSIM model has to be used to predict each cell's velocity and water depth.

The Riverine HABitat SIMulation system (RHABSIM) used in this study is a transformed PHABSIM model. RHABSIM is composed of a hydraulic model and a habitat model. The main function of the hydraulic model is to compute the water level and the velocity and water depth distribution of each cross section for the different flows. The water level value in this study directly uses the water level data from the HEC-RAS model at a certain flow. The RHABSIM hydraulic model computes for the different cross section velocity and depth distribution of different flows finds the corresponding HSC value for the different cross section velocity and depth distribution of different flows. From this, the weight of the river being studied can be obtained by WUA.

2.2. The target species suitability curve

The target species of this study is *Acrossocheilus paradoxus*, an indigenous Taiwan fish species, polyphagic, and inhabits swiftly flowing waters, or clear pools in streams. The fry frequently stays in quiet shoreline areas. Its main sources of food are epiphytic algae on rocks and water insects.

The research sampling area for the suitability curve is turbid water upstream areas. A survey was by the preservation center in 2001 on turbid water upstream fish type habitats and statistical analysis of captured surface fish species were done(Yeh et al, 2001). In addition, the suitability curve was made in terms of velocity and depth for *Acrossocheilus paradoxus* (Figures. 1 and 2.).

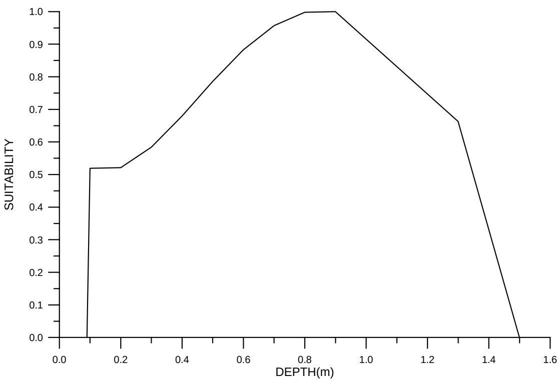

Figure 1. The relationship between depth and *Acrossocheilus paradoxus*.

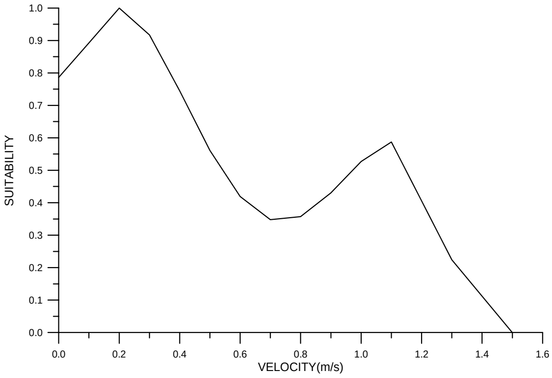

Figure 2. The relationship between velocity and *Acrossocheilus paradoxus*.

3. CASE STUDY

3.1. Research area description

Wu-chi river is located at the eastern part of the Taiwan. The case study is primarily to investigate Wu-chi river’s upstream (Wu-chi river section number 80 – 90; see Figure. 3), 7.2 km long, and average slope of 1/141. The Manning factor used is 0.041.

3.2. Analysis of habitat patterns

In river topography studies, to understand the river configuration of each section, channel sections, depth, and velocity are frequently employed. In general, pool types can be divided into 3-5 types depending on requirements. Nevertheless, no matter what type, the decision method is mainly using velocity (V) and depth (D).

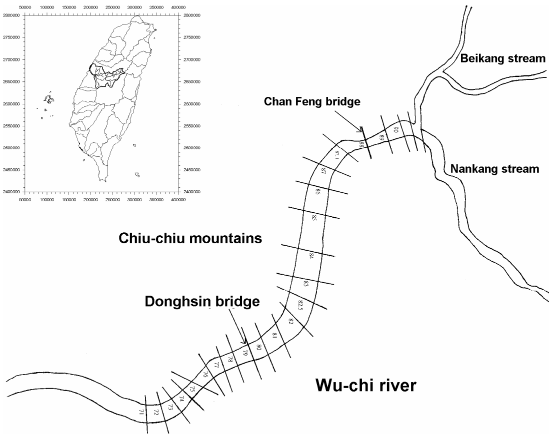

Figure 3. The location of research area in Taiwan.

Based on previous research the lowest requirement of most river fishes for survival is average depth is 0.3 m, velocity is 0.28 m/s (Bovee 1982, Tennant 1976). This study divides the research area habitat patterns into four types, according to the computed habitat differences. The habitat pattern is determined by velocity and depth with the following standards: when velocity is less than 0.3 m/s and the depth is greater than 0.3 m, it is considered a pool. When the velocity is greater than 0.3 m/s and depth is less than 0.3 m, then it is a riffle. When the velocity is greater than 0.3 m and depth is greater than 0.3 m, it is called a run; when the velocity is less than 0.3 m/s and depth is less than 0.3 m , it is a glide.

This study will discuss the four types of habitat, analyzing the different flow changes of the habitat areas and results are shown in Figure 4. It can be known from Figure. 4 that when the flow is less than 6 cms, low flow will make more low speed and low dept areas. Thus, the habitat area is primarily a riffle. However, when the flow is greater than 6 cms, it is converted into a run. The run area increases with flow increase. This is used to offer fishes a rest and refuge pool. But this only appears in under special flow conditions and only occurs in particular sections. Moreover, compared with the area of other habitat patterns, pool areas are insignificantly small. This result means that the habitat type areas in the study are primarily affected by riffles, glides, and runs; furthermore, the diversity of habitat in low flows gives an advantage to high flows while pool flows and other sections should be able to offer fishes good resting places and refuges. However, not all areas and all habitat patterns are suited to the survival of the fish species chosen in this study. Thus, usable area boundaries and usability still have to be further analyzed in order to show the effect of the section researched on the target fish species.

To understand the effect of the section being studied on the target fish species based on channel use boundaries and usability, we analyze the habitat type area changes of WUA and results are displayed in Figure. 5. The figure shows that for low flows, the tendency is similar to Figure. 4 while the explanation for the habitat type change trends of the WUA is similar to the above. Similarly, there are changes in habitat area size and pool characteristics. What is different from the above situation is that high flow WUA slowly tends to stabilize while the water area still continues to rise. The reason for this is because when flow increases, within the water area at a certain portion, the velocity will be too high or the water too deep, leading to the target fish species unwilling or unable to be in that area. Thus, the habitat type change trend of the WUA at high flow areas will tend to stabilize.

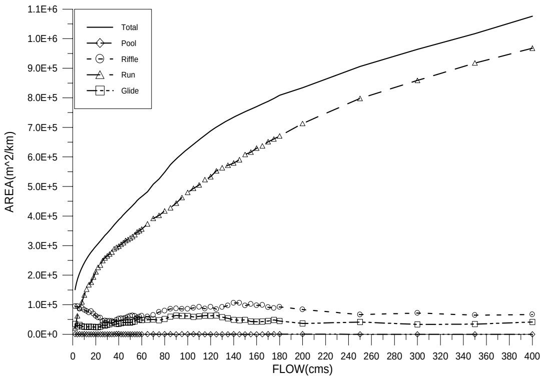

Figure 4. River habitat area changes in different flows.

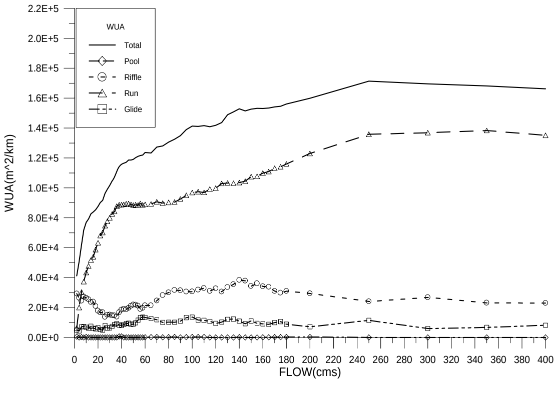

Figure 5. WUA habitat patterns changes in different flows.

The research findings reveal that pools are only found in certain specific flows and sections while most are run type habitats. However, whether flow change will affect each section still has to be analyzed; thus under the same conditions, observing the habitat type distribution of the river section indicates that the area distribution and the habitat area distribution of WUA are significantly different. Taking 10 cms flow as an example (Figure. 6 a, b), the pool proportion using the WUA distribution is larger than the river habitat distribution while the glide proportion using the river habitat distribution is larger than the WUA distribution. Moreover, from the WUA habitat distribution, it can be seen that most of the habitat areas are riffles and runs. This reflects the living environment of *Acrossocheilus paradoxus* which prefers riffles and runs instead of glide areas with slow flows and shallow depths. For flows which are too fast in the run areas (such as section 66), *Acrossocheilus paradoxus* may possibly be unable to cross, resulting in habitat cut offs, and which may hamper survival of this fish species given the habitat conditions.

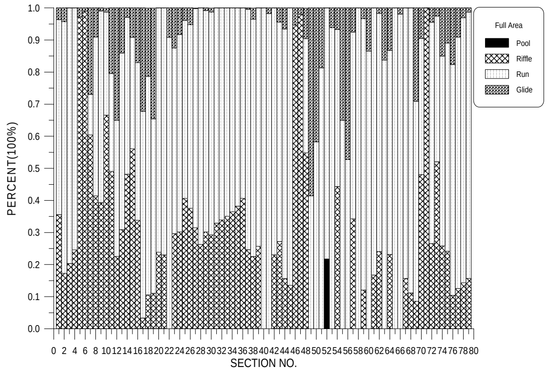

Figure 6(a). Percentage relationships for four types of habitat for the research section (Q=10cms, Pool=0.24%, Riffle=34.26%, Run=55.05%, Glide=10.45%)

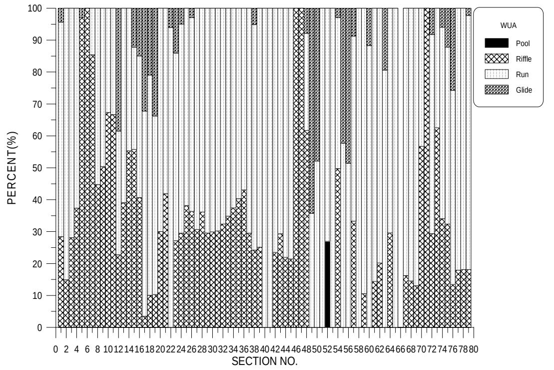

Figure 6(b). Percentage relationship of the four types of habitat for the research section (Q=10cms, Pool=0.42%, Riffle=34.33%, Run=56.38%, Glide=8.87%)

It can be seen that from Figures. 4 and 5, increasing flows lead to subsequent WUA increases as well; however, the increased amount is smaller than the increase in river area. Since WUA computation involves multiplying river area by habitat suitability factor, thus the relationship between habitat suitability factor and flow, results of which are shown in Figure. 7. From Figure. 7, it can be seen that aside from the time when habitat suitability factor is low (less than 10 cms), increasing the flow will also increase habitat suitability factor; for more than 10 cms, it will continue decreasing. The maximum habitat suitability factor at 10 cms is also only 0.32. Because of habitat suitability factor effects, WUA at high flow will tend to be stable.

If each different habitat type CSF is separately analyzed and corresponding relationship with flow is drawn (Figure. 7), when pools occur, the pool habitat suitability factor is higher than other habitat patterns, followed by riffles; moreover, the habitat suitability factor of runs decrease as flow increases. Since habitat suitability factor represents the river area usage rate, the percentages of habitat that can be used in the river area are indicated in Figure. 7 where pool CSF is highest, followed by riffles. In addition, these values are relatively stable, meaning that pool and riffle habitat quality is likewise stable. However, not all flows contain pools since they are affected by flow changes. Furthermore, run and glide CSF values clearly drop as flow increases, and so run area significantly increases with flow increase (Figure.4). However, the usable run area does not widen (Figure.5). From Figure. 4, when flow increases, the increased river area is mainly run area while changes in other types of areas are small. Thus, this is the main reason why the CSF curve of the total WUA seems to be overlapping with the run CSF curve as shown in Figure. 7. *Acrossocheilus paradoxus* best adapts to pools and riffles rather than runs and glides.

Thus, it can be seen from the above conclusions that flow increases can bring habitat space to *Acrossocheilus paradoxus* but this does not necessarily mean better habitat environment. Even if the river section in this research has enough run scouring and transporting use which provides food sources, nevertheless because of fewer sections with pools (only 4 sections), not enough refuge and perches are offered by the pools. In addition, when flow is greater than 200 cms, no pools can be offered by the research section to *Acrossocheilus paradoxus* as shelter during floods. Therefore, during times of high flow or fixed flow, habitat cut offs or absence of pools may possibly affect the survival of *Acrossocheilus paradoxus*.

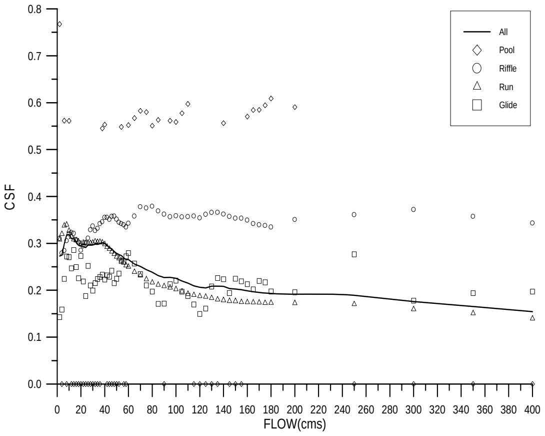

Figure 7. The relationship between each habitat type habitat suitability factor (CSF) and flow

3.3. Habitat diversity index analysis

Regarding description of the habitat, we can know the habitat type favored by the target species in this study and the characteristics of the river section. However, the effect of the entire habitat still has to be further elaborated. In evaluating wildlife, normally, wildlife diversity is used to evaluate the area's species richness while analysis of the whole wildlife diversity is frequently expressed as a Diversity Index (D). When the diversity index is high, this means better multiplicity. This study uses Simpson's diversity index and the modified definition is as follows:

$$D = 1 - \lambda \tag{1}$$

$$\lambda = \sum_{i=1}^{S} P_i^2 = \sum_{i=1}^{S} \left(\frac{n_i}{N} \right)^2 \tag{2}$$

where the D is diversity index, λ is superiority index, P_i is percentage of habitat i, n_i isarea occupied by habitat i, N is the water area of each section and S is total sections.

Analyzing the relationship between the diversity index of the habitat area of the river section and the flow changes (as in Figure. 8), it can be seen that when the flow is less than 10 cms, the habitat area diversity index increases with increasing flow. However, after reaching 10 cms, this lowers. On reaching 24 cms and reaching the lowest point, it gradually rises to 90 cms. Later on, the diversity index of the habitat area lowers as flow increases. But when the flow is larger than 40 cms, the diversity index of the river habitat significantly is smaller than that of WUA. Even if the two tend to lower when flow is larger than 90 cms, nevertheless, the diversity index of the habitat of WUA is still maintained at a certain level ($D_{WUA} \geq 0.26$) and which is better than some low flow diversity index situations of WUA (for example, when the flow is less than 4 cms). The diversity index of the habitat river area continues to lower.

These results compared with those in Figures. 4 and 5 show that although increasing flow affects the distribution change of the habitat area of WUA, nevertheless, the habitat suitability for the survival of *Acrossocheilus paradoxus* still depends on the habitat area value of WUA. Even if increasing flow has an effect on the survival of *Acrossocheilus paradoxus*, however, if enough habitat space can be provided, then the fish species can temporarily survive under the protection of the river pool. Furthermore, based on Figure. 5 results, when the flow is larger than 200 cms, there is no river section pool deep enough in this research that can offer refuge for *Acrossocheilus paradoxus*. When the flood flow is larger than 200 cms, all the *Acrossocheilus paradoxus* fixh types in the research section were swept downstream towards a relatively safer area. Thus, engineering designs on future river sections should consider that the normal flow changes in a river cannot be larger than the biggest flow (where in this research it is 200 cms) to ensure that the *Acrossocheilus paradoxus* in the research area can survive there.

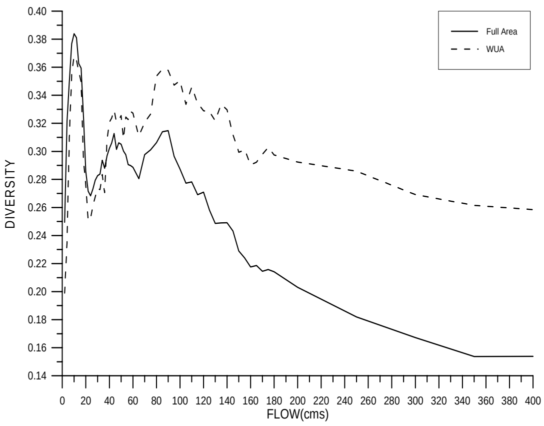

Figure 8. Relationship between habitat diversity and flow changes

3.4. Ecological base flow evaluation standards

This study considers the effects of diversity of habitat and pool to determine the section of this study's ecological base flow range and so maintain the ecological habitat diversity demands of the river section. The standards set are:

- Maintain WUA habitat area diversity index as the optimal value to keep the diversity of the section under study. Moreover, at low flows, it should maintain this standard. The flow should be one of the correct ecological base flows. As shown in Fig. 8, when the flow is 10 cms, the WUA habitat area diversity index is at the largest value (0.37).
- The number of pools for refuge and habitat is very important to *Acrossocheilus paradoxus*. Thus, more pool areas benefit *Acrossocheilus paradoxus* survival. Moreover, from Fig. 7, it can be seen that pools have the largest CSF. Thus, choosing the flow with the most pool area is one of the suitable ecological base flows. As shown in Fig. 4, when the flow is 40 cms, it has the largest pool area (654m^2/km).
- Larger river area usage rate means that the river area has a higher life activity are that can be used by *Acrossocheilus paradoxus* which will beneficial to its survival. Thus, the corresponding flow for biggest river area usage rate is one of the suitable ecological base flows. As shown in Fig. 7, when the flow is 10 cms, the river area usage rate is the largest (31.89%).
- Regarding the excessive flow area of runs (such as section 66), *Acrossocheilus paradoxus* may be unable to pass and habitat cut offs may occur. This will disadvantage the survival of *Acrossocheilus paradoxus* in terms of habitat conditions. Thus, ecological base flow value should not be within the habitat cutoff flow range.

Analyzing the above four conditions, the ecological base flow range should be between 10–40 cms as the optimal conditions for *Acrossocheilus paradoxus* survival.

3.5. The effect of time on habitat

In the river ecology, pools are an important refuge and perch for fishes while how many of these pools are being used will significantly affect whether *Acrossocheilus paradoxus* can survive or not during floods. Thus, analyzing the river area changes and WUA changes for the entire year will allow for understanding of the yearly changes in the river area, WUA, and pools. Average daily flow data comes from the MOEA's water resources planning institute, water resources agency. Records are from 1987 to 2001, a 15 year flow data where the average values are obtained.

Table 1 indicates that in 1997, a total of 288 days failed to meet the ecological base flow standard while the longest number of days which did not meet the ecological base flow standard is 125 days during 1994. These two years should be the worst years for the ecology; if the year where the most number of days meeting the ecological base flow limits are seen as the best year for the ecology, then 1991 is the best (250 days) and then followed by 2000 (245 days). Moreover, Table 1 shows that 1991 has the lowest longest number of days which does not meet the ecological base flow limits (26 days). Thus, 1991 is the best year for the ecology.

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(2)The longest number of continuous days not meeting the ecological base flow limits
(3)The number of days meeting the base flow limits

4. CONCLUSION

This study mainly combines HEC-RAS hydraulic model and RHABSIM hydraulic model with habitat models to make up for analytical shortcomings of the two models. And the result show that When flow increases, the WUA likewise increases but the amount is less than that of the increase in river area. Compared with the areas of the other types of habitats, pools make up a very small area. Furthermore, when there are pools, most of their area is used while the usage rate of run areas continues to decrease. This shows that *Acrossocheilus paradoxus* has poor adaptability to quickly flowing rivers and disadvantages its survival. When the flow is larger than 200 cms, no pools can be offered as refuge from floods for *Acrossocheilus paradoxus* in the section under study. Thus, in the long term, when the flow continues to be high or fixed, this may possibly affect the survival of *Acrossocheilus paradoxus*. The proportion of pools using WUA distribution is larger than the habitat distribution while glide proportion using river habitat distribution is larger than the WUA distribution. Moreover, from the point of view of the WUA habitat distribution, most of the habitat areas are either primarily riffles or runs. This reflects the characteristic of the living environment of *Acrossocheilus paradoxus* which prefers to move in riffles and runs and does not like slow or shallow areas. Furthermore, for flows which are too fast, *Acrossocheilus paradoxus* may possibly be unable to pass and may result in habitat cut offs which mostly happen at low flows (Q 10cms), primarily in section 66.

This study considers the effect of variety of habitats and habitat to set the ecological base flow limits of the section under study and to maintain the ecological habitat diversity required. In addition, we have set the ecological base flow limits for the research section between 10–40 cms as most suitable for *Acrossocheilus paradoxus* survival. From the results, it can be concluded that from 1987 to 2001, 1991 was the year most favorable to the ecology while the worst years were from 1994 to 1997.

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