Research on the Relationship between Riparian Vegetation and the Flood Return Period

Yuh-Rong Guh, Wei-Cheng Zhao, Shih-Hsiung Liang, Chang-Lun Shieh

ABSTRACT

The administration of water resources have long been emphasized the proper utilization of water resources and precautions against natural calamities. With riparian areas compressed under the pressure of development and leading to stream pollution, the ecological preservation and conservation of streams has become valued by relevant scholars in the field of biology, ecology, landscapes and engineering. In river rehabilitation, the stream corridor is the important habitat that connects the watershed upstream and downstream with the greater amphibious area. The riparian plant functions in the stream corridor decrease the water temperature, lower the river nourishment resource load, reduce erosion, provide habitats for numerous creatures and amphibians on land, protect the fish habitat and maintain the rivers ecological food chain integration. River re-conservation is first be bounded the necessary space reserved for riparian vegetation.

This research combines flood frequency analysis with the riparian vegetation features to determine the quantitative river discharge variation frequency relationship between the river width and vegetation characteristics. The findings from this research show that different vegetation life form distributions are impacted by the flood frequency. The initial findings show that the annual plants appear in the river width with a flood frequency of 1.1 ~5 years on average. Perennial plants appear at a 1.1~10 year frequency. Shrubs require a 2.33~20 year frequency, while arborescent plants require 5~50 years. It can be seen that a flood frequency variation that interferes with the river ecology is helpful in promoting riparian vegetation diversity. Therefore, advantage could be taken of the stream flood frequency in combination with related river ecology water conservation projects to provide for future water resources management.

1. PREFACE

Human civilization has developed along riversides since ancient history. The riparian region has become the place for most frequent human activities. Riparian vegetation has sustained a tremendous interference from this human activity. A periodic variation in the watershed hydrology produces periodic floods. These floods impact the water supply and sediment balance for the floodplain, cause morphologic changes in the floodplain and affect the structure and composition of the riparian vegetation community. In other words, the riparian vegetation is interfered by variations in the catchment hydrological characteristics.

In river rehabilitation, banks along the river (called the stream corridor) and catchments that connect the upstream with the downstream (lengthwise) are critical amphibian habitats. Only now do we see how important the riparian vegetation is to the river ecology. References from home and abroad point out that the plants in the stream corridor have multiple functions, including decreasing the water temperature, lowering the river nourishment resource load, reducing riverbank erosion, diminishing sediment flow into the river, providing habitats for land and amphibian organisms, protecting the fish habitat, and maintaining river ecological food chain integration. Thus, the riparian region of rivers provides a variety habitats for aquatic organisms and a sound food chain along the river flow. In the river cross section, habitats and food resource are also provided for inland animals and amphibians. As a result, the biodiversity in this region is therefore higher than that in nearby waters and lands. However,the width of riparian corridor along the rivers is not clearly and quantitatively defined from a academic perspective. Thus, to successfully accomplish stream corridor rehabilitation, one of the priority issues is to bounded the space reserved for riparian vegetation along the breadth of the river ecological corridor.

In Taiwan, boundaries of the river width buffering change according to the different targets being protected (e.g. reservoir protection areas and riverbank protection areas, etc). These boundaries are generally between 30~50 meters. A buffering width is conventionally based on the breadth necessary for riparian vegetation to enter the nourishing river course (e.g. Tzao-Yuan Lin, 1998). River rehabilitation starts from the viewpoint of biology, combining the catchment hydrology with channel characteristics to delimit the stream corridor river width. To date, only a few references abroad have targeted the relationship between riparian vegetation and hydrological features. Research on the interrelationship between qualitative and quantitative assessment needs to be reinforced. This research would combine the flood frequency discharge analysis with the distribution of riparian vegetation to conclude the quantitative relationship between the buffer width and the vegetation based on the flood discharge variation frequency. An integration of river ecology and hydrology technology to bound the width of stream corridor would be accomplished, and suggestions would be provided for future management of the water resources such as constructing location of the dike, and for the reference standard of the application scope.

2. PREDECESSOR'S RESEARCH

2.1 Riparian Vegetation and Stream Ecosystem

The riparian vegetation has many important functions to the stream ecology. Swanson (1982), targeted conifers in the riparian vegetation belt on the west coast of the US. He published a multitude of findings and indicated that the riparian vegetation functioned due to the insulation on the tree-crown that obstructed the sunshine and supplied food for large and small animals. Peter John and Correll (1984) indicated that the groundwater level had a large variation in riparian areas. The water status also experiences significant changes, resulting in the riparian vegetation roots becoming extremely prosperous. The pores in the root system pass the contaminated areas in the flowing water, filter and adsorb pollution, and then reach further by purifying the water quality.

Chen,Hsin-Hsiung, Chen,Ming-Jei (1989) pointed out that riparian vegetation may buffer the wastewater pollution from riverside factories, agriculture and fisheries. Budd (1987) considered that the forest community (riparian vegetation) formed at the riverside is an important index to the quality of the stream corridor. Nakamuru and Paihai (1989) indicated that the crown of the riparian trees upstream would proportionally affect the sunshine shining directly onto the water in rivers, especially in summer. These crowns decrease the water temperature and form an appropriate environment for the growth of organism's. The Chi-Ja-Wan Stream in Central Taiwan possesses the famous Formosan Landlocked Salmon (Oncorhynchus masou (Jordan et Oshima) The water temperature in this stream must be kept less than 16℃ for salmon survival. Due to riverbank collapse and the diminution of large-trees an increase in gaps in the river corridor has occurred. The sun shining on the stream will increase the water temperature, and threaten the Formosan Landlocked Salmon.

Suzuki (1992) assumed that the stream corridor formed by riparian vegetation might provide a refuge habitat for various species. Using fish as an example, the pool-ripple system and riparian vegetation might provide a provisional refuge for fish. Nakamura and Swanson (1994) indicated, from the viewpoint of hazard precautions, drifting woody debris would often block the channel to reduce the cross section area. This could cause a flood hazard. As far as aquatic life is concerned, a pool-ripple system suitable for the fishes could be formed drifting woody debris, sand, and gravel in rivers form a complex microhabitat. The new flow path provides a habitat for fish and aquatic organisms, thus promoting the renewal of the riparian vegetation community. Franklin (1992) indicated that most riverbanks have continuous riparian vegetation, followed by species settlement that would integrate the ecological system in every sub-catchment, enlarging the scope of species' distribution in the whole basin. Other scholars pointed out similar results in their research.

The composition and structure of the natural vegetation community at the riverside is considerably complex, comprised of a number of vegetation layers and the species. In the vertical direction, the vegetation may contain trees, saplings, shrubs (subtree), vines, and herbaceous subshrubs (herb-grass-forb) layers. Carothers etc. (1974) worked at Verde River in Central Arizona and demonstrated that there is a high correlation between the height of the riparian vegetation tree crown and bird habitats along the river. In the horizontal direction, the riparian vegetation in a river corridor is as important as the birds, vertebrates, and invertebrates (Fredrickson 1978, Wharton et al. 1982).

The riparian vegetation buffer strip provides the following functions: (1) Provides shade that reduces water temperature. (2) Cause deposition of (i.e. , filter) sediments and other contaminants. (3) Reduces the stream nutrient load. (4) Stabilizes the streambank. (5) Reduces erosion caused by uncontrolled runoff. (6) Provides a riparian wildlife habitat. (7) Protects the fish habitat. (8) Maintains aquatic food webs. (9) Provides a visually appealing greenbelt. (10) Provides recreational opportunities. It is thus evident that the primary work in conserving a river ecosystem is improving the function of the riparian vegetation. However, the previous research provided no qualitative description, or incorporated the catchment feature factors, the previous research does not provide actions that suit local circumstances.

2.2 Relationship between riparian vegetation and floods

Not many domestic researches examined the correlation between flood discharge and riparian vegetation. Sow-Ming Wang (1991) is the only one that mentioned the plant community on riverside being interfered with by periodic floods. In the rainy season, the water level rises to scour and submerge the vegetation. When the water level falls in the dry season, the soil becomes withered due to lack of rain. The quantitative relationship between the vegetation and flood discharge has not been determined. The overseas researches are more copious, e.g. Tamai (2000) indicated that riparian vegetation often be endures the changes in water level. Jeglum (1975) pointed out that soft-stem plants live easier in areas with frequent floods because they can reduce the water resistance under the high flow velocity and protect the plants alongside the downstream. Teskey and Hinckley (1977) discovered at the end of the 80's that floods affected the vegetation more in high return-periods than in low return-periods. Franciso etc. (2001) used satellite images to compare past and present flood-events to comprehend the interrelationship between the flood variation and riparian vegetation coverage. They stated that human interaction would result in flood discharge variations that would change the riparian plants.

Brown and Giese (1988) considered the riparian vegetation density would be reduced with the flood duration. Richard etc. (1995) assumed that an artificial dike might increase the channel stability in the horizontal direction. However, the disturbance from the floodplain variation in discharge would decrease, which could lower the groundwater level by one meter. Stromberg (1993) thought that the farther the plants were away from the main streamway at higher terrain, the higher the survival rate. Elizabeth's research (1999) showed that certain specific species of vegetation had seeds that required an extremely short time to propagate. These plants grew only in the floodplain after a particular flood scour. Water resource management causes changes in river hydrographs, which leads riparian plants to extinction, and interferes with the food web in the river corridor. This results in the disappearance of birds. Each piece proves that the riparian vegetation is closely associated with the river ecosystem and that this close correlation links the periodic floods with the existence of riparian vegetation. Morris (1978) and Rood and Mahoney (1990) indicated that riparian vegetation is involved with the flood depth, duration and frequency. However, they did not propose an explicit description targeted at the quantitative relationship between the riparian vegetation species and flood frequency.

3. PROCESS AND METHOD

3.1 Researching Process

This research proceeds with an analysis of the flood frequency to calculate each return-period flood. Measured river submerged width and discharge data is used to compute an empirical formula parameter for the river to obtain a regressive discharge formula and the appropriate river width from various sampling sites. The flood discharge in each return-period is set into the river width.

A regression formula, from which the current width responding to the flood discharge in each return-period is then obtained. The relationship between the flood frequency and the riparian vegetation is determined using a field survey of the vegetation distribution. This shows the relationship between the width and the current width responding to the flood frequency. The Research Process Chart is shown in Fig. 1.

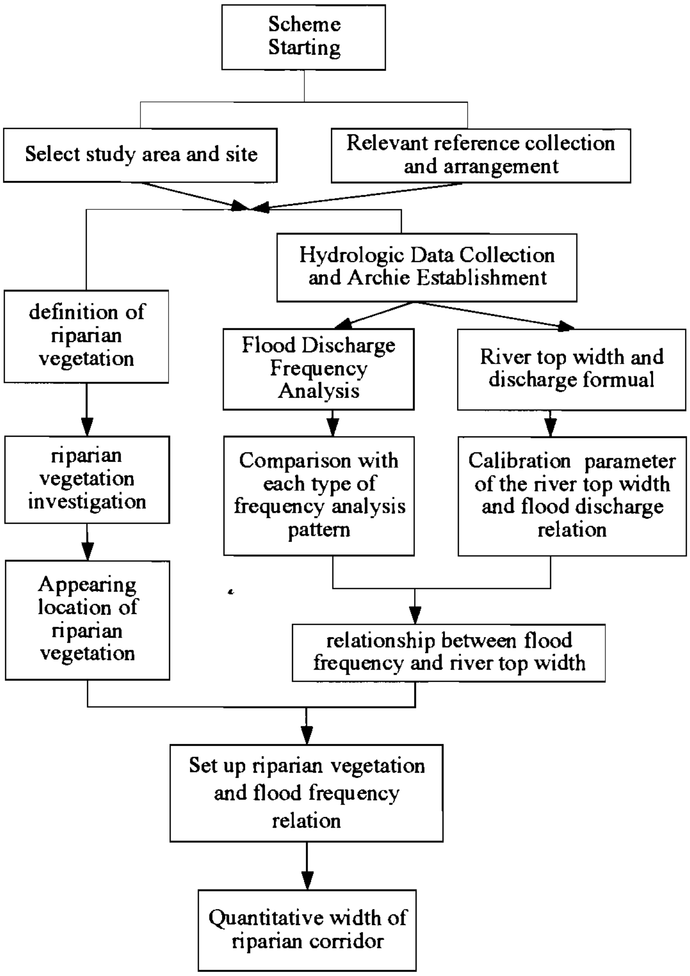


Fig. 1. Researching Process Chart

3.2 Study Area

Owing to the limited number of hydrometric stations, the attainable field investigation, and the suitability for stream morphology formula, this research selected four sites downstream from the four rivers. Sixteen cross sections were used for this investigation and analysis. The four rivers are the Chi San River, Laow Non River, Tzi Liaw River, and Yen Shui River. The four sites located downstream of each river in Southern Taiwan were the San Lin Bridge, Liou Kuei, Zho Tzan, and the Sin Si. After a cross section was randomly selected from each site, another 1~2 sections were selected at a distance of 100m away upstream and downstream as the researching object.

The traits, appearances, and structures of the vegetation community are the response to the characteristics of each habitats. The composition and structure of the plant community is closely associated with its environmental condition. Climate is an important factor the affects the plant community distribution in Taiwan. Temperature and the moisture and coordinate status of are especially important (Ming-Zou Lai; 1999). This research is grounded on the data listed in the Demarcating Sheet of Geographic Climate in Taiwan [published by Su (1985)]. This research selected the San Lin Bridge, Liou Kuei, Zho Tzan, and the Sin Si hydrometric stations, all classified as summer rain climate, for this study. The rainfall occurs primarily in May ~ Sep. making up 80% of the rainfall for the year. This rainfall source is primarily from Typhoons and the annual Plum-Rain Season. The climatical environment at these four sites is similar. The riparian vegetation distribution is only concerned with the periodic stream flood disturbance.

3.3 Researching Method

3.3.1 Establishing a relationship between the river top width and discharge

For a riverbed and riverbank channel unconfined by laccoliths or dikes, or dikes far enough from the mainstream, the water conservation project often uses the relation between the river width and the discharge as follows:

$$B_T = \alpha * \sqrt{Q_T}$$

(1)

where B_T is the river width for T years of the return period; Q_T is the discharge of T years of the return period; α is unsettled coefficient.

This study used the Durbin-Watson statistic to test the regression equation to determine if any correlation in residual error exists for enhancing the estimated accuracy. The NH is the residual error that has no apparent relevance. The Durbin-Watson statistic is shown as follows:

$$DW = \frac{\sum_{i=2}^{n} (e_i - e_{i-1})^2}{\sum_{i=1}^{n} e_i^2}$$

(2)

where DW = Durbin-Watson statistic , e = Residual error

This research adopted the discharge and river width field-measurement data from the Department of Water Conservancy of the Ministry of Economic Affairs, 1997~2001 to proceed with a regression using the Durbin-Watson statistic. The unsettled coefficient α was estimated to conclude the relative river width and discharge formula collected from each station in the study area. The results are shown in Table 1. There is a rather high relevance (R^2 > 90%) between the field-measured data and the regression formula collected from the four sites. The relationship between the river top width and the flood discharge at each gaging stationgaging are shown.

Table 1. The Regressive Relation Formula of the River Top Width and Discharge at Each Station

Gaging station	Regression Equation	R-squared	F-statistic	Durbin-Watson statistic	Determined Result
San Lin Bridge,	$B = 1.2*\sqrt{Q}$	0.95	995.5	1.03	Reject NH
Liou Kuei	$B = 1.5*\sqrt{Q}$	0.96	930.7	1.47	Reject NH
Zho Tzan	$B = 1.9*\sqrt{Q}$	0.91	505.5	1.30	Reject NH
Sin Si	$B = 6.6*\sqrt{Q}$	0.91	1469	1.59	Reject NH

3.3.2 Frequency Analysis for Peak Discharge

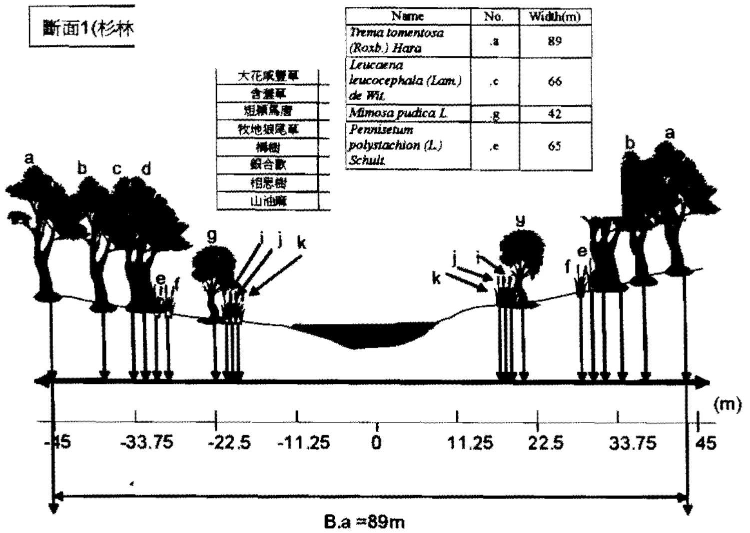
This study adopted the maximum instantaneous discharge data collected by the Department of Water Conservancy of the Ministry of Economic Affairs from 1987~2001 to calculate the flood frequency using four log-normal probability distributions, Pearson type III, log-Pearson type III, and extreme-type I. These methods are commonly used in hydrological engineering. The peak discharge data therein were taken from the annual maximum series to coordinate with this research, discriminating the riparian vegetation with living type such as annual herb, shrubs, and arborescent plant, etc. The general frequency analysis formula is shown as follows:

$$Q_T = \mu + K_T\sigma \tag{3}$$

where Q_T= T years return period for peak flow discharge, μ = peak flow data mean, σ = standard deviation, K_T = frequency factor. This data varied with the dissimilar selected probability distribution. The distribution type and calculation mode for the preceding four probabilities can be found in relevant hydrology references.

3.3.3 Field Survey

The vegetation field survey is comprised of the quantitative investigation and computation mode relating to the vegetation richness, density, coverage, and frequency, etc. The purpose of this research was to determine the correlation between the riparian vegetation and flood frequency. The vegetation survey, measurement and width records appeared for the first time from river center to river bank for each species of the vegetation. The plant definitions are shown in Fig.2. The width is an interval between the identical vegetation plants that appeared from one river bank to another, e.g. B.a is an interval between the "a" plants appearing on both banks.



Name	No.	Width(m)
Trema tomentosa (Roxb.) Hara	.a	89
Leucaena leucocephala (Lam.) de Wit.	.c	66
Mimosa pudica L.	.g	42
Pennisetum polystachion (L.) Schult.	.e	65

Fig. 2. Illustration of the Vegetation Survey
(Example of taking the San-Lin Bridge site cross section)

4. RESULT AND DISCUSSION

Integrating the analytical result for the flood discharge and river top width correlation and the peak discharge frequency; the relations for the discharge in return-period and relative river-width frequency could be obtained within the four probability distributions. Using the field investigation on vegetation, with the Q_T - B_T relation, the relationship between the riparian vegetation and frequency discharge was established.

4.1 Relationship between Q_T and B_T

Using the San Lin Bridge as a sample; the relative river width will be minimum in the Log-Normal distribution when the return period is less than 100 years. The Pearson type III will be minimum when it is more than 100 years (See Table 2). For each river width frequency, the maximum result is calculated with Type I Extreme Distribution. The maximum value for the river-widths at the other site shows similar results. However, no rules can be followed for the minimum value dispersed on the Log-Normal, Pearson Type III, and Log-Pearson Type III probability distributions. The probability distribution at each site has a mean and standard deviation for the frequency river width in various return-period as shown in Table 3.

Table 2. Statistic Table for the Frequency River (B_T) Width at the San Lin Bridge site (unit: m)

Return Period T	Types of Probability Distribution				Odds Value (m)	Odds Value (%)
	Log-Normal	Pearson type III	Log-Pearson type III	Extreme-Value type I		
1.1	25.4*	30.5	31	43.5**	18.1	53
2	49.1*	49.8	49.3	50.9**	1.8	4
2.33	51.7*	52.7	52.2	54.3**	2.6	5
5	62.4*	64	64	67.3**	4.9	8
10	70.7*	71.9	72.7	76.3**	5.6	8
20	78.4*	78.7	80.5	84**	5.6	7
50	88.1*	86.6	89.9	93.1**	5	6
100	95.2	91.9*	96.5	99.3**	7.4	8
200	102.2	97*	102.8	105.1**	8.1	8

Note: * signifies the minimum river width; ** means the maximum river width

Table 3. Statistical Table for the Frequency River Width (B_T) at Each Site (unit: m)

Return Period T	San Lin Bridge		Liow Kwei		Zho Tzan		Sin Si	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
1.1	32.6	7.7	35.2	10.0	35.6	4.9	92.6	15.4
2	49.8	0.8	58.7	2.2	45.7	0.5	128.9	5.0
2.33	52.7	1.1	63.2	2.8	47.2	0.5	133.7	4.9
5	64.4	2.1	81.7	4.1	53.1	0.4	149.9	1.8
10	72.9	2.4	95.7	3.9	57.1	0.8	160.0	5.4
20	80.4	2.6	108.4	3.6	60.6	1.4	168.2	10.9
50	89.4	2.8	121.7	2.7	64.6	2.2	177.8	17.9
100	95.7	3.1	135.9	6.4	67.3	2.9	184.5	22.8

Table 3 shows that the average river width will increase with the increase in return period because the discharge increases with the return period. This is a reasonable phenomenon. The standard deviation is maintained less than 6 m except for 1.1 years of the return period at the Sin Si Site. The reason why is due to floodplain asymmetry on both banks of the Sin Si Site. Adopting the analytical data from the discharge frequency as the annual maximum series, results in a higher error when the return period is 1.1 years.

4.2 The Relationship between Riparian Vegetation and Flood Return Period

This study cites the result with the preceding calculated frequency river top width (B_T), and coordinates with the field investigation to set up the appearing location of various riparian vegetation with probability distribution in each site. Table 4 shows analytical result using partial data from cross section 1 of the San Lin Bridge site. From this we may know that the plant locations with Extreme-Value type I distribution is lower than the other distributions for identical plants, responding to the maximum frequency river top width of Extreme-Value type I distribution.

The vegetation survey on-site demonstrated that the plants are have 29 families, total 72 species of plants, 1 family of Pteridophyte (ferns) with one category of plants, 3 families of monocotyledon with 20 categories of plants; 25 families of dicotyledon with 51 categories of plants. The primary annual herbs are the *Ludwigia octovalvis* (Jacq.) Raven, *Ammannia baccifera* L, Aster *subulatus Michaux*, and *Crassocephalum crepidioides* (Bemth.) S. Moore. The perennial herbs are mainly the *Bidens pilosa* L. var. radiata Sch-Bip, *Paspalum conjugatum* Berg. , *Pennisetum polystachion* (L.) Schult, *Saccharum spontaneum* L. , and *Pennisetum purpureum* Schumach. The shrubs are principally the *Mimosa pudica* L and *Pluchea carolinensis* (Jacq.) G Don. The arborescent plants are mainly the *Trema tomentosa* (Roxb.) Hara, *Trema orientalis* (L.) Blume, *Acacia auriculiformis* A. Cunn. ex Benth. , and *Leucaena leucocephala* (Lam.) de Wit. The cross section data is shown in Table 4. The statistic software R was used to analyze the relationship between the life-form and frequency and mapping a strip-plot using four-probability distributions to explore the relationship between the return period and vegetation. The results are shown in Figs. 3~6.

Table 4 The relationship between riparian vegetation and flood frequency.
(Taking Partial Data of the cross section 1 at San Lin Bridge site as an Example)

Family name	Life-form	Location (m)	Scientific name	Dist. 1	Dist. 2	Dist. 3	Dist. 4
Onagraceae	Annual herb	40	*Ludwigia octovalvis (Jacq.) Raven*	2	2	2	1.1
Poaceae	Perennial herb	40.5	*Saccharum spontaneum L.*	2	2	2	1.1
Asteraceae	Perennial herb	41	*Bidens pilosa L. var. radiata Sch.-Bip*	2	2	2	1.1
Fabaceae	shrub	42	*Mimosa pudica L.*	2	2	2	1.1
Poaceae	Annual herb	60	*Digitaria setigera Roem. & Schult.*	5	5	5	5
Poaceae	Perennial herb	65	*Pennisetum polystachion (L.) Schult*	10	10	10	5
Moraceae	arborescent plant	66	*Broussonetia papyrifera (L.) L'Herit. ex Vent.*	10	10	10	5
Fabaceae	shrub	66	*Leucaena leucocephala (Lam.) de Wit.*	10	10	10	5
Fabaceae	arborescent plant	73.3	*Acacia auriculiformis A. Cunn. ex Benth.*	20	20	20	10
Ulmaceae	arborescent plant	89	*Trema tomentosa (Roxb.) Hara*	100	100	50	50

Note: Dist. 1 : Log-Normal dist., Dist. 2 : Pearson type III, Dist. 3 : Log-Pearson type III, Dist. 4 : Extreme-Value type I

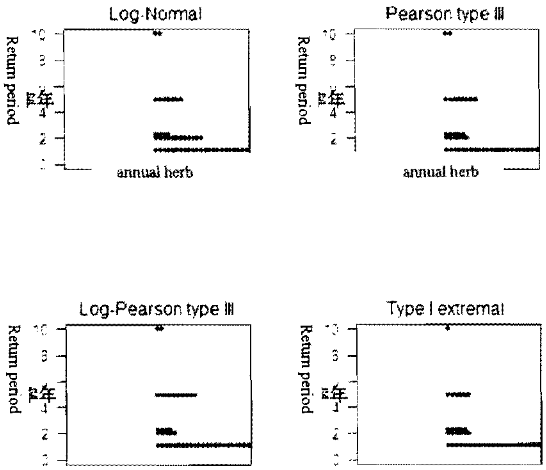


Fig. 3 The relationship between annual herb and flood frequency

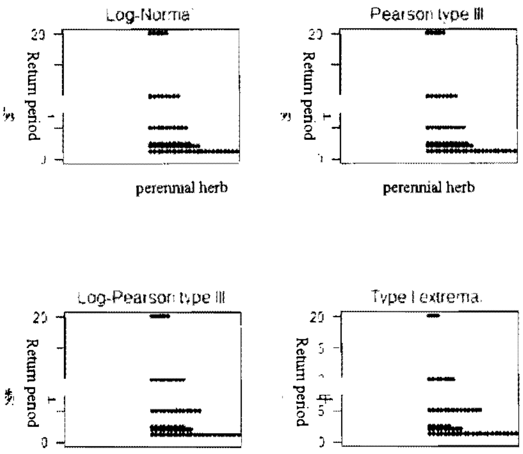
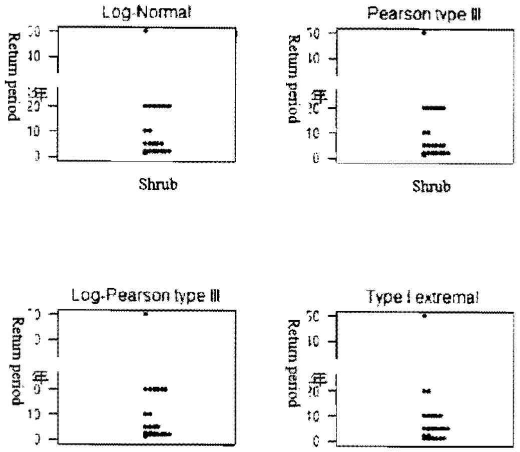


Fig. 4 The relationship between perennial herb and flood frequency



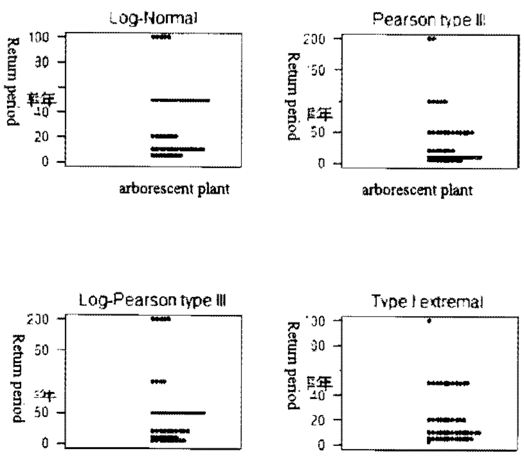


Fig. 5 The relationship between shrub and flood frequency .

Fig. 6 The relationship between arborescent plant and flood frequency

The Fig. 3 shows that corresponding to the return period, the annual herbs first appear (from mainstream to riverbank) centralized *within 1.1~5 years of the flood return period.* Only a few of 1-2 species appear at the site location when the flood return period is 10 years. This means that under the interference of periodic floods, the plants appear often at the riverside where the discharge is mild, but persistently interfered by floods. These plants are the pioneers at the riverside, growing mostly from the mainstream to the floodplain.

The frequency distribution Fig. 4 for the perennial herbs is similar to Fig. 3. The perennial herbs first appear in the duration of 1.1~10 years of the flood return period. These plants appear at 20 years in the return period. Figure. 5 shows that shrub riparian vegetation do not have the herb tendency to centralize in low flood return period. Instead, it is evenly distributed under 20 years of the return period, mostly intervened between 2.33~20 years. These plants appear at an ultimate 50 years of the return period.

Figure. 6 indicates that flood return period for arborescent plant is distributed over a larger range, which is from 5 to 200 years. These plants appear at 100~200 years from the return period. Mostly intervening between 5~50 years. Because of the low flood's interference return period and a high impact on the river environment (heavy discharge, fast velocity, strong shear stress, and huge riverbed variation), the arborescent plants can only exist at the riverbank. The relationship between the riparian vegetation and the flood return period is shown in Table 5, which displays the riparian vegetation distribution from the mainstream to the riverbank. The sequence is annual herbs, perennial herbs, shrubs, and arborescent plant; and ranges of flood return period are respectively 1.1~5 years, 1.1~10 years, 2.33~20 years, and 5~50 years.

Table 5. Relationship between Riparian Vegetation and Flood Return Period

Life-form of Vegetation	Flood Return Period (Year)	Ultimate period individual (Year)	return for Mean plant (Year)	Standard Deviation
Annual Herbs	1.1 ~ 5	10	1.8	1.2
Perennial Herbs	1.1 ~ 10	20	3.3	3.3
Shrubs	2.33 ~ 20	50	7.5	6.9
arborescent plant	5 ~ 50	100-200	23.2	18.7

5. CONCLUSION

1. This study combined flood frequency analysis in hydrology with vegetation community viewpoint in botany to provide a technique to delimit the riparian vegetation buffer strip in restoring a river environment. The flood frequency estimate was targeted using four log-normal probability distributions, Pearson type III, log-Pearson III, and extreme-value type I, coordinated with field-measured river width sites and flood discharge records to determine the relationship between the discharge and river top width at each site. Field-measured vegetation data, preceding the flood frequency analysis, and its corresponding river top width for the return period were used to obtain the quantitative relationship between the riparian vegetation and flood return period.

2. The relationship between the flood return period and riparian vegetation downstream from four rivers in Southern of Taiwan is annual plants, perennial plants, shrubs, and arborescent plants dominant riverbank with the flood return period 1.1 ~ 5 years, 1.1 ~ 10 years, 2.33 ~20 years, and 5 ~ 50 years, respectively.

3. Because a quantitative relationship exists between the riparian vegetation and flood return period, the riparian vegetation can be used as an index for the flood return period. The index plants for 1.1~5 years, 1.1~10 years, 2.33~20 years, and 5~50 years on downstream of the four rivers in the South of Taiwan are, through analysis, respectively the *Ludwigia octovalvis (Jacq.) Raven, Crassocephalum, Bidens pilosa L. var. radiata Sch. Bip. crepidioides (Bemth.) S. Moore, Pennisetum polystachion (L.) Schult, Mimosa pudica L.* , *Leucaena leucocephala (Lam.) de Wit.* , and *Trema tomentosa (Roxb.) Hara*

4. Riversides require multiple-layer vegetation diversification to create a sound

stream ecosystem. Therefore, under the land-use, water-use and riparian stream ecosystem viewpoints, the embankment width must be satisfied with the necessities for herbs, shrubs, and arborescent plants. This provides an environment with periodical flood interference. The embankment width of the sites at San Lin Bridge, Lio Kwei, Zho Tzan, and Sin Si, must satisfy the river width with 50 years of flood return period. This means 89 (standard deviation 2.8), 122 (standard deviation 2.7), 65 (standard 2.2), and 178 (standard deviation 17.9) meters.

REFERENCES

Budd, W. W. , Cohen, P. L. , Saunders, P. R. and Steiner, F. R. , (1987) "Stream corridor management in the Pacific Northwest-management strategies. " Environmental Management, 11, 592-605.

Carothers, S. W. , R.R. Johnson, and S. W. Aitchison. (1974) " Population structure and social organization of southwestern riparian birds ". American Zoology 14: 97-108.

Chen,Hsin-Hsiung, Chen,Ming-Jei (1989) "Studies on the Evaluation of Flood Control and Water Resources Conservation Utility by Forest. " Journal of the experimental forest of National Taiwan University, 3(1): 95-102. Published by the experimental forest of National Taiwan University. (in Chinese)

ELIZABETH M. STRANGE,KURT D. FAUSCH, ALAN P. COVICH. (1999) " Sustaining Ecosystem Services in Human-Dominated Watersheds: Biohydrology and Ecosystem Processes in the South Platte River Basin. " Environmental Management. 24:1, 39–54

Francisco Zamora-Arroyo, Pamela L. Nagler, Mark Briggs A, Dean Radtke B, Hugo Rodriquez B, Jaqueline Garcia B, Carlos Valdes, Alfredo Huete, Edward P. Glenn B . (2001) "Regeneration of native trees in response to flood releases from the United States into the delta of the Colorado River, Mexico." Journal of Arid Environments 49: 49-64

Fredrickson, L. H. (1978) "Lowland hardwood wetlands: current status and habitat values for wildlife. " In Wetland functions and values: the state of our understanding, ed. P. E. Greeson, V. R. Clark, and J. E. Clark. American Water Resources Association, Minneapolis, Minnesota.

Jeglum, J. K (1975) "Classification of swamp for forestry problems. " In: Fraser, J. W. ; Jeglum, J. K. ; Ketcheson, D. E. ; [and others], technical coordinators. Black pruce symposium: Proceedings of a symposium; 1975 September 23-25; Thunder Bay, ON. Symposium Proceedings 0-P-4. Sault Ste. Marie, ON: Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre: 227-241.

Ming-Zou Lai,(1999), "The demarcation of vegetation band in Taiwan." Biodiversity conference 1999. (in Chinese)

Morris, L. A. , A. V. Mollitor, K. J. Johnson, and A. L. Leaf. (1978) "Forest management of floodplain sites in the northeastern United States. " In Strategies for protection and management of floodplain wetlands and other riparian ecosystems, ed. R. R. Johnson, and J. F. McCormick, 236-242. USDA Forest Service General Technical Report WO-12. U. S. Department of Agriculture, Forest Service.

Nakamura, F. , Swanson, F. J. (1994) "Distribution of coarse woody debris in a mountain stream, western Cascade Range, Oregon. " Can. J. For. Res. 24, 2395–2403.

Nobuyuki TAMAI, Shigetoshi OKUDA and Shunroku NAKAMURA, (2000), " Assessing Riverine Environment for Habitat Suitability on the Basis of Natural Potential." University of Tokyo Press.(in Japanese)

Peterjohn, W. T. and Correll, D. L (1984) "Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. " Ecology. 65(5): 1466-1475.

Richard A. Marston et. al. (1995) "Channel metamorphosis, floodplain disturbance, and vegetation development: Ain River, France. " Geomorphology 13 : 121-131

Rood, S. B. , and J. M. Mahoney. (1990) "Collapse of riparian poplar forests downstream from dams in western prairies: probable causes and prospects for mitigation. " Environmental Management 14: 451-464.

Su, H. J. (1985) " Studies on the climate and vegetation types of the natural forests in Taiwan (III): a scheme of geographical climatic regions." Quarterly Journal of Chinese Forestry 18:3, 33-44

Suzuki (1992) "The type of disturbance and structure of riparian forest. " Agri., Foresty and Fish. Research Council, Japan. No. 6, 57-61. (in Japanese)

Swanson, F. J. , Janda, R. J. , Dunne, T. and Swanston, D. N. (eds.) (1982) "Sediment budgets and routing in forested drainage." USDA Forest Service General Tech. Rep. PNW-141.

Teskey, R. O. , and T. M. Hinckley. (1977) "Impact of water level changes on woody riparian and wetland communities ." vols. I, II, and III. FWS/ OBS-77/58, -77/59, and -77/60. U. S. Department of Agriculture, Fish and Wildlife Service.

Tzao-Yuan Lin .(1998). "A study on the width and placement of riparian vegetated buffer strips." Journal of Chinese Soil and Water Conservation. 29(3):261-272. (in Chinese)

United States Army Corps of Engineers (USACE). (1991). "Hydraulic design of flood control channels. " USACE Headquarters, EM1110-2-1601, Washington, DC.

Wang Shou-Min, (1991), "Plant resources and vegetation succession at Taichia Hai estuarine area. " National Chung-Hsing University Department of Plant. (in Chinese)

Wharton, C. H. , W. M. Kitchens, E. C. Pendleton, and T. W. Sipe. (1982) " The ecology of bottomland hardwood swamps of the Southeast: a community profile. " FWS/OBS-81/37. U. S. Fish and Wildlife Service, Biological Services Program, Washington, DC.