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CHANNEL GEOMETRY IN LOWER STREAM COURSES OF TANSHUI RIVER DRAINAGE SYSTEM (TAIWAN)

Abstract: TENG K-H., *Channel geometry in lower stream courses of Tanshui River drainage system (Taiwan)* (ISSN 0084-8948, 1989).

This study uses air photo maps on the scale of 1:5000 published in 1984 and channel geometry data measured from 1970 to 1985 to analyze the channel forms and dimensions in the lower courses of the Thanshui River drainage system.

The study shows that channel gradient is not one of the dominant factors which influence channel sinuosity. The channel gradient is in low negative relationship with sinuosity. The smaller the gradient is, the more the sinuosity becomes, It is found that meander wavelength (L) and bend amplitude (A) are related to channel width (W) and their regression equations are $L = 2W^{1.254}$and $W = 0.298 + 0.172A$, respectively. The channel width of the reach not controlled by hard rock and with less sinuosity normally gets wider downstream. As a result, the channel width got narrower and the channel depth became deeper during the past 15 years, after stored by dams and quarried on chennel beds. At present, the deepened rate on stream beds has reached 20 cm per year in the Tuyng and the Tachi reaches of the Tahan River as well as in the Taipei reach of Thanshui River. The ratio of width to depth is higher in the braided channel but lower in the meandering reach. The maximum ratio is above 500 and the minimum is below 20 in the study area. Usually, cross section areas are supposed to be controlled mainly by flowing discharge, but in this study they are obviously influenced by quarrying bed loads in many reaches. The variation of section asymmetry, positive or negative skewness, is well concordant with meander bend direction and is influenced by the tributary junction. On the whole, section asymmetry is related to bend amplitude. The bend amplitude with a wider rank gets a larger skewness in section asymmetry.

KEY WORDS: Channel Geometry, Sinuosity, Asymmetry, Tanshui R., Taiwan.

Riassunto: TENG K-H., *Geometria delle aste fluviali nel basso corso del Tanshui (Taiwan).* (ISSN 0084-8948, 1989).

La forma e le dimensioni delle aste fluviali del sistema del basso corso del Fiume Tanshui sono state analizzate mediante fotointerpretazione alla scala 1:5000 del 1984 e i valori geometrici misurati fra il 1970 e 1985. Lo studio dimostra che il gradiente di pendio non è uno dei fattori che influenzano in maniera dominante la sinuosità dei canali, anzi al diminuire del gradiente aumenta la sinuosità. È stato trovato che la lunghezza dei meandri (L) e la curvatura (A) sono legate all'ampiezza (W) dei canali e le equazioni di regressione sono rispettivamente $L = 2W^{1.254}$ e $W = 0{,}298 + 0{,}172$ A. L'ampiezza dei canali dei rami fluviali non controllati da rocce dure e con minor sinuosità normalmente produce maggiori approfondimenti. È risultato che, in 15 anni, l'ampiezza dei canali è divenuta minore e la profondità maggiore, dopo lo sbarramento del fiume Tanshui ad opere di dighe e l'escavazione di inerti dagli alvei. Attualmente, l'approfondimento ha raggiunto l'entità di 20/cm anno nei rami del Tuyin e Tachi del Fiume Tahan, così come nel ramo Taipei del Fiume Tanshui. Il valore dell'ampiezza è maggiore nei canali anastomizzati rispetto a quelli dei meandri liberi. Il valore massimo è superiore a 500, il minimo anche inferiore a 20.

Usualmente, le sezioni trasversali si suppongono controllate principalmente dal deflusso, ma in questo caso esse sono senza dubbio influenzate, in molti rami, dalle escavazioni in alveo. La variazione della asimmetria delle sezioni ben concorda con la direzione di propagazione della curva dei meandri ed è influenzata dall'affluenza di canali tributari. In sostanza, l'asimmetria della sezione è legata all'ampiezza della curvatura, una curvatura di ordine superiore produce una maggiore skewness nella asimmetria.

TERMINI CHIAVE: Geometria dei canali, Sinuosità, Asimmetria, Fiume Tanshui, Taiwan.

INTRODUCTION

The Tanshui River is the longest stream in northern Taiwan, which is conjoined by three major tributaries: the Tahan River, the Hsintien River and the Keelung River (fig. 1). The length of the main river is 158.7 km and its drainage area extents to 2726 km^2. The study area only includes the lower stream courses of the Tanshui River system. For comparison study, these courses were divided into nine reaches according to stream flow pattern, channel gradient and bed loads characteristics. The reaches are as follows: (1) Tanshui Outlet Reach; (2) Taipei Meander Reach; (3) Hsingshu Convergent Reach; (4) Tuying Braided Reach; (5) Tachi Braided Reach; (6) Bangho Meander Reach; (7) Chingsin Braided Reach; (8) Shetzu Meander Reach; (9) Hsihu Meander Reach (fig. 2).

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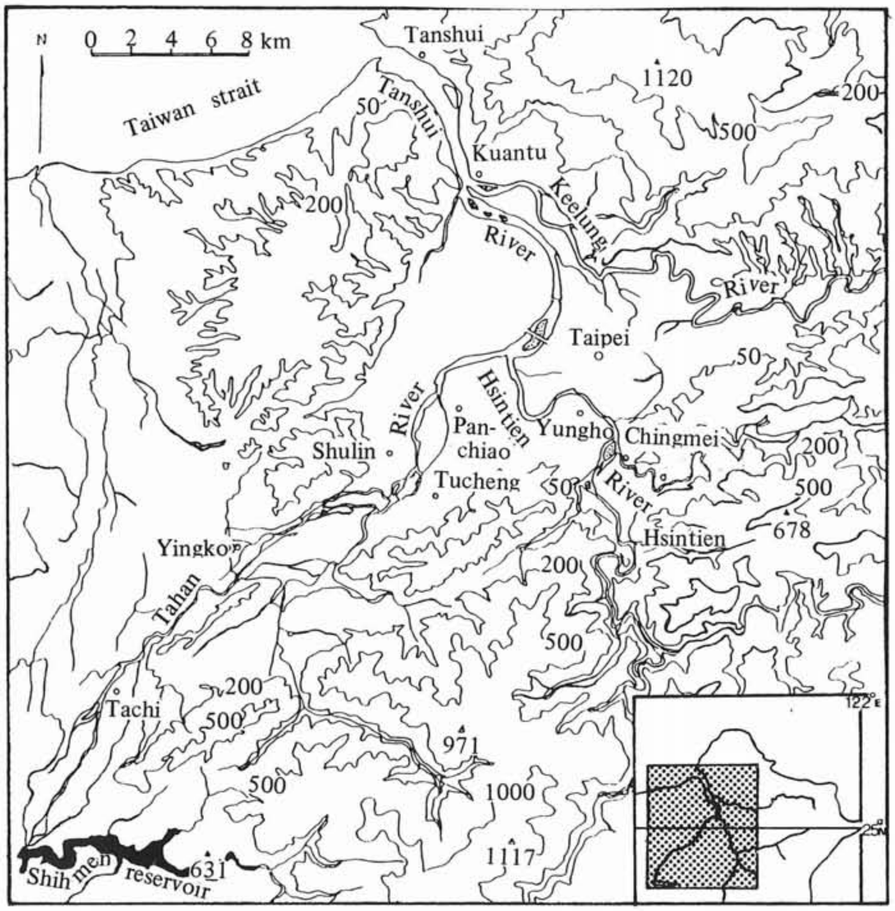


FIG. 1 - Topographical map of the Lower Tanshui River system.

Channel migration, bed gradient, channel synuosity, braided index and grain size of bed loads etc. in the lower stream courses of the Tanshui River drainage system during recent years has been discussed by other papers (TENG, 1986, 1987). This study will focus on channel geometry and analyze the azimuth of stream flow, meander bend amplitude, channel width and depth, cross-section area and its asymmetry. The study methods in this paper are as follows:

1. Measure the azimuth at the middle streamline each 250 m on the channel map in scale of 1:50,000 which is contracted from airphoto maps in scale of 1:5,000.
2. Measure axial and arc wavelenght, and radius of curvature according to inflection point of channel to calculate synuosity and bend amplitude.
3. Use cross-section data surveyed by the Water Conservancy Bureau drawing section profiles to measure section areas, maximum width and mean depth at bankfull stage.
4. Measure the right and left section areas (Ar, Al) divided by a middle line in a cross section (A) to calculate section asymmetry by the equation Ar-Al/A. The positive value of asymmetry means section skewness declining to right bank and the negative one is on the contrary.

CHANNEL AZIMUTH AND BEND AMPLITUDE

The channel azimuthes of the lower stream courses of Hsintien River and the Tanshui River are mainly north to northwestward (fig. 3). They are consequent streams developed along the great slope surface perpendicular to the strike of geologic structure in north Taiwan. When channels are flowing on the alluvium of the Taipei Basin, meandering channels could be freely migrated. If the channels pass by or cut through the surrounding hills of Taipei Basin, channel position and flowing direction were influenced by lithologic structure. for example, the channel direction of Hsintien River from section 18 to 20 is concordant with the attitude of exposed rocks; a water gap in the Tanshui River is found by cutting through a lava flow at Kuantu, and the slight curved channel of the Tanshui Outlet Reach which bends to north is almost the results of compressing by the Kuanying volcanic cone.

The channel azimuthes of the Tahan River are mostly northeasternward and that of the Keelung River are westward dominately. The Tahan River is well-braided and less curved. Channel azimuthes are concentrated between 0° and 80°, but the lower stream course of the Keelung River is well meandering and contains a wider rank of azimuths. The channel direction of the Tachi Braided Reach is formed

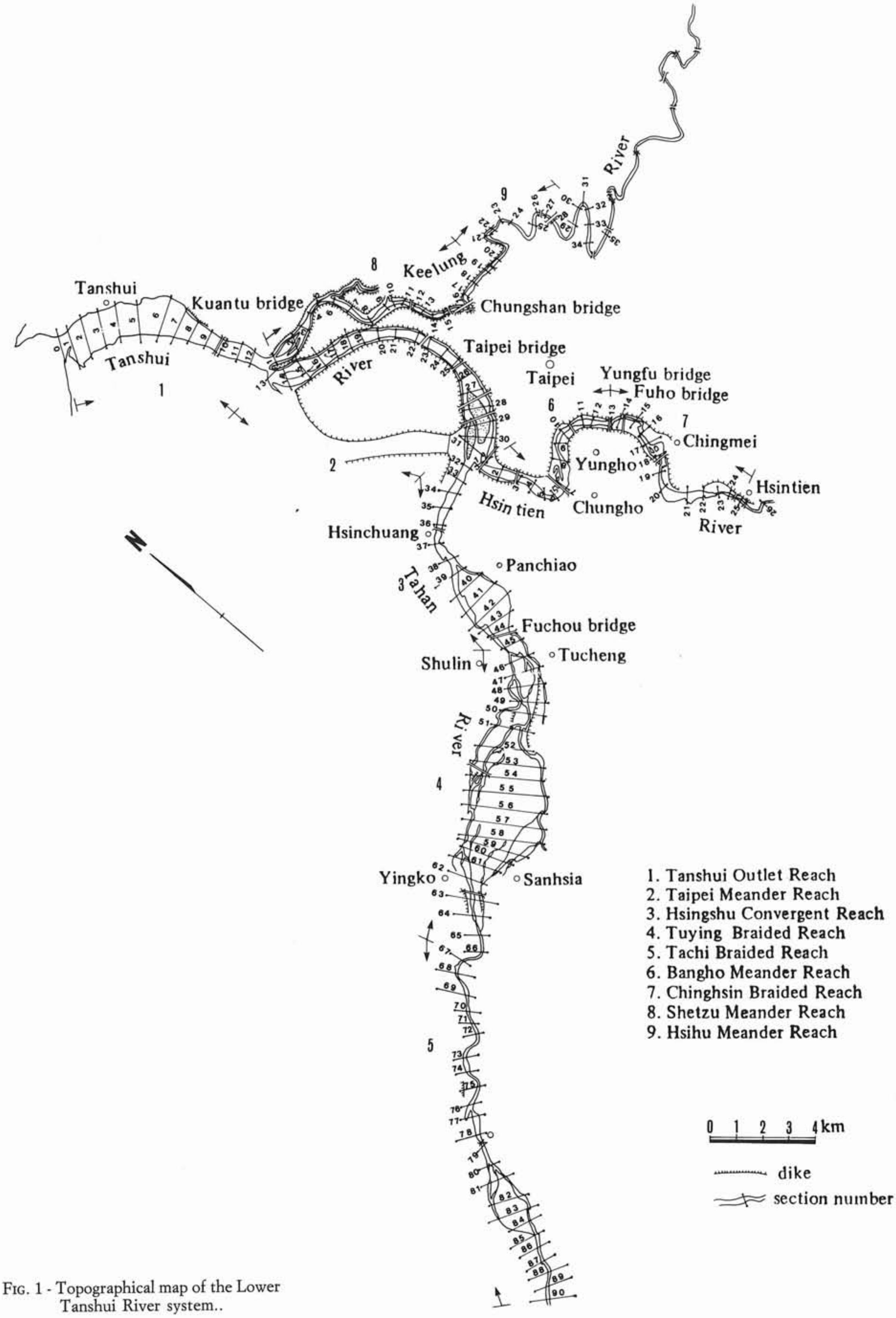


FIG. 1 - Topographical map of the Lower Tanshui River system..

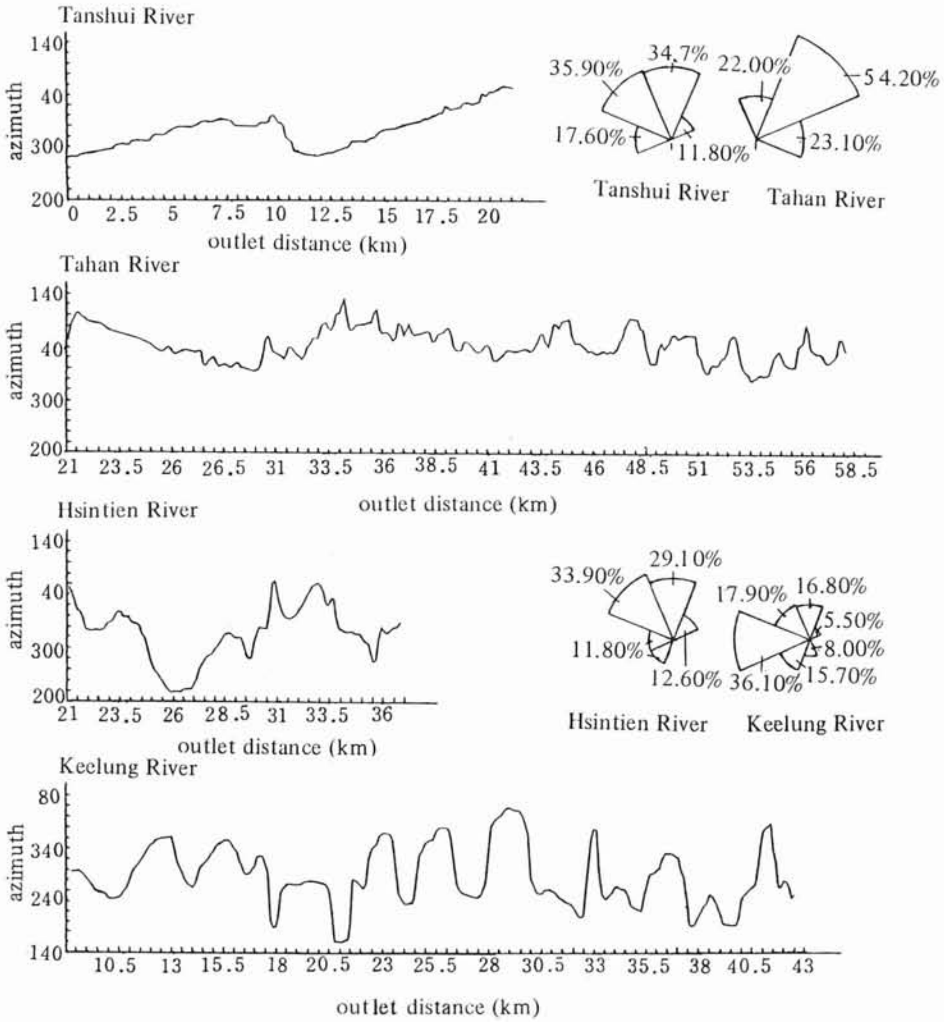


FIG. 3 - Azimuth of channel in the lower Tanshui River system.

TABLE 1. Channel geometry in the lower Tanshui River system

Table 1. Channel geometry in the lower stream courses of Tanshui River system

unit : km

river	Tanshui River		Tahan River			Hsintien River		Keelung River		P.S.
channel reach	1	2	3	4	5	6	7	8	9	1. Tanshui Outlet Reach
meander radius (rc)	0.73	1.53	1.55	1.10	0.29	0.94	0.90	0.38	0.46	2. Taipei Meander Reach 3. Hsingshu Convergent Reach
bend amplitude (A)	1.45	3.05	3.10	2.20	0.57	1.88	1.80	0.77	0.96	4. Tuying Braided Reach
axial wavelength (L)	11.35	10.00	11.80	10.60	2.93	3.73	4.90	2.91	1.77	5. Tachi Braided Reach 6. Bangho Meander Reach
arc wavelength (λ)	12.62	12.75	14.00	12.20	3.28	5.40	6.33	3.52	3.17	7. Chinghsin Braided Reach
synuosity (P)	1.10	1.27	1.18	1.15	1.12	1.45	1.29	1.22	1.84	8. Shetzu Meander Reach
outlet distance (D)	7.88	13.12	28.96	36.46	56.08	26.58	32.57	20.35	45.85	9. Hsihu Meander Reach
width (W)	1.01	0.78	0.81	0.78	0.52	0.49	0.52	0.29	0.19	
depth (d)	4.27	5.47	3.89	4.63	2.46	4.82	6.73	3.70	4.46	unit : m
width : depth ratio	264	167	223	181	308	101	81	92	50	
section area	3127	4132	3125	3483	1677	2190	3410	942	746	unit : m²
section asymmetry	0.16	0.23	0.40	0.19	0.21	0.31	0.11	0.28	0.30	

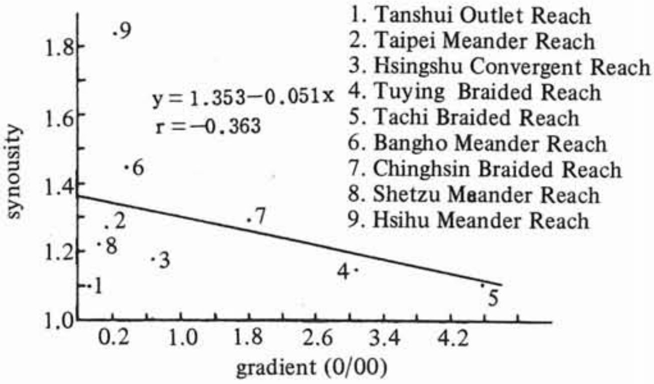


FIG. 4 - Relationship of synuosity to gradient in the lower Tanshui River system.

p.s. The numbers in folowing figures represent the same reaches as this figure.

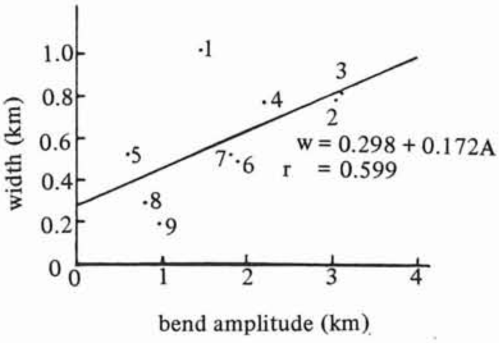


FIG. 6 - Relationship of width to bend amplitude in the lower Tanshui River system.

by rejuvenative erosion and conformed to the ancient channel developed on the Taoyuan Lateritic Terrace surface. As to the channels at the Tuying Braided Reach and the Hsihu Meander Reach are subsequent streams that developed along the Taipei Fault valley. On the other hand, the channels of the Hsingshu Convergent Reach and the Shetzu Meander Reach are belong to insequent streams and exhibite the meandering stream pattern.

Among the four lower streams of the Tanshui River System, the value of channel sinuosity of the Keelung River (1.65) and the Shientien River (1.37) are both higher than the meander threshold and both rivers bear meandering characteristics. However, those of the Tanshui River (1.19) and the Tahan River (1.13) are below the meander threshold and both have the characteristics of straight rivers (Table 1). The relationship between the channel sinuosity and the bed gradients is negative (fig. 4). Our results show discrepancies with those achieved by SCHUMM & KHAN (1967). Their results indicates that, when the gradients are between 0.2% and 1.2%, gradients are in direct proportion to the sinuosity values, and the rivers bear the meandering characteristic. However, in the lower streams of the Tanshui River System the relationship between these two variables is inverse. When the gradients are between 0.1% and 0.5%, the channels bear the braided pattern. In addition, when the slope is slight, the variation of channel sinuosity is still great. It is, then, obvious that there are some other factors that influence the variation of channel sinuosity, such as load, discharge, and bank resistance.

With regard to meandering wavelenght, the average value for the whole river system is 4.20 km. The distribution is the Tanshui River 10.68 km, the Tahan River 5.29 km, the Shientien River 4.20 km and the Keelung River 2.11 km. The distribution is just inverse to that of the channel sinuosity, the smaller the wavelenght. According to ZELLER (1967), the relationship between the meandering wavelenght (L) and the channel width (W) is $L = 10W^{1.03}$. But our results show the relationship is $L = 2W^{1.254}$ (fig. 5).

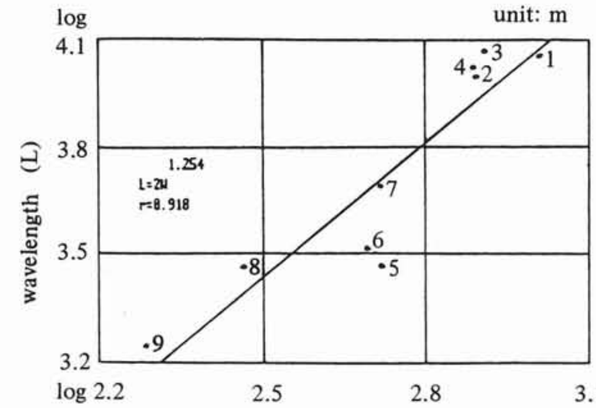


FIG. 5 - Relationship of wavelenght to width in the lower Tanshui River system.

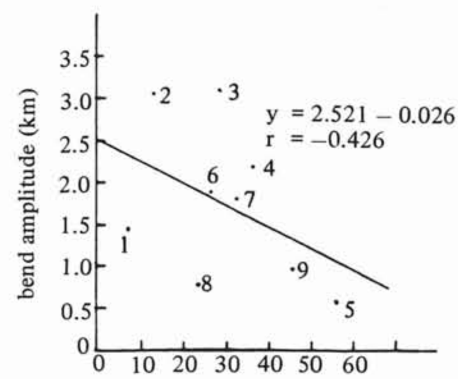


FIG. 7 - Relationship of bend amplitude to outlet distance in the lower Tanshui River system.

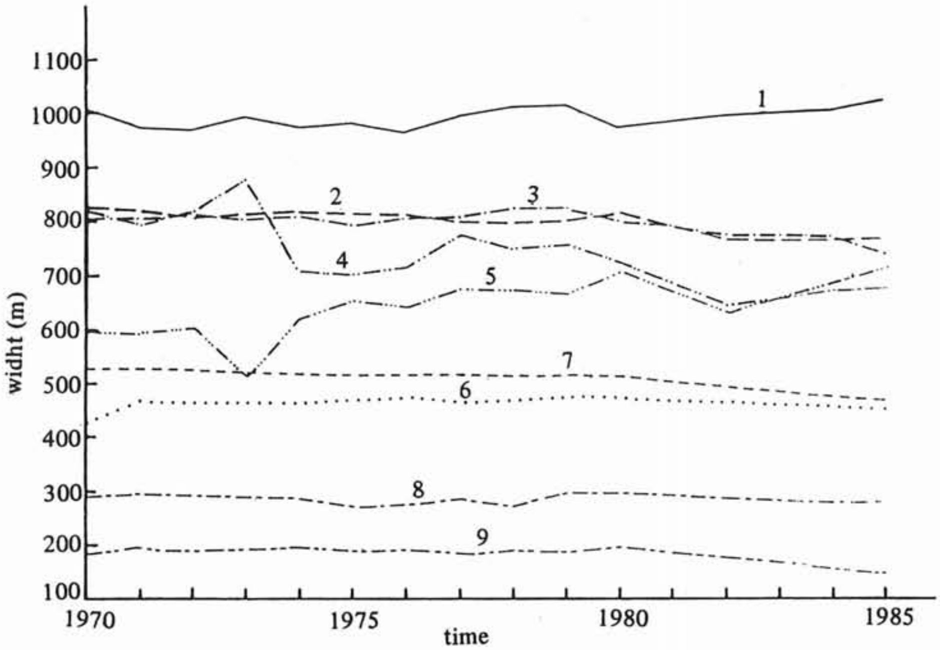


FIG. 8 - Mean width variation in the lower Tanshui River system during 1970-1985.
1. Tanshui Outlet Reach
2. Taipei Meander Reach
3. Hsingshu Convergent Reach
4. Tuying Braided Reach
5. Tachi Braided Reach
6. Bangho Meander Reach
7. Chinghsin Braided Reach
8. Shetzu Meander Reach
9. Hsihu Meander Reach

(p.s. The numbers in following figures represent the same reaches as this figure).

The mean bend amplitudes are 2.25 km for the Tanshui River, 1.84 km for the Shintien River, 1.16 km for the Tahan River and 0.90 km for the Keelung River. The relationship between the mean bend amplitudes (A) and the channel width (W) is positive and their regression equation is W = 0.298 + 0.172A (fig. 6). Though the relationship between the mean bend amplitudes and the average distance to the river mouth is not clearly observed, the mean bend amplitudes seem to get smaller in the upper streams (fig. 7).

CHANNEL WIDTH AND DEPTH (Fig. 8, 9, 10, 11, 12, 13)

The average channel widths are 879 m in the Tanshui River, 716 m in the Tahan River, 488 m in the Hsintien River and 243 m in the Keelung River. Since 1970, channel width of the Tachi Braided Reach affected by quarrying on banks, sediment delivery decreased by dam and banks erosion by flood released from the dam, has appeared wider and wider. But the other reaches of the Lower Tanshui

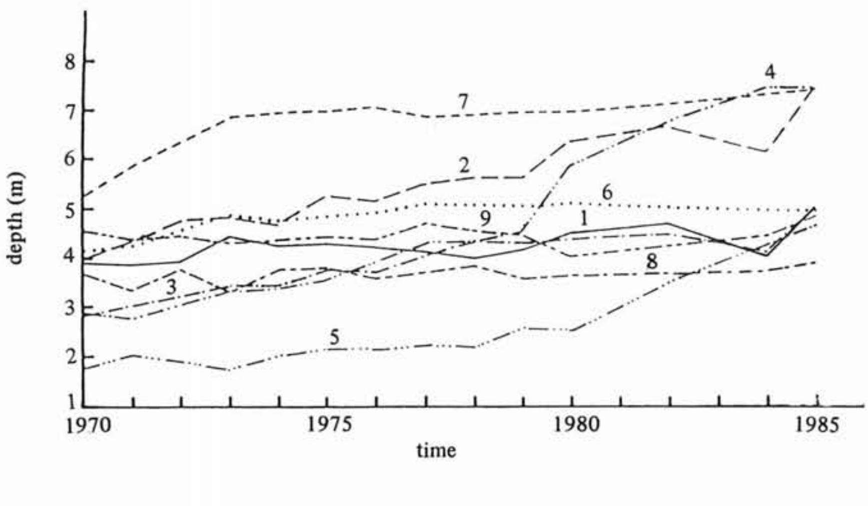
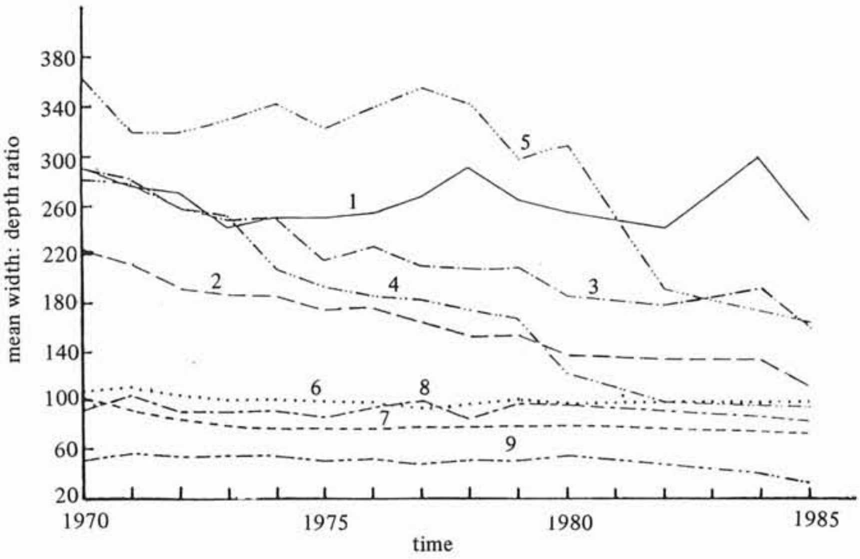


FIG. 9 - Mean depth variation in the lower Tanshui River system during 1970-1985.

Fig. 10 - Mean width; depth ratio in the lower Tanshui River system during 1970-1985.



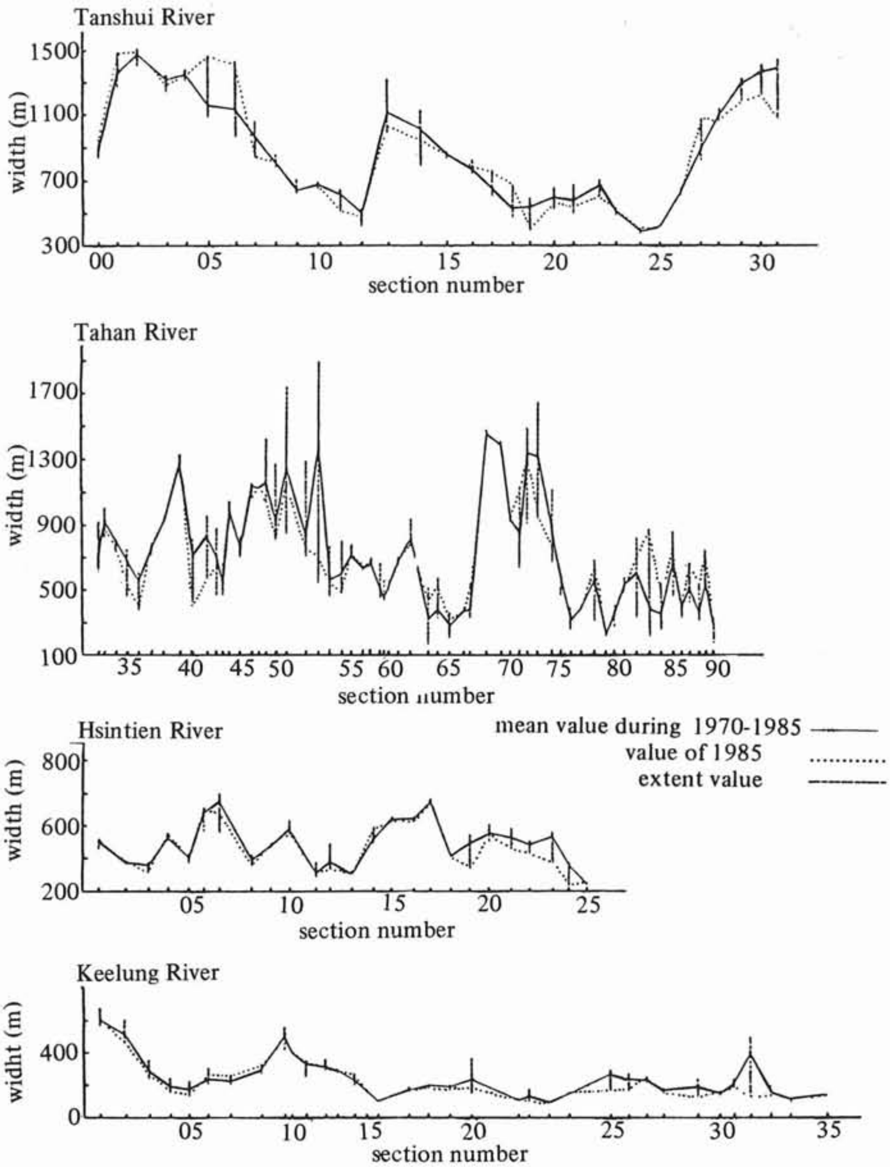


Fig. 11 - Width variation in each section in the lower Tanshui River system during 1970-1985.

River system turned narrower because of (1) decreasing discharge by damming, irrigation, and urban water supply, (2) lessening bank erosion by dikes and embankments, (3) deepenning channels by quarrying, (4) dumping garbage along the banks. Generally speaking, in reaches with hard rock control and with less channel sinuosity, channel width tend to become greater down streams, such as the Tanshui Outlet Reach and Tachi Braided Reach. Yet, river widths may become smaller subject to geological structures and artificial constructions. In terms of geological structures, the Kuantu Gap of the Tashui River and the reach north to Yuansan of the Keelung River (section 16) are all confined and become narrower because there are hills closed to the banks. With regard to artificial constructions, the Tanshui River between the Taipei City and Sanchung and the Hsintien River between the Taipei City and Yungho also become narrower because of the construction of bridges and dikes. Generally, rivers become wider

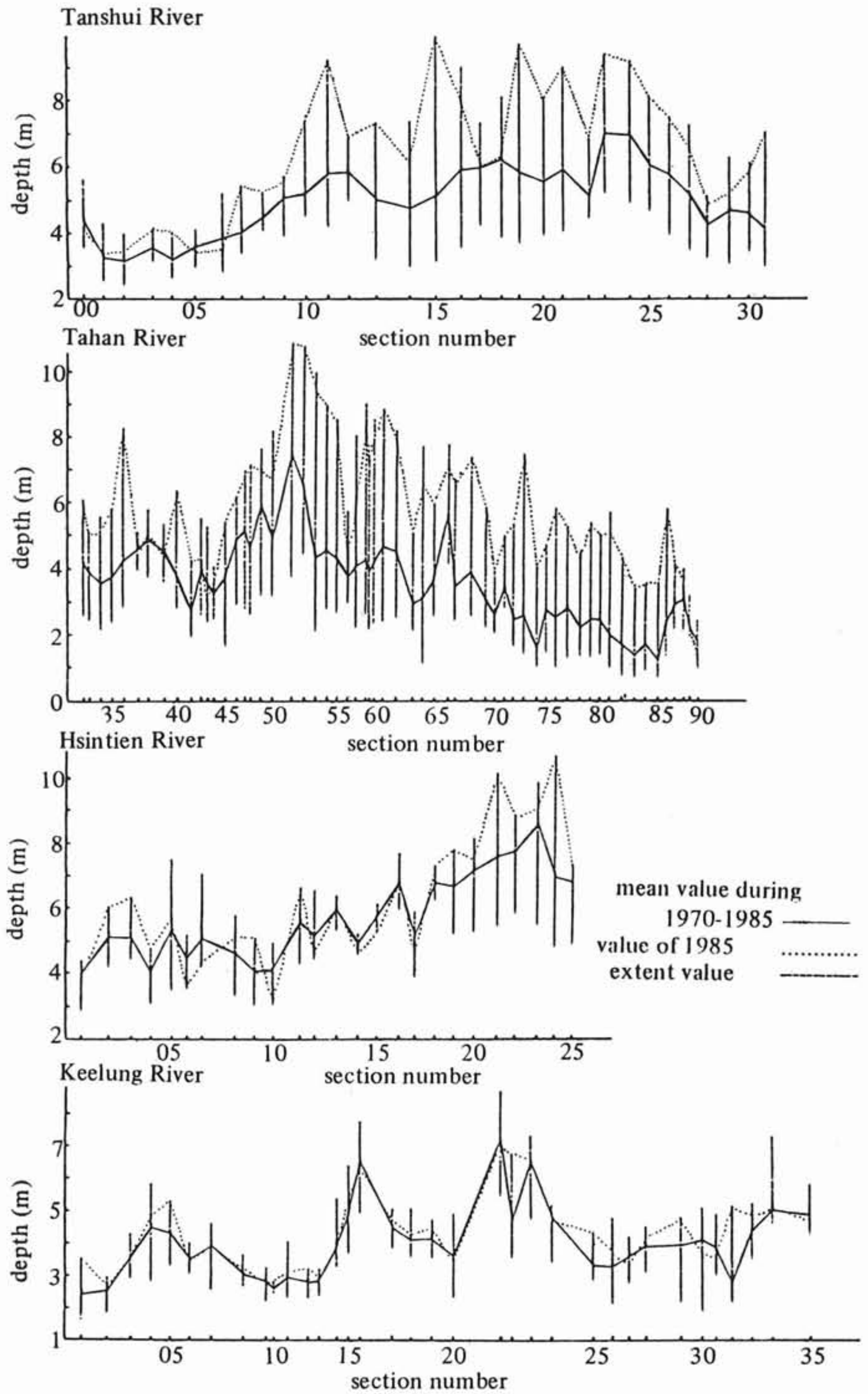


FIG. 12 - Mean depth variation in each section in the lower Tanshui River system during 1970-1985.

in tributary junctions and well-braided channels, such as the confluence of the Chingmei River and the Hsintien River, the Hsintien River and the Tahan River, as well as the Keelung River and the Tanshui River. But the channel widths of the Keelung River do not vary much either in the upper or the lower streams bacause of the intrenched meander channels.

The average depths of the lower streams of the Tanshui River system are 5.74 m in the Hsintien River, 4.98 m in the Tanshui River, 4.03 m in the Keelung River, and 3.57 m in the Tahan River. Among these four, the Keelung River is the only one that has the stable channel depths free of influence from quarrying and damming, but the other three are notably deepended. The distribution of the most deepened channels always accord with that of quarrying areas, such as the Tanshui River from section 12 to 26, the Tahan River from section 58 to 64 and 80 to 86, and the Hsintien River from section 19 to 25.

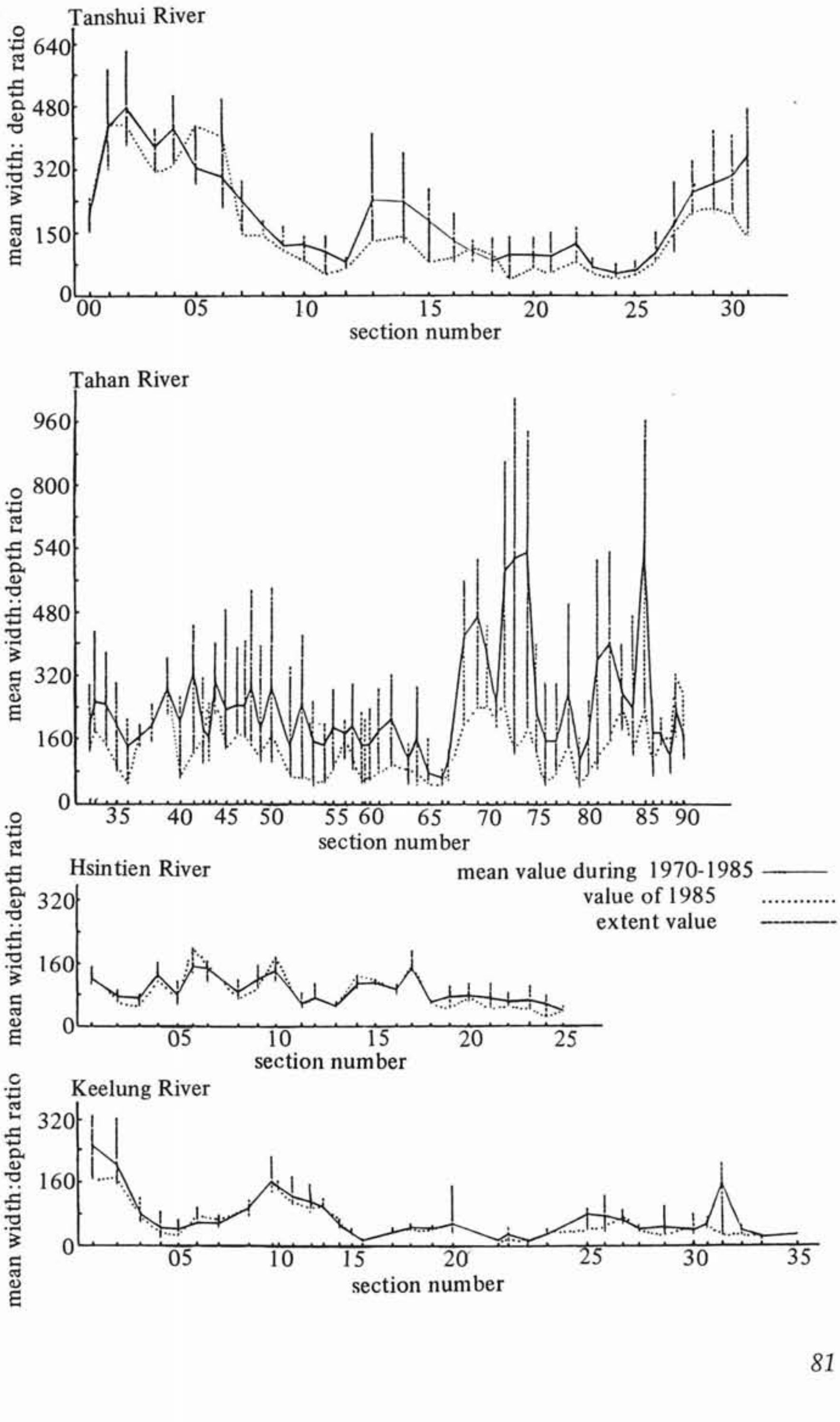


FIG. 13 - Mean width: depth ratio variation in each section in the lower Tanshui River system during 1970-1985.

In general, channel depths are in inverse proportion to channel widths. Well-meandering channels at bend crests and its successional parts are remarkably deepened due to concentrated currents. On the other hand, channels are shallow in tributary junctions, in front of water gap and river mouth due to heavy deposition on channel beds. The ratios of width to depth of the four rivers are 216 for the Tahan River, which is well-braided, 206 for the Tanshui River, 92 for the Hsintien River and 74 for the Keelung River, which is well-intrenched. Normally, the value of width is large and that of depth is small, so the width-depth ratio accords to that of the channel width. However, the width-depth ratios have become much smaller because the rivers are greatly deepened. Besides, we notice that cross-sections with greater width-depth ratios are usually the locations of fast deposition of channel beds.

SECTION AREA AND ASYMMETRY
(Fig. 14, 15, 16, 17)

In general, the cross-section areas of the channels become bigger down streams and are in direct proportion to discharge. However, there are different conditions because of various resistence to erosion. The channels with rocky banks are deep and narrow whereas those with sands and gravels banks and where tributary junctions are shallower and wider. Influence from human activities is great, too, such as quarrying, dumping garbage along the banks, etc. As to the section asymmetry, KNIGHTON (1982) points out that it is subject to both erosion of channel beds and migration of channel bars. BRIDGE (1977) supposed that asymmetry is close related to channel sinuosity. GOTTLIEB (1976) gets from experiments the conclusion that asymmetry is the greatest at bend crests and its successional parts.

The average cross-section areas of the lower streams of the Tanshui River system are 4049 m² in the Tanshui River, 2776 m² in the Hsintien River, 2663 m² in the Tahan River and 858 m² in the Keelung River. Among the four rivers, cross-section areas in the Thanshui River and the Tahan River change and expand most notably due to quarrying. Without quarrying, the channel of the Keelung River is the most stable with the least change; their cross-section areas tend to decrease owing to dumping garbage along the banks. In general, after the damming of the Shihmen Dam, bed materials for the lower streams decreased and thus the cross-section areas increased, when the channel beds are deepended, the gain sizes of the bed materials become larger and form the armer layer, which has the function of preventing the river beds from being deepened, but the main factor resulting in the fast expansion of the cross-section areas of the Tanshui River system is quarrying, which eliminates the protective function of the armer layers. The evidence can be drawn from the accordance of the quarrying sites to the reachs of which the cross-section areas are notably changed. For instance, in the Tanshui River, the Taipei meander reach from section 13 to 18 are the main quarrying sites; the exposed, stream beds of the braided reaches in the Tahan River are, in particular, constantly quarried, and, as a result, the reach between section 67 to 73 posses the biggest cross-section area. On the other hand, cross-section areas are smaller and more stable in reaches near bridges where quarrying is prohibited, and in water gaps with rocky banks. In tributary junctions

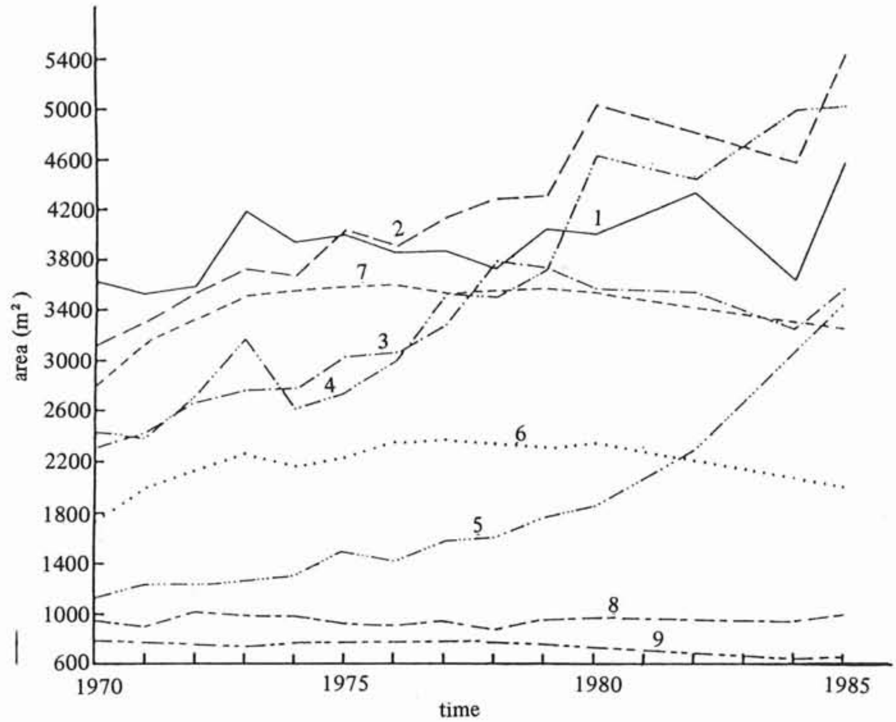


FIG. 14 - Cross section area in the lower Tanshui River system during 1970-1985.

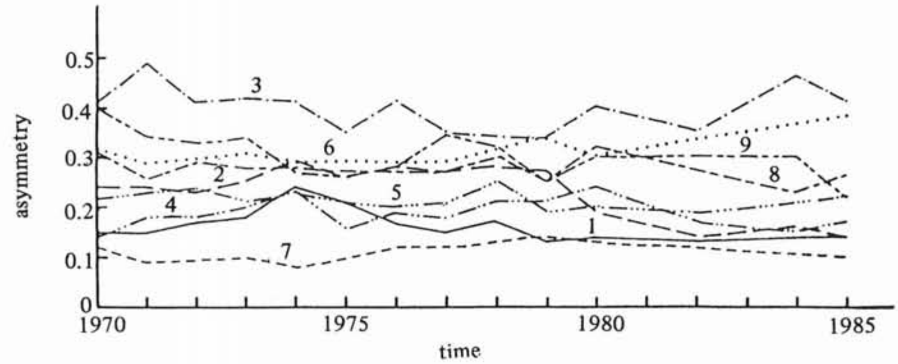


FIG. 15 - Asymmetry of reaches in the lower Tanshui River system during 1970-1985.

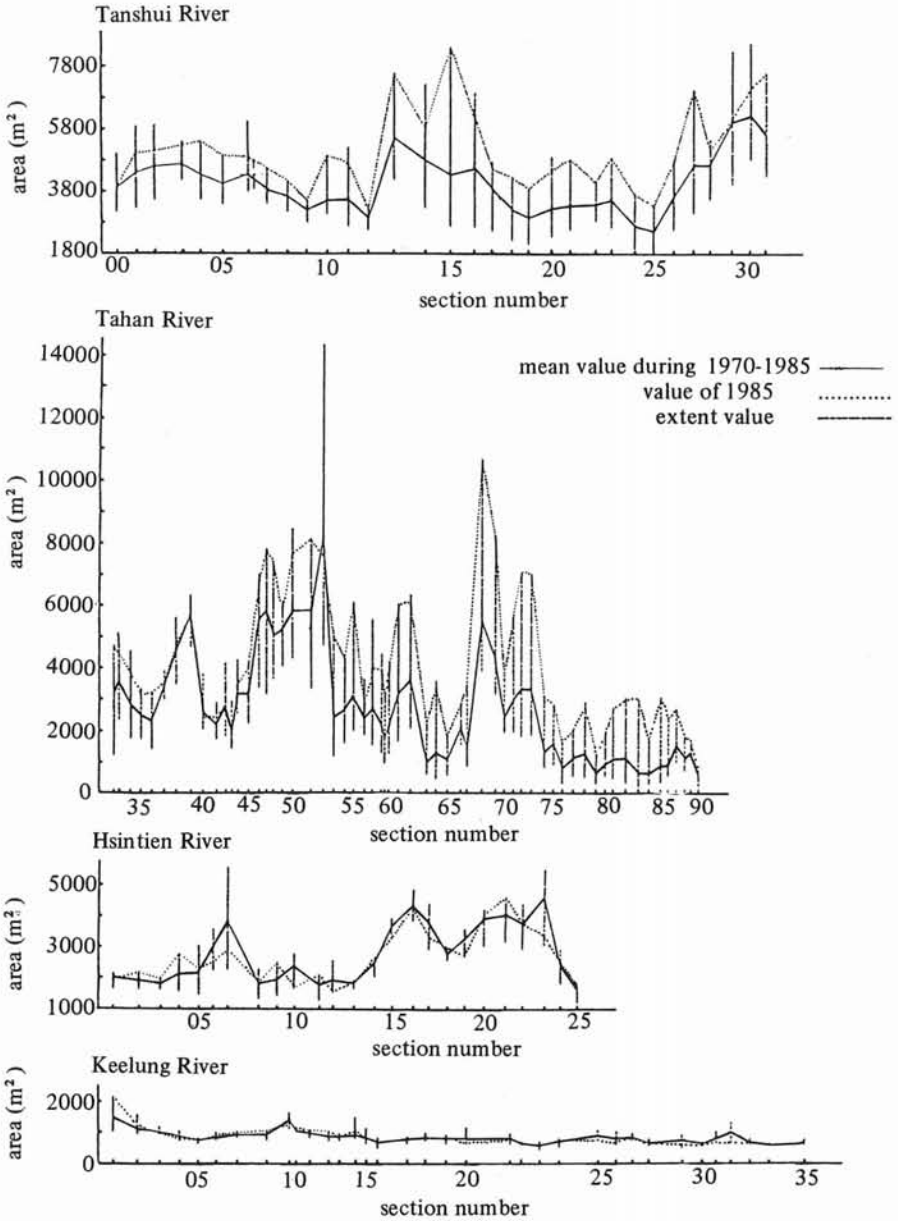


FIG. 16 - Area variation of sections in the lower Tanshui River system during 1970-1985.

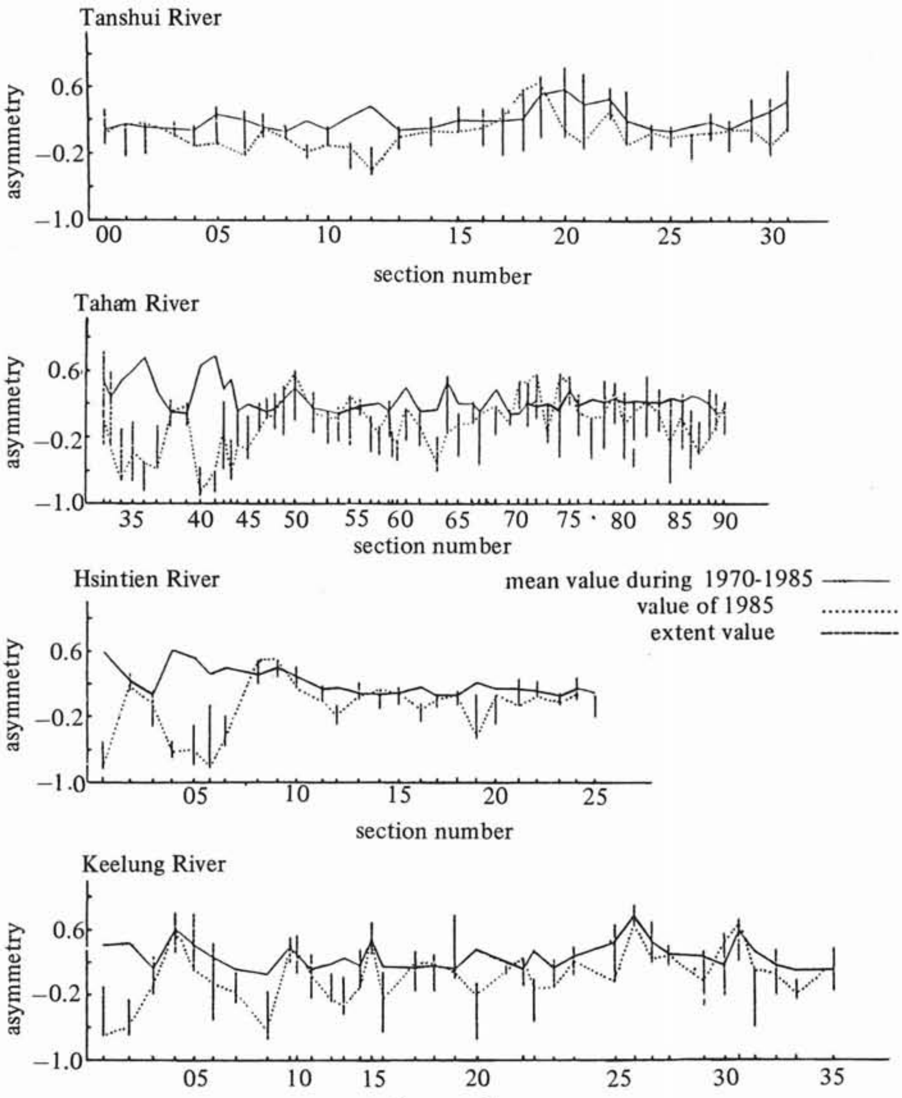


FIG. 17 - Asymmetry variation of sections in the lower Tanshui River during 1970-1985.

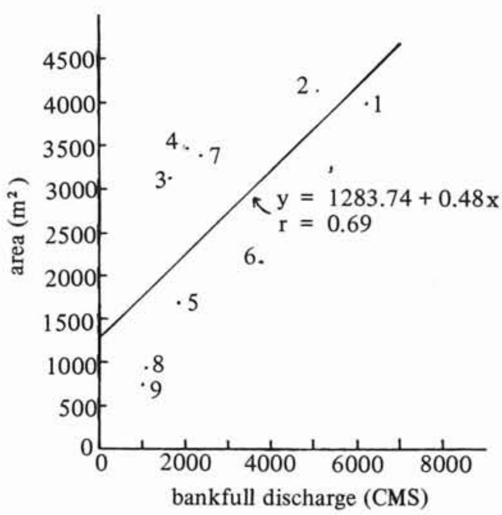


FIG. 18 - Relationship of cross section area to bankful discharge in the lower Tanshui river system.

and their successional lower streams, discharge and cross-section are increased, it is noticeable that the cross-section areas (Y) become larger as the bankfull discharge (X) increases. Their relationship is Y = 1283.74 + 0.48X (fig. 18). In channel of meandering bend crests and their successional parts, currents are concentrated and speeded whereas the cross-section areas are decreased. These changes are the adaption results of the stream flow process to the channel morphology.

The asymmetry of the cross-section of the channels is 0.29 in the Keelung River, 0.25 in the Tahan River, 0.21 in the Hsintien River, and 0.20 in the Tanshui River. Among all the reaches, the Hsinshu Convergent Reach bears the greatest asymmetry value (0.40), and the Chingh-sin Braided Reach bears the smallest (0.11). The positive and negative skewness of asymmetry is in accordance to the variation of the channel bends. Asymmetry is also subject to confluence of rivers. The cross-section is inclined toward to bank where currents concentrated. Thus the greatest asymmetry is usually found in meandering bend crests and their successional channel. It is found that asymmetry is related to meandering. The average asymmetry values in the braided and straight channel reaches in this river system are comparatively smaller, usually below 0.20; those in meandering reaches, however, are usually above 0.28. Judging from the average asymmetry values and the average meandering bend amplitudes of all the reaches, we conclude that the greater the meandering amplitude (X), the greater the asymmetry (Y). Their relationship is Y = 0.123 + 0.060X (fig. 19), which is drawn from regres-

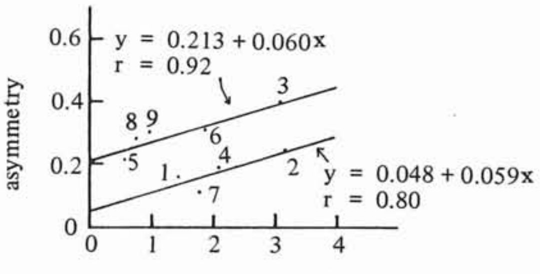


FIG. 19 - Relationship of asymmetry to bend amplitude in the lower Tanshui River system.

sion relation of the Hsinshu Convergent Reach, the Tachi Braided Reach, and the Bangho, Shehtze, Hsihu Meander Reaches. Yet the Tanshui Outlet Reach and the Taipei Meander Reach of the Tanshui River, the Tuying Braided Reach of the Tanhan River and the Chingshin Braided Reach of the Hsintien River are all badly quarried. Their asymmetry value decreases owing to influence from human activities. With the same bend amplitude, the asymmetry value of each reach decrease 0.2 or so.

CONCLUSION

The highest channel sinuosity of the lower streams of the Tanshui River system is that of the Keelung River (1.65), and the second is that of the Hsintien River (1.37); the channel sinuosity of the Tanshui River and the Tahan River (1.17 and 1.13) is below the meander threshold and thus both the rivers belong to the straight channel pattern. The two rivers' channel sinuosity are in inverse properation to their gradient, and this is different from SCHUMM & KHAN'S conclusion (1974). That gradient is not the main factor because the variation of channel sinuosity can also be observed from the facts that the change of channel sinuosity is great in gentle slope areas. Factors such as loads, discharge, bank resistence, etc. play an important role.

The meander wave lengths of the four rivers in order are 10.68 km for the Tashui River, 5.29 km for the Tahan River, 4.20 km for the Hsintien River and 2.11 km for the Keelung River. It is shown that the greater the channel sinuosity, the smaller the meander wave length. In general, the relationship between the meander wave length and the channel width is 1 to 10, and that of the Tanshui River Systems is $L = 2W^{1.254}$. The mean bend amplitudes are 2.25 km for the Tanshui River, 1.84 km for the Shintien River, 1.68 km for the Tahan River, and 0.90 km for the Keelung River. The relationship between the bend amplitude (A) and the channel width (W) is positive and the equation is W = 0.298 + 0.172A.

The average channel widths of the lower streams of the Tanshui River system from 1970 to 1985 are 879 m in the Tanshui River, 716 m in the Tahan River, 488 m in the Hsintien River and 243 m in the Keelung River. From 1970 on, except the Tachi Braided Reach of the Tahan River has been widened, however, the other lower streams of the Tanshui River system has become narrower owing to discharge decreased by the dam, bed deepening by quarrying, bank erosion diminishing by dike construction and garbage dumping along the river banks. Among the narrowed stream, the Tuying and Hsigshu reaches of the Tahan River showed the most obvious change. The Keelung River got the least change.

From 1970 to 1985, the average dephts of the lower streams of the Tanshui River System are: 5.74 m in the Hsintien River, 4.98 m in the Tanshui River, 4.03 m in the Keelung River and 3.57 m in the Tahan River. Among those rivers, the depth of the Keelung River was stable without quarrying or damming on it. The other streams were badly deepened, especially the Tuying and Tachi Braided Reaches of the Tahan River and the Taipei Meander Reach of the Tanshui River, whose deepening rate is over 20 cm/vr. Depths are greater in narrow channel at meandering bend crest and its successional channel, because stream flows gather together and thus gain greater erosion. Depths are smaller in tributary junctions and braided channels due to broadened width and dispersed flows, and in front of water gap and river mouth owing to slow velocity and heavy deposition.

The ratios of width to depth of the low streams of the Tanshui River System are 216 for the Tahan River, which is well-braided, 206 for the Tanshui River, 92 for the Hsintien River, and 74 for the Keelung River. The highest width-depth ratio is over 500, found in the mouth of the Tanshui River and the junction of the Sanhsia River. The lowest ratio is less than 20, measured under the Chungshan Bridge and a meandering bend crest near Tachih of the Keelung River. The variation of width-depth ratios corresponds with that of widths; the wider the river, the higher the ratio. In recent years, because the widths became narrower and the depths got deeper, the width-depth ratios has been decreased.

The average cross-section areas of the lower streams of the Tanshui River System are 4048 m^2 of the Tanshui River, the biggest, 2776 m^2 of the Hsintien River, 2710 m^2 of the Tahan River, and 858 m^2 of the Keelung River. Among them, the Tanshui River and the Tahan River have showed the most distinctive change and enlarged because of quarrying. The cross sections of the Keelung River have maintained stable without the influence of quarrying but has been slightly lessened due to the dumping garbage along the banks. The cross-section areas are smaller in rocky bank, meandering bend crest and the reaches prohibited quarrying adjacent to bridges. The cross-section areas are bigger and changeable comparatively in tributary junctions and quarrying points.

The asymmetry of the cross-sections of the lower streams of the Tanshui River system are: 0.29 for the Keelung River, 0.25 for the Tahan River, 0.21 for the Hsintien River, and 0.20 for the Tanshui River. The positive and negative skewness of the asymmetry corresponds with the variation of meandering bend and is subject to the flow directions of tributary junctions. The greater the amplitudes of the meander bends (X), the greater the asymmetry (Y). Their relations is $Y = 0.213 + 0.060X$.

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