

# The application of range of variability approach to the assessment of a check dam on riverine habitat alteration

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**Abstract** This report uses the intermediate disturbance hypothesis to assess the influence of constructing a check dam on river environment. HEC-HMS and HEC-RAS programs were used to generate hydraulic parameters such as flow discharge, water depth, velocity, water surface width and sediment discharge. Indicators of hydrologic alteration (IHA) and indicator of habitat alteration (IHabA) were used to evaluate the flow and habitat conditions before and after check dam construction. The range of variability approach was used to calculate the degree of hydrologic alteration for each IHA, degree of habitat alteration and overall alteration for IHabA. Variability of river habitats before and after check dam construction was contrasted. Alteration became larger the closer to the dam body. An assessment method for check dam construction is offered which does not require ecological investigation data and combines ecology concepts and hydraulics.

**Keywords** Aquatic ecosystems · Range of variability approach · Habitat alteration · Stream sedimentation · Check dam · Intermediate disturbance hypothesis · Taiwan

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## Introduction

The majority of mountain areas in Taiwan are composed of fractured geological formations. The upstream of catchments areas has been over developed. Erosion is increased by frequent typhoons and year-round heavy rainfall (Typhoon Outlook 2006). In the affected areas, steep terrain often leads to landslides. As a result, the sediment transport rates of streams are extremely high. To prolong the useful life of a reservoir, check dams are built to trap sediment. On an average, there has been at least one check dam per 1 km for rivers in the mountain areas of Taiwan (Taiwan Forest Bureau 1992). Improperly designed and installed check dams can cause negative changes in hydrological and in the sedimentary characteristics of the stream and affect the ecological habitats. Check dams may have short-term benefits for the soil and water conservation, but also may have long-term detrimental consequences. Inefficient mudflow restraint may cause increased sedimentation, which is exactly what a check dam was installed to control. Ecological changes resulting from construction activities may be irreversible.

When a channel slope is altered by building a check dam, water depth and flow velocity decrease below the check dam (Simons 1979; Leopold et al. 1964). If change in flow is too severe, morphological features, including channel width, velocity and water depth, the diversified habitat types of pool, riffle and run may merge into a one uniform stream bottom aquatic habitat.

Main substrates of a natural channel habitat in upland include boulders, cobbles, gravels and sand. The shelter such stream bottom features provide is important in fish

and aquatic insect breeding. After a check dam is built, substrate particle size typically becomes much smaller and finer due to decreased flow speed. Much-needed breeding habitats may be reduced (Alexander and Hansen 1986). Sediment accumulation can also result in the reduction of food resources for aquatic lifeforms (Turnpenny and Williams 1980). Uniform habitat and fine sand silt deposition in front of a check dam may be detrimental to the formation and quantity diversities of alga and aquatic insects (Rosenberg and Wiens 1978; Newcombe and MacDonald 1991).

Construction of a check dam not only changes channel bed slope but also alters river habitat form and structure, impacting river ecology (Winston et al. 1991; Franklin et al. 1995; Paul et al. 1997). In general, there are three ways check dams can reduce river biodiversity: (1) hindrance to anadromous creatures (those that migrate from saltwater to freshwater to breed), (2) population reduction and community segregation, and (3) increasing habitat uniformity. The first two effects come from check dam height, and the third effect indirectly by alteration of streambottom formation and structure.

River habitat diversity and biodiversity have positive correlation (Gorman and Karr 1978; Hunter 1991). Flow fluctuations resulting from check dams can also cause more severe streambed changes, such as riverbank erosion, or flooding (Petts 1984; Cushman 1985; Calow and Petts 1992; Zamora-Arroyo et al. 2001). However, some natural variability in flow may give fresh opportunities for increased aquatic growth, such as invasion, reclamation and reallocation of populations (Diamond 1988; Roberts and Gilliam 1995; Wesche 1985; Strange et al. 1999). These changes could be beneficial for ecological diversity and stability.

To sustain natural flow fluctuations should be the primary management principle for ongoing development of rivers. In other words, moderate changes in streambeds and streamflow could result in higher ecological diversity.

In this study, this concept is tested using intermediate disturbance hypothesis (IDH) (Connell and Slayter 1977). Categorization of river habitats is based on hydrologic criteria such as velocity, water depth, channel slope, and substrate (Leopold 1969; Rosgen 1985; Lisle and Hilton 1982, 1992; Heggenes et al. 1990, 1991). These hydraulic parameters were calculated. Then, the range of variability approach (RVA) (Richter et al. 1997) was used to calculate alteration of velocity, water depth, top width and sediment discharge for each stream section before and after check dam construction.

## Study area

Daipo Check Dam is located in the upstream catchment of Tsengwen Reservoir in the Southeast of Taiwan. The catchment area is 302 km<sup>2</sup>. The main stream originates from the Sheuishan region of the Alishan Mountains Range (elevation 2,609 m). There are 172 days each year with rainfall on average. Average annual precipitation is 3,910 mm, with the highest average rainfall (839 mm) in August and the lowest (47 mm) in November. About 86% of total annual rainfall occurs between May and September.

Daipo Check Dam was completed in 1989. The concrete gravity dam is located at 23°17'54" north latitude and 120°38'11" east longitude. Dam length is 180 m and effective dam height is 19 m. The designed crest level is 239 m and the spillway lip width is 70 m. The distance between the major dam and the secondary dam is 100 m. The capacity designed for sediment storage is about 2,640,000 m<sup>3</sup>. According to field investigation reports for the period from 2000 to 2002, neither fishway nor sediment storage capacity were considered at all in the design and construction of this check dam. Both riversides are national forestlands, composed mainly of bamboo and mixed bamboo and broad-leaf forest. Location and surroundings are shown in Fig. 1.

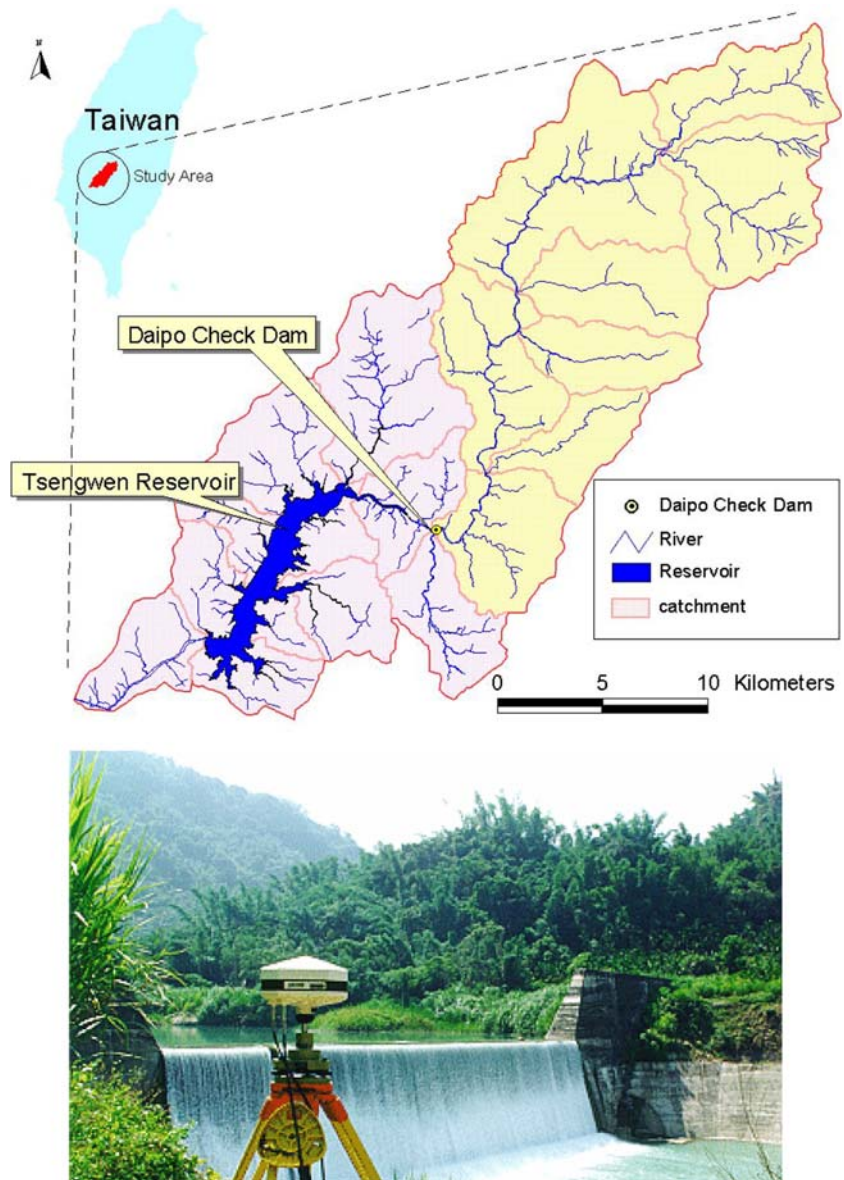
## Research methodology

Stream ecological assessment following dam construction is often hindered by limited monitoring data, uneven sampling, and restriction of target species. Under such circumstances, pre- and post-construction comparative habitat assessment is almost impossible. Monitoring of aquatic fauna is not included in this study.

To better understand stream habitat alteration before and after the dam construction, this study used IDH methods (Connell and Slayter 1977). The river ecology was assumed to be in its best condition before dam construction. This assumption is consistent with applications of RVA for assessing hydrologic alteration (Richter et al. (1997) using five groups of fluctuating hydrologic properties: magnitude, timing, frequency, duration and rate of change.

Richter et al. (1996) suggest using a daily flow record to compute the alteration of before and after hydraulic engineering works. However, the Daipo study area has insufficient measured flow and sediment discharge data. Thus, this study incorporated the rainfall time series from rainfall stations of Shueishan, Yueyei, Lijia, Biaohu and Matoushan between 1975 and 2002, and used Digital Terrain Model (DTM) to Hydrologic

**Fig. 1** Location and photo of Daipo Check Dam



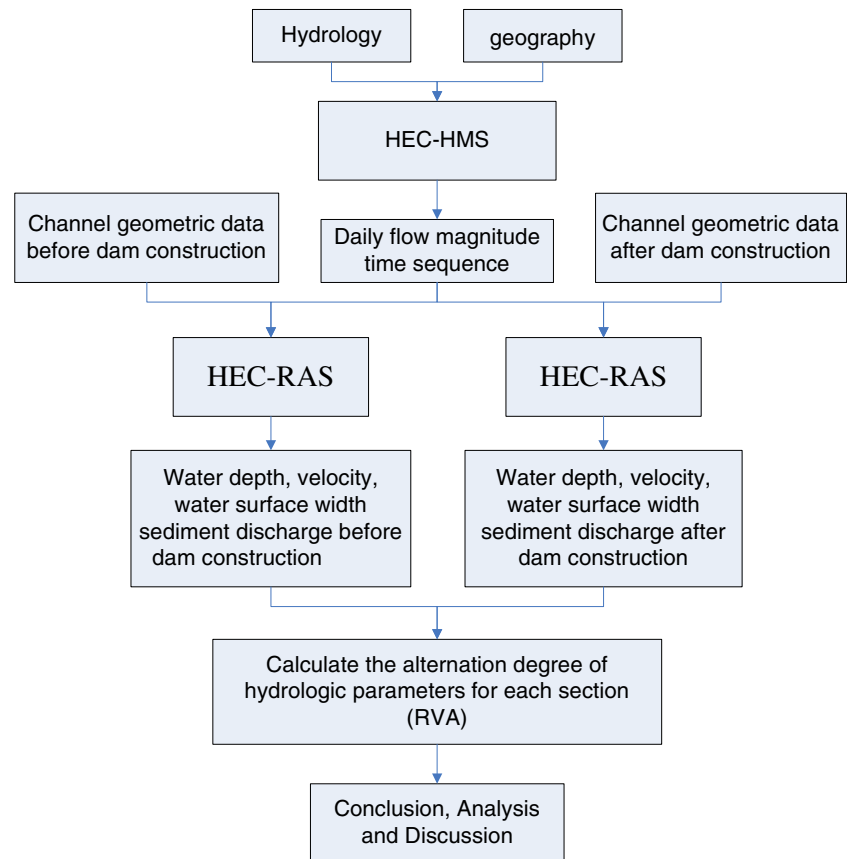
Modeling System (HEC-HMS) to infer the inflow daily discharge of Daipo Check Dam.

Given the hydrologic and hydraulic conditions of Taiwan, a check dam would typically be silted up by a typhoon or other large storm within 1 or 2 years. The duration from dam construction to dam siltation is, relatively short, less than the duration of this study (1975–2002).

This study incorporated information from the first edition (1977) and third edition (1989) of aerial maps published by Aerial Survey Office of Forestry Bureau to generate terrain data such as contours and river centerline using GIS (Geographic Information System). These data were used with HEC-GeoRAS to automat-

ically establish channel geometric characteristics before and after check dam construction. Channel geometric characteristics and sediment grain size data were inserted into a River Analysis System (HEC-RAS) to estimate the velocity, water depth, water surface top width and sediment discharge for each section from 1975 to 2002. RVA analysis was then used to calculate alteration of velocity, water depth, top width and sediment discharge for each section before and after check dam construction. The study flow chart is shown in Fig. 2.

RVA methodology requires long-term daily flow records for calculating the individual alteration degrees of 32 IHA. IHA compares river discharge before and after hydraulic engineering works. Overall degree of

**Fig. 2** Study flow chart

hydrologic alteration based on these 32 IHAs was used to perform integrated calculation of before and after impacts (Richter et al. 1996). IHA software (The Nature Conservancy) was used for IHA and RVA analysis.

These 32 IHAs provided information on conditions for aquatic organisms and river ecology while surface and ground water was altered. To maintain data integrity, variation of discharge and other hydrologic parameters should be under similar natural river conditions. But since this application only uses discharge records, it is insufficient to assess habitat alteration by hydraulic construction.

Other hydrologic parameters, such as velocity, water depth, top width and sediment discharge are needed for calculating alteration. The RVA method was used to obtain Indicators of Habitat Alteration (IHAbA). By combining IHA and IHAbA methods, river ecology assessments become more accurate. Setting the standard of alteration degree of IHA or IHAbA should be based on field investigation data. The IHA and IHAbA parameters are first calculated for each year. Then, for the ensemble of years in the pre- and post-impact periods, the 10th, 25th, 50th, 75th, and 90th percentiles are calculated for each IHA and IHAbA parameter.

The 75th and 25th percentile values were adopted here for the pre-impact period as the upper RVA target and lower RVA target, respectively. Three categories were set up: high, middle, and low. Values greater than the upper RVA target are considered high, values between the lower RVA target and the upper RVA target are middle, and values less than the lower RVA target are in the Low category.

When there is a shortage of field investigation data, Richter et al. (1997) suggested adding or subtracting one standard deviation to each indicator mean value, or the 75th and 25th percentile values in this case, for pre-impact period of each indicator. The default “high pulse” level is the 75th percentile of all pre-impact daily data, and the “low pulse” level is the 25th percentile. In the RVA analysis, the 33rd and 67th percentiles defined the default RVA categories for this study. An alternative calculation for the IHA scorecard used non-parametric statistics based on percentile distributions of the data, followed by the computation of the frequency with which the “post-impact” annual values of IHA parameters actually fell within each of the three categories.

Richter et al. (1997) suggest that water managers should strive to keep the distribution of annual values

of the IHA parameters as close to the pre-impact distributions as possible. If most of the post-impact hydraulic record series still fall within the RVA target of IHA, then it means the impact on river ecology is small and the river is still a relatively natural state.

Richter et al. (1998) use the following equation (1) to quantify the degree of IHA affected by hydraulic engineering works.

$$D_i = \left| \frac{N_o - N_e}{N_e} \right| \times 100\%, \quad (1)$$

where

- $D_i$  number  $i$  of degrees of hydrologic alteration ( $i = 1-32$ )
- $N_o$  observation number, the number of years in which IHA values after dam construction still fall within the RVA target
- $N_e$  expected number, the number of years which IHA values after dam construction are anticipated within the RVA target; may use  $r \times NT$  to assess
- $r$  the ratio of IHA values within the RVA target before dam construction
- $N_T$  the total years of record of flow magnitude influenced after dam construction

There are two methods to estimate the overall alteration. One is the average method developed by Richter et al. (1998), and the other the weighted average method developed by Shiau and Wu (2004). This study used retrieved IHabA of hydraulic parameters velocity, water depth, water surface width and sediment discharge. Equation 1 was then applied to calculate degrees of habitat alteration for all IHabA. Afterwards, both the average method developed by Richter et al. (1998) and the weighted average method developed by Shiau and Wu (2004) were used to calculate overall degree of habitat alteration. The difference between IHA and IHabA is shown in Table 1.

## Results and discussion

### Channel slope alteration

Longitudinal profile of river channel before and after dam construction were simulated (Fig. 3). The lowest downstream section (Section 1) and the upstream section (Section 5) are located at about 50 and 950 m from the spillway, respectively. The average channel slope before check dam construction from Section 1 to 5 was 0.0087, whereas the average slope after construction is 0.0001. There were 87 folds in between; significant changes to the river environment are anticipated.

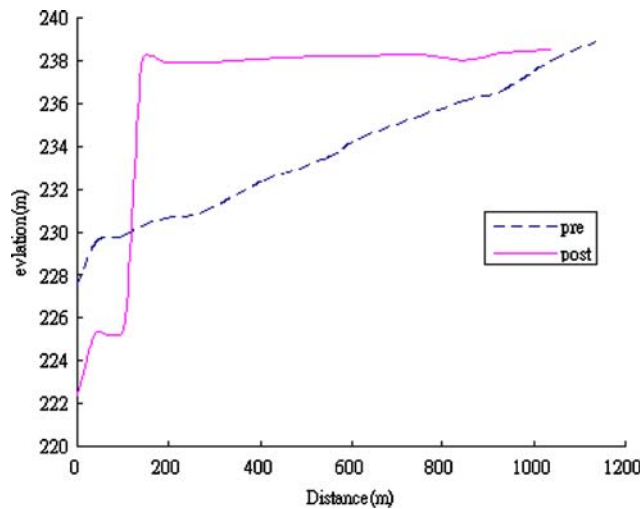
### Alteration of hydraulic characteristics in time series

RVA analysis used the retrieved IHA and IHabA parameters to calculate the alteration degree of river characteristics pre- and post-impact. Water depth hydrograph is shown in Fig. 4 and water depth IHabA and degree of habitat alteration before and after check dam construction in shown in Table 2. The left and right portions of the diagram in Fig. 5 represent the relationship between rainfall and water depth-time variation from 1975 to 2002. Water depth-time variation was calculated before and after dam construction. Maximum, mean and minimum of water depths have decreased after construction. Mean of water depth decreased from 0.87 to 0.44, standard deviation reduced from 0.69 to 0.45.

Paired  $t$  tests were performed against before and after impacts in all stream sections. Only one case (Section 2 sediment discharge before and after impact) could accept null hypothesis, i.e., mean value deviation between before and after impact was insignificant. Others had visible deviation ( $P < 0.05$ ). Alteration of water depth, velocity, water surface top width and sediment discharge before and after check dam construction are evidenced.

**Table 1** Synopsis of IHA and IHabA

Indicator	Impact type	Hydraulic parameters	Degree of alteration	Overall degree of alteration
IHA	Water resources allocation and utilization issues majored with flow magnitude, such as construct hinder dam or diversion weir to retrieve water	Discharge	32 (Degree of hydrologic alteration)	1 (Overall degree of hydrologic alteration)
IHabA	Issues on water resources retrieving and channel type alteration, such as establish check dam	Water depth, velocity, water surface width and sediment discharge	128 (Degree of habitat alteration)	4 (Overall degree of habitat alteration)



**Fig. 3** The channel bed longitudinal section before and after check dam construction

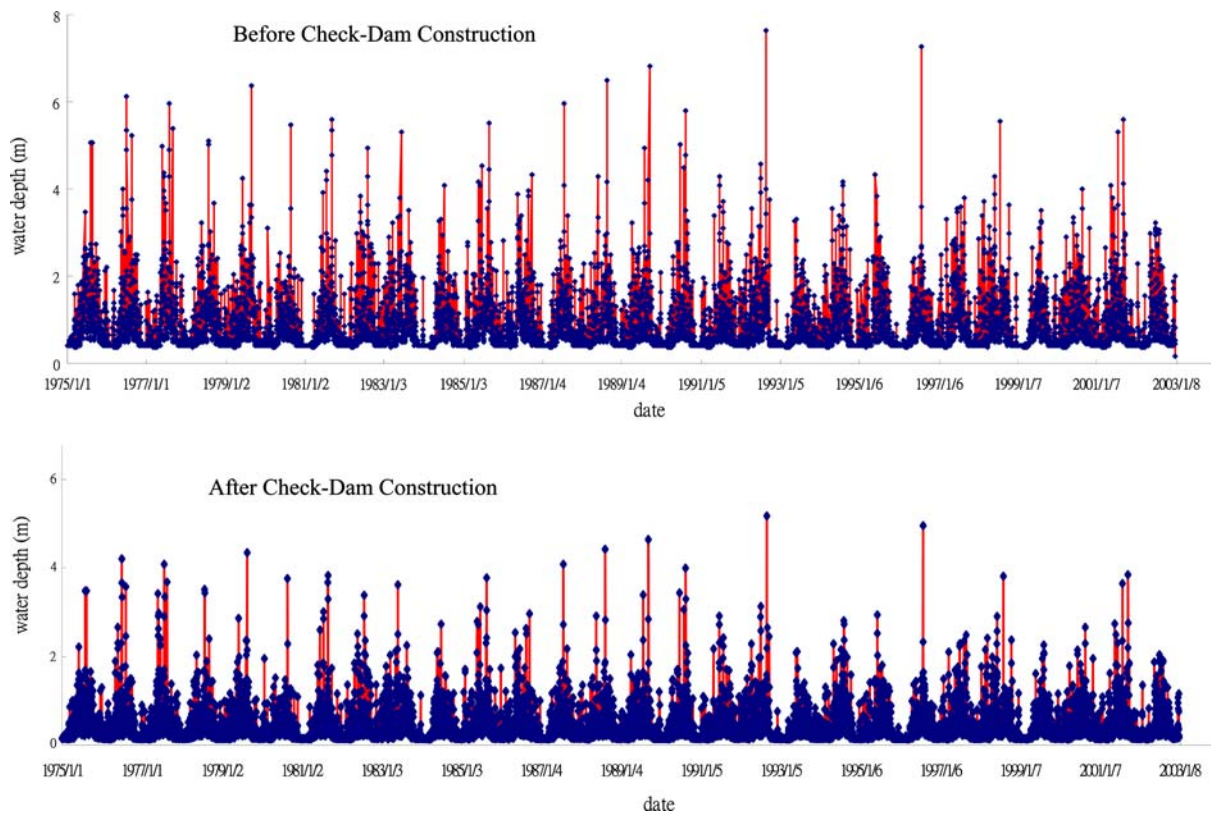
Calculated degrees of water depth alteration for the 32 IHabA based on the daily water depth series between 1975 and 2002 are shown in Table 2. Generally speaking, after construction the medians of Groups 1, 2 and 5 tended downward, whereas Group 3 and 4 tend to go up. This result was consistent with the data shown in Fig. 5.

The space overall alteration of each hydraulic parameter

*The variation of each overall hydraulic alteration on sections*

The length of bed accretion beyond the check dam is about 1 km. In terms of the entire river system, this reach of stream is so short that discharge alteration due to check dam construction can be considered constant. As a result, there was no degree of alteration between each Section. When the four hydraulic parameters are considered, however, alteration is evident. Variance of the four alterations along current direction is shown individually in Fig. 5a–d.

Figure 5a–d shows that the Low category was the more appropriate indicator for whether to build a check dam on a river. This result also indicated that check dam construction exerted a larger influence during low flow periods, which is consistent with common stream morphology and hydraulics. Figure 5a shows overall water depth alteration was becoming larger along the current flow closest to the dam body; the increase was gradual, from 100 to 325%. Changes in overall velocity and top width along the current flow were smaller than overall water depth alteration.



**Fig. 4** Water depth hydrograph of Section 1

**Table 2** Section 1 water depth IHabA and degree of habitat alteration before and after check dam construction

	Pre-impact topography and 1975–2002				Post-impact topography and 1975–2002				RVA targets		Habitat alteration		
	Medians	Coeff. of variance	Range limits		Medians	Coeff. of variance	Range limits		Low	High	(Middle category)	(Low category)	(High category)
			Low	High			Low	High					
<b>Parameter group #1</b>													
January	0.5	0.36	0.4	0.7	0.2	0.45	0.2	0.3	0.44	0.57	-1	2.11	-1
February	0.5	0.66	0.4	1.2	0.2	0.89	0.2	0.6	0.44	0.66	-0.6	1.67	-1
March	0.6	0.32	0.4	1.2	0.2	0.42	0.1	0.6	0.49	0.63	-0.9	2	-1
April	0.7	0.42	0.5	1.3	0.3	0.55	0.2	0.7	0.62	0.78	-0.9	2	-1
May	1.1	0.28	0.7	1.6	0.6	0.36	0.3	0.9	1.05	1.22	-1	2.11	-1
June	1.3	0.29	0.9	2.2	0.7	0.36	0.4	1.3	1.21	1.47	-0.9	2	-1
July	1.3	0.31	0.8	1.6	0.7	0.38	0.4	0.9	1.09	1.41	-1	2.11	-1
August	1.5	0.26	1	1.9	0.8	0.33	0.5	1.1	1.32	1.56	-1	2.11	-1
September	1.1	0.3	0.8	1.7	0.6	0.36	0.4	1	1.01	1.15	-0.9	2	-1
October	0.7	0.16	0.4	1.2	0.3	0.19	0.2	0.6	0.65	0.73	-1	2.11	-1
November	0.5	0.29	0.4	0.7	0.2	0.38	0.2	0.3	0.44	0.57	-1	2.11	-1
December	0.5	0.28	0.4	0.8	0.2	0.38	0.2	0.4	0.45	0.54	-1	2.11	-1
<b>Parameter group #2</b>													
1-day minimum	0.4	0	0.4	0.4	0.1	0	0.1	0.2	0.37	0.37	-1	0	-1
3-day minimum	0.4	0.01	0.2	0.4	0.1	0.02	0.1	0.2	0.37	0.37	-1	27	-1
7-day minimum	0.4	0.03	0.2	0.4	0.1	0.06	0.1	0.2	0.37	0.38	-1	27	-1
30-day minimum	0.4	0.05	0.2	0.5	0.2	0.06	0.1	0.2	0.39	0.4	-1	3.67	-1
90-day minimum	0.4	0.2	0.2	0.6	0.2	0.25	0.2	0.2	0.41	0.47	-1	2.11	-1
1-day maximum	5.2	0.33	3.2	7.3	3.7	0.34	2	5.2	4.33	5.6	-0.5	1.56	-1
3-day maximum	4.1	0.29	2.5	5.5	2.7	0.32	1.5	3.8	3.48	4.35	-0.8	1.89	-1
7-day maximum	2.8	0.27	1.9	3.7	1.8	0.33	1.1	2.5	2.58	3.06	-1	2.11	-1
30-day maximum	1.8	0.18	1.4	2.3	1.1	0.23	0.8	1.4	1.67	1.88	-1	2.11	-1
90-day maximum	1.4	0.13	1.1	1.8	0.8	0.17	0.6	1.1	1.35	1.46	-1	2.11	-1
Number of zero days	0	0	0	0	0	0	0	0	0	0	0	0	0
Base flow	0.42	0.16	0.24	0.54	0.32	0.18	0.28	0.44	0.41	0.45	-0.8	1.89	-1
<b>Parameter group #3</b>													
Date of minimum	67	0.03	62	92	67	0.02	1	92	63	70	0	0.13	-0.13
Date of maximum	217.5	0.14	156	264	219.5	0.13	156	264	209.1	234.3	0	-0.11	0.11
<b>Parameter group #4</b>													
Low pulse count	10	0.38	6	14	30.5	0.29	23	42	9	12	-1	-1	3.67
Low pulse duration	7.3	0.5	3.5	14	6.4	0.27	4.2	9.5	6.27	8.16	0.2	0.33	-0.56
High pulse count	31	0.32	22	43	17	0.5	8	27	28.57	36.43	-1	2.11	-1
High pulse duration	2.8	0.24	1.7	3.6	1.6	0.18	1.3	2.3	2.62	2.99	-1	2.11	-1
<b>Parameter group #5</b>													
Rise rate	0.5	0.21	0.4	0.6	0.3	0.23	0.3	0.4	0.48	0.56	-1	2.11	-1
Fall rate	-0.3	-0.22	-0.4	-0.2	-0.2	-0.23	-0.3	-0.1	-0.33	-0.28	-1	-1	2.11
Number of reversals	126.5	0.13	100	167	124.5	0.13	96	161	123.6	133	0	0.22	-0.25

Overall sediment discharge decreased along the current flow closer to the dam body.

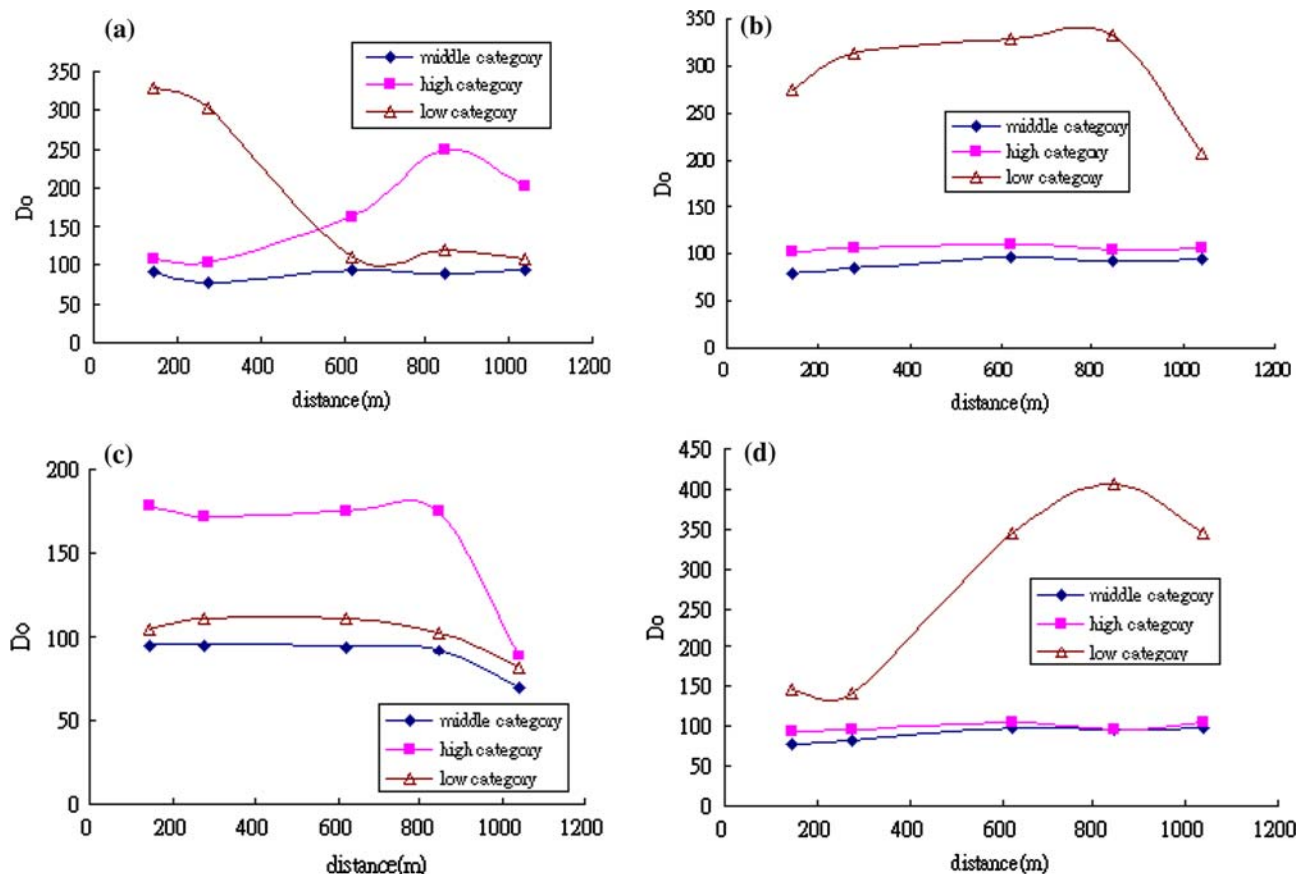
*Variance of integrity overall alteration in space*

This study multiplied overall water depth alterations, overall velocity alterations and overall top width alteration to obtain a new parameter. This derived parameter is labeled “integrity overall alteration”, and is represented by Do’. Do’ within the Low category increased gradually closer to the dam. Do’ within the

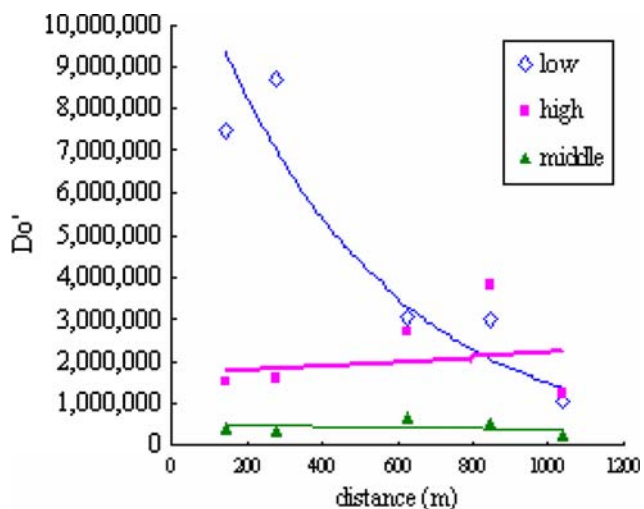
high and middle categories had fewer spatial variations. The results are shown in Fig. 6.

Integrity overall alteration Do’ generally varied with the distance away from check dam body.

This study only applied the daily discharge assessment proposed by Richter et al. (1996). By introducing IHabA, improved RVA and Do’, quantitative assessment of before and after conditions was possible. Using this improved RVA method, it is possible to assess river condition in terms of both time and space.



**Fig. 5** The space variance of four overall alterations on each section. **a** Water depth, **b** velocity, **c** top width and **d** sediment discharge



**Fig. 6** The integrity overall alteration  $Do'$  in fort of check dam

## Conclusions

1. By computing IHaba and using RVA analysis, habitat alteration was calculated. This value was used to assess impact of river ecology by check dam construction.

2. The Low category should be a more suitable range for assessment to evaluate possible changes in the river ecology influenced by construction of a check dam. The integrity overall alteration of the Low category between each section clearly increased closer to the dam site.
3. For additional verification, the integrity overall alteration as defined above could be used as a simple test to show change of river environment.
4. Paired test ( $P < 0.05$ ) was adopted to test diverseness of hydraulic parameters before and after dam construction. The results represent obvious diverseness. Dam construction causes significant effects on riverbed morphology and environment.
5. The indoor assessment method used here can provide a time and effort-saving methodology to assess middle-scale reach condition variations due to check dam construction. This combined method is a good general quantitative technique for river management. River managers may set different RVA targets to do RVA analysis according to their own goals.

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