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Impact of the Yalong-Yellow River water transfer project on the eco-environment in Yalong River basin

WANG LingHe[1,2], YAN DengHua[2,3*], WANG Hao[1,2,3], YIN Jun[2] & BAI YinBaoLiGao[4]

[1] *School of Hydraulic Engineering, Dalian University of Technology, Dalian 116024, China;*
[2] *Department of Water Resources, China Institute of Water Resources and Hydropower Research, Beijing 100038, China;*
[3] *State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100038, China;*
[4] *Department of Hydraulic Research, China Institute of Water Resources and Hydropower Research, Beijing 100038, China*

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The planning Yalong-River water transfer project will transfer 5.65 billion cubic meters water from the Yalong River into the Yellow River per year. The Yalong River will be dramatically impacted hydrologically and ecologically because more than 60% of the runoff will be diverted. An ecohydrological model was used to evaluate the impacts of the project on river corridor and wetland in this study. *Schizothorax* is a typical plateau river species and was used as the indicator species for assessment of the impact of water transfer project. The model simulated the habitat area of *Schizothorax* in the reach between the Reba Dam and the Ganzi Hydrology Station on the Yalong River. The Reba Dam, A'an Dam and Renda Dam will be constructed in the Yalong River for enhancing the water level for water diversion into the Yellow River. The velocity, channel width, runoff, and water depth will be reduced due to the water transfer, especially during flood season. The reduction in the velocity, channel width, runoff and water depth will occur mainly in the reach near the three dams and the reduction will be reduced to a minimum level in a distance about 100 km downstream of the dams. The maximum net water loss of Kasha Lake is only 1197200 m^3, only 0.3% of runoff flowing into the lake. The project cannot bring adverse effect on the lake. The habitat area of *Schizothorax* in the Yalong River might be reduced if the water was transferred from the Reba Dam. The habitat area of this species will be reduced more than 40%.

eco-environment, water transfer project, impact, physical habitat modeling, habitat area, Yalong River

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1 Introduction

Inter-basin water transfer is an effective measure to solve the problem of non-uniform spatial distribution of water resources, improve the guaranteed rate of water resources in the intake area, relieve the contradiction between water supply and usage, realize the reasonable allocation of water resources, and promote economic and comprehensive development and the utilization of water resources in water-deficient areas [1, 2]. With the popularization of science and as natural systems are affected by increased global industrialization, the environment is becoming a subject increased focus. The negative impacts of large engineering projects on the eco-environment must be assessed before the projects are carried out. Hence, it is a premise of the project to evaluate the impacts of a water transfer project on the eco-environment.

Water transfer projects demonstrating little concern for the eco-environment are usually rejected, and the progress

*Corresponding author (email: yandh@iwhr.com)

of the projects is always disturbed. Due to inadequate considerations of the environmental impact, the Indian Sardar Sarova Water Transfer Project was interrupted for nearly four years after it was initiated [3]. The Pakistan West-East Water Transfer Project was completed in the 1970s but faced soil swamping and salinization [4]. Large tracts of land in San Francisco Bay were exposed to salinization after water was transferred from California. Moreover, the water flow into the sea was reduced, thus influencing the existence and reproduction of fish. Water transfer projects have proven that water transfer can result in serious problems, such as seawater invasion, the decline of water quality, sediment, erosion, destruction of the water ecosystem, inundation of large areas of land, involuntary resettlement, and third-party influences [5]. Usually, larger long-distance water transfer projects can elicit complex eco-environment effects. Many different methods have been used to evaluate the impacts of water transfer projects [6]. Considering the physical, chemical, biological and socioeconomic systems influenced by water transfer projects, an evaluation index system has been established to assess the impact of the projects on the eco-environment in water transfer areas, water deliver areas and water intake areas [7]. Many studies have focused on a specific object influenced by water transfer projects, such as fish, birds, higher plants, and endangered animals [8–10]. However, these studies prefer to focus on a single option for protecting the existence and reproduction of the chosen object without considering the impact of the water transfer project on the entire environment of the object. A new method is required to evaluate the impact of water transfer projects.

Ecohydrology is a new discipline to consider the interaction between hydrological and ecological processes. A new tool for water resource management has been supplied by analyzing the soil-vegetation-atmosphere transfer from a hydrological point of view [11–13]. Ecohydrological studies always stem from a physical mechanism, provide a new perspective in the environment field, and supply reasonable measures to solve water and environmental problems [14]. Many studies of semi-arid and arid areas have attempted to clarify the function of vegetation in the hydrological process and in the response of the hydrological process as well as to predict the distribution patterns of regional woody species in dryland ecosystems [15–19]. Ecohydrology is considered as an interdisciplinary approach for wetland management and restoration [20]. Integrated hydrological and ecological modeling has been proven to be a feasible method to assess a nuclear waste repository [21]. In Guadiana Estuary, an ecohydrological model was used to simulate hydrological situations, and impact evaluations were performed after various measures [22]. The ecohydrological approach was used to establish the relationship between vegetation and the hydrological process to analyze the impact of the changes in the hydrological condition on the regional eco-environment. Water transfer projects impact three regions: the water transfer, water delivery and water intake areas. This study solely focused on the water transfer area.

The Yalong-Yellow River water transfer project is a part of the west route of the South-to-North Water Transfer Project. The South-to-North Water Transfer Project is an important project to solve the water problems in North China, involving three routes to transfer water, the east route, the middle route, and the west route. The east and middle routes of the project are in the building phase, while the west route is still in argument. The impacts of the west route project on the eco-environment have not been confirmed, leading to difficulty in decision-making during this period. Attempts were made to establish a regional ecohydrological model based on an ecohydrological framework, mainly concerning the interaction between hydrological and ecological processes, reflecting the link between water and vegetation, and integrating the ecological module with the hydrological module in detail. The ecohydrological model was used to evaluate the ecological impacts of the changes in water due to water transfer on the river corridor, wetland and dry valley. Moreover, physical habitat simulation system (PHABSIM) technology was used to simulate the habitat area of *Schizothorax* between Ganzi Hydrological Station and Reba Dam in the Yalong River mainstream. The remainder of the study was organized as follows. First, the study site and data applied in the ecohydrological model are described in the materials and methods section, where the framework and each module are also introduced. Second, the discussion of the results is presented, and the impacts of project on the river corridor, and wetland are clarified in the results and discussion sections. Third, the habitat area of the species *Schizothorax* is modeled. Finally, the conclusions are presented.

2 Materials and method

2.1 Study area

The project is located in Sichuan Province in the west of China. Three diversion dams will be built in the Yalong River basin, i.e., the Reba Dam in the middle reaches of the Yalong River, the A'an Dam in the Daqu tributary of the Yalong River, and the Renda Dam in the Niqu tributary of the Yalong River. The water transfer scales of the different dams are presented in Table 1. Lianghekou Reservoir is under construction in the lower reaches of the Yalong River, and Yajiang hydrology station, 2.5 km away from the reservoir, is considered the lower boundary of the study area

Table 1 Water transfer volume from the Yalong River basin

Dam	Volume of water diversion (billion m^3)	Annual runoff (billion m^3)	Water diversion ratio (%)
Reba	4.2	6.072	69.17
A'an	0.7	1.031	67.89
Renda	0.75	1.149	65.27

(Figure 1).

The Yalong River basin is located in the eastern region of the Tibetan Plateau, where the elevation is approximately 3000-5000 m. The water transfer area is deep within the inland plateau and exhibits plateau-mountain climate characteristics that significantly change with the latitude and height. The weather is controlled by westerly winds. However, the convective weather system is very active as a function of plateau heat and low air pressure, resulting in low and unevenly distributed precipitation. The water transfer areas are part of the Tibetan Plateau paramos vegetation region, where the vegetation and soil vary according to the plane division and vertical zonation. The types of land cover in the water transfer area mainly include woodlands, shrubs, marsh grasses, meadows, waste grasslands, bare land, and alpine frost desert soil [23]. The water system is diverted into the Yellow River and Yangtze River systems by crossing the Bayan Har Mountains, and the Yalong River belongs to the Yangtze River system.

2.2 Data

Two types of data were required for this study. The first type of data was used to simulate the land surface water cycle and energy process on a small scale, such as a digital elevation model. These data included river morphology data, soil and hydrogeology data, vegetation remote sensing data, land use data, meteorology data, and hydrology data. The second type of data was used to simulate ecological processes and included the leaf type, maximum area of canopy, leaf area index and control indexes in phenology.

The digital elevation model data were derived from 1:250000 topographic data of the national geological system. The hydrology data were obtained from four hydrology stations, the Ganzi, Zhuba, Daofu and Yajiang stations, from 1956 to 2000. Thematic Mapper (TM) image is an image product gained by U.S. Landsat, and it has been applied in many earth survey fields. The vegetation data were derived from TM images collected on July 27, 2006 and October 13, 2008. The field soil data were supplied by the second national census and survey. The land use data were derived from national data from 1986 and 2000. The meteorology data were supplied by 20 national meteorology stations. The ecological data included the production data and the NDVI index of vegetation.

2.3 Evaluation method

First, the characteristics of the water cycle and the eco-environment should be identified, as well as the development and succession laws of the eco-environment in the water transfer areas. Then, an ecohydrological model should be established based on a unified physical mechanism. The changing indexes were analyzed in this system, where the impact of the project on the eco-environment in the water transfer area was analyzed (Figure 2). The velocity of flow, channel width, runoff and water depth of the river corridor, the water need to support biodiversity and the balance of the eco-environment in the wetland were considered in this study.

2.4 Ecohydrological model

A large problem faced during the design and planning stages

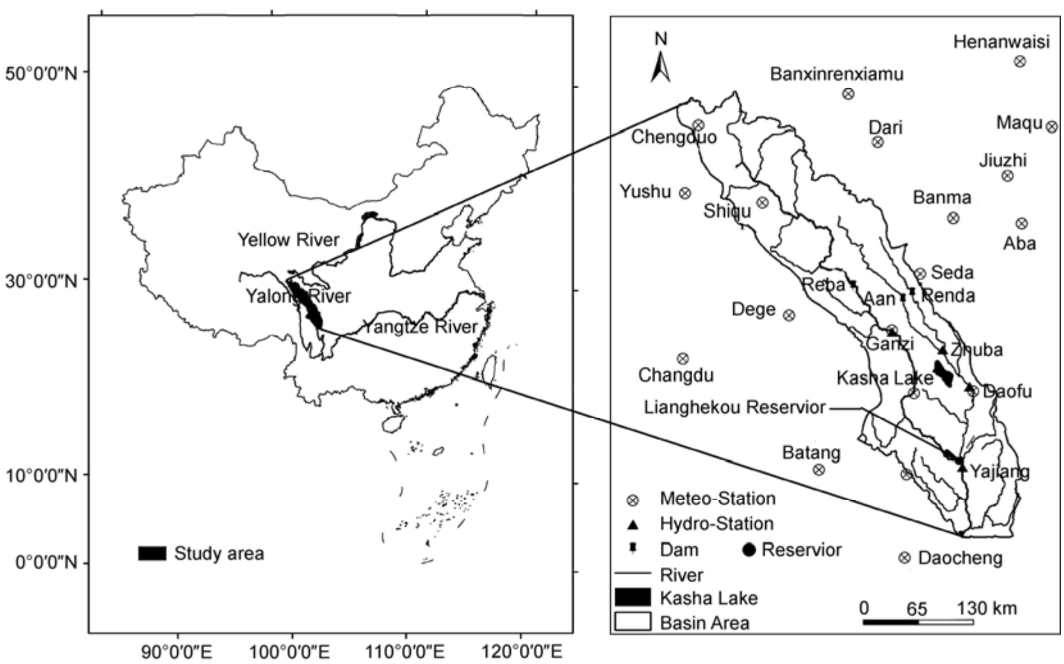

Figure 1 The position and range of study area.

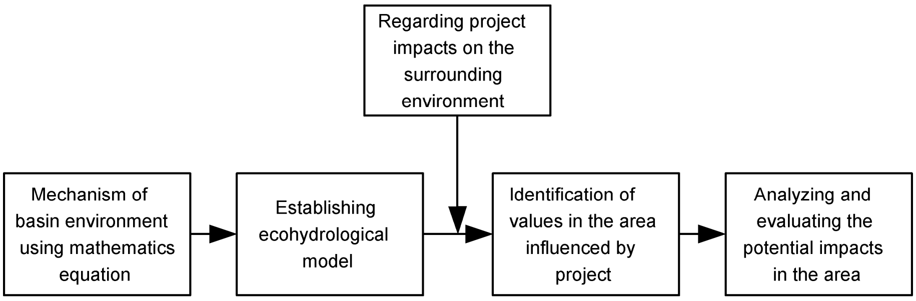

Figure 2 Linkages of evaluating modules and process.

and the focus of stockholder debates are how to recognize the impacts of the project on the water cycle and eco-environment. A good prediction of the impact will be critical for prediction of the water transfer quantity in the running state of the project and will directly influence the benefit and safety of the project.

To satisfy the above demands, the model should incorporate the following functions: (1) to simulate and modify the water cycle and eco-environmental history in the water transfer areas; (2) to distinguish between the interactions among the climate, hydrology and ecology in the water transfer areas; (3) to objectively characterize the dynamic mechanism of the succession in the water cycle and eco-environment; and (4) to simulate the evolvement trend of the water cycle and eco-environment after comprehensive adjustments.

The hydrological and ecological processes were integrated by establishing a relationship between water and the succession of vegetation in this model. Researchers attempted to use this method to simulate the relationship between water and vegetation in different areas. Two characteristics were highlighted that rendered this problem to be extremely daunting to quantitatively analyze: (1) a very high number of different processes and phenomena comprised the dynamics; and (2) the phenomena presented an extremely large degree of variability in time and space. It is necessary to simplify this complex process, and the main modules are as follows: precipitation, vegetation interception, depression storage, infiltration, surface runoff, confluence of the tributaries, soil water, soil evaporation, transpiration, water surface evaporation, photosynthesis, respiration, and net primary production.

2.4.1 *Vegetation interception*

During rainfall, some precipitation is lost due to the interception by vegetation. The amount of rainfall affects the surface runoff and the amount of ground infiltration. The interception by vegetation is also related to the type of vegetation. High altitude cedar and meadows are the dominant vegetation types in the water transfer area. There is an index to describe the interception effect in the model. According to expert experience and observation, different values were given in different sub-watersheds.

2.4.2 *Depression storage*

After the canopy interception process, rain falls on the ground. Due to the uneven surface, rain inevitably fills the uneven areas first, flows as the runoff yield, which is concentrated in the horizontal direction, and infiltrates in the vertical direction. Because the water transfer area is located in a mountainous region, the value of this index should not be large. Each calculated cell gets a value in the model.

2.4.3 *Infiltration*

Infiltration is an important part of the hydrological process. Different surface, vegetation, soil type and soil moisture conditions result in different infiltration rates. There are many infiltration models in use, of which the Green-Ampt model, Horton model, and Philip model are the mainly accepted models. The Green-Ampt model has been chosen in this study. The equations in this model are shown as follows:

$$f = k(1 + A/F), \tag{1}$$

$$F = kt + A\ln\left(\frac{A+F}{F}\right), \tag{2}$$

$$A = (SW + h_0)(\theta_s - \theta_0). \tag{3}$$

where f is the infiltration rate; F is the accumulation; SW is the soil suction in the humid front; k is the soil hydraulic conductivity in a humid region; θ_s is the volumetric soil water content in a humid region; θ_0 is the initial soil water content; h_0 is the depth of depression storage; and t is time.

In the model, three-layer soil infiltration was considered. Jia reported a general form of the Green-Ampt model in multi-layers under nonstable conditions [24]. The three-layer soil infiltration was determined based on the results of the Jia formula in this study.

2.4.4 *Surface runoff*

Stored-full runoff and runoff generation over infiltration are the most common runoff mechanisms. However, the runoff mechanism is very complex in fact. In China there is more precipitation in the south and east than in the north and west generally. Yalong River basin is located in western China in an area with semi-humid climate characteristics. Considering the infiltration capacity and rainfall intensity, both types of runoff mechanisms were used in the model.

Surface runoff refers to the process by which surface runoff flows into the river along a slope. GIS tools are always used to calculate the flow direction of each cell by the maximum gradient direction method. The equations are presented as follows:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q_L, \tag{4}$$

$$S_{\mathrm{f}}=S_0, \tag{5}$$

$$Q=\frac{A}{n}R^{2/3}S_0^{2/3}, \tag{6}$$

where A is the area of flow section; Q is flow; q_L is the flow per unit width in a cell; n is the Manning roughness coefficient; R is the hydraulic radius; S_0 is the gradient of the surface cell or the vertical gradient of the river; and S_{f} is the friction gradient.

2.4.5 *Confluence from tributaries*

Confluence from tributaries refers to the evolution process by which surface runoff or tributaries flow into the channel. GIS software is used to produce the river net and collect the data from control project and channel sections. The Saint Venant equations are used to calculate the concentration of the channel in this model. The equations are shown as follows:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q_L, \tag{7}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial\left(\frac{Q^2}{A}\right)}{\partial x}+gA\left(\frac{\partial h}{\partial x}-S_0+S_{\mathrm{f}}\right)=q_LV_x, \tag{8}$$

$$Q=\frac{A}{n}R^{2/3}S_0^{2/3}, \tag{9}$$

where V is the velocity of flow section and V_x is the component of velocity of flow per unit width in the x direction. The other variables have the same indications to Section 2.4.4.

2.4.6 *Soil water*

Vegetation growth is influenced by soil water. The calculation will be combined with the situation of infiltration in the model. The Yalong River basin is located in a mountainous area, and the topographic relief and the variability of soil water and soil infiltration indexes must be considered. The soil water in the unsaturated soil layer is calculated as follows:

$$R=k(\theta)\sin(slope)Ld, \tag{10}$$

where $k(\theta)$ is the soil hydraulic conductivity along the slope corresponding to the volumetric water content θ; *slope* is the slope of surface; L is the river length in cells; and d is the thickness of the unsaturated soil.

2.4.7 *Evapotranspiration*

The water is returned to the atmosphere by evapotranspiration for new precipitation. In this study three types of water loss are considered from the land to the air in each cell, i.e., soil evaporation, transpiration, and water surface evaporation.

2.4.7.1 Soil evaporation. Soil evaporation is calculated according to the modified Penman Equation as follows [25]:

$$E_{\mathrm{s}}=\frac{(Rn-G)\Delta+\rho_{\mathrm{a}}C_{\mathrm{p}}\delta e/r_{\mathrm{a}}}{\lambda(\Delta+\gamma/\beta)}, \tag{11}$$

$$\beta=\begin{cases}0 & \theta\leqslant\theta_m,\\ \frac{1}{4}[1-\cos(\pi(\theta-\theta_{\mathrm{m}})/(\theta_{\mathrm{fc}}-\theta_{\mathrm{m}}))]^2, & \theta_{\mathrm{m}}\leqslant\theta\leqslant\theta_{\mathrm{fc}},\\ 1 & \theta\geqslant\theta_{\mathrm{fc}},\end{cases} \tag{12}$$

where β is the soil humidity function or evaporation efficiency; θ is the volumetric water content of surface soil; θ_{fc} is the field water holding of surface soil; and θ_{m} is the soil volumetric water content corresponding to soil single-molecule suction (approximately 1000–10000 at atmospheric pressure) [26].

2.4.7.2 Transpiration. Transpiration is calculated using the Penman-Monteith Equation as follows [27]:

$$E=Veg(1-\delta)E_{PM}, \tag{13}$$

$$E_{PM}=\frac{(RN-G)\Delta+\rho_{\mathrm{a}}C_{\mathrm{p}}\delta e/r_{\mathrm{a}}}{\lambda[\Delta+\gamma(1+r_{\mathrm{c}}/r_{\mathrm{a}})]}, \tag{14}$$

$$\gamma=\frac{C_{\mathrm{p}}P}{0.622\lambda}, \tag{15}$$

$$r_{\mathrm{a}}=\frac{\ln[(z-d)/z_{om}]\ln[(z-d)/z_{ox}]}{k^2U}, \tag{16}$$

where RN is the amount of net radiation; G is the heat flux transported to vegetation; δ is the ratio of humid leaf to total leaf; r_{c} is the impedance of flora; Veg is the vegetation coverage; Δ is the derivative of the saturated water vapor pressure on temperature; δe is the difference between the water vapor pressure and saturated water vapor pressure; ρ_{a} is the air density; λ is the latent heat of vaporization of water; C_{p} is the specific heat of air at constant pressure; P is the atmospheric pressure; r_{a} is the aerodynamic resistance; z is the height of observation point for wind velocity, humidity and temperature; k is the constant of von Karman; U is the wind velocity; d is the replacement height; z_{om} is the surface roughness corresponding to water vapor turbulent diffusion; and z_{ox} is the surface roughness. According to Monteith, if the vegetation height is *hc*, then z_{om} = 0.123 *hc* and *d* = 0.67 *hc*.

2.4.7.3 Transpiration. Water surface evaporation is calculated by the Penman Equation as follows [28]:

$$E = \frac{(RN - G)\Delta + \rho_a C_p \delta e / r_a}{\lambda[\Delta + \gamma]}, \quad (17)$$

where the variables are the same as those described in Section 2.4.7.2.

2.4.8 Habitat area

PHABSIM technology is a proven technology following the IFIM (Instream Flow Incremental Methodology) idea. PHABSIM technology consists of hydraulic simulation and habitat area simulation and is often used to simulate the habitat of fish and the environmental water requirement of rivers. Moreover, hydraulic simulation is mainly used for water surface level-discharge relationship simulation and velocity modeling. The equation for modeling the water surface level-discharge is shown as follows:

$$(WSL - SZF) = aQ^b, \quad (18)$$

where Q is the discharge; WSL is the water surface elevation; SZF is the stage of zero flow; a is the constant derived from the measured values of discharge and stage; and b is the constant derived from the measured values of discharge and stage.

The velocity is simulated by the Manning Equation as follows:

$$V = \frac{1.486}{n} S^{1/2} R^{2/3}, \quad (19)$$

where V is the velocity; n is the coefficient of roughness; S is the slope; and R is the hydraulic radius.

To calculate the habitat area, the Weighted Usable Area (WUA) is the target of habitat area simulation. The habitat area in different hydraulic conditions is often described by the curve of the discharge-weighted usable areas. The equation is shown as follows:

$$WUA = \sum_{i=1}^{n} A_i C_i / \mathrm{Re}\,achlenth \text{ (1000 m)}, \quad (20)$$

$$C_i = HSC_v \times HSC_d \times HSC_{cl}, \quad (21)$$

where WUA is the weighted usable area; A_i is the surface area of the cell i; C_i is the combined suitability of the cell i; n is the number of calculations; HSC_v is the suitability associated with the cell velocity in cell i; HSC_d is the suitability associated with the depth in cell i; and HSC_{cl} is the suitability associated with the channel index in i. The value range of HSC_v, HSC_d, and HSC_{cl} is 0–1.

3 Results and discussion

3.1 Impact on the river corridor

3.1.1 Impact on river water quantity

The river corridor consists of the river channel and both sides of the shore zone with a horizontal and vertical spatial structure. The shore zone is composed of riparian plant communities, floodplains and other elements (Figure 3). The river channel between the water transfer dams and the Lianghekou Reservoir was analyzed in this study.

ArcGIS 9.0 software was used to analyze the digital elevation data and to develop the river net from this process. According to the sites of the dams, county boundaries, hydrology station, estuary and other controlling sections, the channel was divided into 19 segments. The catchment area above each section, catchment area, the length of the river intervals and the confluence of water in the lower reaches of the water transfer dam were calculated (Table 2).

The ratio of the dam water transfer quantity to the multi-year mean runoff of engineering section ranged from 65.27% to 69.17%. Based on the confluence volume between the dam section and the estuaries to the river channel, the ratio of the dam water transfer quantity to the multi-year natural mean runoff was gradually decreased. According to statistical analysis, the ratio was reduced to 13.7%–44.6%. In the Lianghekou Reservoir section, the ratio was 37.92%, and in the Daqu River and Niqu River to the Xianshui River Estuary, the ratio was 23.3%. The ratio of the total water transfer quantity of the Daqu River, Niqu River and Yalong River to the flow in the Lianghekou section was 31.66%. The impact of the project on river channel runoff was less along with the increased distance of the section from the water transfer dam.

3.1.2 Impact on the river channel hydraulic indexes

After the completion of the project, the flow of the river downstream from the dam will be reduced. Particularly, the

Figure 3 Typical river corridor in the Yalong River. a, Farmland; b, riparian plant community; c, floodplain; d, river channel.

Table 2 Statistics of flow in the lower reaches of the water transfer dam

River	Range of interval	Interval area (km^2)	Interval length (km)	Confluence of water (billion m^3)
Yalong River	Above Reba Dam	26535	–	6.087
	Reba Dam to the boundary of Dege and Ganzi counties	1411	26.8	0.338
	The boundary of Dege and Ganzi counties to A’da	285	19.2	0.078
	A’da to Ganzi county	4888	50.4	2.062
	Ganzi county to the boundary of Ganzi and Xinlong counties	469	11.8	0.137
	The boundary of Ganzi and Xinlong counties to Xinlong county	2898	85.5	0.840
	Xinlong County to the boundary of Xinlong and Litang counties	5925	98.5	1.878
Daqu	Above A’an Dam	3487	–	1.030
	A’an Dam to the boundary of Ganzi and Luhuo counties	498	43.5	0.152
	The boundary of Ganzi and Luhuo counties to estuary of Daqu	1219	66.6	0.390
	A’an Dam to estuary of Daqu	1717	110.1	0.542
Niqu	Above Renda Dam	4650	–	1.146
	Renda Dam to the boundary of Ganzi and Luhuo counties	633	30.9	0.196
	The boundary of Ganzi and Luhuo counties to estuary of Niqu	1577	78.1	0.629
	Renda dam to estuary of Niqu	2210	109.0	0.825
Xianshui River	The connection of Daqu and Niqu to the boundary of Luhuo and Daofu counties	880	36.9	0.332
	The boundary of Luhuo and Daofu counties to Daofu County	1521	32.4	0.588
	Daofu County to the boundary of Daofu and Yajiang counties	4278	79.1	1.788
	The boundary of Daofu and Yajiang counties to estuary of Xianshui River	595	25.7	0.119
	The connection of Daqu and Niqu to estuary of Xianshui River	7274	174.2	2.827

water depth, velocity of flow, channel width and river runoff will be influenced directly, leading to reduced eco-environmental safety in the river channel. In the lower reaches of the dam the flow into the river channel will be reduced in the river reaches, resulting in a decline in the hydraulic indexes. In the Yalong River basin the changes in the velocity of flow, channel width, run off and water depth in the Ganzi, Zhuba and Daofu sections were calculated and analyzed. The Ganzi section is 96.4 km away from Reba Dam in the mainstream of the Yalong River, while the Zhuba section is 109 km away from Renda Dam in the Niqu River. The Daofu section is 69.3 km away from the connection between the Daqu and Niqu rivers and 155 km away from the A’an Dam in the Daqu River.

Velocity of flow. Figure 4 presents the changes in the monthly means velocities of flow after water transfer in the Ganzi, Daofu and Zhuba sections. After water transfer, the monthly average velocity of flow was decreased. In particular, during the flood period, the values were decreased by 26.78%, 28.14% and 24.33% in the Ganzi, Daofu, and Zhuba sections. However, the proportions of the velocity of flow were only reduced by 16.95%, 15.12% and 15.12% in the non-flood period. Compared with the monthly mean velocity of flow, the change in both velocities of flow was greater in the Zhuba and Daofu sections than in the Ganzi region.

Channel width. Figure 5 presents the changes in the monthly average channel width after water transfer in the Ganzi, Daofu and Zhuba sections. The channel width reached a maximum of 146.8 m in Ganzi among the three sections, while a minimum of 40.7 m was reached in Zhuba. After the water transfer, the channel width changed more in the flood period than in the non-flood period. In these three sections, the monthly mean channel width was reduced by 14.81%, 8.2% and 4.78% in the flood period, while the channel width was reduced by 10.21%, 3.1% and 1.59% in the non-flood period. Due to water from the tributaries flowing into the river channel between the dams and calculated sections, the impact on channel width was reduced with increasing distance between the water transfer dam and calculated sections.

Runoff. Figure 6 presents the changes in the average monthly runoff after water transfer in the Ganzi, Daofu and Zhuba sections. The runoff in Ganzi was maximal among the three sections at the same time of the year, while the minimum was reached in Zhuba. After the water transfer, the runoff tendency did not change. However, the quantity of runoff was reduced. The maximum runoff in the Ganzi section has declined from 603.6 $m^3 s^{-1}$ to 287.9 $m^3 s^{-1}$ after water transfer. The runoff in the flood period also changed greatly, and runoff was decreased by 55.6%, 43.97% and 38.77% in the flood period and 34.78%, 22.16% and 20.69% in the non-flood period. In general, the water transfer project has greatly impacted the average monthly runoff.

Water depth. Figure 7 presents the changes in the monthly average water depth after water transfer in the

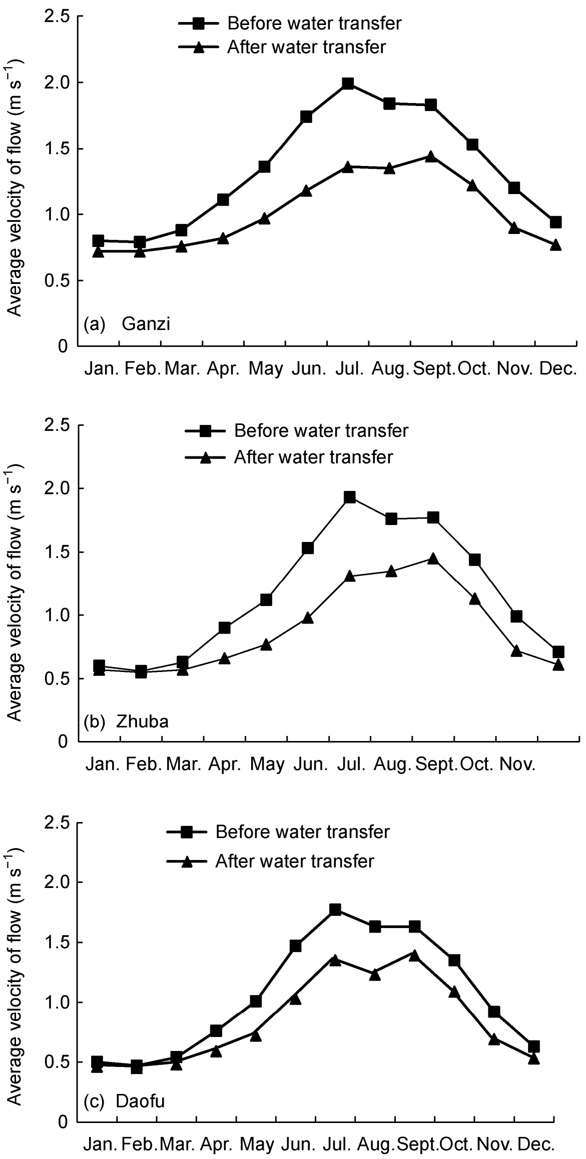

Figure 4 Impact on the average velocity of flow of the Yalong River.

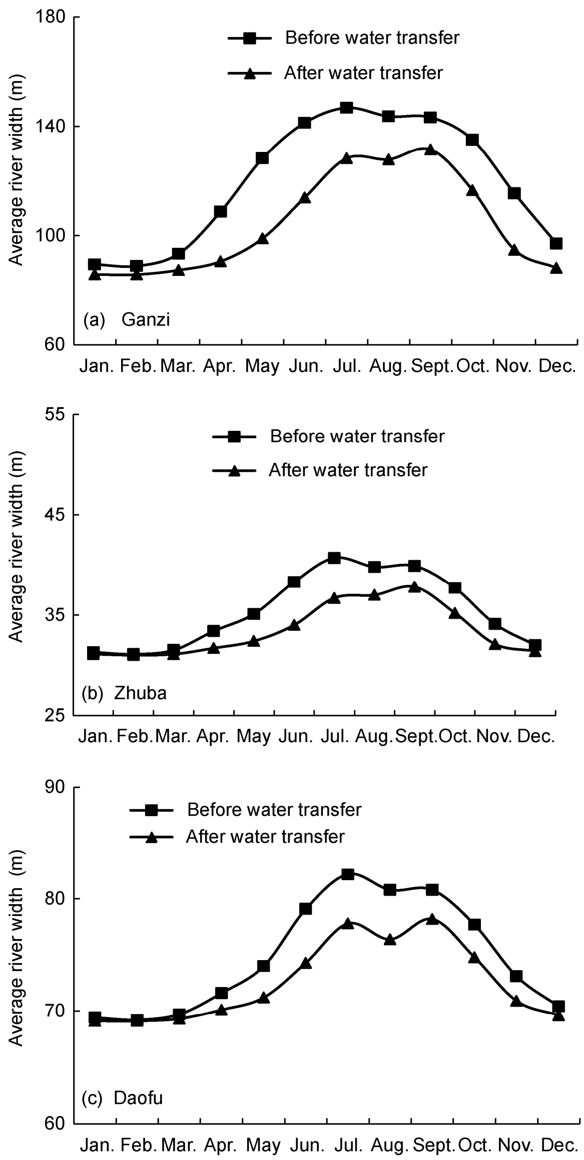

Figure 5 Impact on the average channel width of the Yalong River.

Ganzi, Zhuba, and Daofu sections. The water depth ranged from 0.5 to 2.5 m, and the deepest position reached 2.17 m in the Daofu section during the flood period. The water depth changed more in the Ganzi section than in the Zhuba and Daofu sections. Water depth declined by 28.16% in the Ganzi section and by 15.69% and 15.52% in the Zhuba and Daofu sections, respectively.

Based on the analyses of the impact of the project on the hydraulic indexes of the river corridor, the project has a greater influence on the river corridor in flood periods than in non-flood periods. The Ganzi section is affected more than the other two sections for two main reasons. First, the water transfer quantity of Reba Dam in the upper reaches of the Ganzi section is greater than the other two dams. The other reason is that the distance between the Ganzi section and Reba Dam is short, resulting in little catchment area for water flow to the river channel.

3.2 Impact on the wet land

3.2.1 Distribution of wet land

The wetland area is calculated according to the land use of Sichuan Province in 2000. Based on statistical analysis, the wetland area in the Yalong River was 674.36 km^2 in 2000. The area is 530.98 km^2 in the upper reaches of the three dams and 143.38 km^2 in the lower reaches. The Yalong River wetland is located at the dishing hollow, valley sides and flood land, such as the sources of the Daqu and Niqu rivers. The classic types of the Yalong River wetland consist of meadow and alpine peat wetlands. The wetland area is small in the lower reaches of the dams. The ratio of wetland which has hydraulic relationship with the river channel to the total wetland area in the lower reaches of the dams is 36.42%, and the other wetlands are located at the source of tributaries or lowlands with no hydraulic relationship.

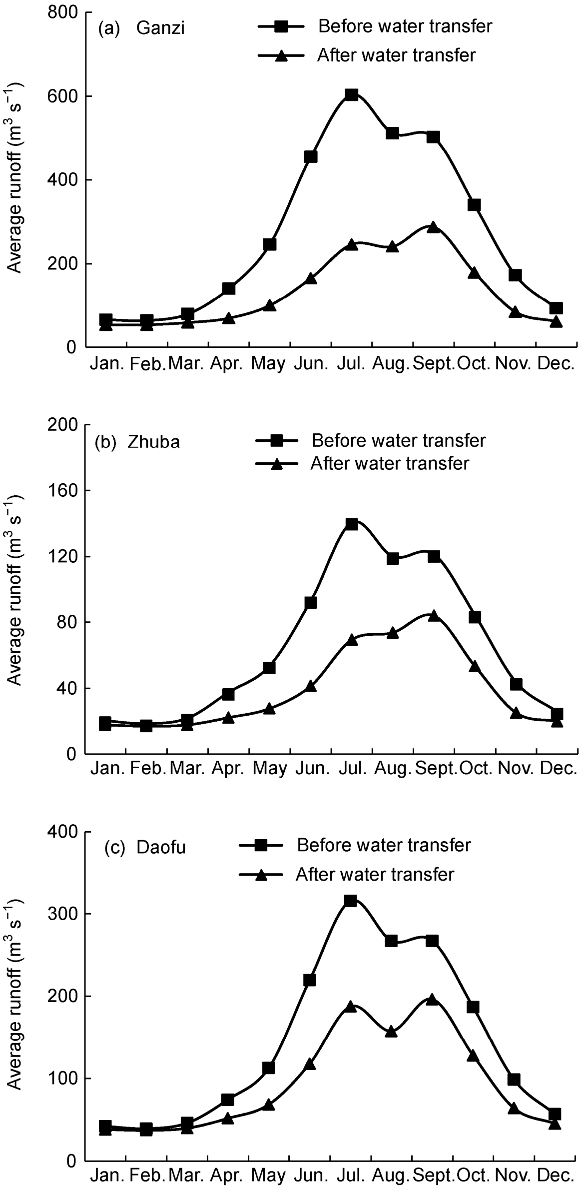

Figure 6 Impact on the average runoff in the Yalong River.

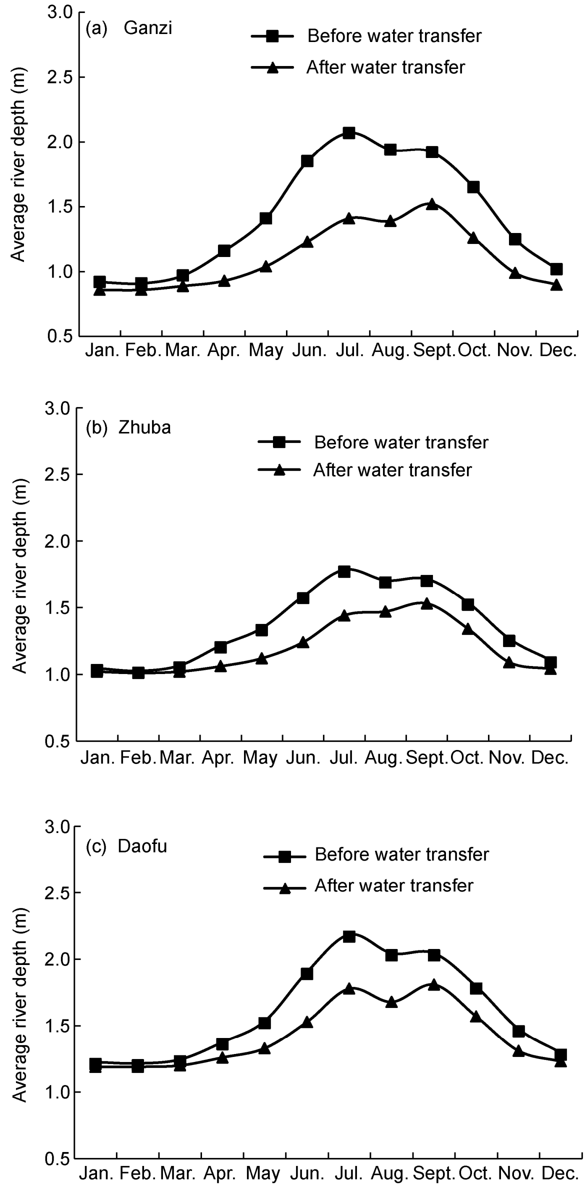

Figure 7 Impact on the average water depth of the Yalong River.

The wetland located in the upper reaches of the dams will not be affected by the project. In contrast, the wetland area will increase due to water level raised by the dams. Other wetlands are located in the lower reaches of the dams, most of which are shown as independent systems with no hydraulic relationship to the river channel. And these wetlands will not changed by the water transfer.

3.2.2 Kasha Lake

Kasha Lake is a wetland nature reserve located between the Yalong River mainstream and Xianshui River (Figure 1). However, no water from either river flows into the lake, and the main protection targets of the lake are the wetlands and birds. As a large water area in the water transfer region, it is necessary to analyze the impact on Kasha Lake.

To maintain a certain lake area, the following conditions must be considered: the evaporation of lake; the precipitation; and the seepage amount of the lake. Due to lack of data, the seepage has not been taken into account, and that means the water storage of the wetland will not be lost. As long as the net water loss of the lake is met, the lake area will not be changed, and the living environment supporting the wetland biology will be suitable. In this specific area the water budget balance is described by the following equation:

$$Q_n = (E - P)A, \tag{22}$$

where P is the multi-year mean precipitation; E is the multi-year mean evaporation; and Q_n is the net water loss; A is the lake area.

According to the data from Luhuo Weather Station, the multi-year mean precipitation is 675.8 mm in a year with normal precipitation (p=50%) and 598.2 mm in a year with low precipitation (p=75%). With the lake area in different years, the net water loss of the lake was calculated in a wet and dry year giving total values of 1.1843 million m^3 and 1.1972 million m^3, respectively. The values in the different months of a year can be observed in Figure 8.

Figures 8 (a) and 8(b) show the net water loss process of Kasha Lake due to evaporation in high and low precipitation years, respectively. Based on Figure 8, the net water loss can only be met by normal precipitation during the flood months of June, July, and September, while in a low precipitation year the loss cannot be met in any month. Not considering the water loss from A'an Dam to Kasha Lake, the multi-year average surface runoff flowing into the lake was 0.41 billion m^3. The maximum net water loss is 1197200 m^3, only 0.3% of the surface runoff flowing into the lake, indicating that the water transfer project has little influence on Kasha Lake.

3.3 Impacts of water transfer on the habitat area of *Schizothorax*

Schizothorax is a typical fish in the Yalong River, which is mainly distributed in the upper reaches of the Yalong River but less in the tributaries, i.e., Xianshui, Daqu, and Niqu rivers. The reaches between the Ganzi Hydrological Station and Reba Dam was chosen for research with the length of 96.4 km in this study. According to the relevant literature, the velocity, depth and channel indexes were confirmed to be suitable in Table 3 [29].

The observed discharge in Ganzi Hydrological Station ranged from 40 to 1500 m^3 s^{-1}, where modeling discharge should exist. In the calculation, 9 discharges are set, i.e., 30, 50, 80, 250, 750, 850, 1000, 1200 and 1500 m^3 s^{-1}, of which 80, 250 and 750 m^3 s^{-1} are set as the calibration discharges. In the model the absolute error of water surface level is controlled below 3 cm. The calculated result of the weighted usable area is shown in Figure 9.

According to Figure 9, the trend of the change in the *Schizothorax* WUA with discharge in the study reaches is shown as wavy change, which can be separated into four stages. In the first stage (0–250 m^3 s^{-1}), the WUA is increased with the growth of discharge. In the second stage (250–800 m^3 s^{-1}), WUA changes little with the increased discharge. In the third stage (800–1000 m^3 s^{-1}), WUA exhibits the same trend as in the first stage. However, the WUA declines with increasing discharge in the fourth stage (beyond 1000 m^3 s^{-1}).

According to the data observed at Wenbo Hydrological Station, near the upper reaches of Reba Dam, the annual average discharge ranged from 60 to 150 m^3 s^{-1} (1993–2004) [29]. It can be judged that the discharge from Reba Dam is in the first and second stages in Figure 9. Because water transfer project would transfer approximately 70% of the discharge in the section of Reba Dam, the annual average discharge will decline to 18–45 m^3 s^{-1}. According to Figure

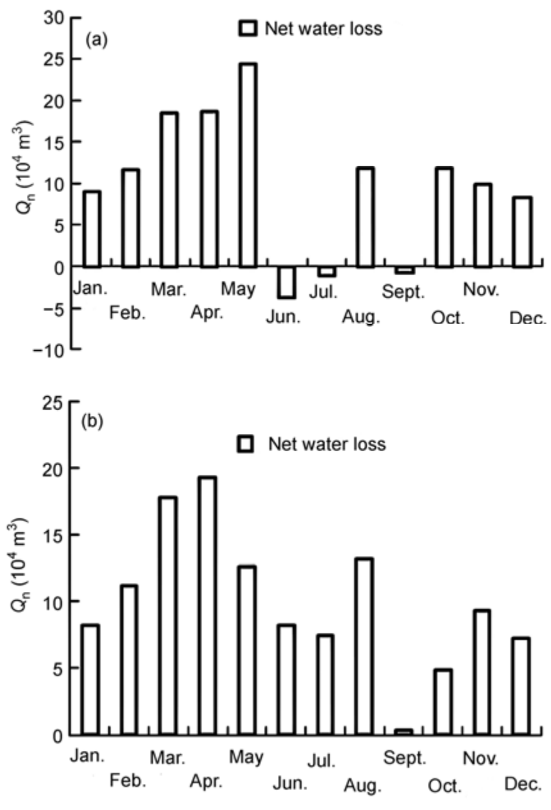

Figure 8 Net water loss process of Kasha Lake due to evaporation. (a) In a high precipitation year; (b) in a low precipitation year.

Table 3 *Schizothorax* HSC criteria coordinates

Velocity (m s^{-1})	HSC_v	Depth (m)	HSC_d	*Cl*	HSC_{cl}
0	0	0	0	0	0
0.2	0	0.3	0	1	0
0.45	1	1	1	2	1
1.74	1	3	1	3	1
3	0	5	0	4	0
100	0	100	0	100	0

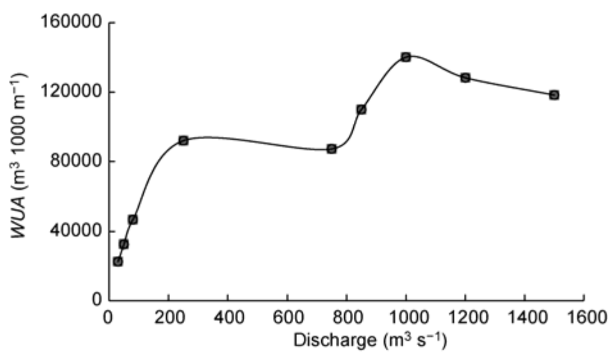

Figure 9 Estimation of the *WUA* for *Schizothorax.*

9, the WUA will decline to 15808.82–30154.62 m^2 1000 m^{-1}. Compared with the value before the water transfer, the WUA and the range declined by 41.33% and 58.23%–71.94%, respectively, indicating that the water transfer has an obvious influence on the habitat area in the lower reaches of Reba Dam. Under the current conditions of water transfer, the existence of *Schizothorax* in the Yalong River will be seriously affected.

4 Conclusions

Based on a premise that does not account for eco-social impacts, the framework of the relationship between hydrology and ecology has been established to describe the interaction between them and to evaluate the impact of the project on the water transfer area. An ecohydrological method has been used to assess the impact of the project on the eco-environment of the river corridor, wetlands and *Schizothorax* in the water transfer area from a new perspective. Several conclusions can be drawn as follows:

(1) After 5.65 billion m^3 of water are transferred from the Yalong River basin, the river corridor will be influenced to varying extents, while the wetland will not be significantly affected by the project. *Schizothorax* will be influenced much in its living area.

(2) The velocity of flow, channel width, runoff, and water depth are affected in different spatial and temporal extents. The project influences the four indexes more during the flood period than in the non-flood period. The Ganzi section is more affected than Zhuba and Daofu sections. The runoff is influenced the most among the four indexes, while the channel width is influenced the least. The runoff in the Ganzi, Zhuba, and Daofu sections after water transfer is reduced by 55.6%, 43.97% and 38.77% in the flood period, respectively. The channel width in the Ganzi, Zhuba, and Daofu sections are decreased by 14.81%, 8.2%, and 4.78%, respectively, in the flood period. The velocities of flow in the three sections are affected with the same trend by the water transfer project, declining by 26.78%, 28.14%, and 24.33%. The project has a greater impact on water depth in the Ganzi section than in the Zhuba and Daofu sections.

(3) The project only influences the wetlands that have a hydraulic relationship with the river channel. And the project will affect the wetlands in the lower reaches of the dams more greatly than those in the upper reaches of the dams. Approximately 36.42% of the wetland area in the lower reaches of the dams has a hydraulic relationship with the river channel, which will be influenced by the project in the dry season. The net water loss of Kasha Lake cannot be met in either high- or low-precipitation years, except in the months of June, July and October. However, the ratio of the net water loss to the total surface runoff flow into Kasha Lake is only 0.3%. The project has little influence on the existence of Kasha Lake.

(4) Water transfer from Reba section will affect the existence of *Schizothorax* in the upper reaches of the Yalong River. After 4.2 billion m^3 of annual water is transferred from Reba Dam, the WUA of this species will decline by 41.33%, and the range of change will decline more than 50%.

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