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Restoration design for Three Gorges Reservoir shorelands, combining Chinese traditional agro-ecological knowledge with landscape ecological analysis

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ABSTRACT

One of the greatest challenges associated with the Three Gorges Dam and Reservoir is the massive extent of the drawdown zone, causing soil erosion, loss of habitats, and landscape aesthetic degradation. Through two rounds of field and interview surveys, we have re-engaged with traditional agro-ecological knowledge as a source of solutions to these challenges. A modified pond-land terrace (MPLT) land/water use system is proposed to maximise shoreland conservation and associated ecosystem services based on local practices of paddy terrace and dike-fish pond farming. The MPLT system has a functional structure comprising water retention ponds at the top, vegetation fields in the middle, and the reservoir lake at the bottom. The design of the system is described in detail in this article by reference to the Wuyang Bay in an urban wetland park. Face-to-face questionnaire survey revealed that the community holds a positive willingness to participate in the MPLT project. Given significant environmental uncertainties in this region, post-construction monitoring is recommended for an extended period in order to determine how its benefits meet the predictions and further inform adaptive management and refinement of the system. The results illustrate the value of combining modern ecological design with traditional land-based knowledge and community engagement when seeking innovative, site-specific, and multifunctional landscape solutions to changing environments.

1. Introduction

Water levels of the Three Gorges Reservoir (TGR) are operated between 145 m during summer and 175 m above sea level during winter. This is opposite to natural river flooding rhythms in China. It has created a complex and completely new ecosystem – drawdown zone – surrounding the TGR, with a total area of 348.9 km^2. The long, erratic water impoundments have brought environmental and social challenges to local people, such as soil erosion, biodiversity reduction, bio-invasion, loss of capacity for filtration of non-point source pollution from the uplands (Huang, 2001; New and Xie, 2008; Yuan et al., 2013), as well as loss of cultural heritage and riverscape aesthetics significant for the tourist industry.

Great opportunities exist to improve drawdown zone ecosystem performance by application of ecological design and management (Mitsch et al., 2008; Yuan et al., 2013). Ecological approaches embrace the notion of mediating human destructive impacts on the environment through working with natural processes (Van der Ryn and Cowan, 2007). They incorporate wider consideration of physiography, climate, vegetation, wildlife, and thereby encourage the development of multifunctional landscapes that deliver ecosystem services and poverty alleviation (McHarg, 1969; McNeely and Scherr, 2003; Nassauer and Opdam, 2008).

Human interactions with nature are often neglected in ecological engineering. However, improved human-ecological design models have been developed to recognise human-nature dependency and “cultural cohesiveness” (Forman, 1995). The ways of integrating cultural considerations are diverse and many projects are conducted largely on a case by case basis (Moshia et al., 2008; Yahner et al., 1995). The overall principle is that design needs to be culturally sensitive: respect local values and knowledge through

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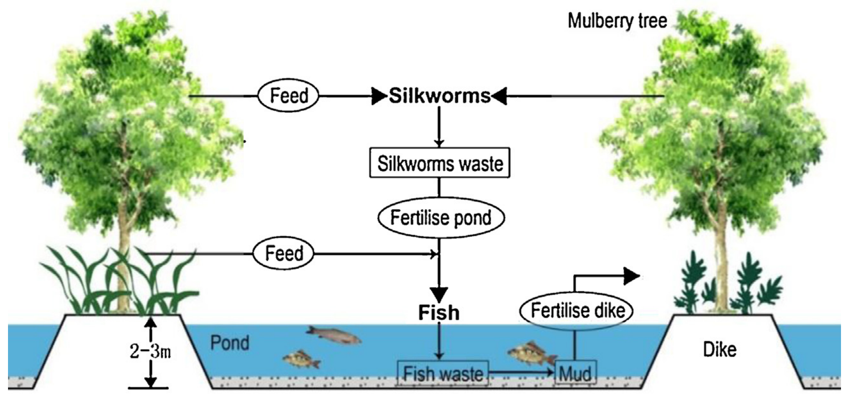

Fig. 1. Concept diagram of traditional dike-fish pond model from southeast China.

integrating bio-physical and socio-cultural inventory of the local environmental history and historical landscape use (Ndubisi, 2002; Steinitz, 1990).

Traditional agro-ecological knowledge is a pivotal source of inspiration for more sustainable solutions to today's environmental problems (Martin et al., 2010). Incorporating such knowledge into eco-friendly land management has recently been practised in the TGR region (Willison et al., 2012; Yuan et al., 2013). For example, dike-pond engineering based on traditional mulberry dike-fish pond, was experimented within Laotudi Bay, Pengxi River, Kaixian (Li et al., 2011). Traditionally, the mulberry trees feed silkworms for sericulture, and waste from the silkworms and poultry provides extra food for the fish, while the accumulated fish waste at the bottom of the pond is dredged and used as fertiliser for the mulberry trees along the dikes (Fig. 1). This integrated system maximises the use of land and water resources, recycles nutrients and captures energy within an overall balanced ecosystem (Ruddle and Zhong, 1988; Zhong, 1982). A recent variant is employed in coastal lowlands to overcome seasonal inundation and salinisation. There the dikes are usually cultivated in a rice-sugar cane rotation with interpolated vegetables (Ruddle and Zhong, 1988). This brings economic benefits to local people in otherwise unproductive coastal land.

Our proposal for rehabilitating the drawdown zone is a modified pond-land terrace (MPLT) system based on hybridising long-established farming practices from southern China and modern ecological restoration design analysis. It was applied to Hanfeng Lake, which became the second largest urban lake in China as a result of TGR formation within Kaixian. With its unique landscape and rich rural culture, it has been designated a national urban wetland park. One of the goals of the park is to use the drawdown land wisely and combine environmental protection and landscape aesthetics to create a multifunctional land use exemplar for other similar locations (Chongqing University, 2010).

Some sections of the drawdown zone around the Hanfeng Lake are already hardened with concrete to protect the shoreline from erosion[1]. Compared with such conventional riverscape practices in China, our design is intended to demonstrate an optimised, ecologically sound shoreland management that is visually and culturally desirable. From 2011 our interdisciplinary team began a comprehensive investigation of local land management practices and environmental variables such as topography, soil types and hydrological conditions. It is anticipated that it will be a valuable reference for comparable areas which have the intention of promoting local culture, ecological integrity and landscape aesthetics against the background of rapid urbanisation and increasingly complex, dynamic environments.

2. Methodology

2.1. Site description

Kaixian of Chongqing Municipality is a new town relocated to higher ground to make way for the TGR. Pengxi River, one of the most important primary tributaries and recharge sources of the Yangtze River, meanders through Kaixian urban areas (Fig. 2). To minimise the adverse effects of dramatic seasonal flooding on the city, a dam has been constructed on the Pengxi River and forms Hanfeng Lake. When the dam is in use, the Hanfeng Lake is operated above a minimum of 170.28 m during summer, by contrast the TGR falls to 145 m. During winter, both TGR and Hanfeng Lake are held at 175 m. Nevertheless, Kaixian has a drawdown zone of 58 km^2, the largest of any town/county within the TGR catchment. The affected land is generally 220–800 m wide on each side (Zhang and Zhu, 2005), of which 72% was previously used for agriculture.

Hanfeng Lake Urban Wetland Park was established with a total area of 13.03 km^2 and drawdown zone area of 3.74 km^2, mainly surrounded by urban and suburban land. The demonstration project (31°10′55″N, 108°27′45″E) is being carried out between the 170.28 m to 179 m elevations on Wuyang Bay of Hanfeng Lake. The total project area is 1.6 ha. Previous land uses were paddy farming, cropping on the flats, and scattered forest which still remains on steep slopes (Fig. 2).

The region has a northern subtropical humid monsoonal climate with an average annual precipitation of 1200 mm, 60–80% concentrated between April and September. The mean air temperature is 18.2 °C, and there are less than 20 frost days per year. The main soil types at the project site are paddy soil (below 173 m) and purple soil. Subtropical broad-leaved evergreen forest is the regional climax vegetation.

2.2. Methods

2.2.1. Data

This study used 2002 SPOT imagery (10 m resolution) and 2012 high resolution (0.5 m) satellite aerial photography to produce

[1] From Kaixian 2012 satellite aerial photography, we calculated that currently for some urban sections of Hanfeng Lake, manicured shoreline greening (trees and flower beds) accounts for 30% of the shoreline plaza.

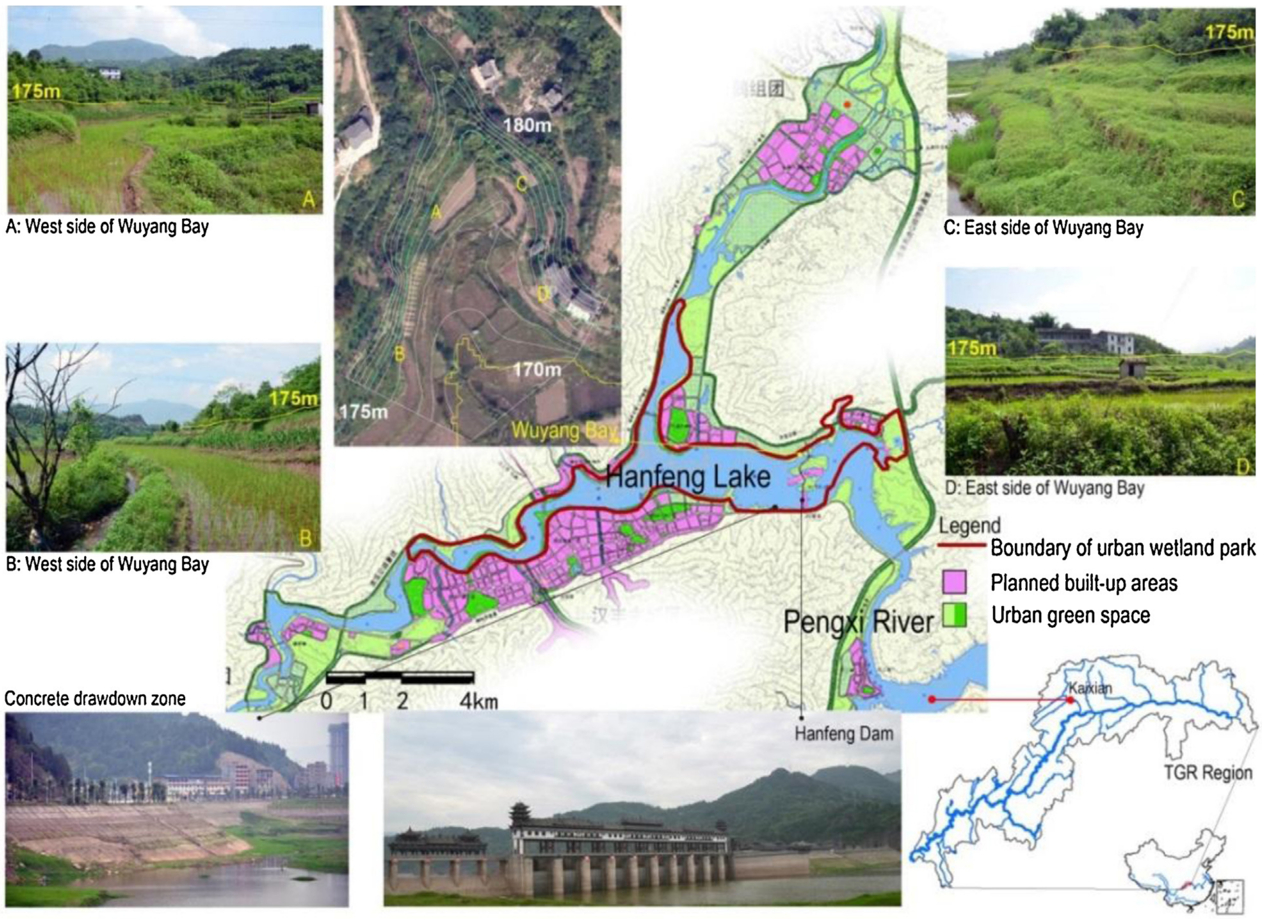

Fig. 2. Location and illustrations of demonstration site in Wuyang Bay on Hanfeng Lake of Kaixian.

digital land use/cover maps before and after reservoir operation. The images were rectified and geo-referenced against a 2010 topographic map (1:2000). Land use/cover categories were created by the object-based classification method in Envi 5.0 (Exelis Visual Information Solutions, Boulder, CO, USA) and ArcGIS 10 (ESRI, Redlands, CA, USA) combined with field survey and ground-truthing. The overall analysis framework is shown in Fig. 3.

2.2.2. Surveys on traditional knowledge and people's attitudes towards the design

Traditional farming knowledge and practices related to natural resource management were revealed through field observation and household-based structured interviews with local people (Balram and Dragićević, 2005; Farizo et al., 2014; Jim and Chen, 2006). The respondents living around the site were selected and asked about their general economic status and agricultural practices, including types of crops, poultry and how they plant/rear them (details see Supplement). Field measurement clarified how the traditional systems work. For instance, we measured less runoff and soil erosion under a land preservation treatment (terraced slopes with straw mulching) than for slopes without such treatment. We also worked alongside farmers in their fields to deepen our understanding of indigenous values and practices (Butler, 2006; Pinto-Correia and Kristensen, 2013). Through this close collaboration we could test our design ideas and learn what the farmers considered to be practical and desirable.

After completion of the design draft, a second survey was conducted. Aside from those farmers who were resurveyed, visitors to Hanfeng park were randomly chosen for face-to-face interviews. We presented them with 5 digital photos showing different views of the current status of the site and 5 showing the effects of MPLT development, and asked about acceptability of the design

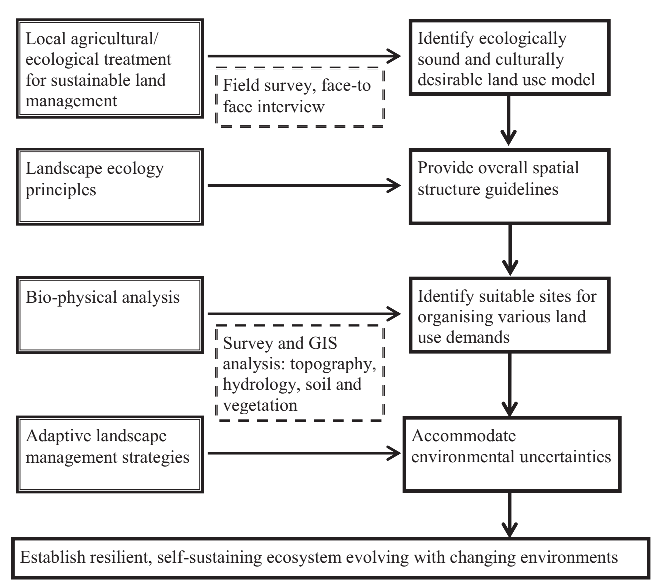

Fig. 3. The framework used to develop a resilient, self-sustaining ecosystem for the TGR shorelands.

(attitudes towards the MPLT system), and if they would be willing to participate in building, management and maintenance the system (willingness to help). Responses were recorded on a five-step Likert scale from highly approve or willing to disagreement or unwilling (Jim and Chen, 2006).

2.2.3. Landscape ecology principles

Landscape ecology provides spatially explicit models that connect configuration with ecological functions and processes on a range of scales (Forman, 1995; Turner et al., 2001). The patch–corridor–matrix model proposed by Forman (1995) is the widely accepted spatial norm for creating networks that maintain ecosystem stability and integrity (Opdam et al., 2006; Taylor et al., 1993).

Patches are the basic unit of the landscape that regulate fluxes of matter and energy in an ecosystem, a process called patch dynamics (Forman, 1995). The characteristics of natural patches (e.g. size, shape, location and species composition) are critical to nature conservation as they may preserve endemic or unique habitats, and provide "stepping stones" that facilitate species' dispersal (Saura and Rubio, 2010; Shafer, 1990). In this exercise, we focus on the preserving patches of remnant native vegetation to form a "native bush patch – road corridor – restored terrace vegetation matrix" network to strengthen the restoration efforts.

2.2.4. Bio-physical analysis

Four main bio-physical factors (topography, soil, hydrology and vegetation) were investigated. Based on a digital elevation model (DEM), the site topography was analysed by Spatial Analyst Tools in ArcGIS 10 (see Supplement). Five to six soil samples from each metre elevation were collected in summer 2012 at a depth of 30 cm. The pH was measured in a 1:2 soil–water slurry with a glass electrode pH meter.

Several transect surveys of floristic composition and structure were carried out around Hanfeng Lake and Pengxi River (Chen et al., 2014). It was expected that the surviving plants, after several full cycles of water fluctuation, would form comparatively stable communities as a result of natural selection (see Supplement).

Runoff and soil erosion from the upland influent catchment were calculated to determine required pond dimensions for the MPLT system.

2.2.4.1. Runoff calculation. The widely used Soil Conservation Service model (SCS) was applied to estimate runoff from the influent catchment (USDA, SCS, 1972; Zheng et al., 2008). The data used, its source and type of analysis are listed in Table 1. The SCS model is defined in Eq. (1).

$$Q_i = \frac{(P-0.2S_i)^2}{P+0.8S_i} \quad (P > 0.2S_i) \tag{1}$$

$$Q_i = 0 \quad (P \le 0.2S_i)$$

$$S_i = \frac{25,400}{CN_i} - 254$$

$$R = \sum_{i=1}^{n} Q_i \times L_i$$

where R is the runoff yield (m^3). Q_i is runoff depth (mm) for land use type i. L_i is the area of land use type i. P is the precipitation, assuming a uniform depth of precipitation across the influent catchment. We calculated the storage capacity of water-harvesting ponds for a 10-year storm event (1999 to 2011) without overbank flooding rather than cumulative average annual runoff. S_i is potential maximum retention or infiltration (mm) for a particular land use type i. It is caculated by the form of a dimensionless runoff Curve Number (CN). CN is the key parameter determined by soil antecedent moisture condition (AMC), soil type, land use/cover, rainfall duration and intensity (see Supplement). Each land use type i has its own CN_i and values range from 0 to 100 (USDA, SCS, 1972).

Table 1
Data used for calculation of runoff from the upland.

Data	Source	Explanation/analysis
Land use/cover	2012 High resolution (0.5 m) satellite aerial photography of Kaixian from Chongqing Public Service Platform for Geographic Information	The classification includes: 1. Rural residential areas; 2. Roads (urban and rural); 3. Exuberant forestland; 4. Sparse forestland; 5. Cropland; 6. Vegetable land; 7. Paddy fields; 8. Ponds; 9. Orchards
DEM	Chongqing Kaixian County Land and Resources Authority	Derived from topographic map on the scale 1:2000
Soil type and distribution	Chongqing Kaixian County Land and Resources Authority	The scale is 1:2000
Precipitation	Kaixian Hualin Hydro-meteorological Station	1999–2011 monthly precipitation (mm)

2.2.4.2. Soil erosion calculation. We estimated the annual average sediment yield using the worldwide applied RUSLE model (Revised Universal Soil Loss Equation) described in Eq. (2) (Wischmeier and Smith, 1978).

$$\begin{aligned} A &= R \times K \times LS \times C \times P \\ S &= A \times Ar \times sdr \end{aligned} \tag{2}$$

where S is the total soil loss of the whole area Ar of the influent catchment. sdr is the sediment delivery ratio. A is the spatial average soil loss per unit area over a selected period, usually on a yearly basis (t ha^{-1} yr^{-1}); R is the rainfall erosivity factor in units (MJ mm ha^{-1} h^{-1} yr^{-1}); K is the soil erodability factor (t h MJ^{-1} mm^{-1}); L is the slope length factor (dimensionless), S is the steepness factor (dimensionless); C is the cover and management factor (dimensionless, ranging between 0 and 1.5); and P is the erosion control (conservation support) practices factor (dimensionless, ranging between 0 and 1). All required data are listed in Table 1. Each factor was extracted and calculated in ArcGIS 10.

2.2.4.3. Water level fluctuation analysis. Since the Hanfeng Lake Dam is not yet fully operational, the current water level fluctuation is different from the future regime. Many relevant studies on this particular area have generally adopted the water levels recorded from the TGR Hydro-meteorological Station which directly observes the water levels at the TGR Dam (Johnson and Rainey, 2012; Li et al., 2011; Wang et al., 2012a). We used the 1D hydrodynamic model to estimate Pengxi River water levels and calculated the inundation duration (the model application refers to Li et al., 2012b). The model uses the 1:2000 topographic map of Pengxi River, daily water levels and volume of the TGR (HoY, 2012) and Wanzhou stations (CQWRB 2012) from 2011 to 2012.

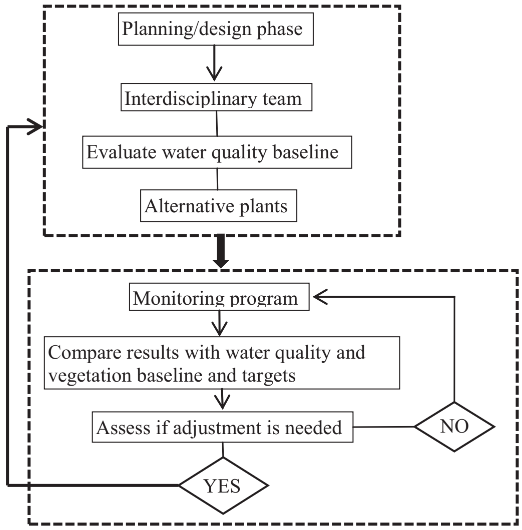

Fig. 4. Adaptive landscape management for MPLT system in two phases.

2.2.5. *Adaptive landscape management strategy*

There are many environmental uncertainties arising both from the reservoir operation and natural events. First, although the reservoir operations are regimented and predictable in general, the water levels are affected by external factors. The most chaotic is extreme weather caused by global and regional climate change, and this in turn may be exacerbated by water usage in upstream regions. Such variations directly affect soil-hydrological condition which is a key driver of nutrient flow, organism dispersal and mortality, and other ecological processes in aquatic environments (MacDonagh et al., 2009; Mitsch and Gosselink, 2000). Therefore, failure of some plants that do not fit the new environments, can be expected even when the plant species are originally selected on the basis of field survey and experiment.

Second, water submergence duration and frequency affects land stability. Without concrete hardening of banks, it is anticipated that the terraces would be subject to movement. Third, herbicides or pesticides are not permitted. Invasive weeds and pests are therefore anticipated to threaten the project given the current spread of species such as the aquatic weed *Alternanthera philoxeroides* and the snail *Pomacea canaliculata*.

It is therefore necessary to design for changing conditions using adaptive management strategies. Adaptive management is a “learning by doing” or “trial and error” iterative process that progressively reduces uncertainty and achieves the desired ecosystem structure and function through continual system monitoring and refinement (Bormann and Kiester, 2004; Moore and Conroy, 2006; Williams, 2011). According to these principles, we address the uncertainties in two phases (Fig. 4):

(1) Planning/design phase: an interdisciplinary team of ecologists, engineers, landscape architects and community residents was set up for problem solving. For example, invasive weeds may only be realistically managed through mechanical or bio-control methods (e.g. releasing natural predators of insect pests, herbivorous fish, or specific fungal agents, see Sainty et al., 1997; Syrett et al., 1999; Shah and Pell, 2003) relying on the cooperation between local communities and our bio-control experts. Plant selection was primarily based on survey and experiment, but alternative plant species were listed if their mortality was less than 80%. (2) Maintenance phase: a monitoring programme has been established to assess the system’s progress towards the objectives, to increase understanding of the drawdown zone ecosystem and to refine the MPLT system overall.

3. Results and design strategies

3.1. *Local agro-ecological knowledge*

Among 62 households, a total of 156 local people were interviewed, mainly comprising elders and women remaining at home. 15% are illiterate; 69% have had a primary education only and the remaining have received secondary education. 82.7% have small farms while 17.3% have non-intensive field crops for self-supply. Female respondents (59%) exceeded males. The senior group (≥60 years old) with 42.3% outnumbered the 40–59 (34%) and 20–39 group (23.7%). The majority of respondents (86.5%) have been resident in Kaixian for several generations, while some are emigrants from surrounding towns/villages through marriage. We summarised their farming practices in Table 2.

Because hills are prone to rapid surface runoff during the summer monsoons, yet subject to drought during the rainless periods, we found that it is common to establish water retention ponds on the hills to store excess rainwater and sediment. And for better use of land, local farmers have practised terraced rice paddy and crop/vegetable field farming for thousands of years in such mountainous areas. Terraced fields are transformed from natural slopes as a receding series of flat platforms that can impound shallow water. Many studies have shown that such agricultural adaptations provide the most effective tillage in hilly areas, as flat surfaces conserve soil and retain nutrient-rich rainwater and silt from the uplands (Butzer, 2005; Sun et al., 2005). The platform surface is recommended to be 5–10 m wide with a slope of less than 5° in order to decrease the overland flow velocity and favour infiltration (Most, 2010). Through field survey and measurement, we found the surface width ranges between 1.5 m and 10 m depending on the slope (Table 3). Such practices are based on the accumulation of local experience verified by modern science.

Beyond their function of sustaining intensive agriculture, terraces have shaped a unique living landscape with a distinctive aesthetic, immediately identifiable now as Chinese rural heritage (e.g. Hanni Terrace, Yunan Province, as UNESCO World Heritage).

3.2. *Overall pattern of MPLT*

In a representative dike-fish pond system with multi-layered crops, vegetables and livestock on the banks surround a central fish pond. The ratio of bank to water area should be at least 2:3 in order to guarantee there is adequate land for establishing suitable plants. Thereby, a self-sustaining system forms even around a single pond. Such a model is commonly practised in the south-eastern China, Zhujiang Delta, characterised by flat, waterlogged lowlands (Ruddle and Zhong, 1988), which is not suitable for hilly areas.

We thus arranged and modified the essential elements of the dike-fish pond and paddy terracing to form a synergistic system suitable for hilly areas. The MPLT system has water-harvesting ponds at the top, vegetation fields in the middle, and lake at the bottom, as shown in Fig. 5. Compared with traditional dike-fish pond systems, the dike/bank is made wider to accommodate more ecological functions. The water retention ponds also make for better use of water resources from the uplands.

The MPLT system is dependent on a range of interactions between the water-harvesting ponds, vegetation fields, the reservoir lake and the wider environment (Fig. 6). During the summer monsoon, runoff from the upper agricultural land carrying water, nutrients and sediment is intercepted and stored by the water-harvesting ponds. After sediment has settled, water can irrigate the

Table 2
Summary of common measures relating to ecological land management.

Measures	Description	Location	Functions regarding to ecosystem services	Illustration
Ponds (fish ponds, or general ponds)	Locally called "Dangjiatang (当家塘)", which means the whole household activity rely on the pond (washing clothes, drinking water, irrigation, etc.)	Around the house; near the agricultural plots	Harvest monsoon rainwater; receive and process waste-water; irrigate fields	
Change slopes to flats (some in rice terrace, while some in dry terrace with vegetables)	Locally called "Titian (梯田)", which means "making the crop fields as steps"	On medium to high slope lands	Store water; conserve soil; nutrient efficiency	
Contour ridges and strip cropping	Ridges are made along the contour lines at spacing. Crops are planted on raised ridges. In some cases, e.g. on medium slope, the land may be divided by stone walls	On low to medium slope lands	Retard runoff and drain out to the shallow ditches located near the ridges	
Bed surface cultivation	Row crops are cultivated on wide beds surrounded by shallow ditches or mud road	No specific requirements	Capture and store water and nutrients; increase infiltration into the ditches	
Burning crop residues/straw for fertiliser	Periodically burn the crop residues on the fields after harvesting, and generally at small-scales according to our field observation	No specific requirements	Reduce chemical fertiliser input; treat agricultural waste; enrich soil	

Table 2 (*Continued*)

Measures	Description	Location	Functions regarding to ecosystem services	Illustration
Crop residues/straw mulching	Using crop residues/straw on the soil surface	No specific requirements	Reduce soil evaporation; increase efficiency of irrigation; increase infiltration; control soil erosion	
Intercropping and crop rotation	Growing two or more crops/vegetables to produce a greater yield on the same land. It is very common practice in local communities, e.g. rotation of rice–vegetables, rotation of various vegetables, such as *Brassica parachinensis* (early spring)–*Cucumis sativa* (summer)–*Spinacia oleracea* or *Pisum sativum* (winter)	No specific requirements	Better use of resources	 Corn-sweet potatoes rotation
Organic matter	Mud from fish ponds, waste from reared poultry and household to fertilise crop land; waste from crop land (e.g. residues), reared poultry and household to fertilise fish ponds	For crop land; for fish ponds	Reduce chemical fertiliser input; treat agricultural and household waste	
Fish and poultry polyculture	Culture two or more fish species in one pond, generally in combination of bighead carp, black carp, silver carp, grass carp, turtles and ducks	In fish ponds	Better use of trophic and spatial niches in the pond	

Source: all photos taken by Chundi Chen.

vegetation fields. In the rainless periods, the reservoir water level is high and can be used for irrigation or refilling the top ponds.

Accumulated silts both in the water-harvesting pond and lower lake may be used to strengthen and fertilise the plant beds in the event that they have been stripped by lake waves actions. Additionally, the reservoir's winter flooding brings nutrients to the fields for the subsequent growing season.

The system outputs are in the form of ecosystem services. Although as for urban parks, economic products are not the principal objective, harvesting is an important part of maintenance in order to reduce adverse impacts caused by plant residues breaking down and releasing soluble nutrients into the lake as water levels rise.

Compared with the Laotudi Bay dike-pond system, our design has three distinct characteristics: (1) focus more on the essence of dike-pond complex, the energy and matter interactions between ponds and surrounding land (Ruddle and Zhong, 1988); (2) Laotudi Bay system is preferable for the gentle drawdown zone with slope less than 15° (Yuan et al., 2013) and narrow-mouth bays, whereas MPLT can be applied to steeper shorelands and more open bays. (3) MPLT is in an urban park setting, therefore, land and nature conservation and aesthetic values are primary drivers.

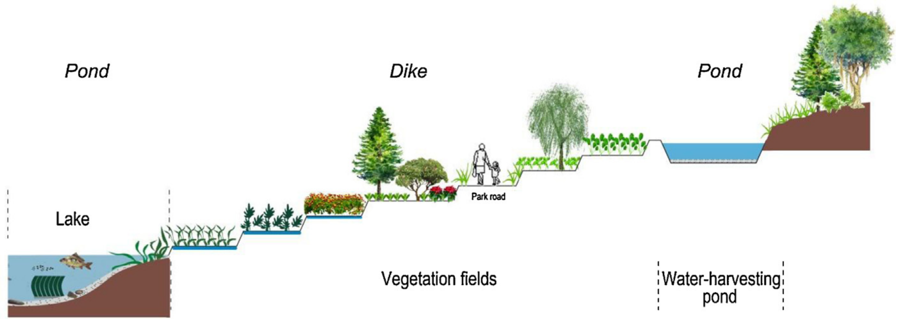

Fig. 5. Concept diagram of proposed MPLT system.

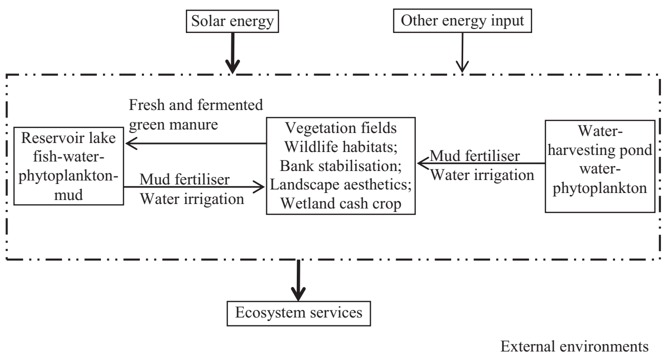

Fig. 6. Components and interactions in the MPLT system through the energy, nutrients and biomass.

Table 3
Summary of parameters of local practices of changing slopes to flats.

Slope before transformation (°)	The terrace step width (m)	The terrace step height (m)	Materials
5–10	9–15	0.3–0.8	Often with clay
10–15	8–10	0.5–1.2	ridges
15–20	5–8	0.7–1.5	Often with block
20–30	3–5	0.7–1.5	stones
>30	1.5–3	1.0–1.5	

3.3. Water-harvesting ponds design

The location of the water-harvesting ponds was determined by modelling the water movement using Hydrology tools of ArcGIS 10. The upper right of the Fig. 8 shows the water network of the influent catchment above the project area. Site 1 (around 179 m) is the most suitable place for a water-harvesting pond, optimising volume, timing and release. Site 2 (around 172 m) was chosen for the lower pond in order to further retard and treat stream flows from larger storms. They all function as a waterscape accessible to park visitors.

The water-harvesting pond design is dependent on the runoff yield of the influent catchment. The largest rain event in the last decade would have produced 5217.5 m^3 of runoff. Accordingly the water-harvesting pond 1 (site 1) was designed with an area of 1374.8 m^2 and average depth of 4 m (5499 m^3). Pond 2 (site 2) with 460 m^2 area and average 2 m depth can sustain the overflow when there is a larger storm event. Saturated sticky clay with slow infiltration from the lake is used as a natural waterproof lining for these ponds rather than concrete. *Nymphaea tetragona* will be planted in these ponds to decrease evaporation, absorb nutrients and improve aesthetics.

Apart from water retention for later irrigation, the ponds also function as sediment traps. The average annual soil loss from the influent catchment is 170 t per year. Given the calculated annual sediment load is limited, local residents are willing to help dredge the ponds every 3–5 years. The extracted mud will be used to fertilise the plant beds.

3.4. Plant selection and design

3.4.1. Plant selection

Fig. 7 lists the estimated inundation duration of different elevations (0.5 m intervals). The 175 m contour is submerged for approximately 3 days, while at 170.78 m it is for around 127 days.

Given the extreme variation in hydrological conditions, especially at the 170.28 to 173 m elevations, plant selection is a challenge and yet is the key to success of any eco-engineering practice (Feng et al., 2007; Wang et al., 2007; Willison et al., 2013; Yuan et al., 2013). Guidelines for selection include using local native plant species with tolerance to flooding while creating diverse habitats. In particular, candidate plants must (1) provide food sources and shelter for wetland birdlife; (2) provide bank stability and protection from erosion; (3) be aesthetically pleasing for park vistas; and (4) support wetland crops for local community. Some appropriate and useful exotic plants that pose no biosecurity risk may be used to add value.

To date drawdown zone restoration has focused on selecting woody plants which can tolerate inundation during the winter and photosynthesize under water (Lu et al, 2010a). Annual herbaceous species have been generally ignored. Our investigation found that some short-lived but fast growing species may fit better with the disturbed drawdown zone environment through their strategy of completing a life cycle within the water recession period. Therefore they, together with inundation-tolerant perennial herbs, should also be considered as suitable plant material. Ye et al. (2014) also

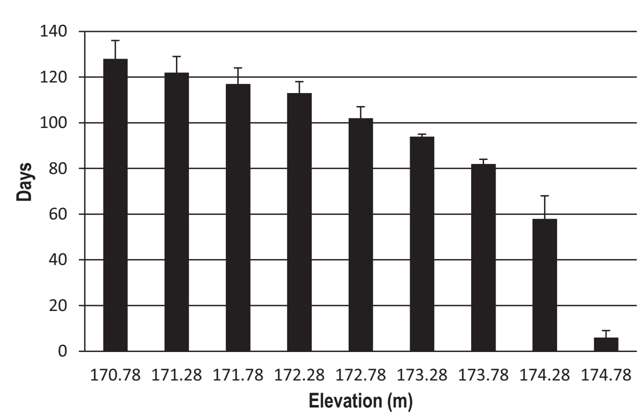

Fig. 7. Estimated submergence duration (days) at different elevations within Hanfeng Lake.

Table 4
Plant selection for the MPLT system.

Plant species	Growth period	Characteristics	Expected functions
Annuals			
Digitaria sanguinalis[I]	Mar.–Oct.	Tolerates drought; Tolerates up to 15 days full submergence[1]	Bs
Stellaria media[I] (A)	Almost all year H: almost all year	Fast growing, great vitality in well-watered areas; Rarely affected by insects, pests or diseases, easy management	Ev: locally common vegetable
Ipomoea aquatica[I]	Apr.–Oct. H: Jun.–Oct.	Same as above	Same as above
Polygonum hydropiper[I] (A)	Mar.–Oct.	Fast growing, vigorous in shallow water; Survives well for 30 days half submergence[2]	Bs; Ev: edible and used as spices
Oryza rufipogon[I]	Mar.–Oct.	Fast growing, vigorous in shallow water	Awb: provide food for wetland birdlife
Perennials			
Cynodon dactylon[I]	Mar.–Oct.	Tolerates drought; Survives well under 5 m submergence in the drawdown zone[3]	Bs
Vetiveria zizanioides[I](A)	Mar.–Oct.	Tolerates drought; Fast growing, vigorous in well-watered areas; Rarely affected by insects, pests or diseases, easy management; Tolerates up to 4 months under 9 m depth of flooding in the drawdown zone[4]	Bs
Paspalum paspaloides[I]	Mar.–Nov.	Tolerates drought; Fast growing, vigorous in well-watered areas; Survives well under 5 m submergence with the flooding pattern in the drawdown zone[3]	Bs
Hemarthria compressa (L.F.) R. Br[I] (A)	Mar.–Nov.	Tolerates drought; Fast growing, vigorous in well-watered areas; Survives well for 82 days fully submerged[5]	Bs
Phalaris arundinacea[I]	Mar.–Nov.	Tolerates drought; Fast growing, vigorous in well-watered areas; Survives well for 3 months in 25 cm depth flooding[6]	Bs; Ev; Awb: with grain and shelters
Saccharum sinense[I]	Apr.–Nov. H: Nov.	Survives well for 15 days half submergence (field observation)	E: locally common cash crop
Phragmites australis[I]	Mar.–Dec.	Growth promoted by dry-wet alternation; Survives well for 180 days under 5 m submergence[7]	La; Awb: with grain and shelters
Shrubs			
Distylium chinense[I]	Evergreen	Endemic to TGR; Tolerates drought; Seedlings survive well for 120 days under 2 m submergence[8]	Bs; La
Salix variegata Franch[I]	Deciduous	Endemic to TGR; Tolerates drought; Survives well for 60 days fully submerged[1]	Same as above
Trees			
Pterocarya stenoptera[I]	Deciduous	Tolerates drought; Survives well for 70 days fully submerged[9]	La: local specimen tree
Salix babylonica[I]	Deciduous	Tolerates drought; Survives well for 60 days fully submerged[10]	Same as above
Populus canadensis[R](A)	Deciduous	Tolerates submergence and drought	Same as above
Metasequoia glyptostroboides[R]	Deciduous	Endemic to China; Flooding-tolerant	Same as above
Aquatics			
Nymphaea tetragona[I]	Mar.–Oct. F: Jun.–Oct.	Suitable in beds with 10–100 cm of water	La; Reduces the evaporation of water-harvesting ponds
Typha orientalis presl[I]	Mar.–Nov. F:Aug.–Sep.	Native to this region; suitable in beds with 10–15 cm water depth	La
Acorus calamus[I] (A)	Mar.–Nov. F: Jun.–Sep.	Suitable in beds with 10–15 cm water depth	La
Sagittaria trifolia var. *sinensis*[I]	Apr.–Oct. F:Jul.–Sep.	Suitable in beds with 10–20 cm water depth	La; Ev: roots as locally common food; Awb
Schoenoplectus tabernaemontani[R] (A)	Apr.–Oct. F: Jun.–Sep.	Suitable in beds with 10–15 cm water depth	La: accompanied by *N.tetragona, S.trifolia* to form tranquil waterscape; Ev: locals use stems to weave mats, baskets, etc.
Eleocharis dulcis [I] (A)	Apr.–Oct.	Suitable in beds with 3–10 cm water depth	Ev: locally common vegetable
Zizania latifolia[I]	Mar.–Sep. H: Aug.–Sep.	Suitable in beds with 20–27 cm soil 15–20 cm water depth	Same as above
Trapa bispinosa[I] (A)	Mar.–Sep. H: Aug.–Sep.	Annual floating-leaf herb; Suitable in beds with >20 cm mud and 100–400 cm water depth	Ev: fruit as locally common food
Euryale ferox[I]	Mar.–Oct. H: Sep.–Oct.	Annual floating-leaf herb; Suitable in beds with >20 cm mud and 80–150 cm water depth	Same as above

[1] Luo et al. (2008); [2] Chen et al. (2008); [3] Tan et al. (2009); [4] Guo et al. (2012); [5] Liao et al. (2009); [6] Song et al. (2012); [7] Qin et al. (2012); [8] Li et al. (2012a); [9] Yi et al. (2006); [10] Zhong et al. (2013). [I] Investigation carried during 2011 to 2013; [R] Literature record; A: plants for alternatives if others failed; H: harvesting period; F: flowering period; Bs: bank stability; Ev: economic values; Awb: attracting wetland birdlife; La: landscape aesthetics.

Table 5
Parameters of graduated terrace steps (ponds and plant beds) in the MPLT system. Each step may contain several ponds or beds.

ID	Elevation (m)	Flood-free period	Types	Average step width (m)	Average ponds/beds water depth (cm)	Suitable plants	Soil texture and pH	Previous land use/cover	Plant area (m^2)
1	Below 170.28	0	Pond 2	/	400	*E. ferox* along pond edge	Cl, 5.8	Pc	500
2	170.5	15 Feb.–30 Sep.	Plant terraces	6	0	Mixed grass: *D. sanguinalis*, *C. dactylon*	Cl, 6.1	Pc	708
3	171	12 Feb.–1 Oct.	Plant terraces	6	0	*P. australis*	Cl, 6.3	P	749
4	171.5	8 Feb.–3 Oct.	Plant terraces	6.5	0	*P. arundinacea* and *O. rufipogon*	Cl, 6.3	P	811
5	172	5 Feb.–4 Oct.	Plant terraces containing two beds	7.5	B1: 13 B2: 0	B1: *T. orientalis* *B2: S. sinense*	Cl, 6.6	P	B1:271 B2:897
6	172.5	31 Jan.–5 Oct.	Plant terraces containing Pond 1, and four beds	5	B3: 13 B4: 18 B5: 5	B3: *T. orientalis* B4: *Z. latifolia* B5: *I. aquatica*	Cl, 6.6	P	B3:303 B4: 75 B5: 43
7	173	24 Jan.–6 Oct.	Plant terrace	5	0	*P. stenoptera*+*S. variegata*+mixed grass	Ml, 6.7	Sc	1182
8	173.5	18 Jan.–20 Oct.	Plant terraces	4	0	*S. babylonica*+ *D. chinense*+mixed grass	Ml, 6.7	Sc	1331
9	174	15 Jan.–24 Oct. 28 Dec.–31 Dec.	Plant terraces	5	0	*M. glyptostroboides*+*S. variegata* Franch+mixed grass	Ml, 6.7	Sc	1200
10	175	All year (only occasional submergence)	Plant terraces	6	0	*S. babylonica*+*A. calamus* for park road greening	Ml, 6.7	Sc	479
11	176	All year	Plant terraces	5	0	*S. babylonica*+*S. variegata*+mixed grass	Ml, 6.7	Sc	656
12	177	All year	Plant terraces	4.5	0	*S. babylonica*+*S. variegata*+mixed grass	Ml, 6.7	Sc	560
13	178	All year	Plant terraces	4.5	0	*M. glyptostroboides*+*S. variegata*+mixed grass	Ml, 6.7	Sc	537
14	179	All year	Plant terraces	4.5	0	*M. glyptostroboides*+*S. variegata*+mixed grass	Ml, 6.7	Sc	548

Cl: clay loam; Ml: medium loam; Pc: paddy fields mixed with cropland; P: paddy fields; Sc: sparse forestland mixed with cropland.

found that the areas with larger herbaceous coverage had more effective capacity for soil restoration in the drawdown zone.

The candidates include *Cynodon dactylon*, *Digitaria sanguinalis*, *Stellaria media*, and others. The sod-forming perennial grasses such as *C. dactylon* generally have dense stolons or rhizomes that offer effective bank stabilisation. Others like *S. media* are popular salad vegetables. The woody plants include *Pterocarya stenoptera* and *Salix babylonica*. Many studies have shown that they survive well within the drawdown zone of the TGR (Yang et al., 2012; Zhang et al., 2013). The shrub *Distylium chinense* is endemic to the TGR and became an endangered species due to the reservoir submerging its original habitats. But now it is successfully cultivated in the Wuhan Botanic Garden. Because of its strong acclimation and tolerance to flooding, it is an especially desirable shrub species for this project. Table 4 presents the selected plants and highlighted features.

It is anticipated other grass species will sprout from the local soil seed bank (Li et al., 2013; Lu et al., 2010b). In this sense it is a self-designed and self-regenerating process, which will add to the project's resilience. We note that some studies have suggested species such as *Humulus scandens* for drawdown zone revegetation (Yang et al., 2012). However this is recognised as an invasive weed which should be avoided, notwithstanding its growth rate and ability to cover the substrate rapidly.

3.4.2. Planting design

Our analysis of shoreline vegetation revealed a statistically significant plant distribution pattern which had naturally established on the drawdown zone. Annual herbs dominate within the 170 m and 173 m while more perennial herbs were found between 173 m and175 m zone, dotted with some flood-tolerant shrubs and trees. Based on the analysis of topography, hydrologic and soil conditions of the Wuyang Bay, we compiled the preferred plant list for the shoreline to land gradient (Table 5). Some remnant forestland is reserved as bush patches within the terrace matrix to enrich landscape biodiversity and provide seed sources for natural revegetation (Eriksson, 1996). The MPLT system design is shown in Fig. 8.

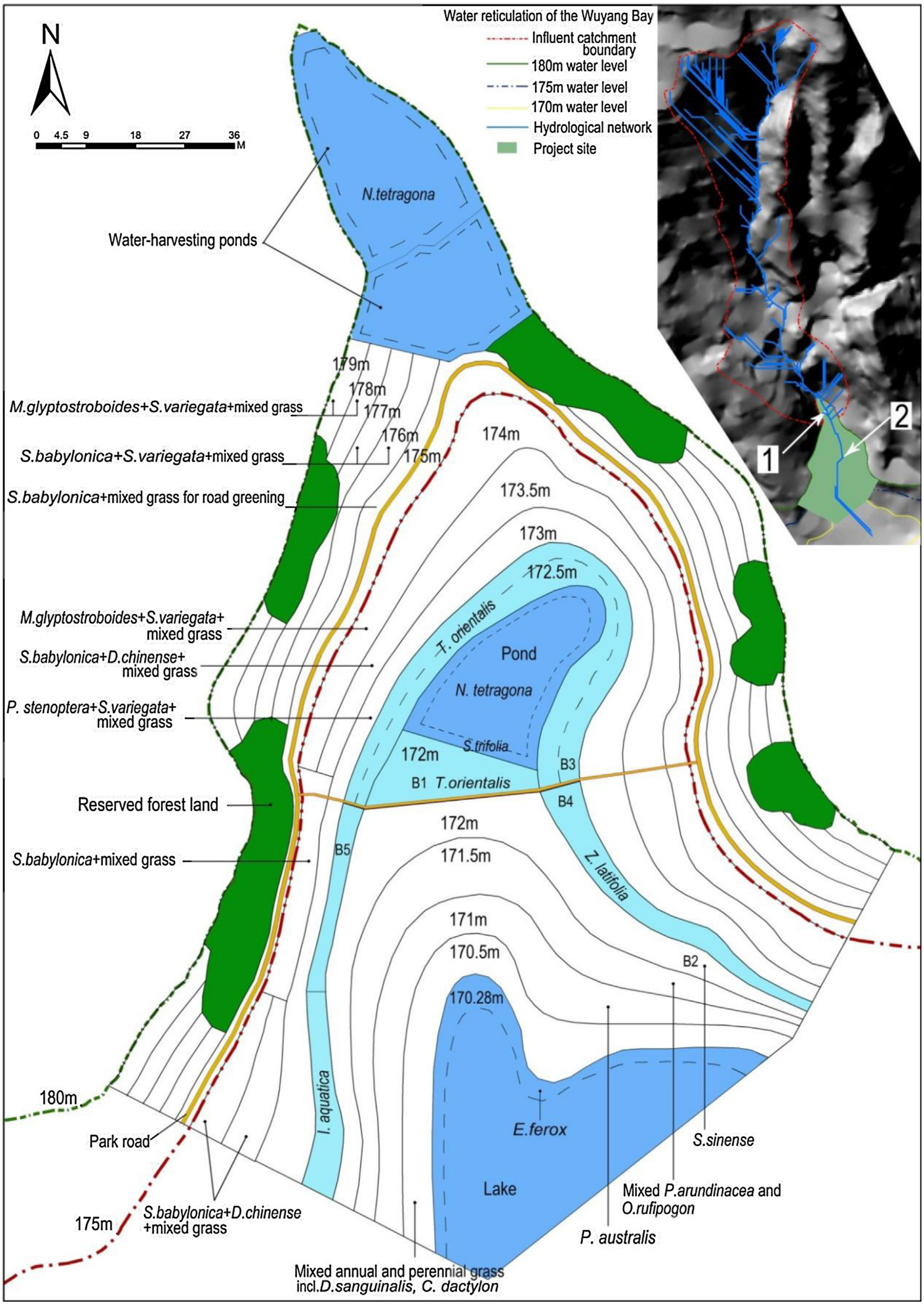

Fig. 8. Planting design of the MPLT system in the Wuyang Bay.

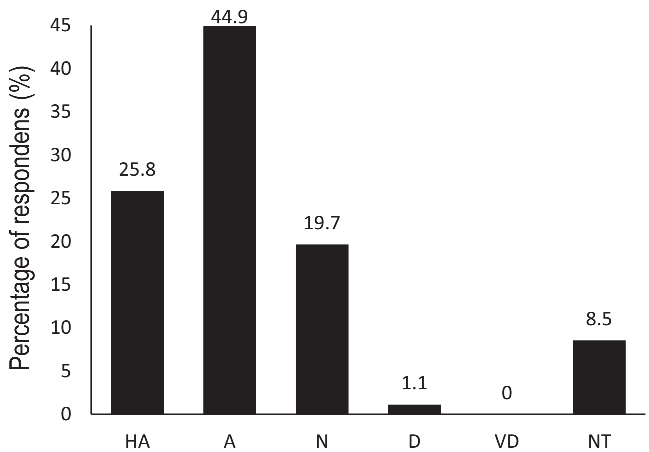

Fig. 9. Attitudes towards the MPLT system
(HA: Highly agree, A: Agree; N: Neutral; D: Disagree; VD: Very much disagree, NT: No thought).

3.5. Perceptions and attitudes towards the MPLT design

There were 178 interviewees in the second round survey. Overall 70.6% of the respondents supported the MPLT system when we introduced to them the design and its benefits (Fig. 9). Some pointed out how similar it was to their terracing fields and felt exhilarated that their agricultural practices would be featured in an urban park (Tian et al., 2012, pers. comms.). Some commented that they actually would like to use the drawdown zone land as well although it is officially forbidden (there are warning signs in places. See Supplement). Agricultural use of the drawdown zone is a common phenomenon according to our observations within the TGR region. Generally they are used by people living nearby for household supply. The 19.7% neutral options can be attributed to the fact that some respondents do not comprehend the idea of the MPLT system being part of an urban wetland park. Such a concept presupposes a theoretical understanding of integration, ecological services and relationships between nature and cultures.

Willingness usually suggests respondents' potential actions. When asked specifically if they were willing to help in building, management and maintenance of the MPLT project, more than 70% said they were willing to participate and help (Fig. 10). Those remaining neutral were concerned about their time, knowledge and energy, or uncertainty about the outcomes and benefits of the project. Overall, less than 5% were unwilling to participate, whereas the great majority of local people showed strong intention to participate in establishing and maintaining the MPLT system in their place.

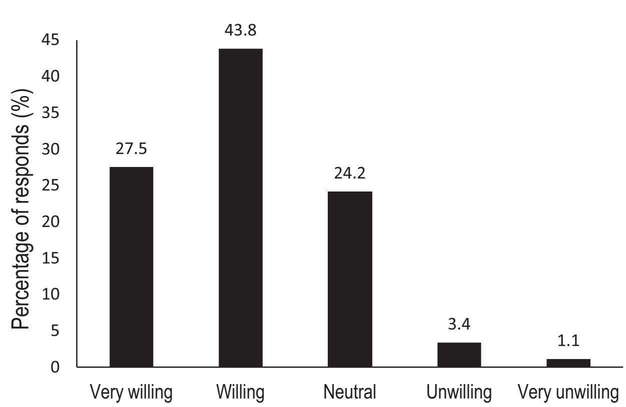

Fig. 10. Willingness to participate in building, management and maintenance of the MPLT project.

4. Post-construction monitoring programme

A long-term post-construction monitoring plan has been set up. Success criteria for this project include structural and functional aspects. Measurable structural indicators include vegetation cover, invasive weed cover, and plant mortality. Measurable functional indicators focus on wetland bird diversity, regeneration demographics of desired species, plant community diversity, and water quality (TN, TP, Chlorophyll *a*) of the Wuyang Bay. Some of these indicators have been measured before construction as a baseline for later comparison. Other lakeshore treatments with conventional riparian concrete surfacing mixed with monoculture planting around the Hanfeng Lake is used as contrasting control plots (See sites and results in Supplement).

5. Discussion

As a transitional zone from urban to rural, the project site offers challenges and opportunities to demonstrate synergy between local practical farming knowledge and modern ecology-based approaches to sustainable land design and management in urban context. Table 6 presents a comparison between the conventional treatments of lake/river bank and ecological design in terms of expected implementation periods, complexity level, required professional skills, ease of maintenance and ecosystem services. The conventional treatment is found to require intensive management (e.g. use of machinery and herbicides) and demands more energy and funds to maintain the neat, sterile appearance. Incorporating ecological knowledge may cost more in the initial stages and is expected to be a prolonged and more complicated process. But it minimises resource depletion and lake pollution risks, and maintains the structural and functional integrity of both natural and managed ecosystems (Mitsch and Jørgensen, 2003). Other eco-engineering practices in the same region have proven that as an ecological filter between the uplands and the reservoir, it effectively reduces nutrients flow and soil erosion from upland (Li et al., 2013). Additionally, it respects local cultures. Our interview survey revealed strong willingness from local people to help the project because the proposed landscape is like a part of their lives and they can potentially be rewarded from the ecosystem services.

Formulating a comprehensive and empirically supported design was particularly important in this restoration given the sensitive and vulnerable environments. Our long-term monitoring programme will evaluate and provide more tangible evidence of the performance of the project and inform adaption and extrapolation to other sites. The demonstration project has implications for ecological design in terms of incorporating cultural sustainability into ecological benefits under the prevailing conditions of changing climate and environment.

First, this design adopts an adaptive management strategy since landscaping success is crucially dependent on responsive capacity to environmental change (including, but not restricted to, dam operation, water fluctuation, ecosystem evolution and climate change at the regional scale). There is an experimental aspect to the landscape development with a degree of uncertainty about outcomes and accordingly we have deliberately built in flexibility to cater for these unpredicted outcomes (Heinimann, 2010). The drawdown zone of the TGR is often defined as a type of wetland

Table 6
A comparison of contrasting shoreland development models by attributes of the design, implementation and maintenance processes.

Model types	Expected implementation period	Complexity level	Required professional skills	Ease of maintenance	Ecosystem services
Conventional concrete bank	Short	Low	Low	High	Adverse impacts
Ecological design: MPLT	Long	High	High	Low	High

(Wang et al., 2009; Willison et al., 2013; Yuan et al., 2013). Since the 2010 winter when the TGR first reached 175 m, the drawdown zone has only been flooded a few times. The soil of the site is still the original purple soil, that is, not yet transformed into a typical wetland soil (e.g. boggy soil, peat soil or having a gley horizon). But some wetland species have already become established spontaneously (Chen et al., 2014; Feng et al., 2007; Wang et al., 2012b). Thus the ecosystem has changed from monsoon woodland and now evolving into a type of wetland. The design therefore needs to consider both the short-term water level changes and long-term ecosystem evolution.

Second, the local knowledge of natural and cultural systems is valuable since it has adapted to the environment over thousands of years. The specific indigenous understanding about soil erosion, efficient use of materials and energy, and multifunctional land use has greatly inspired our design process (Huntington, 2000; Martin et al., 2010). Additionally, our design uses cultural traditions for the form and appearance of landscape to frame ecological function within a familiar context. Ecological quality often looks "messy" and violates cultural norms for tidy appearance of human-dominated landscapes (Nassauer, 1995). Novel and effective ecological design requires translating ecological functions imperatives into culturally recognisable forms (Eaton, 1990; Nassauer, 1995; Nassauer et al., 2009). Using this "cues for care" principle, we have endeavoured to enhance ecological value alongside identity and sense of place, and encourage the local people to become engaged in the landscape stewardship.

6. Conclusions

Our hybrid MPLT system has been designed to maximise ecosystem services from the reservoir shoreland to address the challenging conditions of the water fluctuation zone and surrounding steep hills. It is being implemented as a demonstration in the more modestly fluctuating Wuyang Bay, the TGR region. The design was based on a combination of traditional land–water management experience, cultural values, community engagement and modern ecological analysis in order to frame a culturally acceptable context which can better accommodate the ecological functions. We presented our design concepts to the local community and received positive feedback. The MPLT system may become an exemplar for sustainable engineering that can deal with the new ecosystems formed around the drawdown zone of the wider TGR region. This study also suggests that using adaptive management strategies at both design and monitoring phases is indispensable to dealing with an uncertain world. Future study will follow the project implementation and investigate the response of the new system to the changing conditions and whether local communities genuinely perceive it as part of their living landscape and are motivated to protect and maintain it.

Declaration

All the interviews, survey and preliminary experiments on the plant species comply with the current laws and relevant regulations of P.R. China.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecoleng.2014.07.008.

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