CRITERIA FOR AQUATIC PLANTING DESIGN IN ECOLOGICAL REDEVELOPMENT OF URBAN RIVERFRONTS

by

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ABSTRACT

Urban environmental pollution continues to be exacerbated by a number of factors relating to human population growth including sewage discharged directly into the urban rivers designed with concrete-sealed riverfronts. This has left a number of rivers with deteriorated water quality. Where a riverfront could be the highlight and magnet of the city, it may instead become a stain and waste place.

In 1969 American landscape planner McHarg proposed the landscape planning theory, “Design with Nature." His primary argument was that natural processes provide self-regulatory functions that need to be reflected in our plans and designs. Ecological design aims include restoring or promoting natural processes and automatic (bio-physical, regenerative, and adaptive) stabilizers.

A wide range of scientific knowledge is available to help guide the designer, but designers usually have limited time to complete their designs. Unfortunately, much of this information is diffusely dispersed in research literature and not easily collected and synthesized by the design community. The purpose of this review is to help provide a synthesis of current thought and to help establish the basis for principles that can aid the designer, offering easy-to-understand design guidelines related to the use of aquatic plants in ecological redevelopment along urban riverfronts.

This report focuses on using aquatic plants as the main material to help solve two key problems along riverfront developments: water pollution and flooding. As such this report can serve as a guide for the designer helping them to select aquatic plants using an ecological design approach for the redevelopment of urban riverfronts. It also addresses the essential need to adapt designs based on local site problems and requirements.

Since this report provides a review and a basis for where to start in designing with

aquatic plants in ecological redevelopment of urban waterfronts, it should not be considered as an exclusive source for the designer but rather a complement to local guidelines and information to derive design solutions.

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Chapter I: Introduction

Urban environmental pollution continues to be exacerbated. “Nearly 80% of the world's human population lives in areas where river waters are highly threatened, posing a major threat to human water security and resulting in aquatic environments where thousands of species of plants and animals are at risk of extinction” (Devitt, 2010). Where a riverfront could have been an attractive and functional highlight of the city, often, due to pollution, it can instead become the stain of the city. Also in many cases an entire urban waterfront may have been designed without regard to either aesthetics or regional ecology, so that a city loses its geographic character. However, riverfronts can be elegantly designed to enhance the quality of life, to improve the environment, and to reduce the effects of pollution. The three fundamental ways to purify water are through chemical, physical, or biological systems (Pennington and Cech, 2010). Since the 1970s, many scholars have called for applying the principles of ecological riverfront design (Sun and Huang, 2000). Aquatic plants are one of the tools available in bio-manipulation, or ecological remediation of urban riverfronts. This report offers a review of literature in this field and focuses on the application of aquatic plants to urban riverfront projects.

The challenge of designing for these situations may be considered in the context of a conceptual model based on artistic methods. The model begins with a single point. Everyone knows how to draw a point. The point can become a line, and lines can make shapes. Point, line, shape are the base elements in art. The secret of the artist is how to control those elements. Using this model in riverfront design, the first step, the “point” becomes selecting aquatic plants. The second step, the “line” becomes the optimal allocation of aquatic plants.

And finally the third step, developing “shape” becomes the planning and design process to create a composition. It could be considered ecological art that is not only aesthetically pleasing, but also functional and ameliorative to the environment. Of course, appropriately selecting and placing plants requires an understanding of dynamic bio-physical and socio-economic conditions at the site scale as well as larger watershed and landscape scale conditions and factors. Knowing how much baseline watershed and relevant landscape scale information to gather is never easy, but enough must be collected and evaluated if our work on urban riverfronts is to hold up during periods of flood, drought, and upstream and surrounding land use changes. For more on the restoration, rehabilitation and/or repair of larger river and stream systems refer to Brierley and Fryirs (2009), Brierley and Fryirs (2008), Palmer, et al. (2007), Palmer, et.al. (2005), and Wohl, et al. (2005).

In his review of the Brierley and Fryirs book, Chris Mainstone (Natural England) wrote, “Two messages distilled from the Brierley and Fryirs’ book are that: (1) it is necessary to understand the evolution of the river channel to understand how to fix it (i.e. it is important to look back to look forward); and (2) that we should adopt the ‘art of the possible’ in seeking to restore as much geomorphological and ecological functionality as we can, working within those societal constraints that cannot be removed.”

1. Main manual – how to locate information in this report (Table 1)

	POINT		LINE		SHAPE		ART
	Selecting aquatic plants		**Optimal allocation of aquatic plants**		**The planning and design process**		**Ecological art**
Pollution	3.1 Factors affecting aquatic plant selection for ecological redevelopment	3.1.1 Temperature	4.1 Optimizing the allocation of aquatic plants water purification	4.1.1 Decontamination of river pollution	5.1 Method of aquatic plant design in water self-purification	5.1.1 Buffer size considerations for decontamination of pollution in surface runoff	3.1.1+3.1.2+3.1.3+4.1.1+5.1.1/ 3.1.2+4.1.2+4.1.4+5.1.2/.....
		3.1.2 Depth of water					
		3.1.3 Water Quality - Differences in plant species absorption of pollutants		4.1.2 Decontamination of pollution in surface runoff from adjacent areas		5.1.2 Nonpoint-source water self-purification	
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Flooding	3.1Factors affecting aquatic plant selection for ecological redevelopment	3.1.1 Temperature	4.2 Optimizing aquatic plant allocation to reduce flooding	4.2.1 Natural soft embankment	5.2 Method of aquatic planting design in the flood zone areas	5.2.1 Straight canal	3.1.1+3.2.2+4.2.1+5.2.3/ 3.1.2+3.2.2+3.2.3+4.2.3+5.2.2/.....
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Table 1 Main manual – how to locate information in this report.

Chapter II: The Urban Riverfront

2.1 The urban riverfront

Throughout human development history, the river has been an important and often vital part of urban environments. In addition to the basic natural functions of rivers, such as water purification, material transport, and providing habitat, in urban settings, they can provide leisure, entertainment, and education (Gao et al., 2009). This suggests that a good riverfront design not only can protect the natural environment, but can also improve the recreational and educational functions. A riverfront is at the junction of upland and aquatic ecosystems, and is thus a very dynamic, interconnected, and inherently ecologically fragile zone (Mika et al. 2008). It is where water and land together constitute the dominant element of the environment (Jin, 1994). It is where the heterogeneity of some of the strongest and most complex ecosystems in the world exist (Jung et al., 2002). Urban riverfronts can enhance ecological functioning and the provision of essential biological services, control soil erosion, provide flood and spillway control, and help promote the creation of important environmental standards. They also can be unique and beautiful landscapes where people can be close to water.

2.1.1 River ecological systems

In ecological redevelopment of urban riverfronts, design is based on the ecological system of the river. A riverfront area is typical of an ecotone – the zone where two different types of border areas of the natural environment abut (Ryn and Cowan, 1996). Here the material energy flow and exchange processes are very frequent. Therefore, waterfronts have high biological diversity and productivity. Natural waterfronts allow a natural adjustment to function, in part, due to the permeability of riverine soils which often create an interface having high porosity. Porous riverine soils allow water from the river and groundwater to be exchanged and freely circulate. As such, groundwater can continuously supply water to a river or stream and thus achieve a dynamic water balance. Compatible with the ecological river processes, the performance of waterfront vegetation hinges on species richness and the formation of complex natural communities. In the past few hundred years of world urbanization, however, rivers and waterfront areas have often suffered from development, which interferes with natural forms. The natural forms inevitably meet with varying degrees of damage depending on the intensity and sensitivity of urban developments.

2.1.2 Common environmental pollution problems along urban riverfronts

The riverfront area has always been a popular development focus for urban construction. Riverfront green space suffers when natural stream and river corridors are replaced by concrete or other impermeable and impoverished riverfront space. As a city's population grows, riverfront pollution typically becomes a serious issue. This is especially critical in rapidly urbanizing regions of the world, such as in China. Ecological functions and riverfront performance is negatively affected by two primary concerns: pollution problems and flooding problems.

(1) Pollution problems. Domestic sewage is sometimes diverted and collected in rivers. Human activities produce large quantities of pollutants that are often discharged into water bodies. These pollutants affect the water's physical and chemical properties, and change the composition of biological communities, thereby reducing the value of water use. When a large volume of ozone-depleting organic matter is discharged into water bodies a sharp decline

in dissolved oxygen in water occurs. The result is that water bodies appear green to black, develop odors, and algae growth typically increases. With depleted oxygen levels, aquatic life may die. Due to the flow of urban litter during rainfall events, rivers tend to accumulate a great deal of trash, further polluting and degrading these essential life-supporting features.

(2) Flooding problems: (A) Construction of flood control facilities and drainage works frequently destroy or otherwise undermine riverfront vegetation. Concrete surfaces along riverfronts often prevent the effective movement of water (as vapor or via sub-surface migration) between the river and riverfront vegetation. Not only are living spaces for terrestrial plants lost, but also some aquatic animals and aquatic plants are easily swept away along the smooth concrete surfaces (Sun and Huang, 2000). (B) Changes in the natural river hydrology and riverbed topography. Because straightening channels increases the quantity of flood flows over a shortened period of time, flow velocity and sediment movement are increased. Downstream areas experience increased flood pressure. Because of dam construction and rechanneling groundwater levels can change dramatically. With down cutting of urban streams and rivers water tables can be drawn down and the natural water-regulation function declines. This results in destruction of natural riparian and hydraulic connections between the channel and the groundwater interface and speeds up the channel flow velocity and erosion. Channelization reduces the meandering of rivers and the degree of hardening reduces the embankment roughness, both of which weaken the ability to reduce natural river water energy and frequently cause serious erosion and sedimentation downstream (Tian, 2006). Reducing water pollution problems and flooding problems are thus two key components of successful urban riverfront design.

2.1.3 The urban waterfront as a design problem

Because of pollution problems, more and more communities pay attention to urban waterfront redevelopment. Evidence shows that often designers did not take into account the current riverfront ecosystem functions and structural peculiarities, and waterfronts may have a wide range of design problems. Primary design problems are as follows. (1) Pursuit of formal beauty and/or being confined to engineering requirements, such as simply using artificial green instead of the natural waterfront vegetation (Sun and Huang, 2000). An example would be simply using artificial turf to cover a large area of the waterfront and a row of tall trees along the river. The original diverse habitats are destroyed. (2) Planting a large number of foreign species into the waterfront, which affects native riparian vegetation communities' species and structural stability. The complete exclusion and/or ultimate destruction of the native waterfront vegetation can lead to the entire natural waterfront ecosystem collapse (Sun and Huang, 2000). (3) A concrete riverfront has a certain amount of useful life, but requires regular maintenance and constant repairs. It often increases the financial burden and stresses the local economy. (4) Designs employing in the above stereotyped forms do not regard geomorphological features, local habitats and ecosystems, nor ecological structure and functions. (Tian, 2006)

2.1.4 An alternative ecological design approach for the redevelopment of urban riverfronts

Designing urban waterfronts should be based on urban ecological design and planning principles. Urban ecological design focuses primarily on a few basic principles: It (a) applies local design; (b) protects and saves natural resources; (c) lets nature thrive; and (d) shows off nature (Yu et al., 2001). May in the "Urban Waterfront Manifesto" (1999) suggests that waterfront planning should be "long-range……a system of sustainable growth and operation."

For each riverfront development, “the tendency to clean up waterfronts should be approached carefully so that rich underlying values are not unnecessarily sacrificed.” New developments “should flow from the nature.” Communities apply for aid to clean the riverfront environment of canals, lakes and rivers as well as coasts. Using ecological redevelopment concepts to design the urban riverfront could greatly benefit urban riverfront design.

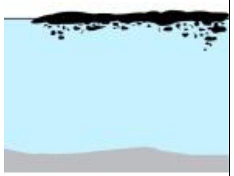
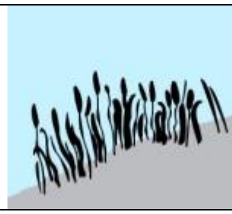
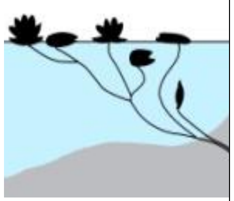
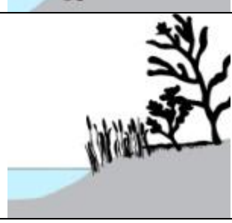
2.2 Aquatic plants

Aquatic plants are the main material which should be used in urban riverfront design. The term “aquatic plant” refers to the part of plants or the entire plants that can live only in the aquatic environment (Deng, 2007). Aquatic plant has both narrow and broad definitions. The narrow definition of aquatic plant is that for the aquatic plant the whole lifecycle must occur in the water environment. The generalized definition of aquatic plants includes wetland plants that have a period of growth in water or are grown in the soil with saturated water content. This report focuses on the more generalized interpretation of aquatic plants. About one thousand kinds of aquatic plants exist in the world.

2.2.1 Classification of aquatic plants

Aquatic plants adapt to live in aquatic environments. They can grow directly in standing or open water or in soil that is saturated with water (and thus can complete their life cycle in water or saturated soils). There are many different ways to classify aquatic plants. For the purposes of urban riverfront design, this report will classify aquatic plants according to five broad types adapted from Arber (1920) (refer to Table 2.2.1). Other authors have elaborated on Arber’s classification with specific ecological functions and design considerations (Taiwan River Restoration Network, 2010).

Table 2.2.1 Classification of aquatic plants (adapted from Arber, 1920)

Type	image	Feature	Ecological functions	Design Considerations
Free floating		Whole plant's body floating on the water.	1) Manufacturer of large quantities of oxygen. 2) Provide aquatic animal food. 3) Have fruit and flowers.	1) Growth in the quiet waters environment, usually not growth in the flow of waters. 2) Asexual reproduction mechanism allows plants to rapidly cover the entire surface of the water. 3) If the density is too high, it will affect other aquatic plants' photosynthesis. 4) Growth at least water 20-30 cm deep.
Totally submersed		1) Whole plant immersed in water. 2) Root fixed at the bottom.	1) Provide aquatic animal food. 2) Provide nesting and habitat to other organisms.	1) Growth in water 30-100 cm deep. 2) Create oxygen underwater, curb the growth of algae in water pollution, and improve water quality and efficient viewing.
Bottom rooted and floating		1) Leaf is supported by petiole to affix on the surface float of water. 2) Root or underground stem fixation in the bottom of water.	1) Manufacture of large quantities of oxygen. 2) Provide aquatic animal food. 3) Provide nesting and habitat to other organisms. 4) Have fruit and flowers.	1) Growth in water 30-100 cm deep.
Emergent and rooted		Part of the roots and stems growth in the water, most of the stems and leaves come out of the water.	1) Provide nesting and habitat to other organisms. 2) Have fruit and flowers.	1) Growth in water 100-150 cm deep.
Wetland vegetation in upland areas		Growing in wet areas.	1) Provide nesting and habitat to other organisms. 2) Have fruit and flowers.	1) Pay attention to plant height and rooting characteristics.

2.2.2 Structure of aquatic plants in river ecosystems

The main features of the water environment are low light, hypoxia, high density, high viscosity, smooth temperature changes and that they can dissolve a variety of inorganic salts. Aquatic plants are an important part of aquatic ecosystems and the main primary producers. The role of aquatic plants in the ecosystem is cycling and transmission of material and energy. Aquatic plants have well-developed aerenchyma cells to ensure the supply of oxygen. Leaves of aquatic plants underwater multi-split into a ribbon, wire, and thin, to increase the absorption of sunlight, inorganic salts, and CO_2, so that the potentially increased surface area can absorb more water (Li, 2000). An aquatic plant not only has ornamental value, it also has several ecological functions.

Some of aquatic plants can improve the efficiency of water purification. Aquatic plants typically absorb oxygen, carbon dioxide, and other nutrients in water. They absorb pollutants and harmful substances, providing filtering, decomposition and transformation of such substances in order to achieve removal of pollutants in water and achieve the purpose of the water body restoration. Another role of wetland plants is to consolidate the soil to stabilize banks, an important role in rainy seasons. Through a variety of design strategies for plant optimization to exert different strengths, the designer can improve the self-purification capacity of water. At the same time it helps create a rich urban waterfront landscape (Liu, 2003).

Many functions of aquatic plants are common knowledge, however in 2012 Taiwan Endemic Species Research Institute noted other specific functions as described below.

2.2.3 Functions of aquatic plants in river ecosystems

1) Adjust the water flow

Aquatic plants, as a group, have a natural ability, for example, during rainstorms to absorb and store rainwater. They can also reduce silt.

2) Protect slope

The roots of aquatic plants can reinforce soil; increase penetration; improve soil to prevent soil erosion and prevent revetment collapse.

3) Intercept sediment

Aquatic plants, which comprise a buffer zone of revetment, can provide surface infiltration. When runoff occurs, it can increase the infiltration capacity, reduce the surface flow velocity and flow rate, so that it can capture precipitation and provide filtration of silt.

4) Improve polluted conditions

Aquatic plants can absorb nitrogen and phosphorus directly from rivers and sediment.

5) Producer

Aquatic plants can provide food for humans or other animals.

6) Ecological asylum

Most of the aquatic plants have photosynthesis. They can absorb CO_2 and release O_2, which can support fish respiration. The foliage of aquatic plants can be used by fish and other aquatic animals such as waterfowl as a refuge places.

7) Adjust climate

Aquatic plants can reduce the local temperature and local reflective radiation.

8) Landscaping

Throughout history aquatic plants have been used as garden ornamentals.

2.2.4 Aquatic plants as water cleansing agent

Human activities have the potential to discharge a large amount of industrial, agricultural and domestic wastes into water so that contamination of water occurs. Water pollution can be attributed to the contamination of impurities that are divided into the three categories of chemical , physical and biological pollution. Of these, chemical is the primary pollution. For the removal of these pollutants, the plant plays a very important role. Its rapid growth enables it to absorb large amounts of pollutants, and has the advantage of easy post-processing, providing an economically viable method for sewage treatment (Qian, 2008).

1) Aquatic plants in the removal nitrogen and phosphorus

Aquatic plants can adjust the nutrient concentration of water in shallow lakes (Brenner et al., 1999). Biological debris settles nitrogen and phosphorus to the bottom of soil. Submerged aquatic plants absorb nitrogen and phosphorus through their roots, which has more than any other water plant category in ability to absorb nitrogen and phosphorus. In the distribution area of the submerged aquatic plants, chemical oxygen demand (COD), biochemical oxygen demand (BOD), phosphorus, ammonium nitrogen content are generally far lower than areas without distribution of submerged aquatic plants (Wang and Xu, 1994). Freshwater submerged aquatic plant systems are very good in their role in the removal of nutrients. They remove nitrogen mainly through denitrification and they remove phosphorus by biological uptake (Gumbricht, 1993).

2) Aquatic plant removal of heavy metals

Aquatic plants have strong absorption ability for Zn, Cr, Pb, Cd, Co, Ni and Cu. Metals are different from organic matter and cannot be degraded by microbial activity. They can be removed only by biological absorption from the environment. Submerged plants and floating aquatic plants can absorb many different kinds of heavy metals, but as this absorption is increasing it leads to the loss of nutrient elements and can lead to plant death. Submerged aquatic plants and floating aquatic plants are suitable for absorbing heavy metals in low-pollution areas. They may also be used as monitors of the metal content in the water (Wang et al., 2002). Aquatic plants control the distribution of heavy metals within themselves, generally having more heavy metal accumulation in the roots. The roots of aquatic plants carry heavy metal contents generally higher than stems and leaves.

3) Aquatic plant removal of toxic organic pollutants

Aquatic plants can degrade organic pollutants from water, because they can promote the precipitation of substances and promote the role of microbial decomposition. They play a role in the absorption and accumulation of DDT, PCB and other residues. Aquatic plant fruits have been documented to absorb more than other plant parts; leaves absorb more than roots (Vaquer, 1973).

4) Aquatic plants assist in biological removal of algae

Aquatic plants can inhibit the growth of phytoplankton, so thereby algae are reduced in water. Because aquatic plants are typically the dominant plants, they compete with algae nutrition, light and living space. Also, aquatic plants play a role with micro-organisms in producing allelopathic secretions that remove algae, which is important in the prevention and treatment of eutrophic water pollution (Qian, 2008).

2.2.5 Some negative aspects of aquatic plants

Aquatic plants have many positive characteristics, but they also possess some negative aspects. Some aquatic plants can be used for human and animal nutrition; however, some aquatic plants are poisonous. Although aquatic plant growth can promote water purification, some aquatic plants may need to be removed from a site because of a reduction in dissolved oxygen, which causes secondary pollution. Also some aquatic plants become invasive species, such as Common Water Hyacinth *(Eichhornia crassipes* Mart. Solms), which is an invasive species in China, and Purple Loosestrife (*Lythrum salicaria* L.), one of a number of common invasive wetland plants in North America. Obviously, designers should avoid specifying invasive species when choosing aquatic, wetland and/or other plants for riverfront settings.

2.3 Landscape ecology

Ecological principles are at the core of landscape architecture and ecological planning and design. In fact, Lyle argues that landscape architecture revolves around the "human ecosystem" (Lyle, 1985). "Landscape ecology" first was described in 1939 by German biogeographer Carl Troll. He defined landscape as "the total spatial and visual entity" of human living space, integrating the biosphere and human activities. In the 1990s, landscape ecology has been generally accepted and applied by international urban design and landscape design (Yu and Li, 2003). According to the United States Environmental Protection Agency (US-EPA), landscape ecology is "an interdisciplinary science framework that studies the relationship between spatial patterns of landscape characteristics and conditions of and risks to ecological resources, including forests, rangelands, wetlands, rivers, streams, lakes, and urban environmental settings. Local, regional, national, and global economies depend upon both goods and services resulting from ecological resources." Landscape ecology encourages minimum or targeted design using the maximum forces of nature. It is a system based on natural regeneration and the self-renewal capacities of organic design (Lyle, 1994).

Urban waterfront landscape ecology should: use plants which are locally and/or regionally adapted as the primary materials; plants should be specified in a scientific and rational way (recognizing for example, the appropriately-sized boulders and rocks often need to be combined with vegetation to effectively stabilize streams and/or river banks); design should include aesthetic considerations; and should include intent to be achievable at lower development cost and maintenance requirements.

2.3.1 Benefits of ecological in urban riverfront

Ecological riverfront regulation plays a large role in protection of the urban environment. The riverfront can be restored with a natural river or in some cases a permeable artificial revetment. This can improve the water exchange and regulatory function between the riverside and river water, improving management of flood episodes, and improve the functionality of the river hydrological and biological processes (Sun and Huang, 2000).

Ecological urban riverfronts use natural materials to form a permeable interface. In wet periods, river water can infiltrate to the groundwater aquifers, aiding flood mitigation; in dry seasons, groundwater will infiltrate to the river, thus regulating the water level. Aquatic plantings in ecological waterfronts also can provide some water storage. They improve the porosity of the interface, providing more potential for biological growth with more velocity change for fish and other aquatic animals and amphibians habitat, breeding grounds and shelter. One of the most important aspects of the ecological remediation approach is that aquatic plants create ecological niches and restore natural processes.

2.3.2 Aquatic planting design in ecological remediation of urban riverfronts

Aquatic plants can improve the efficiency of water purification, create an ecological revetment, and improve the environmental quality of urban waterfronts as well as the aesthetic landscape. Ecologists believe aquatic restoration is a low-energy and eco-friendly system (An 2008). Different types of aquatic plants in the water ecosystem occupy different ecological niches and they have different roles in the urban waterfront. Through selection of different plant types, vegetation structure can be optimized to speed up the recovery process and optimize the community structure (Ma, 1997; An 2008).

Chapter III: Selecting aquatic plants

3.1 Factors affecting aquatic plant selection for ecological redevelopment

The living environment of aquatic plants is a complex, sometimes volatile and unique ecosystem. Many factors influence the ecological role and growth of aquatic plants. Understanding those factors is crucial to selecting and designing with aquatic plants. Following is a brief description of the many factors that affect the selection and successful use of aquatic plants for specific purposes.

3.1.1 Temperature

Temperature extremes certainly affect the range and distribution of aquatic plants, but temperature also influences their physiology *in situ*. Water temperature affects bottom-rooted, floating-emergent and rooted aquatic plants. Generally, floating-emergent and rooted aquatic plants become dormant following exposure to 0° C, and their optimal temperature range for growth is 25 - 28 °C. Growth ceases at temperatures above 35°C. The ability of aquatic plants to absorb and process pollutants is, in part, constrained by temperature. Within the optimal temperature range for plant growth, increased temperature increases plant growth and metabolism, which also accelerates nitrogen, phosphorus and other nutrient removal from a river (An, 2008).

3.1.2 Depth of water

Both water depth and water quality affect aquatic plants. Turbid water reduces sunlight penetration, which limits growth of some species. Where water clarity and light penetration are better, totally submersed aquatic plants are better able to thrive. Depth of adaptability for emergent and rooted aquatic plants is generally 10-60 cm, for those in the bottom rooted and floating category optimal depths are generally 80-120 cm.

3.1.3 Water Quality -Differences in plant species absorption of pollutants

Aquatic plants have varying growth rates, demands for nutrients and absorptive capacity, and they vary in the role of promoting the growth of microorganisms. As a result their abilities to purify bodies of water also vary. Water purification efficiency in many cases results from plant growth characteristics that differ from characteristics that promote plant cultivation (An, 2008). Due to differences in aquatic plants' metabolism, they range in their documented ability to absorb toxins and purify water (see table 3.1.3). Also, because of these differences among species, combinations of aquatic plants in a composition are often more effective in purifying bodies of water than a single species would be (An, 2008).

Table 3.1.3 Chemicals and portions removed from water by selected species. (Zhu *et al.*, 2005)

Aquatic Species	**COD* (%)**	**NH4 (%)**	**NO3-N (%)**	**NO2-N (%)**	**P (%)**	**N (%)**
Elodea spiralis 伊乐藻	53.93	65.38	97.59	96.89	89.91	62.57
Alternanthera philoxeroides 水生花	40.77	86.92	95.49	98.98	94.79	63.57
Zizania caduciflora 茭草	38.20	96.15	82.40	91.30	89.91	85.57
Vallisneria spiralis 苦草	34.19	65.00	96.14	71.25	13.19	72.82
Lemna paucicostata 浮萍	33.36	97.51	98.08	91.30	95.05	80.00
Hydrilla verticillate 轮叶黑藻	27.26	69.23	89.11	88.46	06.23	44.39
Pistia stratiotes 水浮莲	26.32	96.77	98.30	69.16	98.95	74.27
Myriophyllum spicatum 聚草	21.03	73.10	98.63	70.02	76.04	85.29

***COD =** Chemical Oxygen Demand

3.2 Aquatic plant selection principles

Aquatic plant selection is a foundation step in designing the riverfront. The designer must generally pay attention to four aspects in the choice of aquatic plants (Bentrup, 2008).

Selected plants should be: (1) fast growing, easy to maintain, and perennial; (2) available locally; (3) ecological suitable; and (4) potentially economically beneficial (have a utilization value) and be reflective of cultural values and/or regional landscape conditions.

3.2.1 Classification of aquatic plants in water purification

Before choosing specific aquatic plants, the on-site water pollution conditions must be identified. Plant selection for this function may then be prescribed, based on plant category, documented evidence as a toxin remover (see Table 3.2.1), availability, growth characteristics and/or aesthetics.

Table 3.2.1-1Relative pollutant removal ability of aquatic plant types (Li, 2007).

Type – and relative removal ranking of:	**Nitrogen and Phosphorus**	**Heavy Metals**	**Toxic Organic Pollutants**	**Algae**
Free floating	4*	3	3	1
Totally submersed	1	1	1	1
Bottom rooted and floating	2	2	2	1
Emergent and rooted	3	4	4	1

*Ranking, where 1 is highest removal ability and 4 is lowest.

After selecting the type of aquatic plants based on site pollution characteristics, the next step is to choose the specific aquatic plants within each plant type category. Following are specific examples of aquatic plants in each type category based on pollutant removal performance (see Table 3.2.1-2).

Table 3.2.1-2. Examples of aquatic plant species of each type and pollutant removal function (Gu *et al*., 1994; Liu, 2002; Jiang *et al*., 2000; Rai *et al*., 1995).

Aquatic Plant Type	**Known Pollutants Removed**			
	N and P	**Heavy Metals (Zn, Cr, Pb, Cd, Co, Ni, Cu)**	**Toxic Organic Pollutants***	**Algae**
Free floating	*Eichhornia crassipes* (Mart.) Solms Laub.	*Eichhornia crassipes* (Mart.) Solms Laub.	*Azolla imbricata* (Roxb.) Nakai	*Eichhornia crassipes* (Mart.) Solms Laub.
	Spirodela polyrrhiza (L.) Schleid.	*Spirodela polyrrhiza* (L.) Schleid.	*Spirodela polyrrhiza* (L.) Schleid.	*Pistia stratiotes* L.
Totally submersed	*Elodea canadensis*	*Vallisneria natans* (Oour) Hara	*Ceratophyllum demersum* L.	*Vallisneria natans* (Oour) Hara
Bottom rooted and floating	*Ludwigia peploides* (Kunth) *Kaven subsp. Stipulacea* (Ohwi) Raven	*Trapa japonnica* Fler.	*Brasenia schreberi*	*Potamogeton malaianus*
Emergent and rooted	*Acorus calamus* L.	*Typhax orientalis* Presl.	*Sagittaria sagittifolia* L.	*Phragmites australis*

*Example toxic organic pollutants include DDT, etc.

3.2.2 Aquatic plant selection principles in the consolidating of embankment stability

From a plant structural standpoint in embankment consolidation, designers should generally consider plant establishment, growth habit, and rooting characteristics. Moreover, preferred plant selections for bank stabilization should be based on the following five characteristics. Plants should (1) possess deep and spreading root systems to help stabilize slopes; (2) include low, spreading shrub species; (3) be relatively fast growing; (4) be tolerant of inundation and flexible have flexible stems; and (5) be perennial. Section 4.1 of this document provides more information about the selection process.

3.2.3 An additional plant type for applications in embankment consolidation (sediment control)

In sites where additional consolidation of the embankment extends further inland, a fifth plant type (upland species) should be considered. Examples of upland plants based on growth habit are included in Table 3.2.3 (next page), which provides other useful fundamental plant characteristics for the designer. While some species are invasive in some parts of the world, they are not invasive in their native environments, such as the following examples from China.

Table 3.2.3. Planting design details of selected example species.

	Species	Chinese Name	Flower Color	Flower Season	Fruit	High (cm)
Free floating	*Spirodela polyrrhiza* (L.) *Schleid.*	浮萍	N	N	N	1
	Eichhornia crassipes (Mart.) *Solms* Laub.	凤眼莲		Summer	N	30-50
	Azolla imbricata (Roxb.) *Nakai*	满江红	N	N	N	1
	Pistia stratiotes L.	大薸		Summer, fall	Y	20
Totally submersed	*Elodea canadensis*	伊乐藻	N	N	N	30—60
	Vallisneria natans (Oour) Hara	苦草		Summer	N	20-30
	Ceratophyllum demersum L.	金鱼藻		Summer	N	40-150
Bottom rooted and floating	*Ludwigia peploides* (Kunth)	黄花水龙		Summer	N	30 500 Spread
	Trapa japonnica Fler	菱		Fall	Y	60
	Brasenia Schreb schreberi J.F. Cmel.	莼菜		summer	N	600-1000 Spread
	Potamogeton malaianus	马来眼子菜		Summer, fall	Y	Spread-ing
	Acorus calamus L.	菖蒲		Summer	Y	60-140
	Typha orientalis Presl	香蒲		Summer	Y	120-200
	Sagittaria sagittifolia L.	慈姑		7-9	Y	120
	Phragmites australis	芦苇		7-11	N	100-300
Wetland vegetation in upland	*Ligustrum lucidum*	女贞		6-7	Y	450
	Salix integra	杞柳		4	Y	300
	Cynodon dactylon (L.) Pers	百慕大		N	N	5

Chapter IV: Optimal allocation of aquatic plants

Natural riverfronts are comprised of plant communities. Observationally selecting aquatic plants for disturbed riverfronts can accelerate redevelopment of vegetation processes that increase river self-purification (Liu 2003) and reduce flood zone problems. Determining the selection of aquatic plants as a thickened "line" in riverfront design, with more structural and species diversity is the second step in our conceptual model of riverfront design and

redevelopment (see Figure 4.1).

Figure 4.1 Conceptual model of the "line" in riverfront planting design.

4.1 **Optimizing the allocation of aquatic plants for water purification**

Designers can achieve an optimal allocation of aquatic plants along the "line" to improve the potential for decontamination or self-purification of a waterway, as follows.

4.1.1 **Decontamination of river pollution**

Free floating, totally submersed, bottom rooted-floating and emergent-rooted aquatic plants can decontaminate water pollution. Selecting all four of the above aquatic plant types provides more decontamination than selecting only one or two types. The optimal allocation order is shown in the figure below (see figure 4.1.1).

Figure 4.1.1 Decontamination of river pollution

4.1.2 Decontamination of pollution in surface runoff from adjacent areas

Upland aquatic plants are buffers which can decontaminate rain water as it drains from uplands toward rivers. These plantings can reduce non-point pollution removing total nitrogen (TN) and total phosphorous (TP). Deep-rooted and densely integrated grasses (forming a consistent soil covering) are the best upland plants to remove TN and TP, followed secondarily by forbs and shrubs, and then by trees. Where enough space exists for the optimal allocation of these plantings, grasses, shrubs and trees are the best allocation to move TN and TP; grasses with forbs and shrubs are next best choice, and a composition of grasses with trees are the third choice. These plantings should be designed to have trees near the river, and then shrubs, with grasses nearer the non-point pollution (Wu et al., 2008). (See figure 4.1.2). This illustration suggests an effective horizontal distance for effective buffering.

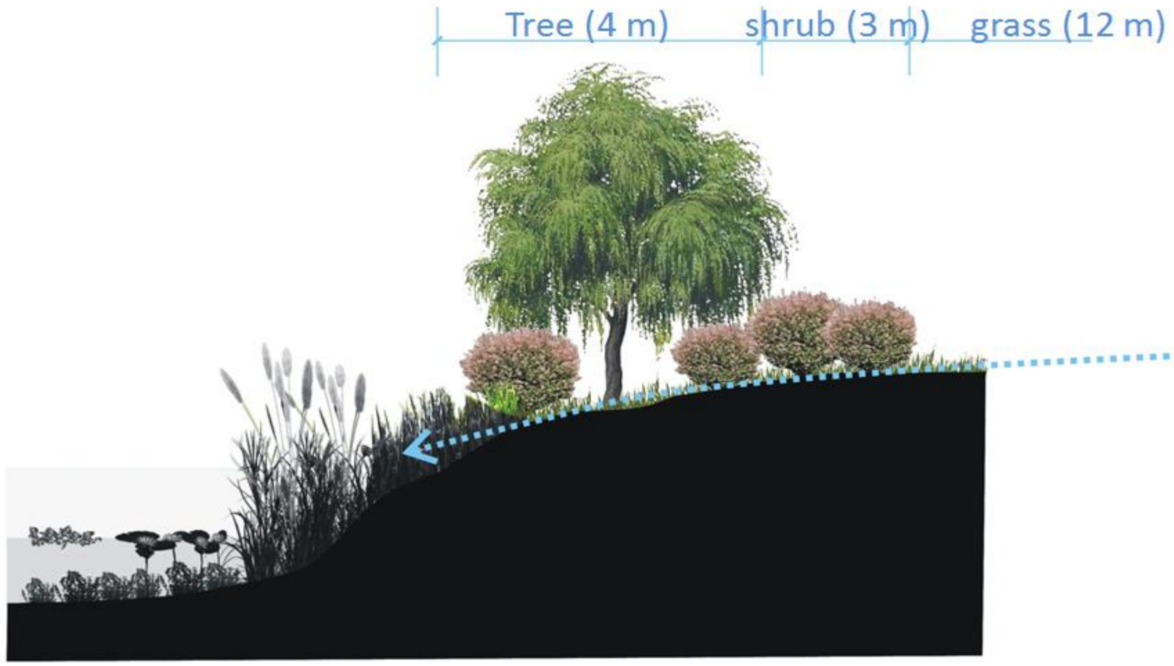


Figure 4.1.2 Decontamination of pollution in surface runoff

4.1.3 Decontamination of pollution in shallow groundwater

Upland buffers may contact shallow groundwater. Selecting upland plants with adequate rooting (0.6-0.9m) depth allows these plants to intercept the groundwater flow in order to remove some pollutant transported in it. Most nitrate reduction in shallow groundwater occurs within 9m to 100 feet of entering a buffer (Bentrup 2008) (see figure4.1.3).

Figure 4.1.3 Decontamination of pollution in shallow groundwater.

4.2 Optimizing aquatic plant allocation to reduce flooding

Bentrup (2008) notes: "Herbaceous plants with fibrous root systems are better for protecting banks from surface erosion. Woody species with deeper roots will be better at increasing soil cohesion and reducing mass slope failure. Select woody species that re-sprout from roots or from broken branches. The best approach is often a combination of plant types."

Sun and Huang (2000) classify four different kind of ecological embankments. These four zones of embankment are: (1) the bottom area is the part below the normal water level; (2) water and bank mix area is the part between the flood level and the normal water level; (3) bank mix area is between flood level and top part of the shore; and (4) the top area is embankment above the bank (see Figure 4.2).

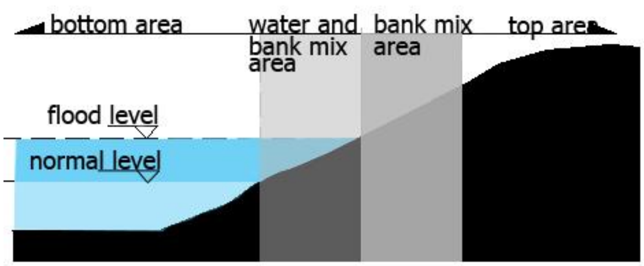


Figure 4.2 Optimizing aquatic plant allocations to reduce flooding

4.2.1 Natural soft embankment

Natural soft embankment mainly uses aquatic vegetation protection of the embankment. This system uses plant roots, stems, leaves and the combined plant configuration consolidates the embankment. To create this system, the goal generally is to select emergent-rooted and totally emergent aquatic plants with developed roots. Natural soft embankment is suitable for use where the bank slope is minimal, the bank has enough space; and river erosion of the bank is not serious. The natural soft embankment design is illustrated below in Table 4.2.1 (Changsha City ecology embankment design guide, 2009).

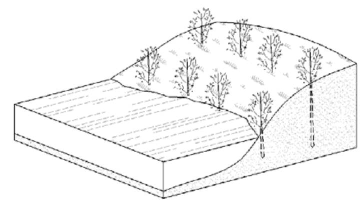
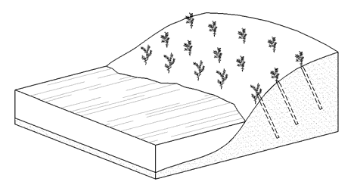
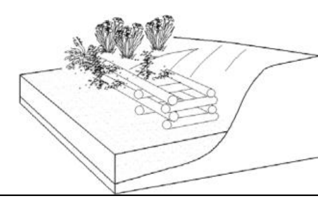
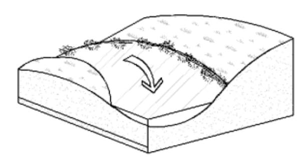
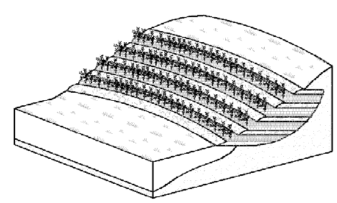
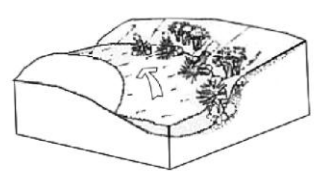
Type	Method	Zone	Illustration
Planting tree method	Cultivar tree in a square or triangle.	water and bank mix area	
Planting tree stump method	Select the live and easy-to-root species of trees to cut branches, put directly into in the soil.	water and bank mix area and bank mix area	

Table 4.2.1. Natural soft embankment.

4.2.2 Natural semi-soft embankment

Natural semi-soft embankment design uses aquatic vegetation, natural stone and wood to protect the bottom of bank and to enhance capacity to withstand flooding. One example of this system uses wooden stakes and/or stones as fish habitat/nesting in the bottom of the embankment. Construction of the embankment slopes incorporates vegetation. Generally, this plant composition would include trees, shrubs, forbs and grasses (the emergent and rooted and upland aquatic plan) to steady embankment. This natural semi-soft embankment approach is mainly used for steeper slopes or a more serious erosion section. The natural semi-soft embankment is illustrated below in Table 4.2.2 (Changsha City ecology embankment design guide 2009).

Type	Method	Zone	Illustration
Wooden cage wall method	Place the wood interlock with box-shaped, filling soil and plant aquatic plant.	Bottom area	
Trees pave -ment method	The rope will complete a series of the withered tree together in a bundle, and rivet into the embankment.	Bottom area	
Vegetation grid method	Aquatic plants will be live in between the layers of the soil in natural or synthetic fabrics, package materials used in conjunction with the container bars.	Bottom area and water and bank mix area	
Wood and roots fill surfacing method	With the wood filler compacted into the embankment. The rivets provide habitats for biodiversity.	Bottom area and water and bank mix area	

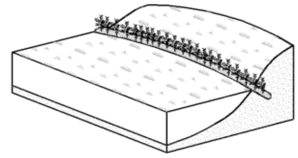
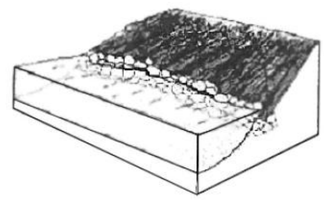
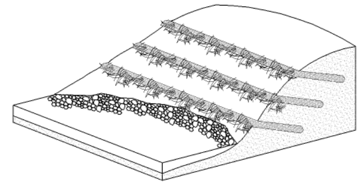
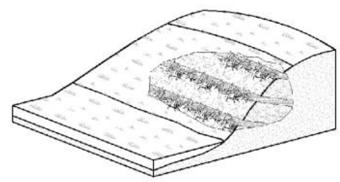
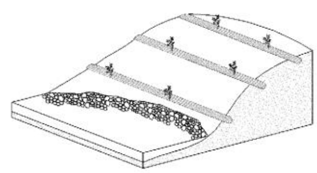
Palm fiber volume method	Using rope to roll brown fibers as a cylindrical structure. Put it in the foot of the slope.	Bottom area and water and bank mix area.	
Land Branches method	Branches with all branches of in vivo-slope direction, forming a sunken bed, all branches are cut into the foot of the slope protection structure.	Water and bank mix area	
Branches criss-cross and overlap method	All branches will be live in a criss-cross and overlap of the insert in the soil layers in the water, and suitable for cross-strait and embankment with staggered.	water and bank mix area and bank mix area	
Drape the container method	Drape the container, wood piles and pinched back fill with water, suitable for cutting and embankment.	Water and bank mix area and bank mix area	
Cylindrical-shaped pieces of wood method	All will live in cylindrical-shaped pieces of wood tied and placed in contour orientation on the slope of the shallow strait drainage, suitable for bulkhead.	Bank mix area	

Table 4.2.2. Natural semi-soft embankment

4.2.3 Natural hard embankment

Natural hard embankment is based on natural semi-soft embankment methods plus hard materials such as reinforced concrete to increase the flood control capacity. It primarily uses reinforced concrete columns or timbers to create frames fill within large stones or reinforced concrete columns and aquatic plants to promote fish habitat. Natural hard embankment is a dry ecological embankment with natural rigid material or brick. It can resist strong water flows, but the decision to apply this technique would generally be based on Geographical Information Systems (GIS) and would involve experts from disciplines including civil engineers, hydrologists, geomorphologists, biologists and/or ecologists. Examples of this type of system are shown in Table 4.2.3 (Changsha City ecology embankment design guide 2009).

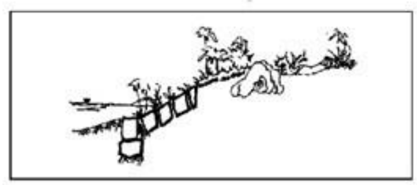
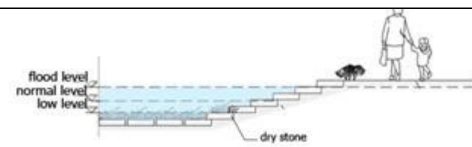
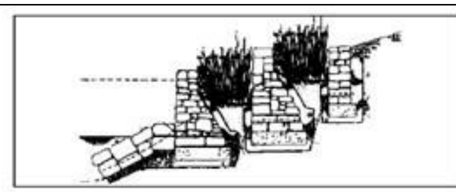
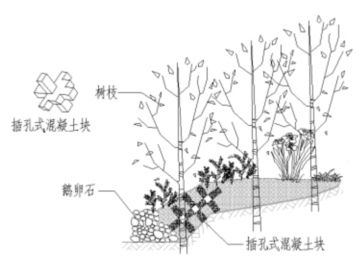
Type	Method	Illustration
Rock fill method	Using stone or brick dry pile up without mortar. Planting aquatic plants.	
Vegetation and concrete cover method	Land out porous concrete and put water conservation materials and insoluble fertilizer as topsoil. Planting aquatic plants.	
Step method	Transformed embankment into stepped terrain, stepped can grow plants or as a rest venue.	
Skeleton within grass method	The concrete frame divided embankment into a number of block structure, in each block structure planting aquatic plants.	
Jack-style Concrete block method	Precast concrete blocks Chain placed the bottom of embankment, plant aquatic plants between the concrete blocks and use soil compaction.	

Table 4.2.3 Natural hard embankment.

4.2.4. Comparing natural embankment types

Classification	Material	Hardness	Ecological effect	Economy	Scope of application	Revetment space	Illustration	Plant optimal allocation
Natural soft embankment	Vegetation	soft	good	smallest and cheapest	Slope is relatively shallow, gentle flow.	large		Based on highly integrated with aquatic plants. Selected emergent and rooted + totally emergent (tree)
Natural semi soft embankment	Vegetation + rock and wood	semi soft	medial	Moderate quantities, short construction period	For variety of slopes, flow gentle or medium; embankment < 3m.	medial		Based on highly integrated with aquatic plants. Selected roots developed emergent and rooted + totally emergent (shrub)
Natural hard embankment	vegetation+ rock and wood + Precast reinforced concrete frame	hard	range	Larger investment	Currents, steep revetment (3-5m above)	structure		Based on highly integrated with aquatic plants. Selected roots developed emergent and rooted + totally emergent (shrub, liana)

Table 4.2.4. Comparing natural embankment types.

4.2.5 Concrete embankment transformation

In transforming concrete embankment to more natural embankment, the key is to not affect the river's function and the adjacent road embankment's stability. Protection of the embankment slope must be maintained while stepping back the levee. Obviously, some sites lack enough space to build the natural embankment; such sites can be transformed only in the original vertical concrete embankment.

A vertical concrete embankment can be divided into three zones for restoration, which are the vertical zone, the slope zone, and transition slope zone, as shown in Figure 4.2.5 (Changsha City ecology embankment design guide 2009).

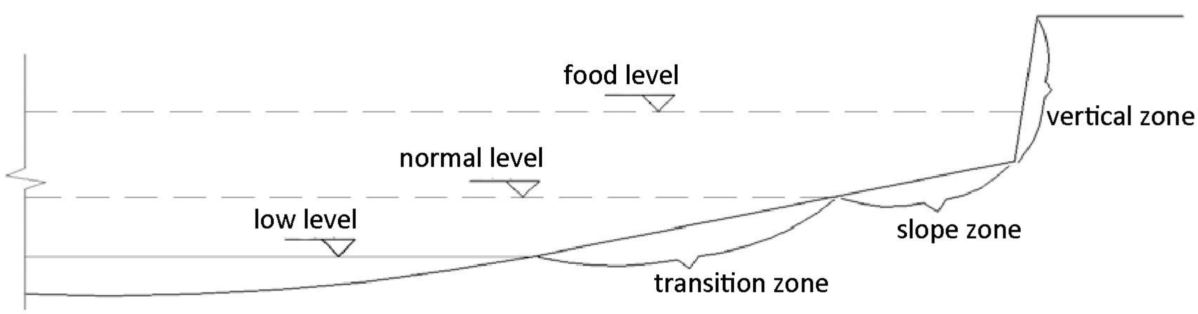


Figure 4.2.5 Concrete embankment transformation.

The vertical zone uses vegetation concrete, which is mix dry powder, humus soil, concrete, concrete additives, vegetation, water, and the slow-release fertilizer as planting material (Changsha City ecology embankment design guide 2009). Vegetation concrete should have good anti-erosion ability and have a good bond with the original slope. Often grasses and forbs are planted by hydro-mulching systems in these circumstances.

In the case of the slope zone, stability of the embankment can be improved by punching openings through the concrete reaching the embankment soil. This allows exchange of water and nutrients between soil and vegetation concrete (Changsha City ecology embankment design guide 2009).

The technique in the transition slope zone (width 1.5-2m) uses porous concrete components and reserves holes to fill in with base planting. Aquatic plants are then planted into the gaps.

Chapter V: The planning and design process for urban riverfront improvement

After the previous two steps which are selecting and setting aquatic plants ("Point" and "Line" in the conceptual model), the third step is to design based on site characteristics that may include pollution problems or flooding zone problems or both. Using the analogy that art is composed of points and lines, the last step for the designer is to create an environmental work of art. In other words, just as the artist moves from gaining the skill of drawing a point, to skill with the line and finally to creating a composition, the designer composes with plants and other materials.

5.1 Methods of aquatic planting design in water self-purification

Larger urban areas can have more water pollution pressure because of more concentrated population and more land covered by concrete. In urban areas this pollution is characterized as point-source and nonpoint-source pollution. Generally, designers create buffer zones to ameliorate point- and non-point source pollution, with the following principles in mind.

5.1.1 Buffer size considerations for decontamination of pollution in surface runoff

The plant community buffer size is calculated after choosing the optimal allocation of plant types. There are several important elements for buffer size design.

(1) Effective buffer zone (B) may be smaller than the gross area buffer. It depends on the upslope runoff area (A) (see figure 5.1.1-1).

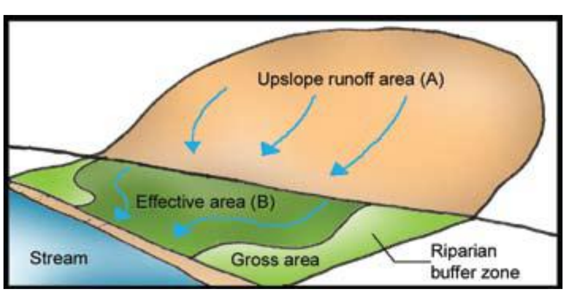


Figure 5.1.1-1. Relative buffer zone sizes (Bentrup, 2008).

(2) Buffer zone widths should be based on runoff loads and site conditions. In the following two figures, illustration D depicts a preferable design for this site (see figure 5.1.1-2).

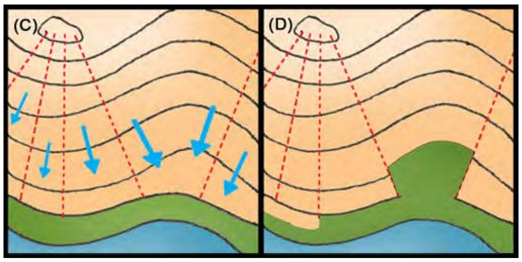


Figure 5.1.1-2. Buffer zone widths based on runoff loads and site conditions (Bentrup, 2008).

(3) A rule of thumb is that the steeper the slope, the wider the buffer zone should be (see figure 5.1.1-3).

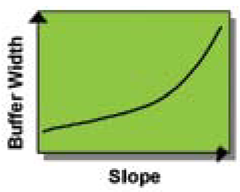


Figure 5.1.1-3. Buffer zone width should increase with increased slope (Bentrup, 2008).

(4) Using the Riparian Ecosystem Management Model (REMM) a designer can calculate how long the buffer should be, and estimate the expected erosion rate (see figure 5.1.1-4).

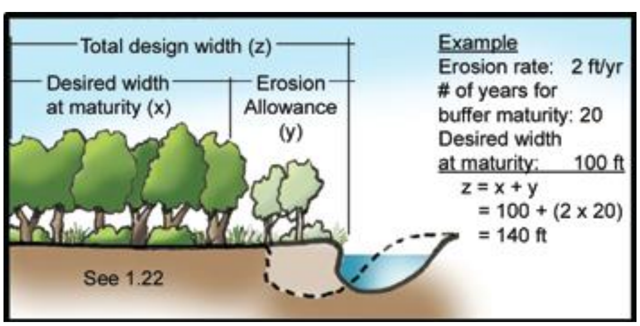


Figure 5.1.1-4. Riparian Ecosystem Management Model (REMM) (Bentrup, 2008).

5.1.2 Nonpoint-source water self-purification

Nonpoint-source pollution occurs as pollutants migrate from off site into waterways primarily through runoff. In these cases aquatic plants are specified based on the principles in Chapters 2 and 3 in this report.

5.1.3 Point-source water self-purification

Throughout much of the world, much of the point-source water pollution comes from raw sewage and wastewater. Ideally, the design and construction includes forcing this waste stream through water treatment/sewage treatment plants before release into waterways. In areas where this is not economically feasible, the goal becomes diverting it through wetlands before it is gradually released to the waterway (see figure 5.1.3). This slower form of water self-purification system can also be applied to nonpoint-source pollution situations.

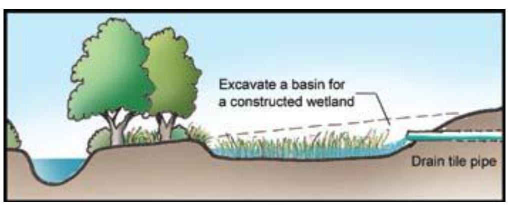


Figure 5.1.3 Point-source water self-purification (Bentrup, 2008)

Gowanus Sponge Park is good design example of using wetland vegetation in nonpoint-source pollution situations.

5.1.4 Case study- Gowanus Sponge Park (USA)

Gowanus Sponge Park is in Kings County (Brooklyn), New York. The idea of this project is to let the storm water go through wetland before it reaches the river (see figure 5.1.4). The wetland was designed on the top of the bank and around the Gowanus Canal. All stormwater is collected and diverted to the wetland water self-purification zone, and then to the river.

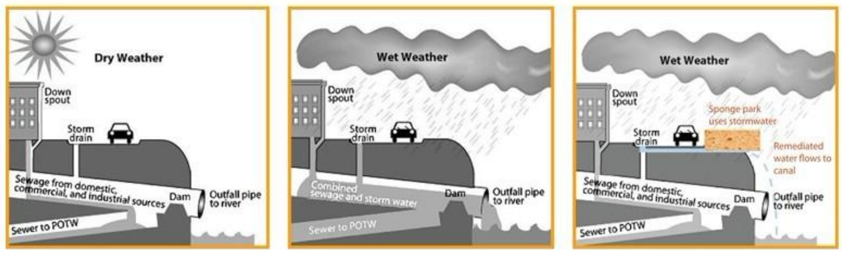


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Figure 5.1.4 Gowanus Sponge Park, N.Y. (Drake, www.asla.org)

5.2 Methods of aquatic planting design in flood zone areas

The two main causes of flooding problems in urban areas are that formerly naturally curving canals are redesigned as straight lines to conserve much needed space coupled with the fact that population tends to concentrate in urban centers, resulting in buildings being constructed in flood zones. After the flooding episodes, people know it is not safe to build in these flood zones, so these areas are renovated in such a way that flood zone land becomes elevated and buildings are then constructed at increased elevations. As the city grows, more and more buildings are built in flood zone. One of the common solutions becomes construction of concrete banks along these canals, which only exacerbates problems with increased water flow. As the city eventually needs even more space, rivers are sometimes partially covered with more buildings and/or roads. Ultimately, this leads to poor water quality and increased potential for flood damage. This is an all too common scenario for urban river development. This also is the development history of ChonGae Canal in South Korea.

5.2.1 Straight canal

Rivers through erosion, transport and accumulation of the three hydraulic way interactions forming a rich fluvial geomorphology: meander, wetland, lake and so on. These geomorphic features provide great contributions to natural rivers in the water regulation function. It is able to weaken flood pressure by consumption of the momentum of the flood, thus ensuring the stability of the riverbed morphology. This weakens the pressure on the lower reaches of the flood. Renovating the straight-line canal back to the more natural sweeping curved canal is the best way to control fooling with relatively low investment and maintenance costs. Designers need to understand ideas from landscape ecology and use Geographic Information Systems (GIS) as an analytical tool to set the stage for selecting embankments types. to calculate and estimate what the river form will be in the future-- meander, wetland or lake. An ultimate goal for designers and planners in designing the riverfront would be to protect space for it. Designers need to be involved in the process as well as civil engineers, hydrologists, geomorphologists, biologists/ecologists.

When designing the meandering river, the designer should identify stable parts and unstable parts of the river. The natural soft embankment or natural semi soft embankment approach would be applied in areas of more gentle water flow, which usually is the inside bend of river. The natural hard embankment system would likewise be used in areas of more turbulent water flow, which is typically the outside bends of river (see figure 5.2.1). The choice of embankment is based on location and space allowed.

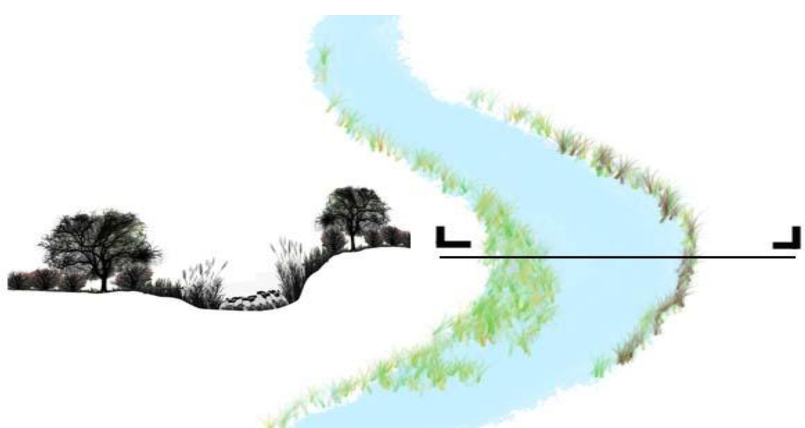

Figure 5.2.1

For renovated concrete embankments designers should consider how to create space both to allow people to interact with the river and to not affect the flood control system in city. ChonGae Canal Source Point Park is a good example that solved this problem.

5.2.2 Case study- ChonGae Canal Source Point Park (Korea)

ChonGae Canal Source Point Park is located in Seoul, Korea. ChonGae Canal had been polluted and covered with roadways. It has very high concrete banks because it needs to withstand 100-year storm events. The design created a new space on the bottom of the bank, which not allowed access for people to be close to the water, but also did not affect the flood control system in city. It is designed so that when the flooding does occur, it will cover this space and public access will close; however, after the flood water recedes, people can once again gain access to enjoy this space again. This project was inspired and can succeed, not only because it is a redeveloped waterway attempting to solve the pollution problems, but also because the design can connect with local culture and create its own environmental art.

5.2.3 An alternative view of stream evolution and the floodplain interface

Rosgen (1997), in his studies of stream evolution, modeled the meandering stream in plan and elevation views over time. Figure 5.2.3 shows the contrasts between stream types C4 through G4 and how adjustments in the flood plain affect them in both plan and elevation. Ideally, the design team would assess and appropriately account for geomorphic processes to determine the ultimate width of the stream/river and keep that space open as landscape space with no permanent buildings as an ecological and maintainable way to promote public safety.

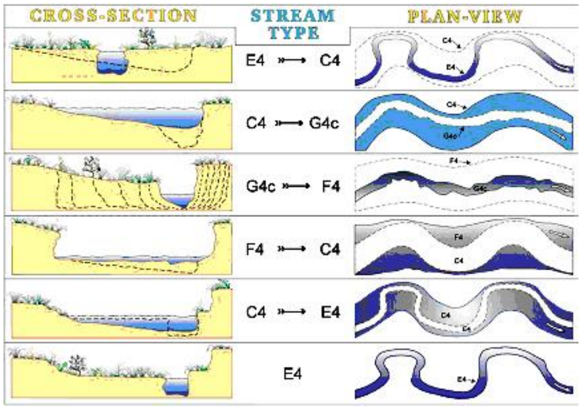

Figure 5.2.3 Rosgen's classic stream types (Rosgen 1997).
(Add U.S. EPA http://water.epa.gov/scitech/datait/tools/warsss/successn.cfm)

5.2.4 Case study-Port Lands Estuary: Reinventing the Don River as an agent of urbanism (Canada)

Port Lands Estuary project, in Toronto, Ontario, Canada, is a good example of relocating the river to where it wants to be. The goal of this project once again is to solve flooding problems. The previously designed, man-made straight canal, caused flooding in the city. This plan includes expansion of open landscape space and actual relocation of the Don River. The project is estimated to be completed by 2030 to reduce effects of flooding on the city and enhance the local ecosystem.

Conclusions

This report, based on the "Designing with Nature" approach, reviews problems, state of the art solutions, and provides general guidelines for using aquatic plants for the ecological redevelopment of urban waterfronts. It attempts to simplify the complex task of renovating urban riparian ecosystems using a conceptual model that employs a three-step method of plant selection: 1) Selecting specific plants for specific functions (the "point") in the conceptual model. This would be based on the existing type(s) of pollution and relevant plant/rooting characteristics. 2) Optimal allocation of aquatic plants (the "line"). This depends on where the pollution originates and helps to determine which type of embankment system to apply. 3) Determining placement in relation to the waterway (the "shape") in the conceptual model. This would depend on topography and evolution of the river channel and watershed. And finally 4) creating a design solution using aquatic plants (the "art" or the "composition") in the conceptual model. Ultimately, this would be based on location, culture and financial commitments to create and maintain the special riverfront landscape. Again, in a rapidly industrializing and urbanizing nation such as China, this model becomes even more useful. The goal is to solve typical riverfront problems such as pollution, flooding, erosion and runoff, aesthetics and providing pedestrian access for recreation and education.

Although aquatic plants possess many beneficial characteristics for such applications, they also have potential drawbacks. For example, some aquatic plant species, especially some of the free floating types, grow at fast enough rates that their proliferation may produce the deleterious side effect of creating a water pollution problem. Also for some aquatic plants, after they collect the heavy metals in plant parts, they cannot transform these elements to non-toxic forms in the water. Thus, designers need to consider habitat functions and values, uptake of heavy metals and the need to harvest and collect certain plant materials so that the heavy metals will not be re-released into the environment. Therefore, the wise selection of plant materials is vital to the design in our attempts to ecologically renovate urban riverfronts.

Some aquatic plants work well in water purification in some situations, a number of well-adapted species may be considered as invasive species. Plant materials specification is regionally (and in some cases locally) based, which suggests a need for more regionally based aquatic plant handbooks and guidelines.

References

An, J. (2008). Aquatic eutrophication of water bodies repair mechanism and influencing factors of Review. *Guangxi Journal of Light Industry-- Resources and Environment*, 6, p. 96-97.

Arber, A., (1920). *Water Plants*. Cambridge University Press, Wheldon & Wesley.

Bentrup, G., (2008). *Conservation buffers-design guidelines for buffers, corridors, and greenways*. Asheville,NC: Department Of Agriculture, Forest Service, Southern Research Station.

Brenner, M., Whitmore, T. J， & Lasi, M. A.， et al. (1999). A multi-proxy trophic state reconstruction. for shallow Orange Lake， Florida， USA: Possible influence of macrophytes on limnetic nutrient concentrations. *Journal of Paleolimnology*, 21(2):215-233.

Changsha City Construction Committee. (2009). *Changsha City ecology embankment design guide* (The pilot). Changsha City works to build local technical standards. Changsha City: Changsha City Construction Committee.

Deng, F., (2007). *Wetland plants and its application*. Kunming: Yunnan Science and Technology Press.

Devitt, T., (2010). University of Wisconsin-Madison. World's rivers in 'crisis state'. *ScienceDaily*, 9(29). Retrieved. from www.sciencedaily.com/releases/2010/09/100929132521.htm.

Drake, S., (2010). Gowanus canal sponge park. Retrieved from http://www.asla.org/2010awards/064.html website: http://www.asla.org.

Fryirs, K., & G. J. Brierley. (2009). Naturalness and place in river rehabilitation. *Ecology and Society* 14(1): 20. [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art20/

Gao, G., (1996). *Elodea, Hydrilla* clean fish sewage effects test. *Journal of Lake Sciences*, 8(2): 184- 188.

Gu, L., Cheng, J., & Cheng, W., et al. (1994). Vallisneria planting water on algal growth. *Journal of Shanghai Normal University*. 23(1):62-68.

Gumbricht, T., (1993). Nutrient removal processes in freshwater submersed macrophyte systems. *Ecological Engineering*. 2(1):1-30

Jiang, B., and Lin, B., (2000). Heavy metal toxic effects on algae research progress. *Journal of Liaoning University*. 27(3):282-287.

Ryn, S., & Cowan, S. (1996). *Ecological Design*. Washington, D. C: Island Press. p. 131-134.

Jung, W. M., Muhar, S., & Schmutz, S., (2002). Re-establishing and assessing ecogical integrity in riverine landscapes. *Journal of Freshwater Biology*, 47: 867-887.

Li, B., (2000). Curriculum materials for the 21st century: *Ecology*. Beijing,China: Higher Education Press.

Liu, J., (2002). The impact of pollution on aquatic plant physiological indexes of polycyclic aromatic hydrocarbons (naphthalene). *Journal of East China University of Science*. 28(5):520-536.

Liu, L., (2003, June 1). Purification of aquatic plants and their ecological design in landscape water applied research. Retrieved from www.cnki.com.cn/ website: http://cdmd.cnki.com.cn/Article/CDMD-10335-2003071064.htm.

Li, L., (2007). The hydrophytes'purging to the pollutants and its applied research. *Journal of Hunan Environment-Biological Polytechnic*, 13(1):20-22.

Lyle, J., (1985). *Design for Human Ecosystems: Landscape, Land Use, and Natural Resources*. New York: Van Nostrand Reinhold Company, Inc.

Lyle, J. T., (1994). *Regenerative Design for Sustainable Development*. John Wiley & Sons, Inc.

Ma, J., Yan, G., & Luo, Y., (1997). Wuhan East Lake by aquatic plants in the control ecosystems to restore the structural optimization and water quality dynamics, *Lake Sciences*, 9(4):359-363.

Mainstone, C., (2009). *Environmental Conservation.*36(02):172-173. doi:10.1017/S0376892909990117.

May, C., (10 July 1999). "Urban Waterfront Manifesto." Waterfront Center, Web. < http://www.waterfrontcenter.org/index.html >.

Mika, S., Boulton, Ryder & Keating. 2008. Ecological Function in Rivers: Insights from Crossdisciplinary Science. *River Futures: an Integrative Scientific Approach to River Repair*. Washington, DC: Island Press.

Palmer, et.al. (2005). Standards for ecologically successful river restoration. http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2664.2005.01004.x/full

Palmer, Allan, Meyer & Bernhardt (2007). River Restoration in the Twenty-First Century: Data and Experiential Knowledge to Inform Future Efforts - http://onlinelibrary.wiley.com/doi/10.1111/j.1526-100X.2007.00243.x/full

Pennington, K., & Cech, T. (2010). Water quality. In: *Introduction to Water Resources and Environmental Issues* (p. 99). New York: Cambridge University Press.

Port Lands Estuary: Reinventing the Don River as an Agent of Urbanism, Toronto, Ontario, Canada. (2008). Retrieved from http://www.asla.org/awards/2008/08winners/013.html website: http://www.asla.org.

Qian, J. (2008). Aquatic plants of pollutants to waters clear and its applications. *Journal of Hebei Agricultural Sciences*, *12*(10):73-74, 77.

Rai, UN., Sinha, S., Tripathi, RD., & Chandra, P., (1995). Wastewater treatability potential of some aquatic macrophysics: removal of heavy metal. *Ecological Engineering.* p. 5-12.

River Futures: an Integrative Scientific Approach to River Repair. (2008). Edited by: Gary J . Brierley And Kirsty A. Fryirs. Island Press, Washington, DC, USA.

Rosgen, D. L., (1997). A geomorphological approach to restoration of incised rivers. Retrieved from http://www.wildlandhydrology.com website: http://www.wildlandhydrology. com/ assets/a_geomorphological_approach_to_restoration_of_incised_rivers.pdf http://water.epa.gov/scitech/datait/tools/warsss/successn.

Ryn, S., & Cowan, S. (1996). *Ecological design.* Washington,D. C: Island Press. p. 131-134.

Sun, P., & Huang, Z., (2000, May 10). Follow the natural process of urban rivers and waterfront landscape design. *City Planning Review*, 24(9):19-22.

Taiwan River Restoration Network. (2010). Ministry of Economic Affairs Water Resources Agency, Water Planning Research. Aquatic plant manual Retrieved from website: http://trrn.wra.gov.tw/trrn/download/view.do?id=12c310b7666000009e59.

Tian, S., (2006). Ecological model in the planning and design of urban river revetment. *China Water Resources*, 20:13-16.

Vaquer, A., (1973). Absorption and accumulation of residues from certain pesticides and polychlorobyphenyls by the natural aquatic vegetation and by rice in the Camargue. *Oecol Plant*, 8(4):353-365.

Wang, l., li, W., & Wu, Y., (2002). Aquatic plants in vivo distribution of heavy metals in a number of lakes in the middle reaches of the Yangtze River. *Environmental Sciences*, 15(6):1-4.

Wang, W., & Xu, T., (1994). On the submerged plants in Dianchi Lake Caohai. *Guangxi Plant Journal*, 14(14):334-337.

Wohl, et.al. (2005). River restoration. http://www.wou.edu/las/physci/taylor/g473/refs/wohl_etal_2005_restoration.pdf

Wu, J., Wang, M., & Yang.Z., (2008). Optimization of Plants: Community of Riparian Buffer Zones. *Journal of Ecology and Rural Environment.* 24(4): 42-45.

Yu, K., Li, D., & Ji, Q., (2001, June). Ecological design for landscape and city: Concepts and principles. *Chinese Garden*. (6):3-11.

Yu, K., & Li, D., (2003). Landscape architecture: the profession and education. *Beijing: China Building Industry Press*. p. 70-92.

(2009). Chongae canal source point park: Sunken Stone Garden, Seoul, Korea. Retrieved from http://www.asla.org/2009awards/091.html website: http://www.asla.org.

(2012). Aquatic plant resources. Endemic species research institute Retrieved from http://tesrieng.coa.gov.tw/show_index.php
website: http://tesrieng.tesri.gov.tw/show_index.php

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