Ecological restoration for river ecosystems: comparing the Huangpu River in Shanghai and the Hudson River in New York

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Abstract. Starting in the 1960s, a great deal of effort and capital was invested in an endeavor to significantly improve the quality of surface water around the United States, particularly in metropolises like New York City, New York. The Hudson River has been at the forefront of these efforts and has benefited immensely from this campaign. In parts of the developing world, such as China, similar efforts are beginning to gather the same type of momentum. Within the past decade, the Huangpu River, which flows through Shanghai into the Yangtze Estuary, has been a target for ecological restoration and management. It is possible to draw parallels between the cleanup efforts involved in improving the environmental conditions of the Huangpu and Hudson Rivers. Using the methodologies of series comparison (SCM), water quality index (WQI) modeling, consideration of ecological engineering, and policy strategy design, we comparatively studied the topography, functions, environmental conditions, ecological engineering countermeasures, and management policies of the two rivers to assist future forecasting of ecological restoration efforts in China.

Key words: ecological restoration; Huangpu River, China; Hudson River, New York, USA; management policy; river ecosystem; Shanghai, China; water quality index (WQI) modeling.

Introduction

Starting in the 1960s, a great deal of effort and capital was invested in an endeavor to significantly improve the quality of surface water around the United States, particularly in metropolises like New York City, New York. The Hudson River has been at the forefront of these efforts and has benefited immensely from this campaign. In parts of the developing world, such as China, similar efforts are beginning to gather the same type of momentum. Within the past decade, the Huangpu River, which flows through Shanghai into the Yangtze Estuary, has been a target for ecological restoration and management. It is possible to draw parallels between the cleanup efforts involved in improving the environmental conditions of the Huangpu and Hudson Rivers. This study aims to compare and contrast the topography, functions, environmental conditions, eco-engineering countermeasures, and management policies of the Huangpu and Hudson Rivers, and thus move to a greater understanding of the process and strategies for the ecological restoration and management of river ecosystems.

These two rivers share many similar characteristics, including that both flow through large urban areas: Shanghai and New York City. Both metropolises have discharged massive amounts of pollutants into their rivers, mostly in the form of sewage and other forms of municipal wastewater. For the purposes of this study, the essential difference between the Huangpu and Hudson is that there has been a concerted effort to reduce pollutant discharge into the Hudson since the 1970s, whereas the Huangpu is only in the initial stages of environmental remediation and ecological restoration. Although different motives and agents are driving the remediation of each river, an examination of the cleanup efforts in terms of both ecological restoration and management policy will provide a greater understanding of the key issues involved.

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Methodology

A series comparison of complex ecosystems

Series comparison method (SCM) analysis for complex ecosystems was conducted using the characteristics of the socioeconomic and natural ecosystems of the Huangpu and Hudson rivers by selecting some key indexes, such as topography, function, water environmental quality, water resources, hydrology, river history, and comprehensive features. An analysis of statistical data from 2001 to 2010 and a field investigation along the two rivers was also carried out.

Modeling of water quality index (WQI)

Modeling methods have been applied for water quality research and risk management in recent years. Scholars such as Martin-Carrasco et al. (2013) have proposed a methodology for interpretation of index values that led to conclusions about the reliability and vulnerability of systems to water scarcity of the Ebro river basin (Spain), as well as to diagnose their possible causes and to propose solutions. Delgoda et al. (2013) proposed a multiple model to predict flood control in regulated river systems with uncertain inflows. Saadatpour and Afshar (2013) carried out a multi-objective simulation-optimization approach in pollution spill response management model in reservoirs. Sang (2013) improved the wavelet modeling framework for hydrologic time-series forecasting. Sharma and Panu (2013) studied a parsimonious model for Canadian hydrological drought predicting. In this study, we employed a new method for assessing water quality, the water quality index (WQI), which uses four parameters to describe a comprehensive water-quality class as follows:

\[
WQI = \frac{1}{n} \sum_{i=1}^{n} P_i
\]

where \( n \) is the number of pollutant types, and \( P_i \) is the pollution index of pollutant \( i \):

\[
P_i = \frac{C_i}{S_i}
\]

and \( C_i \) is the measured concentration value of pollutant \( i \) and \( S_i \) is the corresponding value in the Chinese national environmental standard (according to designation GB3838-2002, State Bureau of Environmental Protection, China).

We divide WQI into six classes: good (WQI < 0.2), acceptable (WQI 0.21–0.40), mildly polluted (WQI 0.41–0.70), moderately polluted (WQI 0.71–1.00), heavily polluted (WQI 1.01–2.00), and severely polluted (WQI > 2.01). We can then compare comprehensive water quality WQI to the pollution index \( P_i \) for each pollutant \( i \), compare the gap between WQI class and functional class (see Results and analysis: Status of the Huangpu River and Wang [2004]), and identify the number of single water quality factors that cannot meet the water function objective from among all the factors involved in the comprehensive water quality assessment.

Ecological restoration methods

The use of ecological restoration methods has been considered in this study, i.e., methods to increase the natural breakdown of river pollutants by introducing an oxygen barge in the Huangpu River, which can pump oxygen into the water in order to improve dissolved oxygen (DO) levels and cultivate beneficial aerobic bacteria. Similarly, eco-engineering plants in different sections of Huangpu River were placed as a countermeasure for natural water purification. Historically, eco-engineering plants were also used in the Hudson River for water restoration (Limburg et al. 1986, NYSDEC 1996, 2002).

Comprehensive and centralized management policy

Comprehensive and centralized policy and strategies for river environmental management have been considered in this study, which included enhancing the function of environmental NGO involvement and international cooperation, enhancing the risk management action plans for complex water resource systems, restricting wastewater emissions from key industries, cleaning tributaries and upstream areas, decreasing agricultural wastes and major impacts of fast urbanization, and investing much more capital in wastewater treatment infrastructure.

Results and Analysis

Geographic comparison of study areas

In order to effectively compare the Huangpu and Hudson rivers, we must first understand their basic geographic characteristics, and the surrounding landscapes. Both rivers are classified as estuaries (because they experience tidal influence; Figs. 1 and 2) for at least a portion of their length. Saltwater intrusion also occurs in each river, although the strength of estuarine circulation depends on the volume of freshwater entering each river. Table 1 shows a general comparison of geographic characteristics of the two rivers.

Comparison of functions

Functions of the Hudson River

The Hudson River flows through New York State from its source in the Adirondack Mountains to its confluence with New York Harbor at the Battery in Manhattan, a distance of \(~315 \text{ miles} \) (\(~507 \text{ km}\)). The Hudson River
has provided important natural resources and services to the residents of the Hudson River Valley since the earliest days of human settlement (Hudson River Trustee Council 2002). Today, the Hudson River is an important part of the state economy, accounting for 15% of New York State’s population and employment (Stein 2001). In 1999, thousands of jobs were tied directly to the river, creating total annual revenue of at least US$288 million, by a highly conservative estimate. The Hudson serves many direct functions, such as providing municipal water, as well as indirect functions, such as its aesthetic appearance, which plays a role in enhancing tourism in the Hudson River Valley. The historical functions of the Hudson are displayed in Table 2, according to chronology and order of importance.

Tourism is the prime function of the Hudson River today, and it was designated an American Heritage River by Congress in 1996. The Hudson is also a crucial area for biodiversity, evidenced by the fact that the New York State Department of Environmental Conservation (NYSDEC) has listed over 16 500 acres of the estuary as “significant coastal fish and wildlife habitat” (NYSDEC 1996). Additionally, the Hudson River Valley provides a setting for urban and residential areas. New York City surrounds the lower Hudson River and has a population of over 8 100 000 people and a Gross City Product of over US$400 billion. The Hudson is also a valuable resource for municipal water supplies. Although New York City only uses the Hudson as a water source during emergencies, there are many communities that

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**Fig. 1.** The Hudson Estuary, with the Lower Manhattan skyline in the background (New York, New York, USA). Photo credit: X. Wang.

**Fig. 2.** The southeastern Huangpu Estuary, within the Yangtze River Estuarine Area, China. Photo credit: X. Wang.
do use the Hudson as their primary source of potable water. These include the districts of Highland and Port Ewen, and the cities of Waterford, Rhinebeck, and Poughkeepsie. It is not feasible to use the Hudson for drinking water below Poughkeepsie, due to the intrusion of saline water.

**Functions of the Huangpu River**

Shanghai has a large population of over 24.7 million (1.17% of China’s population) and an area of 6340.5 km². Within this area, the per capita income is over US$12,784 (Shanghai Statistics Bureau 2011), which is exceptionally high by Chinese standards. Today the Huangpu supplies ~80% of Shanghai’s water. Although a new reservoir (Qingcaosha) has been built in recent years, which will gradually shift the source of Shanghai’s water. The Huangpu River is used by ferries, which although not drinkable.

Looking back on the history, the Huangpu River was a beheaded river (the headwaters were blocked by a natural dam) until the Warring States Period (ca. 475–221 BCE), when it was managed to protect the people living in that basin from drought and flood. It then became an entrance of the Yangtze River to the East China Sea. The whole water system was formed during the Ming Dynasty when the Huangpu was combined with the upstream Wusong River, effectively solving sedimentation problems. Then the harbor and related industry developed along the Huangpu River, accelerating the rapid maturation and internationalization of Shanghai. Currently, the Huangpu is the only river without any sluice, and the largest river in the Lake Tai basin perimeter, with the most storage capacity for tidal water and flood discharge.

Today, the Huangpu provides a variety of functions for Greater Shanghai, such as water supply, waste disposal, transportation, tourism, and industrial uses. According to the categorization system of the Shanghai Water Authority, the Huangpu has three areas, including a landscape water area of grade B, a quasi-protected water area, and a protected drinking water area (Fig. 3). Grade B refers to the GB12941-91 designation (State Bureau of Environmental Protection, China) and indicates landscape water in national key scenic spots and leisure water with nondirect contact permitted. Water in quasi-protected areas is under some regulation, but is not drinkable.

With the importance of tourism to the economy of Shanghai, which accounts for ~17% of Shanghai’s GDP, i.e., US$49.715 billion in 2011 (Shanghai Statistics Bureau 2011), and the central location of the Huangpu River in the city, a dirty and foul-smelling river would negatively affect tourism, and a vibrant unpolluted waterfront would enhance the urban tourism industry. Abelson (2001) said that even five years ago, walking along the famous Bund area was not a pleasant experience because of the bad smell emanating from the Huangpu River. Sun et al. (2013) studied the musty odor and its main causative compounds in the Huangpu River through a yearly investigation using flavor profile analysis combined with HSPME-GC-MS analysis. Their investigation showed that 2-methylisoborneol (2-MIB) with a concentration level between 28.6 and 71.0 ng/L was responsible for the musty odor in summer from July to September. Microscopic observation confirmed that Phormidium spp., which accounted for 80–95% of the algal cell density, was the microorganism responsible for the production of 2-MIB, with a yield of 0.022 pg/cell. Due to this poor water quality, aquatic life in the Huangpu was severely limited in the lower and middle reaches.

The Huangpu is also important for shipping, in part because it is wide and ice-free throughout the year. Shanghai itself is the largest port in China, and the Huangpu is important in augmenting Shanghai’s shipping needs. In addition to commercial shipping, the Huangpu River is used by ferries, which although declining in popularity, still carry passengers along the river.

### Comparison of environmental quality

**Status of the Hudson River**

In comparison, the Hudson River is fairly clean, as the inflow of pollutants that once troubled it has been

| Characteristic       | Huangpu | Hudson |
|----------------------|---------|--------|
| Length (km)          | 113.4   | 512    |
| Width (m)            | 300–770 | 700–1000|
| Flow volume (m³)     | 315     | 600    |
| Origin               | Lake Tai| Lake Tear of the Clouds |
| Final ocean          | Pacific | Atlantic |
| Watershed (km²)      | >10000  | 21 565 |
| Precipitation (cm)   | 112.7–120.5 | 102–122 |
| Temperature (°C)     | 15.4–16.4 | 8.3    |
| Main tributary       | Suzhou Creek | Snake River |

### Table 1. General comparison of geographic characteristics of the Huangpu (Shanghai, China) and Hudson (New York, USA) rivers.

### Table 2. The functions of the Hudson River in different historical stages

| Historical stage | Function |
|------------------|----------|
| Pre-Columbian    | habitat, fisheries, transportation |
| European settlement (early 1600s–late 1800s) | transportation, fisheries, artistic inspiration, habitat, waste disposal |
| Early 1900s      | industry, fisheries, transportation, tourism, power generation, waste disposal, habitat, municipal water |
| Today            | tourism, habitat, irrigation, municipal water, power generation |
significantly diminished. There are still pressing issues in the Hudson, but they are different and not as severe as those in the Huangpu. For example, there are vast deposits of polychlorinated biphenyls (PCBs) in river sediments, invasive species play a highly detrimental role in the river, many fisheries are depleted, and nonpoint sources drain pollutants into the Hudson (Bloomberg and Ward 2003). Of these issues, PCBs have caused the most havoc, by damaging ecosystems within the Hudson and almost single-handedly shutting down the fisheries of the Hudson River. PCBs are a group of manmade substances, mostly dumped into the Hudson River by the General Electric Company from the 1940s to the late 1970s. It is estimated that General Electric released between 91 and 590 Mg of PCBs during this period. It is now known that PCBs cause cancer, reproductive damage, low birth weight, and a variety of other serious ailments in humans and other organisms. In the early 1970s, elevated levels of PCBs were found in fish in the Hudson, causing fish consumption advisories to be implemented in 1975, which remain to this day. This has effectively closed the commercial fisheries of the Hudson, leaving only the shad fishery and “catch and release” sport fishing. After decades of legal battles with General Electric, the Environmental Protection Agency (EPA) ordered General Electric to clean up the PCBs.

Another challenge facing the Hudson is the various invasive species that have colonized it. There are 113 established invasive species in the Hudson, but the two most significant are water chestnut (Trapa natans) and zebra mussels (Dreissena polymorpha). Water chestnut, which was introduced in 1940 from Germany, has had a significant impact on the Hudson River. Because water chestnut is able to outcompete native submerged aquatic vegetation, it has been detrimental to biodiversity. Additionally, in places, it grows in sufficient densities to block recreational access. The other major invasive species to have colonized the Hudson is the zebra mussel, which has caused problems ranging from economic damage caused by blocking pipes to dramatic decreases in microzooplankton and to the cost of manually removing these tenacious mussels from boats and docks.

Nonpoint sources of pollution remain a major issue for water quality in the Hudson (Phillips et al. 1998). By definition, nonpoint sources are difficult to track, which also makes them difficult to control. The major sources of nonpoint pollution in the Hudson River Valley are agriculture and sewage. Also important are emerging pollutants, which include pharmaceuticals, household products, and other substances not removed by
wastewater treatment plants. As of yet, the ecological effects of these pollutants are not entirely known, but some are known to have adverse effects on biota. Another large source of pollution, especially for urban areas, is combined storm overflows (CSOs). CSOs, which are the largest source of pathogens in the New York City Harbor, become a source of pollution when large amounts of water (usually from a storm) enter a sewer system, which overwhelms the capacity of wastewater treatment plants, and causes a mixture of storm- and wastewater to be discharged, untreated, from the plant.

**Status of the Huangpu River**

Although significant efforts to clean the Huangpu River have been made over the past decade, it remains a highly degraded river. The Chinese method for grading surface water quality takes the most important pollutant indicators into account and then rates the water on a five-class scale, with Class I being the best and Class V the worst (Wang 2004). Most sections of the Huangpu are in a range that goes from Class III to beyond Class V, meaning that the Huangpu is severely polluted.

This pollution is caused by the dumping of sewage (42%), agricultural runoff and byproducts (40%), and industrial discharges (18%; Shanghai EPB 2004; Fig. 4). The geographical source of this pollution encompasses the entire watershed of the Huangpu, but the majority comes directly from Lake Tai and Shanghai (Shanghai Municipal Government 1994).

Six sections upstream along the Huangpu River, including Dianfeng, Songpu Bridge, Lin River, Southern Water Plant, Yangpu Bridge, and Wusong Kou, are monitored by the Shanghai Environmental Protection Bureau (SEPB). On the basis of functional compartments of the water system in Shanghai and relative standards of water quality control, water quality of the Dianfeng and Songpu Bridge sections should be equal to Class II, the Lin River section Class III, and the Southern Water Plant, and Yangpu Bridge and Wusong Kou sections Class IV. An index was calculated in Fig. 5 to show the status of water quality from 2008 to 2012.

In 2008, water quality of the Huangpu River remained at a low level, while things went well in 2009. Water quality in 2010 was persistently better, with composite indices of water quality increasing 1.1% and 2.0% at the Lin River and Southern Water Plant sections, and decreasing 13.5%, 4.2%, 1.9%, and 2.1% in the other four sections. From 2011 to 2012, as the monitoring data show, water quality of all the main streams along the Huangpu River remained stable, although the composite indexes of water quality decreased 8.1% at Dian Feng.

Essentially, the ecological issues in the Huangpu are dwarfed in importance by pollution. Even so, there are already invasive species, such as water hyacinth (*Eichhornia crassipes*), which would warrant considerable concern if there were not more pressing matters. As Fig. 4 shows, the largest source of pollution (42%) for the Huangpu is sewage. The current daily sewage discharge from Shanghai is ~5.8 million m³. Of this, only slightly more than 3 million m³ receives any treatment prior to release. Predictably, most of this sewage goes directly into the Huangpu River. There has been a large focus within the past few decades to improve sewage collection and treatment in Shanghai, but obviously much work remains.
Agriculture runoff and byproducts are the second largest source (40%) of pollution in the Huangpu. Due to agriculture, 4600 Mg of nitrogen and 900 Mg of phosphorus enter the Huangpu annually from rural areas. This stems not only from fertilizers and pesticides leaching off of crop fields, but also from the large amounts of animal wastes that are generated at livestock farms. It is difficult to estimate the precise amount of animal waste that enters the Huangpu, but in 1992 7.2 million Mg of animal waste were generated within the Huangpu watershed. Since then, Shanghai has carried out strict countermeasures to close the livestock farms along the Huangpu to improve water quality.

Industry is the other source of pollution (18%) in the Huangpu. This pollution comes from both rural thermal vacuum environment (TVE) enterprises and also from large factories located within Shanghai. Due to recent efforts, pollution from industrial sources has declined rapidly. However, the decentralized nature of TVEs has made it difficult to enforce standards and control wastewater emissions. The “dispersion [of TVEs] has made the infrastructure (e.g., water and electric supply, transportation, road construction, and disposal of waste) more difficult to install and less efficient” (Li 1997). TVEs are no longer the dynamic and competitive force that they were even a decade ago, due to their small scale, relatively backward technology, and overall inefficiency. Still, they represent a significant portion of industry within the Huangpu River watershed and create a disproportionate amount of pollution.

Comprehensive comparison of the two rivers

When the river was seriously polluted (as determined by chemical oxygen demand and biochemical oxygen demand), NH$_3$-N, phosphorus (measured as orthophosphate), oil, and hexavalent chrome were main pollutants in the Huangpu River, where the water quality is affected by polluted water from upstream and non-point pollution sources. In the Hudson, which begins as fresh water in Troy, gradually turns brackish near Hudson Highlands, and becomes noticeable salty at the Tappan Zee Bridge, PCBs, heavy metals, furans, dioxin, pesticides, and polycyclic aromatic hydrocarbon (PAHs) were the main pollutants.

Countermeasures of Ecological Restoration

Cleanup of the two rivers

Hudson River

In a stark contrast to the Hudson River of today, the Hudson in the 1970s faced serious environmental degradation. With increased urbanization, industrial activity, and chemical agriculture along the Hudson, water quality dropped rapidly. One particularly compelling demonstration of low water quality was the concentration of dissolved oxygen (DO). Most fish require at least 5–6 mg/L DO, yet during the early 1970s, the average level of DO was only 3 mg/L, and the Hudson River became anaerobic for long periods of time, forming “dead zones” around Albany and New York City (Brosnan and O’Shea 1996).

These low levels of DO can be attributed primarily to the vast amounts of raw and untreated sewage that flowed into the Hudson River from Albany and New York City. This also led to high concentrations of fecal coliform bacteria, an indicator of the amount of untreated feces in the Hudson. While sewage was undoubtedly the largest reason for the decline of the Hudson’s water quality, the role of industry and agriculture should not be overlooked. Overall, the Hudson River was seriously degraded, which was hardly unusual for the environment surrounding any large city in that age. However, the late 1960s and early 1970s marked a change in American views on the environment, as people across the nation began to pay more attention to pollution and the state of the natural world. In the Hudson River Valley, the fight for Storm King Mountain personified this growing awareness. This saga was initiated when the Consolidated Edison Company announced in 1962 that they would be building a massive pumped storage facility for power production. This project would have had severe impacts upon the local vistas, the biota of the Hudson River, and also would have destroyed part of the cultural heritage of the Hudson River Valley. In order to fight against the construction of the Storm King Facility, a group of concerned citizens formed the Scenic Hudson Preservation Conference (which is known today as Scenic Hudson) and sued to stop the Storm King project. This was a radical new step, as prior to this time American citizens had little influence over the environmental costs of development. In order to help decide the proper course of action, the New York State legislature formed the Hudson River Valley Commission (HRVC). “The Commission was directed by law to review proposed projects within its jurisdiction ‘which would destroy or substantially impair significant historic or recreational resources or bring about a major change in the appearance or use of the water in the Hudson River or the surrounding land’” (records relating to the Storm King Case 1966–1967; available online). This was the first time that such a body was created by the state, and although the Commission was denied veto power, it was given substantial power over the issue of development along the Hudson River. The court battle lasted until a settlement in 1980, but “the battle itself set important precedents in environmental law and is generally credited with spawning the modern environmental movement” (see footnote 1).

1 http://library.marist.edu/archives/hrvc-Storm%20King/hrvcStormKing.xml
Against this backdrop, a number of groups became involved with the environment of the Hudson River Valley. From the federal government came the Environmental Protection Agency (EPA), which was formed in 1970 and took a strong hand in helping municipalities construct wastewater treatment plants and setting standards for industrial pollutants. Another key actor was New York City, through the New York City Department of Environmental Protection (NYCDEP), which took extensive actions to preserve the Catskill and Delaware watersheds, in order to ensure itself a supply of clean drinking water. However, New York State has been the most important player, starting with the founding of the HRVC. The HRVC became an integral part of New York State’s approach to combating the pollution that saturated the Hudson, and it served to recommend courses of action to the state legislature. There was a gradual recognition that governmental action was necessary in order to protect the Hudson. This was especially true with regard to waste disposal, and the HRVC impressed this need to the state legislature. Today, the HRVC’s duties have been passed onto the NYSDEC, which was founded in April 1970 (NYSDEC 2002). Throughout this time period, citizen advocacy groups played an increasing role. Scenic Hudson was but the first of many environmental interest groups that were formed in the following decades. These nongovernmental organizations (NGOs) played an instrumental role in cleaning up the Hudson, by gathering legislative support, pressuring polluters, and increasing public awareness.

Working both independently and cooperatively, these organizations managed to create substantial gains in the water quality of the Hudson River and also created institutions to ensure its protection. Perhaps the most influential organization was the EPA, which provided over US$6 billion for municipalities to construct and upgrade sewage treatment programs between 1972 and 1985. During that time, 70 wastewater treatment plants were built in the Hudson River watershed, which combined to keep a total of 2,225,000 m$^3$ of raw sewage from directly entering the Hudson each day. Also, regulations were imposed on factories and farmers, prohibiting the use or improper disposal of many pollutants.

These actions had measurable effects in the Hudson River. “Many of the significant improvements seen in the New York Harbor follow the construction, upgrading, and operation improvements at [waste water treatment plants] of the region” (Bloomberg and Ward 2003). Today, New York City has 14 wastewater treatment plants, which treat more than 4,921,000 m$^3$ of wastewater daily. The most important indicators of water quality have improved drastically since the early 1970s. Fecal coliform levels dropped from 3,000–4,000 cells/100 mL (during peak times) in the early 1970s to under 300 cells/100 mL during 2000–2010 (Bloomberg and Ward 2003). Secondary benefits of the cleanup campaign were numerous. Beaches that had been closed because of pollution were able to reopen. Riverfront areas became increasingly desirable, and tourism revenues rose. Additionally, as the water quality of the Hudson River improved, it became a better source of potable water for upstream municipalities. The cleanup of the Hudson also led to a resurgence in biota population and health. Furthermore, through the cleanup centering on the Hudson, public awareness of the river increased drastically.

Even though the Hudson became significantly cleaner, there remains a constant need for further improvement and attention to the river. Since 1994, US$368 million of state and federal money has been spent on environmental projects for the Hudson. These include a variety of programs designed to cover a wide range of issues (Table 3).

**Huangpu River**

The Huangpu River is able to deal with a certain amount of the pollutants that enter it through ecological processes. Natural processes such as sedimentation, aeration, mixing, dilution, and bacterial processing all help break down wastes and return them to the natural environment (De Villiers 2001). Based on the simulation of algae-caused black bloom using a Y-shaped apparatus for modeling natural conditions, both undredged and dredged sites in three areas of Taihu Lake, China, were studied by He et al. (2013) to estimate the effects of dredging on the prevention and control of black bloom. During the experiment, drained algae were added to all six sites as an additional organic load; subsequently, DO decreased rapidly, dropping to 0 mg/L at the sediment–water interface. However, the Huangpu can only deal with a finite amount of the pollutants that enter the river, and the total pollution load far exceeds that. As understanding of ecological processes has become more comprehensive, methods have been devised to increase the natural breakdown of pollutants in the Huangpu River. An oxygen barge can pump oxygen into the water in order to improve DO levels and cultivate beneficial aerobic bacteria. At the same time, some eco-engineering plants in different sections of the Huangpu River have been installed as a countermeasure for purifying water quality (Fig. 6).

Houtan Park in the midstream of the Huangpu River is an outstanding example of natural water purification along the Huangpu. Built during the 2010 Shanghai EXPO, and winning the Outstanding Project Award of ASLA in 2010, Houtan Park was once located within iron factory and ship repair areas with workshops and shipside works. With an area of 14.2 km$^2$ and a Huangpu waterfront of 1.7 km, Houtan Park has four dominant areas for water purification, including the Bing Jiang rushes belt, an inland wetland purification belt, a terrace land belt, and a natural wetland protected...
area. After flowing through the park, the water quality of the Huangpu reaches Class III and even Class II from over Class V (according to the national surface water standard). This can provide 2400 m$^3$ of water per day for landscape and washing in the EXPO Park. Plants grown in the wetland are listed in Table 4.

A far more common method used to improve water quality is to eliminate the sources of pollution. Beginning in the early 1980s, one important action has been restricting industrial wastewater emissions. TVEs are among the worst industrial polluters and are also difficult to manage, as they are spread throughout the countryside. For example, the 15 000 TVEs in the rural area of Shanghai are spread over 4000 different sites (Li 1997). The SEPB became active in fixing this problem shortly after it was formed in the early 1980s. Some of the actions included consolidating all of Shanghai’s electroplating industries into one area for easy monitoring and also shutting down many paper mills, which had until then had been responsible for 25% of pollution as determined by biochemical oxygen demand in the Huangpu. These efforts have made significant progress in the realm of industrial pollution. “By 1996, 82% of industrial wastewater was reportedly treated.

Table 3. Environmental protection programs for the cleanup of the Hudson River.

| Program | Mission |
|---------|---------|
| New York State Agricultural Environmental Management Program (NYSAEMP) | Designed to combat non-point agricultural pollution, initiated by New York State in August 2004. |
| New York/New Jersey Harbor Estuary Program (NY/NJHEP) | Deals with environmental issues around the mouth of the Hudson. Established by the Environmental Protection Agency (EPA) in 1988: brings together many interest groups, i.e. government, industry, businesses, environmental groups, and local elected officials. |
| New York State Department of Environmental Protection (NYCDEP) | Deals with environmental issues in New York City, jurisdiction includes Delaware and Catskill watersheds. Manages HREAP. |
| New York State Department of Environmental Conservation (NYSDEC) Hudson River Estuary Action Plan (HREAP) | Overarching plan for restoring the Hudson; first version made in May 1996. Goals are to reduce pollution, promote stewardship, improve water quality, and promote public use of the river. Constitutes a vast partnership between all levels of government, academic institutions, and government subsidized organizations, supports local governments and NGOs in protecting water quality, biodiversity, habitat, and scenic resources. Latest version is 2005–2009: focuses on fisheries, conserving and protecting critical river habitats, biodiversity, streams in the watershed, preserving historical settings, public and education, revitalizing waterfront, and reducing pollution. At least US$40 000 000 has so far been set aside for this stage. |

Fig. 6. A hypothetical example of an eco-engineering cleanup of the Huangpu River, in which aquatic and riparian-zone plants “draw” pollutants out of the river (arrows) in the process of transpiration and growth.
amounts of eight major harmful substances (heavy metals, lead, oil, etc.) discharged into industrial wastewater peaked in the 1980s and have since declined markedly, according to the available statistics” (Edmonds 1998). Despite the relative declines in industrial pollution, further work is required.

One of the visibly successful campaigns has been cleaning important tributaries of the Huangpu, such as Suzhou Creek. The Shanghai Suzhou Creek Rehabilitation Project began in 1996. The efforts focus primarily on eliminating incoming pollution, as opposed to removing existing pollution. The objective was to achieve a Class IV standard in the lower 24 km of Suzhou Creek, and Class III for the rest, by the time of project completion in 2010. The total cost for the entire project is estimated at US$876 million, with the Asian Development Bank providing the funding. So far, Suzhou Creek has achieved Class V status, and the water is no longer black or noxious. While there have been tangible benefits, much work remains for this tributary. A general lack of environmental understanding is also a reason why improvements have not been faster. “Some people still fail to realize the importance of protecting the environment and continue to dump waste into Suzhou Creek” (Shanghai EPB 2004). From 1987 to 1995, World Bank Group developed the Shanghai Environment Liquid Waste Project (ID No. P003449, and US$145 million loan), which was directed at improving environmental conditions in Shanghai through building sewerage facilities for the removal and disposal of wastewater, and to create and develop the institutions for providing sewerage services, managing water resources, and protecting the environment. In addition, this project provided a model to demonstrate the policies and measures needed to resolve the rapidly growing issue of environmental pollution in China’s larger cities (World Bank Group 1996). Additionally, it will never be truly clean until the pollution levels drop in its source, Lake Tai.

Lake Tai has been polluted by urbanization, industrial waste, untreated sewage, and agricultural byproducts since the 1960s. The lake experiences eutrophic conditions, especially in the northern and western sections, where large amounts of untreated sewage flow into the lake. Jiangsu and Zhejiang provinces are also both major sources of agricultural wastes and rural effluent. Paper industries produced a majority of the pollution determined by biochemical oxygen demand until 1996, when smaller factories were closed and large factories were forced to undergo treatment (Edmonds 1998). TVEs, such as breweries, chemical fertilizer plans, leather tanneries, electroplating, and textile dyeing factories, release chemical pollutants and heavy metals into Lake Tai. In 2001, the State Council approved a plan for 2001–2005 to reduce the total number of pollutants entering the lake by 10–25% (from 2000 levels). According to SEPA, this required US$2.6 billion dollars for the construction of 81 wastewater treatment plants, which will be able to treat 3.91 million Mg of sewage daily. Additionally, 13 facilities will be constructed to deal with urban waste, and 87 facilities will be built to control industrial waste. These efforts are already beginning to show success.

Infrastructure-related projects have received the most attention and will do the most to decrease organic pollution in the Huangpu. The largest individual projects are known as the Shanghai Environment Liquid Waste Project, the Second Shanghai Sewerage Project, and the Shanghai Environment Project. These projects have received a substantial portion of their funding from World Bank loans (World Bank 1994). The main focuses of these projects have been on wastewater collection, sewerage, sanitation, and water supply. Because these projects were funded partially by loans obtained from the World Bank, there has been a drive to highlight efficiency, involvement of the private sector, and cost effectiveness (Table 5).

There has also been an emphasis on terminating those farms that produce very large amounts of pollutants. Livestock farms have been heavily targeted. “A third of major livestock farms in the suburbs of Shanghai will be shut down in two years because municipal authorities say the farms are a source of pollution” (Shanghai Water Authority 2009).

### Table 4. Organisms used in the wetland of Houtan Park, Huangpu River, Shanghai.

| Type                        | Organisms                                                                 |
|-----------------------------|---------------------------------------------------------------------------|
| Emergent aquatic plants     | Acorus calamus, Oenanth javanica, softstem bulrush (Schoenoplectus tabernaemontani), Alisma plantago-aquatica, water chestnut (Eleocharis dulcis), wildrice stem (Zizania latifolia), Sagittaria sagittifolia, Sheathe monochoria, Monochoi avaginali S, Cyperus alternifolius, Oryza sativa, Phragmite australis, Lythrum salicaria, Triarrhencas acchariflora |
| Submerged plants            | Hydrlaver ticila, Vallisineria natans, Potamogeton distinctus, Myriophyllum spicatum, Potamogeton crispus, Ceratophylum demersum, Elodea canadensis Michx |
| Aquatic animals             | Chub, Mallotus villous, Parabramis pekinensis, Mandarin fish (Siniperca chuatsi), freshwater shrimp, mussel, corbicula, snail, tadpole |
variety of organizations (12) working to improve its health. Initially, the policies of Shanghai water supply and treatment started with a government monopoly on control. However, as remediation and eco-restoration efforts have gotten underway, other organizations have become more invested in the process and have gotten more input and power.

Also important is the World Bank, which provides development-related loans and has been extremely active in Shanghai. “Since the 1980s, the World Bank has been a major source of support, together with the Asian Development Bank during the mid-1990s. It provided some US$800 million in environmental loans to China annually” (Edmonds 1998). These loans have provided the necessary funding for many of Shanghai’s projects. The World Bank has also led a push to privatize, to increase water tariffs, and to generally involve the private sector in what were once exclusively governmental functions. It sought to do this because under exclusive governmental control “underpricing of water and minimal fees for sewerage and municipal waste collection have resulted in a lack of investment in urban infrastructure, hampering its ability to keep pace with economic development and population growth” (Edmonds 1998). By providing billions of dollars in loans, the World Bank has sufficient political clout to pursue personal goals like privatization.

Partly because of the push by the World Bank, and partly due to governmental reforms, the private sector is having an increasingly important role in Shanghai’s water issues. Many approve of the involvement of the private sector in Shanghai, through investment and handling projects. “Chinese experts believe that the influx of private investment will solve the financial difficulties in urban sewage treatment and, furthermore, speed up the establishment of new administrative systems for sewage treatment in Shanghai” (Lee 2003). The governmental reforms that began in 1978 also allowed for foreign companies to play a role. “It is as a consequence of its economic reforms that China has become subject to external influence by the private sector” (Edmonds 1998). Two of the up-and-coming companies in the private sector are Vivendi Water China, which manages water supply and distribution in the Pudong New Area, and Youlian Consortium, which has signed a contract with Shanghai’s municipal government to build, operate, and then transfer the Zhuyuan Wastewater Treatment Plant. The Youlian Enterprise Development Company, in conjunction with two other companies, will invest 870 million yuan in the Zhuyuan wastewater treatment plant over the next 20 years (Song 2004).

Public activism and NGO environmental organizations do not play the strong role in Shanghai that they did in the cleaning of the Hudson. Still, there are signs that they could eventually have influence on Shanghai’s water politics. “The growing increase of interest in environmental protection among students and communities (as well as greater requirements of multilateral projects to include public participation in environmental projects) will in due course provide a significant platform for Shanghai environmental NGOs to have a bigger voice in shaping governmental water policies” (Lee 2003). Although environmental advocacy groups do not currently play a major role, there is increasing room for their input.

There are a large variety of organizations that are involved in cleaning up the Huangpu River, and many different strategies and tactics have been implemented over the years. Some methods include ecological engineering, restricting TVE wastewater emissions, cleaning tributaries and upstream areas, decreasing agricultural wastes, and investing millions in wastewater treatment plants.

### Comparing and contrasting the Hudson and Huangpu

In examining the cleanup efforts in the Hudson and Huangpu Rivers, one can see a variety of trends and similarities. It is instructive to compare the different groups that have had roles in the cleaning of each river. In both cases, there were emerging national environmental protection organizations that were able to set the course of the nation. The operating budgets for the EPA during the 1970s and the SEPA beginning in the 1990s are comparable, as are their aims. For example, the total budget of SEPA’s Eleventh Five Year Plan was US$30.77 billion dollars, which occupied ~3% of total GDP income (from 2005 to 2010). One-third of this had been set aside for water pollution control. The heavy national emphasis on wastewater treatment plants is one particularly crucial aspect and was taken to heart by both the EPA and SEPA. It is only with the support of the national government that New York and Shanghai were able to establish the capital needed for establishing

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### Table 5. Some large projects for water environmental protection carried out since 1987 in Shanghai.

| Project                              | Date carried out | Focus                          | Total funding       | World Bank loan |
|--------------------------------------|------------------|--------------------------------|---------------------|-----------------|
| Shanghai Environment Liquid Waste Project | 14 Apr 1987–31 Dec 1995 | wastewater collection | $145 million       | $145 million     |
| Shanghai Environment Project         | 31 Dec 2002–8 Mar 2004 | water supply, sanitation       | $456.6 million      | $160 million     |
| Second Shanghai Sewerage Project    | 21 Mar 1996–30 Jun 2004 | wastewater collection, sanitation | $594.8 million      | $250 million     |

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wastewater treatment plants.

Still, there is a significant difference between the groups involved with environmental remediation and eco-restoration efforts in the Hudson and Huangpu, as citizen participation through environmentalist groups in China is not nearly as extensive. The lack of environmental organizations in the Huangpu can be traced partly to the Maoist governmental traditions of China, in which power was concentrated almost exclusively in the state (Shapiro 2001). It was only after the economic reforms of the late 1970s that nongovernmental groups had the option to be involved in such things as environmental protection. “The Shanghai Government’s dominance of water pollution control policies in the 1980s and 1990s was waning and political space was opening for non-state actors such as environmental NGOs and enterprises” (Lee 2003). It appears likely that environmental advocacy organizations will gain an influence on pollution-control strategies in time. In the meantime, the Huangpu will be negatively impacted due to the lack of these organizations, which so effectively served the Hudson by both arousing public opinion for environmental reform and serving as watchdogs.

Another difference is that there is a strong involvement by international organizations in Shanghai, particularly in installing the necessary wastewater pollution control infrastructure. This is primarily due to the participation of organizations such as the Asian Development Bank and the World Bank. These organizations have been responsible for providing the loans that are needed for the large infrastructure projects that Shanghai desperately needs. Without their support, wastewater treatment in Shanghai would be much worse than it is today, and the Huangpu would not improve in the foreseeable future. One side effect of World Bank loans has been the push toward privatization in Shanghai’s wastewater issues. This is aimed at creating greater efficiency in the cost of pollution control in Shanghai, but it could also lead to a lack of service for the poor.

This highlights the obvious issue of differences in wealth. The involvement of the World Bank and other lending institutions has allowed for cleanup efforts in the Huangpu to emulate the capital-intensive strategies employed by the United States. Despite Shanghai’s relatively high per capita income (by Chinese standards), it still is part of a developing nation, and therefore faces a range of considerations that New York did not. For example, much of the impetus for cleaning up the Huangpu results from practical considerations, such as providing potable water for Shanghai, as opposed to aesthetic motives.

Another issue is that Shanghai is still in a period of rapid urbanization, which reached 88.76% in 2011. Because the population and economy of the Shanghai area are increasing rapidly, it will be difficult to install adequate wastewater infrastructure at the necessary rate to keep up with population growth. The rapidly increasing “floating population” of informal migrants will prove a source of many difficulties. One related consideration is that the absolute population of Shanghai far outstrips that of New York, making the installment of infrastructure a much larger project. This will make it more difficult for the Huangpu to follow in the steps of the Hudson River.

Politically, the cleanup efforts in the Huangpu and Hudson have been at the cutting edge. Urbanization, which has been a major cause of pollution, has also led to remediation efforts in these cities, because it resulted in both being centers for innovation, population, high personal income, and investment. In the United States, concerns about surface water that started comparatively early in the Hudson spread quickly to the rest of the country. However, China is a much larger place, and it seems unlikely that other, less prosperous areas will be able to follow in the footsteps of Shanghai in the immediate future. This is particularly aggravated by the vast disparity between urban and rural areas.

The management techniques in the two rivers are also quite different. Although both rivers have the same diversity of institutions, the Hudson has a much more comprehensive and centralized management style, through the Hudson River Estuary Action Plan (HREAP). This was only initiated within the past decade, but HREAP currently provides clear direction and promotes a centralized approach. In comparison, the Huangpu has a large number of different organizations that maintain independence and answer to different allegiances. It is true that the management needs for each river are different, as the Hudson faces subtler dilemmas than the Huangpu, yet it seems that a more unified approach would be beneficial.

**Conclusion and Suggestions**

That both the Hudson and the Huangpu (and their surrounding areas) can benefit enormously from clean rivers is clear. Through tourism, recreation, fishing, and quality of life issues, a clean river enhances the community. It is practically impossible to assess the damage that pollution is currently inflicting. A variety of institutions have been successful in significantly reducing the quantity and impact of pollution in the Hudson River since the early 1970s. Many of the same strategies are being used contemporarily in the Huangpu, which should result in an improved river. Nonetheless, the task of ensuring the environmental health of the Hudson and the Huangpu is a tricky and thoroughly unpredictable process. Time will tell whether the Huangpu will be able to follow in the footsteps of the Hudson.

The Hudson is fairly clean, and although much work remains, if it follows on the current track, the Hudson River Valley will continue to realize the benefits of an increasingly clean river. The works that are underway
(such as the new draft for the Hudson Estuary Management Plan) should make a serious difference. However, the Huangpu is still seriously polluted. There are a variety of beneficial projects underway, but certain approaches need to be changed. While projects are now being done to increase wastewater treatment capacities through upgrading and building new wastewater treatment plants, this needs to happen considerably faster. Additionally, more focus is needed on the collection of wastewater, especially in areas along the suburban fringe of Shanghai. Other crucial actions include making sure that all industrial water is treated before release and that the wastewater meets emission standards. Also, the focus on upstream areas must be further integrated. This highlights the problem of the need for better organization within the Huangpu River basin. The management situation would be vastly improved if there were one central coordinating agency that could direct the actions of the other organizations. Additionally, a centralized management policy would help promote a stronger focus on long-term issues. These rivers have so far served as successful and inspirational case studies for other cities across both nations, but attention must also be paid to helping other areas make comparable strides toward the sustainable improving of water quality.

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