CHINA URBAN WATER BLUEPRINT

Exploring innovative conservation solutions to China's water challenges

The Nature Conservancy
大自然保护协会

Nature-based solutions to China water challenge

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FOREWORD

Everyone in the world needs and uses water every day. We fill our pots with it for cooking. We use it for bathing. We use it to make new products and create energy. Most importantly, we drink it.

But around the world, clean water is becoming harder to find. In fact, half of the world's population is impacted by water shortages. Meanwhile, water demands from cities, agriculture, businesses and people are growing. City and business leaders, farmers and conservationists are competing for limited resources. We must find ways to balance the water needs of people and nature.

China is experiencing the full force of these water security challenges. At least one-third of China's lakes and rivers are too polluted for human use, and 73 percent of the watersheds that supply water to fast-growing cities face medium to high pollution levels. Given the rise of cities and the scale of the water quality challenge, we must work together to build a sustainable water future for China.

For the past several years, The Nature Conservancy has been studying the state of water around the world. This year, we decided to dive deeper into China given the country's challenges and importance to the global economy, environment and human development. In our latest report, the China Urban Water Blueprint, we analyzed the state of the 135 surface water sources tapped by China's 30 largest and fastest growing cities, and we found opportunity.

Roughly half of China's water pollution comes from land use and degradation, especially fertilizers, pesticides, and livestock waste carried into lakes, rivers, wetlands, aquifers and coastal waters. By restoring forests, improving agricultural practices and implementing other conservation solutions alongside traditional water infrastructure, China can improve water quality for more than 150 million people and reduce pollution that impacts nature. Additionally, savings in water treatment could offset a significant portion of the catchment conservation costs.

Water funds provide one way for China to implement these types of nature-based solutions at scale. This governance and financial tool is being used around the world, from Ecuador to Kenya. When designed properly, water funds can improve water quality as well as provide a range of co-benefits to people and nature including improved agricultural outputs, more reliable energy generation by hydropower facilities, and carbon sequestration. Water funds create a win-win situation for all involved by supporting continued economic growth and safeguarding natural resources.

China is already putting wheels in motion to address its current water challenges. Let's be sure that nature is part of the equation used to solve the problem.

Dr.Giulio Boccaletti
Global Managing Director, Water
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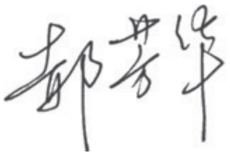
Urban water sources are a fundamental component for meeting the needs of an urban population and are intimately tied to people's quality of life and economic production. In China, water catchments that supply urban areas are suffering from high pollution levels, with a portion of lakes and rivers too polluted for human use. Non-point pollution is increasingly contributing the majority of urban water pollution, particularly through land use change and intensive agricultural production. Curbing non-point pollution is quite challenging, as its extensive spatial nature makes it more difficult to control, especially by using engineered solutions. The management of non-point pollution and conservation of urban water supply catchments to ensure urban water security have become the essential requirements for the rapid sustainable development of urban China.

The Nature Conservancy is focused on addressing the challenges of China's urban water catchments, including management of non-point pollution through nature-based solutions. The Nature Conservancy takes a scientific approach to conservation and has achieved measurable gains by applying this approach worldwide.

The China Urban Water Blueprint provides a scientific understanding of the current status of urban water sources and the potential for nature-based conservation in China. This report surveyed the source water catchments of the 30 fastest growing, large cities in China and compared and analyzed the effectiveness and economic valuation of nature-based conservation as compared to engineered solutions. Notably, the China Urban Water Blueprint emphasizes the importance of employing market-based mechanisms, such as water funds, to provide the financial and governance mechanisms needed to implement conservation in urban water catchments at the scale necessary for water security.

As urbanization progresses increasingly further with rising population and rapidly expanding cities, the demand for clean water will continue to grow. Accordingly, as land is converted from natural areas, non-point pollution is driving higher pollution levels in urban water catchments.

The combined pressures related to insufficient water quantity and quality threatens the overall sustainability of China's urban socio-economic development. In this context, by investing in nature, the natural solutions applied to urban water supply catchments, along with market mechanisms to support the implementation of these solutions at scale, can improve urban water security. The China Urban Water Blueprint demonstrates the important role nature plays in improving urban water security and management of non-point pollution.



Prof.Hao Fanghua
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EXECUTIVE SUMMARY

Where China's water comes from

The water sources of China's major cities are a critical resource for the health of China's people and its economy. Two-thirds of China's population live in urban water supply catchments and, including urban areas, these catchments in 2010 accounted for an estimated US $2.7 trillion, or 55 percent of China's GDP. The socio-economic status of 860 million people is therefore intimately tied to ecosystem functions provided by a vast landscape that collects, filters and transports water before it is delivered to man-made infrastructure.

China's urban water sources are extremely important to nature and people. Collectively, these catchments account for 42 percent of the country's national priority biodiversity conservation areas, and 40 percent of total stream length in China fall within the priority areas. Urban water supply catchments also represent roughly half of China's Ecological Functional Conservation Areas that have been designated as providing essential services for people.

The demand on these catchments for water is enormous and growing. China's 30 largest and fastest growing cities already use some 29.6 billion cubic meters of surface water per year, a volume equivalent to China's largest freshwater lake. Critically, however, less than 6 percent of China's land mass provides more than two-thirds (69 percent) of the country's water supply. Therefore, there is great potential to secure a significant portion of water supplies for major cities by investing in natural infrastructure in small and medium sized catchments (those less than 100,000 square kilometers in size).

The state of China's water sources

More than 50 percent of the land surrounding one in three water sources has already been converted to working landscapes, including agriculture and urban areas. Development and land degradation are driving higher water pollution levels upstream of urban water intakes. Seventy-three percent of surveyed urban water supply catchments face medium to high pollution levels. For example, sediment pollution affects the water sources for 82 million people in China's largest and fastest growing cities.

This same degradation is impacting the most important biodiversity in China, including 8,900 kilometers of streams within national priority biodiversity areas. In all, more than 650 threatened or vulnerable vertebrate species have habitat ranges in portions of the source water catchments. Our analysis also indicates that there are 12 million hectares in national priority conservation areas and three Alliance for Zero Extinction designated sites within degraded catchments.

It has been estimated that roughly half of China's water pollution comes from land use and degradation, especially fertilizers, pesticides, and livestock waste carried into lakes, rivers, wetlands and coastal waters. The pollution is also carried into underground aquifers by rainfall and snowmelt. As water quality falls below thresholds for a specific use, such as drinking, fishing or industrial production, water pollution plays a role in ongoing water scarcity in China. The Chinese phrase for this scarcity translates as "water-quality-driven water shortage."

Natural solutions to reducing water pollution in China

Land conservation and improved land use practices offer solutions to curbing pollution loads, especially nutrients and sediments, from non-point sources. Through the analysis presented in this report, we estimate that by targeting conservation strategies to a cumulative area of roughly 1.4 million hectares sediment and nutrient pollution could be measurably reduced – by at least 10 percent – in small and medium sized water sources serving China's largest and fastest growing cities. While large, this area represents less than 3 percent of the area of water sources.

The annual investment required to achieve this impact is an estimated US $300 million per year, which represents less than 4 percent of China's current expenditure on its national eco-compensation programs, which averaged US $8 billion over the most recent 5-year period. Targeted reforestation of just 340,000 hectares could measurably reduce sediment loading in the water sources that serve more than 40 million urbanites. Targeted agricultural best management practices alone could measurably reduce nutrient loading in water sources for 148 million people living in downstream cities. Importantly, these working lands also would remain productive.

Savings in water treatment costs could significantly offset the cost of catchment conservation for half of China's largest and fastest growing cities. For four cities, conservation could effectively be cost-neutral.

In addition to cost savings realized by cities, investment in water supply catchments holds great potential benefits for nature. Within the water supply catchments serving these cities, identified national priority biodiversity areas account for 25 percent of the total catchment and intersect with eco-regions containing roughly one-fifth of China's fish and terrestrial animal diversity. This makes improving water security for people and nature possible at a low cost for cities.

Putting market−based mechanisms to work for people and nature

As is the case in most countries, responsibility for urban catchment conservation is shared between multiple governmental agencies. Because catchment conservation concerns both land and water, it is a challenging policy issue that demands extensive coordination between these separate governmental units, many of which have different incentives. In China, local governments play a particularly critical role.

This report suggests that collective action water funds offer an as yet untapped financial and governance mechanism to implement conservation at scale. Building on the popularity of payment for ecosystem services (PES) programs, a user-pays pricing approach would allow local government and industrial concerns to influence and protect water sources and the people and wildlife that inhabit them. By investing in the conservation of water sources through collective water funds, water users can cost-effectively improve water security for themselves while providing a suite of broader socioeconomic and ecological benefits, including the protection of critical terrestrial and aquatic habitat. It's a win-win solution that has an important role to play in China's continued economic growth and the safeguarding of its natural heritage.

INTRODUCTION

Urban water sources are under growing pressure around the world.[1] Most cities rely on surface water catchments to provide drinking water, which is then channeled through a large network of reservoirs, canals and pipelines to urban water users. Despite this engineering-intensive system, most urban water catchments rely on various forms of natural capital — so-called "natural infrastructure" such as forests and wetlands — to protect water quality. However, as cities grow and these natural capital resources are degraded, water quality benefits are diminished, making it more difficult and far more expensive to provide clean water to urban residents.[2]

While the challenge of adequately protecting urban water sources is one that confronts many cities, the problem is especially acute in China given the high rate of urbanization and extremely high levels of water pollution.[3,4] China's urban population has been increasing at a rate of 4.5 percent in recent years, one of the highest growth rates in the world.[5] By 2030, nearly 1 billion Chinese will live in urban areas, an increase of some 300 million people in the span of only two decades.[6] Providing sufficient clean water for this urban population will require massive investments to address the physical infrastructure needs and severe environmental degradation. The 12th Five-Year Plan called for an investment of CNY 430 billion, or US $69 billion, an increase of 17 percent over the comparable total during the 11th Five- Year Plan, with 57 percent of this new investment total designated for pipeline expansion and the remainder for wastewater treatment capital construction and improvements.[7]

Despite China's rapid economic development, nearly one-fourth of its urban residents lack access to proper drinking water and sanitation facilities.[8] In addition, according to the latest State of the Environment report issued by China's Ministry of Environmental Protection, at least one-third of China's lakes and rivers are too polluted for human use, and in urban areas the proportion is much higher.[9] New evidence indicates that 60 percent of China's groundwater is polluted, underscoring the severity of the country's environmental woes.[10] High levels of water pollution have been linked to the existence of "cancer village" clusters,[11] and the direct health-related costs of water pollution were estimated at US $8 billion in 2003, a figure that has likely increased over the subsequent decade,[12] while the most recent annual costs for water pollution are in the range of US $34 billion to US $44 billion.[13,14,15,16]

Water pollution is such a driver of scarcity that Chinese experts have coined a phrase for it "water- quality-driven water shortage."[17] From manufacturing to poorly treated sewage to industrial spills, China's point sources of pollution are well understood and increasingly well publicized.[18] But few realize that roughly half of China's water pollution comes from land use and the degradation associated with fertilizers, pesticides and livestock waste. This pollution is carried into lakes, rivers, wetlands and coastal waters, and to underground aquifers by rainfall and snowmelt.[19] Non-point pollution has proven difficult to control globally, but there is growing evidence that natural systems can effectively protect and rehabilitate water supply.[20]

Catchment conservation offers proven strategies for curbing pollution loads, especially nutrients and sediments, from non-point sources. Forested areas are particularly important in preventing erosion, while wetland areas are effective natural water treatment systems that filter contaminants.[21, 22] Working landscapes, such as cropland, can also play an important role in reducing water pollution depending on the adoption of particular land management approaches. When these strategies are targeted on the landscape to areas of greatest hydrological importance using modeling, catchment conservation can offer a cost-effective alternative to traditional treatment.[23]

Given the rise of cities and the scale of the water quality challenge, this report examines how China can improve urban water security by investing in nature. Its primary objective is to diagnose the potential for catchment conservation strategies to reduce non-point pollution in China's major drinking water sources, paying special attention to the distinctive features of its economic and political system. Accordingly, this report consists of four primary sections. The first examines where China's 30 largest and fastest growing cities get their water. The second describes the status of land degradation and non-point pollution of small surface water catchments, which make up the bulk of water supplies for China's major urban areas. The third section describes the potential impact and relative cost-effectiveness of catchment conservation on sediment and nutrient loading in urban water sources. Finally, the fourth section offers some recommendations for how China might capture this value, notably through opportunities to expand market mechanisms such as collective action water funds and water rights trading.

As more and more people and businesses move to urban areas in China, the demand for clean water will continue to grow.[24] Continued growth of the Chinese economy cannot be sustained without water.[25] This analysis will help frame the costs of catchment conservation at a landscape-scale that would help safeguard China's economic growth, the livelihood of its people and the natural endowment upon which they depend.

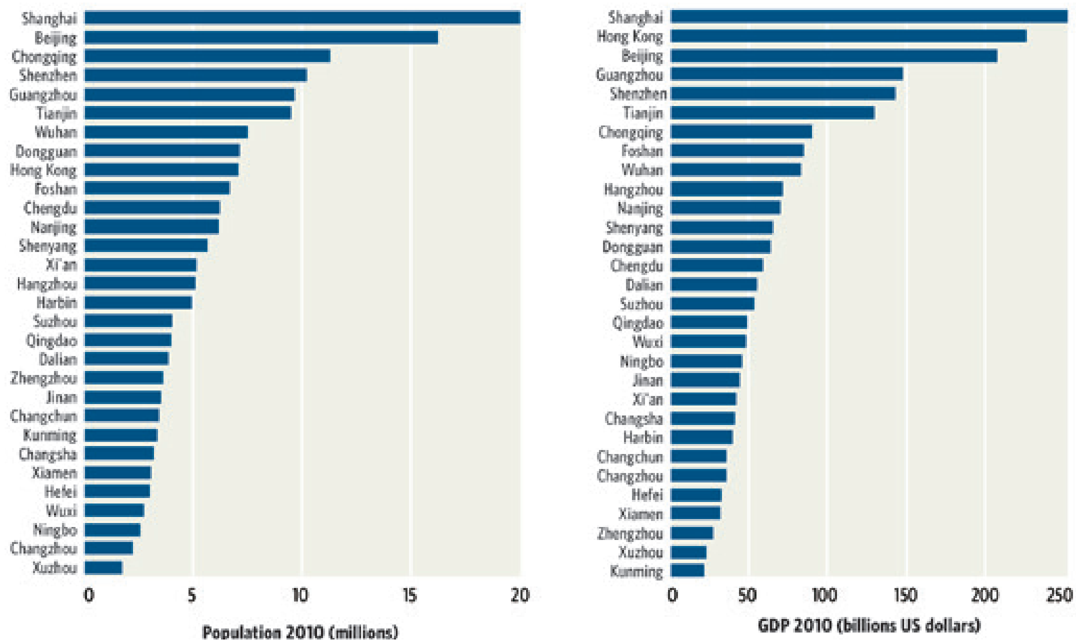
Chapter 1

Where China's Water Comes From

China's largest and fastest growing cities

Today, cities are home to roughly half of China's population.[26] By the turn of the century, 1 billion people are projected to live in urban areas.[27] Nearly one-third appear fated to live in one of China's 30 fastest growing cities. Already home to over 180 million people, China's fastest growing cities represent over US $2 trillion in economic activity, or nearly half of total GDP (Figure 1-1). Unfortunately, ecological and environmental problems threaten the overall sustainability of these cities and their socio-economic development.[28]

Figure 1–1. Population and economic activity in surveyed cities

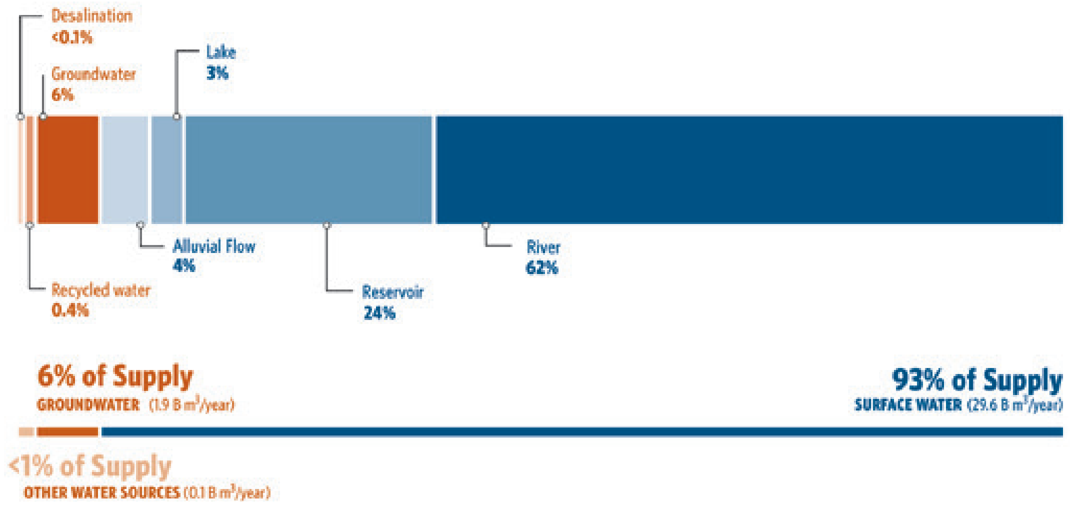


For 30 surveyed cities, estimated urban population and gross domestic product (GDP) in the year 2010

Urban water sources

Each of these cities will need consistent supplies of ample clean water to thrive. According to our survey of urban withdrawals[29] reported by water utilities and others,[30] 93 percent of municipal water supply currently comes from surface water sources in China's fastest growing cities (Figure 1-2). According to this new dataset, we estimate that China's fastest growing cities currently use some 29.6 billion cubic meters of surface water per year for drinking water and industrial use, a volume equivalent to China's largest freshwater body, Poyang Lake. This survey suggests average urban utility water withdrawals for households and businesses have exceeded 400 liters per person per day, which is in line with previous national estimates.[31]

Figure 1–2. Urban drinking water sources



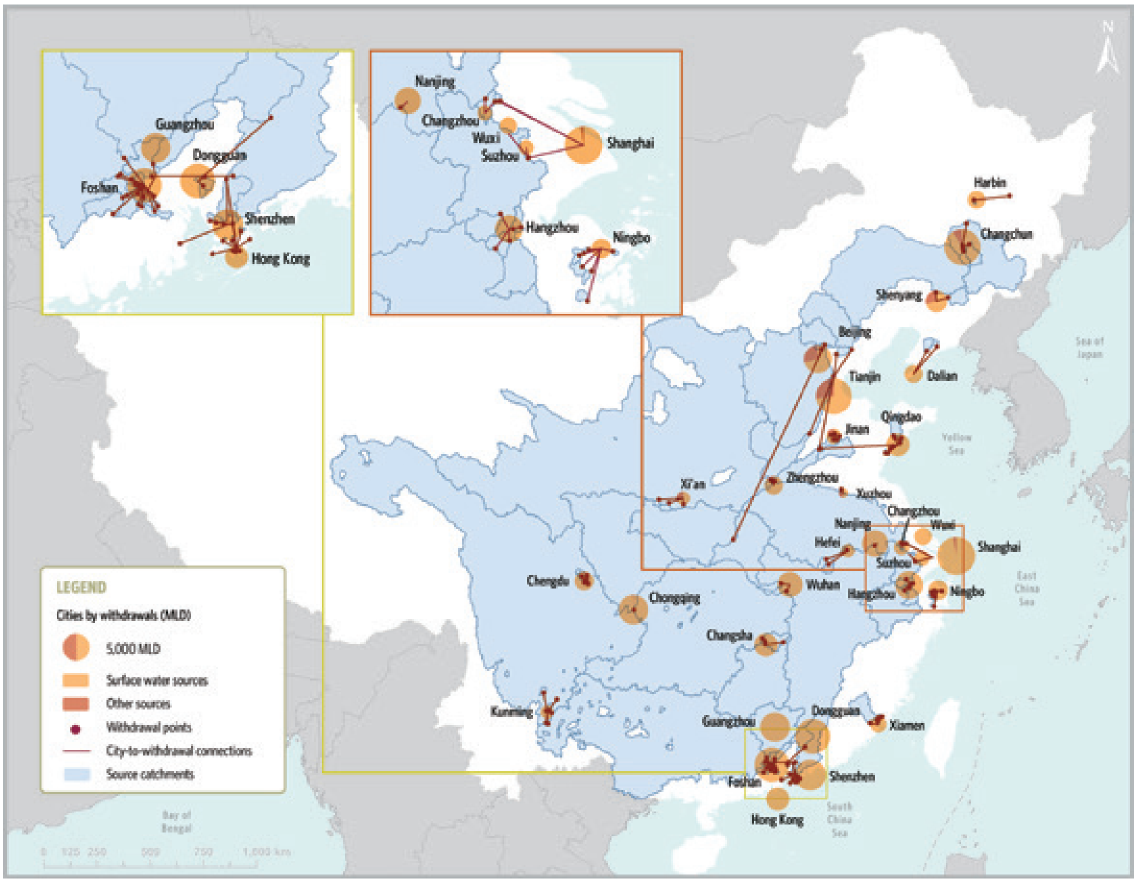
Comparison of drinking water supply withdrawals by source type across all 30 surveyed cities

Groundwater withdrawals for surveyed sample of cities comprise a smaller proportion of urban drinking water supply as compared to national water use statistics.[32] However, groundwater remains critical to water security for China. Indeed, over 40 percent of cities in the survey sample have at least some groundwater use. At the provincial level, where agricultural withdrawals are significant, groundwater can make up a significant proportion of withdrawals. For example, according to the Food and Agriculture Organization of the United Nations (FAO), in the five northern provinces of Beijing, Tianjin, Hebei, Shanxi and Inner Mongolia, 65 percent of water withdrawals were from groundwater in 2005.[33] For this study, the focus is limited to municipal and industrial demand represented by the volumes that cities collect, treat and distribute to urban water users. While not examined explicitly in this study, groundwater also plays an important role in defining the potential benefits of catchment conservation. Where cities rely more heavily on surface water sources than groundwater — the case for most of the cities in our dataset — there can be great potential for improving water quality through catchment conservation.

Urban water catchments

The supply of potable water for households and industrial users alike is a fundamental component of the environmental, economic and social health of cities.[34] This fact ties the fate of China's cities to the land their water comes from and the communities and wildlife for whom this land is home. China's 30 fastest growing cities depend on 135 surface water catchments for water supply. Collectively, these catchments cover 365 million hectares—an area equivalent to 39 percent of the total land mass of mainland China. The catchments collect, filter and transport water before it reaches man-made infrastructure (Figure 1- 3).

Figure 1–3. Cities and their water source catchments[35]



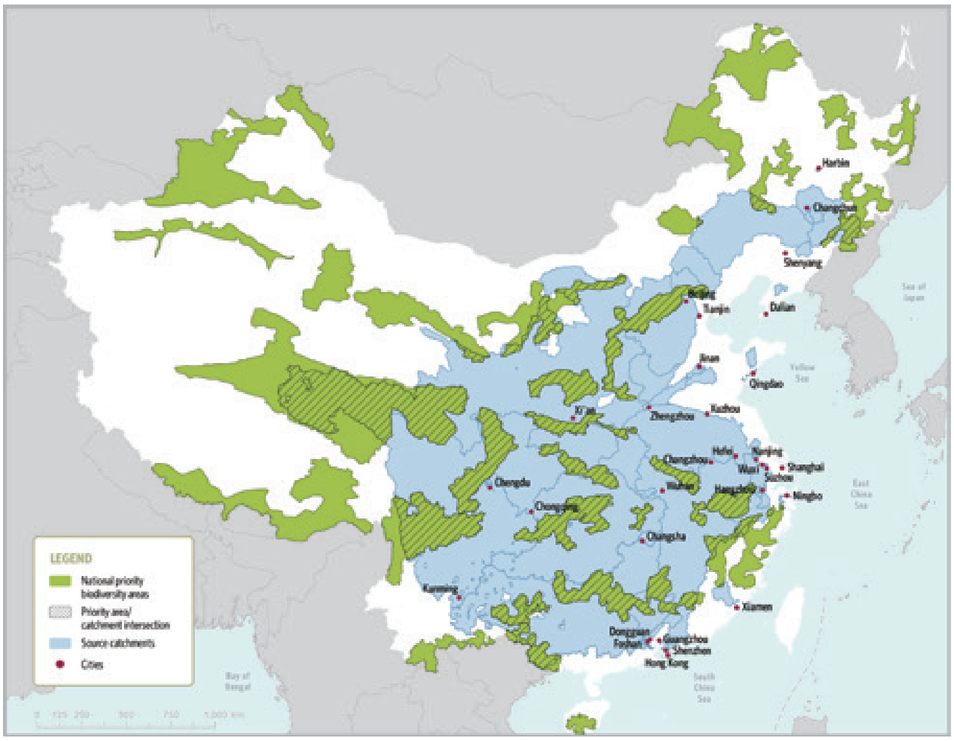
Map of 30 surveyed cities and the surface water catchments supplying their drinking water. Pie charts at city centers further indicate the proportion of surface versus all other water supplies for each city.

As China's urban population and economy grow, water demand can exceed the accessible clean water supply within local source catchments, forcing city leaders and water managers to develop multiple, and often distant, water sources. For example, the South-North diversion project will transfer some 44.8 billion cubic meters of water annually from the water-rich south to the water-scarce north.[36] The project costs approximately US $81 billion and requires more than 2,400 kilometers of canals and tunnels to ensure water supply for the northern region of the country, including the capital city of Beijing.[37]

Water catchment significance

The catchments of the 30 cities play important roles in the economy. Two-thirds of China's population live within urban water supply catchments. Including urban areas, these catchments in 2010 accounted for an estimated US $2.7 trillion, or 55 percent, of GDP.[38] That's more than 860 million people whose socio-economic status is intimately tied to the ecosystem functions provided by this landscape. The Yangtze River basin alone accounts for more than 70 percent of the country's rice production, 50 percent of its grain and more than 70 percent of fishery production.[39]

Figure 1–4. Overlap of important biodiversity areas with source catchments



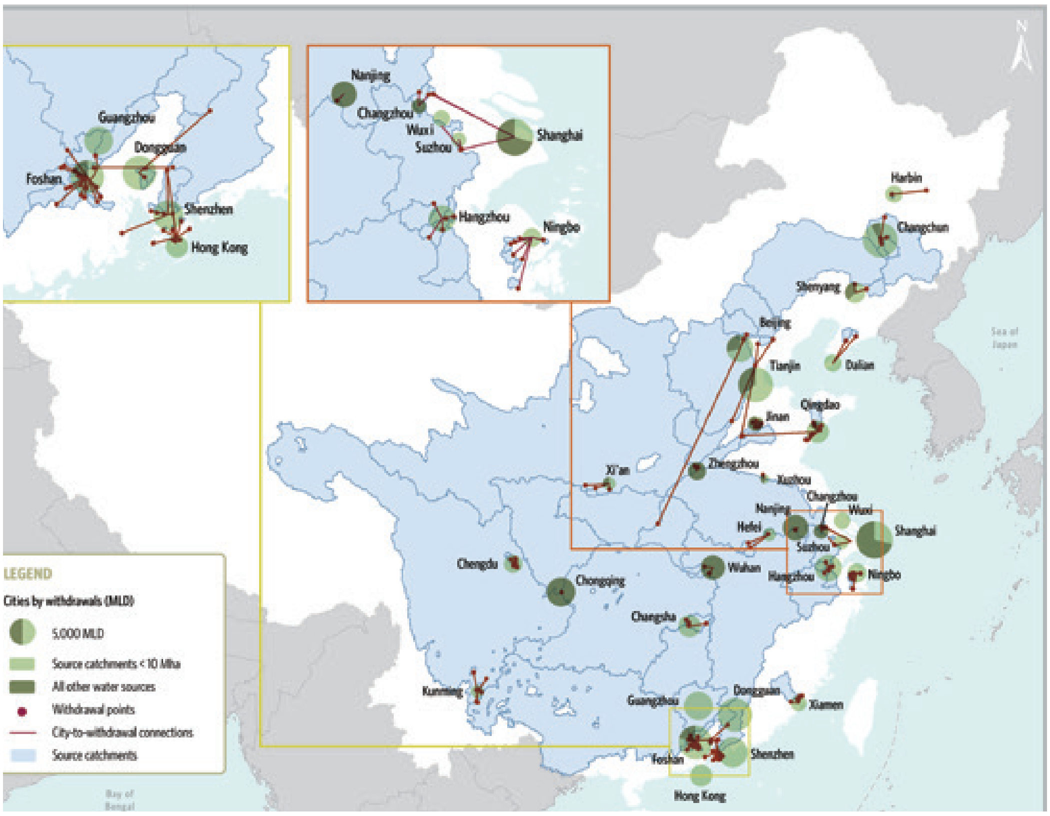
Source catchments for all 30 cities in relation to nationally designated priority areas for biodiversity conservation.

These urban water supply catchments also include significant portions of areas of national biological importance. The National Biodiversity Conservation Strategy and Action Plan identified priority areas for biodiversity conservation within China for both terrestrial and aquatic biodiversity. Collectively, these catchments account for 42 percent of all designated national biodiversity priority conservation areas, including 40 percent of total stream length within priority areas. [40] Thus, these catchments not only supply water for a large and growing urban population, they also sustain some of the most important areas for terrestrial and freshwater biodiversity in China.

The value of healthy catchments includes ecosystem functions critical to China's sustainable development. Some 3,000 Chinese scientists conducted an extensive national ecosystem assessment between 2011 and 2014, mapping seven major ecosystem services from food production to biodiversity conservation and carbon sequestration.[41] The land areas for the services were delineated as Ecological Functional Conservation Areas. They comprised all, or portions of, 782 counties. This analysis suggests that urban supply catchments overlap with roughly half of China's EFCAs and provide essential services for people such as water supply, soil retention and flood mitigation. Unfortunately, as has been well documented elsewhere,[42] the impact of current economic forces within source catchments can degrade eco-system functions. For example, the economic success of the Taihu Lake catchment, which ranks among the wealthiest areas of China with a per capita GDP that is 3.5 times the national average, has come at a huge environmental cost, including water pollution levels that frequently overwhelm water treatment capacity.[43]

Significance of catchment size

Figure 1–5. Source catchment size and urban drinking water supply



Map of 30 surveyed cities and surface water catchments supplying their drinking water. Pie charts at city centers indicate the proportion of supply attributable to catchments smaller than 10 million hectares versus all other supply sources.

The availability and quality of China's urban water supply, and hence the costs to move and treat it, depend heavily on how land in those catchments is used.[44] While healthy ecosystems purify and regulate water flows, a degraded landscape introduces impurities and intensifies floods and droughts. Water managers understand this relationship between land use and water quantity and quality. For many large Chinese cities, however, this land falls outside their municipal boundaries. So while municipal and utility decision-makers have direct control over water treatment and distribution, the forces that govern the quality and regulation of water sources are largely beyond the influence of urban water managers. The majority of cities and water providers in China currently do not have a mandate to allocate funds to full catchment conservation, even when it is in their best interest. Indeed, catchment protection is often limited to areas near water intakes.[45]

This report is designed to help city leaders, industry, water managers and the general public better understand their water challenges and the potential for transformation. Scientists with The Nature Conservancy and its partners have mapped and analyzed the water sources for the 30 fastest growing cities in China. For this analysis, we distinguish between large catchments of more than 10 million hectares, and comparatively smaller catchments of less than 10 million hectares.[46] In large scale catchments, such as the Yangtze River basin (180 million hectares), individual city water withdrawals represent just a small fraction of total supply. In these larger catchments, disproportionately large conservation investments would be required for even relatively small benefits to urban supply. In contrast, cities represent an important and influential water user in smaller catchments. Indeed, there is already precedent in China and abroad for cities exerting meaningful influence over the management of small catchments. For example, to protect the safety of drinking water for Beijing, the city has invested directly in promoting protective land use change in the upper reaches of the Miyun Reservoir catchment. [47]

A spatial analysis of this dataset shows the basic rationale for the distinction between large and comparatively smaller catchments. As discussed previously, the source catchments for China's 30 fastest growing cities collectively represent a large proportion of Mainland China – 39 percent of total mainland area or roughly 365 million hectares. Those smaller than 10 million hectares represent just 5.6 percent of total area (52 million hectares), but account for 69 percent of total water supply (Figure 1-5). In other words, smaller water catchments have disproportionately greater significance on the water security of China's cities and the economic activity they represent.

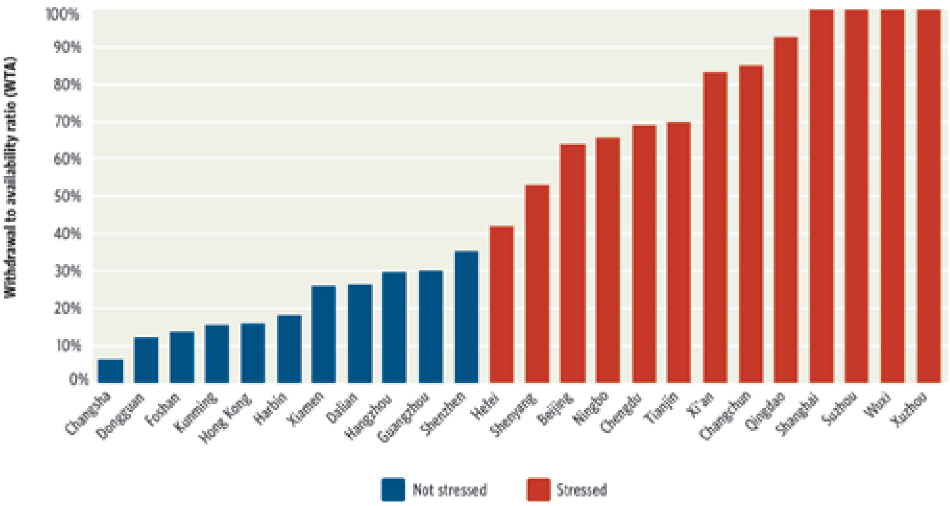
For 24 of China's largest and fastest growing cities, smaller catchments account for at least 25 percent of their total supply. The following chapter takes a closer look at the current state on these 110 water catchments, which are not only of vital importance to water security, but also represent a landscape that can plausibly be reshaped through conservation practices by forward thinking leaders. In doing so, decision-makers and their supporters have an unprecedented chance to remake the path of development in which water security is achieved in harmony with nature.

Chapter 2

The Degradation of Urban Water Resources

Water availability

Figure 2–1. Water stress in source catchments



Estimated withdrawal to availability (WTA) ratio for catchments smaller than 10 million hectares, aggregated by city.

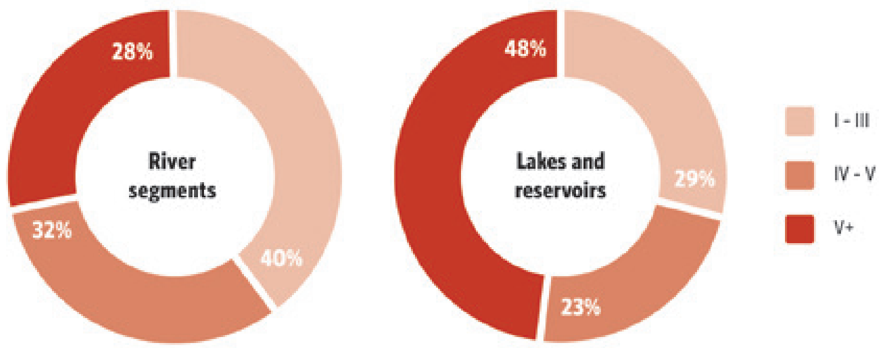
Despite huge investments in recent years in water supply infrastructure, one of the greatest challenges to continued growth and prosperity in China remains access to sufficient clean water. This challenge is a result of combined pressures related to insufficient water quantity and water quality. While China encompasses almost 20 percent of the world's population, the country contains only 7 percent of the world's fresh water,[48] which leaves it with much less annual fresh water available per capita than most other countries. In fact, China only has 22 percent of the average water availability of all G20 countries.[49]

Research indicates that water demand in two-thirds of China's cities exceeds the water that is available, and 17 percent experience severe shortages.[50] In fact, our analysis confirms that nearly half of the 24 fastest growing cities currently experience annual water stress, defined as occurring when water withdrawals exceed 40 percent or more of available water (Figure 2-1).[51] It is important to note that this annual water stress estimate does not include seasonal water stress, when water allocations in a given month are greater than water available in that month, which affects an even greater number of cities.

Water pollution: point vs. non–point

Of the water that is available, much of it is so polluted that it is unfit for the desired use. For example, although surface water quality is generally improving across China, 28 percent of rivers and 40 percent of lakes and reservoirs are still unfit for human contact (Figure 2-2).[52,53] Groundwater continues to decline in quality, with the number of groundwater aquifers in the'bad'to'very bad'categories increasing from 55 percent in 2011 to 61 percent in 2014.[54]

Figure 2–2. Water quality in China's rivers and lakes



Water quality status of rivers and lakes/reservoirs in 2006, where Grade I–III are considered fit for drinking water use, Grade IV–V are polluted, and Grade V+ are severely polluted.[55]

One strategy to address water stress in China is to focus on the water quantity challenge by increasing the productivity of water use (GDP per cubic meter of water withdrawn), which is currently one-fourth of the G20 average.[56] This is a critical strategy that China must continue to employ, especially in water stressed areas, in order to meet increasing demands. Another parallel strategy is to improve the water quality in China's freshwater sources so that the volume of water available is suitable for a larger variety of uses. Severe water pollution effectively reduces the quantity of water available for certain uses. One-fourth of China's water is so polluted that it is classified as unfit even for industrial use.[57] One key advantage of this strategy is that it not only results in economic benefit but can serve potential health and well-being goals as well.

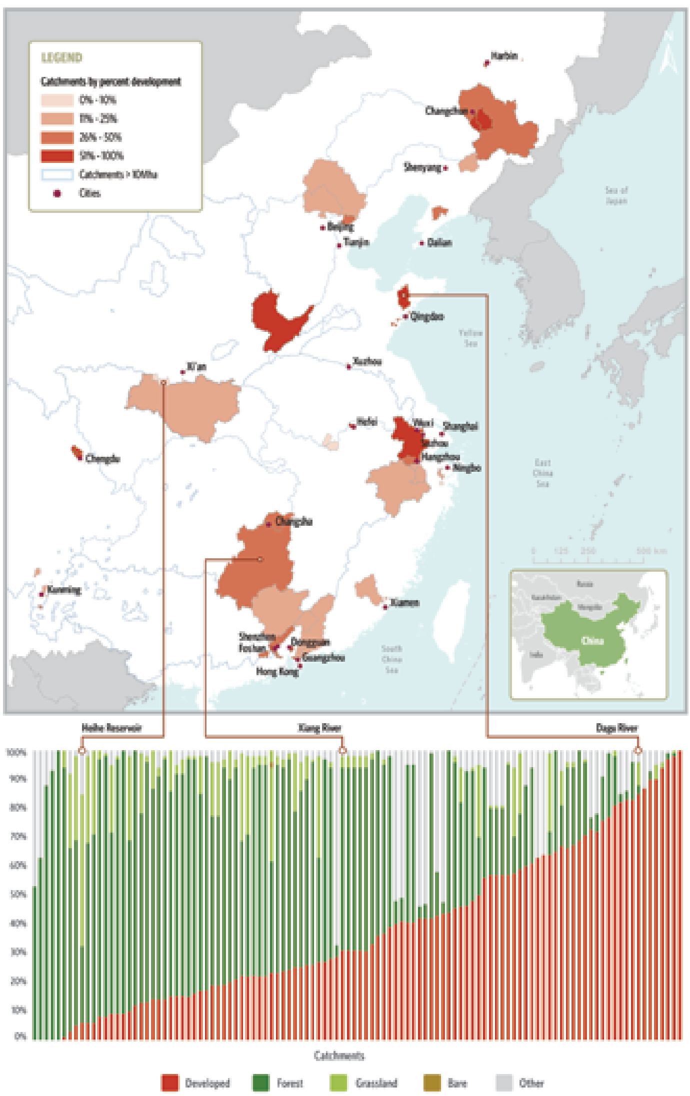
While much of the attention around China's water quality challenge has focused on point source pollution, non-point source pollution is a huge contributor to poor water quality. In fact, non-point source pollution is the main driver behind eutrophication of surface water, when dissolved nutrients stimulate plant and algae growth resulting in the depletion of dissolved oxygen and the death of animal life. Non-point pollution accounts for as much as or more than the loading of total nitrogen and total phosphorus from point sources and atmospheric deposition combined.[58] This excess load of nutrients and resulting eutrophication has caused major water supply crises, including the 2007 Lake Taihu algal bloom, which disrupted water supply to the city of Wuxi for more than a month.[59] In all, over 57 percent of China's 40 largest freshwater lakes have become eutrophic or hypertrophic.[60] Therefore, if China aims to improve water quality in its lakes and rivers, it must target non-point source pollution.

Changes in land use, particularly the conversion of forest and other natural land covers to pasture or cropland, can also increase erosion and the volume of sediment running off into streams. For example, destruction of vegetation has led to soil erosion in the upper reaches of the Yangtze River.[61] One reason to care about sediment rates is that high sediment yield leads to higher operations and maintenance (O&M) costs in water treatment. For instance, higher turbidity caused by increased sediment loading leads to greater use of coagulants, increasing costs and the amount of time water needs to remain in settling basins. A high concentration of sediment is also associated with more complex treatment technologies used in water treatment plants. For instance, New York City avoided having to build a filtration plant for its main source watersheds by agreeing to source catchment conservation, thus saving US $110 million per year. High sediment concentration in source water generates more wastewater and sludge, which are costly to treat and transport. Increased sediment also increases the need to dredge sedimentation tanks.[62] Sedimentation can depreciate storage infrastructure (through silting) and affect water supply, hydropower generation and freshwater ecosystem functionality.

Catchment degradation

Figure 2-3 shows the 2010 distribution of land cover for the 110 relatively small catchments that provide water to the 24 fastest growing cities in China. These water catchments vary widely in land use portfolios, but there is a strong trend toward alteration of natural land cover. In fact, in about one-third of these catchments, more than 50 percent of land cover was converted to working landscapes and urban area.

Figure 2–3. Land development in source catchments



Source catchments less than 10 million hectares classified by percent development. Developed land includes cropland and urban areas.

Non–point pollution in catchments

Figure 2–4. Sediment and nutrient pollution in source catchments

City	SEDIMENT Pollution	NUTRIENT Pollution	City	SEDIMENT Pollution	NUTRIENT Pollution
Beijing	1	1	Kunming	3	3
Changchun	1	2	Ningbo	3	3
Changsha	2	1	Qingdao	3	3
Chengdu	3	3	Shanghai	1	2
Dalian	2	2	Shenyang	1	1
Dongguan	2	3	Shenzhen	3	2
Foshan	2	3	Suzhou	1	1
Guangzhou	2	2	Tianjin	1	2
Hangzhou	1	1	Wuxi	1	1
Harbin	3	3	Xiamen	2	2
Hefei	2	3	Xi'an	2	2
Hong Kong	3	2	Xuzhou	3	3

Estimated sediment and nutrient pollution in source catchments, aggregated by city. Categorized into equal groups by relative pollution yield, where'3'indicates greatest pollution.

As water runs off these catchments and into the surface water sources upon which cities depend, the water quality can be severely impacted by land-use practices. Loading of sediment and nutrients into these water supplies increases in catchments with less natural land cover. Figure 2-4 summarizes the average sediment and phosphorus loading for the water supply of the 24 cities that obtain a substantial portion of their water from comparatively smaller (< 10 million hectares) catchments. In all, 82 million people in these cities are affected by elevated sediment pollution and 88 million are impacted by elevated phosphorus pollution due to runoff from developed catchments. In practice, phosphorus and nitrogen loading—hereafter"nutrient pollution"are highly spatially correlated, meaning that if one occurs it is likely that the other will as well. Given this correlation, this report limits the analysis to focus on one nutrient, phosphorus, but the conclusions and recommendations based on this analysis apply to both nutrients.

Increased pollutant loads can have a variety of negative impacts on urban populations. As water supply quality degrades the cost for treating water before sending it out to city residents increases. Operations and maintenance costs may rise incrementally over time, or incur new extreme peaks during high flow periods. At some point the city water utility might also need to invest in an upgraded water treatment system, which carries huge capital and increased operations and maintenance costs. These costs may be carried by the city itself, taking money away from other urban expenses, or be shared among water users, resulting in an increase in the cost for water use by industry and residents.

Another impact of increased pollutant loading is the potential for a temporary shutdown of the water system. For example, an increased sediment load during storm events could simply overwhelm the capacity of the utility treatment plants. In September 2015, the water supply for Taipei and New Taipei City shut down due to unsafe turbidity levels caused by excess sediment entering the system during Typhoon Dujuan.[63] In July 2013, a similar water supply cut-off accident happened in Chengdu following flash floods and mudslides.[64] In the case of excess nutrient loading, and in particular during periods of high temperatures, there is the risk of dangerous algal blooms forming in water bodies from which urban utilities draw their supply. Examples of algal blooms requiring temporary shutdowns of water supply systems are found around the world with increasing frequency.[65,66,67] The impacts on the urban economic and human well-being from shutdowns that stem from an overload of non-point source pollutants can be devastating.

Pollution and land development impacts on people and nature

Figure 2–5. Polluted source catchments and important biodiversity areas

Intersection of polluted source catchments with nationally designated priority areas for biodiversity conservation. Catchments categorized into equal groups by relative sediment or nutrient pollution yield.

In addition to people who depend on these catchments for their water supply, land degradation and resulting non-point source water pollution can affect wildlife that depend on these natural resources. Of the water supply catchments for the 24 cities included in this study, 73 percent show medium or high pollution levels (Figure 2-5) that threaten the water quality of 8,900 kilometers of streams within national priority biodiversity areas.[68] Water quality is one of the key elements for ecological integrity of freshwater systems, and once degraded, can have detrimental impacts on aquatic species, including species important for fisheries and other economic uses, as well as those that are threatened and endangered.

Beyond water pollution, land degradation can also have direct impacts on biodiversity residing in the catchments, including terrestrial species facing extinction. In all, more than 650 threatened or vulnerable vertebrate species have habitat ranges in portions of the source water catchments of the 24 cities. Figure 2-6 analyzes the intersections among urban source catchments and priority conservation areas, as outlined by the China National Biodiversity Conservation Strategy and Action Plan and the Alliance for Zero Extinction (AZE). This analysis indicates that there are 10 million hectares of national priority biodiversity conservation areas and three AZE designated sites within these degraded catchments, emphasizing the importance of addressing land management for both urban populations that rely on these areas as water supply sources and threatened species that depend upon them for survival.

Figure 2–6. Developed source catchments and important biodiversity areas

Intersection of developed source catchments with priority biodiversity areas and Alliance for Zero Extinction (AZE) sites. Catchments categorized into equal groups by percent development.

Figure 2–7. Population in source catchments

Estimated population (2010) living in source catchments. Note that source catchments can include urban areas.

Catchment pollution and land degradation also affect people living in source catchments, reducing food security and impacting livelihoods. More than 144 million people live within the 110 smaller catchments of the 24 top cities (see Figure 2-7) and are often more vulnerable than urban dwellers to the adverse impacts of pollution and land degradation on health and livelihood. This is especially true of the millions who have no access to safe drinking water. The World Bank estimated that water pollution more broadly is already costing China about 1 percent of GDP each year.[69] By addressing the water pollution at its source, these adverse health impacts can potentially be reduced.

Time is of the essence to better manage the land use in urban source catchments in China. Given the predicted annual GDP growth of 3.5 percent through 2050, demands for food and other raw materials, as well as energy production and water supply are expected to multiply. Continued development in urban source catchments to meet this demand will increase the non-point source pollution burden for cities and nature. Between 1970 and 1996, prior to the implementation of recent forest protection measures, annual forest loss in China occurred at a rate of 3 percent, roughly 50 million hectares.[70] Similarly, from 1978 to 2008, China's total wetland area decreased by one-third, or by more than 10 million hectares.[71] Grasslands have also been developed extensively, losing nearly 20 million hectares of high-quality grasslands across China since the 1950s.[72] Further development — accompanied by increasing non-point source pollution — is likely to continue unless changes are made to protect and restore natural lands and improve management of working lands.

For cities, water stress and the number of people and amount of economic activity at risk will increase in the future. Urban population is projected to comprise more than 75 percent of China's total population by 2050.[73,74] In fact, urban population growth is increasing at such a rapid rate that China is building the equivalent of a city with a population of 1.8 million people each month. Unless there is a change in the direction of land use practices in urban water supply catchments, water quality from non-point sources will continue to degrade. Even if point source pollution is controlled through regulation and enforcement, non-point source pollution will continue to threaten the critical rivers and lakes on which cities depend for survival.

Economic drivers of catchment degradation

China's economic development strategy is undergoing a historic transformation, one that presents significant opportunities to pursue nature-based solutions for the water security challenge. Indeed, the scale of the water security challenge stems in large part from China’s approach to economic growth over the past 40 years, which has relied on consistently and rapidly increasing output to the detriment of environmental protection.

Despite its political centralization, the Chinese government has relied upon extensive delegation of authority to local officials to drive growth. These officials have been incentivized to maximize growth through two mechanisms. The first, known as the cadre evaluation system or kaohe, essentially ties the promotion of local government officials to meeting certain quantitative targets, the most important of which is the annual rate of increase in Gross Domestic Product (GDP) within their respective jurisdictions. Historically, environmental and quality-of-life indicators have not been part of the kaohe system, meaning that local officials have little incentive to pursue long-term investments in natural capital or catchment conservation.[75]

The second mechanism driving local decision-making regarding catchment conservation concerns the sale and development of real estate. From a fiscal perspective China is one of the most decentralized countries in the world and local governments are responsible for providing a wide range of services, including most aspects of environmental protection. However, there is a consistent shortfall in funds transferred from central to local levels, meaning that local governments are expected to raise a significant portion of their own annual expenditures.[76]

The primary means of meeting this shortfall[77] is through borrowing financed through the sale and development of land lease rights under local government ownership. The sale of land lease rights accounts for approximately 35 percent of local government revenue throughout China and as much as 50 percent in cities like Tianjin and Chongqing.[78] The dependence of many local governments on the sale and development of land generally means that local officials may prefer short-term gain over long-term investment in nature, including conservation of forested or wetland areas. The net effect of these two mechanisms is to incentivize short-term output increases over long-term investment, especially in natural capital resources. In the process, urban water resources are often degraded.

However, a historic shift in China's economic development strategy promises to help reverse this unfortunate trend. Beginning with the Twelfth Five-Year Plan (2011-2015), the Chinese government signaled its intention to move away from a manufacturing-intensive, export-oriented growth strategy to a higher value-added economic model that can stimulate the development of less pollution-intensive industries and be coupled to more prominent and more stringent environmental protection regulations.

An important component of this shift was passage of a revised Environmental Protection Law that took effect at the beginning of 2015 and requires environmental performance objectives to be included as part of the kaohe evaluation process.[79] At the same time, local government debt accrued as part of the rapid development of real estate has raised considerable concern on the part of the Chinese government and foreign investors, suggesting that Beijing may soon attempt to revisit the incentive structure that drives local officials to develop land at the expense of conservation and ecosystem service protection.

Chapter 3

The Untapped Value of Catchment Conservation

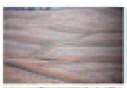
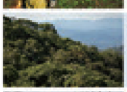
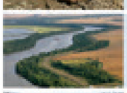
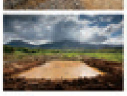
Water quality and quantity problems are among the central challenges cities will have to face in the 21st century. Chinese cities are confronting these challenges by consistently re-plumbing their water infrastructure to access new and often distant water sources. This approach is leading to an ever more expensive approach to water management and one that does not engage the fundamental problem faced by cities: sharing a limited supply across multiple uses.

There are alternatives. For water quantity, one can introduce mechanisms to share water and compensate users. For water quality, catchment conservation can maintain water quality in the face of land use change. In this chapter, we present a blueprint of the potential impact and relative cost-effectiveness of specific catchment conservation activities that can help maintain water quality.

What's on the conservation menu

Catchment conservation can be accomplished through a wide range of natural solutions that prevent pollution, increase infiltration and filter out pollutants prior to reaching surface water bodies. This suite of conservation activities — from wetland construction to forest restoration — can be employed to address non-point pollution in water source catchments (Figure 3-1).

Figure 3–1. Conservation strategies to help secure water for cities

	Strategy	Description
	Agricultural Best Management Practices	Implementation of cover crops, contour farming to prevent sediment and nutrient runoff
	Forest Fuel Treatment	Conducting controlled burns or mechanical treatment to reduce wildfire severity and related sediment and ash pollution
	Forest Protection	Purchase of easements, land rental, conservation agreements, fencing and funding for park guards to maintain naturally forested areas
	Irrigation Efficiency	Shift from flood to variable rate and precision irrigation, and lining irrigation canals to reduce leakage and net water consumption
	Ranching Best Management Practices	Reduce cattle-related land degradation with silvopasture practice, rotational grazing and fencing as well as livestock waste disposal to protect water quality
	Reforestation	Restoration and planting of native trees and shrubs in critical areas to reduce erosion and related sediment transport
	Riparian Restoration	River bank restoration and protection to reduce erosion and improve water quality
	Road Management	Construction of sediment traps and culverts along roadways and resurfacing of dirt and gravel roads to reduce sediment runoff into waterways
	Wetland Installation	Conversion of portions of farmland to constructed wetlands to trap nutrient runoff

Multiple conservation strategies can be applied across a range of catchment landscape types to improve water quality and quantity management. Strategies highlighted in blue are assessed in this report.

For this analysis we assessed the potential of four conservation activities to address non-point source pollution in 110 water supply catchments focusing on 24 fast-growing cities that rely significantly on surface water supply from catchments smaller than 10 million hectares. These four conservation activities were selected based on their proven performance and wide applicability across natural and working landscapes: forest protection, reforestation, riparian restoration and agricultural best management practices.

Each strategy improves water quality and regulates water flow in unique ways. Typical costs range among conservation strategies (see methodology for more details). While forest protection is the most affordable strategy of those assessed, there are other factors that influence the efficacy of a strategy in a particular location, such as its applicability and overall ability to reduce pollution.

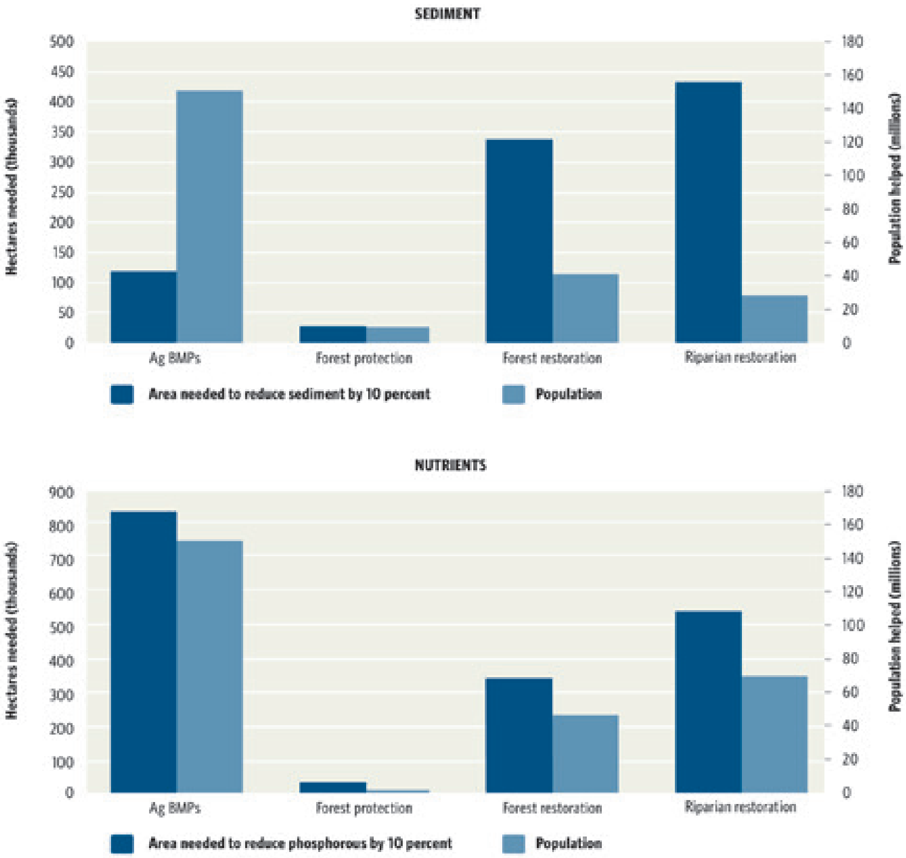
The scale of conservation needed to impact water pollution

Implementing catchment conservation practices could reduce sediment and nutrient pollution for urban water supplies. Our analysis shows that if the four conservation activities we examined were implemented at sufficient scale in areas of hydrological importance each has the potential to significantly impact water pollution in China's largest and fastest growing cities. For the purposes of comparison, "significant impact" on non-point source pollution is defined here as a 10 percent reduction in sediment and/or nutrient (P) loading.

In general, conservation investments will be attempting to achieve multiple outcomes beyond mitigating sediment or nutrient pollution, necessitating customized 'portfolios' of activities for each catchment. While we are unable to forecast such optimal portfolios across activities, we estimate a cumulative area of roughly 1.4 million hectares under conservation could reduce both sediment and nutrient pollution loading for these 24 cities by at least 10 percent. While large, this area represents less than 3 percent of the area of smaller catchments that deliver water to the 24 cities. What's more, while areas of hydrological importance such as steep slopes and river banks would need natural vegetation restored, much of the catchment landscape is likely to remain in production under better management practices.

The conservation activities vary in effectiveness across catchments, due in part to limitations on where they can be applied (Figure 3-2). Implementing agricultural best management practices has the greatest scope to impact water quality across our sample of catchments for 110 water source intakes. Agricultural BMPs alone are likely to measurably reduce nutrient loading in water sources for 148 million people living in cities. Collectively, this could mean prioritizing conservation on just 1 percent of farmland if infield practices were targeted to cropland with the highest nutrient runoff. Importantly, these working lands could remain productive and still achieve a 10 percent reduction in nutrients. Forest restoration, in contrast, would require taking some agricultural areas out of production. As with agricultural best practices, the scope of impact on water quality is vast. Our findings suggest that targeted reforestation on just 340,000 hectares could reduce sediment loading by 10 percent in water sources for over 40 million urbanites.

Figure 3–2. Sediment and nutrient reduction for four common conservation strategies

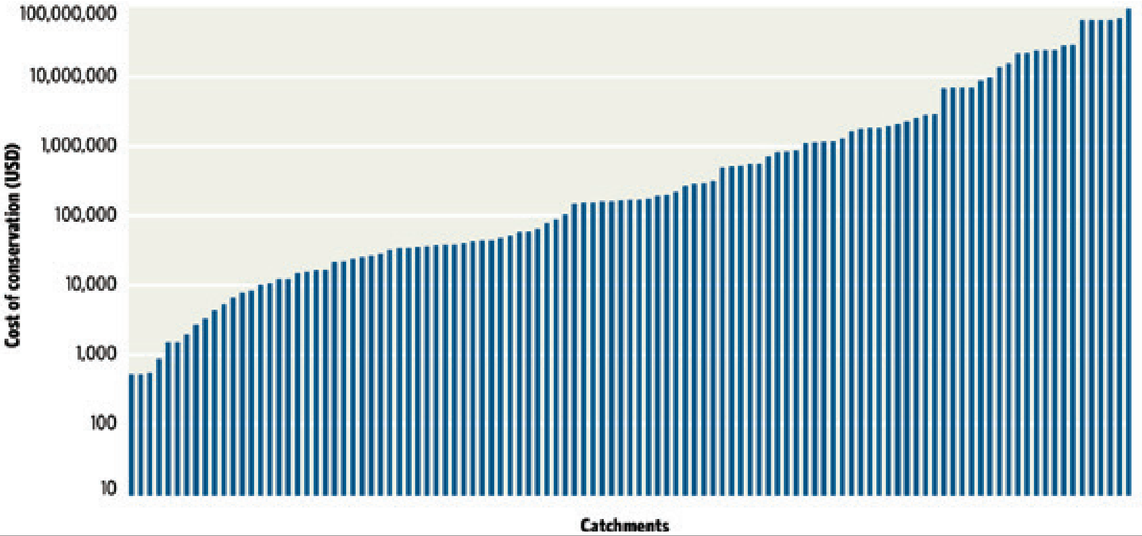


Comparison of conservation area needed to reduce sediment (top) or nutrient (bottom) yield by 10 percent, and estimated urban population helped by each strategy

What conservation at scale costs

Based on the area required to make a measurable reduction in sediment and nutrients, we are able to estimate the potential cost to improve water quality through investing in nature (Figure 3-3). Using average costs for conservation based on literature review of China's national expenditure, we estimate the total cost across selected conservation activities to be upwards of US $300 million per year with the largest investment in agricultural lands and riparian restoration. Of course, the costs vary widely across catchments and cities. In Shanghai's Huangpu River catchment, for example, which provides over 25 percent of the city's drinking water, the estimated conservation cost would be over US $14 million per year. In contrast, the cost across Guangzhou's source catchments would be roughly half that. In aggregate, US $300 million represents the scale of investment to measurably decrease water pollution in China's largest and fastest growing cities. Notably, this figure also represents less than 4 percent of what China already invests in national eco-compensation programs, which averaged US $8 billion over the last 5 years.[80] More notable still, the potential financial burden on urbanites would average $2.3 per person per annum, which is significantly less than 0.1 percent of the average annual salary in China.

Figure 3–3. Costs of catchment conservation



Representative costs of conservation to reduce sediment or nutrient pollution by 10 percent. Estimated as median cost across all applicable strategies for catchments smaller than 10 million hectares.

Preventing pollution reduces treatment costs

Figure 3–4. Potential return on investment from catchment conservation

Low ROI	Moderate ROI	High ROI
(where savings in water treatment operational costs would cover no more than 10 percent of estimated catchment conservation costs)	(where savings in water treatment operational costs would cover at least 10 percent of estimated catchment conservation costs)	(where savings in water treatment operational costs would cover 100 percent of estimated catchment conservation costs)
Beijing	Changchun	Harbin
Changsha	Chengdu	Ningbo
Guangzhou	Dalian	Qingdao
Hangzhou	Dongguan	Xuzhou
HongKong	Foshan	
Shanghai	Hefei	
Shenyang	Kunming	
Shenzhen	Xi'an	
Suzhou		
Tianjin		
Wuxi		
Ximen		

As previously discussed, improved source water quality has a direct impact on the cost of water treatment. For conventional treatment, on average, improving water quality by 10 percent results in an estimated 5 percent reduction in water treatment operations and maintenance costs.[81] These savings in operations and maintenance costs could be used to offset the cost of conservation. When we compare these savings with the actual cost of conservation, we estimate that for four cities conservation could effectively be cost neutral (Figure 3-4). The cities — Harbin, Qingdao, Ningbo, and Xuzhou — all draw water from relatively small catchments. A full evaluation of the return on investment from source catchment conservation for a utility requires detailed information on the hydrology of the source catchments, sources of pollutants, and the treatment processes in use at the water treatment plant. Such a detailed return on investment analysis can only therefore be calculated on a case-by-case basis. Our estimates are nevertheless predictive of where possible investment returns are greatest for particular cities and in aggregate they capture a generalized view of the potential for cities to realize favorable investment returns. Savings in water treatment could offset a significant portion[82] of catchment conservation costs for half of China's largest and fastest growing cities.

A much broader set of cities can be helped by source catchment conservation if the water utility is not expected to pay the full cost of conservation. In many cases, large private water users or governmental agencies with related objectives may be willing to financially support catchment conservation in order to realize their own benefits. Such benefits could include a range of economic activity generated by these conservation investments. For example, one economic study from the United States suggests that every dollar invested in conservation generates twice as much economic activity.[83] In the context of our analysis here, this would suggest nearly US $600 million a year in economic benefits from such catchment investments. While outside the scope of this report it is important to highlight that the benefits from catchment protection investments extend well beyond avoided treatment costs alone, with a potentially far greater economic valuation.[84]

Figure 3–5. Potential conservation investment return and important biodiversity areas

Intersection of source catchments with priority areas for biodiversity conservation. Catchments categorized by potential investment return from avoided treatment costs.

Prioritizing conservation for water security also benefits nature

The benefits of catchment conservation do not apply to cities alone. While avoided treatment costs are an important incentive, there is also significant conservation value for nature and for people whose livelihoods are connected to natural systems.[85] As one of the most biologically diverse countries in the world, conservation of these natural systems is a critical priority for China.[86] Indeed, China has formally committed to the reformation of an "ecological civilization" that integrates economic and environmental outcomes.[87]

Catchment conservation activities, such as forest protection and agricultural BMPs assessed here can benefit biodiversity directly and indirectly. Terrestrial species can benefit directly from protected or improved habitat, while aquatic species stand to benefit from improved riparian corridors and water quality conditions.[88] China's large-scale forest conservation program (Natural Forest Protection Program), which includes ecosystem payment components, has demonstrated the potential to support terrestrial habitat for critical species while also improving surface water conditions.[89]

For those cities with favorable avoided treatment cost returns (13 cities accounting for 16 million hectares of catchment area), we see that these water supply catchments represent areas of biodiversity importance by multiple measures. As previously discussed, the National Biodiversity Conservation Strategy and Action Plan identified priority areas of conservation within China for both terrestrial and aquatic biodiversity. For water supply catchments with favorable conservation investment returns, identified national biodiversity priority areas account for one-quarter of the total catchment area. Looking at species richness, catchments where conservation is likely to be most cost-effective intersect eco-regions representing about 20 percent of China's fish and 19 percent of its terrestrial animal diversity.[90,91] Accordingly, conservation activities in these catchments present the opportunity to support the dual objectives of urban water security and biodiversity protection.

Though our analysis precludes the possibility of attributing specific outcomes to specific species or habitats, the scale of conservation investment and alignment with national biodiversity conservation priority areas indicates that, collectively, there is strong potential to support biodiversity conservation in China through urban source catchment protection. These biodiversity gains are additive to the benefits of avoided treatment costs and economic activity, supporting potential "win-win" scenarios that benefit both people and nature.

Governance structures that influence urban water sources

As is the case in most countries, responsibility for urban catchment conservation is shared between several governmental agencies at the central and local levels. Because catchment conservation concerns both land and water, it is a challenging policy issue that demands extensive coordination between these different governmental units which often have different incentives. In China, the Ministry of Environmental Protection (MEP) has primary jurisdiction over water pollution and quality issues, and therefore is nominally responsible for urban watershed conservation. However, most land use issues are handled by the Ministry of Land and Resources (MLR), while the Ministry of Housing and Rural-Urban Development (MOHURD) deals with construction-related issues, including those that may degrade urban water catchments. In addition, the State Forestry Administration is responsible for forest management and reforestation programs. Each of these line ministries have offices at provincial and sometimes local levels of government, where they deal with separate territorial administrations that are responsible for local land use planning, infrastructure planning and financing. Finally, the Ministry of Water Resources (MWR) operates several river basin commissions, which are responsible for the planning and coordination of pollution control, among other activities, at the regional scale (Figure 3-6).[92]

Figure 3–6. Governance of source catchment conservation in China

	Rural	Urban
Land	Ministry of Land and Resources State Forestry Administration	Ministry of Housing and Urban-Rural Development Municipal / Prefectural Government
Water	Ministry of Water Resources	Ministry of Environmental Protection Water and Sanitation Bureaus (Local Government)

Public institutions with primary responsibility for elements of source catchment conservation

Although each of these entities bears considerable responsibility for different aspects of catchment conservation in China, local governments play a particularly critical role. In most urban areas, water supply and sanitation are the responsibility of different local government entities, referred to as water affairs and wastewater bureaus, respectively. These entities are part of the formal government bureaucracy, but in recent decades they have in some cases divested considerable portions of their operations to state-owned and foreign joint venture enterprises. As of 2007, some 50 water and 100 wastewater projects in China had some element of private sector participation.[93] Most such divestitures involve urban water supply concession agreements to Chinese state-owned enterprises, but foreign participation is growing, and the French firm Veolia holds some 22 municipal and nine industrial urban water supply contracts.[94] The increasing private sector participation adds another layer of complexity to the governance dimension of urban catchment conservation, but it also creates opportunities to develop innovative financing mechanisms for catchment conservation, especially for investment in natural capital and ecosystem service protection.

In appealing to local governments, this report suggests that the best approach is likely to emphasize ultimate benefits in terms of improving water quality, rather than the economic benefits per se. Because local officials are so target driven, they are likely to be more responsive to the beneficial impact of source water protection on water quality levels than on financial benefits; because of the nature of financing between central and local levels of government, as well as among state-owned water supply and treatment facilities, financial signals are not likely to be as direct as they would be in the West. Currently, water quality targets emphasize overall pollutant concentrations, but improvements are obviously easier to achieve and measure in the case of point sources. Achieving additional gains from reducing non-point source pollution is likely to be much more challenging, and so an appeal to local officials on the grounds that catchment conservation can help reduce non-point source pollution may well find success.

Chapter 4

Putting Market-based Mechanisms to Work for Urban Water Security

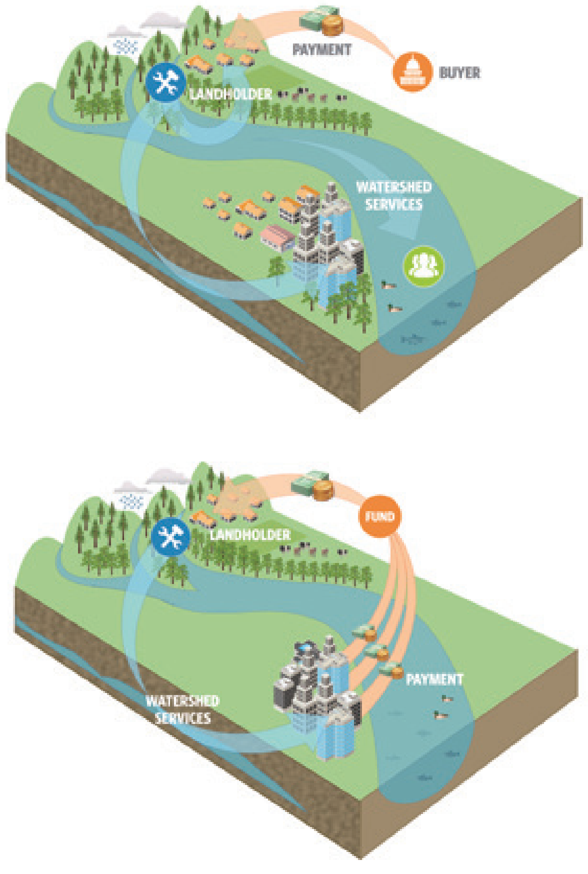
In 2013, the Third Plenum of the 18th Party Congress announced that China would undertake a "decisive move to the market." China remains determined to move from an economy powered largely by high levels of state-led investment to one animated primarily by domestic consumption, with a much greater role for the private sector and for market forces in most every part of the economy. This renewed emphasis on the market extended to the field of environmental policy as China began developing pilot cap and trade programs for carbon dioxide, and prompted serious debate on a wide range of environmental externality taxes, including for carbon.[95] Of more direct relevance to urban catchment conservation, the move to the market also put fresh energy behind the development of Payments for Ecosystem Services (PES) programs, which aim to commoditize beneficial by-products of natural capital resources such as forests and wetlands. Many PES schemes are intended to protect or enhance the quality of urban drinking water, and some of the most successful PES model programs, such as New York City's Catskills preservation initiative, pursue this objective.

PES programs have been popular in China since the 1980s, particularly in the forestry sector. The country has spent an estimated US $41.6 billion since 1999 on catchment investments.[96] Such large scale eco-compensation programs like the Conversion of Cropland to Forest and Grasslands program use public subsidies to reward land managers for enhancing or protecting ecosystem services. Despite high-level political interest, challenges to meeting the full potential of this program include unclear title to land and water rights, lack of regulatory clarity, insufficient local government awareness and interest, difficulties in quantifying ecosystem services benefits, and lack of sufficient fiscal resources, particularly at the local level. Also, unlike New York City's Catskills program, in these programs the funder is not necessarily the primary beneficiary. As a result, China's current investments in catchment services are not generally optimized for urban water security.

Collective action water funds

An alternative exists that gives greater responsibility to local water users, namely collective action funds involving one or multiple water users compensating one or more upstream parties for activities that deliver water benefits to the payer(s) (Figure 3-1). This user-pay model puts the financial burden on beneficiaries of these ecosystem services. From South America to East Africa, there is growing precedent for competing water users to invest jointly in a "water fund," a process that establishes a financial and governance mechanism to direct funds toward targeted catchment investments based on impartial science. That mechanism offers the greatest return to all investors, both public and private. Such an institutional arrangement also serves an important governance function, providing a forum for collective planning and decision-making while also giving investors a voice in how water resources are managed.

Figure 4–1. From public subsidies to collective action water funds



Two models of catchment conservation financing— public subsidies (top) and collective financing from downstream users (bottom). Figures excerpted from Forest Trends, "Gaining Depth:State of Watershed Investment," 2014.

The Nature Conservancy is currently involved in over 60 of these water funds, where competing public and private water users come together, often alongside local government, to invest collectively in conservation of the catchments that provide their sources of water supply. One-third of these 60 water funds are already in full operation, mostly in Latin America, but the model is now spreading across four continents. Once an opportunity is identified, a growing body of research and tools now exists to help water users decide where in the catchment to invest. For example, RiOS is a free and open source software tool that combines biophysical, social and economic data to help users maximize the ecological return on investment from catchment conservation.

There is already precedent for water funds in China. In 2005, for example, Beijing and the city of Chengde, in neighboring Hebei province, entered into a five-year agreement in which Beijing paid Chengde CNY 20 million per year to abate soil erosion in upstream watersheds, an agreement that was extended in 2011.[97] The Beijing's Paddy Land to Dry Land (PLDL) program aims to reduce both agricultural nutrient and chemical run-off and siltation by offering a subsidy to farmers to switch from water-intensive rice cultivation to corn, which requires less water and also, because it does not require drainage, leads to less nutrient and sediment runoff.[98]

Local government and industry

There remains an untapped potential for user-pay PES schemes like the PLDL to capture greater, more targeted value for cities and urban industrial concerns. Regional cooperation in China remains the exception, as the political system discourages horizontal cooperation in favor of central-local control. Accordingly, barring major developments in the policy architecture surrounding source watershed, local governments will remain the most important players in protecting water sources, as well as in financing conservation strategies like forest protection and agricultural management practices. This was the case in Beijing, for example, where the local Development and Reform Commission took the lead. Although the approval (and often financial support) of higher-level authorities will likely be necessary, local officials are the crucial gatekeepers.

Local government will likely find common cause with industrial users, who are projected to represent one-third of water demand by 2030. Although agriculture still makes up the majority of the total demand, industrial and urban water uses are the fastest growing, at approximately 3 percent per annum.[99] Industry faces a dual challenge of decreasing water resources and increasing pollution, which often require acquiring new, and often distant water sources. These issues are particularly relevant to large industrial users, such as energy companies and those involved in metals and mining, which face both water and energy challenges. For example, according to the World Resources Institute, more than half of China's proposed coal-fired power plants are slated to be built in areas of high or extremely high water stress.[100] Companies that rely on a high level of water quality for production of foods and beverages also face increasing costs as water pollution worsens. Accordingly, many large private water users support watershed conservation and have shown leadership and a willingness to pay.[101]

The central government recognizes these challenges and is taking a strong stance on addressing water quality issues. The central government recently issued a policy known as the "Three Red Lines" which stipulates that 95 percent of waterways in the country must meet water quality standards by 2030. As the target date approaches, local officials and industrial users are likely to feel growing pressure to address non-point source pollution, alongside point source pollution, in order to meet these targets.[102]

Investing in China's future

Now is the time for China to invest in smart land use policies and programs that protect the critical habitats that provide water supply for growing cities and industry. The analysis presented in this report demonstrates the capacity of a sample of these natural solutions (forest protection, reforestation, agricultural best management practices and riparian restoration) to measurably reduce the loading of the most common non-point source culprits — nutrients and sediment.

Importantly, in addition to savings in water treatment, investments in natural solutions hold benefits for nature and people, such as the protection or enhancement of critical terrestrial habitats, improvements to water quality for freshwater species and improved water security to rural communities living in urban water catchments. While not evaluated here, natural solutions promote a suite of other co-benefits, including job creation and public health in rural areas, improved opportunities for tourism or recreation, and protection or enhancement of carbon storage in soil and vegetation.

In China, collective action water funds offer an untapped mechanism to implement these natural solutions at scale. Building on the popularity of payment for ecosystem services (PES) programs, this approach allows local government and industrial concerns to influence and protect their water sources and the people and wildlife that inhabit them.

By connecting with the places that cities depend on for water, and making targeted investments in natural solutions in these source water catchments, China has the opportunity to invest in its water future.

CASE STUDIES

Miyun Reservoir

Government & Public Collaboration to Improve Beijing's Water

Local Conditions

The Miyun Reservoir is currently the main surface water source for Beijing, the capital of China and the country's foremost political center. Located about 80 kilometers northeast of the city, Miyun reservoir supplies Beijing with about 70 percent of its drinking water, meeting the needs of over 20 million people.[103] Roughly one-fifth of the catchment resides within Beijing's municipality district, while the remaining 80 percent fits entirely within Hebei Province, and contains two major river systems: the Chao River and White River.[104] When the Miyun Dam was completed in 1960, with a potential storage capacity of 4.37 billion cubic meters, its primary purpose was simply to meet growing agricultural needs.[105] However, economic development in the 1980s led to increased water demand, and as Beijing's Guanting Reservoir became polluted, Miyun gradually became a very important source of domestic water for the region.

Figure 1: Miyun Reservoir. The red line indicates the border Beijing's municipality. The rest of the catchment area, shown in green, resides in Hebei Province. (Zheng, H.; Robinson, B. E.; Liang, Y; et al., 2013)

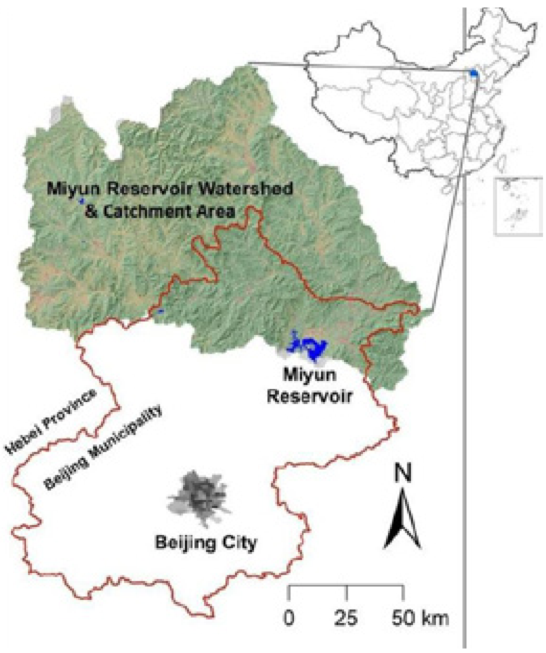


Figure 2: Miyun Reservoir, Beijing, Aug. 28, 2010 (Tiger King /CC BY-NC-SA 2.0

In recent years, the Miyun Reservoir catchment has witnessed two new challenges. First, climate change has greatly reduced precipitation, causing less reliable replenishment to the water supply.Today, the reservoir only regularly fills up to one-third of its designed capacity as a result of constant drought and growing agricultural withdrawals for irrigation practices. Second, non-point source pollution has degraded the quality of the water that is available.[106] Although less than one million people live within the watershed catchment area, 92 percent of them are involved with agriculture.[107] Over the years, the increased application of fertilizers and pesticides on farmland and the impact of aquaculture on the catchment have had detrimental impacts on the receiving streams. By the early 2000s, the resulting high concentrations of total nitrogen and total phosphorus, equivalent to about four times of those in the late 1980s, also began to pose health and economic risks to local communities.

Action and Opportunity

By 2003, rice cultivation alone reached 80,937 hectares, consuming nearly 200 million cubic meters of water from the basin every year, all the while returning harmful chemicals to the system. It was this same year that local government decided to take action to help ensure Beijing's water security. A three-step plan called the "Paddy Land-to-Dry Land" (PLDL) was soon implemented, which compensates farmers' economic losses for converting their cropland from rice to less water intensive crops. The pilot project was run in 2,347 hectares of catchment under Beijing's administration and was estimated to save 4,000,000 cubic meters of water on an annual basis. To amplify the effect, a second PLDL project was implemented in 2006. During this second phase a total of 7,041 hectares of paddy land within the Hei River basin was converted to water-saving crops such as corn and soybeans. From January to October 2006, the entry water flowing in to the Hei River increased by nearly 9 million cubic meters, significantly improving the reservoir's water quantity and quality.[108] Before the end of the year, the Beijing City Government and Hebei Province Government signed the Strengthening Economic and Social Development Cooperation Memorandum to carry out an additional 6,867 hectares of PLDL projects within the three big water catchment districts feeding the Miyun Reservoir (Bai River, Chao River and Hei River) and to be sure that farmers would be adequately compensated throughout.

The Miyun PLDL is an excellent example of a government-led ecosystem compensation mechanism, evident by the measurable results, but also the support of NGOs and the encouragement of local communities. Beijing urban residents, earning three times the income of farmers living in the Miyun catchment area, found it worthwhile to fund changes in agricultural practices in order to increase the security of their drinking water. These payments from Beijing not only ensure that farmers who participate in PLDL projects will not lose income, but allow them to make a minor profit. Benefits for the people and city extend well beyond such direct monetary incentives however. Naturally clean and improved water contributes to better public health and helps avoid the potential harmful outcomes of using polluted water. Likewise, costs to improve water quality or quantity through man-made infrastructure (treatment plants, transportation mechanisms, etc.) are consequently reduced. A study from the Chinese Academy of Sciences and Beijing Water Institute showed that PLDL projects not only increased the supply by 18.2 million cubic meters of water per year, but also reduced total phosphorus and total nitrogen by 10.36 and 4.34 tonnes respectively.[109]

Beijing's Miyun Reservoir ecological compensation mechanism was particularly successful for two main reasons. First, the government was able to lead the entire project from design to implementation due to the special political status of Beijing. Second, the significant research that estimated the environmental and economic benefits that such projects could give to communities provided the momentum and guidance for the PLDL implementation.

Dahuofang Reservoir

Importance of Agricultural BMPs and Collaboration

Local Conditions

Dahuofang Reservoir is the People's Republic of China's first Five-Year Plan reservoir, built in 1954 at the start of the nation's rapid industrialization period. It is the largest centralized drinking water source in Liaoning Province with a water surface area of 91.2 square kilometers, and a supply capacity of 2.5 billion cubic meters per year. It is mainly fed by the Hun River and the Suzi River, two very large basins located upstream. The Dahuofang Reservoir supplies fresh water to roughly 25 million people in the cities of Shenyang, Fushun, Liaoyang, Anshan, Yingkou and Dalian. Because of high demand, residents consume an average of 820 cubic meters per person (less than one- third of the national per capita average). A new water supply project in the province also intends to eventually add five cities to those served by the reservoir. While this will further threaten Dahuofang's ability to meet water demands, the reservoir faces a greater risk of water quality degradation from the agricultural industry that dominates the catchment, covering a land area of 542,000 hectares.

Each year, an estimated 2,556 tonnes of chemical fertilizers and 25 tonnes of pesticides flow into the Dahuofang Reservoir due to poor farming techniques and industrial practices in the region. This equates to an annual load of 74,979 tonnes of sediment, 1,700 tonnes of total nitrogen and 74 tonnes of total phosphorus.[110] Most of this sediment and nutrient loading occurs during the summer months and is strongly correlated with agricultural runoff.[111] This pollution and soil erosion not only degrades the catchment but also its natural ability to filter contaminants and restore itself.

Figure 1: Location of Dahuofang Reservoir, 2015 (Longzhu Wang / TNC)

Action and Opportunity

In 2014, the Liaoning provincial government adopted an "adjustment, governance, cultivation, and management" principle to use conservation practices to address the water quality crises the cities were facing. The first step was to identify high-priority catchment zones to protect and then convert farmland in those areas back to natural forest. Totaling 2,213 hectares, this first zone used financial incentives, rented farmland from growers and employed conservationists to plant trees and restore wetlands. For areas located just outside of the priority zone, agricultural practices had to become organic and industrial enterprises had to meet strict ecological standards or were told to relocate.

Liaoning Province also enacted a Five-Year Plan on organic agriculture, catalyzing Dazhiran Ltd. Co. to develop its "Double Zero Project." The plan aims to use no fertilizer or chemical pesticides in multiple pilot projects over 635 hectares of farmland within the Dahuofang Reservoir catchment of Qingyuan County. In 2015, The Nature Conservancy signed a cooperation memorandum with Dazhiran to monitor this work and analyze the results as it expands to 1,300 hectares by 2016, and 67,000 hectares by 2020. In the first year, the switch to organic agricultural methods reduced production by only 10 percent. Working with the Qingyuan County government, the Conservancy is also able to help the region monitor and showcase the services that healthy ecosystems can provide to people and cities. The hope is to provide China with support and guidance on how to implement a water funds strategy and receive these benefits from nature in years to come.

By improving local regulations, implementing ecological compensation mechanisms and establishing specialized law enforcement agencies, sustainable management of these protected districts has continued to strengthen.

Overall, the new conservation activities that Liaoning Province adopted help reduce pesticide and fertilizer runoff while increasing the natural function of forests and wetlands to filter out pollutants and act as a barrier to sedimentation. In turn, the quality of water in Dahuofang Reservoir is improved for both people and wildlife, consequently lowering water treatment costs for cities. The ecosystem services of the upper catchment area of the Dahuofang Reservoir have recently been estimated to have a value of CNY 90-656 million.[112]

Figure 2: Dahuofang Reservoir, 2012 (Patrick Lepetit)

Heqing Caohai

Wetland Protection for People and Wildlife

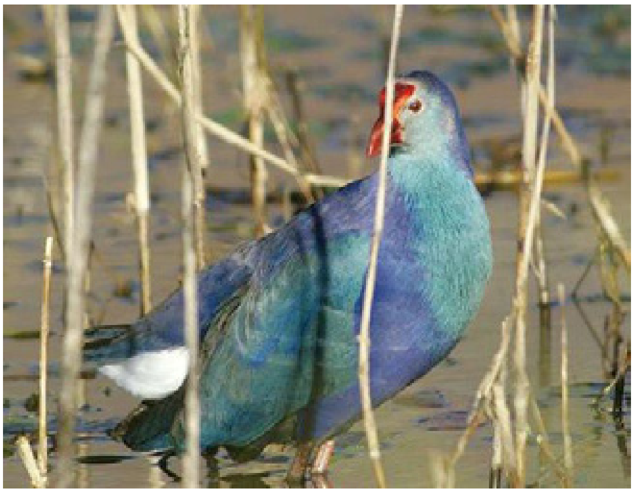
Local Conditions

Wetlands are an important part of urban catchments; not only are they a source of drinking water, they also provide other beneficial services to communities such as flood absorption and storage, drought prevention, climate mitigation, wildlife habitat and water filtration. According to the second national wetland resources survey, however, natural wetland areas in China decreased almost 3.3762 million hectares in the past decade.[113] Additionally, many of the wetland ecosystems still in existence are weakened from development, industry, and lack of conservation and regulations, consequently degrading the public amenities they could provide.

"China's freshwater resources are mainly contained in riverine wetland, marsh wetland, and reservoir and pond wetland, which contain a total of about 27,000 tons of fresh water, or 96 percent of usable freshwater resources in China." [114]

Located in China's Yunnan Province, Heqing County is abundant in wetlands, both in number and variety. With plentiful groundwater resources and hundreds of spring lakes, protecting wetlands has become a high priority for the region. In recent years, the Caohai wetland and its surrounding catchments have become a focus within Heqing, providing irrigation water for almost 4,500 hectares of farmland, delivering drinking water for more than 20,000 surrounding residents and providing important habitat for migratory birds and wintering birds in western Yunnan.

Figure 1: A Purple Swamphen at Caohai Lake, 2010 (WildChina)



Recent surveys completed by The Nature Conservancy China found there were 9,570 wintering waterbirds utilizing this wetland during migration. The largest known group of the rare Purple Swamphen is also found here with an estimated population of 300-500, the largest in China.[115]

Sadly, anthropogenic activities have caused the Caohai wetland to evolve more and more into alake, desecrating its natural buffers to better regulate flow and filter out pollutants. Influent and effluent are instead subject to strong artificial control from agriculture and livestock runoff and include degrading pollutants such as fertilizers, pesticides and hormones. Sewage from local villages, pollution from tourism and toxic waste from gold and silver handicraft manufacturing are also a source of harm to these catchments.

Action and Opportunity

In 2013, the Laohegou Natural Reserve in Pingwu County of Sichuan Province became the first preserve to be supervised by the local Chinese government and managed by a non-governmental organization: in this case, The Nature Conservancy. The efforts quickly inspired several other conservation projects, and in December 2014 the Conservancy signed a three-year cooperation agreement with the Heqing County Government and the Sichuan Nature Conservation Foundation (SNCF) to establish the Heqing West-Caohai Wetland Conservation project.[116]

Recognizing that pollution directly threatens the water environment and ecology of the Caohai wetland, new strategies have been established to convert lands back into wetlands, forbid fisheries in certain locations, restore natural habitats and even build artificial wetlands to help purify the surrounding agricultural wastewater before it reaches the natural ecosystems. To reduce pollution, the new plan is utilizing appropriate prevention methods respective to the type, source and severity of the pollution, including:

- To address agricultural non-point source pollution, artificial wetlands are being installed within irrigation canals.

- To reduce solid waste from rural life in the surrounding communities, the government will be constructing confined sewage disposal systems and appropriate processing facilities, while strengthening community awareness education around the importance of environmental protection.

- Because pollution produced by handicraft manufacturing has much greater toxicity, regulations are becoming stricter to process wastewater separately while increasing hydrological monitoring and assessment of the impacts and needed future steps.

A historic ethnic group local to the area, the Bai, also has customs and traditions that have respected and loved water since the Yuan dynasty (roughly 7,000 years ago). The Heqing West- Caohai Wetland Conservation Project plans to bring back and encourage the Bai's ecofriendly traditions in order to incorporate sustainability in the everyday lives of local residents.

To effectively manage the different efforts, the Caohai project has also classified the wetland into areas of conservation, education, eco-agriculture, rural folk customs and tourism. Each zone is treated with management and enforcement techniques suitable to that area’ s need. The project also seeks to increase the heterogeneity of the habitat to protect 8,000 to 10,000 wintering migratory birds.

The Caohai project emphasizes the opportunity for wetland conservation to benefit both people and wildlife and the potential gains when local societal traditions are assimilated. Protecting and improving catchments is a benefit for local biodiversity and catalyzing services for surrounding communities can result in clean water for irrigation, drinking, and recreation.

Jiaquan Catchment

A Public–Private Partnership in Longmen

Local Conditions

Within South China's Guangdong Province resides the Jiaquan catchment of Longmen County. In recent years, the catchment has become extremely important because it is located upstream of the Dongjiang River, a major source of drinking water for Hong Kong, Guangzhou, Shenzhen, Huizhou and other large cities.

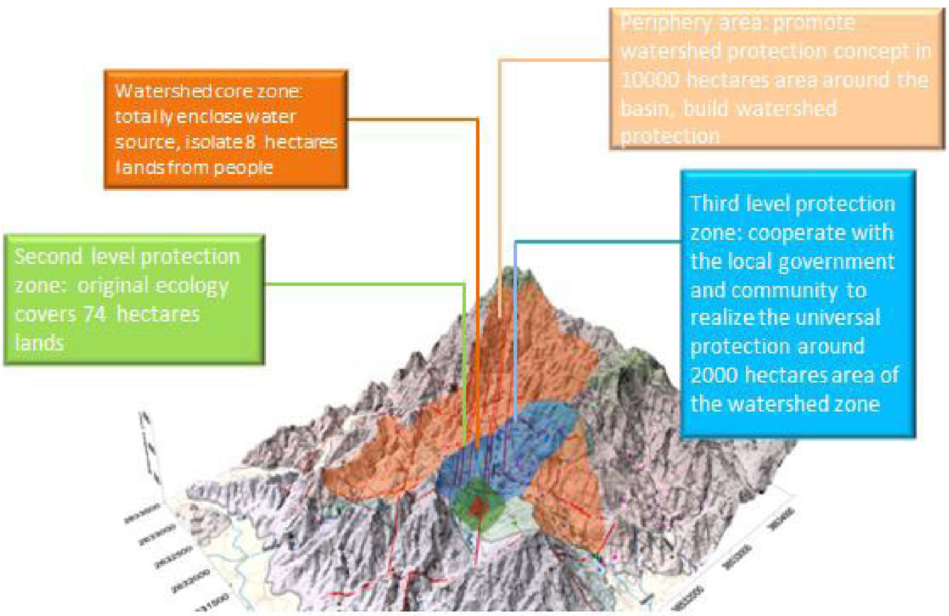
Action and Opportunity

Danone Waters China (DWC) is a subsidiary of the Danone Group, a global food and beverage company. In the late 2000s, DWC started to bottle Jiaquan water for its mineral water product. DWC is willing to be socially and environmentally responsible. With help from the International Union for Conservation of Nature (IUCN), Danone was able to identify the Longmen County Government as an unexpected ally in trying to build Longmen into an ecological area for the sake of its people and those downstream. Aligning with Danone's global strategies, IUCN worked with DWC and the local government in 2011 to establish a three-stage plan for restoring the Jiaquan catchment.

After receiving appropriate approval from Longmen County, Danone purchased one hectare of land around its local spring within the catchment and began implementing conservation practices and monitoring of water flow and quality. This enclosed management approach was the first step in their catchment restoration plan.

The second step of the restoration plan was the identification of a larger area of 12 hectares located around the original acre in which better agricultural and forestry practices could be implemented; particularly the practice of leasing land from farmers and converting it back to natural and native vegetation. The third and final level encompassed an even

Figure 1: The 2011 Longmen Jiaquan catchment protection strategy, a public–private partnership, 2015 (Danone)



greater area in which Danone collaborated with the local government, community and villagers to promote a transition to ecological agriculture. Helped by the IUCN, pilot projects were conducted to provide farmers with technological support, management guides and the ability to compare the impacts of chemical-dependent traditional agriculture with eco-farming practices. At the same time, Danone supported packaging and marketing their goods, making the famers' sustainable practices profitable. Under these protection methods, monthly samples of Jiaquan water have yet to report the presence of pollutants.

It is important to note that this approach to water protection and catchment restoration in the Jiaquan catchment initially found success because all of the stakeholders benefitted from it.

Desiring to ensure the quality of their products and the sustainability of their production process, Danone was motivated to provide the technical and financial support needed to see the project through. Longmen County Government, meanwhile, was eager to balance local economic development and outside political pressures with the value of achieving environmental quality. Forming a public-private partnership with the help of IUCN proved a perfect solution for both parties, while benefitting local farmers through employment and eco-agricultural technology gains and downstream users through improved water quality.

Figure 2: Original forests next to plantation forests in Longmen County, Guangdong, China 2011 (LI Jia / IUCN)

Longwu

A Milestone for China's Water Fund Model Implementation

Local Conditions

Figure 1: Longwu Reservoir, 2015 (Haijiang Zhang / TNC)

Longwu Reservoir is located northeast of Huanghu Town in the Yuhang District within China's Eastern province of Zhejiang. While the abundant manufacturing of goods is a major contributor to Zhejiang's booming economy, it's still commonly known as "the land of fish and rice", a reference to its thriving agricultural sector. However, as the province focuses more and more on development and urbanization, the increasing demand on its resources is becoming unsustainable and water supplies are at risk of overconsumption and degradation.

Figure 2: Longwu catchment areas indicating fertilized plots in red, 2015 (Dezhi Wang / TNC)

Originally sourced for irrigation in the 1970s, Longwu Reservoir is now primarily used to meet domestic needs, supplying drinking water to roughly 3,000 people near the villages of Qingshan and Cibi. With a total storage capacity of 354,400 cubic meters and a water supply capacity of 340 cubic meters per day, the reservoir is actually quite small. To protect urban water supplies in the province, Zhejiang government has begun investing in large to midsize reservoirs, but has overlooked smaller sources such as Longwu.

In July 2014, Beijing University of Agriculture released a water monitoring report that showed almost all of the reservoir's quality indicators (26 out of 29) met China's level I and level II standards. However, the total nitrogen, total phosphorus and dissolved oxygen fell into the country's level III and IV standards, and these three indicators alone reduces the overall water quality of the reservoir and threatens the drinking water supply.

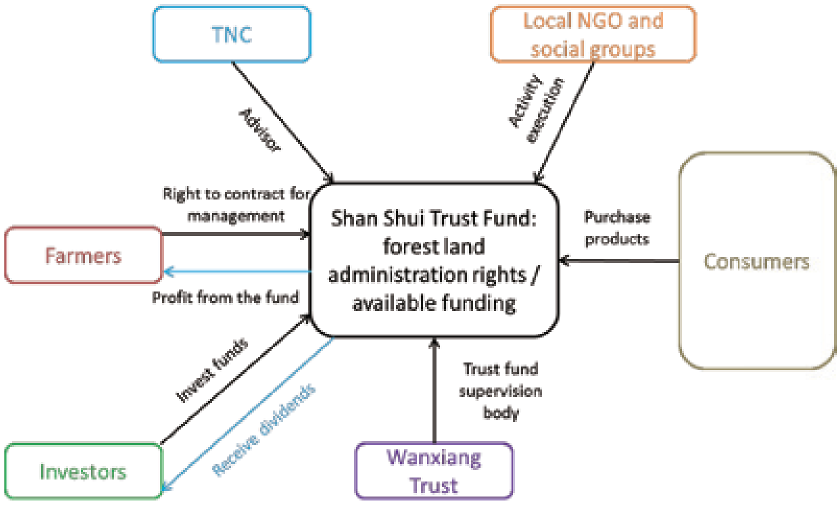
While no residents live within the catchment area of Longwu Reservoir, the bamboo industry covers 107 hectares or approximately 61 percent of the total catchment. Assessments found that the fertilizers and herbicides used on the bamboo were the major contributors causing the nutrient pollution.

Action and Opportunity

A 2014 field survey by The Nature Conservancy found that on average, farmers who used fertilizer on their bamboo plots earned CNY 23 in net profits per hectare, while non-fertilizer farmers earned CNY13.2 per hectare each year. Since income from the bamboo only contributes from 1- to 20-percent of their total income, farmers have relatively low dependency on bamboo, which contributes to the opportunity of providing an affordable compensation fee to grow eco-bamboo shoots instead. Household interviews also revealed that farmers are much more concerned about the quality of their drinking water and desire to get involved with water security practices.

In order to address the reservoir pollution and to secure safe drinking water for residents, the Conservancy began exploring opportunities to apply a new trust fund model of urban catchment management. In 2015, the Conservancy signed an agreement with Huanghu Town that allowed the government, local farmers, non-governmental organizations's and a trust company to collaborate and find a new business model to environmentally manage lands. The Longwu project was The Nature Conservancy China's first water fund to use the water trust fund model (Fig. 3).

Figure 3: The water trust fund structure of the Longwu project (Haijiang Zhang / TNC)



The Longwu project's aim is to eliminate non-point source pollution, solve the downstream residents'water security problem and explore the new trust fund model to manage the water source through conservation. By providing farmers with viable alternatives, such as eco-bamboo shoots and eco-experience tourism, the local bamboo industry can become sustainable. If this land trust project is successful in improving catchment management and reservoir quality it has the potential to extend into surrounding areas, or even be replicated in other basins around the world.

Ningbo

Finding the Right Opportunities for Water Security

Local Conditions

Ningbo is a historical and thriving city located south of the Yangtze River Delta in the eastern reaches of Zhejiang Province.[117] Its name literally translates to "serene waves" and alludes to its coastal position meeting the East China Sea. With a focus on economic prosperity in the last several decades, Ningbo has experienced rapid urbanization and expanding infrastructure alongside its ever growing industries of manufacturing and agriculture. From 2000 to 2010, the population increased at a rate of 27.56 percent, and by 2013 the city and its districts together exceeded 10 million people.[118] The GDP of Ningbo is close to CNY 712.89 billion; per capita, an average that is three times that of the national GDP per capita average.

The city has been undergoing two major changes over the last few decades. It has witnessed an increasing scale of population growth and land use. And it has seen transformation from primary and secondary industries (agriculture and manufacturing) to secondary and tertiary industries (the service sector).[119] Today, Ningbo's port is one of the busiest in the world. But such development has dramatically reduced and degraded the region's resources, jeopardizing its sources of clean water.

Ningbo's freshwater sources include groundwater, the Yao River, the Fenghua River and the Yong River. Even though total precipitation is abundant in the Ningbo area during the monsoon season (May to September), annual surface runoff is around 7.336 billion cubic meters and the available water per person is relatively low.[120] At only 1,260 cubic meters, Ningbo's average per capita water use is one-sixth of the world's per capita average and 1,700 cubic meters lower than the global water shortage middle red-line level.[121] The city has become aware of its water shortage and quality risks and is beginning to take strides in the right direction.

Figure 1: Ningbo’s coastal location in southeast

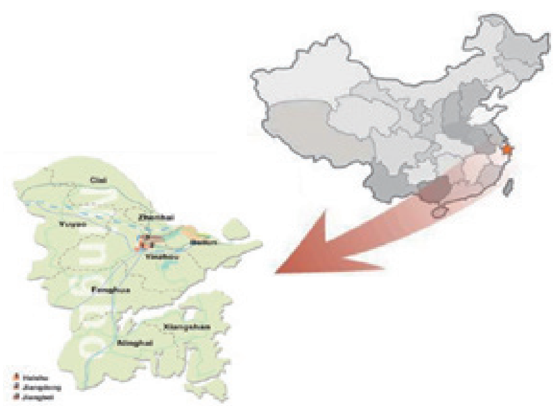
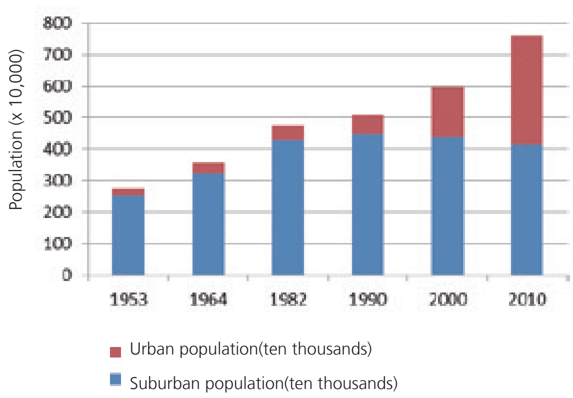


Figure 2: Ningbo Census 1953–2010 (National Bureau of Statistics of China, 2011)



Action and Opportunity

As a first step to solving the water crisis, Ningbo adopted a strategy that supplies water according to quality and type of user. The water supply for drinking water was transferred to large to midsized reservoirs as a collective source.

Ningbo municipal government is now cooperating with Xinchang County to invest CNY 2.688 billion in an additional reservoir called Qincun. Once dam construction is completed, water will be transferred through tunnels to Ningbo's Tingxia Reservoir, which can supply an average 126 million cubic meters of high quality water to the urban districts.[122] Suppling water to different users by quality, and constructing a new reservoir, is expected to only help meet the projected demand to 2020. Thus, a new focus is being placed on improving agricultural practices around Ningbo's existing catchments in an effort to reduce the amount of fertilizers, herbicides and pesticides polluting freshwater sources. Ningbo's municipal government has already moved forward with:

- A new policy implementing a new system of water treatment that addresses five core concerns (sewage, flood, water-logging, water supply and water saving). This new approach requires all related government departments to work together, but distinguishes leadership through the river segment responsibility policy. The government published the Ningbo Drinking Water Protection and Pollution Prevention Method publication, the Drinking Water Source Emergency Contingency Plan, and the Ningbo Farmers Drinking Water Project Long-term Operation and Management Appraisal Plan (draft).[123]

- Catchment protection, completing the Ningbo Water Resource General Plan, the Ningbo Drinking Water Source Environmental Protection Plan, and the integrated ecological protection red-line and revised Ningbo Urban Development Plan (2006-2020).[124]

- Conservation funding, exploring the ecological compensation mechanism and, in 2004, piloting its first ecological forest project. Since then, the local government has actively promoted the benefits of ecological wetland systems, small and clean catchments, soil and water conservation projects, etc. The total investment in water source conservation is about CNY 80 million.[125]

Because water consumption and required treatment is much greater in primary and secondary industries, a continued transition to tertiary industries could also be an effective way to ease water demand and reduce the pressures pollution causes.

Improvements in the urban catchments have been observed in recent years, but pollution sources from industry as well as rural agricultural and domestic waste still need to be addressed. Implementing water funds will likely be a future mechanism because of the ability to connect city planners and government with rural upstream users. Urban residents, social organizations, corporations and industries are all stakeholders that stand to receive ecological benefits from investing in healthier ecosystems. By contributing to a water fund, such practices as natural habitat restoration, organic farming and forest compensation to farmers can continue improving the quality and quantity of Ningbo's water sources.

Qingdao

Balancing Water Sources

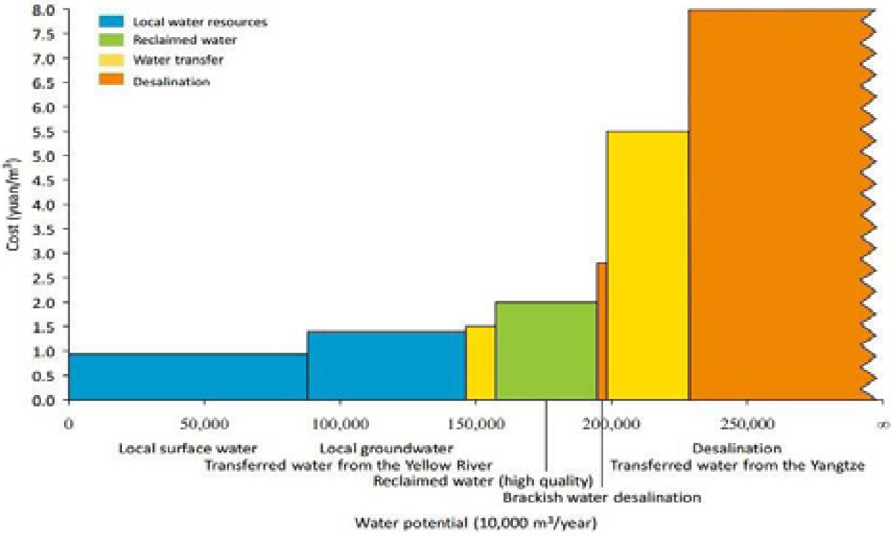
Local Conditions

The coastal city of Qingdao resides on the Jiaodong Peninsula of northeast China. While it is the largest industrial city and economic center within the Shandong Province, Qingdao naturally lacks sufficient freshwater supplies to accommodate the needs of its 8.71 million people. In 2010, the GDP per capita was CNY 75,763, an equivalent 2.2 times above that of the country's average. But while the strong economy financially benefits the local people, the limited availability of water allows only an average per capita use of 313 cubic meters a year; a mere 12 percent of the national average per capita water use. Even though the amount consumed by local residents is notably low, it unfortunately still exceeds the city's supply capacity of 171 cubic meters per capita — an amount similar to the Middle Eastern country of Jordan.[126] About 40 percent of local water resources are exploited for city water use while the demand continues to rise, exceeding 1 billion cubic meters.[127]

Action and Opportunity

Protecting surface water quality and quantity in Qingdao has been important to the city's survival since the late 20th century. Its most important local water source is the Dagu River, the largest river on the Jiaodong Peninsula, which includes a catchment accounting for 78 percent of Qingdao's total drainage area. The city built two large reservoirs, Chanzhi and Yinfu, to provide Qingdao with a main source of surface water. However, protecting this supply alone is neither sufficient nor sustainable enough to meet the city's growing needs. In order to acquire enough fresh water to meet demand, Qingdao has begun utilizing other tactics, such as building desalination plants,long-distance inter-basin transfers and reclamation of wastewater. Given that each water allocation method will simultaneously have a direct impact on energy consumption and greenhouse gas emissions, finding the right source balance is an important step toward minimizing both cost and pollution.

Figure 1: Energy Requirements for Water Production for Qingdao (Wen,Zhong,Fu and Spooner, 2014)



According to the World Resources Institute's (WRI) water costs assessment report, using local surface water is the most cost effective method to provide water, especially when compared to a desalination plant requiring almost 10 times the energy.[128] Since most of China's power derives from burning coal, maximizing efforts at its desalination plant would increase Qingdao's greenhouse gas emissions by 80 percent per cubic meter of water produced.[129] Thus, the more water supplied by local surface reservoirs, the lower the energy and pollution costs. Protecting the quality and quantity of local surface water will not only help ensure water security, it also contributes to a cleaner water supply at the same time as it saves costs through reduced energy needs, which in turn reduces greenhouse gas emissions.

Qingdao's case thus suggests that the effectiveness of environmental protection in securing a city's drinking water supply is actually quite conditional. Catchment conservation is not a universal solution for all places, and cities such as Qingdao need to look at local conditions and natural resources in order to find the right solutions. It is no doubt necessary to systematically screen which cities are particularly appropriate for water funds and which ones need alternative mechanisms. In addition to creating reservoirs, Qingdao had to find alternative freshwater sources to balance cost efficiency and environmental health. Four lessons in particular can serve other cities:

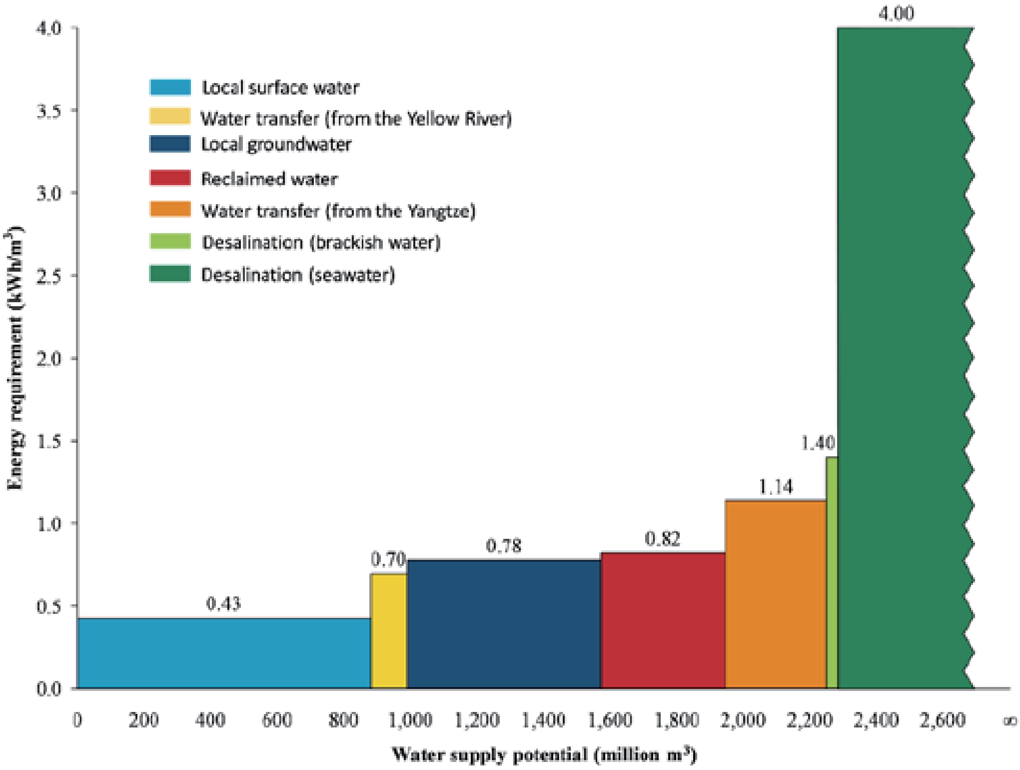
- Local water sources are often the most cost effective and least energy intensive water source.[130]

- Protecting local water sources can help cities avoid major capital costs and pollution.

- As population grows, cities will nevertheless need to diversify their water supply.

- When considering new water sources, a comparison of the full costs, including pollution and energy, can help cities find the right balance to secure water at lower financial and environmental costs.

Figure 2: Cost of water production via various sources in Qingdao (Wen,Zhong,Fu and Spooner, 2014)



METHODOLOGY

City Water Map

City selection

This study builds upon The Nature Conservancy's previous work characterizing water risks and opportunities for cities around the world.[131] Previously, the Conservancy collected information on water supply sources for more than 500 cities, including 18 cities in China. For the current study, we focused on some of the fastest growing and largest cities in China.

Large cities were defined as cities with populations greater than 2 million people, as estimated within the McKinsey Global Institute (MGI) Cityscope database.[132] Within this set we identified 30 showing the fastest growth, as determined by projected GDP growth between 2010 and 2025 (again using the MGI Cityscope database). This list included all 18 Chinese cities within our existing data set and thus represented the addition of 12 cities (Table 1). Not all cities had easily obtainable data, however, and if it was not possible to find adequate information on water supply for a given city, we moved to the next city on our list.

Table 1. List of cities surveyed within our data set.

Surveyed Chinese cities	
Beijing*	Kunming*
Changchun*	Nanjing*
Changsha	Ningbo
Changzhou	Qingdao*
Chengdu*	Shanghai*
Chongqing*	Shenyang
Dalian*	Shenzhen*
Dongguan*	Suzhou
Fozhou	Tianjin*
Guangzhou*	Wuhan*
Hangzhou	Wuxi
Harbin*	Xiamen
Hefei	Xi'an*
HongKong*	Xuzhou
Jinan	Zhengzhou*

Cities marked with an “” also were included in the previously published Urban Water Blueprint report.*

As has been noted elsewhere, defining the boundaries for cities within China is uniquely challenging, with varying administrative definitions having evolved over time.[133] This ambiguity can result in inconsistencies and incompatibilities among differing data sources. To the best of our ability, efforts to collect data on urban water supply sources focused on main urban districts and new development districts for a given municipal- or prefecture-level city. We excluded from our analysis rural counties administered by cities.

Intake data collection

For each city in our sample we consulted a variety of data sources to collect information about water supplies (Table 2). Where possible we utilized official government or water utility publications as primary data sources. When such data sources were not readily accessible or provided incomplete data other sources were consulted, including personal communications, academic literature, periodicals and general internet searches. Additionally, the collected data was typically compared against multiple sources as further verification. Information on source names, source types and suppliers were, in general, readily identified. Other information, including intake coordinates and diversion volumes, were more difficult to establish. In some cases, we had to use data sources of lower certainty, such as the website of the water utility or official press releases, which often listed water sources. Once the place names of water sources were identified, we geo-located the sources. Unique place names were identified using Google Earth or other geographical atlases. In some cases, a text description of a source (e.g., "three miles upstream of the city along the same river that flows through the city") was mapped in a geographical information system (ArcGIS 10.2).

Table 2. Primary data collected for each city, source and supplier

City	Water source	Supplier
Name Coordinates of city center Utilities served by	Name Source type Annual diversion volume by source Approx. coordinates of source intake points	Name Water source(s) Annual diversion volume by source

The resultant data was merged with an existing database of city water sources and associated attributes, termed the City Water Map (CWM). The CWM is a relational database with hierarchical structure, allowing for the complexity of connections between cities, sources and suppliers. For example, utilities often rely on one or more water diversions, potentially supplying water to one or more cities.

Defining contributing areas

Our analysis focused on surface water sources and, unless otherwise noted, all of our calculations concerned surface water sources. We also accounted for the fraction of water that comes from other sources (e.g., groundwater, desalination) in our risk and opportunity metrics. We included so-called alluvial groundwater sources in this set of surface withdrawal points to acknowledge the water is primarily surface water pulled through a river bank, primarily as a means of cleaning the water (bank filtration). The locations of surface freshwater withdrawal points were adjusted ("snapped") to match the underlying hydrographic river system; in this case these are represented by the global high resolution hydrographic dataset HydroSHEDS.[134] If the snapping adjustment step is not performed small spatial errors in the location of a point could lead to large errors in the estimation of the available water. First, we selected withdrawal points within 10 kilometers of the coast and manually adjusted their location to ensure that, in the underlying hydrographic system, they were not falling on areas that are considered saline water. Second, for withdrawal points on lakes we adjusted the location to be at the outflow of the lake, defined as the lowest point of the lake feature in a global database of lakes, reservoirs and wetlands (GLWD).[135] This correction allowed the catchment of the lake and its corresponding water availability to be correctly derived. Finally, using the Snap Pour Point command in ArcGIS, we adjusted the location of withdrawal up to five cells (2.5 kilometers) to match the point of greatest flow accumulation.

Water quality

Pollutants

We focused our analysis of surface water quality on two types of pollutants often of concern to water utility managers: sediment and phosphorus (P). While other types of pollutants are also quite important for water managers (e.g., fecal coliform contamination) these two pollutants are most often targeted by the kind of conservation activities considered in this report.

In our previous study, we considered both nitrogen (N) and phosphorus (P) pollution loading in catchments.[136] In practice, we find that estimated loadings of N and P are highly correlated. Accordingly, for the sake of brevity and clarity, in this report we refer to P alone when considering nutrient pollution loading. Our results would look similar if we reported values for N.

Sediment model

Global sediment loading was estimated using a modified version of the Universal Soil Loss Equation: Sediment Load = RKLSCP.

The R-factor is rainfall erosivity, and a global map of this factor for current climate was obtained from the website climatewizard.org. The K-factor is soil erodibility, which was estimated by converting the soil texture values found in the Harmonized World Soils Database to K values using the methodology of Roose.[137] The LS-factor is the slope-length, and it was estimated using the HydroSHEDS 15 arc-second DEM using a methodology similar to that of the Sediment Retention Model of the Natural Capital Project.[138] The crop and practice (CP) factors relate to land cover and land use practices, and average values for different land use types were taken from the STEPL model and the Water Treatment Model.[139] For land cover, we utilized the China 1:250,000 Land Cover Remote Sensing Investigation and Monitoring Database for the year 2005 produced by Data Sharing Infrastructure of Earth System Science.[140] Land cover classes were reclassified into six categories: Agricultural, Grassland/Pasture, Forest, Barren, Urban, and Water/Other.

To estimate sediment loading at the catchment scale, we used similarly estimated source loadings in the United States compared against the SPARROW dataset, an empirically based estimate of loading calculated from thousands of direct stream measurements.[141] Correlations between our loading estimates and those in the SPARROW dataset were generally strong (R ~0.8). We calibrated our results in China to the SPARROW estimates using a log-log linear regression. All results shown in this report are for the calibrated sediment loading calculations.

Nutrient model

Phosphorus loading was estimated using an export coefficient approach, in which each land cover type exports a certain amount of P from the pixel. For forest, barren, urban, and water/other, the export coefficient was constant, using average values for different land cover types taken from the STEPL model and the Water Treatment Model. For agriculture and grassland/pasture, we based P export on the global grids of the Global Fertilizer and Manure (GFD), Version 1, dataset.[142] Agricultural land was assumed to have both manure and fertilizer applied at the rates specified by the GFD, while grassland/pasture was assumed to have only manure applied at the rates specified by the GFD. The nutrient utilization efficiency (NUE, the fraction taken up by plants or soil, and not exported) was estimated using continent level data in NUE taken from Bouwman et al.[143]

As with sediment, to estimate P loading at the catchment scale, we used similarly estimated source catchment loadings in the United States compared against the SPARROW dataset. Correlations between our loading estimates and those in the SPARROW dataset were generally strong (R~0.8). We calibrated our results to the SPARROW estimates using a log-log linear regression. All results shown in this report are for the calibrated P loading calculations.

Water quality risk metrics

Our metrics of surface water quality risk are sediment yield (tonnes/km^2) and P yield (kg/km^2), which is loading relative to catchment area. Pollutant yield can be easily calculated with the available 15 arc-second resolution models we constructed of sediment and P loading, as well as the upstream contributing area for each source as defined on the HydroSHEDS DEM.

For our analysis of the opportunity of source catchment conservation to reduce pollutants, we use information on changes in pollutant load in our calculation. Pollutant concentration, which is what most often economically impacts Operations and Maintenance (O&M) costs of water treatment plants (WTPs), is calculated as:

$$Concentration = \frac{Load}{Flow}$$

Note that in this study we are considering how changes in pollutant loading in one catchment will affect water quality. Assuming the effect of the conservation activity on flow is negligible, the proportional change in pollutant loading is the same as the proportional change in concentration because the flow terms cancel out:

$$\triangle Concentration = \frac{Load_{after}}{Flow} \div \frac{Load_{before}}{Flow}$$

Water quality opportunity metrics

We developed four water quality opportunity metrics, each intended to represent a commonly used category of source catchment protection measures. Additional descriptions of these conservation activities is provided in the box below (Box 1) and in Chapter 3 of this report.

Box 1. Description of the four representative conservation practices evaluated

OVERVIEW OF CONSERVATION PRACTICES

Forest protection involves designating natural habitat as protected from development or other human land uses that would convert the natural habitat to other land covers. This report focuses on forest protection, although other natural habitat types can also be important to protect in different contexts. Forest protection can involve fee-simple purchase of the land from its owners, the purchase of just the development rights in countries that allow such conservation easements, or the direct designation of land as protected by governments using the power of eminent domain. Note that forest protection removes a future risk of increased sediment or nutrient transport, rather than reducing current annual loading of pollutants.

Reforestation involves enabling areas that are currently cleared to revert to forest, either through natural regeneration or through tree planting. In this report we focus only on reforestation of pastureland, assuming that cropland is too economically important to be reforested at a large scale. We also look only at reforestation in areas where forest is the natural land cover. Reforestation reduces sediment and nutrient transport by stabilizing soil, but it also reduces nutrient transport by eliminating the deposition of manure and fertilizer to pastureland.

Agricultural best management practices (BMPs) are changes in agricultural land management that can be aimed at several positive environmental outcomes. This report discusses BMPs on croplands, specifically those focused on reducing erosion and nutrient runoff. A wide variety of cropland BMPs exist. Our calculations are based upon average effectiveness values for the use of cover crops outside the growing season, as this type of BMP is widely used and applicable in many different types of cropland. We emphasize, however, that our results would likely be similar if we considered other cropland BMPs that were aimed at reducing erosion or nutrient runoff.

Riparian restoration, also called riparian buffers, involves restoring natural habitat within a small strip on either side of a river or stream. In this report we focus on the installation of riparian restoration on agricultural lands, where the buffers can play an important role in filtering runoff from the agricultural field, preventing sediment and nutrients from reaching the riparian area itself.

Each water quality opportunity metric had a similar structure. The average effectiveness of the practice in preventing sediment and P loading was quantified through a literature review (See Table 3). This literature also shed light on where each practice could be effectively implemented. In a GIS system, we examined all pixels where a practice could be implemented, quantifying the reduction in sediment and P from applying the practice on one hectare of land. Pollutant loading for a source catchment is just the sum of the individual loads from specific pixels. Table 3 describes the approach for modeling these practices in greater detail.

Table 3. Parameters used in calculation of opportunity metrics.

Practice	Area where applicable	Percent reduction in sediment or phosphorus	Citations
Forest protection	Currently forest pixels that are in their natural area, as defined in WWF ecoregions.	The expected increase in pollutant load, defined as the probability of habitat loss multiplied by the change in pollutant load if that occurs. Probability of natural habitat loss without action calculated as biome averages based on 10 year forest loss rates. If that loss occurs, then changes calculated as follows: •Sediment: Change in CP factor from natural land cover to agricultural or pasture •Nitrogen and phosphorus: Change in export from natural land cover to agricultural or pasture	Percent forest loss calculated as loss-only of tree cover extent area between 2000-2014 using the Global Forest Change data set. [144] See citations above for CP factors.
Reforestation	Currently grassland/ pasture pixels that are in natural forested area, as defined in WWF ecoregions.	Sediment: Change in CP factor from grassland to forest. Nitrogen and phosphorus: Change in export from grassland to forest	See citations above for CP factors.
Agricultural BMPs	All agricultural pixels.	Sediment: 72 percent reduction. Phosphorus: 77 percent reduction.	See citations above for CP factors.[145]
Riparian restoration	Agriculture pixels along riparian corridors, as defined with the HydroSHEDS DEM.	Buffers are assumed to be 10 meters on either side of a stream or river. The upland contributing area of a given stream segment is assumed to be one 15 arc-second cell. Sediment: 86 percent reduction. Phosphorus: 71.9 percent reduction.	Based on average results for implementing 10 meter buffer.[146]

Each source catchment contains multiple pixels, so there are multiple places where a practice could be performed. The median or average return on investment from a practice in a catchment may not be the most meaningful metric since conservation action will likely focus on sites where it will yield the greatest return. We calculated the area that would need to be worked on to achieve a nominal 10 percent reduction in each pollutant, assuming conservationist action started at the pixels with the highest return.

Note that in some cases, it is not possible to get to a 10 percent reduction in a pollutant using a specific activity. For instance, if there is not much pastureland in a catchment where it is possible to do reforestation then this conservation activity may be unable to reduce sediment load by 10 percent. We have omitted these catchments from summary values.

Note also that forest protection reduces a future risk of increased sediment or nutrient loading (rather than reducing current pollution loading, as would be the case in the other three practices). For this activity, we calculated the amount of land on which the activity would need to be conducted to reduce future pollutant loading by 10 percent, where future loading is defined as the current baseline pollutant load plus the expected future increase in loading over a 10-year period.

Focus on comparatively smaller catchments

For our results on risks and opportunities (Chapters 2 and 3, respectively), we have restricted our analysis to catchments of relatively smaller land area and to cities significantly dependent on these smaller surface water sources. As explained in Chapter 1, conservation practices are most likely to be effective in catchments where the scale of implementation is most feasible. In general, such feasibility is closely associated with the amount of absolute pollution reduction required — or in terms of implementation, the total area of conservation required — in order to achieve the same reduction in pollutant concentration. For example, all other factors being equal, a 10 percent reduction in sediment pollution loading would require a considerably greater area of conservation for a basin the size of the greater Yangtze (180 million hectares) versus one at the scale of the Miyun Reservoir catchment (approximately 1.5 million hectares).

Smaller catchments are defined as those less than 10 million hectares in area. We selected this threshold based on literature review of user-pay payment for watershed service schemes, we found no examples greater than 10 million hectares. Cities that are significantly dependent on smaller surface water sources are defined as those cities sourcing at least one quarter (25 percent) of total supply from these smaller catchments (relative to surface water and all other sources combined). From our original list of water sources for the fastest growing cities (see Chapter 1), 110 of 135 catchments are smaller catchments, with 24 of 30 cities significantly dependent upon these smaller catchments for their overall water supply.

Aggregating city−level data

For this report, the fundamental unit of analysis is the city level. In order to conduct analysis at this level, attribute information collected at the level of a water diversion point had to be aggregated to the city level. For any attribute collected at the water diversion level, the aggregate city-level value was calculated as the volume-weighted average of all diversions that supply that city.

As discussed previously, for water quality opportunity metrics we only considered smaller catchments in which a given conservation practice could achieve a 10 percent reduction in sediment or P pollution. At the city level we further restricted our results to those catchments that account for at least one quarter (25 percent) of a city's total water supply. Then we only displayed opportunity results if the conservation activity could achieve a 10 percent pollution reduction for at least one quarter of a city's total withdrawals.

For certain city-level metrics (e.g., the total area of conservation required for a city), we further aggregated opportunity results across applicable conservation practices for each pollutant type. In these cases we presented median values in order to represent the range of volume-weighted averages for a given city. For results that further combine sediment and P values, the presented totals are the sum of median values for both sediment and P. For example, the median area required for conservation activities for a given city might be 30,000 hectares for sediment and 40,000 hectares for P. We estimated the total area of conservation by taking the simple sum of these component values, which in this example would equal 70,000 hectares. The assumption here is that conservation activities for sediment and P would take place on separate areas of the landscape, thus the presented aggregate totals can be considered conservative estimates of conservation potential.

Comparing costs to water quality

Estimating O&M costs

As described previously in greater detail, we collected information on treatment technologies used by water treatment plants (WTPs) for about 100 cities in the United States and about 30 international cities.[147] We collected information on about 500 WTPs, including more than 30 fields documenting the presence or absence of specific treatment processes, as well as information on the quantity of water treatment. For the U.S. cities only we have reported information from utilities on water treatment costs (O&M). WTPs were classified into seven treatment-type categories based on those in Kawamura and McGiveney.[148] O&M costs were estimated following Kawamura and McGiveney for all 500 WTPs in our sample, based on the size of the plant, the treatment category, and the presence of any additional processing steps. All costs were standardized to 2007 USD, using the ENR Construction Cost Index (ENR-CCI).

For our sample of water sources in China, we had information on treatment technology only for a subset of diversions and WTPs. For consistency across sources and cities, the O&M costs presented here assume conventional treatment technology using cost estimates derived as described above. We further assume that each diversion point is processed by a separate treatment plant, thus potentially overestimating treatment costs by underestimating economies of scale for bulk treatment that might combine two or more sources.

Comparing treatment costs to water quality

Also described previously,[149] O&M costs were compared with sediment and phosphorus (P) yield estimates from our global models. For a more detailed discussion, see Appendix B and C of the Urban Water Blueprint.

In brief, sediment and phosphorus yields were compared with data collected on reported O&M costs for water treatment plants for more than 100 cities in the United States. For the subset of water treatment plants with predominantly surface water sources, higher sediment yield was associated with higher treatment costs. A 10 percent reduction in sediment was found to be associated with a 2.6 percent average reduction in O&M costs. This estimate does not include the cost of dredging large reservoirs outside the water treatment plant, which can be substantial. For instance, Crowder estimated the decreased reservoir capacity in the United States due to sedimentation cost between $597 million and $819 million in 1987. Nutrient yield (P) was also compared to O&M costs.[150] Plants that draw water from low nutrient sources have treatment costs that are lower than water treatment plants that draw water from high nutrient sources. On average, a 10 percent decrease in nutrient pollution is associated with a 1.9 percent decrease in costs.

Estimating implementation costs

The costs of conservation were estimated using local data sources and derived from existing conservation or PES programs, where possible. Costs and references for the four conservation practices analyzed in this report, and descriptions of how they were calculated, are specified below (see Table 4). Unless otherwise noted, all costs are presented as USD per hectare per year.

Table 4. Implementation costs of conservation action assumed in our analysis, based upon a literature review.

Conservation Practice	Cost per ha (USD/year)	Reference
Agricultural Best Management Practices	$202	United States National Resources Conservation Service[151]
Forest Protection	$27	China Forestry Statistical Yearbook, the Natural Forest Protection Project (2011-2013)[152]
Forest Protection (Forest and Riparian)	$273	National Development and Reform Commission (2014), China Forestry Statistical Yearbook (2011-2013)[153]

Agricultural Best Management Practices

As described above in Box 1, agricultural best management practices (BMPs) are changes in agricultural land management that can be directed towards several positive environmental outcomes.

The costs associated with implementing agricultural BMPs were derived from several studies conducted by the United States National Resources Conservation Service (NRCS) in selected regions of the United States.[154] A cost per hectare (ha) value ($202) was calculated by determining the average cost across these studies, all of which were in US dollars.

Forest Protection

The cost of forest protection in China was derived directly from the China Forestry Statistical Yearbook (Yearbook).[155] Specifically, an average cost per hectare ($27) was calculated from the data provided for 2009-2011 by dividing the total costs by the total area for each year, and then subsequently taking the average of those resultant costs. The cost data provided in the Yearbook was aggregated into the following four categories for conceptual purposes (Figure 1): administration, maintenance, capital expenditure, and compensation.[i] For the period 2011-2013, the total average cost of forest protection was $3,299,000,000 (USD/year), while the total average area was 122,500,000 hectares.

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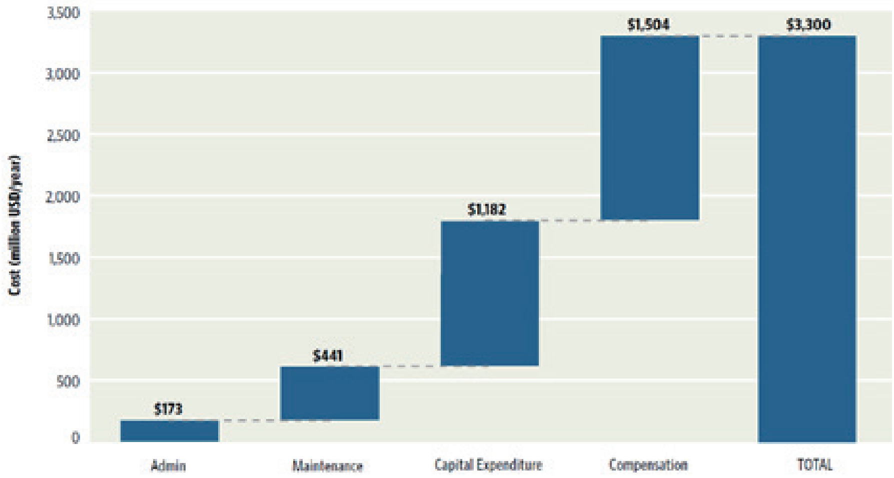
[i] Categories further defined as follows:

- Administration includes costs that are not directly related to the implementation or maintenance of Forest Protection (i.e. 'other').
- Maintenance includes costs that are related to the upkeep and servicing of Forest Protection.
- Capital Expenditure includes costs that are related to the management of Forest Protection operations, reserve resources, and public welfare forests.
- Compensation includes costs that are related to the remuneration of affected parties, including ecological, social, and political compensation.

Figure 1. Component and total average cost of forest protection in China (China Forestry Statistical Yearbook)[156]



Reforestation and Riparian Restoration

The cost of restoration was derived from a policy announced by the National Development and Reform Commission (NDRC) in 2014.[157] This policy intends to facilitate a more unified approach to forest management that permits all forest categories to share the same subsidy system. The policy specifies that a total compensation of 1,500 CNY/mu over a 5-year period will be provided for restoration projects, including an income subsidy of 1,200 CNY and a seeding subsidy of 300 CNY. Accordingly, restoration costs were calculated by aggregating the total cost of this policy over 5 years ($3,530 USD/ha) with the total cost of implementing forest protection for the subsequent 25 years ($674 USD/ha, based on 25 years of the annual cost data specified for Forest Protection). Finally, total cost was annualized over a 30-year period at an interest rate of 5 percent. The resultant cost per hectare used in this analysis is $273 (USD/year).

Return on investment

Calculation of a return on investment (ROI) requires information on both the value of benefits for the water utility and the costs of doing conservation. The value of utility benefits are assumed to be equal to O&M costs for achieving a 10 percent reduction in sediment or P (see Estimating O&M costs). Costs of conservation are estimated as described above (see Estimating implementation costs). ROI is just the ratio of benefits for the water utility relative to the costs of conservation activities.

Note that this is a rough approximation of ROI, and should only be used for screening purposes. Detailed planning with a city's water utility will be needed to more fully evaluate the ROI of conservation investment. Note also that this is a city-level average ranking. Many cities use more than one source watershed, and individual source catchments may have high investment potential even if the overall city ranking is low.

We also wish to stress that this estimate of ROI only accounts for one particular way that increased raw water quality can save a utility money — through decreased water treatment costs alone. There are other potential cost savings, such as avoided capital spending or avoided dredging costs for a reservoir. In addition, other stakeholders and sectors in the basin might benefit from better raw water quality. For example, hydroelectric power production may be more efficient, with less sedimentation and thus more storage behind a dam.

Additional Catchment Parameters

In addition to water quality metrics, we use other data to characterize both the challenges and opportunities for catchment conservation.

Water quantity risk

We assessed annual water quantity risk for our sample of cities using the approach previously described.[158] At the catchment level, we used the ratio of water use to water availability as estimated from the global hydrologic model WaterGAP.[159] Any value greater than 0.4 is considered water stressed. Many other surface water analyses have used a threshold of 0.4. (See the discussion in Vörösmarty, et al., for more detail on the history and use of this threshold.[160]) We aggregated these water stress values at the city level using the approach previously described.

Land use

For information about land cover and land use we utilized the same data set as that used for our sediment model, which represents land cover for the year 200.[161] We further adopted the same land cover classes previously described (Agricultural, Grassland/Pasture, Forest, Barren, Urban, and Water/Other).

Socioeconomic data

City population figures are derived from estimates for the corresponding urban agglomerations within the UN World Urbanization Prospects database.[162] To estimate economic activity we used the McKinsey Global Institute's (MGI) Cityscope database, as described previously (see City selection). The MGI database estimates GDP for the urban areas of cities. This distinction is important since the administrative boundaries of a given city often include both urban and rural areas. Current and future Gross Domestic Product (GDP) for each city are estimated using a proprietary econometric model. MGI provides a more detailed discussion of their approach in the report "Preparing for China's Urban Billion."[163]

At the catchment level, we used national, spatially-explicit data sets on population and GDP for the year 2010.[164,165] These data sets were produced by the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) as 1 kilometer grids based on national census statistics. GDP figures were converted to 2010 U.S. dollars using the annual exchange rate from the World Development Indicators database.[166]

Biodiversity data

Given the paucity of accessible, comprehensive, and spatially-explicit data on species distribution in China, we evaluated the potential significance of water risks and catchment conservation for biodiversity using several global datasets. For terrestrial biodiversity, we utilized the WildFinder database developed by the World Wide Fund for Conservation (WWF) which includes information on the ecoregional distribution of four main taxa (mammals, amphibians, reptiles and birds).[167] We also reference Alliance for Zero Extinction (AZE) sites for imminently threatened species.[168] For aquatic biodiversity, we used the Freshwater Ecoregions of the World (FEOW) database developed by a broad consortium of organizations and individuals including WWF and TNC.[169]

For biodiversity data at the scale of ecoregions (WildFinder and FEOW), we inferred potential species significance through simple overlay analyses. It is important to note that both eco-region biodiversity data and catchment conservation data cannot be used to infer results at sub-unit scales. For ecoregional data, the actual distribution of species or habitat ranges within an ecoregion are unknown. Similarly, for catchment conservation data, the actual activity locations for a given conservation practice type are not known. In those cases the overlay of ecoregion and catchment data can be used to infer potential synergies, but such inferences are not definitive. For example, the ray-finned Cyprinus longzhouensis is believed to be endemic to the Xi Yiang ecoregion of Southeastern China. While conservation practices in Foshan water supply catchments within this ecoregion could potentially help support improved water quality conditions for longzhouensis, we cannot determine this definitively without having data on both biodiversity and conservation practices at the stream reach level. The biodiversity results presented here are intended to characterize potential rather than predicted benefits.

In addition to ecoregion and species data, we also overlaid catchments with the biodiversity priority areas identified through the China National Biodiversity Conservation Strategy and Action Plan (2011-2030).[170] These priority areas include both terrestrial and freshwater biodiversity considerations. To infer terrestrial biodiversity benefits, we overlaid the boundaries for these 32 priority areas with water supply catchments to assess areas of intersection. To infer freshwater biodiversity benefits, we additionally quantify total stream network length within these intersecting areas using the HydroSHEDS data set.

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