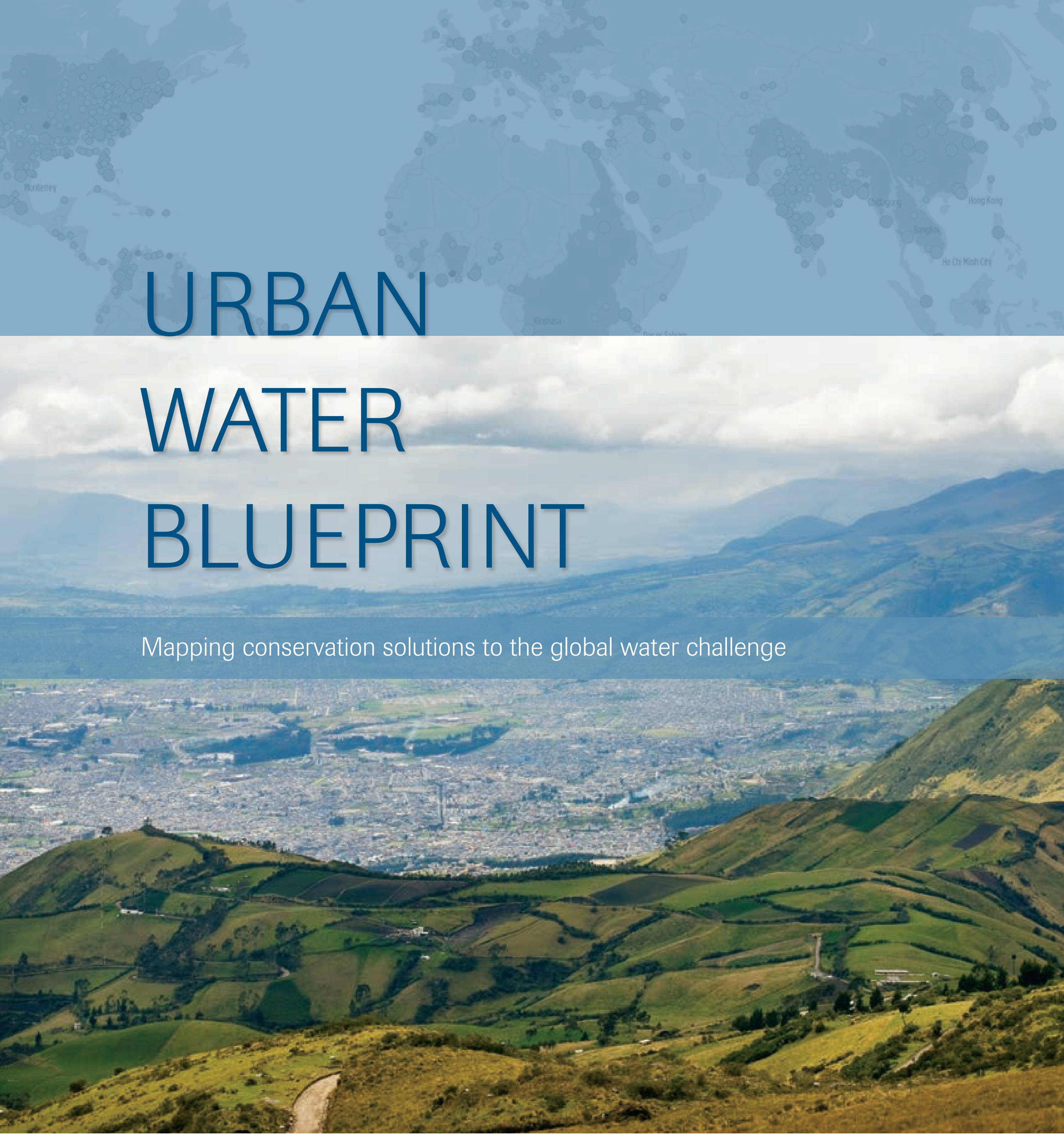

URBAN WATER BLUEPRINT

Mapping conservation solutions to the global water challenge

The Nature Conservancy
Protecting nature. Preserving life.

In partnership with

C40 CITIES
CLIMATE LEADERSHIP GROUP

IWA
the international water association

700,000,000

Conservation strategies can measurably improve the quality of water sources serving more than 700 million people living in the 100 largest cities.

Photo: ©Mark Godfrey

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Photo: ©Scott Warren

1 in 4

One in four cities would see a positive return on investment from investing in watershed conservation.

Photo: ©Scott Warren

FOREWORD

This report addresses a critical issue facing mayors in cities around the world: access to clean and adequate water supplies. The growth of urban populations, coupled with incidences of sudden climate stress and long-term land degradation of drinking watersheds, pose increasing risks to urban water supply with serious implications for the future health and well-being of urban residents. Without water, cities cannot thrive.

The pages to follow show us that one in four of the world's largest cities, representing more than 800 million people, are currently water stressed[1] and many more face scarcity in terms of water quality. And C40's own research tells us that 98 percent of our global network of megacities report that the current or anticipated effects of climate change present significant risks to their city.

In response, mayors are investing in infrastructure and delivering a range of policies, projects and programs to secure clean water for their citizens. But there are significant, creative and untapped opportunities for further action to conserve drinking water sources, which often lie outside the jurisdictional boundaries of local governments.

Through case studies representing five proven strategies to watershed conservation — protecting both the quantity and quality of urban water supplies — this report demonstrates that investment in natural infrastructure to preserve drinking watersheds is both an economically viable and environmentally sound approach available to developed and developing cities alike.

I am proud that C40 has partnered with The Nature Conservancy in cooperation with the International Water Association, bringing our own database of findings to the table, to produce this seminal piece of research. In doing so, we are highlighting solutions that can be shared and implemented more broadly by cities around the world.

The kind of knowledge sharing and cooperation among cities that this report engenders is at the heart of the solution to climate change. As Chair of C40 and Mayor of Rio de Janeiro, I look forward to doing my part in helping current and future water-stressed cities address this critical challenge and build a sustainable future for their citizens.

Eduardo Paes
C40 Chair, Mayor of Rio de Janeiro

1 When the total water use by all sectors exceeds 40% of total water available.

40%

Forty percent of urban watersheds have experienced significant forest loss over the past decade.

Photo: ©Scott Warren

MESSAGE FROM THE NATURE CONSERVANCY LEADERSHIP

With three billion new consumers coming onto the world's global economic stage, and over half of human beings living in cities, the question of how to sustainably manage water resources to ensure water security is at the top of the global agenda.

Freshwater issues have been at the heart of The Nature Conservancy's work for several decades. We believe that freshwater ecosystem function is complementary to the water security of communities. This report is a critical contribution to that broad theory. It attempts to answer — for the first time — the fundamental question of what quantitative investments can be made to incorporate the management of nature in the delivery of clean water to cities.

Rob McDonald, Daniel Shemie and dozens of colleagues from programs across the Conservancy have worked tirelessly to bring together this first comprehensive view of the potential for conservation to deliver clean water. This view is based on years of scientific study and on-the-ground conservation work. The report supports three important points:

1. Conservation can be a material contributor to the toolkit of water managers around the world.

2. We must expand the boundaries of conservation from traditional protection of pristine ecosystems to include conservation on working landscapes.

3. Under the right conditions, conservation is a financially viable and economically advantageous solution to water issues.

Much still remains to be done. We imagine a future in which the sustainable management of watersheds and river basins is integral to the provision of services to cities and their users. For this to happen, a reliable mechanism to deliver these interventions at scale will have to be developed. Building that track record will be essential to mobilize investment capital into conservation. But above all, we need urban citizens to understand where their water comes from, and to be willing to share the responsibility to protect nature for their water security.

Giulio Boccaletti, PhD
Global Managing Director, Water
The Nature Conservancy

EXECUTIVE SUMMARY

More than half of humanity now lives in cities. Large cities alone represent US $21.8 trillion in economic activity, or 48 percent of global GDP [1]. All cities, regardless of size, need a clean, consistent water supply to thrive, so it is little wonder that capital expenditures on water supply are large—US $90 billion per year—and growing. Unfortunately, drinking water sources are increasingly insecure. Cities face twin challenges: water that is both scarce and polluted. Rising demand has been allowed to grow unchecked, competing users upstream do not talk to or trust one another, increasingly unpredictable rainfall patterns have been altered by climate change, and the watersheds where our water comes from have been degraded.

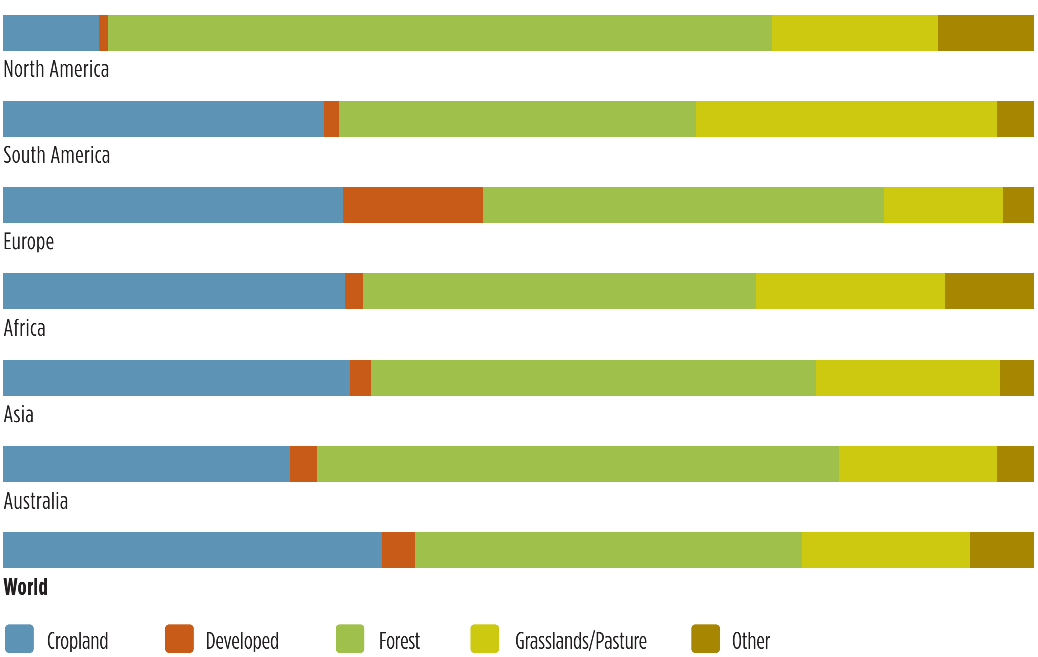
This report is about how investing in nature can help address these challenges. We evaluate one set of solutions to the growing urban water challenge: source watershed conservation. Scientists at The Nature Conservancy (TNC), in partnership with the C40 Cities Climate Leadership Group and International Water Association, present findings on how and where conservation strategies in watersheds can have a material impact on drinking water—drawing on three years of comprehensive, in-depth analysis of the source watersheds that serve over 500 medium and large cities worldwide.

Where our water comes from

Although the 100 largest cities in the world occupy less than 1 percent of our planet's land area, their source watersheds—the rivers, forests and other ecosystems from which they get their water—cover over 12 percent. That's an area of land roughly the size of Russia—1.7 billion hectares—that collects, filters and transports water to nearly a billion people before reaching man-made infrastructure.

The availability and quality of that water supply, and hence the costs to move and treat it, depend heavily on how land in those source watersheds is used. Presently, the average source watershed is covered by 40 percent forest, 30 percent cropland, and 20 percent grassland and pasture. However, in developing countries, where urban population growth is fastest, source watersheds have a higher percentage of agriculture. The variation across regions is shown in Figure E-1.

Figure E-1. Average land use in source watersheds of the 100 largest cities, by region



Source water area by percentage

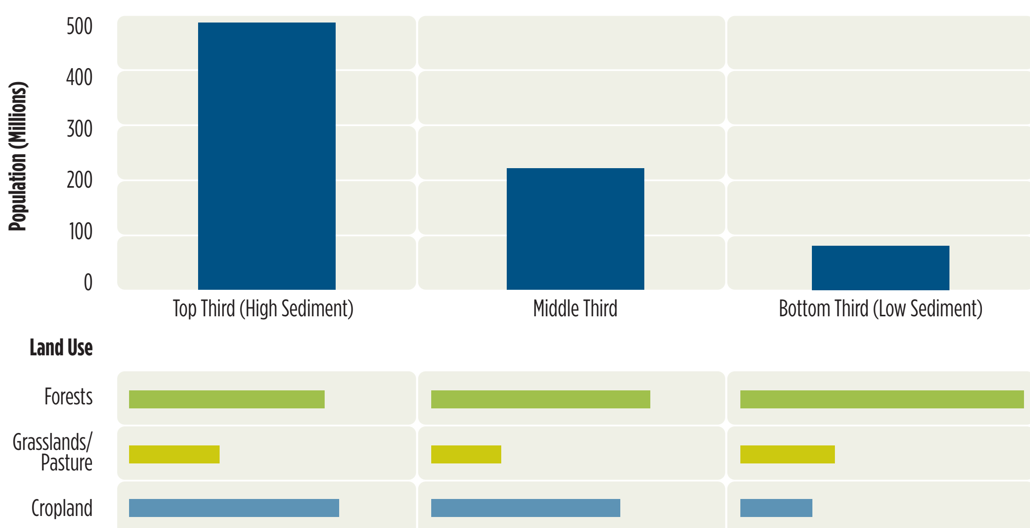
Water quality is often degraded by nutrients from excess fertilizer washing into streams and lakes. This problem will grow more severe in coming years, with cropland projected to increase 10 percent by 2030 and fertilizer use by a staggering 58 percent over the same time period. Moreover, water quality is often degraded as forests are converted into cropland or ranchland, which increases sedimentation in water sources. Our analysis reveals that this phenomenon is widespread, with two out of every five source watersheds experiencing significant forest loss over the past decade.

An unsustainable trajectory

With urban demand on the rise, and watersheds and their water quality increasingly degraded, cities are looking farther and farther from their boundaries for water. We estimate that the hundred largest cities in the world currently transfer 3.2 million cubic meters of water a distance of 5,700 kilometers every day in artificial channels. That means roughly 43 percent of water supply is obtained by "interbasin transfer"— moving water from one river basin to another.

Around 500 million people in the 100 largest cities get their water from sources with high sediment levels, while around 380 million people get water from sources with high nutrient levels. Figure E-2 shows how watersheds with more forest cover and less cropland have less sediment, on average.

Figure E-2. Influence of land use on sediment load



Population in the 100 largest cities that have surface sources with high, medium, or low levels of sediment. The full report also features trends for nutrient pollution.

Wealthy cities have the option of importing water, while lower-income cities mostly have to rely on water resources found nearby, as they cannot afford the same level of infrastructure. Our analysis shows that cities with higher GDP per capita supplement their supply with twice as much water from imported sources. By comparison, lower-income cities rely more heavily on local water sources than interbasin transfer.

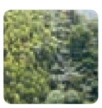
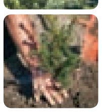
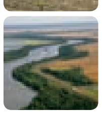
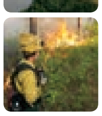
Cities that can afford to will be tempted to direct future investments toward moving more water ever greater distances to meet demand, but this is not a sustainable long-term solution. It may also not be climate adaptive—even when taking into account interbasin transfers, one in four large cities are already facing water stress today—and it will likely continue to be unaffordable to many cities, especially those in developing countries.

A different approach is possible: using the lands that source our waters more wisely. Investing in nature can change how land use in source watersheds affects water quality—and, over time, possibly water quantity. This report therefore highlights something water managers will already be familiar with: the difference between supply and useful supply. This report also offers something new: a systematic quantification of the global potential for source watershed conservation to help cities secure water for people.

Watersheds as natural infrastructure

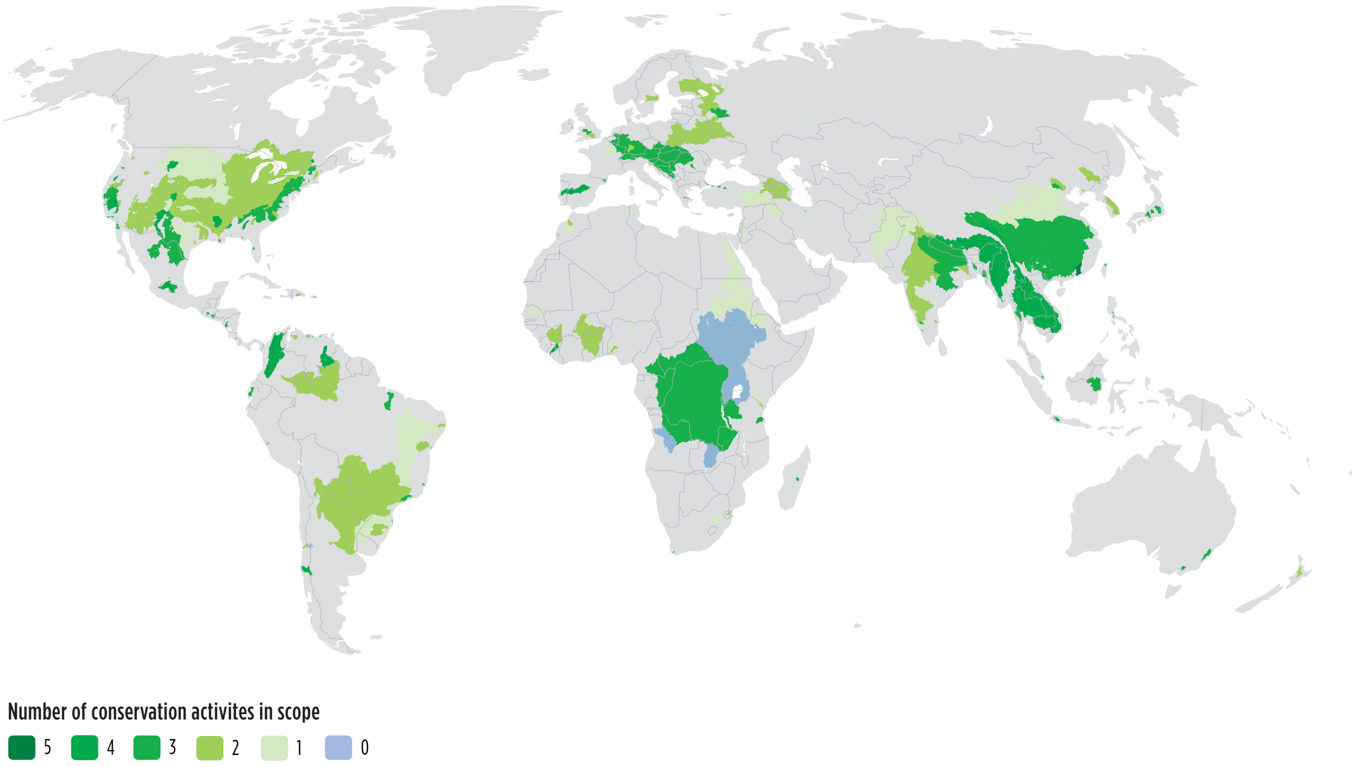
To help determine where watershed conservation can help secure water for cities, we estimated the effectiveness of five common conservation strategies: land protection, reforestation, riparian restoration, agricultural best management practices, and forest fuel reduction (Figure E-3). For each strategy, we evaluated how effectively it reduces sedimentation and nutrient pollution in more than 2,000 source watersheds that serve over 500 cities.

Figure E-3. Five conservation strategies to help secure water for cities

	Strategy	Description
	**Forest Protection**	Purchase of easements, land rental, fencing out cattle, and funding for park guards to maintain watershed services
	**Reforestation**	Restoration and planting of native trees, grasses, and shrubs in critical areas to reduce erosion and related sediment transport
	**Agricultural Best Management Practices**	Implementation of cover crops, contour farming to prevent—and wetland and terrace construction to trap—sediment and nutrient runoff
	**Riparian Restoration**	River bank restoration and protection to reduce erosion and improve water quality
	**Forest Fuel Reduction**	Conducting controlled burns and/or mechanical treatment to reduce wildfire severity and related sediment and ash pollution

This analysis finds that conservation strategies could measurably improve the quality of water sources serving over 700 million people living in the 100 largest cities. What's more, at least one of the five conservation strategies could achieve a significant reduction in sediment or nutrient pollution in the vast majority of the world's urban source watersheds (Figure E-4).

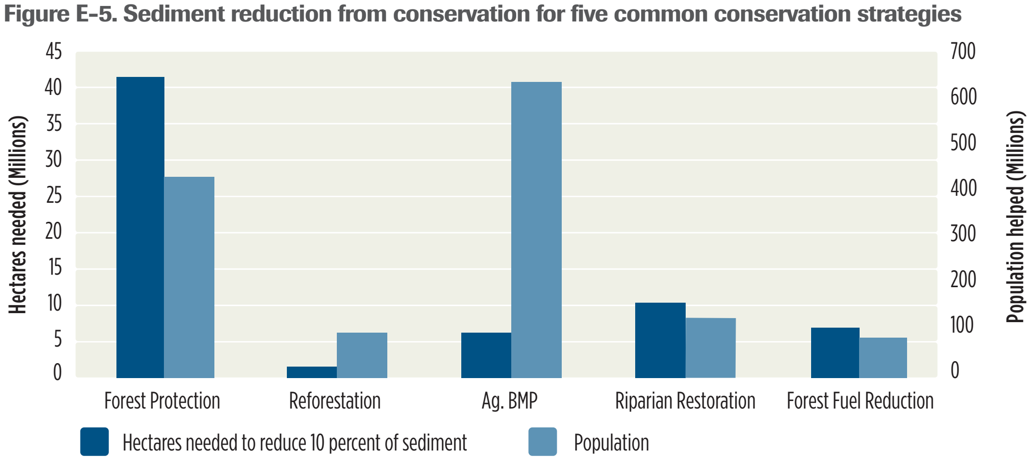
Figure E-4. Number of applicable conservation strategies



Number of conservation strategies that are able to achieve a 10 percent reduction in sediment or nutrient pollution, by urban source watershed.

Water quality benefits can be achieved by targeting conservation on a small fraction of the area in source watersheds. For instance, implementing agricultural best management practices on just 0.2 percent of the area where large cities get their water could reduce sediment pollution by 10 percent. Predictably, the area of conservation it would take to reduce pollution by 10 percent, as well as the number of people whose water supply would improve, varies significantly across the five conservation strategies evaluated in this report (see Figure E-5).

Figure E-5. Sediment reduction from conservation for five common conservation strategies



The full report also features trends for nutrient pollution.

Our findings suggest that the greatest potential to secure water for cities lies in improving the management of agricultural lands. This is especially true for sediment reduction, where over 600 million city dwellers would see a material improvement in the quality of their water sources if agricultural best management practices were applied in a targeted way to some 6.4 million hectares.

Forest protection would benefit the second greatest number of people, about 430 million. However, to achieve the same impact on water quality as agricultural best management practices, this strategy would require conserving an area of land six times greater, some 41 million hectares. The same trend is true of riparian restoration, suggesting that the additional benefits of forests, from recreation to carbon sequestration, would need to be monetized in order to fund source watershed conservation at a global scale.

Promising opportunities in forest fuel reduction also exist in some regions of the world, including the southwestern United States and Australia. When combined with revenue from timber and avoided damages from forest fires, this conservation strategy holds great promise for wider implementation.

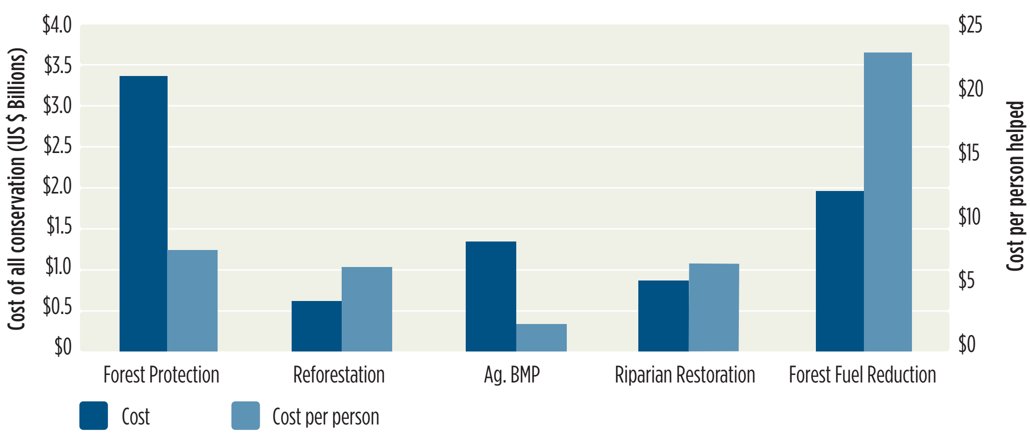
The global market potential for watershed conservation

Not all watershed conservation is equally cost-effective. The amount of land on which conservation activity would have to be conducted to achieve a measurable reduction in a pollutant varies widely among cities. Effectiveness is greatest for small source watersheds, where action on a relatively small number of hectares can significantly change concentrations of pollutants. Estimates of effectiveness for more than 500 cities in our analysis are catalogued in Appendix A of this report and online at nature.org/waterblueprint, which displays more detailed information, including maps of each city's water sources.

The cost for watershed conservation is a function of how many hectares on which the activity must be conducted. For sediment reduction, the market potential across all five activities is US $8.1 billion per year, with the largest costs being forest protection and forest thinning. Figure E-6 shows, however, that the cost per person is lowest for agriculture best management practices.

For nutrient reduction, the market potential across all five activities is US $18.1 billion, with the greatest total costs in agricultural best management practices and reforestation. In this case, however, the cost per person is lowest for forest protection.

Figure E-6. Cost and effectiveness of watershed conservation for sediment reduction



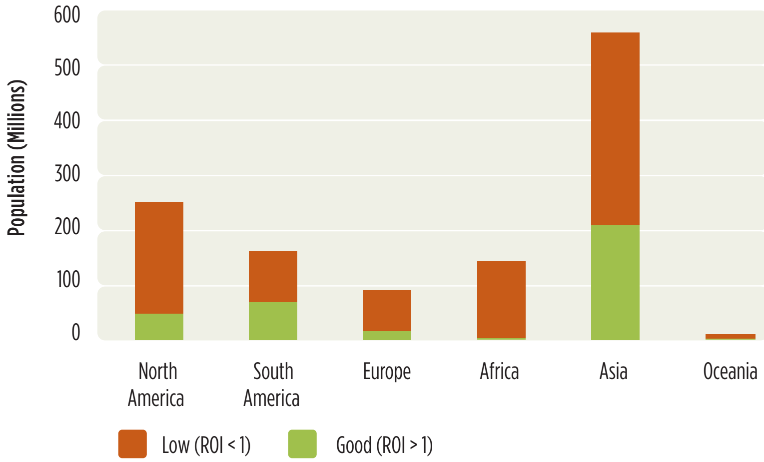
The full report also features trends for nutrient pollution.

The return on investment for water treatment

Using information on reported water treatment plant operations and maintenance (O&M) costs from a sample of cities, we show that reductions in sediment and nutrients lead to significant reductions in treatment plant O&M. A reduction in sediment and nutrients by 10 percent leads to a roughly 5 percent reduction in treatment costs. If all possible conservation strategies were applied, global water savings on treatment plant O&M would be US $890 million per year.

Out of all 534 cities analyzed, one in four would have a positive return on investment for implementing watershed conservation. Of course, the return on investment would vary widely among cities. The geographic distribution of where the return on investment is positive is shown in Figure E-7.

Figure E-7. Potential return on investment for watershed conservation by continent



Potential return on investment for watershed conservation by continent.

Source watershed conservation saves money for utilities in other ways as well. For instance, investing in conservation strategies is likely to reduce capital expenditures over time for utilities, as cities can continue using cheaper water treatment technologies rather than upgrading to more complex, expensive technologies. Watershed conservation also creates value to cities beyond water treatment, including recreation, economic development, and biodiversity.

The way forward

This report lays out a basic set of facts about the market potential for conservation to improve the supply of water, in particular its quality. Our findings provide an important basis for comparing engineered and natural solutions and exploring how the two can be integrated to provide a more robust system.

The report also lays out some elements of a scale-up recipe, including developing a reliable track record of delivery, monetizing the value of conservation, and stimulating demand. Combined, these building blocks represent an agenda to drive conservation down a path to scale—an agenda that requires action from a number of stakeholders if we are to truly unlock the potential for conservation in the urban water sector.

Cities are drivers of stewardship for hundreds of miles around them. They shape the landscape, and in doing so end up defining a route of development for both themselves and their neighbors in rural areas. Water managers should extend their definition of water infrastructure to include the entire river systems and watersheds that their cities depend on, and incorporate investment in those watersheds as part of their normal toolkit of securing water for people.

For the one in four cities fortunate enough to have a positive return on investment, watershed conservation can likely be funded in-full by utilities through avoided costs in treatment. Here the challenge should not be securing adequate funds, but deploying these funds on investments outside municipal jurisdiction.

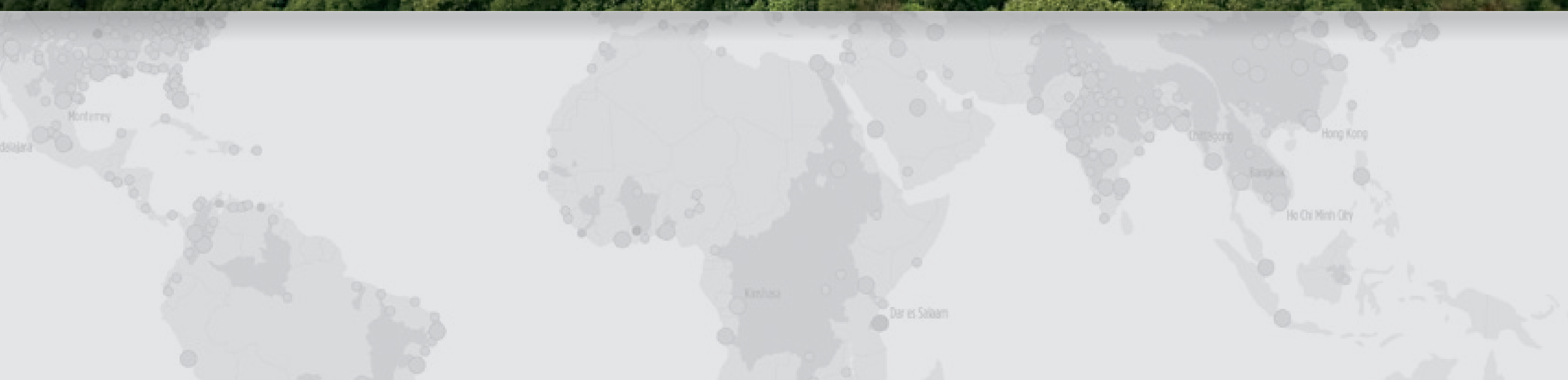
For most cities, it is unlikely to be cost-effective for utilities to pay the entire cost of water conservation. In these cases, cities should consider investing jointly with competing water users in a water fund, a process that establishes a financial mechanism to direct funds toward watershed conservation investments based on impartial science. Alternatively, cities can monetize the extended benefits of watershed conservation. While the multiplicity of benefits increases the chances of mobilizing funds, it also makes establishing a reliable payment model more challenging.

Securing adequate, clean water supply for cities is a global challenge that will require investment in both engineered and natural solutions. Cities that embrace both these approaches will not only meet future water demand; they will reshape our planet's landscape for the better.

$890,000,000

Water utilities surveyed could save up to $890 million each year in treatment costs if they invested in all possible watershed conservation activities.

Photo: ©Scott Warren



INTRODUCTION

Cities may achieve better water security at a lower cost by investing in their watersheds. Most utility managers are well aware of the relationship between their ability to provide water services and the health of the watershed they depend on. Yet widespread use of watershed conservation is rare in the water sector. All too often, water utilities and downstream water users are forced to accept the water resource in whatever state it is in.

The quantity and quality of drinking water depends on land. While a healthy ecosystem purifies and regulates flood waters for release later, a degraded landscape introduces impurities and intensifies floods and droughts. Water managers understand this relationship between land use and water quantity and quality. For the most part, however, neither cities nor the water utilities that serve them exert much control over the land where their water comes from.

Instead, most cities rely primarily on engineered solutions to secure drinking water supply. Whether through building filtration plants, pumping deeper wells, desalinating seawater, constructing dams or transferring huge volumes of water vast distances, cities overcome water scarcity through brute force, spending US $90 billion a year in capital expenditures [2].

Water managers trust these engineered solutions, but they perform within narrow margins. This makes engineered solutions especially vulnerable to variability in the quantity and quality of source water due to land degradation, upstream competition for water, and climate change. The high cost of engineered solutions also puts such solutions out of reach for many cities.

Protecting water at its source can be cheaper and more efficient than treating it after it has already been polluted. Research has shown, for example, that increased forest cover can lead to lower operating and management costs for water treatment plants [3]. New York City famously found that watershed protection can also help avoid capital costs. New York's more than US $1.5 billion investment in its watershed is sizable, but the value to the city extends far beyond avoided treatment costs and regulatory compliance [4].

Conserving the natural landscapes around water sources creates value to cities beyond drinking water. Natural landscapes provide recreational benefits to residents and visiting tourists alike. Investing in watersheds also creates jobs and can provide important economic benefits to surrounding rural communities [5]. In addition, conserving natural landscapes is the surest path to protecting and restoring healthy ecosystems.

Why then are investments in watershed protection so rare? Some institutional obstacles are apparent. Water regulators often do not recognize source water protection as one way of meeting adequate compliance. Also, jurisdiction may limit utility spending to within the metropolitan area. But while these challenges vary widely across cities and countries, one obstacle is encountered globally: the value of source water protection remains vague and hence utility managers do not trust it.

This report helps fill the knowledge gap by establishing how much watershed conservation can help utilities and where the opportunities for watershed conservation are greatest. This report does not attempt to assess related values (co-benefits) of watershed conservation, such as recreation, economic development, and biodiversity. It is worth noting that such additional benefits are likely to be of equal or greater value to cities in some cases [6].

This report outlines the case for source water conservation as follows.

Chapter 1 presents findings from mapping the water sources of 534 large and medium cities and examines trends in water quality and quantity across the 100 largest cities in the world. Among other things, the analysis reveals how much land and what kind of land cover is influencing urban water sources.

Chapter 2 offers a re-evaluation of where water quantity and quality risk is concentrated across the world's largest cities. Specifically, for water quantity the analysis accounts for the steps cities have already taken to overcome stress, including interbasin transfers. For water quality, the analysis looks specifically at two important parameters—sediment and nutrient concentration—that affect the cost and complexity of treatment works.

Chapter 3 highlights real-world examples of city and water managers who have succeeded in making conservation investments to secure water. It evaluates the global potential of five conservation activities:

1. Reforestation – replanting trees where forest previously existed
2. Agricultural best management practices – adding a cover crop after harvest
3. Riparian restoration – creation of riparian buffers with native vegetation
4. Forest protection – preventing future conversion of land through land rental or purchase
5. Forest fuel reduction – mechanical thinning of forest to reduce the risk of wildfire

Chapter 4 presents a global comparison of these five conservation strategies, including their costs and benefits. When taken separately, each strategy represents a different market potential. Likewise, some strategies offer more favorable return on investment to cities.

Finally, Chapter 5 outlines recommendations for cities, water utilities, and partners interested in realizing the market potential described in this report. It also lays out some elements of a scale-up recipe that includes suggestions for how to develop a reliable track record of delivery, monetize the value of watershed conservation, and stimulate demand.

CHAPTER 1

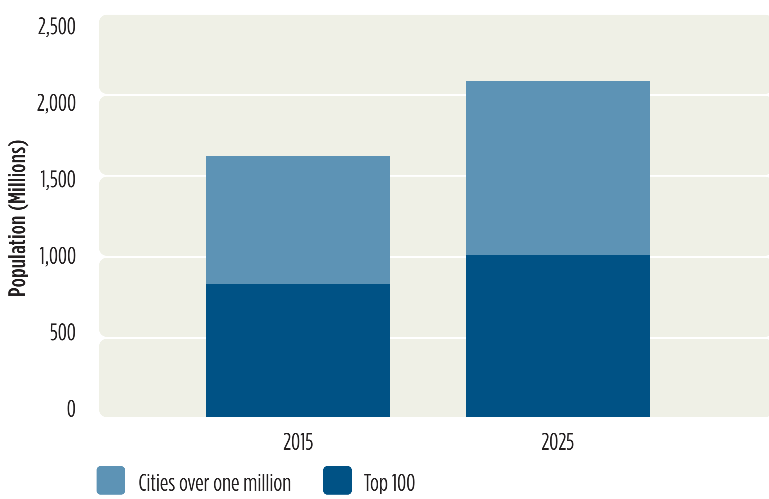
WHERE OUR WATER COMES FROM

Rising demand in cities

We live in an urbanizing world. Today, large cities (as defined by having a population greater than 750,000) represent US $21.8 trillion in economic activity or 47.7 percent of global GDP [1]. Over one-third of that economic activity, US $7.9 trillion, is concentrated in the world's 100 largest cities. Seeking jobs and access to services, people all over the world are living in or moving to cities. Large cities worldwide are already home to 1.7 billion people, about 24 percent of the world's population, and the top 100 largest cities alone are home to 823 million people [7].

Most urban population growth in the next 30 years will occur in cities of developing countries, where urbanization is occurring at higher rates [7]. Africa and Asia will grow by 82 percent and 38 percent, respectively, over the next twenty years. The majority of urban growth will occur in small to mid-sized cities. This report focuses on large cities, which will capture about one-third of all urban growth (Figure 1-1).

Figure 1-1. Over a billion people will move to cities by 2025, and one in three to large cities.



Economic growth goes hand-in-hand with this urban growth. Over the next 20 years the global economy will add trillions of dollars in services, mostly tailored to the growing urban population. But the impacts of economic growth will extend well beyond urban specific economic activity, as trade flows and production patterns increasingly will cater to an urbanizing world. Without an ample and consistent supply of clean water, no city can thrive. Indeed, the supply of potable water is a fundamental component of the environmental, economic, and social health of cities and the economies they support.

Water utilities are investing US $90 billion a year in water supply infrastructure to deliver clean water to their customers [2]. With per-capita water consumption growth outpacing urban population growth at around 2.6 percent per year [8], annual expenditures in water supply appear certain to increase. Such expenditure increase will overwhelmingly occur in urban areas and will increasingly be paid for by people living in cities. If current trends continue, the volume of urban water delivered will have to increase by around 80 percent by 2030.

In this context, the security of urban water supplies becomes crucial. The World Economic Forum, not surprisingly, classified water security as one of the greatest threats to global prosperity in its 2014 risk report [9]. This perception was in no small measure due to the risk urban economies face when securing access to safe, reliable supplies of clean water.

Managing water resources and water services

A fundamental distinction is often made in the water sector between the management of water resources and that of water services. The management of water resources often refers to the management of large-scale rivers and watersheds. The primary uses of water are agricultural, industrial, and environmental. Water for urban use is a small fraction of the total demand. In fact, when considering consumptive uses—those that eliminate water from a system altogether, as opposed to those that simply use water that then gets returned in different form—cities barely register as significant users. The world of water resources is a world of canals, dams, reservoirs, and diversions deeply connected to the hydrology of the watershed.

The management of water services, on the other hand, refers to that small portion of water that is taken from a condition of raw water and treated to levels of quality and reliability that make it fit for human consumption or industrial use. The world of water services — a world of treatment plants, desalination, distribution networks, and wastewater plants — seems only marginally connected to the large-scale resource problem. The distinction between resource and service permeates institutional structures, with administrative and managerial powers often dividing along these lines.

The majority of water utilities do not have the mandate to allocate funds to watershed conservation even when it is in their best interest. Accordingly, most utilities set prices to recover only the cost of delivery water [10]. This is because of the institutional structure in which a watershed organization provides water permits (including for utilities), sometimes for a fee or at no cost at all. For many cities, the raw water quantity and quality of their sources depends on land that largely falls outside of their administrative 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 less influenced by water managers.

In some cases management of water resources and water services meet, as is the case of the New York water system. But this highlights the difficulty of integrating the two, as New York has had to develop unique models of governance to connect its urban water use to the management of the watershed upstream. It is thus not surprising that water experts often single out New York and a few other cities not only because they are interesting examples of recognized and integrated ecosystem services, but because they are relatively uncommon.

Managing upstream of water intakes

This report argues for a revolution in the context of urban water management. Increasing population, climate change, and environmental degradation are putting unprecedented pressure on the watersheds of the world. Those pressures raise the cost for cities to manage a dwindling water source of deteriorating quality.

It is time to change the paradigm. Cities that invest in watershed conservation can no longer be rare exceptions to the general trend of non-engagement. Rather, such investment needs to become a regular part of the toolbox for water managers.

Urban citizens need to understand where their water comes from and take responsibility for the impact their choices have on the quality of the resource they share with other economic and social uses. They also have an unprecedented opportunity: to help shape the landscape they depend on for miles around them, and to drive a more sustainable management of watersheds that will increase resilience for all.

Cities in developed countries have an opportunity to reconsider their relationships with their watersheds. A recent survey found that more than 75 percent of American citizens have no idea where their water

comes from [11]. The need to replace or modernize the water infrastructure of these cities offers an opportunity to reconsider the integration of the investment decisions with the broader landscape of watersheds that surrounds them.

Developing countries, however, provide an even greater opportunity. Over the coming years thousands of new cities will embark in the development of modern water systems. City leaders have an unprecedented chance to design the utility models of the future. When William Mulholland made that choice for Los Angeles at the start of the twentieth century, he committed the city to specific paths of development [12]. Today, thousands of city leaders face equally significant choices about how to secure adequate, clean water. This report is targeted to them in an attempt to illustrate the potential for transformation that lies in their hands and to demonstrate how consequential those choices might be.

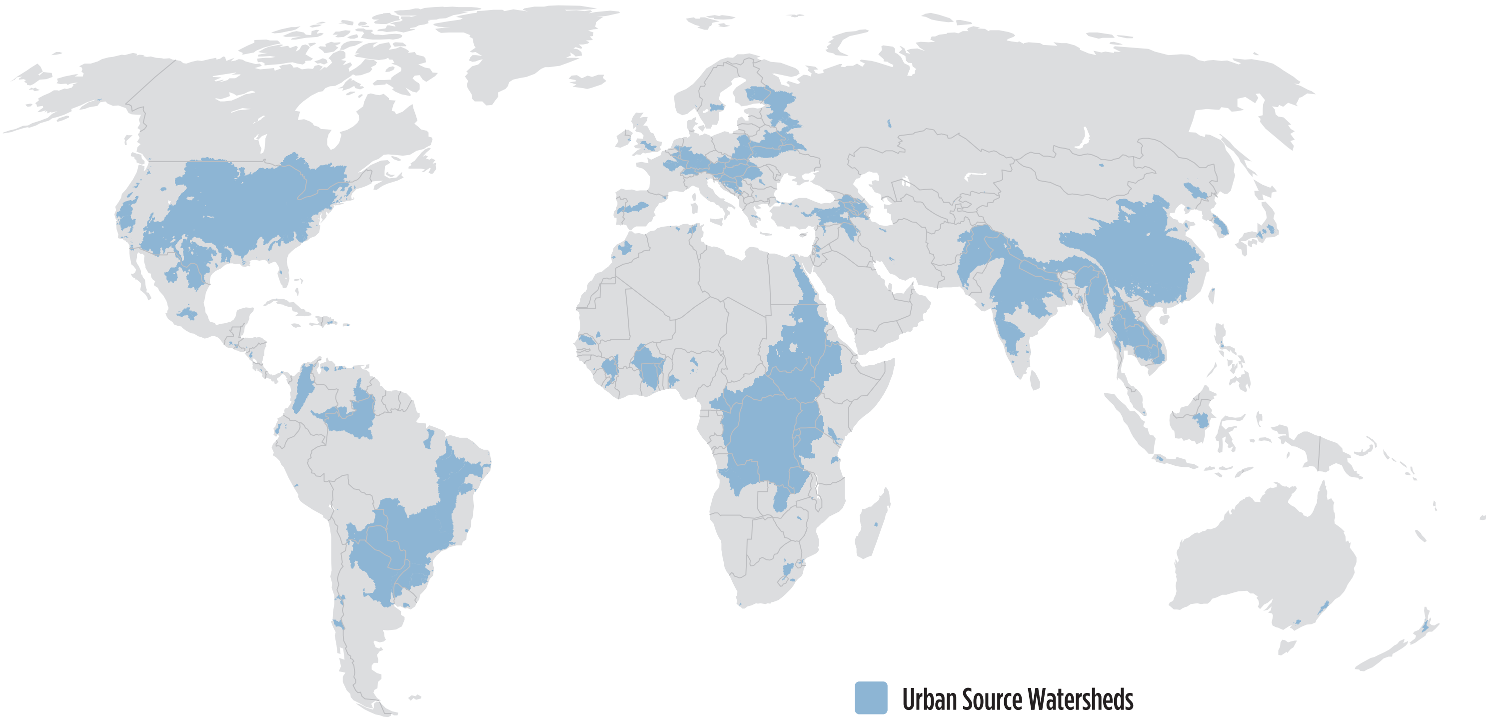
Cities and their water sources

To help city leaders, water managers, and the general public better understand where their water comes from and what the scope of their impact could be, scientists from The Nature Conservancy mapped and analyzed the water sources for 534 large cities worldwide. This includes almost all of the 100 largest cities in the world[2] and a representative sample of over 400 large and medium-sized cities. (See Appendix D for detailed methodology.) An extensive data analysis, review of annual utility reports, and expert interviews together shed light on the influence of watersheds on drinking water supply risk. We focus our analysis on surface water quality and quantity, and while we account for the importance of groundwater in urban water supplies, we do not evaluate the sustainability of groundwater sources.

A spatial analysis of the footprint of this dataset shows the basic rationale for this work. Although the top 100 cities occupy less than 1 percent of the planet's surface area, their water sources represent 12 percent, an area of roughly 1.7 billion hectares. The 534 cities in our sample draw water from 20 percent of the world's land surface (see Figure 1-2) or nearly 3.0 billion hectares, which is roughly the size of the African continent.

2 Data limitations prevented the authors from mapping the water intakes for eight of the largest 100 cities: Foshan, Hangzhou, Shenyang, Suzhou, Jinan, Wuxi, Taiyuan, and Lahore.

Figure 1-2. The source watersheds

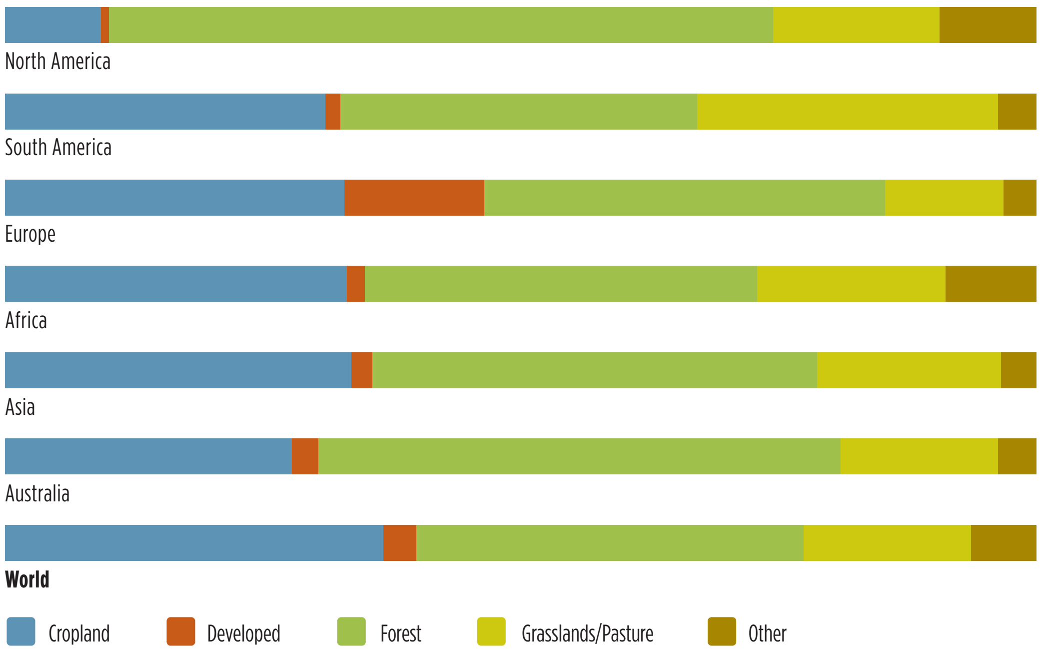


Continent	Top 100 cities (million ha)	All cities mapped (million ha)	Fraction of land serving top 100	Fraction of land serving all cities mapped
North America	161	612	6.0%	22.9%
South America	305	519	19.9%	33.8%
Europe	57	222	5.8%	22.3%
Africa	678	774	22.5%	25.8%
Asia	508	785	11.4%	17.6%
Australia	2	4	0.3%	0.5%
World	**1,712**	**2,916**	**12.7%**	**21.7%**

The source watersheds of the 534 cities mapped in this report (top panel) as well as cumulative source watershed area for each continent (bottom). Note that urban source watersheds vary widely in size, and cumulative area figures are dominated by a few cities in each region. For instance, in Africa, Cairo and a few other cities draw from the Nile, which has by far the largest source watershed in the region.

Source watersheds provide the natural infrastructure that collects, filters, and transports water. The next step in our analysis is to examine what is happening in these watersheds. On average, the source watersheds of the largest 100 cities are 42 percent forests, 33 percent cropland and 21 percent grassland, which includes both natural and pastureland. Of course, the relative importance of land cover varies by region. For example, the average urban source watershed in North America and Australia is predominantly forested. Figure 1-3 shows the average composition of urban watersheds for the 100 largest cities in this dataset.

Figure 1-3. Average land use in the source watersheds of the 100 largest cities, by region



Source water area by percentage

These findings reflect both the land development and economic development of those regions in the last century. The Northeast of the United States, for example, is the archetype of the forested region. A century ago, agriculture and extensive logging had greatly reduced the forests of the Northeast. But the transition to a more service-intensive economy and the movement of agricultural activity further west has returned much of this land to forest [13]. Cities in the Northeast of the United States tend to draw water from these forested watersheds [4], a general trend that holds for North America as a whole; on average, urban source watersheds in North America are more forested than those in any other continent.

Predictably, European cities have on average the most developed land in their source watersheds of any regions. The state of watershed land use in Europe reflects the history of urbanization and intensive agriculture that has dominated that part of the world for several centuries. On average, urban source watersheds in Europe are more developed than those in any other continent.

Developing countries have a different pattern of watershed use. On average, urban water sources in Asia and South America have source watersheds that have a significant fraction of their area in cropland. That scenario speaks to the challenge facing countries like India and China as they manage the tension between food security and urban development. Taking into account watershed land use and the corresponding degradation of water supply, middle-income countries in Asia and South America will face the most intense conflict between agricultural and urban uses of water.

Watersheds as natural infrastructure for cities

Our global analysis suggests that natural infrastructure in the form of forest and grasslands makes up the largest proportion of areas providing water to cities. However, when we weight the source areas by the receiving population, more people get water from areas that are predominantly agricultural, thanks in part to the concentration of population in large cities in China and India, where cropland dominates water sources.

It is important to consider the land use of a source watershed before evaluating the possible source watershed conservation activities. New York City—possibly the most famous example of protected watershed for water supply—has one of the most heavily forested watersheds in the dataset at over 95 percent. New York is often held up as a replicable example of watershed protection, and this approach is relevant for source areas around the world dominated by standing forest. These occur in all global regions, so this approach can be targeted to the subset of cities where forests do dominate in source watersheds. However, a different approach would be needed for a city like Beijing, which gets a portion of its water from surface watersheds that are on average 60 percent cropland.

We can help mayors, utility managers, and citizens understand which natural infrastructure approaches best suit their situation by identifying the land cover in their source watersheds. The dataset allows us to map the type of land use on which each city most depends, whether forest, cropland, or grasslands.

Figure 1-4. Population versus forested land cover

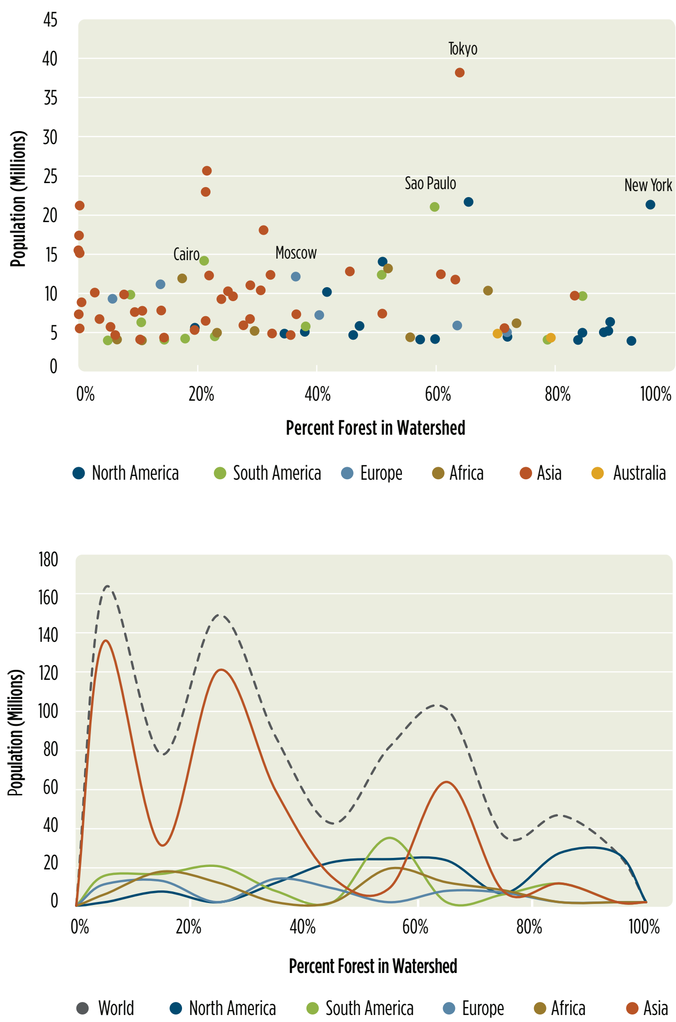


Figure 1-5. Population versus cropland cover

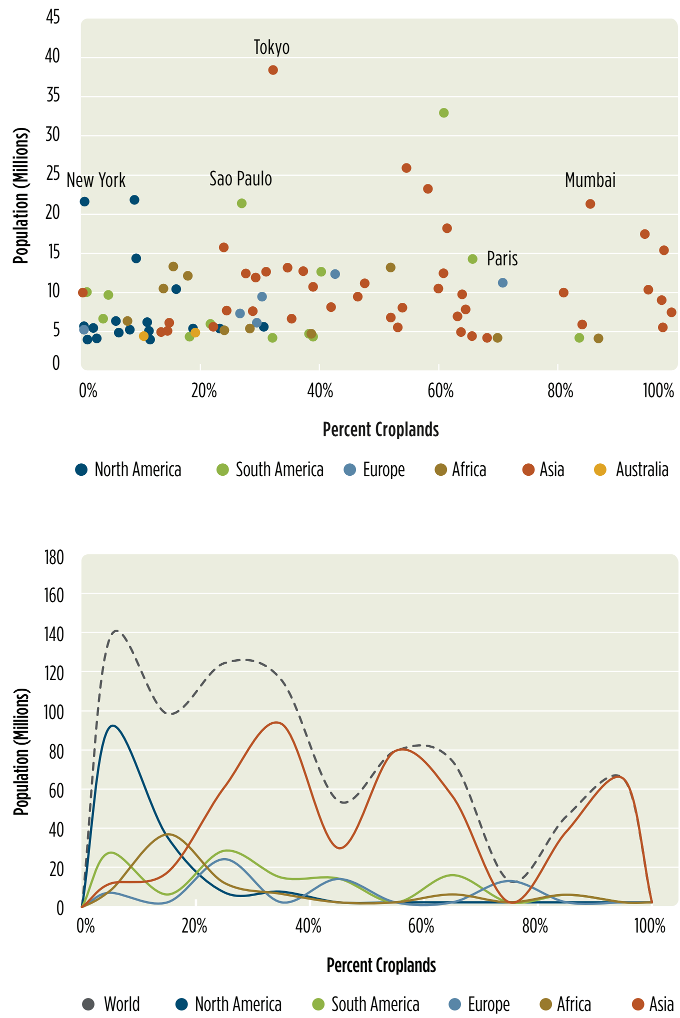
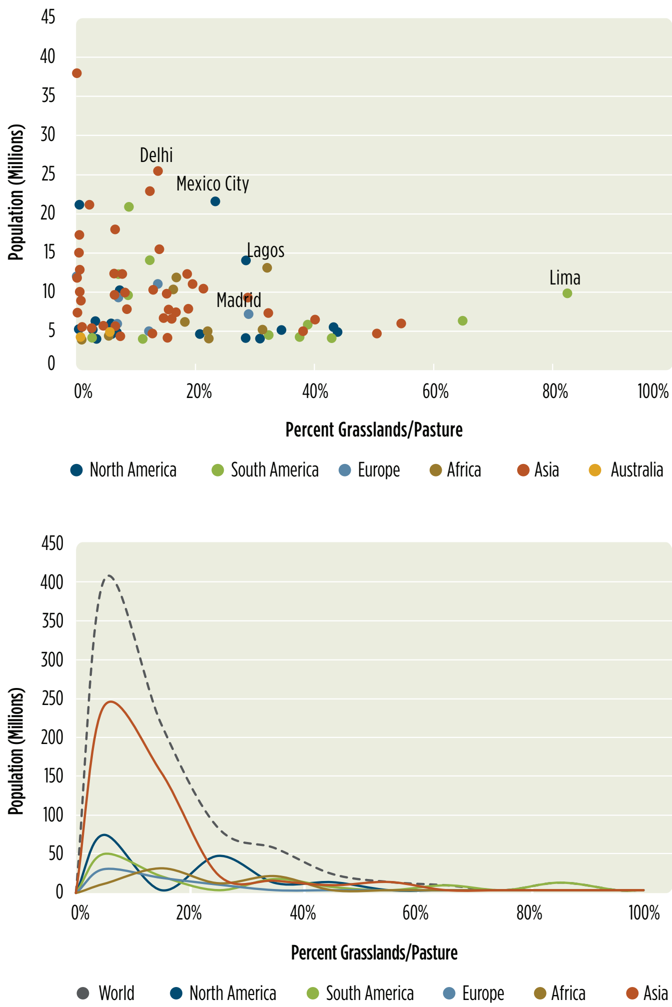


Figure 1-4 shows the scatter plot of forest cover for the top 100 cities as well as the distribution of population by forest cover. Worldwide, 286 million people get their water from watersheds that are more than 50 percent forested, indicating that a forest protection strategy could be very beneficial. Large cities where the most people will benefit from such strategies include Tokyo, São Paulo, and New York. North America has the highest proportion of people getting drinking water from mostly forested watersheds. Since forests play an important role in stabilizing soil and preventing erosion, forest loss or restoration has an important impact on water quality.

Figure 1-5 shows the scatter plot of cropland cover for the top 100 cities as well as the distribution of population by cropland cover. In this case 172 million people get their water from watersheds that are more than 50 percent cropland, indicating that agricultural best management practices could be very beneficial. Asia has the highest proportion of people getting drinking water from mostly agriculturally dominated watersheds. Because croplands can be a major source of nutrient and sediment runoff, as well as a source of artificial fertilizers, agricultural best management practices have important impacts on water quality downstream.

Figure 1-6. Population versus grassland/pasture cover



Likewise, Figure 1-6 shows the scatter plot of grassland and pasture cover for the top 100 cities as well as the distribution of population by grassland and pasture. Twenty-two million people get their water from watersheds that are more than 50 percent grass or pastureland, indicating that the water utility would have to focus on ranching management practices to influence water quality. South America has the highest proportion of people getting drinking water from largely grass and pastureland-covered watersheds. Because grasslands play an important role in stabilizing soil and preventing erosion, grassland loss or restoration has an important impact on water quality. Forest and grasslands are often converted to pasture for cattle ranching, which can also lead to adverse impacts on surface water quality.

Watersheds are the primary natural infrastructure for cities, and their features help define the basic properties of quantity, quality, and reliability for the water supply of almost a billion people. It is critical to understand the basic properties of a watershed, such as land use, because these in turn determine which potential conservation strategies to secure water supply are best. Chapter 2 demonstrates how these properties also define the challenges cities face.

CHAPTER 2

AN UNSUSTAINABLE TRAJECTORY

Moving water—how cities build their way out of scarcity in quantity and quality

From the perspective of cities, one basic function of watersheds is to collect and transport sufficient quantity of water for all uses. It is therefore not surprising that we should start the analysis of watershed services from the question of quantity. And this is the first area where the integration of natural and engineered infrastructure comes to the fore.

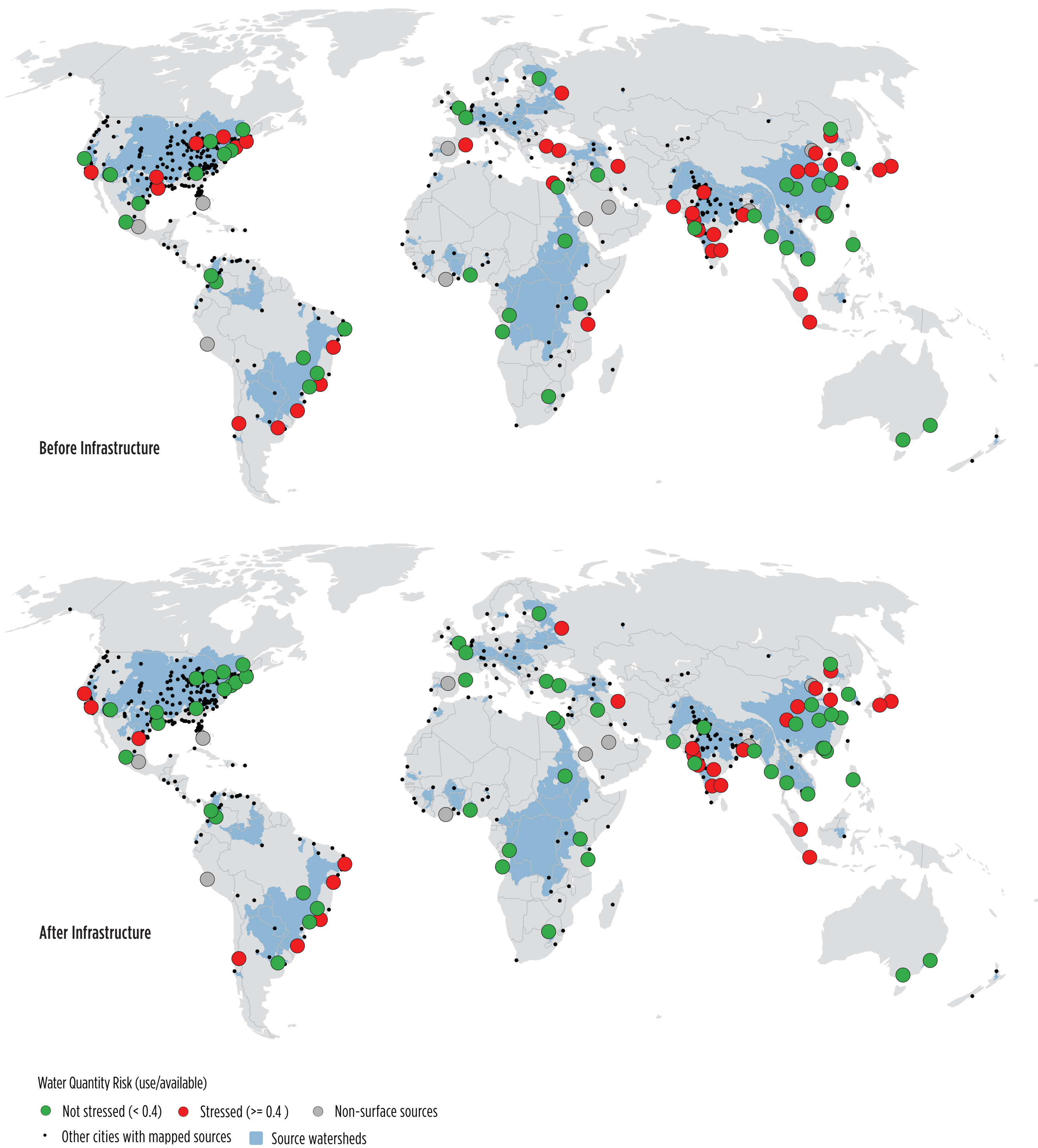
Many cities around the world are located in water stressed watersheds[3]—according to our analysis, more than half of the largest 100. But this fact results in an apparent paradox. If so many cities are located in water stressed areas, why is it that cities from Lima to Las Vegas thrive and their populations continue to grow in spite of this water stress? How to reconcile the common narrative that we are essentially facing catastrophe with the observation that most citizens can be blithely unaware of the scarcity they face?

The answer lies in the way in which water is managed today. In reality cities rely on extensive supply infrastructure to transfer water from multiple, often distant sources to satisfy their needs, thus escaping their particular local conditions. To understand the water stress cities actually face, it is therefore critical to include the cities' constructed infrastructure when evaluating cities' water risk [14].

Our mapping efforts allow us to differentiate between local water sources and those connected to cities via extensive infrastructure. These maps reveal for the first time how dependent many major cities are on water sources that are far afield (Figure 2-1). After interbasin transfers are taken into account, many cities escape water stress.

3 We follow the convention in the literature, defining water stress as occurring when the total water use by all sectors exceeds 40 percent of total water available. See Appendix A: Methodology for details.

Figure 2-1. Urban water stress before and after interbasin transfer



Top 100 cities, surface sources

The difference between the water stress applied to cities before and after accounting for urban water infrastructure is startling. In many countries—particularly those in the developed world—cities that ought to be under severe stress are actually not because they import water from distant watersheds. Los Angeles is a classic example of a city that has had to build a large infrastructure system to obtain water. The Metropolitan Water District of Southern California is the major supplier of water to the Los Angeles area, and it draws water from the Colorado River at Lake Havasu, some 380 kilometers from downtown Los

Angeles. Despite this immense infrastructure system, Los Angeles is still classified as water stressed in our analysis, because a large fraction of the available water in the Colorado River basin is now withdrawn in most years.

Interbasin transfer secures 180 million people from scarcity in the largest 100 cities in the world. That's 17 of the world's largest cities that would otherwise be water stressed. The largest cities import 43 percent of their water supply from interbasin transfer, making them responsible for transferring 3.2 million cubic meters of water a distance of 5,675 kilometers every day.

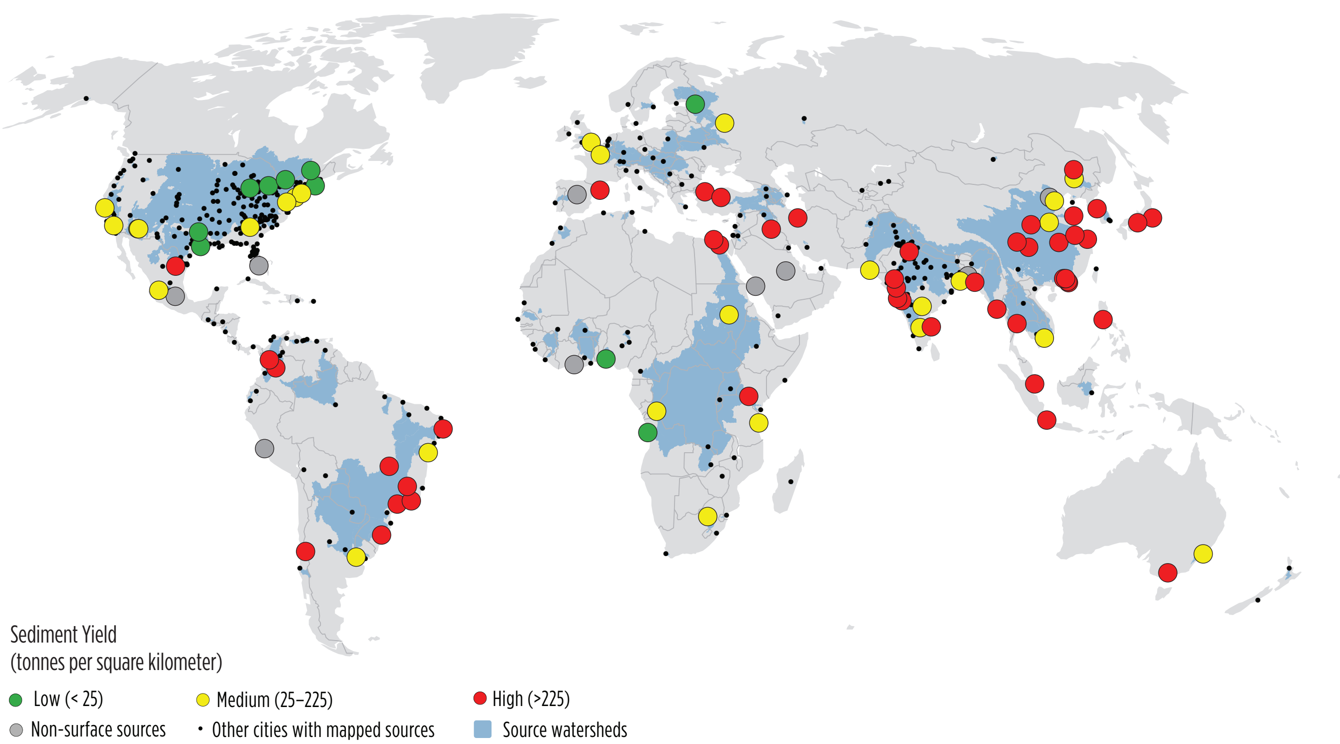
Water quality is also a major motivation behind interbasin transfer. Indeed, several of the world's largest cities have chosen to import relatively clean water from distant sources rather than clean up contaminated local sources. For example, New York gets its water not from the Hudson River but largely from the Catskills watershed, over 100 kilometers north of the city. So important is the water quality of sources that some cities favor importing water from water stressed areas rather than using abundant local sources. This explains why large cities, like Recife, Brazil, and San Francisco, California, appear more water stressed after interbasin transfer in Figure 2-1.

There is a catch. The infrastructure for long distance transport of water is not cheap. Managing watersheds as simple reservoirs of water that can be moved around may ultimately prove to be too expensive to be a universal answer to scarcity and quality management [15]. Some small countries face another challenge: many viable water sources that could be tapped via infrastructure lay outside their borders. In addition, infrastructure is prone to damage, and breakage or repairs can put an entire city at risk of losing its water supply.

Water the color of mud

Watersheds and their land use greatly influence the quality of water cities receive, a dependence that becomes clear when significant changes happen. Changes in land use, particularly the conversion of forest and other natural land covers to pasture or cropland, often increase sedimentation and nutrient pollution. Increased human activity and the expansion of dirt roads in source watersheds can also lead to many other pollutants increasing in concentration, impacting the cost of water treatment and the safety of urban water supplies.

Figure 2-2. Cities grouped by sediment yield

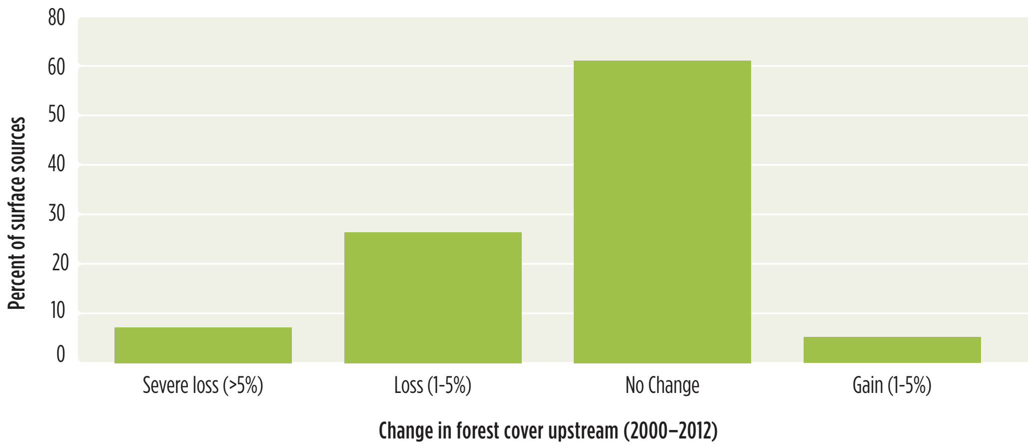


Top 100 cities, surface sources

Nearly 500 million people, or two-thirds of those living in the 100 largest cities, get their drinking water from surface sources in the high-sediment category (Figure 2-2). This analysis divides the water sources of the world's large cities into three categories based upon their level of sediment yield. Cities in the high sediment yield category often have sources downstream from highly agricultural areas, such as in the Ganges Basin in India and in the Yellow River in China. Alternatively, they may be located downstream of areas with naturally high siltation rates, such as the steep mountain ranges with erodible soils along the western coast of South America.

If current trends continue, land use changes in source watersheds will continue to increase sediment loading, posing an additional challenge to cities across the world. More than 40 percent of source watersheds have had significant forest loss over the past decade (Figure 2-3). Because forests play an important role in stabilizing soil and preventing erosion, if global trends continue, sediment yield may increase for many urban source watersheds.

Figure 2-3. Forest loss 2000–2012



Trends in forest loss in the world's urban source watersheds over the period 2000–2012.

One of the reasons to care about sediment rates is that high sediment yield leads to higher operations and maintenance (O&M) costs in water treatment. Our analysis finds that a 10 percent reduction in sediment on average reduces treatment costs by 2.6 percent,[4] although for individual water utilities this figure may be much higher. For instance, increased sediment and turbidity 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 watershed conservation, thus saving US $110 million per year. High sediment concentration in source water generates more wastewater and sludge which are both costly to treat and transport. Increased sediment also increases the need to dredge sedimentation tanks [16]. Sedimentation can also depreciate storage infrastructure (through silting) and can significantly affect ecosystem functionality. The data in Appendix B show that cities with higher levels of sediment are more likely to use more complex treatment technologies.

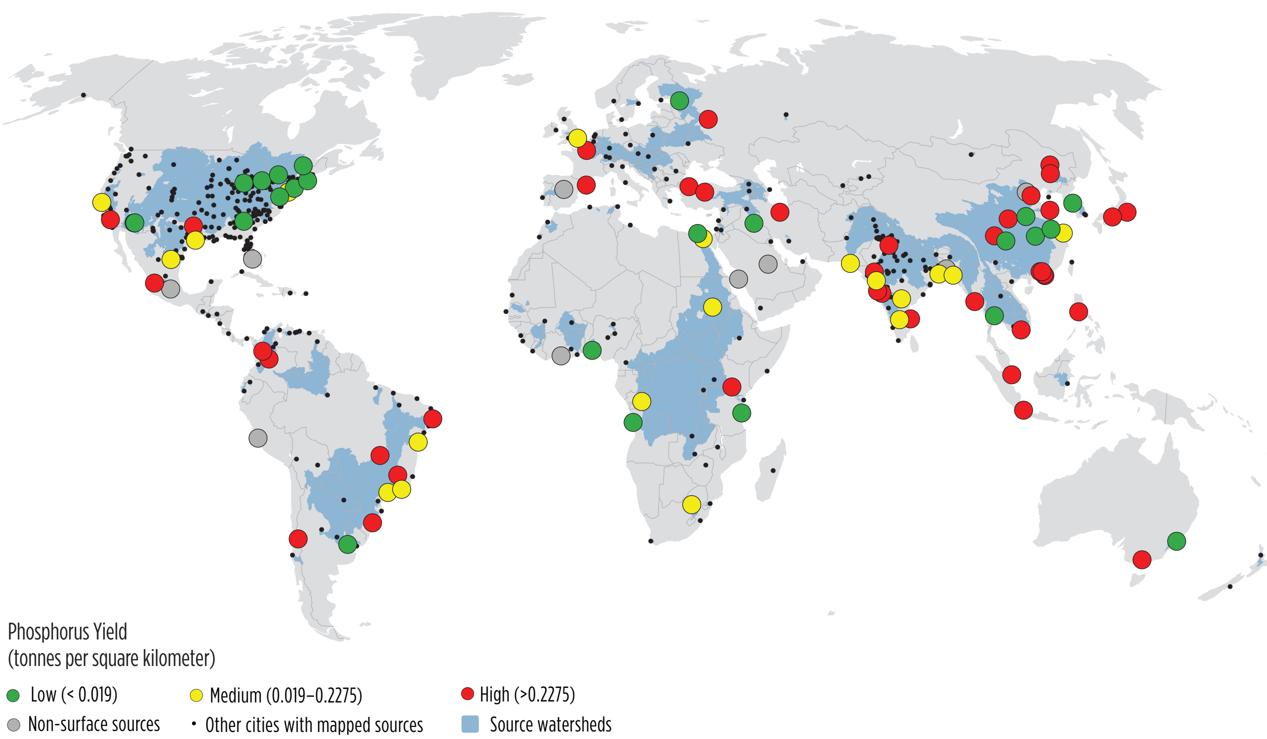
4 See Appendix B for more information on our statistical estimation of the effect of sediment on water treatment costs.

The cost of fertilization

Impacts on water quality are not limited to sedimentation rates. As watersheds are exploited for agricultural purposes, and as agriculture turns intensive, the use of fertilizers increases and more fertilizers end up in the water. The two most common nutrients that cause problems are excessive phosphorus and nitrogen, which come primarily from agriculture and pastureland. 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. This report includes information for phosphorus due to space limitations.[5]

More than 384 million urbanites (46 percent of all people living in the 100 largest cities) get their drinking water from watersheds with high nutrient pollution. This analysis divides the water sources of the world's large cities into three categories, based upon their level of nutrient yield. As with sediment, the task of raw water quality maintenance seems harder for the developing world than for the developed (Figure 2-4).

Figure 2-4. Cities grouped by phosphorus yield



Top 100 cities, surface sources

If current trends continue, nutrient pollution will worsen over the next decade. For instance, agricultural area is forecast to increase by 70 million hectares by 2030. Perhaps more significantly, fertilizer use is forecast to increase by 58 percent globally over the same time period [17]. Overall, the cities that are likely to have the biggest increase in nutrient loading from agriculture are located in Brazil, Argentina, and parts of sub-Saharan Africa.

While human wastewater is a minor part of the overall nitrogen and phosphorus cycle in many water sources, in rivers such as the Ganges, wastewater from multiple cities (often released without treatment) becomes the drinking water source for other cities. In these basins, increased access to sanitation and the installation of basic treatment for wastewater is needed to prevent a further decrease in raw water quality.

5 See Appendix C for more information on the effect of nutrient pollution on water treatment costs.

As with sedimentation, high nutrient levels leads to higher O&M costs for water treatment. Our analysis finds that a 10 percent reduction in nutrients on average reduces treatment costs by 2 percent. Higher nutrient concentration is associated with a greater frequency and intensity of algae blooms and higher organic matter content. Both lead to more frequent filter cleaning and additional treatment processes to remove unwanted colors or odors from the water.

In extreme cases, nutrient levels have even led to plant shutdowns. High nutrient levels in source water also generate more wastewater, which in turn increases the cost of treating effluent exiting a plant. The use of chlorine, for example, as a disinfectant in the presence of organic matter can lead to unwanted disinfection byproducts, some of which can have negative health effects [18].

Higher levels of nutrients are also associated with more complex treatment technologies and hence higher capital costs. See Appendix C for a quantitative look at this trend.

A tale of two cities—rich versus poor

Not all cities can afford to move water vast distances to meet the needs of their citizens and economies. We have divided our dataset into "rich cities"—those with average income per capita above US $44,000 (the top quartile)—and "lower income cities"—those with average income per capita below US $2,500 (the bottom quartile). In our dataset we have 20 "rich cities" and 20 "lower income cities." Their distribution is not surprising: 90 percent of rich cities are in Europe and North America.

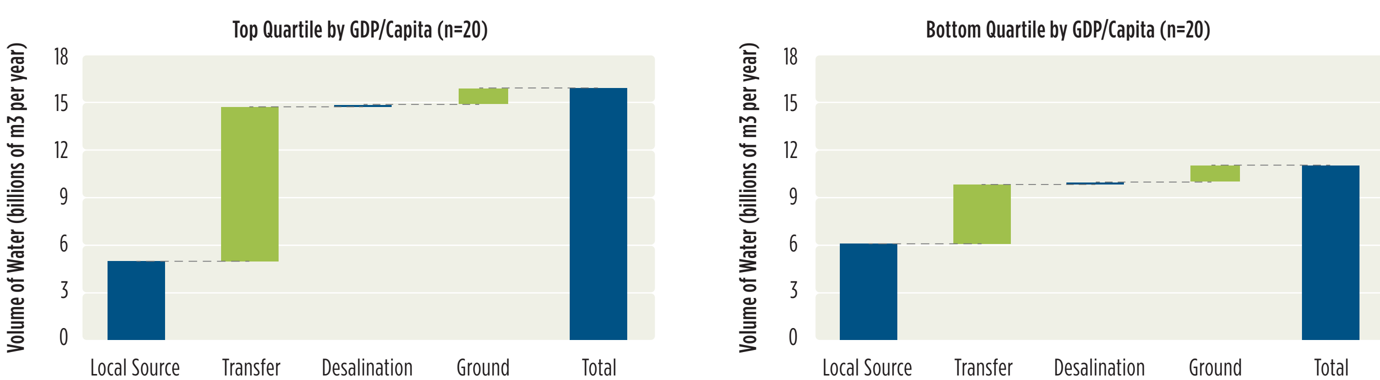
Rich, large cities are able to build their way out of scarcity by transferring water from distant sources. The world's richest cities rely on 9.9 cubic kilometers of water supply from interbasin transfer, almost twice as much as the 5 cubic kilometers of local water source they use. For example, Los Angeles relies on 47 water intakes from an average distance of 71 kilometers. Tokyo's water supply comes from even further away—a distance of 100 kilometers—from 21 individual intakes. Overall, our data show that rich cities supplement supply with twice as much interbasin transfer.

By comparison, lower income cities rely more on local water sources than interbasin transfer: 6.1 cubic kilometers of water from local sources and just 3.6 cubic kilometers of water from interbasin transfer. For example, Dhaka, capital of Bangladesh and home to 7 million people, relies on six surface water intakes with an average distance of less than 10 kilometers. Similarly, the water supply for Lagos—Africa's most populous city—comes from just four intakes an average distance of 30 kilometers.

The asymmetry in management approach is shown in Figure 2-5. The left graph shows the breakdown of total supply by type of source for top quartile cities in terms of GDP per capita. The right graph shows the same for the lower quartile. The top quartile relies more on transfers than local sources, while the lowest quartile relies on the opposite.

This speaks to dramatically different approaches to the management of watersheds. Wealthy cities are being pushed toward importing water rather than managing their local watersheds, while lower income cities mostly rely on managing their watersheds, presumably in part because they cannot afford the same level of infrastructure.

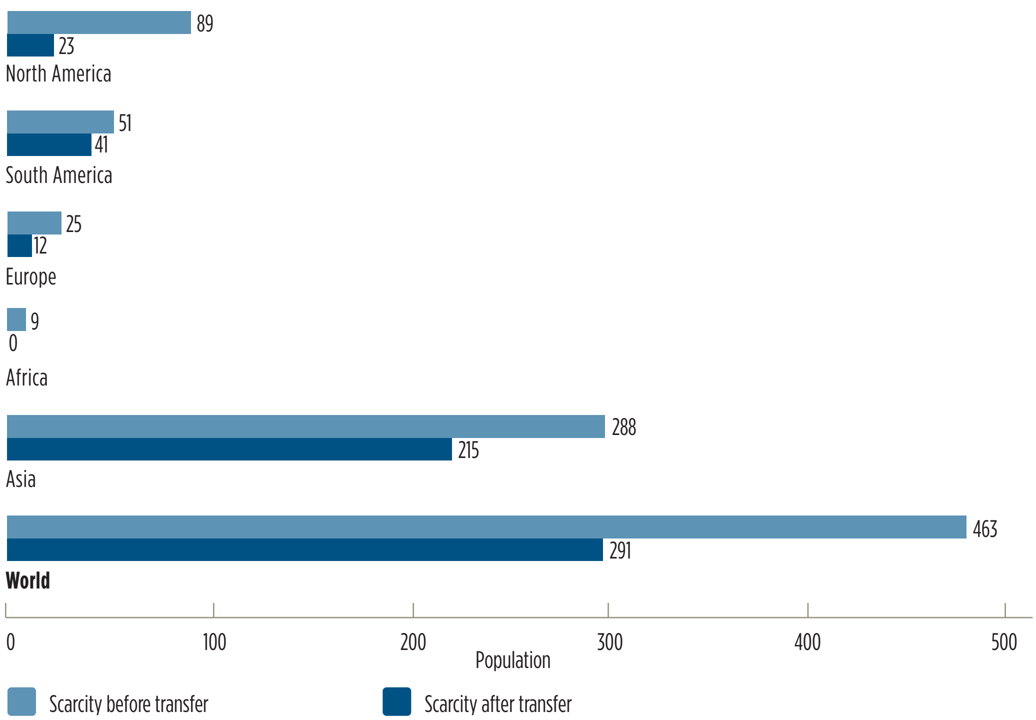
Figure 2-5. Volumes from water sources for top 100 cities (top GDP/capita quartile versus bottom GDP/capita quartile)



It should be noted that while not critical across the board, desalination plays an important role in the supply portfolio. Twenty cities in our sample overcome apparent water scarcity with desalination. However, this is again a “rich city” story. Desalination is energy intensive, and it is only being used at significant rates to supply drinking water to cities in countries that are both water scarce and oil-rich. For example, Dubai’s sole water source is desalination. Desalination is also growing in popularity in closed systems where water supply cannot be augmented easily by interbasin transfer. For example, Sydney invested US $1.8 billion to build a desalination plant that, when operating at full capacity of 250 megaliters, will supply up to 15 percent of the city’s drinking water supply. The impact of transfers can be seen in Figure 2-6, where the numbers of people subject to scarcity are shown with and without accounting for transfer infrastructure.

It is important to note that these figures do not account for the challenge of access within a city due to failures of distribution. Many people who in principle do not live in water stressed cities still face scarcity as their homes may not be connected to the supply infrastructure because they cannot pay water fees or rates, or the supply infrastructure might fail to deliver water reliably.

Figure 2-6. Water scarce population before and after transfers



Interbasin transfers end water stress for 172 million people in largest 100 cities. Note that water scarcity as defined in this report looks only at problems of insufficient water quantity at the municipal water source, not at other problems related to insufficient water quality. Moreover, we do not look at problems of delivery of municipal water to poor neighborhoods, which can be a significant problem for many cities in the developing world.

An alternative path—the sustainability of water use in watersheds

Clearly, while water transfers will continue to be part of the toolkit of water managers, the figures above show that by themselves they simply cannot be the answer to unconstrained growth. Other approaches must be adopted, and the place to start is with the sustainability of the demands on the watersheds themselves.

Cities face a significant challenge because they are often the minority water user in their basins. However, they have greater purchasing power than almost any other user. Increasingly, mayors and water managers seek sustainability in their city water supplies by finding compromise solutions among different users. Because the vast majority of consumptive water use in a basin is typically agriculture, many solutions involve transferring water from the agricultural sector to the municipal sector.

To ensure an equitable result, compensating upstream water users, such as farmers, for using less water becomes an essential part of the answer.

Various institutional mechanisms exist to aid these kinds of approaches. Functional water markets exist in only a few countries. For example, the Murray-Darling Basin in Australia has nearly US $2 billion in annual transactions between urban and agricultural users [19]. Water markets are growing, however, as Chile demonstrates its resilience and China announces a pilot water market program [20]. San Diego, California, illustrates the complexity of these transfers.

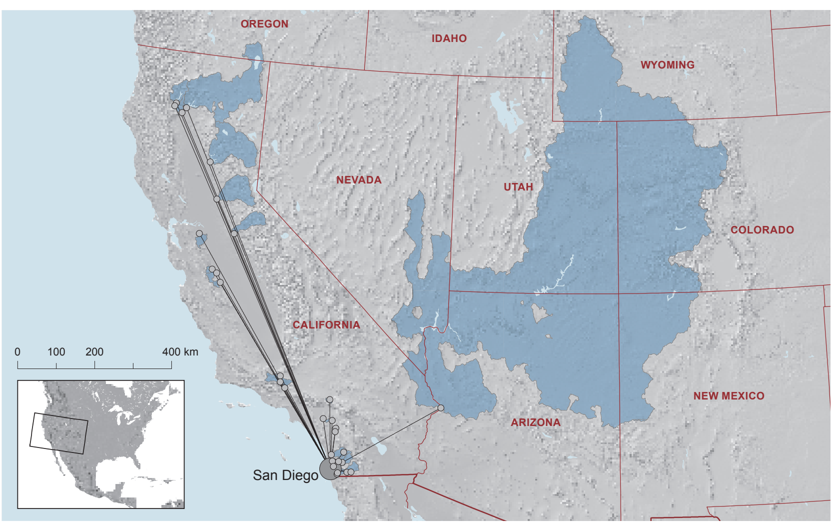
The San Diego story

San Diego depends on the Colorado River for more than half of its water. Many users upstream from San Diego also claim rights to the river – to irrigate farms, fill Las Vegas fountains, or water suburban lawns and golf courses. In a bad year, such as 2012, when rain and snow fall well below normal, the Colorado quickly runs out of water. With a rapidly changing climate, every year may soon be a bad year.

The Colorado River Basin includes seven states and a complex, contentious series of agreements dating back nearly a century that determines who gets how much of the river's water. The latest turn in this long-running drama came in 2003, when the federal government reduced and capped Southern California's share—an accord that sent San Diego scrambling to find water. The local government implemented a controversial solution: buy water from farmers at a price twice the cost of existing supplies (10).

San Diego pays farmers in the Imperial Valley to consume less water. The city then uses the water saved to augment its water supply. This has given farmers the incentive to line irrigation canals to prevent water loss, to use more efficient irrigation techniques such as drip irrigation or micro sprinklers, and to let fields lie fallow some years.

Figure 2-7. Water sources of San Diego, California



From one perspective, the most direct approach to augment supply would be for the state or city to buy farmers out entirely. But that weakens farming communities by lowering demand for seed, equipment, labor, and so on. Hence the need for a system of rotational fallowing, determined by a lottery among the farmers to determine who fallows when.

The San Diego agreement is the largest farm-to-city water transfer ever. In 2011 alone, the farmers sent the city nearly 100 million cubic meters of water, an amount that will increase to over 245 million by 2021. A subsequent agreement involves lining two major irrigation canals to reduce leakage. Together, these agricultural conservation measures will provide 37 percent of city water supply by 2020.

San Diego's future water supply plans depend heavily upon water conservation, both in urban water use through raising the price to consumers and in agriculture water use through the agreement with the Imperial Irrigation District. These water conservation strategies will account for more than 50 percent of planned water supply increases by 2020, and are highly cost-effective investments.

Other aspects of the deal, however, spark public controversy as well as lawsuits among water management agencies in Southern California. Farmers in the valley fear that San Diego will come back for more water. Stella Mendoza, president of the Imperial Irrigation District, voiced the fears of the farmers who opposed the sale. "I don't trust that San Diego will not come back for more," she said. "Once you take out the first pickle from the jar, the rest come easy [21]."

The controversy over sharing water between farms and cities in Southern California has a simple cause: not enough water to go around. The contentious issues are allocation and value. Should farmers in the Imperial Valley continue growing water-intensive crops, such as alfalfa and lettuce, or should the residents of San Diego continue consuming some 600 liters per person per day (five times the consumption of residents in Amsterdam)? This is a debate many mayors and utilities would like to avoid. But with projections suggesting a dry future for cities in arid and semi-arid areas like San Diego, and given the high costs of alternative sources, including San Diego's new billion dollar desalination plant, it's up to decision-makers to choose wisely where to spend their political capital.

Water quality and quantity problems are in many ways the central challenges cities will have to face in the twenty-first century. Cities of the world are confronting these challenges by consistently re-plumbing their watersheds. 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 is an alternative. For water quantity, one can introduce mechanisms to share water and compensate users. For water quality, source watershed conservation activities can maintain water quality in the face of land use change. In the chapter that follows, we present a blueprint for how five specific conservation activities can help maintain water quality.

CHAPTER 3

THE GLOBAL POTENTIAL FOR WATERSHED CONSERVATION

Watersheds as natural infrastructure

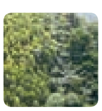
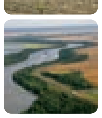
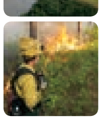
One in three of the largest 100 cities worldwide is currently in water stress, and hundreds of millions of urbanites draw water from sources with low quality, either because of high sediment or nutrient loading. As urbanization and development proceed, the number of high quality source watersheds will inevitably decrease, while the number of watersheds that are over-allocated will grow. Managing watersheds for quality and quantity is therefore a high priority today and will be an even higher priority in coming decades.

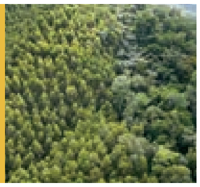
In this context, cities must urgently consider alternatives to traditional approaches, especially in low- and middle-income cities where urban population is also growing the fastest [7] and where most of the new infrastructure required will be built. Moreover, water management responsibility in many developing countries is being devolved in many cases from national to municipal-level authorities, which increases the burden on municipalities, but also opens up new possibilities for innovative approaches to delivering clean water to their residents.

This chapter explores the value of watershed conservation as a complement to traditional engineered solutions. Watershed conservation strategies represent investments in the natural infrastructure that serves cities just as much as traditional engineered solutions.

To understand the viability of watershed conservation as a strategy for urban water utilities, we have estimated the potential impact of applying five conservation solutions (Figure 3-1) across 2,000 urban water sources. These strategies were selected for their proven performance and wide applicability across natural and working landscapes. They are forest protection, reforestation, riparian restoration, agricultural best management practices, and forest fuel reduction. Each strategy improves water quality and regulates water flow in a different way.

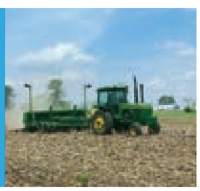
Figure 3-1. Five conservation strategies to help secure water for cities

	Strategy	Description
	**Forest Protection**	Purchase of easements, land rental, fencing out cattle, and funding for park guards to maintain watershed services
	**Reforestation**	Restoration and planting of native trees, grasses, and shrubs in critical areas to reduce erosion and related sediment transport
	**Agricultural Best Management Practices**	Implementation of cover crops, contour farming to prevent—and wetland and terrace construction to trap—sediment and nutrient runoff
	**Riparian Restoration**	River bank restoration and protection to reduce erosion and improve water quality
	**Forest Fuel Reduction**	Conducting controlled burns and/or mechanical treatment to reduce wildfire severity and related sediment and ash pollution

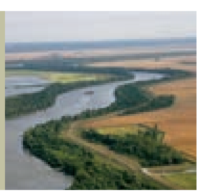


Forest protection involves designating natural habitat as protected from development or other human land uses that would convert the natural habitat to other land covers. This report focuses on forest protection, although other natural habitat types can also be important to protect in different contexts. 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. We discuss below the use of land protection in Cape Town, to avoid degradation of natural habitat on steep slopes in the city's source watershed.

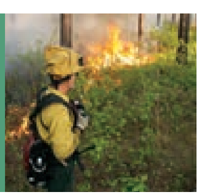
Reforestation involves enabling areas that are currently cleared to revert to forest, either through natural regeneration or through tree planting. In this report, we focus only on reforestation of pastureland, assuming that cropland is too economically important to be reforested at a large scale. We 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. Below, we discuss the use of reforestation in São Paulo's source watershed.



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, and 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. Our case study city for agricultural BMPs is Beijing, which has moved to protect its surface water supply using this strategy.



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. In the discussion below, we present the case study of riparian restoration in Manila, where it is one of several strategies used to maintain water quality.



Forest fuel reduction is a strategy frequently employed in areas where forests are prone to catastrophic wildfires. This abrupt conversion from forest cover to a barren land cover can be particularly problematic when the fire is followed by a large rainstorm, which can cause massive erosion of the unsecured hillsides. Fuel reduction is achieved either through mechanical thinning or through controlled burns, with the goal of reducing the fuel loads and thus reducing the risk of a catastrophic fire. Note that this strategy, similar to forest protection, aims to reduce a future risk of increased sediment or nutrient transport, rather than reducing current annual loading of pollutants. Below, we discuss Albuquerque and Santa Fe, which both draw water from the Rio Grande and are exploring forest fuel reduction as a way to secure their municipal supplies.

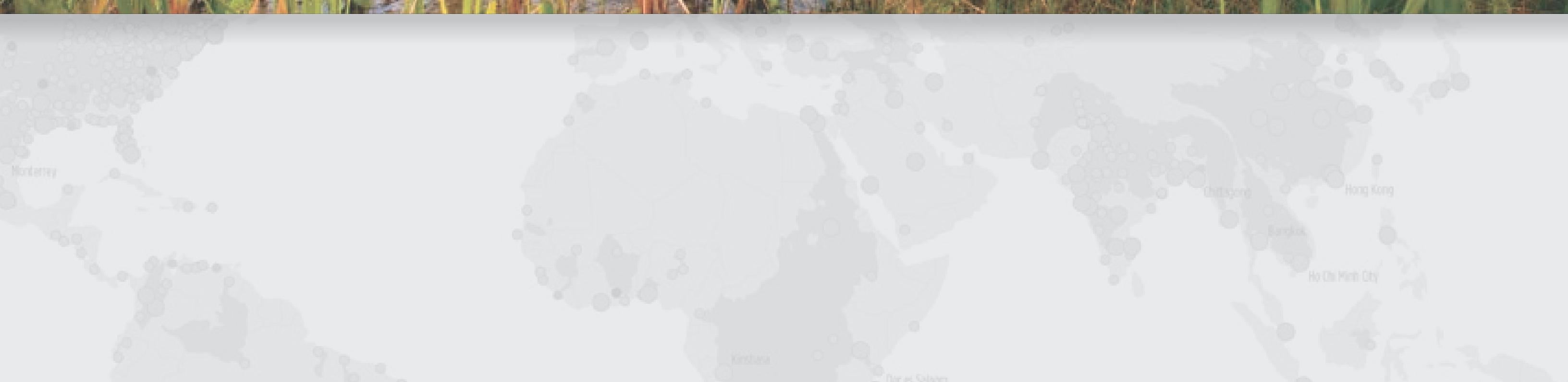
Photos from top:
©Scott Warren, ©Patrick Cavan Brown, ©Tim Lindenbaum, ©Doug Blodgett, ©Robert Clontz

Five archetypes for a solution

The following five case studies, or “archetypes,” show how specific cities have applied the conservation activities discussed above. For each case study, we offer a narrative of how the city has adopted specific conservation practices. We then provide an analysis of the specific potential for that conservation activity, including a comparison of where that city fits in the overall potential across cities in our dataset, and an economic and technical analysis of the watersheds that the city draws on.

Following each archetype we have produced a map of the global potential for that conservation solution. We can consider this map a sort of “market potential” assessment for conservation. Cities with the darkest green dots are those where a 10 percent reduction of sediment or nutrient runoff can be achieved with the least amount of conservation effort, whereas lighter shades of green indicate more conservation effort is required. Cities in grey are those in our dataset where a 10 percent reduction cannot be achieved by working on their watersheds, either because they rely primarily on nonsurface sources of water or because a particular conservation activity is not relevant in that landscape.

Photo: ©Ian Shive



Beijing—Agricultural BMPs to reduce erosion and nutrient runoff


Photo: ©Scott Warren

Miyun Reservoir, some 50 miles northeast of downtown Beijing, is the main surface water source for 20 million people. Miyun is not particularly large as reservoirs go—the reservoir behind the Three Gorges Dam, 750 miles to the south, is nearly ten times its size—but Miyun may be the most important single reservoir on the planet.

Miyun Reservoir was never intended to play such a crucial role in Beijing's water supply. It was meant to supply rural areas while another reservoir, Guanting, northwest of the city, would provide water for industrial use and urban waterways. But by 1997, Guanting had become so polluted and so full of silt it had to be abandoned. The same things were happening in Miyun, so officials began implementing a plan to keep open the crucial lifeline for the city.

Near Beijing, the Paddy Land-to-Dry Land (PLDL) program pays farmers to convert their croplands from rice to corn. It has been popular with farmers: in just four years, the government of China convinced all farmers growing rice in this area to switch to corn, greatly improving both water quality and the quantity that reaches city residents downstream.

According to Jingshun Liu, the commissioner of department of regional economic cooperation, National Development and Reform Commission (NDRC) Beijing office, the main goal of the PLDL program is to store up a quantity of pristine water for Beijing. The Chao River is the critical source of water for the Miyun and Guanting reservoirs. The rice growing upstream in Hebei Province takes up 80 cubic meters of water per hectare per year. "More importantly," says Liu, "the sewage from upstream farming is discharged directly into the Chao River, threatening the water quality of Miyun Reservoir."

The shift from rice to corn reduces both water consumption and pollution. Rice paddies are constantly flooded and often located on steep slopes, leading to significant fertilizer and sediment runoff. Corn, meanwhile, requires much less water, and fertilizer is more likely to stay in the soil. Miyun Reservoir could reduce sediment by 10 percent by instituting best management practices on 17,000 hectares and could reduce phosphorus by instituting those practices on 13,000 hectares (Figure 3-4).

The major challenge to the program is that farmers earn almost three times more money growing rice. To ease the transition, the government compensates farmers to make up the difference, a subsidy that is crucial to the program. In the long term, there will need to be a mechanism for ecological compensation with a clear standard, funding source, and evaluation criteria. But for now, door-to-door surveys reveal that the compensation program has mostly improved peoples' livelihoods. Farmers are making more money and, because corn is a less time-intensive crop to grow, they have more time to farm elsewhere or work other jobs.

The program costs about US $1,330 per hectare of farmland to implement, but it produces US $2,020 per hectare of benefits, calculated as the value of increased water yield and improved water quality. According to researchers at Stanford University, water quality tests show that fertilizer runoff declined sharply while the quantity available to downstream users in Beijing and surrounding areas increased [22]. The researchers calculated that people on both ends of the deal were receiving similar returns: upstream landowners were experiencing a 1.2 benefit-cost ratio and downstream consumers were experiencing a benefit-cost ratio of around 1.3. Even with overpaying for corn, the program provides a significant net benefit.

Improving source watersheds through agricultural best management practices is possible in many other places around the world as well (Figure 3-2).

WHERE ELSE COULD THIS PRACTICE HELP?

Figure 3-2

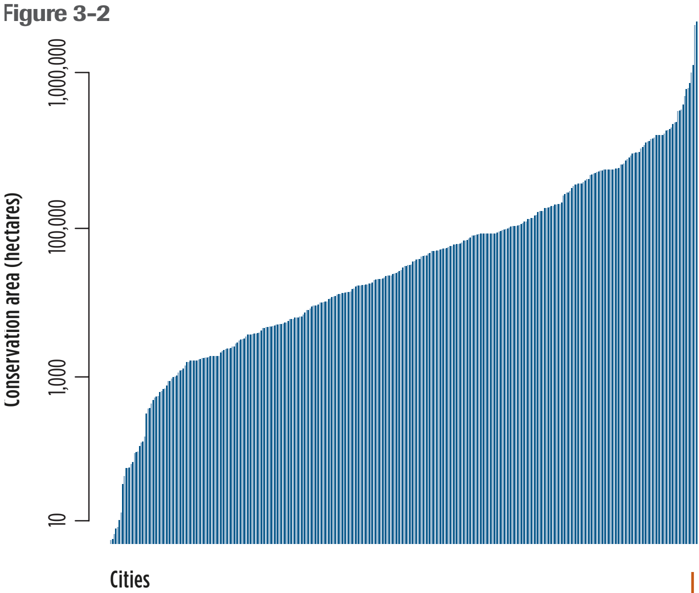


Figure 3-2. Area of Ag. BMPs to get a 10 percent reduction in phosphorus

The area of agricultural BMPs needed to get a 10 percent reduction in phosphorus varies widely across cities. Note that as Beijing relies primarily on groundwater, it is not one of the cities shown in the bar graph.

- 347 of 550 cities could reduce phosphorus by 10 percent.
- Median hectares for phosphorus is 15,000; varies from less than 10 hectares to more than 10,000,000 hectares
- Cities in the top 100 where the least area is needed to achieve a 10 percent reduction in phosphorus:
  - Boston, MA, United States
  - San Francisco, CA, United States
  - New York, NY, United States
  - Shenzhen, China
  - Bogota, Colombia

Figure 3-3

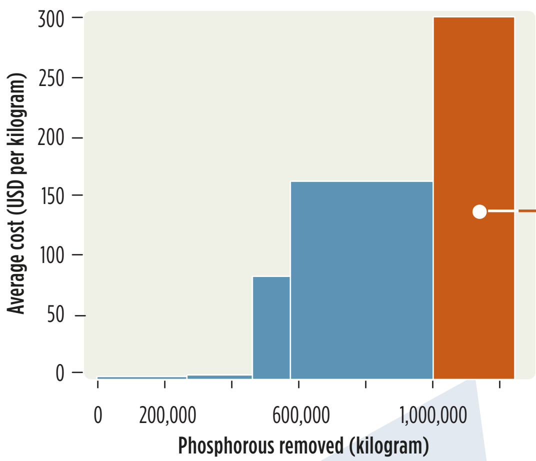


Figure 3-3. Beijing watersheds, Ag. BMPs to remove 10 percent of phosphorus

The cost of using agricultural BMPs to reduce nutrients by 10 percent for Beijing's sources.

- Beijing's five surface sources vary in phosphorus removal cost from US $1.4 per kilogram to US $297 per kilogram.

Figure 3-4

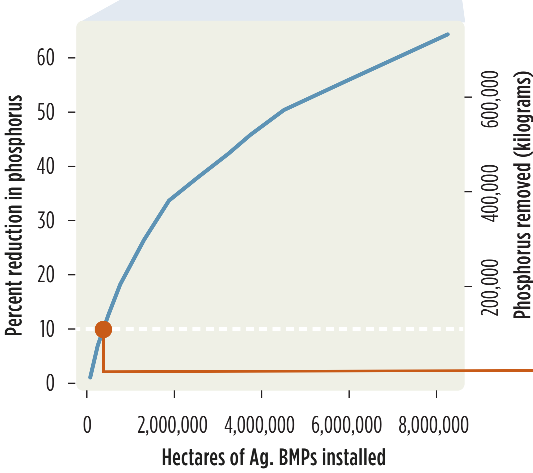
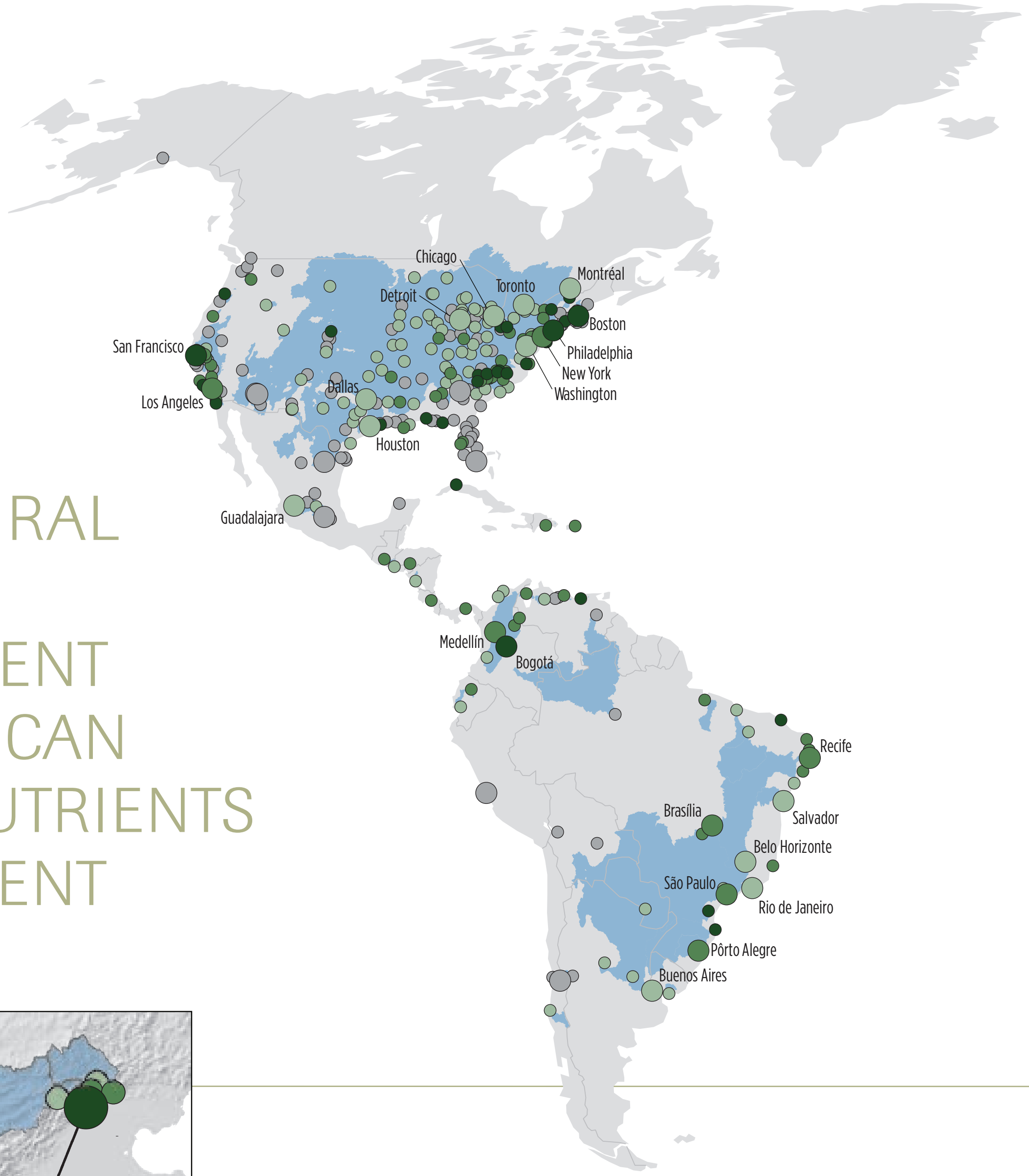


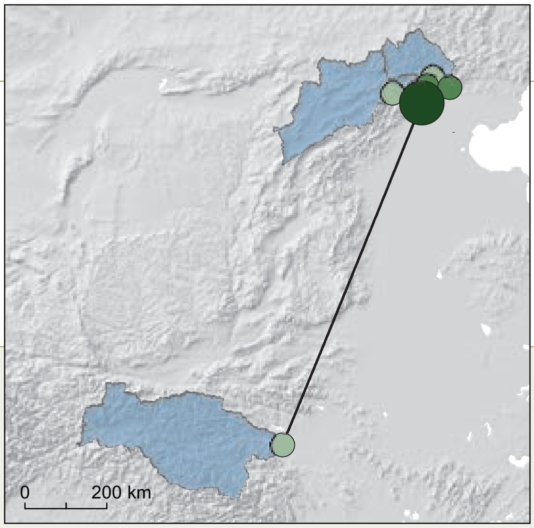
Figure 3-4. Miyun Reservoir, Beijing water system

The reduction in nutrients that could be achieved through agricultural BMPs at one Beijing source.

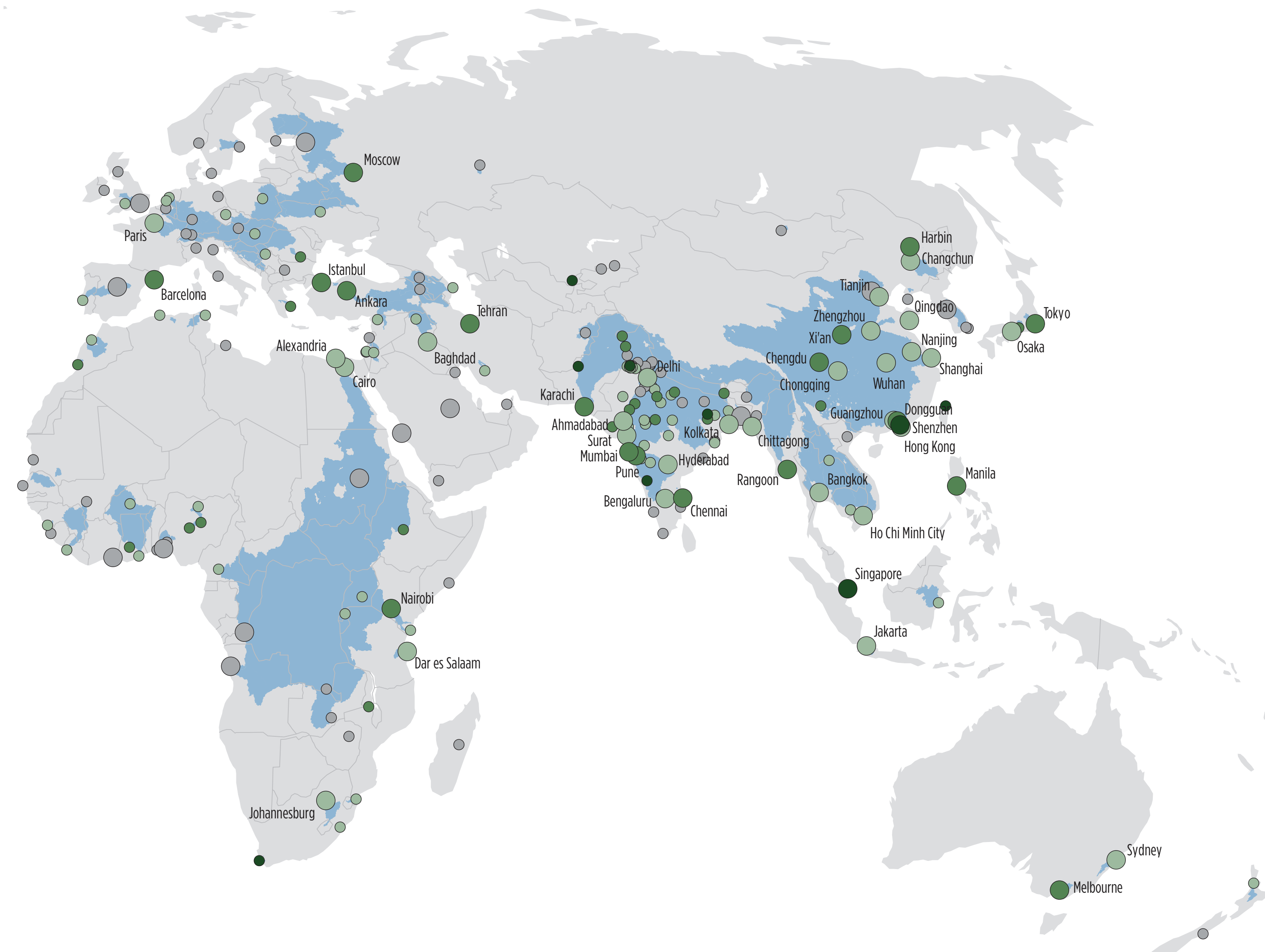
- Miyun reservoir could reduce sediment by 10 percent by implementing agricultural BMPs on 17,000 hectares.

WHERE AGRICULTURAL BEST MANAGEMENT PRACTICES CAN REDUCE NUTRIENTS BY 10 PERCENT





Beijing, China



Conservation Area

100 largest cities
Other cities with source data

< 1,000 hectares
1,000 – 10,000 hectares
> 10,000 hectares
Other cities

Source watersheds for mapped cities

(Color indicates scale of intervention required)

Area of cropland upstream, in hectares, on which best management practices (eg. cover crops) would need to be installed to reduce the amount of nutrients entering surface water sources by 10 percent.

Manila—Riparian restoration to reduce erosion

Photo: ©Andrew Hautzinger

Weather and topography suggest that the city of Manila should not run short of freshwater. After all, the Philippines receives abundant rainfall and numerous rivers and streams provide ready access to water. Yet, almost a quarter of the country's population of 100 million still do not have access to potable water on a sustained basis because there are few investment opportunities for infrastructure development for public water supply.

The 15 million people who live in and around metropolitan Manila get nearly all of their water from three watersheds—Angat, Ipo, and La Mesa—located in Quezon and Bulacan provinces. These watersheds provide over 4 million liters per day of water, just enough to meet current demand. But Manila is growing rapidly, and rainfall patterns are changing as a result of climate change and repeated El Niño events. In the next few decades, Manila could face significant water shortages. No new water sources have been developed for Manila in some 40 years.

Both the public and private sectors have been actively looking for solutions. Water privatization began in Manila in 1997, and today it is the largest population served by private operators anywhere in the developing world.

One of the private concessionaires in Manila is the Manila Water Company, and it is often held up as an example of successful privatization. Through aggressive strategies, since 1997 it has reduced nonrevenue water from 63 percent before privatization to just 11 percent, an effort that by itself was the equivalent of constructing a new dam. Its flagship program, Tubig Para Sa Barangay, or Water for the Poor has connected nearly 2 million people in low-income communities to the water network, significantly reducing disease and improving health and sanitation.

The Metropolitan Waterworks and Sewerage System (MWSS), the government agency responsible for the country's water infrastructure, is looking for new water sources to meet the projected demand, sources that must be resilient to the impact of climate change. New built infrastructure like dams and treatment plants will be part of the solution, but the existing sources must be protected. While the Angat Watershed is largely intact, only 40 percent of the Ipo Watershed retains its forest cover.

Reforestation of riparian areas has thus become an important strategy for Manila Water, along with the city's other concessionaire (Maynilad), and MWSS. They have adopted a variety of methods, including an Adopt-a-Watershed program in partnership with various stakeholders that helps volunteers to replant denuded hillsides. In Ipo Watershed, the city and the water concessionaires have already reforested a total of 560 hectares. Manila Water, in partnership with various academic, private, and public organizations, planted more than 88,000 trees in about 155 hectares of Ipo Watershed. Maynilad also reforested about 190 hectares of Ipo in partnership with volunteer organizations.

Using this scientific approach, MWSS announced in 2012 that it would reforest nearly 5,000 hectares including riparian areas by 2016. This will be coupled with a standardized watershed protection program, which will be applied to watersheds all over the country. MWSS is also working closely with the Dumagats, an indigenous group residing in the watershed, and the Philippine President, Benigno Aquino III, even considered deploying the army to help protect the watershed.

One success has been uniting watershed protection with eco-tourism. The La Mesa Ecopark, just ten miles northeast of downtown Manila, lies at the foot of the vital La Mesa dam and reservoir. Now a popular destination for city residents who come for the swimming pool, picnic pavilions, climbing wall, and zipline, it was a former wasteland: 15 years ago illegal loggers and settlers had stripped it nearly bare.

Efforts began in 1999 to reforest 1,500 hectares of the La Mesa Ecopark and Nature Reserve. Visitors pay an entry fee of just over US $1 to help cover the costs of conservation. Each hectare costs approximately US $1,500 to reforest and maintain. On an average weekend day some 4,500 people visit the park, and 800 visit on weekdays. Nearly 700,000 trees have been planted, and only 200 hectares now remain to be reforested.

The ecopark is just one element in the broad effort to secure Manila's water. Manila Water and MWSS are working on an integrated watershed management system for all the watersheds that supply the city. They are learning that investing in nature must be a fundamental part of their strategy, and that it is an investment that will pay significant dividends.

WHERE ELSE COULD THIS PRACTICE HELP?

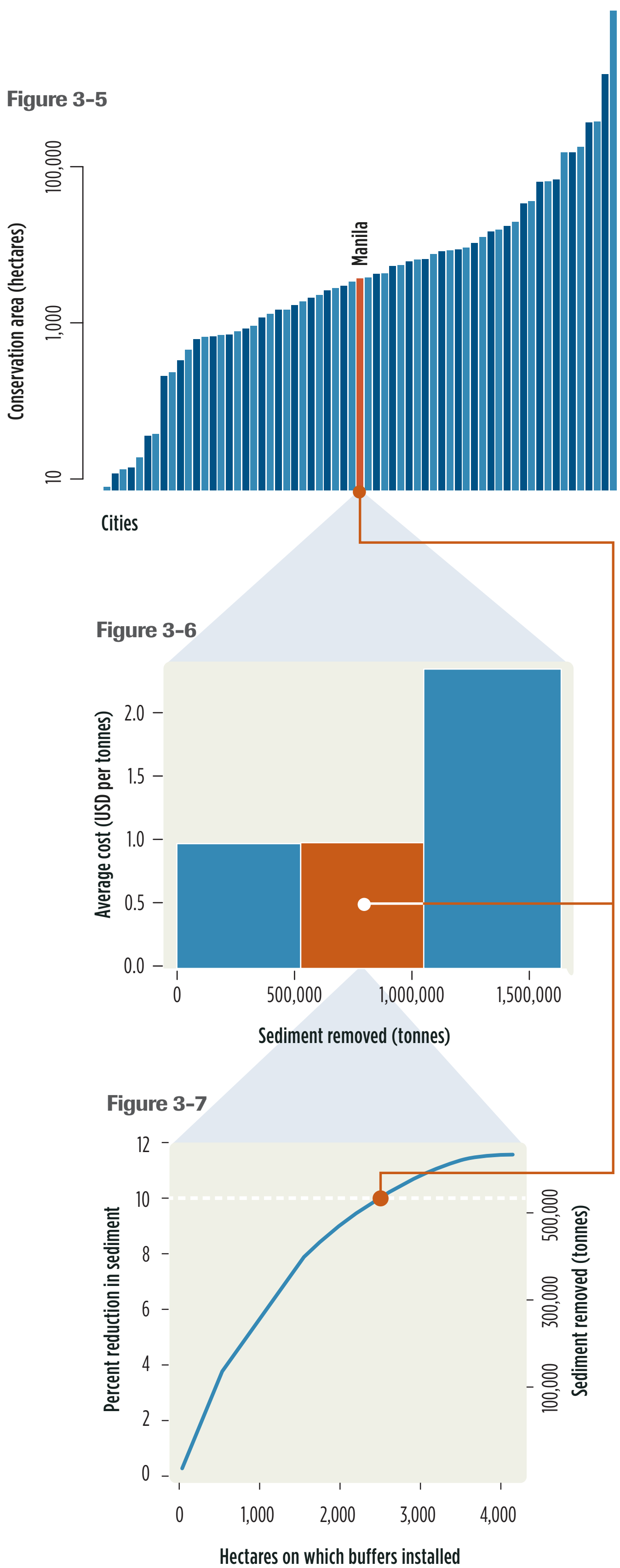


Figure 3-5. Hectares with buffers to get a 10 percent in sediment

The area of riparian restoration needed to get a 10 percent reduction in sediment varies widely across cities.

- 63 of 550 cities could reduce sediment by 10 percent.
- Median hectares for sediment is 3,700; varies from less than 10 hectares to more than 100,000 hectares.
- Cities in the top 100 where the least area is needed to achieve a 10 percent reduction in sediment:
  - Medellín, Colombia
  - Recife, Brazil
  - Harbin, China
  - Mumbai, India
  - São Paulo, Brazil

Figure 3-6. Manila watersheds, buffers to remove 10 percent of sediment

The cost of using riparian restoration (buffers) to reduce sediment by 10 percent for Manila's sources

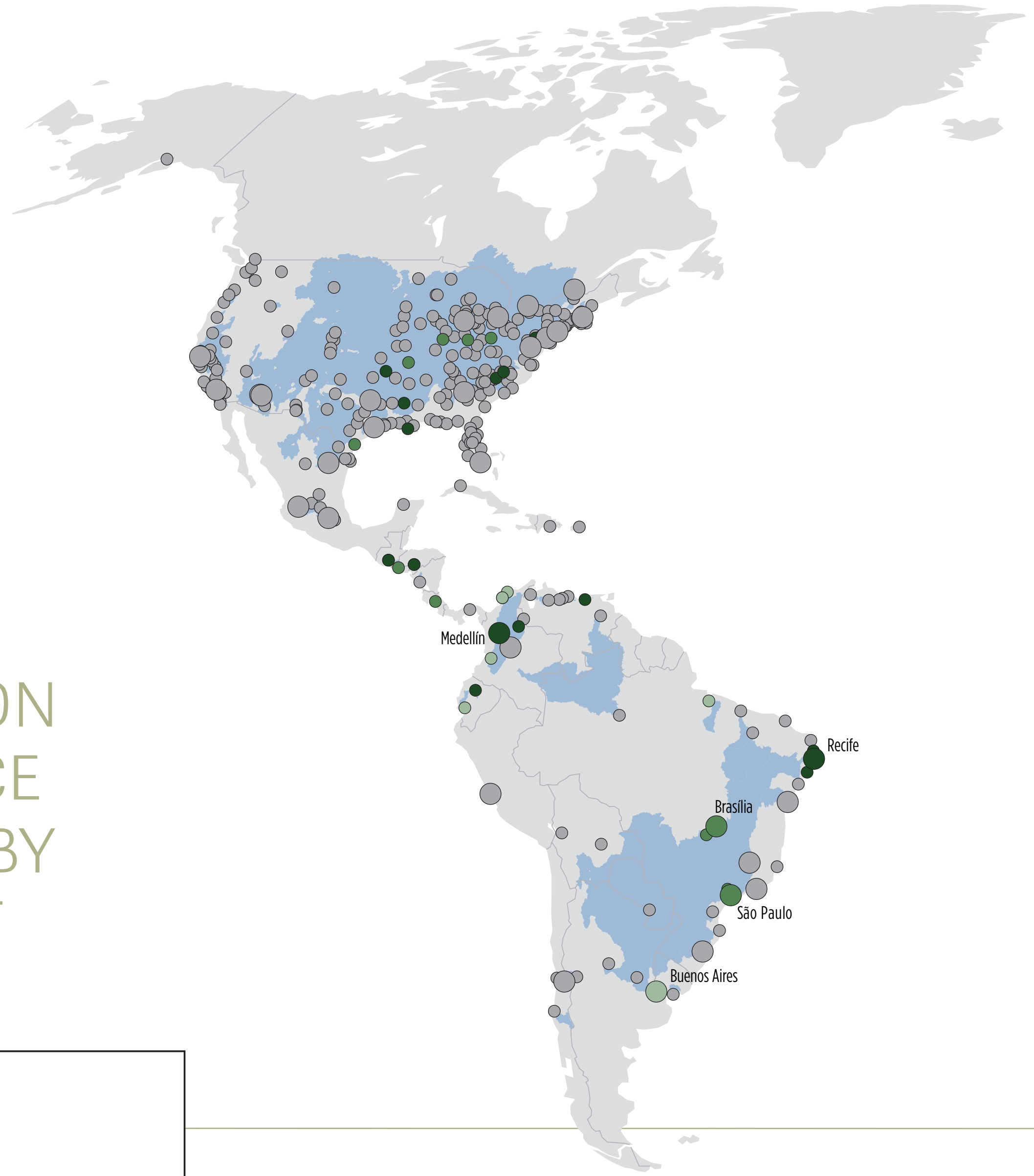
- Manila's three surface sources vary in cost effectiveness for reducing sediment from US $1.0 to US $2.4 per tonne.

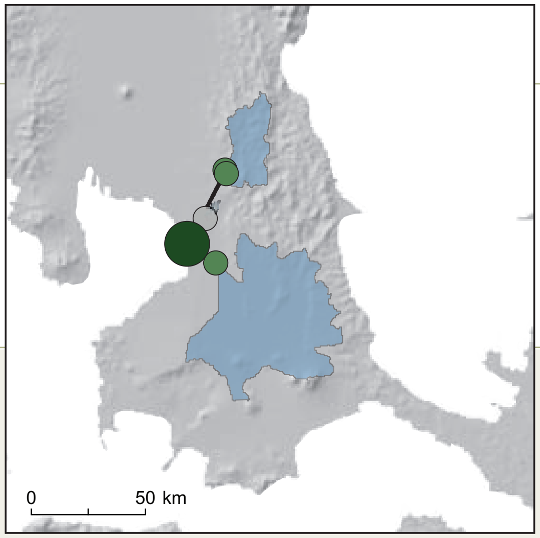
Figure 3-7. Angat Reservoir, Manila

The reduction in sediment that could be achieved through riparian restoration at one Manila source.

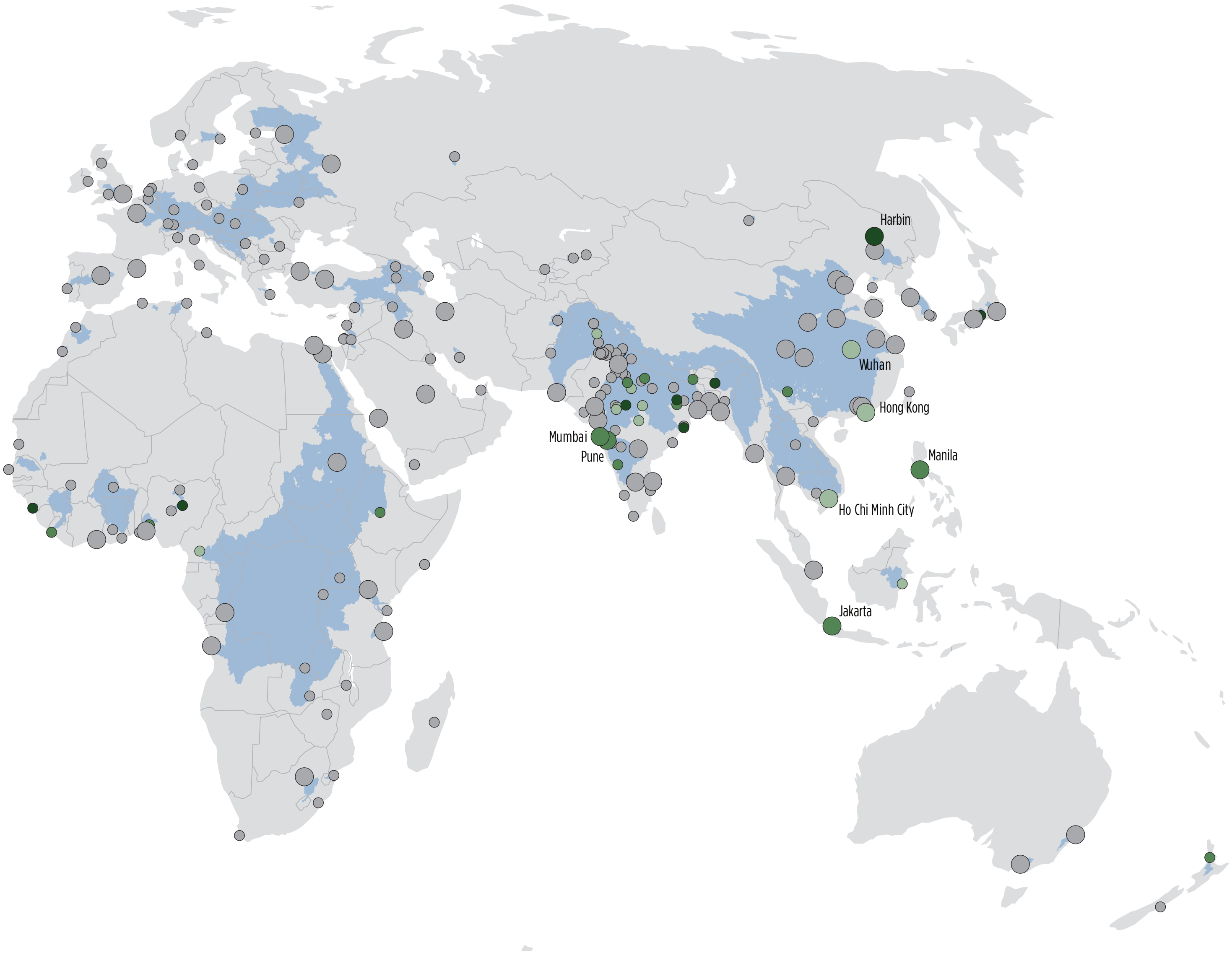
- Angat reservoir could reduce sediment by 10 percent by installing riparian restoration on 2,500 hectares.

WHERE RIPARIAN RESTORATION CAN REDUCE SEDIMENT BY 10 PERCENT





Manila, Philippines



Conservation Area

100 largest cities
Other cities with source data
< 1,000 hectares
1,000 – 10,000 hectares
> 10,000 hectares
Other cities
Source watersheds for mapped cities

(Color indicates scale of intervention required)

Area of cropland upstream, in hectares, on which riparian restoration would need to be restored to natural land cover to reduce the amount of sediment entering surface water sources by 10 percent.

Santa Fe and Albuquerque—Forest fuel reduction to reduce wildfire risk


Photo: ©Chris Crisman

Years of drought and fire suppression have left many watersheds in the Southwestern United States dry, dense and ready to burn when lightning strikes. To reduce the risk of catastrophic fires, foresters restore natural forest density by thinning accumulated fuel, such as low brush and branches, or prevent the spread of fires by creating a fire line. In the spring of 2000, foresters targeted a controlled burn to address tree encroachment in a high-elevation meadow 15 miles southwest of the city of Los Alamos.

Fire is a complex thing, sometimes beyond the control of even the most seasoned managers. In 2000, a stray ember and the vagaries of weather, topography, human error, urgency, and climate change led to a cascading series of events that turned this routine burn into a raging fire that sent 20,000 hectares up in flames, the largest wildfire in New Mexico's history. Hundreds of people in Los Alamos lost their homes, and the Cerro Grande fire remains vivid in residents' memories.

Just 25 miles away, on the other side of the Rio Grande and the Caja del Rio, residents of Santa Fe watched anxiously, and not just because of the unnerving possibility that nuclear material stored at Los Alamos would catch fire. People feared that a fire this intense in the watersheds above the city would strip the hillsides bare, and subsequent rains would carry topsoil, ash, and debris into streams and rivers, and eventually reservoirs. That is exactly what happened in Los Alamos; one year after the fire, reservoir sediment accumulation was 140 times higher than the previous 57 years combined, and remained significantly elevated for five years. The cost to clean up the damage to the water supply was US $17 million.

Santa Fe city leaders realized they were at even greater risk. The population is far larger than Los Alamos, and the city depends on just two reservoirs within the Santa Fe National Forest for a third of its water. A fire the scale of Cerro Grande on those hills could leave the reservoirs useless.

Shortly after the Cerro Grande fire, city officials in Santa Fe received US $7 million in federal funding to begin thinning forests in the Santa Fe River watershed, using chainsaws and other equipment because it was too dangerous to burn. But this was just the beginning. The city estimated it would need roughly US $250,000 per year for 20 years to enact a comprehensive watershed management plan, including a plan to burn every hectare with low-intensity fires once every seven years, a rough approximation of what once happened naturally; these forests typically burn every four to 11 years.

A quarter million dollar expense is no trifle for a city the size of Santa Fe, which has a population of fewer than 70,000. But it is a simple choice because the cost of inaction is vastly greater: a 2,800 hectare wildfire in the Santa Fe River watershed would cause damages of approximately US $22 million. That includes the price of fire suppression and dredging of ash-laden sediment from the reservoirs.

Investing in forest fuel reduction to reduce the risk of fire was the economically sensible thing to do, even though it comes on the heels of a major infrastructure project, the Buckman Diversion, to bring water to the city from the Rio Grande River. So while the city of Santa Fe was developing its watershed plan, Laura McCarthy from The Nature Conservancy began to explore how to use revenues from urban water users to help fund those efforts, looking to replicate the success of similar water funds in Latin America.

When the final Santa Fe Municipal Watershed Plan was published in 2009, it included the idea of a ratepayer contribution program. In a rare stroke of good fortune, the Buckman Diversion came in under budget, so there was no need to raise rates to pay for efforts to maintain the watershed. Nevertheless, education efforts have been so successful that there is broad public support for the idea of paying to protect the city's water supply from the risk of catastrophic wildfire. A March 2011 poll found that 82 percent of ratepayers were willing to pay a charge of 65 cents per month, while the plan actually costs only about 54 cents per month for the average household.

In many ways, Santa Fe can serve as a "proof of concept" for how cities in the United States can successfully invest in watershed conservation. The next step is to apply this same water fund model to the much larger Rio Grande watershed that supplies the city of Albuquerque and surrounding communities. This analysis suggests that it would take some 324,000 hectares of forest thinning to get to a 10 percent reduction in sediment risk in Albuquerque (see Figure 24). New Mexico's experience demonstrates that while people across the West are exquisitely attuned to the risks of fire, many also support the idea of using preventative measures like prescribed burns to manage forests. More than ever, they understand the connection between the forests, the fires, and the water they need to survive.

WHERE ELSE COULD THIS PRACTICE HELP?

Figure 3-8

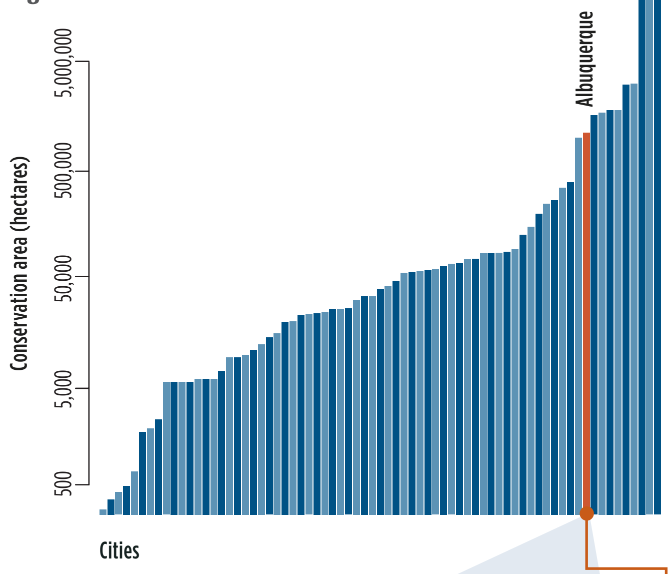


Figure 3-9

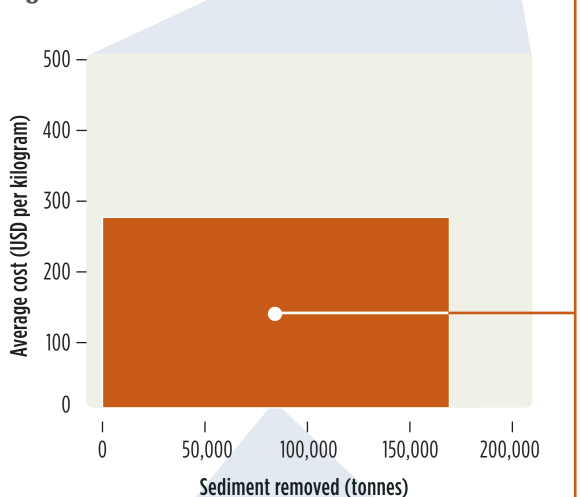


Figure 3-10

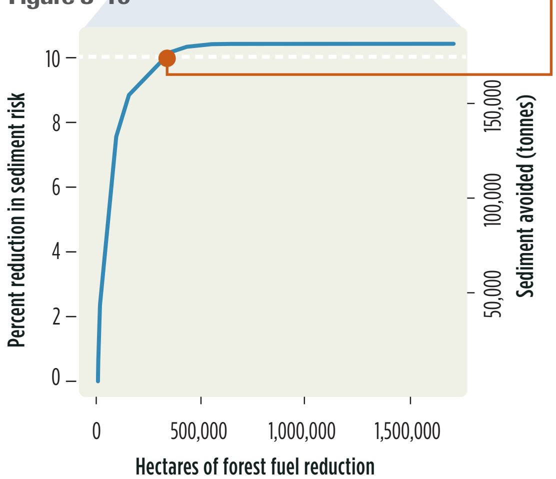


Figure 3-8. Forest fuel reduction to reduce sediment risk 10 percent

The area of forest fuel reduction needed to get a 10 percent reduction in sediment risk varies widely across cities.

- 71 of 550 cities could reduce sediment by 10 percent.
- Median hectares for sediment is 12,800; varies from less than 100 hectares to more than 5,000,000 hectares.
- Cities in the top 100 where the least area is needed to achieve a 10 percent reduction in sediment risk:
  - Los Angeles, CA, United States
  - Melbourne, Australia
  - Sydney, Australia
  - Dar es Salaam, Tanzania
  - Monterrey, Mexico

Figure 3-9. Albuquerque, forest fuel reduction to reduce sediment risk 10 percent

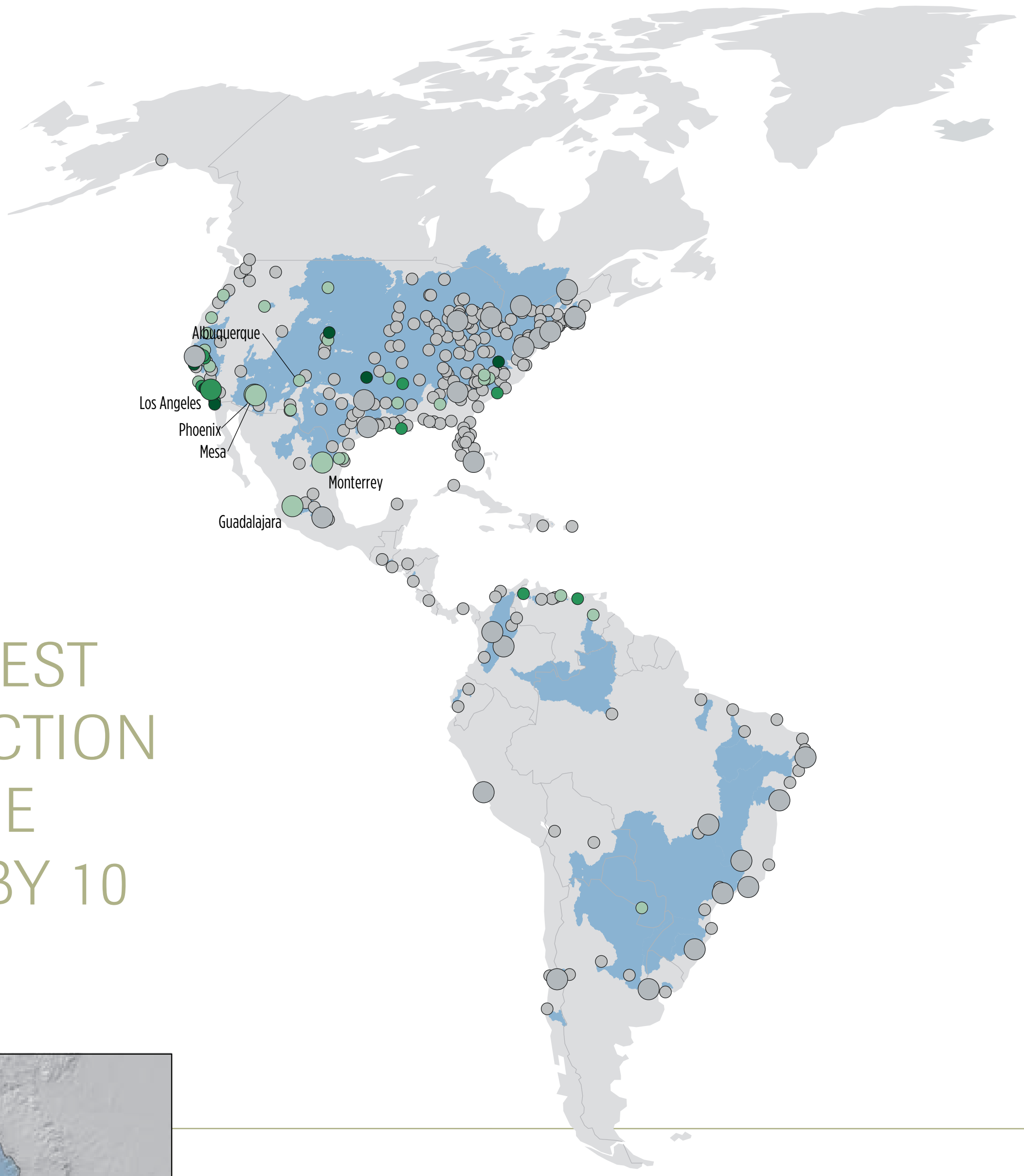
The cost of using forest fuel reduction to reduce sediment risk by 10 percent for Albuquerque's sources.

- Albuquerque's sole surface source has an average cost of US $270 per ton of sediment risk reduced.

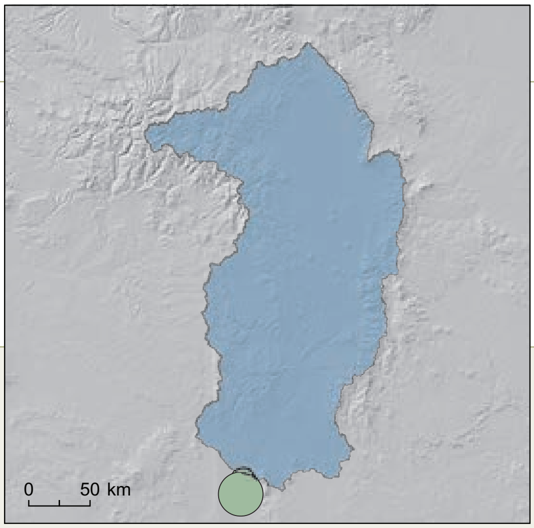
Figure 3-10. Rio Grande, Albuquerque water

The reduction in sediment risk that could be achieved through forest fuel reduction at one Albuquerque source.

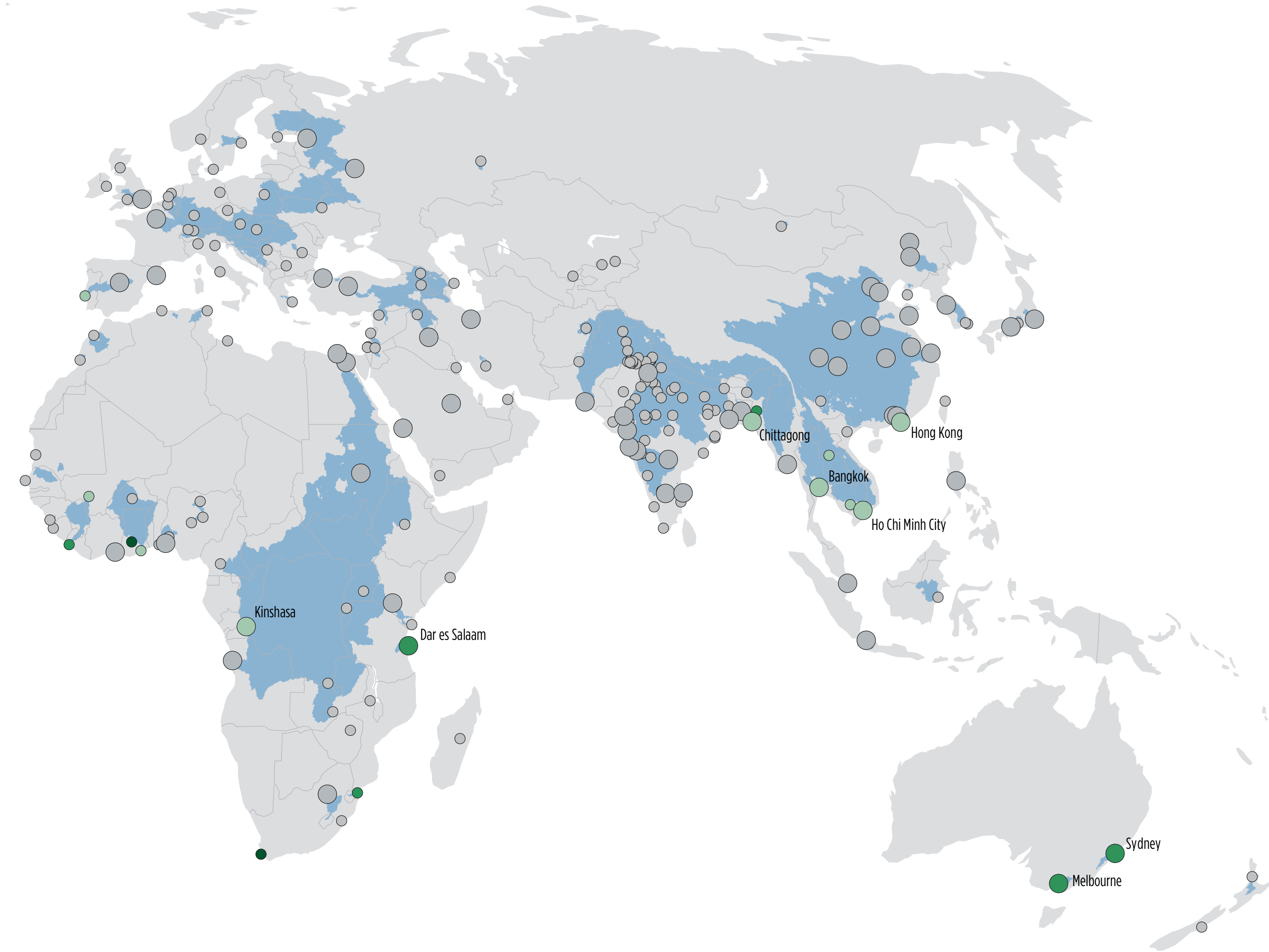
- Albuquerque's intake on the Rio Grande could reduce sediment risk by 10 percent by conducting forest fuel reduction on 350,000 hectares.

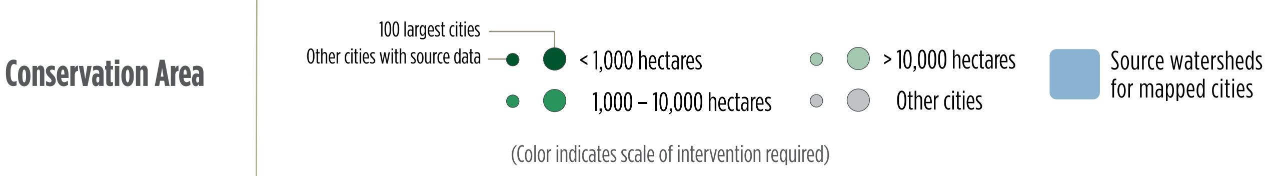


WHERE FOREST FUEL REDUCTION CAN REDUCE SEDIMENT BY 10 PERCENT



Albuquerque, New Mexico





Area of forested land, in hectares, upstream prone to burn which would need to be thinned to reduce by 10 percent the risk of an increase in sediment.

São Paulo—Reforestation to reduce erosion and nutrient runoff


Photo: ©Mark Godfrey

Paulo Henrique Pereira's office is full of awards. As Secretary of Environment for Brazil's Extrema municipality, about 100 kilometers from São Paolo, the energetic Pereira is a key figure in Extrema's history of proactive watershed management, which has been recognized around the world and accounts for the overflowing international recognition.

Perhaps the most telling feature of Extrema's approach to water management lies just past the office walls, not in the plaques and proclamations that adorn them. Right next to the building where Pereira works is a tree nursery containing more than a hundred different species. The trees are destined to be replanted in hydrologically sensitive areas—along rivers and on steep slopes north of the city. The investment in reforestation is part of Brazil's first Water Producer Program, an innovative program to protect the water supply of Extrema's 25,000 residents along with the larger Cantareira water system that supplies São Paulo.

The Cantareira water system supplies nearly half of São Paulo's water by moving it between different basins. The Cantareira watersheds have lost 70 percent of their original forest cover, aggravating the sedimentation of rivers and dams and decreasing their ability to supply water. Sediment from eroding hillsides has reached the reservoirs that supply São Paulo, reducing their capacity.

Every cubic meter of storage has never been more important to Brazil's largest city which represents 23 percent of the country's GDP and is currently suffering one of the worst droughts since records began in 1930. Pitiful rainfall and high rates of evaporation in scorching heat have caused the volume of water stored in the Cantareira system to dip to less than 10 percent of capacity. As an emergency stopgap to provide water to the city, the government of São Paulo spent US $36 million on emergency constructions to allow access to water stored below the level of the pumps. Known to water managers as "dead volume," this water was never intended to be part of the water supply, and the reservoirs are now, essentially, operating at a deficit. The prospect that the largest metropolis in South America could literally run out of water in the foreseeable future is no longer a nightmare, but the waking reality of its governor and state water utility.

Pereira and others in Extrema saw the problems earlier than most, as well as the opportunities. In 2005, the municipality established the first water payment for ecosystem services (PES) scheme in Brazil, Conservador das Águas. The program pays farmers and ranchers US $120 per hectare to reforest or terrace their fields, among other strategies to improve water quality. The money for the program comes from Extrema's budget, the São Paulo watershed committee, and Brazil's federal government. The federal watershed committee collects fees from water users that then go to the farmers and ranchers who protect or restore riparian forests on their lands.

So far, about 3,500 hectares have been reforested or put under improved soil management practices through the program. An analysis by TNC-Brazil suggests that restoring an additional 14,200 hectares of deforested areas and preventing erosion on just over 2,000 hectares within the basins of the Piracicaba, Capivari, Jundiaí, and Alto Tietê rivers can cut the concentration of sediment of the entire system in half. Such strategic investment can bring enormous benefits to more than 13 million inhabitants of the São Paulo Metropolitan Region who also get their drinking water from the Cantareira water system; the investment also benefits Extrema, while helping farmers and ranchers to stay on their land.

But that only hints at the potential. Reforestation can also measurably reduce the nutrient loading in São Paulo's water supply, as it can in over 247 other cities worldwide. "People who allow nature to produce clean air and water on their lands—by letting their forests grow, for example—should be financially compensated for what they produce, just like a farmer earns money for the crops he sells," Pereira says. "Changing our thinking about producing and valuing these resources is the only way we're going to get these areas that protect our resources properly restored."

WHERE ELSE COULD THIS PRACTICE HELP?

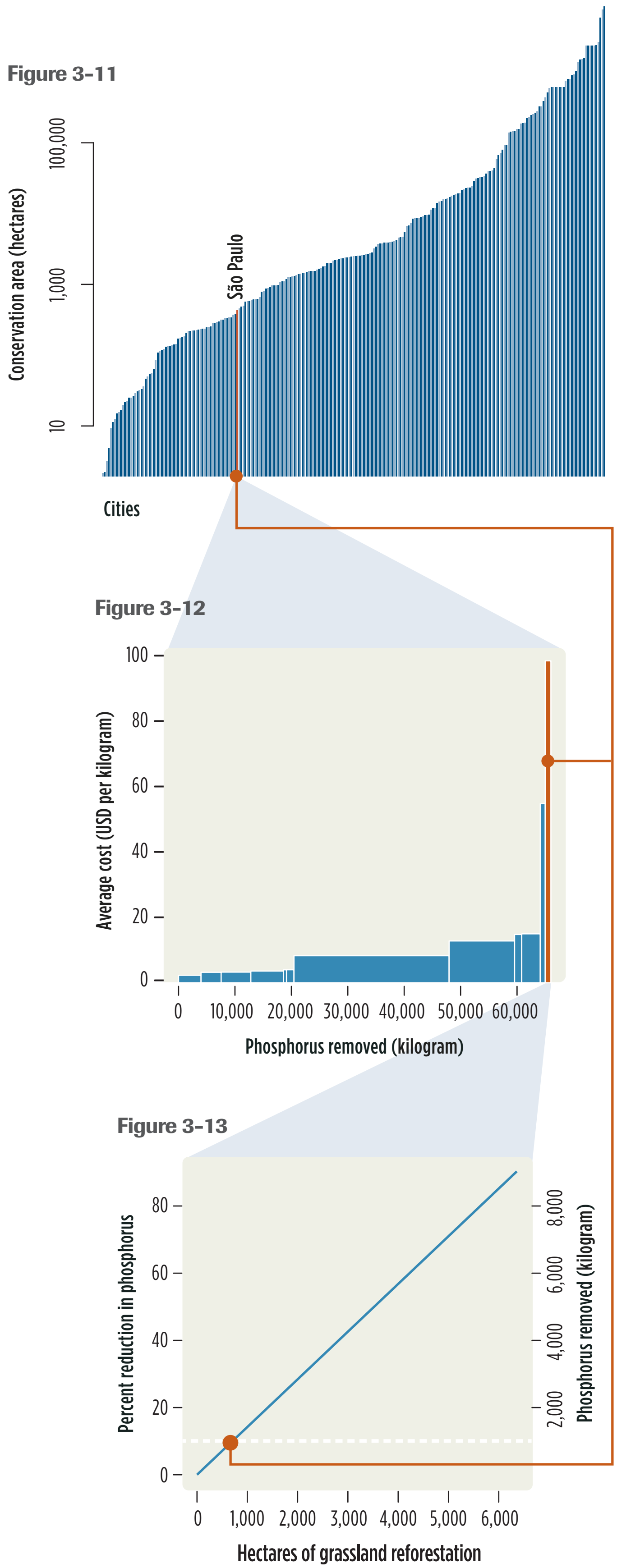


Figure 3-11. Area of reforestation to get a 10 percent reduction in phosphorus

The area of reforestation needed to get a 10 percent reduction in phosphorus varies widely across cities.

- 247 of 550 cities could reduce phosphorus by 10 percent.
- Median hectares for phosphorus is 2,400; varies from less than10 hectares to more than 100,000 hectares.
- Cities in the top 100 where the least area is needed to achieve a 10 percent reduction in phosphorus:
  - Boston, MA, United States
  - Harbin, China
  - San Francisco, CA, United States
  - Melbourne, Australia
  - New York, New York, United States

Figure 3-12. São Paulo, reforestation to remove 10 percent of phosphorus

The cost of using reforestation to reduce nutrients by 10 percent for São Paulo's sources.

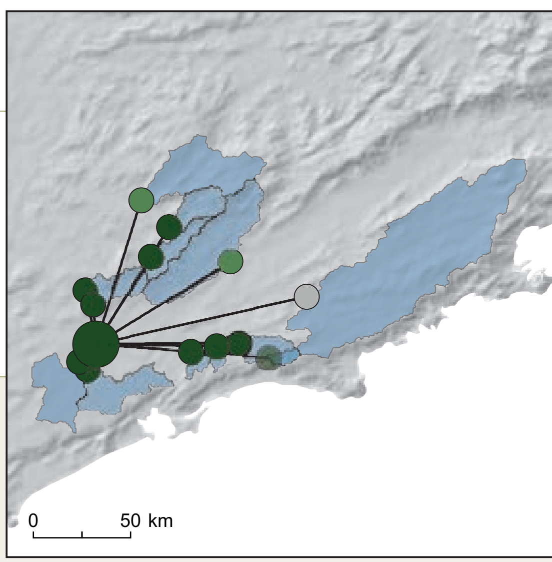
- São Paulo's 12 surface sources vary in cost effectiveness for reducing phosphorus from US $2.3 to US $98.4 per kilogram.

Figure 3-13. Guarapiranga Reservoir

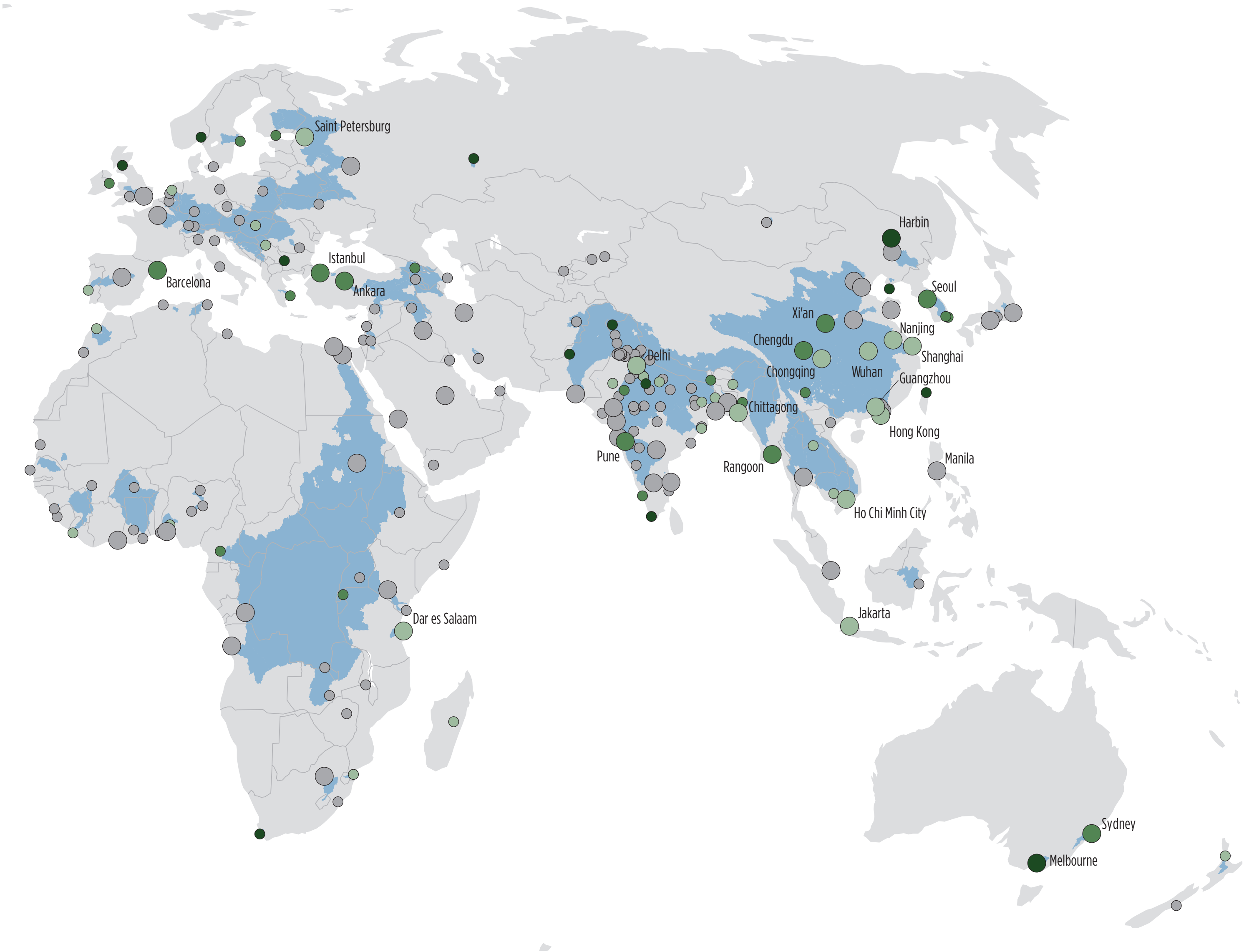
The reduction in nutrients that could be achieved through reforestation at one São Paulo source.

- The Guarapiranga Reservoir of São Paulo could reduce phosphorus by 10 percent by reforesting pastureland on 700 hectares.
- The linear shape of the blue line is due to the lack of spatial variation in nutrient loading among the limited pastureland in this watershed. According to our coarse global data, reforestation on one pasture is as good as reforestation on another.

WHERE REFORESTATION CAN REDUCE NUTRIENTS BY 10 PERCENT



São Paulo, Brazil



Conservation Area

100 largest cities
Other cities with source data

< 1,000 hectares
1,000 – 10,000 hectares
> 10,000 hectares
Other cities
Source watersheds for mapped cities

(Color indicates scale of intervention required)

Area of pastureland upstream, in hectares, which would need to be reforested to reduce the amount of phosphorus entering surface water sources by 10 percent.

Cape Town—Forest protection and management to reduce erosion

The City of Cape Town, South Africa, has one significant water supply advantage over many other cities. Since it sits in the heart of one of the most biologically diverse areas on Earth, a 78,000 square kilometer area called the Cape Floristic Region, much of Cape Town's land is already under some type of formal land protection. In the three major water source areas for the city — Boland Mountains, Groot Winterhoek and Table Mountain — some 60 percent of the land is protected. The nature conservation agencies managing the protected areas from where Cape Town extracts significant water include the Cape Peninsula National Park and Cape Nature.

So, unlike many cities, Cape Town does not need to invest heavily in buying and setting aside protected areas. What it does need to do, however, is ensure that the water source areas stay healthy.

The biggest threat in South Africa, both inside and outside the protected estate, are invasive plants like pine, acacia, and eucalyptus that escape from commercial plantations and woodlots. The invasive plants take up enormous amounts of water, reducing the flow into streams and reservoirs. The problem is most severe in the region around Cape Town, where invasive plants have reduced annual runoff by nearly one-third. One study estimates that invasives in South Africa cover 9.7 million hectares, and use 1 billion cubic meters of water in excess of that used by native vegetation every year (almost 7 percent of the runoff of the country). If left unchecked, the economic losses could increase to more than US $3.8 billion.

One solution is an innovative program called Working for Water that addresses both poverty and water scarcity while maintaining the ecological integrity of the landscapes – many of which provide habitat for species found nowhere else on Earth. Funded by the national government as an environment and job creation program, Working for Water employs about 32,000 low-skilled workers every year to remove invasive plants. In partnership with this program, the City of Cape Town controls invasive plants in the water source area of the Wemmershoek Dam, one of the main dams supplying water to Cape Town as well as in the Peninsula watershed. The city also controls aquatic weeds on its various rivers within the city to improve the health of the freshwater ecosystems.

When the Working for Water program began operations in 1995 it focused largely on land within protected areas, though it has now expanded beyond those boundaries as well. For example, the Trans Caledon Tunnel Authority, which manages the Berg River Dam, concluded that payments for watershed services would be a worthwhile financial investment and signed a contract to pay US $750,000 to Working for Water over three years to clear the watershed that supplies its water. The project cleared invasive plants from more than 13,000 hectares, resulting in annual long-term stream flow gains of between 1.8 and 2.6 million cubic meters. On the other hand, if nothing had been done and invasive plants had been allowed to completely overtake the area, annual water losses could have increased to between 4.3 and 6.2 million cubic meters.

Cape Town has relatively few options for increasing its water supply. Desalination plants and massive infrastructure projects to bring water from wetter areas of the country thousands of miles away, are not economically viable and would take years, if they were possible at all. The city will need to be more efficient in the way it uses water, and wise in the ways it manages the watersheds that provide it. In this case, removing thirsty alien tree species and restoring native vegetation is a critical to safeguarding the water services that forests provide. Since the value of this investment extends beyond Cape Town's water supply to rural economic development and profitable ecotourism, so too has the availability of public funds.

WHERE ELSE COULD THIS PRACTICE HELP?

Figure 3-14

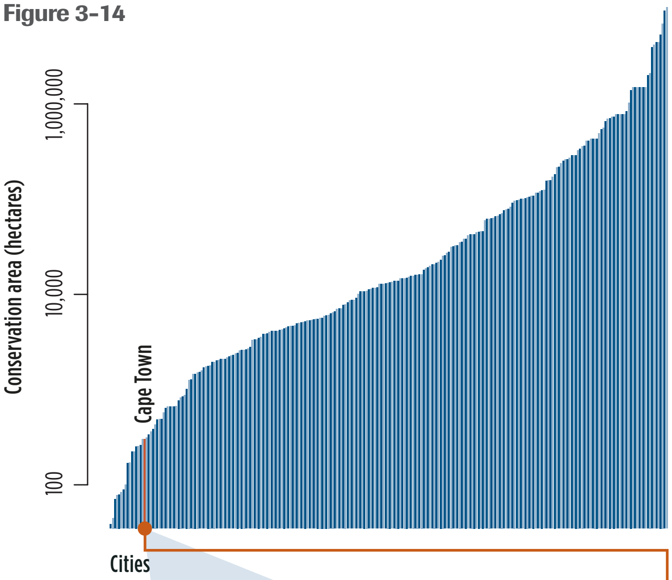


Figure 3-14. Forest protection to reduce sediment risk 10 percent

The area of forest protection needed to get a 10 percent reduction in sediment risk varies widely across cities.

- 264 of 550 cities could reduce sediment risk by 10 percent.
- Median hectares for sediment is 13,000; varies from less than 10 hectares to more than 1,000,000 hectares.
- Cities in the top 100 where the least area is needed to achieve a 10 percent reduction in sediment risk:
  - San Francisco, CA, United States
  - Los Angeles, CA, United States
  - Boston, MA, United States
  - Bogota, Colombia
  - Rangoon, Myanmar

Figure 3-15

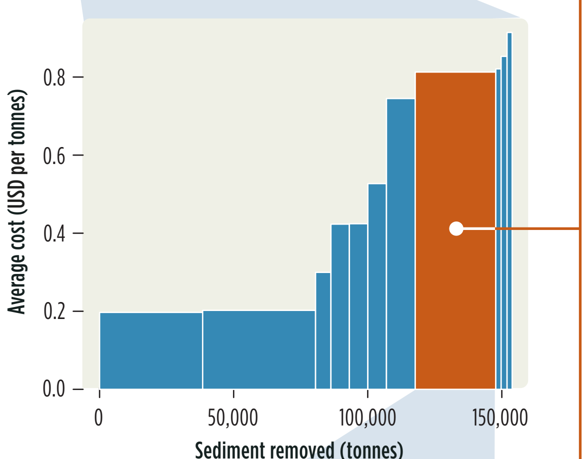


Figure 3-15. Cape Town watersheds, land protection to reduce sediment risk 10 percent

The cost of using forest protection to reduce sediment risk by 10 percent for Cape Town's sources.

- Cape Town's 12 sources vary in cost effectiveness for reducing sediment risk from US $20.1 to US $93.6 per tonne.

Figure 3-16

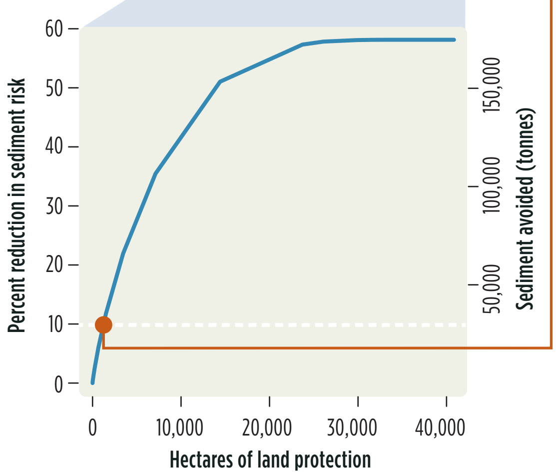
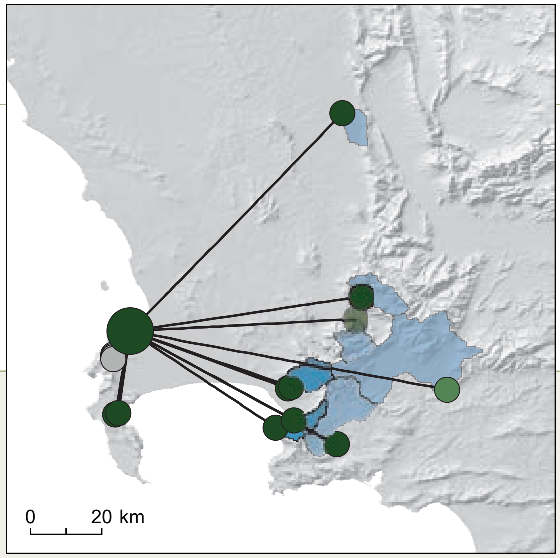


Figure 3-16. Theewaterskloof reservoir, Cape Town system

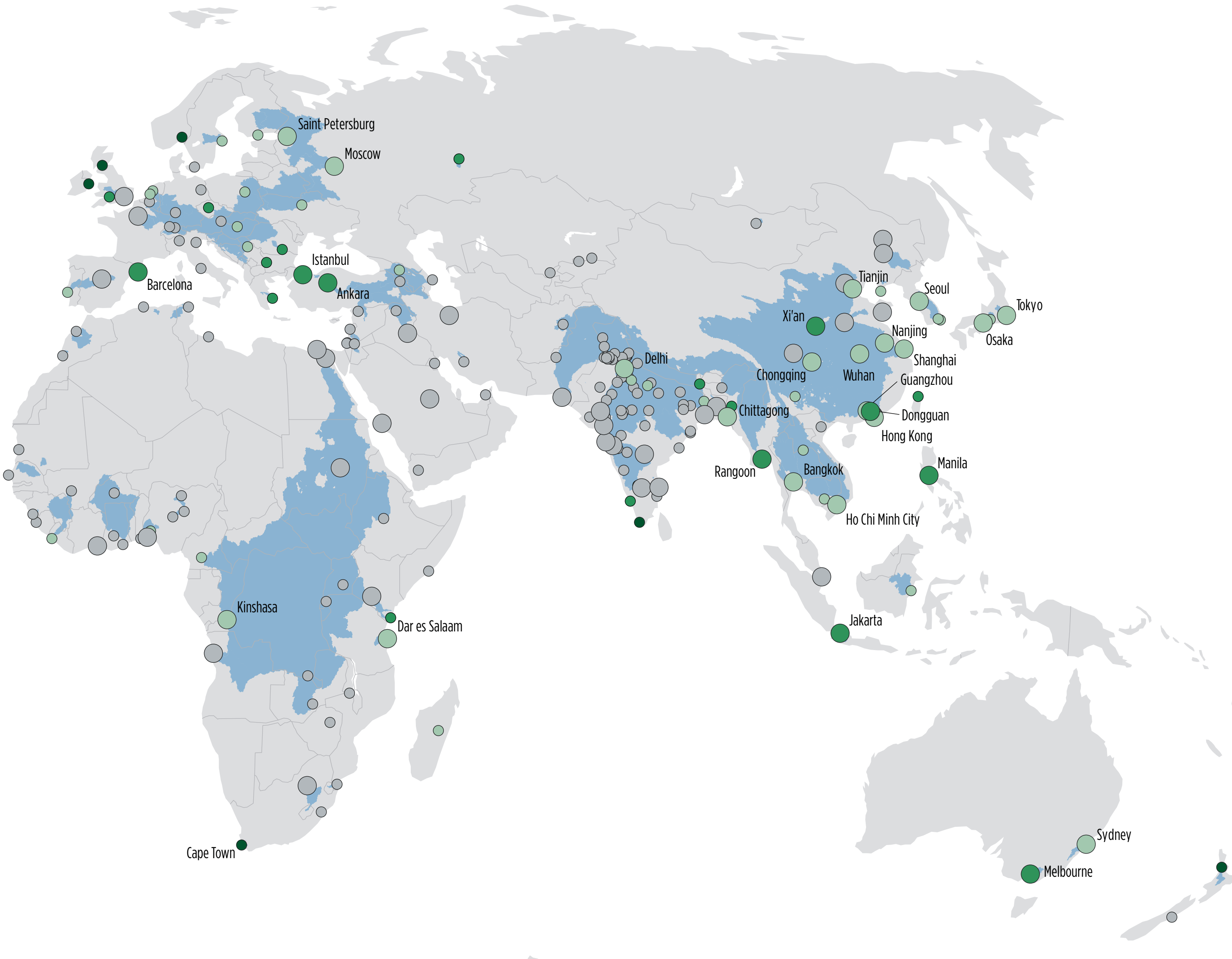
The reduction in sediment risk that could be achieved through forest protection at one Cape Town source.

- Theewaterskloof Reservoir could reduce sediment risk by 10 percent by protecting forest on 1,500 hectares.

WHERE FOREST PROTECTION CAN REDUCE SEDIMENT BY 10 PERCENT



Cape Town, South Africa



Conservation Area

100 largest cities
Other cities with source data

< 1,000 hectares
1,000 – 10,000 hectares
> 10,000 hectares
Other cities

Source watersheds for mapped cities

(Color indicates scale of intervention required)

Area of forested land upstream, in hectares, which would need to be protected to reduce by 10 percent the risk of a future increase in sediment.

600,000,000

Population that would see improved water quality sources if agricultural best management practices were applied to targeted pieces of land.

Photo: ©Erika Nortemann

CHAPTER 4

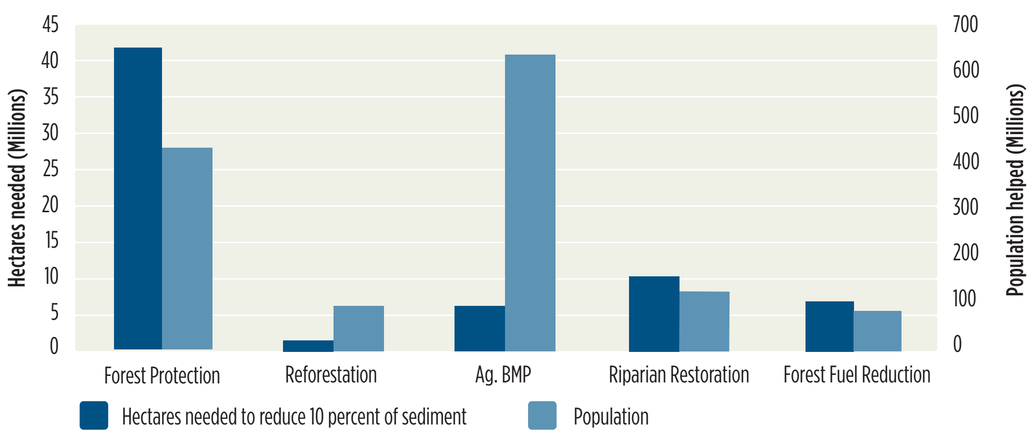
THE RETURN ON INVESTMENT

The global potential for watershed conservation

The five conservation activities presented in Chapter 3, if implemented at sufficient scale, have the potential to significantly improve the quality of water for over 690 million people in the top 100 cities alone. Figure 4-1 shows the cumulative impact of conservation activities on sediment in terms of people affected and hectares impacted.

Conservation activities have different reach and spatial requirements. For example, agricultural best management practices could improve water quality by 10 percent in many cities in the top 100: to reduce sediment yields in watersheds serving 640 million people, agricultural best management practices such as cover crops would need to be applied to approximately 6.4 million hectares. By contrast, applying forest fuel reduction practices to a similar area (7.0 million hectares) would reduce sediment by 10 percent only for a population of roughly 86 million urban residents living mostly in the Western United States and Australia. Targeted reforestation of 1.6 million hectares of pastureland could reduce sediment loads by 10 percent for around 95 million people. The point is that different interventions have vastly different returns, in part because of where they can be used and in part because of their aggregate impacts on the watersheds.

Figure 4-1. Sediment reduction for five common conservation strategies



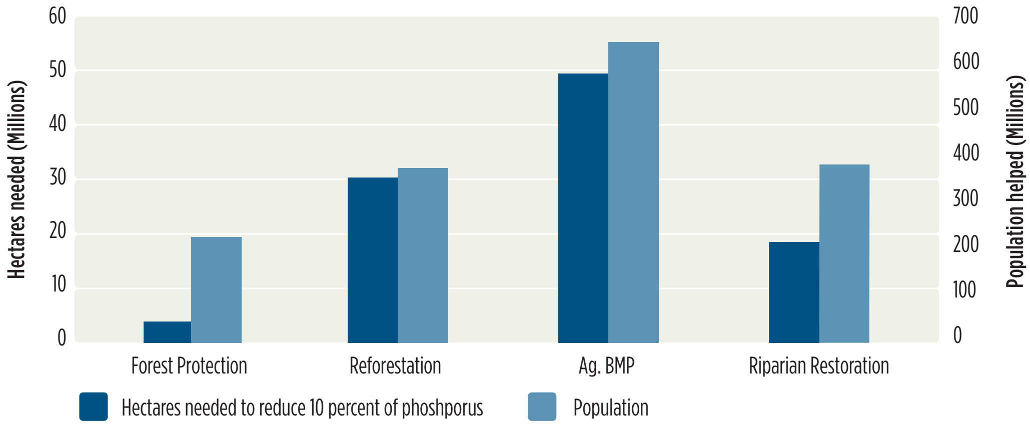
Area needed to conserve to reduce sediment yield 10 percent (comparison of five conservation strategies) in top 100 cities.

Things get more complicated when introducing other effects from conservation. Consider the impact on nutrient loading, for example. If implemented at scale, conservation activities have the potential to reduce phosphorus by 10 percent for over 720 million people in the top 100 cities alone (Figure 4-2).

For example, agricultural best management practices alone could also reduce nutrient loading by 10 percent for 640 million people. However, these practices would have to be applied to 49 million hectares. In contrast, in cities with forested areas, protecting some of that forest — specifically 3.7 million hectares — could reduce the risk of a future increase in nutrients by 10 percent. This strategy would benefit 225 million people.

So the relative weight of different conservation interventions largely depends on the impact that is being sought. In general, conservation will be attempting to achieve multiple impacts on several variables, leading to the need for customized portfolios of conservation activities in a particular location.

Figure 4-2. Phosphorus reduction from conservation (n=92)



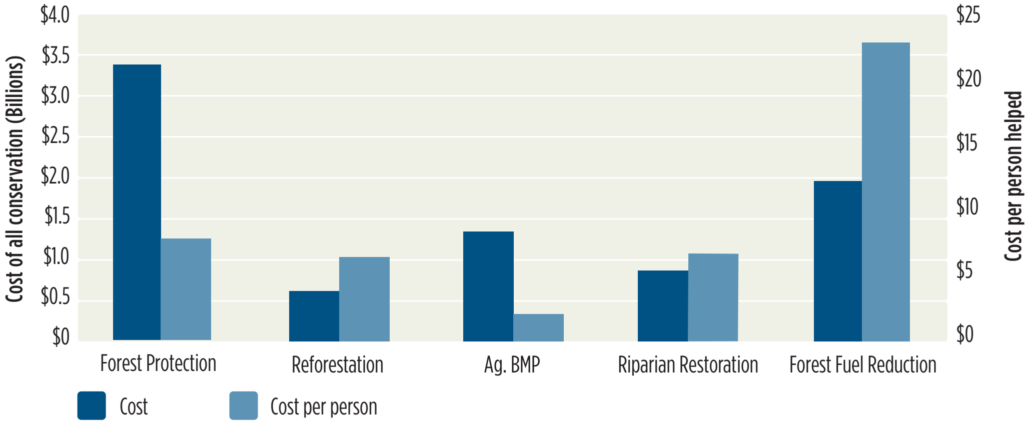
Area needed to conserve to reduce nutrient concentration 10 percent in top 100 cities. Comparison of four conservation strategies, as forest thinning is not assessed for nutrient impacts.

The costs of watershed conservation

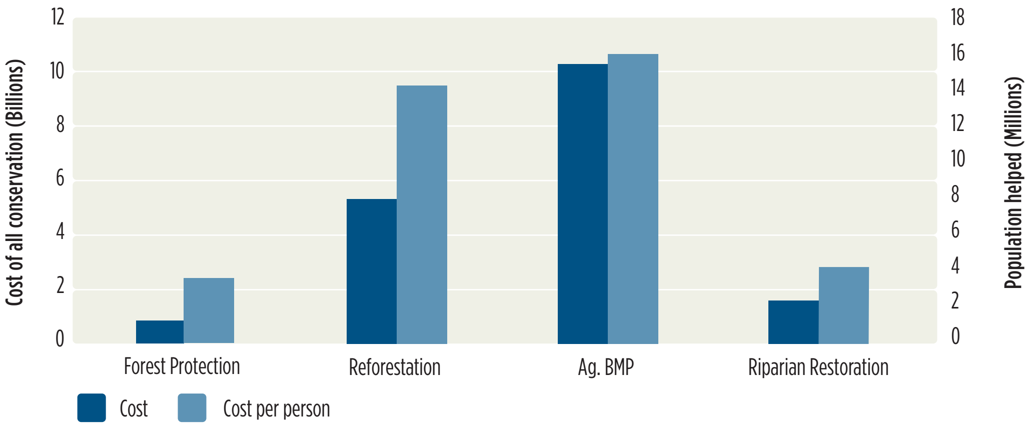
The cost of conducting a specific conservation intervention is a function of the number of hectares on which the activity must be conducted. Making some simple assumptions about the per-hectare cost of conservation in each continent, we have estimated the total cost of conservation if every conservation activity was conducted in every location where it was possible to get to a 10 percent reduction in sediment or nutrients (Figure 4-3). For sediment, the total cost across all five activities would be US $8.1 billion, with the largest costs being forest protection and forest fuel reduction. For nutrients, the total cost across all five activities would be US $18.1 billion, with the greatest total costs in agricultural BMPs and pastureland reforestation. These total costs represent an upper bound on conservation activities in urban source watersheds because not all this investment is cost-effective or has a good return on investment. If costs were not a barrier to implementing source watershed conservation, or if utilities were not responsible for paying for the full costs of source watershed conservation, this is the level of investment that water utilities would like to see in order to achieve a 10 percent reduction in pollutants.

We conducted our analysis to identify the scale of conservation (in hectares) that would be needed to achieve a 10 percent reduction in pollutants. Watersheds with more hectares of activity cost more. One simple metric of the cost-effectiveness of our conservation strategies is the cost per person whose water source has been improved by the conservation. Agricultural BMPs are the best activity for sediment removal, followed by reforestation and riparian restoration. Forest protection and forest fuel reduction are relatively expensive ways to remove sediment, which is why their total costs are high. For nutrient removal, riparian restoration is the most cost-effective activity. Interestingly, forest protection is also a cost-effective activity because it avoids the large increase in nutrient loading that would occur if forest became agricultural land.

Figure 4-3. Sediment reduction cost and effectiveness



Nutrient reduction cost and effectiveness



The cost of all conservation activities possible for cities in the top 100, as well as the cost per person helped.

Our results imply that the cost effectiveness of conservation actions on working landscapes, such as agricultural best management practices or riparian restoration, appears to be similar to that of implementing forest protection practices, and in some cases is superior. This does not mean that one should prefer conservation on working landscapes to forest conservation—there are other benefits that are not accounted for here. However, it is clear that a limited perspective on source watershed conservation that only contemplates the protection of virgin territory and undisturbed forests would miss out on some cost-effective conservation investments.

The return on investment of watershed conservation

How should cities evaluate the return on investment of these conservation activities? When should conservation be the preferred answer to a water quality problem versus more traditional engineered solutions? After all, the potential for impact of conservation should be compared, for example, to the economics of treating water in a utility.

Watershed protection typically offers the greatest return on investment in small watersheds that serve large cities. The factors that control return on investment of watershed conservation are:

Size of watershed. The total area on which a conservation activity must be conducted to meaningfully change water quality tends to be larger in larger source watersheds. Working on areas of hydrological importance, such as high slopes, stream banks, and headwaters can focus conservation on the areas within the watershed with the greatest return on investment, but regardless, large watersheds tend to require a greater area of conservation activity.

Population density in source watershed. If watershed protection requires working with many landowners, costs will increase with the number of people who must be convinced. This helps explain why the largest watershed protection examples in the world—such as Quito, Ecuador—tend to occur on public or communal land. While not insurmountable, the transaction costs of working with many small private landowners can be prohibitive.

Population served. Because large cities have a larger revenue base, the ability of a city or utility to pay for watershed protection increases with the number of customers.

Treatment technology. Since the complexity of water treatment plants is partly a function of source water quality (see the section below on cost analyses for utilities), managers of highly complex water treatment plants are less likely to be concerned with the quality of the source water. While avoided O&M costs can be significant across all types of water treatment plants, it is avoided capital expenditures—as in New York City—that are likely to motivate large-scale investments in watershed protection.

A full evaluation of the return on investment of source watershed conservation for a utility requires detailed information on the hydrology of the source watersheds, sources of pollutants, and the treatment processes in use at the water treatment plant. Such a detailed return on investment (ROI) analysis can only therefore be calculated on a case-by-case basis. However, the general principles discussed above, combined with the information collected in our dataset of 534 large cities, allow for rough calculations that can provide guidance about whether source watershed conservation is likely to be a smart investment for a utility.

As discussed in Chapter 2, a 10 percent reduction in sediment and phosphorus on average reduces treatment costs by 5 percent, although for individual water utilities this figure may be much higher. There are other ways that higher raw water quality may reduce costs for utilities. Our study did not consider the cost of irregular dredging of reservoirs, which can be considerable and has been shown to be on average roughly the same order of magnitude as the direct savings from reduced treatment costs. So the estimate that a reduction of sediment and phosphorus of 10 percent might reduce water treatment costs by 5 percent on average is a conservative one.

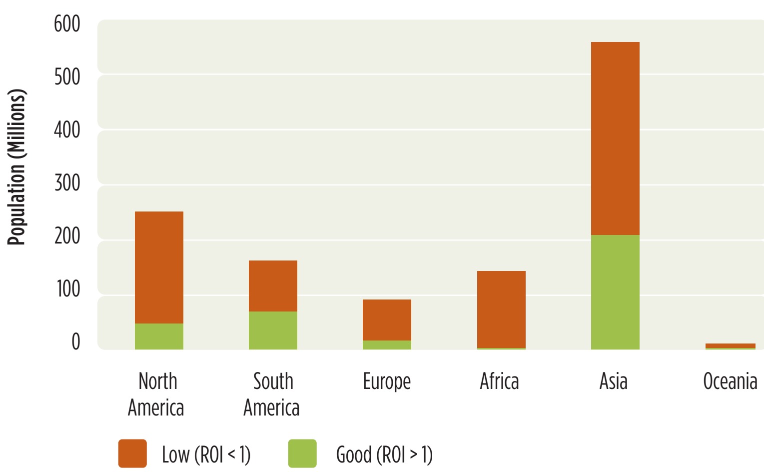
Of course, the costs of running a water treatment plant are only one component of overall O&M costs for water utilities. We are not aware of any global estimates specifically of water treatment plant O&M for the water sector. One study [2] estimated US $480 billion in expenditures (both capital and operating expenditures) in the world's water market. Of this, US $220 billion was capital expenditures on water or wastewater infrastructure (46 percent), while the rest (54 percent) was operating expenditures. Out of capital expenditures for water infrastructure, only US $17 billion was for water treatment plants, around 8 percent of total capital expenditures in the water sector. If this fraction also applies to operating expenditures, then a rough estimate would be that 8 percent of the US $260 billion in operating expenditures, some US $21 billion, was for water treatment plant O&M.

Figures 4-1 and 4-2 show that conservation actions can achieve a 10 percent reduction in sediment and phosphorus in top 100 cities containing around 700 million people, around 85 percent of the people in those cities. This would cost US $8.1 billion and US $18.1 billion, respectively (Figure 4-3). Assuming conservation action can help a similar fraction (85 percent) of communities globally, if conservation was performed to help all cities possible and they reduced their water treatment plant costs by 5 percent, the total reduction in water treatment plant O&M costs would be around US $890 million per year.

Note, however, that just because conservation action is possible does not mean that it is always a cost-effective way to reduce water treatment costs. Calculation of the potential ROI for source watershed conservation for a particular city needs to be informed by specific information on water treatment plant costs. However, we used a simple methodology to estimate the ROI of source watershed conservation for all cities for which we had water source data. While the results are not robust enough to present ROI results for particular cities, in aggregate they capture the general trend. Out of all the surface water dependent cities in the dataset, one in four (28 percent) have a ROI greater than one. That is, a 5 percent reduction in water treatment plant costs for these cities is more than sufficient to cover the costs of conservation actions needed to achieve the requisite 10 percent reduction in sediment or phosphorus.

The greatest potential for source watershed conservation projects that have an ROI greater than one is in Asia, at least if potential is measured in terms of number of people that can be helped (Figure 4-4). More than 200 million people live in cities in Asia that have at least one conservation activity with an ROI greater than 1. Asia has the most potential simply because so many of its people live in cities. For cities in the top 100, Oceania (which includes Australia) has the largest fraction of its urban dwellers that could be helped by source watershed conservation projects that have an ROI greater than one.

Figure 4-4. Potential return on investment for watershed conservation by continent



Number of people who could be helped by a conservation investment with a good return on investment, by continent.

A much broader set of cities can be helped by source watershed conservation if a utility is not expected to pay for the full costs of conservation. In many cases, other water users in the basin or governmental agencies interested in the public welfare and the environment may be willing to pick up significant portions of the cost. If a utility only had to pay 50 percent of the costs of conservation, then one in three cities can make an investment in source watershed conservation with an ROI above one.

Cost analysis for a utility

Next we explore some examples, outlining simple ROI calculations for a few utilities. The calculation begins with an estimate of the economic benefits of reducing sediment and phosphorus concentrations by a certain fraction. For instance, if a 100 megaliter-per-day plant uses conventional treatment at an average annual cost of US $1.7 million [23], a 10 percent reduction in pollutant load might reduce treatment costs by 5 percent, saving US $85,000 per year.

Avoided replacement costs can be much larger in absolute terms than avoided treatment costs. The New York City water system, due to EPA regulations, faced a large capital cost in excess of US $4 billion if it was required to switch from a no-filtration plant to one that used filtration [4]. For more typical plants, the benefits of avoided replacement costs provided by source watershed protection will be smaller. For instance, a 100 megaliter-per-day conventional treatment plant suffering from problems of raw water quality might eventually have to add extra processes, such as ozone or granulated activated carbon (GAC) filtration, which might raise total capital cost required from about US $140 million to US $180 million (approximately a 30 percent increase in capital required [23]). Because the need for additional replacement costs due to degradation of raw water quality is so specific to a particular site, water treatment plant, and regulatory context, the example analyses do not include this factor, but note that in practice avoided capital costs are often larger than avoided treatment costs.

The next step is to calculate the hectares of a particular conservation activity required to get to a 10 percent reduction in sediment and phosphorus. The hectares required vary widely across different basins (see Chapter 3). This matters because the cost of conservation activities scale with the number of hectares on which an activity is conducted; that is, the fixed costs of source watershed conservation are relatively small compared with variable costs. All else being equal, larger watersheds require conservation action on a greater number of hectares, and thus cost more to achieve a 10 percent reduction in pollutant load. If the cost of this conservation action is less than the utility's willingness to pay, then it makes sense as a direct investment by the utility. If the cost of conservation action is more than the utility's willingness to pay, then it may not make sense for the utility to bear all the burden of paying for this conservation action, although it still might have good reason to partner with other stakeholders and users in the watershed who also would benefit from conservation.

It may be helpful to walk through some examples with real data. Srinagar, India, draws a significant portion of its surface water, 121 megaliters per day (MLD), from the Sindh River, at two intake points located close together. The upstream contributing area of the sources is 1,120 hectares, and is predominantly (94 percent) cropland. Assuming a conventional treatment plant sequence, treatment costs for just this 121 MLD fraction of its water supply might be US $1.8 million per year [23]. Assuming a 5 percent reduction in costs from our target 10 percent reduction in sediment and phosphorus, the utility's willingness to pay for source watershed conservation would be US $90,000 per year. If investment in agricultural best management practices (BMPs) started at the sites where it would help avoid the most sediment and phosphorus, 32 hectares of agricultural BMPs would need to be installed to remove 10 percent of sediment and phosphorus. In other words, working on 3 percent of the cropland is sufficient to reduce sediment and phosphorus in the basin by 10 percent. Assuming a US $360 per hectare per year payment to get farmers to follow agricultural BMPs (see Appendix D on methodology for details), this works out to a payment of US $12,000 for the utility. Such an investment clearly seems like one with a positive return on investment for the utility: the benefits of conservation are almost nine times the costs.

Bangkok, Thailand, on the other hand, gets its water principally from the Chao Phraya River, withdrawing 3,931 MLD. The upstream contributing area of the intake point is 14.4 million hectares. Only half (51 percent) of the watershed is in cropland. Again, assuming a conventional treatment plant sequence, annual treatment costs might be US $5 million [23], and the willingness to pay for conservation might be US $250,000 per year. Starting at the sites where agricultural BMPs would most reduce sediment, working on only 6 percent of the cropland area in the landscape is sufficient to reduce sediment and phosphorus by 10 percent. However, in such a large basin this is a large area: 415,000 hectares, which—assuming a US $360 per hectare per year payment to get farmers to follow the agricultural BMPs—implies a US $149 million per year program. Here, the benefits in terms of reduced treatment costs due to the conservation investment would be substantially outweighed by the costs of taking conservation action.

In large basins like the Ganges River in India, individual action by a particular city's water utility may not make economic sense. However, 467 million people live in the Ganges Basin [24] and 88 million live in cities that rely on the Ganges for water. In addition, many farmers in the Ganges basin use its water for their crops and livestock, and poor raw water quality lowers agricultural yields. Thus any conservation action undertaken in the Ganges would benefit multiple cities and water users downstream. Although each action alone may not have enough benefit to solely fund conservation, collective action may make economic sense.

The extended benefits of watershed conservation

We found that in 72 percent of cases, it is unlikely to be cost-effective for utilities to pay the entire cost of watershed protection. However, cities may still value watershed protection for other reasons, including regional economic development, recreation, and biodiversity conservation.

Natural landscapes harbor biodiversity and provide attractive recreational benefits to visitors and residents alike. In Austin, Texas, for example, residents voted to protect water quality of Barton Springs, a popular swimming hole that has become a beloved city landmark, with about 800,000 swimmers visiting it every year. Since 1998, Austin has spent more than US $145 million from voter-approved bond packages to buy and protect nearly 27,000 acres of environmentally sensitive land in and around the city [6].

Partnering with farmers on working landscapes also contributes to the economic development of the surrounding region, which can help curb migration to cities. Founded in 1995, the Working for Water Program, whose main goal is to eliminate invasive alien species in South Africa Western Cape, creates around 32,000 jobs per year to provide a wide range of benefits, from increased water supply and quality to profitable ecotourism [5]. A study of India's National Rural Employment Guarantee Act also found that the increase in annual income for a village curbs distress migration to cities, driving down urbanization rates [25].

Source watershed conservation can help the vast majority (85 percent) of urbanites that depend on surface water sources improve their water quality by reducing sediment or phosphorus by 10 percent. In a quarter of cities, the benefits to the water utility in terms of reduced water treatment costs is greater than the costs of conservation.

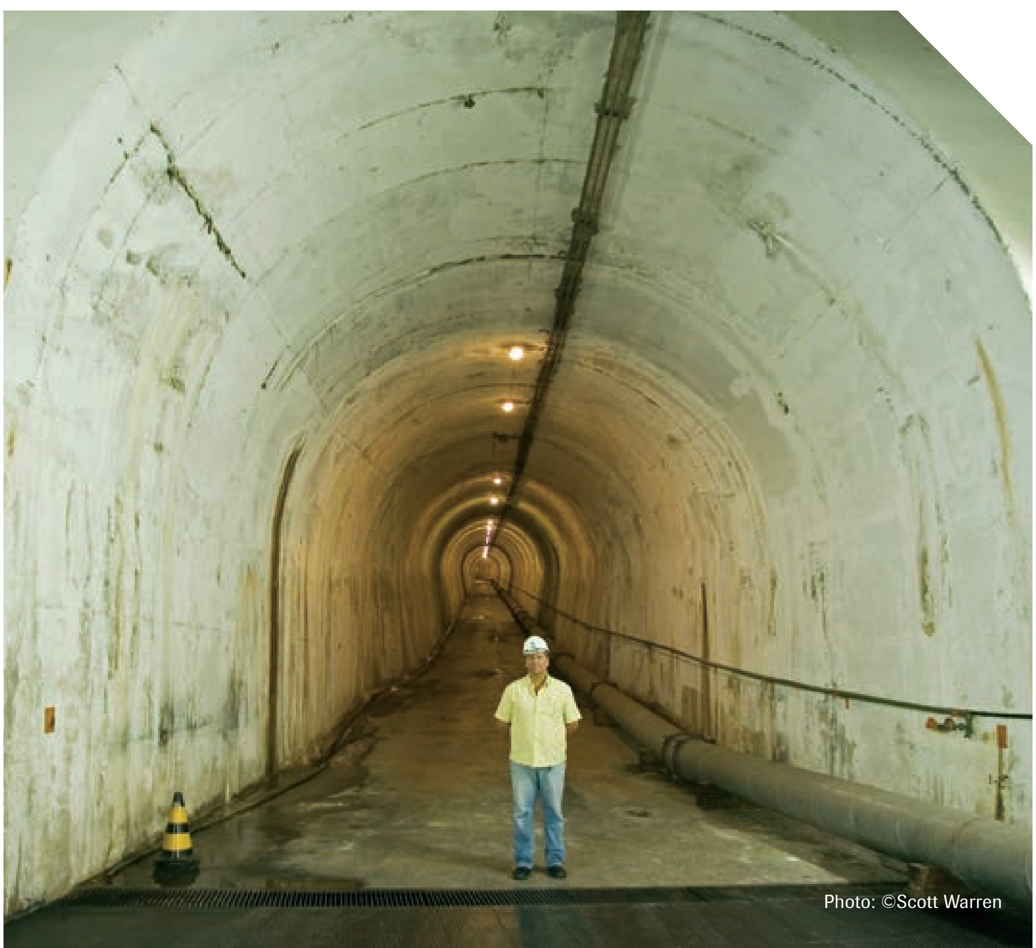


Photo: ©Scott Warren

CHAPTER 5

THE WAY FORWARD

The problem of scale

How can the interventions discussed in this report be conducted at a sufficient scale? We have described a dataset of 534 cities, and watershed conservation has significant potential to improve water quality for many of them. What will it take for them to consistently adopt watershed conservation measures over a large area? This is the fundamental problem of scale.

It is fair to say that broad-scale application has remained elusive for most ecosystem services solutions, including those focused on water. The example of New York City's water supply system has been available for over a hundred years now: a city that protected water at its source, thus offsetting the need for additional infrastructure. But, as this report makes clear, a number of specific conditions need to be true for that to be a reliable and economically viable strategy; these include a relatively small watershed, relatively natural land cover, and few regulatory barriers. Few cities have replicated that model.

Functional improvement in water quality and increased supply from watershed management depend on a number of physical features. Our findings suggest that chief among these features is land use, notably cropland, which is a major source of nutrients alongside human and industrial waste. Also important are landscapes features like slope and soil type, as well as flow, all of which greatly influence the concentration of sediment and nutrients.

Whether it is cost-effective for a city or utility to invest in a given watershed also depends on a set of factors. On the cost side, the size of the watershed, land values, as well as the cost of conservation strategies are important considerations. On the revenue side, the avoided costs of treatment and the size of population served are critical. Cutting across both is the size of the watershed and treatment capacity: where watershed size implies higher costs and where treatment capacity is limited, cost avoidance is likely to be more pronounced.

Replication at scale requires establishing a market for the services that would deliver the conservation activity. At least three conditions are required for scale:

> **A reliable track record of delivery.** There has to be a reliable track record for conservation and a reliable model of delivery that results in predictable costs of adoption and measurable impact.
>
> **A source of value.** There has to be a replicable business model where sources of value can be monetized, and in which revenue is reliable enough to allow for financing where that is required.
>
> **A consistent demand.** Users need to demonstrate demand for these kinds of solutions, and therefore, there has to be a recognition of the multiple values they bring.

A reliable track record

It is widely reported that protecting watersheds can improve water quality, regulate flow, prevent soil erosion, and—in some areas—influence rainfall regimes and local climate [26]. But there is a difference between the anecdotal evidence often provided when describing ecosystem services and the reliable specification of costs and impacts required to turn these interventions into a scalable solution. Users must be able to rely on a consistent return for their investment and to predict it to justify the investment. Such a track record would also have to be coupled with a reliable delivery mechanism.

Today, a city can easily source a treatment plant because many similar treatment plants have been built over the decades, making their cost predictable and their output reliable; an industry of suppliers has developed business models to serve their clients in so doing.

Both of these conditions are absent for watershed conservation measures. While individual cases have been studied in depth, our ability to generalize the impact of conservation activities is limited, and there is no reliable mechanism for consistent delivery. If a city decides to explore the role of source water protection in its portfolio of capital investments, it is hard pressed to know who to turn to for service and advice. Solving the issue of track record and delivery is a necessary step in enabling the replication and scale-up of these solutions.

Nevertheless, some tools and examples are beginning to contribute to building that track record and delivery mechanism. In fact, there is growing precedent—from South America to East Africa—for competing water users to invest jointly in a "water fund," a process that establishes a financial mechanism to direct funds toward watershed 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.

The Nature Conservancy is currently involved in over 60 of these water funds, where competing water users come together, often alongside a municipality, to invest in conservation upstream. One-third of the water funds are already in operation, mostly in Latin America, but the model is now spreading across four continents. Once an opportunity is identified, water users can look to a growing body of research and tools to guide watershed investment. 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 watershed conservation.

Such tools can help estimate and forecast the impact on water quality and the timing of water flow, benefits that will affect all water users, from irrigators to beverage companies. Guided by this science, water funds have accomplished targeted conservation on over 250,000 hectares across seven countries, an area equivalent to Yosemite National Park. That said, the monitoring currently in place is insufficient to fully substantiate the track record required, and more science will be needed to establish a fully replicable model.

The examples presented in this report, from New York to Beijing, offer some lessons of how cities have been able to successfully approach investing in their watersheds and operationalizing conservation. Some of the key lessons include:

Secure an agreement with the minimum number of landowners needed to participate before beginning interventions. The more landowners in the watershed, the higher the transaction costs of watershed protection. Transaction costs are not insurmountable, but they may nevertheless slow down deployment of conservation strategies. This helps explain why large-scale watershed protection usually takes place on public or communal lands. Involving upstream communities in project planning can help facilitate this process. For instance, The New York City Department of Environmental Protection asked that the farming community commit to obtain 85 percent participation in the Whole Farm program within five years before a single investment was made in source watershed conservation.

Work closely with regulators and lawmakers to facilitate spending beyond metropolitan boundaries. Jurisdictional limits on public spending may need to be overcome to invest revenue from water bills outside of the metropolitan area. Regulators and politicians can influence what utilities spend this revenue on. Good city leaders think about regional growth, not just city growth; thus, state and regional governments are likely to be key partners.

Partner with regulators to recognize conservation measures as a procurable asset. Regulators and lenders may not always recognize watershed protection as equivalent or complementary to traditional treatment technology. Regulator endorsement will help normalize the value of natural infrastructure, which is a necessary step for private sector interest. Environmental and academic institutions are likely to be key partners in building the case.

These and other insights are currently being developed through practices on the ground and form the basis of a delivery model that will need to be replicated further.

Monetizing value

Even if a reliable track record were available, so that a city were able to predict beforehand both the cost and the performance of natural infrastructure, without a reliable cash flow that can pay for conservation these solutions would not be adopted.

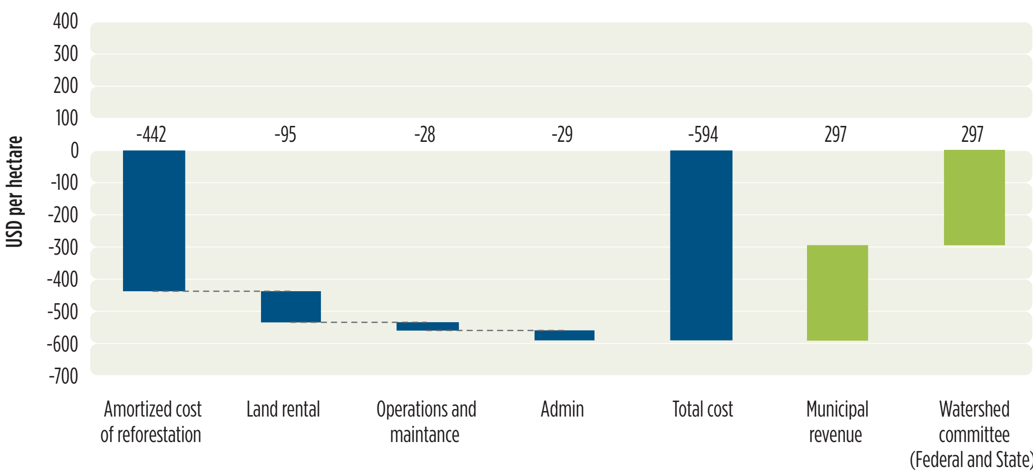
A comparative advantage of land use–based solutions as compared to traditional water services infrastructure is that such solutions provide multiple benefits well beyond water impact. For example, land protection creates additional value through the creation of recreational opportunities or the protection of aesthetic benefits to nearby landowners. So in principle the sources of revenue for conservation ought to be multiple.

And in fact, conservation solutions that improve water supplies have been paid for over the years through many different sources: general city taxation, real estate tax, ratepayers, and voluntary payments by users. For example, the municipal water company in Quito, Ecuador, dedicates 2 percent of ratepayer revenue to protecting grassland and restoring its water sources. In contrast, San Antonio, Texas, has successfully raised funds to protect the recharge area of its groundwater drinking source by appealing directly to voters with a ballot measure for a 1/8-cent sales tax.

While the multiplicity of benefits increases the chances of mobilizing resources, it also makes establishing a reliable and replicable payment model more challenging. Often multiple institutions need to be engaged to secure the resources. Likewise, when the revenue model is custom-designed to fit local circumstances that can make it hard to replicate elsewhere. Identifying a set of revenue models is essential for scale-up and replication if cities are to have a finite menu of options from which to choose a viable model.

But there are cities where those values are being tapped. For example, in Extrema, Brazil (see Chapter 3) the cost of reforesting a degraded watershed—about US $600 per hectare per year—was prohibitive for the small municipality. However, since the improvements in watershed function also benefitted water users farther downstream, including the city of São Paulo, the Cantareira System watershed committee chose to cover half the costs (Figure 5-1). While each water user alone could not find enough benefit to solely fund conservation action, collective action made economic sense.

Figure 5-1. Annual cost of reforestation per hectare in Extrema, Brazil



Assumes average $6,800 per hectare direct fixed cost, amortized over 30 years at 5 percent.

Where benefits to water users alone cannot justify watershed protection, the next step is to quantify related benefits like recreation, rural development, and biodiversity protection. Partnering with farmers on working landscapes also contributes to the economic development of the surrounding region, which can help curb distress migration to cities. Quantifying these related benefits can lead to coalitions of support for investment and may even reveal benefits of equal or greater value than water quality.

Figure 5-2. Costs and benefits of forest fuel treatment in Mokelumne Watershed, California.

Costs		
Fuel Treatment	$68,000,000	$68,000,000
Benefits	**Low**	**High**
Structures Saved	$32,000,000	$45,600,000
Avoided Fire Cleanup	$22,500,000	$22,500,000
Carbon Sequestered	$19,000,000	$71,000,000
Merchantable Timber from Treatment	$14,000,000	$27,000,000
Avoided Suppression	$12,500,000	$20,800,000
Biomass from Treatment	$12,000,000	$21,000,000
Avoided Road Repairs and Reconstruction	$10,630,000	$10,630,000
Transmission Lines Saved	$1,600,000	$1,600,000
Timber Saved	$1,200,000	$3,130,250
Avoided Sediment for Utilities (water supply)	$1,000,000	$1,000,000
Total Benefits	$126,430,000	$224,260,250

For example, a recent estimate of the cost avoidance associated with forest fuel treatment of 40,000 hectares in the Mokelumne Watershed—the source of drinking water for Oakland, California—found that the economic benefits of modeled forest fuel reduction treatments are two to three times the costs [27]. However, the broad diffusion of benefits would require a similarly diverse set of investors. The economic benefits of forest fuel reduction treatments accrue to a wide range of landowners, public and private entities, taxpayers, and utility ratepayers. The potential cost avoidance for the water utility, for example, is only a small fraction of the total costs. Only by quantifying co-benefits in structures saved and sales from timber does this conservation action make economic sense (Figure 5-2).

These examples show that interventions with multiple benefits not only can be identified, but can be quantified and in many cases monetized, making conservation happen. The challenge will be to systematize these approaches so that the full potential of conservation interventions can be captured.

Stimulating demand

Finally, the challenge for natural infrastructure is a lack of consistent demand across a big enough portfolio of locations that can support a real market. This is due in part to lack of awareness and in part to the opportunity costs faced by utility managers and other water users. While the conservation intervention might create multiple benefits, not all of them are aligned. The risk of failure—or of not delivering a reliable outcome—is a real cost that few users are prepared to bear.

So while in principle conservation delivers benefits in the water sector and beyond, in practice it faces stiff competition with traditional solutions. Stimulating demand requires education of the end users and leadership on the part of a few who are able to set an example. Ecosystem payments systems, of which these schemes are an example, have had success in creating individual pilots, but their broad-scale adoption remains elusive. At an individual city level some of the interventions to stimulate further demand for these initiatives include:

> **Building awareness among customers of where their water comes from.** Water customers would be aware of their source if water levels were announced alongside the daily weather, as they are in San Antonio, Texas, or printed in newspapers, as they are in Australia [10]. Ideally customers would see this cost on their water bill, but many cities have succeeded in raising funds outside of water tariffs by going directly to voters. Environmental institutions are likely to be a key ally.

Publicizing returns on investment of appreciating assets. As with any infrastructure project, large-scale investments in natural infrastructure will take years to generate a return. Unlike traditional infrastructure, however, natural assets will by and large appreciate over time. (For example, the ability of trees to reduce erosion only improves as their roots get deeper.) Maintenance costs still exist, but these also create long-term jobs.

Learning from success and failures of peers. Peer-to-peer learning enables direct discussion and feedback, and participating in network organizations can help access knowledge and best management practices. City networks like the C40 Cities Climate Leadership Group can help attract attention and leverage additional resources when they are able to show cities successfully implementing actions. Most important, learning from other cities not only improves the quality of projects, but also reduces transaction costs that typically delay or hinder implementation.

Building consistent demand among institutions and the public for source water protection interventions is critical to creating the space for the adoption of these solutions.

The path to scale

Cities, utilities, and partners can assess their water supply risks and what—if anything—can be done outside the four walls of a water treatment plant to reduce those risks. A recent C40 survey indicates that cities that have completed a water stress assessment are taking action on high priority items at a 34 percent higher frequency. This report, and the underlying data available online, can be a valuable contribution to filling this knowledge gap.

This report has laid out a basic set of facts about the market potential for conservation to improve the supply of water, in particular its quality. Our approach provides a basis for comparing engineered and natural solutions and how the two can be integrated to provide a more robust system. We have also laid out some elements of a scale-up recipe. Combined, these building blocks represent an agenda to drive conservation down a path to scale. Such an agenda would require action on the part of a number of stakeholders if we are to truly unlock the potential for conservation in the water utility sector.

Science-based institutions need to develop a focused program of work and monitoring to build the performance track record behind the adoption of these conservation solutions. They are at different points in the cycle of evidence collection. Some are advanced, such as agricultural best management practices; some are less advanced, such as riparian restoration. Other conservation practices have not been included in this report, but nevertheless hold significant promise, including wetland protection and restoration, as well as various ranching best management practices such as rotational grazing and silvopasture.

For those cities where risks and opportunities align, learning from peers will be an invaluable resource. Water utility networks—both international, like the International Water Association, and regional, like the American Water Works Association—have been playing a convening role for years; such groups need to be leveraged to promote new ideas. More recently, several city networks, namely C40, 100 Resilient Cities, and the Urban Sustainability Directors Network, have emerged with the mandate and resources to further convene and facilitate peer learning among city leaders.

Securing adequate, clean water supply for cities is a global challenge that will require investment in both engineered and natural solutions. Accordingly, decision-makers will want to consider other strategies not evaluated here. Investments in wastewater treatment of point source pollution from industry and people is likely to be an important first step to improving drinking water quality as well as reducing important local health related risks.

Cities that embrace natural and engineered solutions can not only meet future water demand; they can reshape our planet for the better.

APPENDICES

Photo: ©Bridget Besaw

APPENDIX A

WATERSHED CONSERVATION POTENTIAL TABLE FOR 534 CITIES

- 1 = High potential (< 1,000 hectares of conservation action needed to get a 10 percent reduction)
- 2 = Medium potential (1,000 hectares – 10,000 hectares)
- 3 = Low potential (> 10,000 hectares)
- 4 = Unlikely scope (more detailed analysis needed; not possible in our analysis to achieve a 10 percent reduction)

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Abidjan	Ivory Coast	4	4	4	4	4	4	4	4	4
Abilene	USA	2	3	4	4	4	4	4	4	4
Abuja	Nigeria	1	2	4	4	4	4	4	4	4
Accra	Ghana	3	3	4	4	4	4	4	1	3
Addis Ababa	Ethiopia	1	2	4	4	4	4	2	2	4
Agadir	Morocco	2	2	4	4	4	4	4	4	4
Agra	India	3	3	3	4	4	3	4	3	4
Ahmedabad	India	2	3	4	4	4	4	4	3	4
Aizawl	India	4	4	2	4	3	2	4	4	2
Akron	USA	1	1	2	3	4	1	4	4	4
Albany	USA	4	4	1	1	4	1	4	4	4
Albuquerque	USA	3	3	3	4	4	3	4	4	3
Alexandria	Egypt	3	3	4	4	4	4	4	4	4
Algiers	Algeria	2	3	4	4	4	4	4	4	4
Allahabad	India	4	4	4	4	4	4	4	3	4
Aleppo	Syria	3	3	4	4	4	4	4	4	4
Almaty	Kazakhstan	4	4	4	4	4	4	4	4	4
Alwar	India	4	4	4	4	4	4	4	4	4
Amarillo	USA	4	4	4	4	4	4	4	4	4
Amman	Jordan	2	3	4	4	4	4	4	4	4
Amritsar	India	4	4	4	4	4	4	4	4	4
Amsterdam	The Netherlands	3	3	3	3	4	3	4	4	4
Anchorage	USA	4	4	4	4	4	4	4	4	4
Ankara	Turkey	1	2	2	2	2	2	4	4	4

City	Country	Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
		Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Ann Arbor	USA	1	2	3	4	4	4	4	4	4
Antananarivo	Madagascar	2	4	3	4	2	3	4	4	4
Antioch	USA	2	3	3	4	4	1	4	4	4
Appleton	USA	2	3	4	4	4	4	4	4	4
Aracaju	Brazil	3	3	4	4	4	4	4	4	4
Asheville	USA	4	1	1	2	4	1	4	1	4
Asunción	Paraguay	3	3	4	4	4	4	4	4	3
Athens	Greece	2	2	2	3	4	2	4	4	4
Athens-Clarke County	USA	1	4	2	4	2	1	4	4	4
Atlanta	USA	4	4	2	4	4	1	4	4	4
Atlantic City	USA	1	1	1	2	4	1	4	4	4
Auckland	New Zealand	2	3	1	4	4	3	2	4	4
Augusta-Richmond County	USA	4	3	3	3	4	2	4	4	4
Aurangabad	India	2	3	4	4	4	4	4	3	4
Aurora	USA	2	4	3	4	3	3	4	4	3
Austin	USA	3	3	4	4	4	4	4	4	4
Baghdad	Iraq	3	3	4	4	4	4	4	4	4
Bakersfield	USA	2	2	4	4	4	4	4	4	4
Baku	Azerbaijan	3	3	4	4	4	4	4	4	4
Baltimore	USA	3	3	3	3	4	2	4	4	4
Bamako	Mali	2	4	4	4	4	4	4	4	3
Bangkok	Thailand	3	3	3	4	3	4	4	3	3
Baramati	India	3	3	4	4	4	4	4	3	4
Barcelona	Spain	1	2	2	3	4	2	4	4	4
Barcelona	Venezuela	1	1	2	2	4	1	1	1	2
Bareta	India	3	3	4	4	4	4	4	3	4
Barnstable Town	USA	4	4	4	4	4	4	4	4	4
Barquisimeto	Venezuela	2	3	3	4	4	1	4	1	4
Barranquilla	Colombia	3	3	3	3	4	3	3	4	4
Basel	Switzerland	4	4	4	4	4	4	4	4	4
Bathinda	India	1	1	4	4	4	4	4	4	4
Baton Rouge	USA	4	4	4	4	4	4	4	4	4
Beaumont	USA	3	4	3	4	4	2	4	4	4
Beijing	China	4	4	4	4	4	4	4	4	4
Beirut	Lebanon	4	4	4	4	4	4	4	4	4
Belém	Brazil	2	2	4	4	1	4	3	3	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Belgrade	Serbia	3	3	3	3	3	3	4	4	4
Belo Horizonte	Brazil	2	3	4	4	2	2	4	4	4
Bengaluru	India	2	3	4	4	4	4	4	4	4
Berkeley	USA	1	2	2	2	4	1	4	4	4
Berlin	Germany	4	4	4	4	4	4	4	4	4
Bhilwara	India	1	2	4	4	4	2	4	4	4
Bhopal	India	1	2	4	4	4	4	1	2	4
Bhubaneswar	India	3	3	4	4	4	3	1	4	4
Bhucho	India	4	4	4	4	4	4	4	4	4
Billings	USA	3	3	3	4	3	4	4	4	3
Binghamton	USA	2	2	3	3	4	2	4	4	4
Birmingham	USA	1	2	2	3	4	1	4	4	4
Bishkek	Kyrgyzstan	4	4	4	4	4	4	4	4	4
Bogotá	Colombia	1	1	2	2	4	1	4	4	4
Boise City	USA	3	3	4	4	4	3	4	4	3
Boston	USA	4	1	1	2	4	1	4	4	4
Boulder	USA	1	4	2	4	1	1	4	4	4
Brasília	Brazil	1	2	4	4	4	4	2	4	4
Brazzaville	Congo	3	4	3	4	4	4	1	4	3
Bremerton	USA	4	4	1	4	4	4	4	4	4
Bridgeport	USA	4	4	1	1	4	1	4	4	4
Bristol	United Kingdom	3	3	2	4	2	4	4	4	4
Brooksville	USA	4	4	4	4	4	4	4	4	4
Brownsville	USA	3	4	3	4	3	4	4	4	4
Brussels	Belgium	4	4	4	4	4	4	4	4	4
Bucaramanga	Colombia	1	2	3	4	4	1	1	1	4
Bucharest	Romania	2	2	2	3	4	4	4	4	4
Budapest	Hungary	3	3	3	3	4	3	4	4	4
Budhlada	India	3	3	4	4	4	4	4	3	4
Buenos Aires	Argentina	3	3	4	4	4	4	3	3	4
Buffalo	USA	3	3	3	4	4	3	4	4	4
Burlington	USA	4	1	3	3	4	2	4	4	4
Busan	Korea	4	4	3	3	4	2	4	4	4
Cairo	Egypt	3	3	4	4	4	4	4	4	4
Cali	Colombia	2	3	4	4	4	3	3	3	4
Campinas	Brazil	2	3	4	4	4	2	2	4	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

City	Country	Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
		Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Canton	USA	4	4	4	4	4	4	4	4	4
Cape Coral	USA	4	4	4	4	4	4	4	4	4
Cape Town	South Africa	1	1	1	2	1	1	4	4	1
Caracas	Venezuela	1	2	4	4	4	2	4	4	3
Cartagena	Colombia	1	3	4	4	4	4	4	4	4
Casablanca	Morocco	3	3	4	4	3	3	4	4	4
Cedar Rapids	USA	3	3	4	4	4	4	4	4	4
Champaign	USA	4	4	4	4	4	4	4	4	4
Changchun	China	3	3	4	4	4	4	4	3	4
Changwon	Korea	4	4	3	3	4	2	4	4	4
Charleston	USA	4	4	3	4	4	1	4	4	4
Charlotte	USA	4	2	3	3	4	1	4	4	3
Chattanooga	USA	4	3	3	3	4	2	4	4	4
Chengdu	China	1	2	4	4	4	2	4	2	4
Chennai	India	1	2	4	4	4	4	4	4	4
Chicago	USA	3	3	3	4	4	3	4	4	4
Chittagong	Bangladesh	4	3	3	4	3	3	4	4	3
Chongqing	China	3	3	3	4	4	3	4	3	4
Christchurch	New Zealand	4	4	4	4	4	4	4	4	4
Cincinnati	USA	3	3	3	4	4	3	4	4	4
Ciudad de Guatemala	Guatemala	1	2	2	3	2	1	4	4	4
Ciudad Guayana	Venezuela	3	4	3	4	3	1	4	4	3
Ciudad Juárez	Mexico	4	4	4	4	4	4	4	4	4
Clarksville	USA	3	3	3	3	4	3	4	4	4
Cleveland	USA	3	3	3	4	4	3	4	4	4
Colorado Springs	USA	1	4	3	4	2	2	4	4	4
Columbia	USA	4	3	2	3	4	2	4	4	4
Columbus	USA	1	3	4	4	4	4	2	3	4
Conakry	Guinea	1	3	4	4	4	4	1	4	4
Concepción	Chile	3	3	3	3	4	3	4	3	4
Concord (CA)	USA	1	1	2	4	4	1	4	4	4
Concord (NC)	USA	1	2	2	3	1	1	1	4	3
Copenhagen	Denmark	4	4	4	4	4	4	4	4	4
Córdoba	Argentina	2	3	4	4	4	4	4	4	4
Corpus Christi	USA	2	3	4	4	4	3	2	4	4
Cotonou	Benin	4	4	4	4	4	4	4	4	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Cúcuta	Colombia	1	2	3	3	4	1	4	4	4
Curitiba	Brazil	1	1	1	2	1	1	4	4	4
Cuttack	India	4	4	4	4	4	4	4	4	4
Dakar	Senegal	4	4	4	4	4	4	4	4	4
Dalian	China	4	4	3	2	4	1	4	4	4
Dallas	USA	2	3	4	4	4	4	4	4	4
Danbury	USA	1	1	1	1	4	4	4	4	4
Dar es Salaam	Tanzania	2	3	3	4	4	3	4	4	2
Davenport	USA	3	3	3	4	4	4	4	4	4
Dayton	USA	4	4	4	4	4	4	4	4	4
Dehradun	India	4	4	4	4	4	4	4	4	4
Delhi	India	3	3	3	4	4	3	4	3	4
Deltona	USA	4	4	4	4	4	4	4	4	4
Denver	USA	1	4	3	4	2	2	4	4	4
Des Moines	USA	2	3	4	4	4	4	4	4	4
Detroit	USA	3	3	3	4	4	3	4	4	4
Dewas	India	3	3	4	4	4	4	3	3	4
Dhaka	Bangladesh	4	4	4	4	4	4	4	2	4
Dhanbad	India	2	3	4	4	4	3	4	3	4
Dongguan	China	1	2	2	4	4	4	4	2	4
Dubai	UAE	4	4	4	4	4	4	4	4	4
Dublin	Ireland	4	4	1	2	1	2	4	4	4
Duluth	USA	4	3	3	3	4	2	4	4	4
Durban	South Africa	2	3	4	4	4	4	4	4	4
Durham	USA	2	2	2	3	4	1	4	4	4
East Rand	South Africa	3	3	4	4	4	4	4	4	4
El Paso	USA	3	3	3	4	3	4	4	4	3
Elkhart	USA	4	4	4	4	4	4	4	4	4
Erie	USA	3	3	3	4	4	3	4	4	4
Eugene	USA	4	4	3	4	4	1	4	4	4
Evansville	USA	3	3	3	4	4	3	4	4	4
Fairfield	USA	1	2	2	3	4	2	4	1	2
Fargo	USA	2	3	4	4	4	4	4	4	4
Faridabad	India	4	4	4	4	4	4	4	4	4
Fayetteville	USA	4	2	2	4	1	2	4	4	4
Flint	USA	3	3	3	4	4	3	4	4	4
Florianópolis	Brazil	1	1	3	3	1	1	4	4	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Fort Collins	USA	1	1	1	4	1	1	4	4	1
Fort Smith	USA	4	2	2	3	4	1	4	4	3
Fort Walton Beach	USA	4	4	4	4	4	4	4	4	4
Fort Wayne	USA	2	3	4	4	4	4	4	4	4
Fort Worth	USA	2	3	4	4	4	4	4	4	4
Fortaleza	Brazil	1	1	4	4	4	4	4	4	4
Frederick	USA	2	3	3	3	4	2	4	4	4
Freetown	Sierra Leone	1	4	4	4	4	4	1	4	4
Fresno	USA	2	2	3	3	2	2	4	4	3
Gainesville	USA	4	4	4	4	4	4	4	4	4
Gastonia	USA	4	2	3	3	4	1	4	4	3
Glasgow	United Kingdom	1	4	1	2	1	1	4	4	4
Goiânia	Brazil	2	2	4	4	4	4	2	3	4
Goniana	India	3	3	4	4	4	4	4	3	4
Grand Rapids	USA	3	3	3	4	4	3	4	4	4
Grande São Luís	Brazil	3	3	4	4	4	4	4	4	4
Grande Vitória	Brazil	1	2	3	3	4	4	4	2	4
Green Bay	USA	3	3	3	4	4	3	4	4	4
Greensboro	USA	1	1	2	3	2	1	4	4	4
Greenville	USA	1	1	2	2	4	1	4	4	4
Guadalajara	Mexico	3	3	3	4	3	3	4	4	3
Guangzhou	China	2	3	3	3	3	3	4	3	4
Guayaquil	Ecuador	2	3	4	4	4	3	3	3	4
Gurgaon	India	1	1	4	4	4	4	1	1	4
Guwahati	India	3	4	4	4	4	3	4	3	4
Gwalior	India	1	2	4	4	4	1	2	2	4
Hagerstown	USA	2	2	3	3	1	2	4	1	4
Hanoi	Vietnam	4	4	4	4	4	4	4	4	4
Harare	Zimbabwe	2	4	4	4	4	4	4	4	4
Harbin	China	1	2	4	1	4	1	1	2	4
Harlingen	USA	3	4	3	4	4	4	4	4	3
Harrisburg	USA	3	3	3	3	4	3	4	4	4
Hartford	USA	4	1	1	2	4	1	4	4	4
Havana	Cuba	1	1	4	4	4	1	4	4	4
Hazaribagh	India	1	1	4	4	4	4	1	4	4
Heidelberg	Germany	4	4	4	4	4	4	4	4	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Helsinki	Finland	4	4	3	3	4	2	4	4	4
Hemet	USA	4	4	4	4	4	4	4	4	4
Hickory	USA	4	1	3	3	4	1	4	4	3
High Point	USA	1	1	2	2	1	1	4	4	4
Ho Chi Minh City	Vietnam	3	3	3	3	3	3	3	3	3
Hong Kong	S.A.R. China	3	3	3	3	3	3	3	3	3
Houma	USA	1	2	2	3	2	3	1	2	2
Houston	USA	3	3	4	4	4	3	4	4	4
Hubli-Dharwad	India	1	1	4	4	4	4	2	2	4
Huntington	USA	3	3	3	3	4	3	4	4	4
Huntsville	USA	4	3	3	3	4	2	4	4	4
Hyderabad	India	3	3	4	4	4	4	4	3	4
Ibadan	Nigeria	2	4	3	4	4	3	4	4	4
Indianapolis	USA	2	2	4	4	4	4	2	2	4
Indore	India	3	3	4	4	4	4	3	3	4
Istanbul	Turkey	1	2	2	3	4	2	4	4	4
Jabalpur	India	2	3	4	4	4	4	3	3	4
Jackson	USA	2	3	3	3	4	2	4	4	4
Jacksonville	USA	4	4	4	4	4	4	4	4	4
Jaffa	Israel	4	4	4	4	4	4	4	4	4
Jagadhri	India	4	4	4	4	4	4	4	4	4
Jaipur	India	4	4	4	4	4	4	4	4	4
Jakarta	Indonesia	2	3	2	4	4	3	2	3	4
Jammu	India	2	2	4	4	4	4	3	3	4
Jeddah	Saudi Arabia	4	4	4	4	4	4	4	4	4
Jhansi	India	2	3	4	4	4	4	3	3	4
João Pessoa	Brazil	1	2	4	4	4	4	4	2	4
Jodhpur	India	3	3	4	4	4	3	4	3	4
Johannesburg	South Africa	3	3	4	4	4	4	4	4	4
Johnson City	USA	4	4	3	3	4	1	4	4	4
Jos	Nigeria	1	2	4	4	4	4	1	4	4
Kabul	Afghanistan	4	4	4	4	4	4	4	4	4
Kalamazoo	USA	4	4	4	4	4	4	4	4	4
Kampala	Uganda	3	3	4	4	4	4	4	4	4
Kano	Nigeria	2	3	4	4	4	4	4	4	4
Kanpur	India	3	3	3	4	4	3	4	3	4
Kansas City	USA	3	3	4	4	4	4	4	4	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Karachi	Pakistan	4	2	4	4	4	4	4	4	4
Kenosha	USA	3	3	3	4	4	3	4	4	4
Khanna	India	4	4	4	4	4	4	4	4	4
Khartoum	Sudan	3	4	4	4	4	4	4	4	4
Kiev	Ukraine	3	3	3	3	4	4	4	4	4
Kigali	Rwanda	2	3	4	4	4	2	4	4	4
Killeen	USA	2	3	4	4	4	4	4	4	4
Kinshasa	Congo (DRC)	3	4	3	4	4	4	4	4	3
Kissimmee	USA	4	4	4	4	4	4	4	4	4
Knoxville	USA	4	3	3	3	4	2	4	4	4
Kobe	Japan	1	3	2	3	4	4	4	3	4
Kolkata	India	2	3	4	4	4	4	4	3	4
Kot Fatta	India	3	3	4	4	4	4	4	3	4
Kozhikode	India	4	4	2	4	3	2	4	4	4
Kumasi	Ghana	1	2	4	4	4	4	4	4	1
Kunming	China	1	2	3	4	3	2	2	2	4
Kuwait City	Kuwait	4	4	4	4	4	4	4	4	4
La Paz	Bolivia	4	4	4	4	4	4	4	4	4
Lafayette (IN)	USA	4	4	4	4	4	4	4	4	4
Lafayette (LA)	USA	4	4	4	4	4	4	4	4	4
Lagos	Nigeria	2	4	4	4	4	4	4	4	4
Lake Charles	USA	4	4	4	4	4	4	4	4	4
Lakeland	USA	4	4	4	4	4	4	4	4	4
Lancaster	USA	3	3	3	3	4	2	4	4	4
Lansing	USA	4	4	4	4	4	4	4	4	4
Laredo	USA	3	4	3	4	3	4	4	4	4
Las Cruces	USA	4	4	4	4	4	4	4	4	4
Las Vegas	USA	3	4	4	4	4	3	4	4	4
León	Mexico	4	4	4	4	4	4	4	4	4
Lexington-Fayette	USA	1	3	3	4	1	2	4	4	4
Lilongwe	Malawi	2	2	4	4	4	4	4	4	4
Lima	Peru	4	4	4	4	4	4	4	4	4
Lincoln	USA	4	4	4	4	4	4	4	4	4
Lisbon	Portugal	2	3	3	3	3	3	4	4	3
Little Rock	USA	4	4	1	1	4	1	4	4	2
London	United Kingdom	4	4	4	4	4	4	4	4	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Long Beach	USA	1	2	1	4	1	1	4	4	2
Los Angeles	USA	1	2	1	4	1	1	4	4	2
Louisville	USA	3	3	3	4	4	3	4	4	4
Luanda	Angola	3	4	4	4	4	4	4	4	4
Lubbock	USA	4	4	4	4	4	4	4	4	4
Lubumbashi	Congo (DRC)	1	4	4	4	4	4	4	4	4
Lucknow	India	1	2	4	4	4	4	2	2	4
Lusaka	Zambia	3	4	4	4	4	4	4	4	4
Macao	S.A.R. China	3	3	3	4	4	3	3	3	4
Maceió	Brazil	1	2	4	4	4	4	1	2	4
Macon	USA	2	4	3	3	4	2	4	4	4
Madison	USA	4	4	4	4	4	4	4	4	4
Madrid	Spain	4	4	4	4	4	4	4	4	4
Malout	India	3	3	4	4	4	4	4	3	4
Managua	Nicaragua	2	3	4	4	4	3	4	3	4
Manaus	Brazil	3	4	3	4	4	4	4	4	4
Manchester	USA	4	4	1	2	4	1	4	4	4
Manila	Philippines	2	2	2	3	4	4	2	2	4
Mansa	India	3	3	4	4	4	4	4	3	4
Maputo	Mozambique	2	3	4	4	4	3	4	4	2
Maracaibo	Venezuela	1	2	2	2	4	4	4	4	2
Maracay	Venezuela	2	4	4	4	4	4	4	4	4
Marysville	USA	4	4	4	4	4	4	4	4	4
Mathura	India	4	4	4	4	4	4	4	3	4
Maur	India	3	3	4	4	4	4	4	3	4
McAllen	USA	3	4	3	4	4	4	4	4	3
Medellín	Colombia	1	2	3	3	4	1	1	2	4
Medford	USA	4	2	3	3	4	2	4	4	3
Meerut	India	4	4	4	4	4	4	4	4	4
Melbourne	Australia	2	2	2	1	4	1	4	4	2
Memphis	USA	4	4	4	4	4	4	4	4	4
Mendoza	Argentina	4	4	4	4	4	4	4	4	4
Merced	USA	4	4	4	4	4	4	4	4	4
Mérida	Mexico	4	4	4	4	4	4	4	4	4
Mesa	USA	2	4	3	4	3	3	4	4	3
Mexico City	Mexico	4	4	4	4	4	4	4	4	4
Miami	USA	4	4	4	4	4	4	4	4	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Milan	Italy	4	4	4	4	4	4	4	4	4
Milwaukee	USA	3	3	3	4	4	3	4	4	4
Minneapolis	USA	3	3	3	4	4	3	4	4	4
Mission Viejo	USA	3	4	2	4	1	3	4	4	2
Mobile	USA	1	1	2	4	2	1	4	4	4
Modesto	USA	1	2	3	4	2	2	4	4	2
Mogadishu	Somalia	4	4	4	4	4	4	4	4	4
Mombasa	Kenya	2	3	2	4	4	4	4	4	4
Monroe	USA	1	2	3	3	4	3	1	2	3
Monrovia	Liberia	2	3	3	3	4	3	2	3	2
Monterrey	Mexico	2	4	2	4	4	2	4	4	3
Montevideo	Uruguay	2	3	4	4	4	4	4	4	4
Montgomery	USA	2	4	3	3	4	2	4	4	3
Montréal	Canada	4	3	3	3	4	3	4	3	4
Moscow	Russia	1	2	3	3	4	4	4	2	4
Mosul	Iraq	3	3	4	4	4	4	4	3	4
Mumbai	India	1	2	4	4	4	4	2	2	4
Murfreesboro	USA	1	2	2	3	4	2	4	4	4
Muskegon	USA	3	3	3	4	4	3	4	4	4
Mussoorie	India	4	4	4	4	4	4	4	4	4
Myrtle Beach	USA	3	3	3	3	1	3	4	4	2
Nagoya	Japan	2	2	3	3	4	4	4	2	4
Nagpur	India	2	3	4	4	4	4	3	3	4
Nainital	India	4	4	4	4	4	4	4	1	4
Nairobi	Kenya	1	2	4	4	4	4	4	4	4
Nanjing	China	3	3	3	4	4	3	4	3	4
Nashua	USA	1	4	2	3	4	1	4	4	4
Nashville- Davidson	USA	3	3	3	3	4	3	4	4	4
Natal	Brazil	1	2	4	4	4	4	4	4	4
New Bedford	USA	4	4	1	4	4	4	4	4	4
New Haven	USA	4	4	1	1	4	4	4	4	4
New Orleans	USA	3	3	3	4	4	4	4	4	4
New York	USA	4	1	2	2	4	1	4	1	4
Newark	USA	4	4	1	1	4	1	4	4	4
Norfolk	USA	1	1	2	2	4	2	4	4	4
Nouakchott	Mauritania	4	4	4	4	4	4	4	4	4
Oakland	USA	1	2	2	4	4	1	4	4	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Ocala	USA	4	4	4	4	4	4	4	4	4
Odessa	USA	3	3	4	4	4	4	4	4	4
Oklahoma City	USA	3	3	1	4	1	1	4	4	1
Omaha	USA	3	3	3	4	4	4	4	4	4
Orlando	USA	4	4	4	4	4	4	4	4	4
Osaka	Japan	2	3	3	3	4	4	4	3	4
Oslo	Norway	4	4	1	2	4	1	4	4	4
Ouagadougou	Burkina Faso	2	3	4	4	4	4	4	4	4
Oxnard	USA	1	1	1	1	4	4	4	1	1
Panama City	Panama	1	2	4	4	4	4	4	2	4
Panama City	USA	1	1	2	3	1	1	4	4	4
Paris	France	3	3	4	4	4	4	4	4	4
Patna	India	4	4	4	4	4	4	4	4	4
Pensacola	USA	4	4	4	4	4	4	4	4	4
Peoria	USA	3	3	4	4	4	4	4	3	4
Philadelphia	USA	2	2	3	3	4	2	4	4	4
Phnom Penh	Cambodia	3	3	3	4	3	3	4	3	3
Phoenix	USA	2	4	3	4	3	3	4	4	3
Pittsburgh	USA	3	2	3	3	4	3	4	4	4
Port Arthur	USA	2	1	3	4	4	2	4	4	4
Port St. Lucie	USA	4	4	4	4	4	4	4	4	4
Portland (OR)	USA	4	1	2	2	4	4	4	4	4
Portland (ME)	USA	4	4	2	2	4	1	4	4	4
Pôrto Alegre	Brazil	1	2	4	4	4	4	4	4	4
Prague	Czech Republic	2	3	2	3	4	4	4	4	4
Pretoria	South Africa	3	3	4	4	4	4	4	4	4
Providence	USA	4	4	1	3	4	1	4	4	4
Puducherry	India	4	4	4	4	4	4	4	4	4
Puebla de Zaragoza	Mexico	4	4	4	4	4	4	4	4	4
Pueblo	USA	2	3	3	4	3	3	4	4	4
Pune	India	2	2	4	4	4	2	2	2	4
Qingdao	China	3	3	4	4	4	4	4	4	4
Querétaro	Mexico	2	3	3	4	3	4	4	4	4
Quetta	Pakistan	1	1	4	4	4	1	4	4	4
Quito	Ecuador	1	2	4	4	4	4	1	4	4
Racine	USA	3	3	3	4	4	3	4	4	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Rajkot	India	1	2	4	4	4	4	4	4	4
Rajshahi	Bangladesh	3	3	3	4	4	3	4	3	4
Raleigh	USA	4	1	2	3	4	1	4	4	4
Raman	India	3	3	4	4	4	4	4	3	4
Rampura	India	4	4	4	4	4	4	4	4	4
Ranchi	India	1	2	4	4	4	4	2	2	4
Reading	USA	1	2	2	4	4	1	4	4	4
Recife	Brazil	1	2	4	4	4	4	1	2	4
Redding	USA	4	4	3	4	4	3	4	4	3
Reno	USA	1	4	2	2	4	1	4	4	4
Richmond	USA	2	3	3	3	4	2	4	4	4
Rio de Janeiro	Brazil	2	3	4	4	4	2	4	4	4
Riyadh	Saudi Arabia	4	4	4	4	4	4	4	4	4
Roanoke	USA	1	2	2	3	4	1	4	4	1
Rochester	USA	3	3	3	2	4	3	4	1	4
Rockford	USA	4	4	4	4	4	4	4	4	4
Rome	Italy	4	4	4	4	4	4	4	4	4
Rosario	Argentina	3	3	4	4	4	4	4	4	4
Rotterdam	The Netherlands	2	3	3	3	3	4	4	4	4
Sacramento	USA	3	3	3	4	4	4	4	3	3
Saginaw	USA	3	3	3	4	4	3	4	4	4
Saint Louis	USA	3	3	4	4	4	4	4	4	4
Saint Paul	USA	3	3	3	4	4	3	4	4	4
Saint Petersburg	Russia	4	4	3	3	3	3	4	4	4
Saint Petersburg	USA	1	2	4	4	2	2	4	4	4
Salem	USA	4	1	3	2	4	1	4	4	3
Salinas	USA	4	4	4	4	4	4	4	4	4
Salt Lake City	USA	2	3	3	4	4	3	4	4	4
Salvador	Brazil	2	3	4	1	1	3	4	4	4
Samarinda	Indonesia	3	3	3	3	4	4	3	3	4
San Antonio	USA	2	4	4	4	4	4	4	4	4
San Diego	USA	1	2	1	4	1	1	4	4	2
San Francisco	USA	4	1	1	2	4	1	4	4	4
San Jose	USA	1	2	4	4	4	2	4	4	4
San José	Costa Rica	1	2	2	2	4	1	2	2	4
San Juan	Puerto Rico	1	2	2	3	4	4	4	2	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
San Luis Potosí	Mexico	4	4	4	4	4	4	4	4	4
San Salvador	El Salvador	2	3	3	3	3	3	2	3	4
Sana'a	Yemen	4	4	4	4	4	4	4	4	4
Sangat	India	3	3	4	4	4	4	4	3	4
Santa Ana	USA	1	2	1	4	1	1	4	4	2
Santa Barbara	USA	1	1	2	2	4	4	4	4	2
Santa Clarita	USA	1	1	2	4	4	2	4	4	2
Santa Cruz	USA	4	4	1	1	4	4	4	4	1
Santa Cruz de la Sierra	Bolivia	4	4	4	4	4	4	4	4	4
Santa Fe	USA	4	4	3	4	4	3	4	4	4
Santa Maria	USA	2	2	3	4	4	2	4	4	3
Santa Rosa	USA	1	2	2	3	4	1	4	4	4
Santiago	Chile	4	4	4	4	4	2	4	4	4
Santo Domingo	Dominican Republic	1	2	2	3	4	4	4	2	4
Santos	Brazil	1	1	4	4	4	1	4	4	4
São Paulo	Brazil	1	2	2	4	4	1	2	4	4
Savannah	USA	4	4	4	4	4	4	4	4	4
Scranton	USA	4	1	1	1	4	1	4	4	4
Seattle	USA	4	4	2	4	4	4	4	4	4
Seoul	Republic of Korea	4	4	3	3	4	2	4	4	4
Shanghai	China	3	3	3	4	4	3	4	3	4
Shenzhen	China	1	1	4	4	4	4	4	1	4
Shiraz	Iran	3	3	4	4	4	4	4	4	4
Shreveport	USA	2	3	3	3	4	1	4	4	4
Siliguri	India	2	2	2	4	4	2	2	4	4
Simi Valley	USA	2	2	2	4	1	3	4	4	2
Singapore	Singapore	1	1	4	4	4	4	4	2	4
Sioux City	USA	3	3	4	4	4	4	4	4	4
Sioux Falls	USA	4	4	4	4	4	4	4	4	4
Sofia	Bulgaria	1	4	2	4	4	1	4	4	4
Solapur	India	3	3	4	4	4	4	4	3	4
South Bend	USA	4	4	4	4	4	4	4	4	4
Spartanburg	USA	4	2	1	3	4	1	4	4	4
Spokane	USA	4	4	4	4	4	4	4	4	4
Springfield (IL)	USA	2	2	4	4	4	4	2	4	4
Springfield (MA)	USA	4	4	1	2	4	4	4	4	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Springfield (MO)	USA	2	3	4	4	4	2	2	4	4
Srikakulam	India	4	4	4	4	4	4	4	4	4
Srinagar	India	1	2	1	4	4	1	4	1	4
Stockholm	Sweden	4	4	3	3	4	2	4	4	4
Stockton	USA	2	2	2	4	2	2	4	4	2
Surat	India	3	3	4	4	4	4	4	3	4
Sydney	Australia	2	3	3	4	4	2	4	4	2
Syracuse	USA	1	2	2	2	4	3	4	4	4
Taipei	Taiwan	4	1	2	2	4	1	4	4	4
Tallahassee	USA	4	4	4	4	4	4	4	4	4
Tampa	USA	1	2	4	4	2	2	4	4	4
Tashkent	Uzbekistan	1	1	4	4	4	4	4	4	4
Tbilisi	Georgia	2	4	3	4	4	2	4	4	4
Tegucigalpa	Honduras	1	2	2	4	4	2	4	2	4
Tehran	Iran	2	2	4	4	4	4	4	4	4
Tel Aviv	Israel	2	3	4	4	4	4	4	4	4
Teresina	Brazil	3	3	4	4	4	4	4	4	4
Thane	India	2	3	4	4	4	4	2	3	4
Thiruvananthapuram	India	4	4	1	2	1	1	4	4	4
Thousand Oaks	USA	1	2	2	4	1	1	4	4	3
Tianjin	China	3	3	3	4	4	4	4	3	4
Tijuana	Mexico	1	1	2	2	1	1	4	4	1
Tokyo	Japan	1	2	3	3	4	4	4	2	4
Toledo	USA	3	3	3	4	4	3	4	4	4
Toluca de Lerdo	Mexico	1	2	2	3	2	2	4	4	4
Topeka	USA	3	3	4	4	4	4	4	4	4
Toronto	Canada	3	3	3	4	4	3	4	4	4
Torreón	Mexico	4	4	4	4	4	4	4	4	4
Trenton	USA	2	2	3	3	4	2	4	4	4
Tripoli	Libya	4	4	4	4	4	4	4	4	4
Tucson	USA	4	4	4	4	4	4	4	4	4
Tulsa	USA	2	3	2	4	4	1	1	4	4
Tumkur	India	2	3	2	4	4	4	2	3	4
Tunis	Tunisia	2	3	4	4	4	4	4	4	4
Tuscaloosa	USA	2	2	3	3	4	1	4	4	4
Tyler	USA	2	4	4	4	4	2	4	4	4
Udaipur	India	1	2	4	4	4	4	4	2	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

		Ag. BMPs		Forest protection		Reforestation		Riparian restoration		Forest fuel reduction
City	Country	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment	Nutrient	Sediment
Ujjain	India	1	3	4	4	4	4	4	3	4
Ulaanbaatar	Mongolia	4	4	4	4	4	4	4	4	4
Utica	USA	4	1	2	2	4	1	4	4	4
Uttarkashi	India	4	4	4	4	4	4	4	4	4
Vadodara	India	3	3	4	4	4	4	3	3	4
Valencia	Venezuela	1	4	4	4	4	4	4	4	4
Vallejo	USA	1	2	2	3	4	2	4	1	2
Valparaíso	Chile	4	4	4	4	4	4	4	4	4
Vancouver	Canada	4	4	2	2	4	1	4	4	4
Venice	Italy	4	4	4	4	4	4	4	4	4
Vienna	Austria	4	4	4	4	4	4	4	4	4
Vientiane	Laos	3	3	3	4	3	3	4	4	3
Virginia Beach	USA	2	2	2	3	4	2	4	4	4
Visalia	USA	4	4	4	4	4	4	4	4	4
Waco	USA	2	3	4	4	4	4	4	4	4
Warsaw	Poland	3	3	3	3	4	4	4	4	4
Washington	USA	3	3	3	3	4	3	4	4	4
Waterbury	USA	4	4	1	1	4	1	4	4	4
Waterloo	USA	2	3	4	4	4	4	4	4	4
Wichita	USA	2	3	4	4	4	4	4	4	4
Wilmington	USA	2	3	3	4	4	2	4	4	4
Winston-Salem	USA	4	2	3	3	4	2	4	4	4
Winter Haven	USA	4	4	4	4	4	4	4	4	4
Worcester	USA	1	1	1	1	4	4	4	4	4
Wuhan	China	3	3	3	4	4	3	3	3	4
Xi'an	China	1	2	2	3	4	2	4	4	4
Yakima	USA	2	2	3	4	4	4	4	4	4
Yamunanagar	India	4	4	4	4	4	4	4	4	4
Yangon	Myanmar	1	2	2	2	2	2	4	4	4
Yaoundé	Cameroon	2	3	3	3	4	2	3	4	4
Yekaterinburg	Russia	4	4	2	4	4	1	4	4	4
Yerevan	Armenia	4	4	4	4	4	4	4	4	4
Yokohama	Japan	1	2	2	3	4	4	4	2	2
York	USA	1	2	2	4	4	2	4	4	4
Youngstown	USA	1	1	2	2	4	1	4	4	4
Zhengzhou	China	3	3	4	4	4	4	4	4	4
Zurich	Switzerland	4	4	4	4	4	4	4	4	4

Opportunities: 1 = High potential, 2 = Medium potential, 3 = Low potential, 4 = Unlikely scope

APPENDIX B

THE IMPACT OF SEDIMENT ON TREATMENT COSTS

This section revisits content in Chapter 2 and expands upon it to discuss the impact of sediment on water treatment costs, including our analysis of the statistical relationship between sediment yield and treatment costs for a large sample of cities.

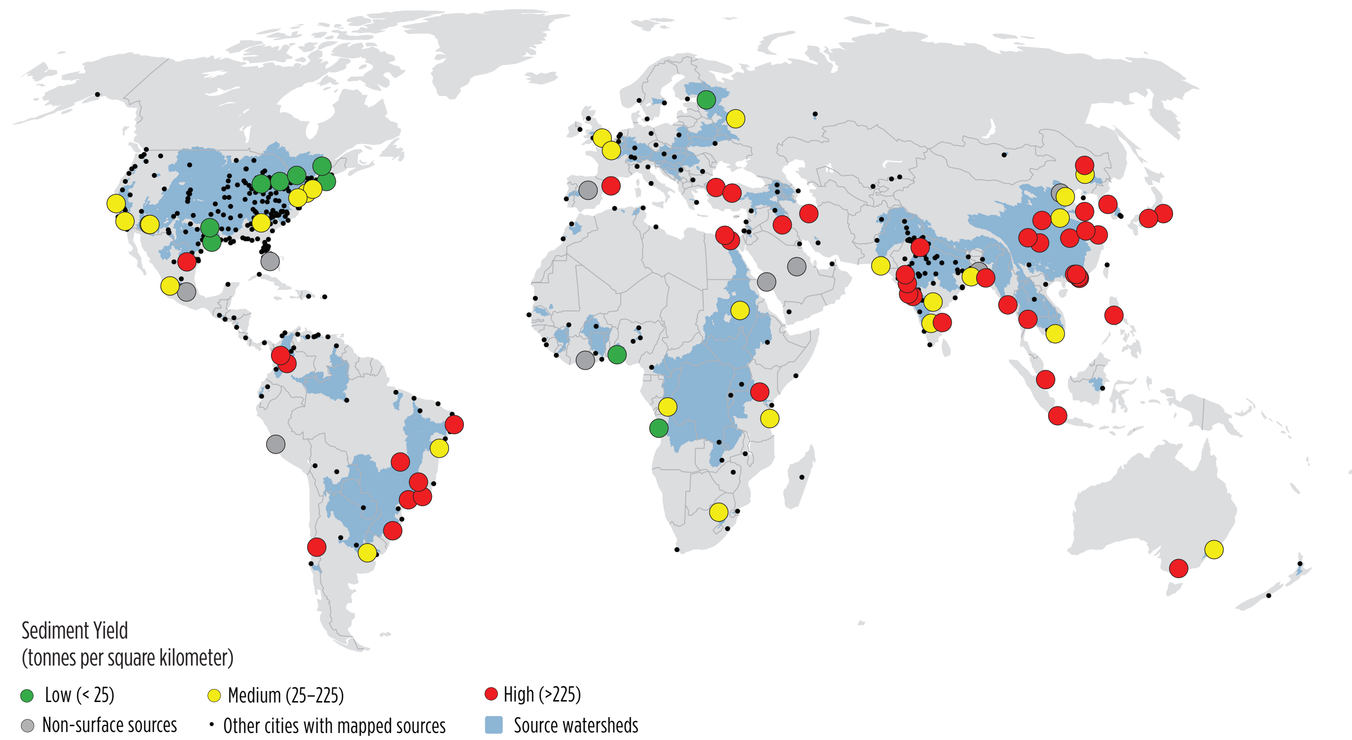
From mountains to the sea—sediment loading in watersheds

If the demands on watersheds can be managed to meet the challenge of sufficient quantity, the issue of water quality reveals how deeply interconnected cities are with the watersheds they depend on. This dependency becomes clear when significant change takes place. Changes in land use, particularly the conversion of forest and other natural land covers to pasture or cropland, often increase sedimentation and nutrient pollution. Increased human activity and the expansion of dirt roads in source watersheds can also lead to many other pollutants increasing in concentration, impacting the cost of water treatment and the safety of urban water supplies.

In particular, increases in sedimentation and the associated increase in turbidity are a common challenging facing many cities [16]. Changes in turbidity not only affect the ecosystems of rivers but also change the management regime of engineered infrastructure. Additional sediment runoff can shorten the life of storage infrastructure and increase the costs for water treatment. Changes in sediment balance can ultimately also affect the nature of coastal areas, shifting the balance between coastal erosion and the replenishment of the coastline by silty rivers.

Nearly two-thirds of people living in the 100 largest cities source their drinking water from watersheds with high sediment yield (Figure B-1). This analysis divides the water sources of the world's large cities into three categories, based upon their level of sediment yield. Cities in the high sediment yield category often have sources downstream from highly agricultural areas, such as in the Ganges Basin in India and in the Yellow River in China. Alternatively, they may be located downstream of steep mountain ranges, with erodible soils, such as the western coast of South America.

Figure B-1. Cities grouped by sediment yield

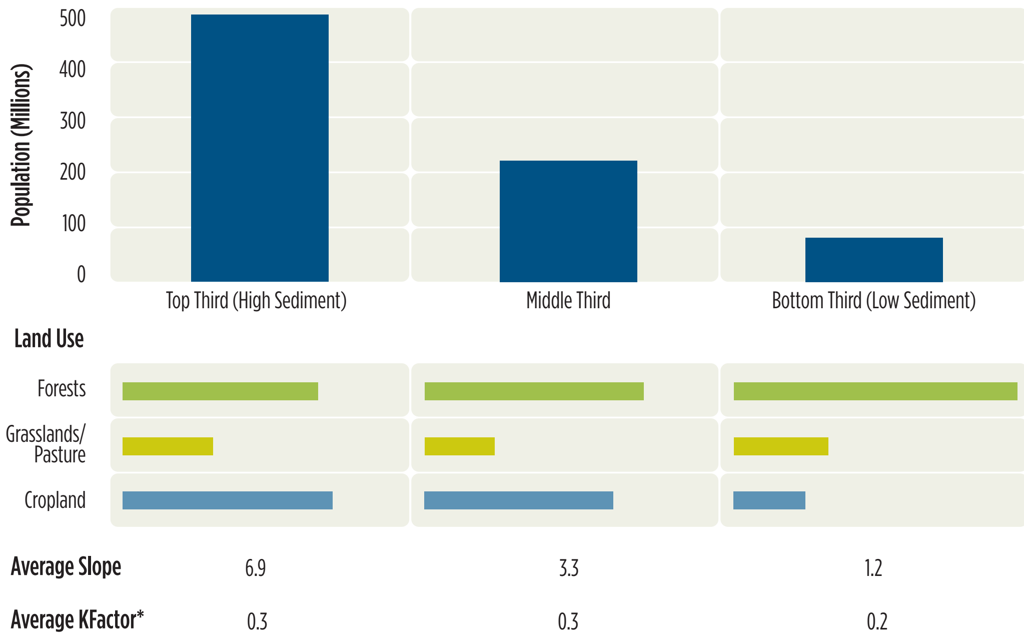


Top 100 cities, surface sources

Around 500 million people get their drinking water from surface sources in the high-sediment category (Figure B-2). This is 60 percent of the people in the sample of 100 cities. While many developed countries face sedimentation problems, the challenge of sedimentation is greater for cities in the developing world. Worldwide, 220 million people live in cities that draw water from sources in the medium sediment category. Only around 80 million people (10 percent of sample of cities) have water sources with low sediment yield, mostly concentrated in the United States.

Cities whose water sources have high sediment are lower in forest cover than the global average (Figure B-2). They also have a higher fraction of their source watershed devoted to agriculture. Steep slopes are also correlated with high sedimentation rates. Particular parts of the world with highly erodible soils, such as the Loess Plateau in China, also are prone to high erosion rates if natural land cover is cleared. The net effect of these various factors is substantial variance among urban source watersheds in the baseline, natural level of sedimentation. Moreover, there is substantial variance among urban source watersheds in their vulnerability to increases in erosion above that baseline rate due to land conversion.

Figure B-2. Influence of land use on sediment load



*KFactor is a measure of soil erodibility. A low KFactor represents low risk of erosion. KFactor typically ranges from 0 - 0.4.

Average watershed features by quartile. Raw water quality in this case is driven primarily by clearing for agriculture, erodible soils, and high slope.

Higher sediment, higher cost

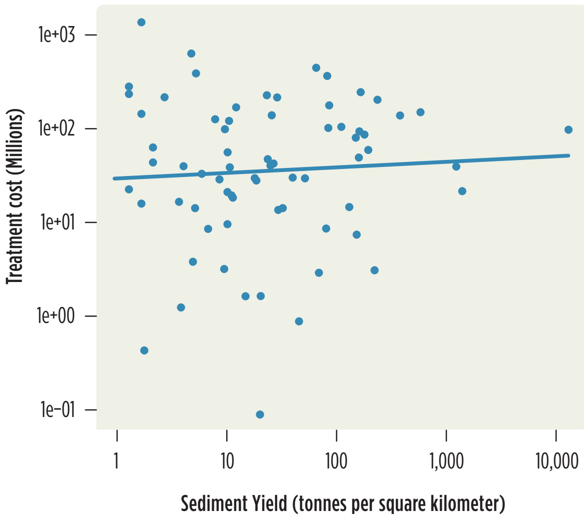
One of the reasons to care about sediment rates is that high sediment yield leads to higher operations and maintenance (O&M) costs in water treatment. For instance, increased sediment and turbidity leads to greater use of coagulants, increasing costs and the amount of time water needs to remain in settling basins. High sediment concentration in source water generates more wastewater and sludge, which are both costly to treat and transport. Increased sediment also increases the need to dredge sedimentation tanks. Moreover, if not removed, sediment can prevent adequate filtration and disinfection of other pollutants and pathogens [16].

Of course, the costs of running a water treatment plant are only one component of overall O&M costs for water utilities. For instance, New York City avoided having to build a filtration plant for its main source watersheds by agreeing to source watershed conservation, thus saving US $110 million per year. This number has to be seen in the context of the overall budget for the water utility, around US $1.1 billion. Even excluding the roughly US $400 million spent for wastewater treatment by the utility, that still implies that water treatment plant costs are only around 16 percent of the total O&M costs of the utilities [28]. This section discusses the O&M costs in water treatment plants only.

We are not aware of any global estimates specifically of water treatment plant O&M for the water sector. One study [2] estimated US $480 billion in expenditures (both capital and operating expenditures) in the world's water market. Of this, US $220 billion was capital expenditures on water or wastewater infrastructure (46 percent), while the rest (54 percent) was operating expenditures. Out of capital expenditures for water infrastructure, only US $17 billion was for water treatment plants, around 8 percent of total capital expenditures in the water sector. If we assume this fraction would also apply to operating expenditures, we might roughly estimate that 8 percent of the US $260 billion in operating expenditures, some US $21 billion was for water treatment plant O&M.

We collected data 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 is associated with a 2.6 percent average reduction in O&M costs (Figure B-3). This estimate does not include the cost of dredging large reservoirs outside the water treatment plant, which can be substantial. For instance, Crowder [29] estimated the decreased reservoir capacity in the United States due to sedimentation costs between US $597million and US $819 million a year in 1987.

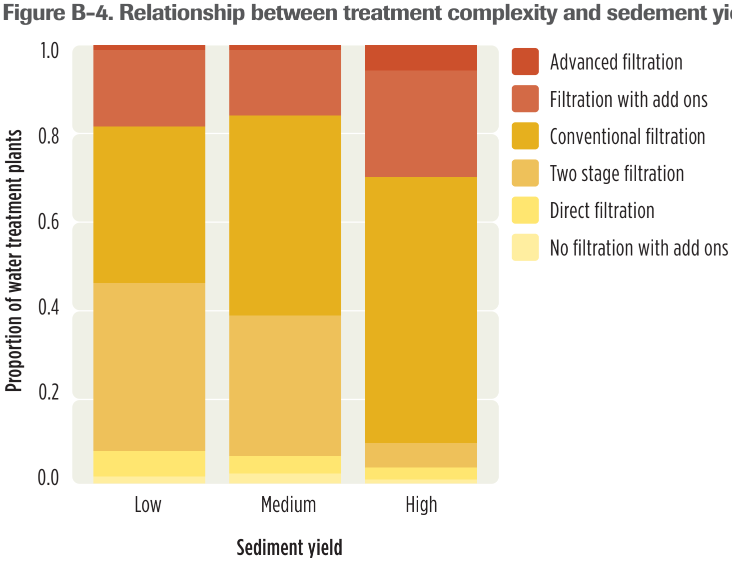
Figure B-3. Correlation between treatment cost and sediment yields



A high concentration of sediment is also associated with more complex treatment technologies used in water treatment plants (Figure B-4). Water treatment plants whose sources are low in sediment are 5.8 times more likely to operate without filtration (an inexpensive way to set up a treatment plant that depends on good raw water quality) than those with high sediment. Similarly, water treatment plants with water with low sediment are 4.7 times more likely to use two-stage filtration than those with high sediment. Conversely, advanced filtration technologies (e.g., membrane filtration) are 6.3 times more likely to be used in high sediment waters than in low sediment waters. Treatment plants using "filtration with add-ons" (e.g., ozonation and GAC filtration) are 4.3 times more likely to be used in water treatment plants whose waters have high sediment than those with low sediment.

Technologically more complex water treatment plants cost more to build [23]. The average cost of a 100 megaliter-per-day (MLD) plant varies depending on its treatment technologies. A no-filtration plant is the cheapest, costing US $50 million. At the other extreme, advanced filtration plants can cost US $110 million. Thus, high sediment levels can significantly increase capital costs for new water treatment plants.

Figure B-4. Relationship between treatment complexity and sedement yield

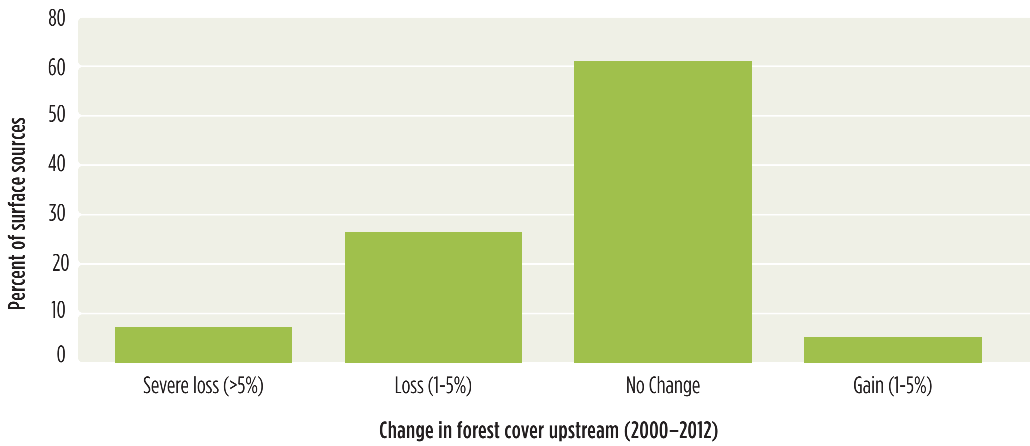


The future of sedimentation in the world's watersheds

Sedimentation not only impacts the cost of operating the infrastructure, it can also affect the depreciation of storage infrastructure (through silting) and can significantly affect ecosystem functionality. Changes in land use occurring across the world will likely have a significant impact on the rates of sedimentation across watersheds, posing an additional challenge to many cities.

If global trends continue, sediment yield may increase for many urban source watersheds. For instance, an analysis of high-resolution global satellite imagery of forest cover shows a consistent trend towards forest loss. More than 40 percent of source watersheds have had significant forest loss over the past decade (Figure B-5). In contrast, virtually none of the source watersheds had a significant increase in forest cover. Since forests play an important role in stabilizing soil and preventing erosion, this trend of forest loss has likely increased sedimentation.

Figure B-5. Forest loss 2000–2012



Trends in forest loss in the world's urban source watersheds over the period 2000–2012.

A larger global population also means there will be close to a 60 percent increase in food production over the next 30 years. While some of this increase will be due to increased productivity, the Food and Agriculture Organization of the United Nations forecasts a 70 million-hectare increase in crop area globally [17]. Since the source watersheds of large cities cover close to half the land area globally, it is likely that a significant fraction of agricultural expansion will occur in urban source watersheds. This could lead to increased sedimentation in the future, as source watersheds are further degraded.

While land use practices are not a common domain for urban water managers, if these trends persist, most cities will have to worry about changes in the management of their watersheds. Chapters 3 and 4 discuss how conservation measures may provide some answers for this challenge.

APPENDIX C

THE IMPACT OF NUTRIENTS ON TREATMENT COSTS

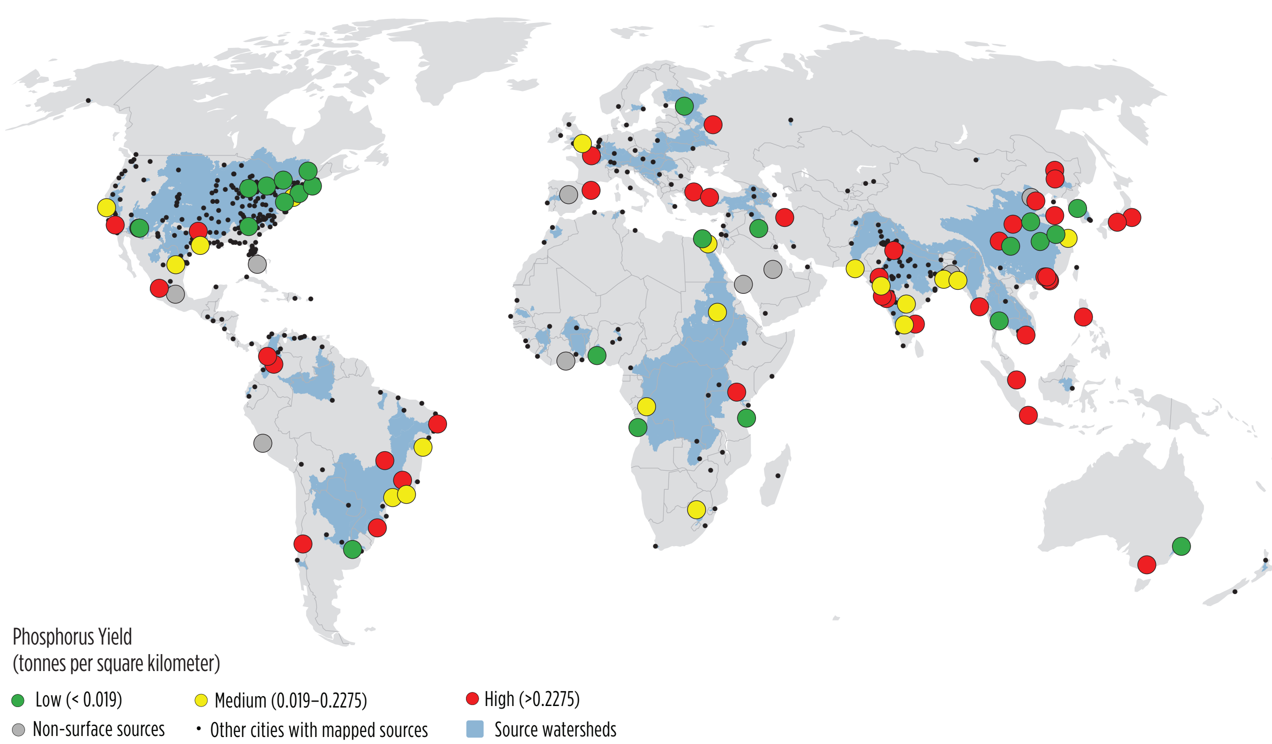
This section revisits content in Chapter 2 and expands upon it to discuss the impact of nutrients on water treatment costs, including our analysis of the statistical relationship between nutrient yield and treatment costs for a large sample of cities.

Excessive nutrient loading

Impacts on water quality are not limited to sedimentation rates. As watersheds are exploited for agricultural purposes, and as agriculture turns intensive, the use of fertilizers inevitably increases and more fertilizers end up in the water. Many source watersheds face challenges to their raw water quality from excessive nutrient loading. The two most common nutrients that cause problems are excessive phosphorus and nitrogen which come primarily from agriculture and pastureland. In practice, phosphorus and nitrogen loading—hereafter "nutrient pollution"—are highly spatially correlated, and in this report we show primarily information for phosphorus due to space limitations.

Nutrient pollution can pose problems for water treatment plants. Nitrogen in some forms is toxic at high concentrations and is widely regulated. Most freshwater systems are phosphorus-limited, so adding phosphorus to a body of water eventually leads to algal blooms, which have many direct and indirect effects on the costs of water treatment.

Figure C-1. Cities grouped by phosphorus yield



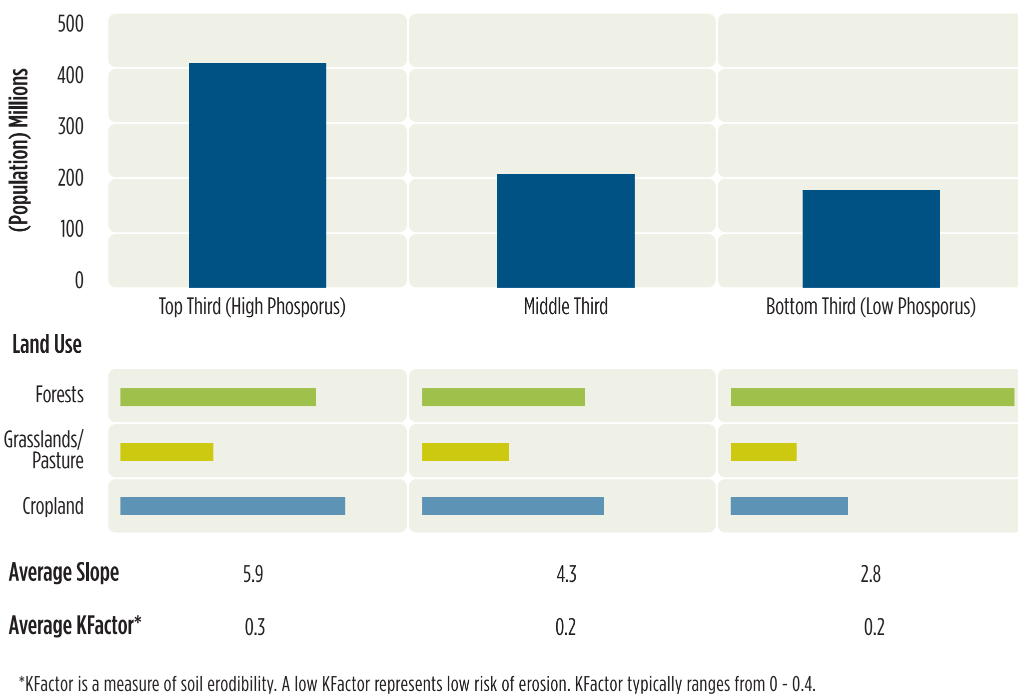
Top 100 cities surface sources


Photo: ©Kent Mason

More than 384 million urbanites (46 percent of all people living in the 100 largest cities) get their drinking water from watersheds with high nutrient yield. As with sediment, the task of raw water quality maintenance seems harder for the developing world than for the developed. In contrast, only 180 million people are in the low category.

Landscapes with low nutrient pollution tend to be high in forest or other natural land cover, which also tends to be associated with the absence of more intense human land uses. Nutrient pollution is generally due to agricultural or ranching practices. Fertilizer and manure application to cropland is the major source of phosphorus loading from cropland, while from ranchland one of the main sources is simply animal excrement, whose quantity is a product of the animal stocking density. The global variation in the intensity of agriculture (both cropland and ranchland) means that protecting raw water from excess nutrient loading will be far more difficult in some places than in others.

Figure C-2. Influence of land use on nutrient load



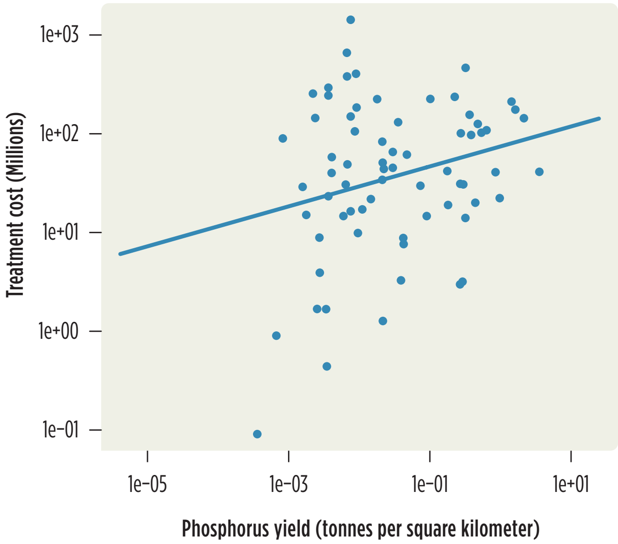
Average watershed features by tier (high, medium, and low).

The cost of fertilization

High nutrient levels lead to higher O&M costs for water treatment plants. High phosphorus is associated with a greater frequency and intensity of algae blooms and higher organic matter content. Both lead to more frequent filter cleaning and additional treatment processes to remove unwanted colors or odors from the water. In extreme cases, nutrient levels have even led to plant shutdowns. High nutrient levels in source water also generate more wastewater and, in turn, increase the cost of treating effluent exiting a plant. The use of chlorine, for example, as a disinfectant in the presence of organic matter can lead to unwanted disinfection byproducts, some of which can have negative health effects [18].

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 (Figure C-3).

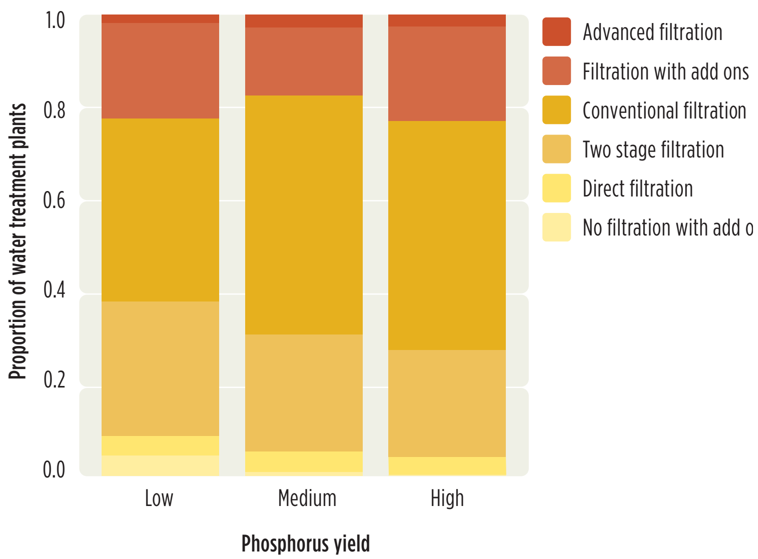
Figure C-3. Correlation between treatment cost and nutrient yield



A high concentration of nutrients is also associated with the use of more complex treatment technologies in water treatment plants (Figure C-4). Plants drawing water from sources of low phosphorus yield are 6.8 times more likely to have no filtration than those drawing from high sources. Similarly, two-stage filtration, another relatively simple method of water treatment, is 5.3 times more likely to occur in plants whose sources have low phosphorus than those whose sources have high phosphorus. Conversely, advanced filtration techniques like membrane filtration is 7.6 times more likely when drawing on a source with high phosphorus yield.

More complex treatment technologies cost more to build, raising capital (replacement) expenses [23]. Since phosphorus yield in part determines treatment technology uses, it is directly related to capital expenses. Numerically, this effect is most important for water treatment plants that use relatively simple treatment technologies, since water managers have a strong incentive to avoid having to replace it with a more complex plant. Note again that conservation practices that reduce both sediment and phosphorus will affect water treatment technologies used through both pathways.

Figure C-4. Treatment complexity



The future of watersheds under high nutrient loading

If current trends continue, nutrient pollution may worsen over the next decade. For instance, agricultural area is forecast to increase by 70 million hectares by 2030. Perhaps more significantly, fertilizer use is forecast to increase by 58 percent globally over the same time period [17]. Indeed, in least developed countries, getting poor farmers access to sufficient, affordable fertilizer is often a key part of increasing productivity and boosting rural economic development. Overall, the cities that are likely to have the biggest increase in nutrient loading from agricultural growth are located in Brazil, Argentina, and parts of sub-Saharan Africa.

Human population growth will increase nutrient pollution. From 1950 to 2000, global population increased from 2.5 to 7.2 billion [7]. Forecasts state that by 2050 this will climb to 9.3 billion. Human population is correlated with many human activities that will increase nutrient loading, so this increase likely will be associated with increased nutrient pollution. For instance, while in many basins human wastewater is a minor part of the overall nitrogen and phosphorus cycle, in some rivers such as the Ganges, wastewater from multiple cities (often released without treatment) becomes the intake for other cities. In these basins, the installation of basic treatment for wastewater may be necessary to prevent a further decrease in raw water quality, as population growth increases sewage loading.

APPENDIX D

METHODOLOGY

City water map

City selection

The goal of this study was to characterize the water risks and opportunities for cities, with a special focus on large cities (greater than 750,000 people). These cities are surveyed as part of the World Urbanization Prospects (WUP) [7] report conducted by the United Nations Population Division. The WUP lists the past and current population of each city greater than 750,000 people (cumulatively, 1.5 billion people in 2010).

In the first phase of our project, we targeted the 50 cities with largest population for data collection. We also targeted primary cities, the largest urban agglomeration in a country, if they were larger than 750,000 people.

In the second phase, since it was not feasible to collect information on all cities in the WUP list, we targeted a sample of cities. This sample was stratified into categories by city size (< 1 million, 1 million to 2.5 million, 2.5 million to 5 million, or > 5 million), crossed with geographic region (Asiatic Russia, Australia/New Zealand, Caribbean, Central America, Central Asia, Eastern Africa, Eastern Asia, Eastern Europe, European Russia, Middle Africa, Northern Africa, Northern America, Northern Europe, Polynesia, South America, Southeastern Asia, Southern Africa, Southern Asia, Southern Europe, Western Africa, Western Asia, Western Europe). The target number of cities we aimed to survey in each category was proportional to the number of cities in that category. Within each category, cities from the WUP were randomly ordered into a list, and we attempted to survey cities in that order, beginning at the top of the list. Not all cities had easily obtainable data, however, and if it was not possible to find information on one city we searched for the next city on the list. In some cases, particularly in the United States, a single city is served by multiple utilities, each with a separate water supply system, and we mapped each separate supply system where the population it served was greater than approximately 100,000 people.

In the third phase, we added easily available data for cities in the United States, including some that are well below our 750K threshold, using data from Padowski and Jawitz [30]. We also added some specific cities that were important for particular institutions. We obtained information on all remaining cities greater than 1 million in Latin America. This Latin American sample was obtained to facilitate strategic decision-making by the Latin American Conservation Council, which is deciding where to expand its source watershed conservation activities. We also obtained information on the remaining cities that are part of the C40 Cities Climate Leadership Group that were not surveyed in Phase 1 or Phase 2 of our sampling. In addition, we obtained information where possible on cities that have already been selected by the Rockefeller Foundation as one of its Resilient Cities.

Data collected

The resultant sample of cities we call the City Water Map (CWM), version 2. For each city in our sample, we used web searches in the primary language used in the city to find the names of the water utilities or agencies that supply water. Once that name was obtained, we usually found annual reports or information supplied to national governments that listed water sources and the amount of water withdrawn. In some cases, we had to use sources of lower certainty, such as the website of the water utility, which often listed water sources. Once the place names of water sources were identified, we geolocated the sources. Unique place names were identified in Google Maps 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).

The resultant database of city water sources and associated attributes, termed the City Water Map (CWM), has a hierarchical structure. Variables collected at the city level include the WUP urban agglomeration to which it belongs, which allows the processing of data at the urban agglomeration level of resolution (see below). Data collected at the utility level included the name of the utility, the population it served, and the total volume of water it supplies. Utilities rely on one or more water diversions, and the data collected at the diversion level included its name, its spatial location, its type (surface, groundwater, saline water, etc.), and the volume diverted by the utility from that diversion.

Defining contributing areas

Our analysis focuses on surface water sources. Unless otherwise noted, all of our calculations involved surface water sources. We did account for the fraction of water that comes from other sources (e.g., groundwater, desalination) in our risk and opportunity metrics. Cities that do not predominantly rely on surface sources are marked as "not applicable" or "insufficient scope" on our maps.

For surface freshwater withdrawal points, their location had to be adjusted ("snapped") to match the underlying hydrographic river system, in this case represented by the global high resolution hydrographic dataset HydroSHEDS [31]. We included so-called alluvial groundwater sources in this set of surface withdrawal points, since in this case the water is primarily surface water, pulled through a river bank primarily as a means of cleaning the water (bank filtration). The HydroSHEDS digital elevation model was created from NASA's Shuttle Radar Topographic Mission (SRTM) [32] and further processed to ensure correct hydrographic flow paths. 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 as defined in a global database of lakes, reservoirs, and wetlands (GLWD) [33]. This correction allows the watershed 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 km) to match the point of greatest flow accumulation.

Aggregating data up to the utility or city level

For this report, the fundamental unit of analysis was the city level. In order to conduct the analysis at this level, attribute information collected at the level of a water diversion point or water utility had to be aggregated to the urban agglomeration level. For most water diversion points we knew the volume of water withdrawn annually, and for any attribute collected at water diversion level the average value for the urban agglomeration was calculated as the volume-weighted average of all diversions that service that urban agglomeration. For cities where diversion-specific water withdrawal information was not available, for any attribute collected at water diversion level the average value for the urban agglomeration was calculated as the simple average of all diversions.

Water quantity

Estimating water availability and water risk

Our source of information on surface water availability and water quantity risk was the WaterGAP 3 model. The global integrated water model WaterGAP consists of two main components: (1) a water balance model to simulate the characteristic macro-scale behavior of the terrestrial water cycle in order to estimate water availability; and (2) a water use model to estimate water withdrawals and consumptive water uses for agriculture, industry, and domestic purposes [34]. The model operates on a 0.1 x 0.1 degree resolution.

Based on the time series of climatic data, the hydrological model calculates the daily water balance for each grid cell, taking into account physiographic characteristics like soil type, vegetation, slope, and aquifer type. Runoff generated on the grid cells is routed to the catchment outlet on the basis of a global drainage direction map [35], taking into account the extent and hydrological influence of lakes, reservoirs, dams, and wetlands.

Spatially distributed sectoral water withdrawals and consumption are simulated for the five most important water use sectors: irrigation, livestock-based agriculture, industry, thermal electricity production, and households and small businesses. Countrywide estimates of water use in the manufacturing and domestic sectors are calculated based on data from national statistics and reports and are then allocated to grid cells within the country based on the geo-referenced population density and urban population maps [36].

The amount of cooling water withdrawn for thermal electricity production is determined by multiplying the annual thermal electricity production with the water use intensity of each power station, respectively. Input data on location, type, and size of power stations were based on the World Electric Power Plants Data Set. The water use intensity depends on the cooling systems and fuel sources of the power stations. Four types of fuels (biomass and waste, nuclear, natural gas and oil, coal and petroleum) with three types of cooling systems (tower cooling, once-through cooling, and ponds) are distinguished [37].

Net and gross irrigation requirements, which reflect an optimum supply of water to irrigated plants, are computed based on a digital global map of irrigated areas [38] as a starting point for simulations. The model simulates cropping patterns, growing seasons, and net and gross irrigation requirements, distinguishing 21 crop types [39]. Water withdrawals for livestock are computed by multiplying the number of animals per grid cell by the livestock-specific water use intensity [35].

Water quantity risk

We considered two metrics of surface water quantity risk: annual water quantity risk and low-flow water quantity risk.

For annual quantity risk, we used the common metric of water stress: annual withdrawals (cubic kilometers per year) divided by available (cubic kilometers per year). This ratio of water use to available is a common water stress metric. Any value greater than 0.4 was considered water stressed. Many other surface water analyses have used a threshold of 0.4; see the discussion in Vörösmarty et al. [40] for more detail on the history and use of this threshold.

For low-flow water quantity risk, we extracted from the WaterGAP output the Q90—that is, the water availability threshold that the river exceeded 90 percent of the time (and hence river flow is less than this threshold 10 percent of the time). This characterizes well average low-flow conditions in the river. It does not characterize the risk of extreme droughts (e.g., Q99), which are difficult for any global hydrologic model to adequately characterize. Because such extreme events are by definition rare, there are not enough of them in the 30-year time period analyzed in WaterGAP to statistically estimate such thresholds with precision.

The Q90 value (expressed as an annual rate, cubic kilometers per year) was divided by the rate of withdrawals (expressed also as an annual rate, cubic kilometers per year) to calculate our low-flow water quantity risk. Our metric of low-flow water quantity risk essentially quantifies what fraction of available water will be used by humans during low-flow conditions.

Water quality

We focused our analysis of surface water quality on three types of pollutants often of concern to water utility managers: sediment, nitrogen (N), and phosphorus (P). While other types of pollutants are also quite important for water managers (e.g., fecal coliform contamination), these three are the pollutants that are most often targeted by the kinds of conservation activities considered in this report. In practice, estimate loadings of N and P are highly correlated, so in the body of the report we only report values for P. 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 [34]. 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 [41]. 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. Our global land cover map was the GlobCover 2009 dataset, reclassified into six categories: Agricultural, Grassland/Pasture, Forest, Barren, Urban, and Water/Other.

Our estimated sediment loading for source watershed loadings in the United States was compared with the SPARROW dataset [42], which is an empirically based estimate of loading calculated from thousands of direct stream measurements in the United States. 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 sediment loading calculations.

Nitrogen and phosphorus model

Nitrogen and phosphorus loading were estimated using an export coefficient approach, where each land cover type exports a certain amount of N and 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 N and P export on the global grids of the Global Fertilizer and Manure (GFD), Version 1, dataset. 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 (the fraction uptaken by plants or soil, and not exported) was estimated using continent level data in NUE taken from Bouwman et al. [43].

As with sediment, our estimated N and P loading for source watershed loadings in the United States was compared with the SPARROW dataset [44]. 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 N and P loading calculations.

Water quality risk metrics

Our metrics of surface water quality risk are sediment, N, and P yield, in tonnes/km2 of watershed area. Pollutant yield can be easily calculated with the available 15 arc-second resolution models we constructed of sediment, N, 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 watershed conservation to reduce pollutants, we use information on changes in pollutant load in our calculation. Pollutant concentration, which is what most often has economic impacts on the Operations and Maintenance (O&M) costs of water treatment plants (WTPs), is of course load divided by river flow. Note that in this study we are considering how changes in pollutant loading in one watershed 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:

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

Water quality opportunity metrics

We developed five water quality opportunity metrics, each of which represents a commonly used source watershed conservation activity. See Chapter 3 for more detailed definitions of each of the five activities, as well as a description of how it has been implemented in a particular city.

Each water quality opportunity metric had a similar structure. The average effectiveness of the practice at preventing sediment, nitrogen and phosphorus loading was quantified through a literature review. The literature also sheds light on where the practice can be effectively implemented. In a GIS system, we examined all GIS pixels where the practice could be implemented, quantifying the reduction in sediment, nitrogen and phosphorus from applying the practice on one hectare of land. Pollutant loading for a source watershed is just the sum of the individual loads from specific pixels.

Each source watershed 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 watershed 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 amount of hectares that would need to be worked on to get to a nominal 10 percent reduction in the 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 watershed where it is possible to do reforestation, then this conservation activity may be unable to reduce sediment load by 10 percent. We have marked these cases as “insufficient scope” on our maps in the report.

Many utilities rely on non-surface sources of water, such as groundwater or desalination, either in whole or in part. To account for this in our analysis, we first calculated the average opportunity index for a city’s surface sources. Then, we only display on our maps a city’s opportunity score if the conservation activity can help at least one in three of a city’s sources (or, in cases where we know the specific volume taken from each source, 33 percent of a city’s total withdrawals). The assumption here is that for cities that predominately rely on non-surface sources, our opportunity score is not that meaningful.

Note that forest protection and forest fuel reduction reduce a future risk of increased sediment or nutrient loading. For these two activities, 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.

Table D-1. Effectiveness factors used in calculation of opportunity metrics

Practice	Area where applicable	Percent reduction in sediment, nitrogen, and 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 times the change in pollutant load if that occurs. Probability of natural habitat loss without action calculated as biome averages between GlobCover images. 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	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 Nitrogen: 61 percent reduction Phosphorus: 77 percent reduction	Based on average results for implementing cover crops [45]
Riparian restoration	Agriculture pixels along riparian corridors, as defined with the HydroSHEDS DEM. All agricultural pixels.	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 [46]
Forest fuel reduction	Current forest pixels that are in their natural area, as defined in WWF ecoregions.	The expected increase in pollutant load, defined as the probability of forest fire times the change in pollutant load if that occurs. Probability of forest fire calculated from Global Fire Emissions Database, version 4. Forest thinning reduces probability of a severe fire by 70 percent, based on review paper. If fire occurs, then changes calculated as the change in CP factor from natural land cover to barren.	Fuel management effectiveness average based on Martinson and Omi [44]

Comparing costs to water quality

Estimating O&M and capital costs

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. Note that cities often have multiple sources and multiple WTPs, which may treat water from one or more sources. Collectively, our sample amounts to information on around 500 WTPs. Information collected on each WTP follows that is used by the EPA in its surveys of water utilities. It includes 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). For the purpose of this project, WTPs were classified into seven categories, based on the categories in McGiveney and Kawamura [47]: No filtration; No filtration with additional processing; Direct filtration; Two-stage filtration; Conventional filtration; Filtration with additional processing, and Advanced filtration (e.g., membrane filtration). Examples of additional processing include iron and manganese removal, lime and soda ash water softening processing, dissolved air filtration, pre-ozonation, or GAC filters. O&M and capital costs were estimated following McGiveney and Kawamura 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 are standardized to 2007 $US, using the ENR Construction Cost Index (ENR-CCI). These are preliminary design estimates, and are likely to be off from actual replacement costs by +50 percent to –30 percent. However, by using a standard methodology we can consistently estimate replacement costs for all the WTPs in our sample. Similarly, many water utilities do not provide information on the value of their WTPs or list book value (the cost of previous construction of the plant, sometimes far in the past), which makes comparison among WTPs difficult.

Comparing to water quality data

O&M and capital (replacement) costs were compared with sediment, nitrogen (N), and phosphorus (P) yield estimates from our global models. For the WTPs in the United States (~100 cities), SPARROW estimates were also compared with cost data. Regression results are explained in the main body of the text. Where it was necessary or desirable to combine O&M and capital costs, we have expressed capital costs as annualized costs of paying a hypothetical 30-year, 5 percent municipal bond to finance construction of the replacement WTP. While obviously the structure and interest rates of water utility debt payments varies widely from country to country, it was helpful for our global analysis to have a consistent way of annualizing costs to focus our analysis on how raw water quality affects WTP design and costs. Varying the interest used by country or city would considerably affect the pattern shown by our results. Cities in developing countries, for instance, have generally higher interest rates, and so they are relatively more affected by how a decline in raw water quality might increase the need for more complex water treatment technologies, and hence increase capital costs. In contrast, cities in developed countries with lower interest rates are relatively less affected by a decline in raw water quality, since the cost of a more complex water treatment technology is more easily financed.

Calculation of a return on investment (ROI) requires information on both the benefits to the utility and the costs of doing conservation. For the conservation activity that takes the least number of hectares to reduce sediment or phosphorus by 10 percent, we estimated costs of conducting the conservation activity using broad, region-specific averages (see Table D-2). We also estimated the benefit to a water treatment plant, basing our calculation of O&M costs on a conventional treatment plant processing the city's volume of water. Based on a statistical analysis of empirical data for about 100 cities' water treatment plants (see body text for details), a 10 percent reduction in pollutant is worth around a 5 percent reduction in O&M costs. ROI is just the ratio of benefits for the water treatment plant to costs of conservation activity.

Note that this is a rough, ballpark calculation of ROI only, 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 it is a city-level average ranking. Many cities use more than one source watershed, and individual source watersheds 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. There are other ways, 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 instance, hydroelectric power production may be more efficient with less sedimentation and thus more storage behind a dam.

Table D-2. Implementation costs

Location	Reforestation (one-time USD/ha)	Riparian restoration (one-time USD/ha)	Ag. BMPs (annual payment USD/ha)	Forest Thinning (one time USD/ha)	Forest Protection (one time USD/ha)
North America	$3,700.00	$6,700.00	$188.00	$2,160.00	$2,914.00
Europe	$3,700.00	$6,700.00	$188.00	$2,160.00	$1,682.00
Oceania	$3,700.00	$6,700.00	$188.00	$2,160.00	$2,875.00
South/Latin America	$2,148.00	$1,095.00	$101.00	$2,160.00	$2,355.00
Africa	$800.00	$643.00	$101.00	$2,160.00	$300.00
Asia	$750.00	$643.00	$101.00	$2,160.00	$417.00

Implementation costs of conservation action assumed in our analysis, based upon a literature review. In addition to the implementation costs listed, we assumed that maintenance and administrative costs were equal to the annualized project capital costs (i.e., in our return on investment calculation we increased the annualized numbers below by a factor of two to account for maintenance and administrative costs).

APPENDIX E

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If cities were to fully deploy conservation activities, the potential market would be upwards of $18 billion.

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