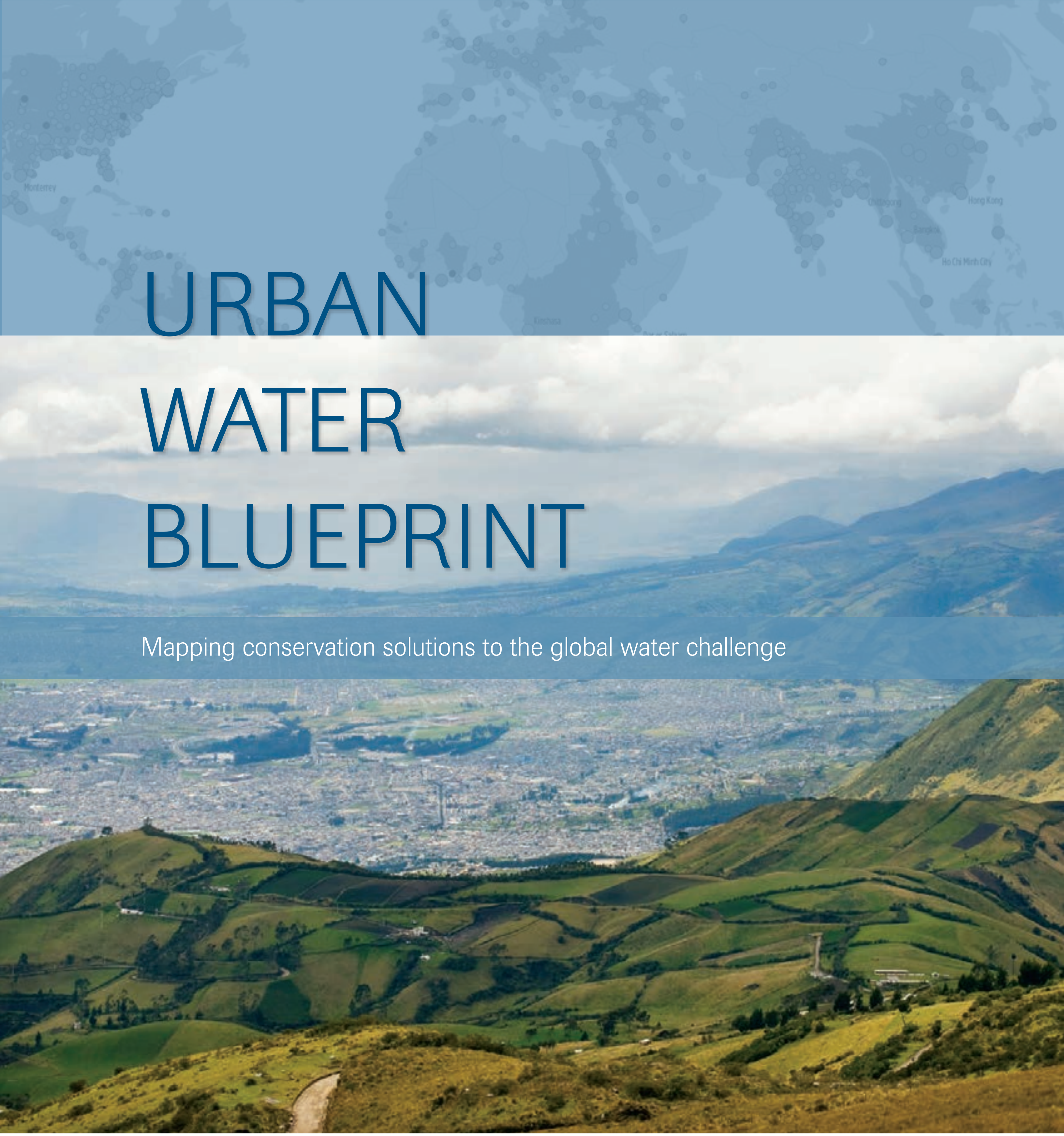


URBAN WATER BLUEPRINT

Mapping conservation solutions to the global water challenge

The Nature Conservancy
Protecting nature. Preserving life.®

In partnership with

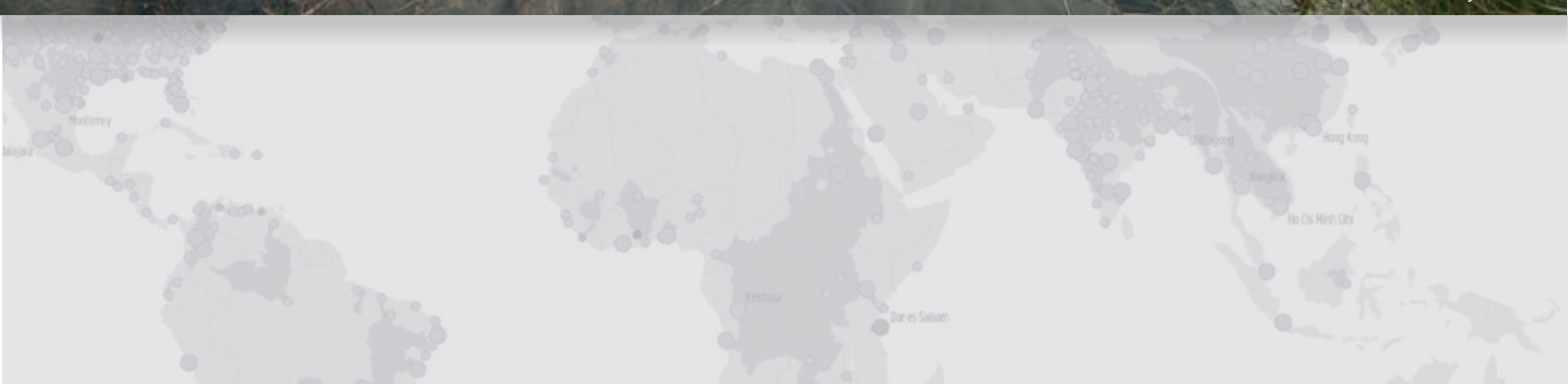
C40 CITIES CLIMATE LEADERSHIP GROUP

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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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.

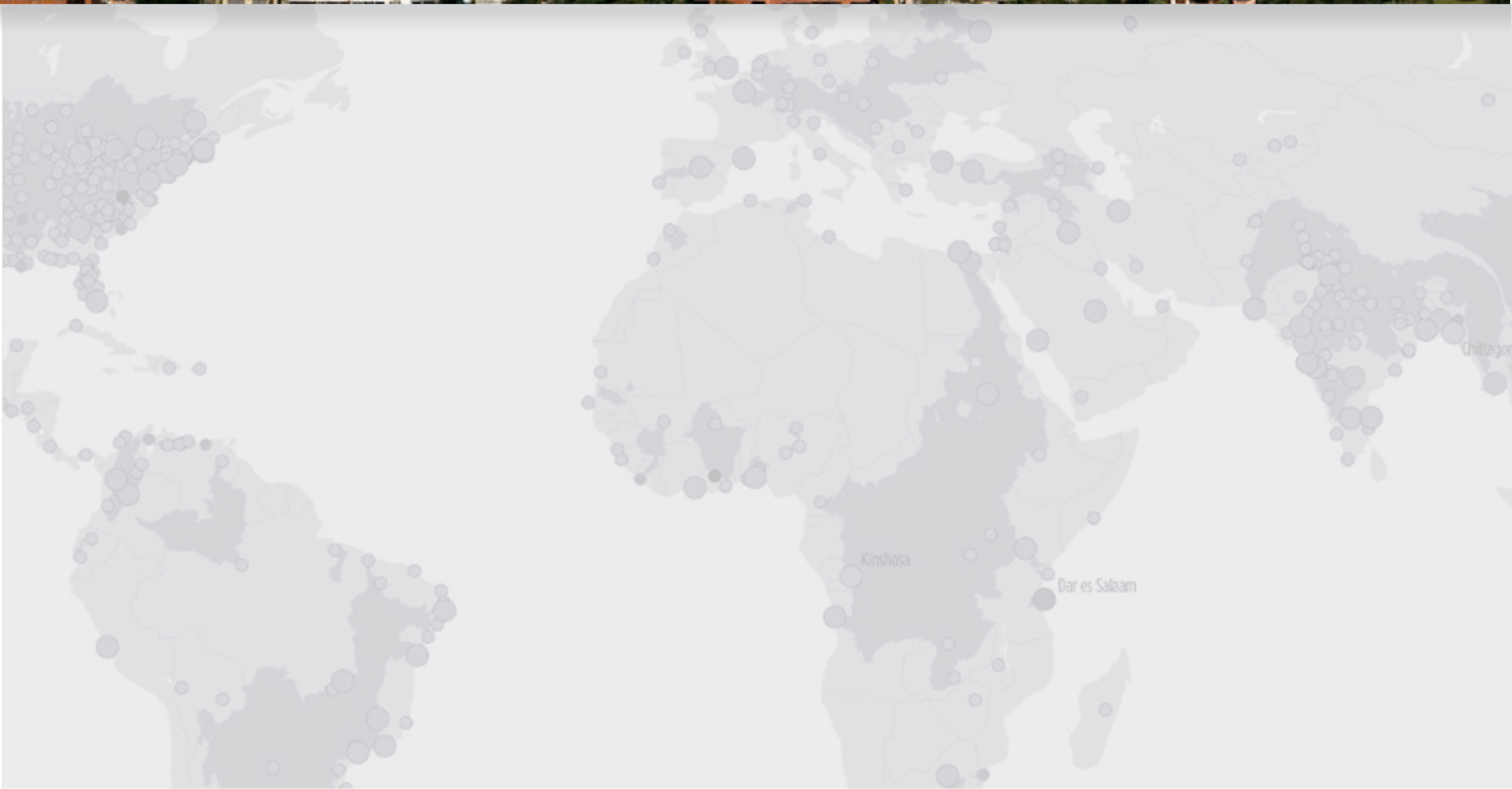
Eduardo Paes
C40 Chair, Mayor of Rio de Janeiro

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

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



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.

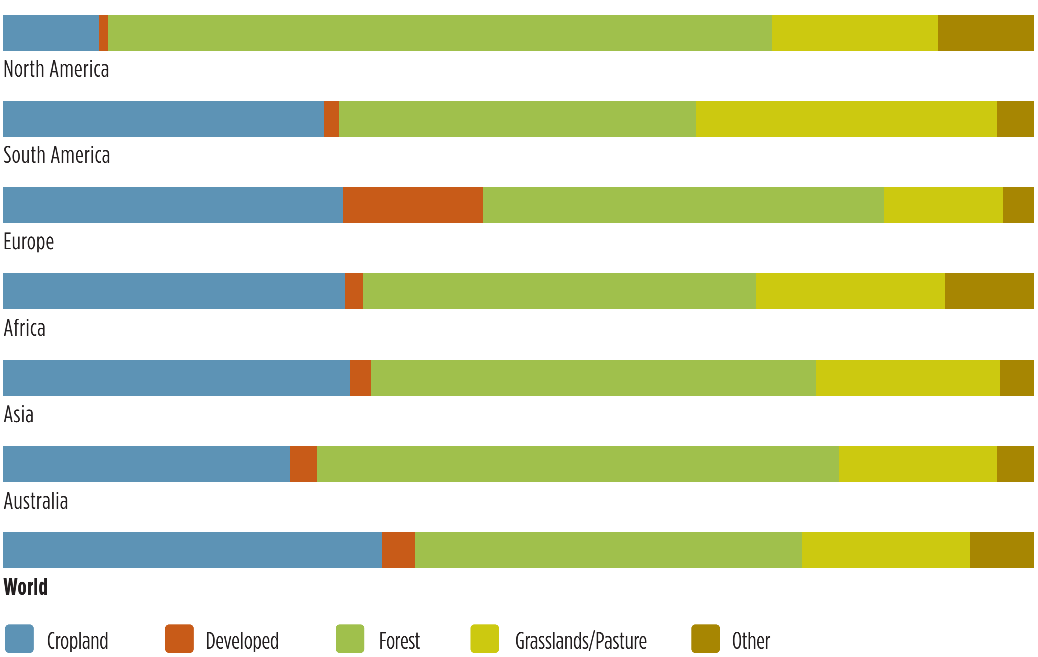
This report is about how investing in nature can help address these challenges. We evaluate one set of solutions to the growing urban water challenge: source watershed conservation. Scientists at The Nature Conservancy (TNC), in partnership with the C40 Cities Climate Leadership Group and International 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

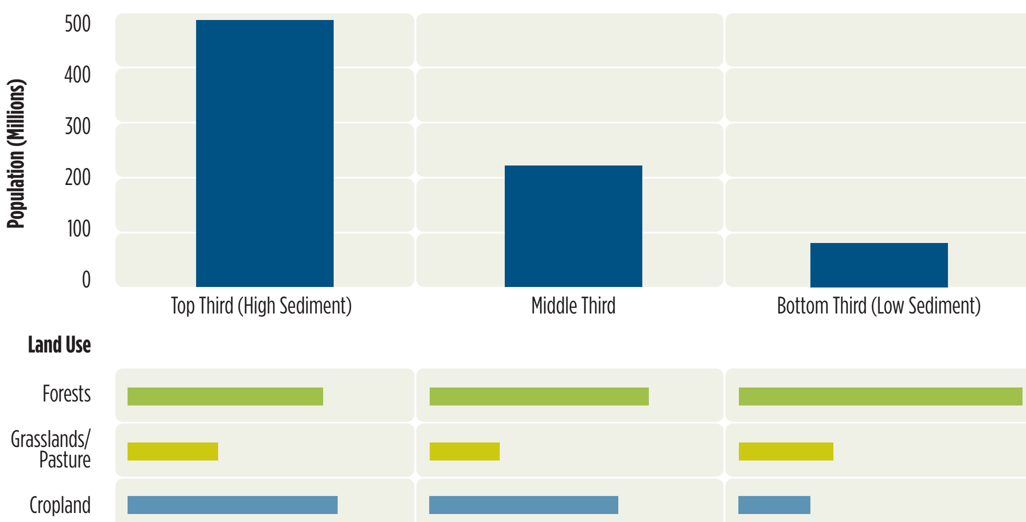
Water quality is often degraded by nutrients from excess fertilizer washing into streams and lakes. This problem will grow more severe in coming years, with cropland projected to increase 10 percent by 2030 and fertilizer use by a staggering 58 percent over the same time period. Moreover, water quality 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.

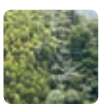
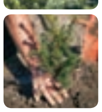
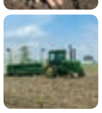
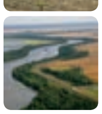
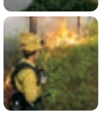
Cities that can afford to will be tempted to direct future investments toward moving more water ever greater distances to meet demand, but this is not a sustainable long-term solution. It may also not be climate adaptive—even when taking into account interbasin transfers, one in four large cities are 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

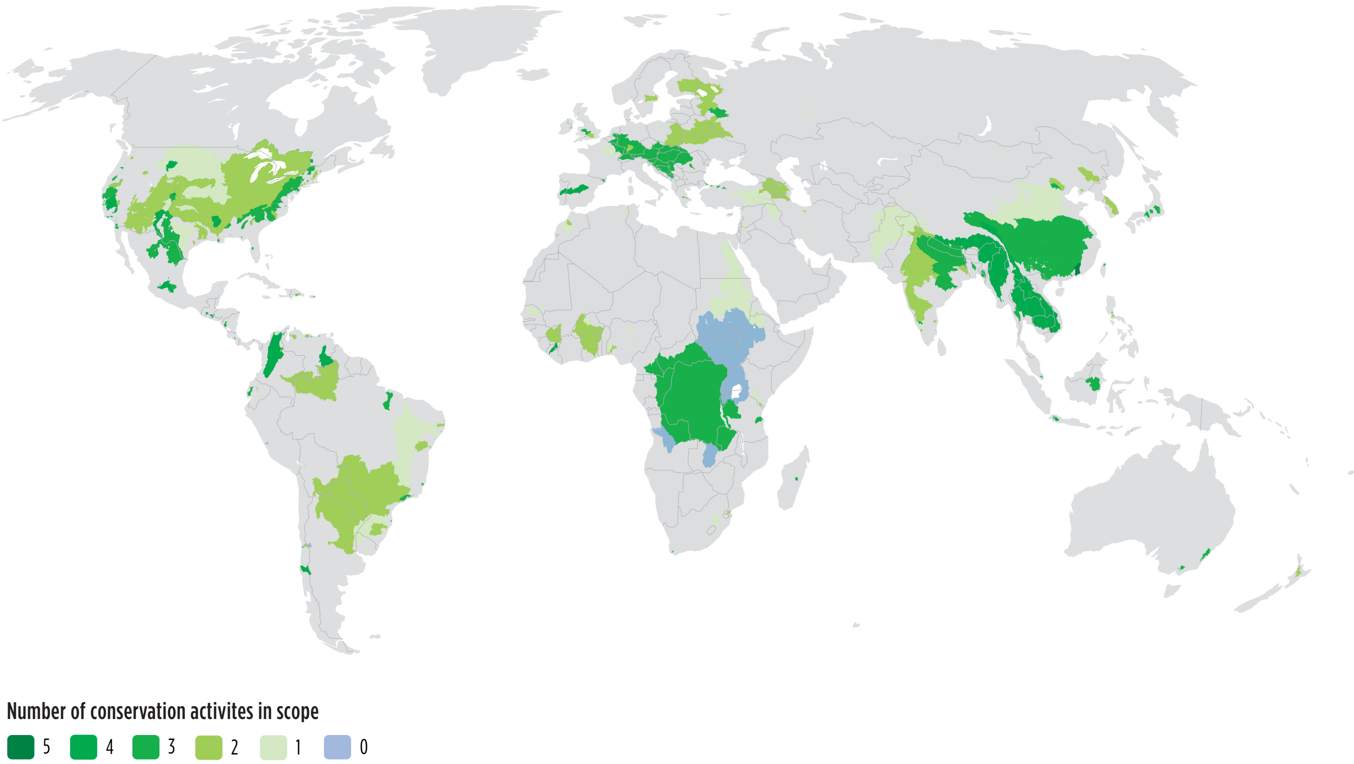
To help determine where watershed conservation can help secure water for cities, we estimated the effectiveness of five common conservation strategies: land protection, reforestation, riparian restoration, agricultural best management practices, and forest fuel reduction (Figure E-3). For each strategy, 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 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).

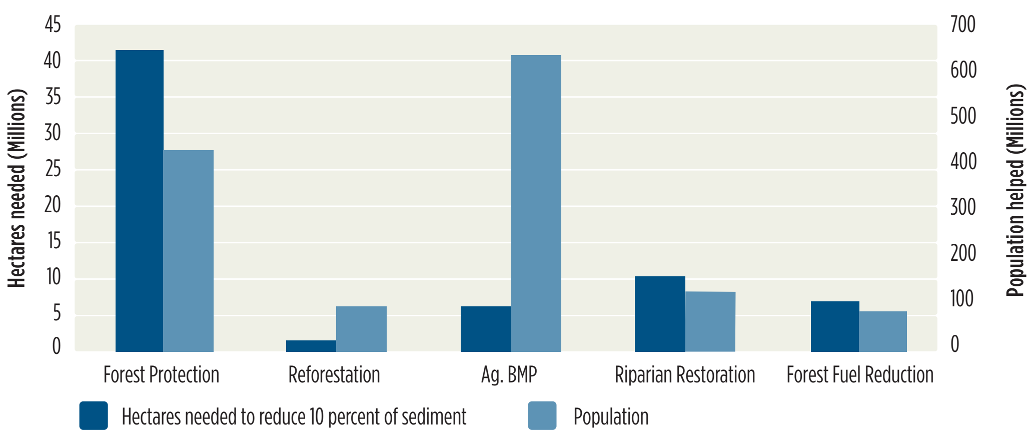
Figure E-4. Number of applicable conservation strategies



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.

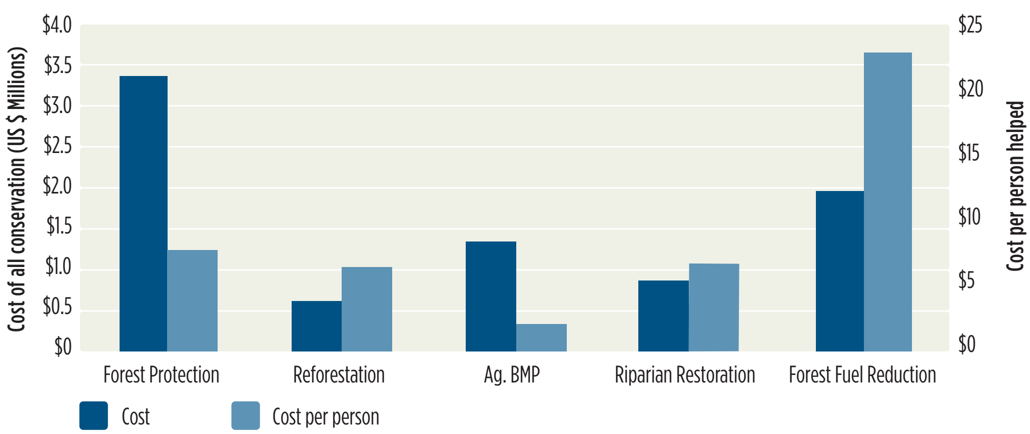
The global market potential for watershed conservation

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



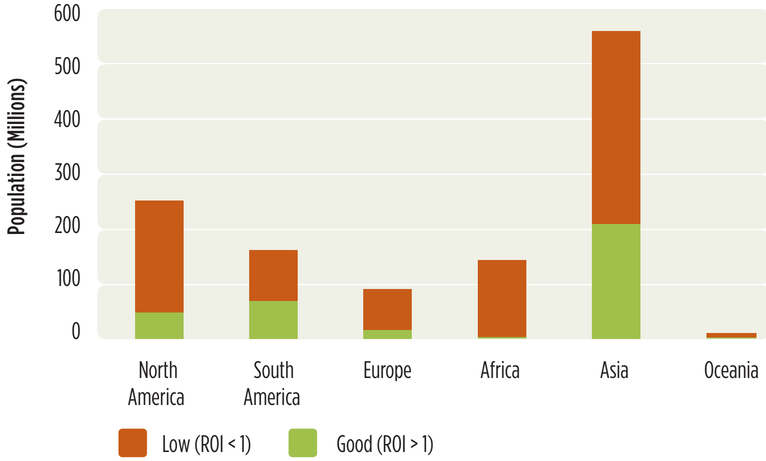
The full report also features trends for nutrient pollution.

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.

40%

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

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

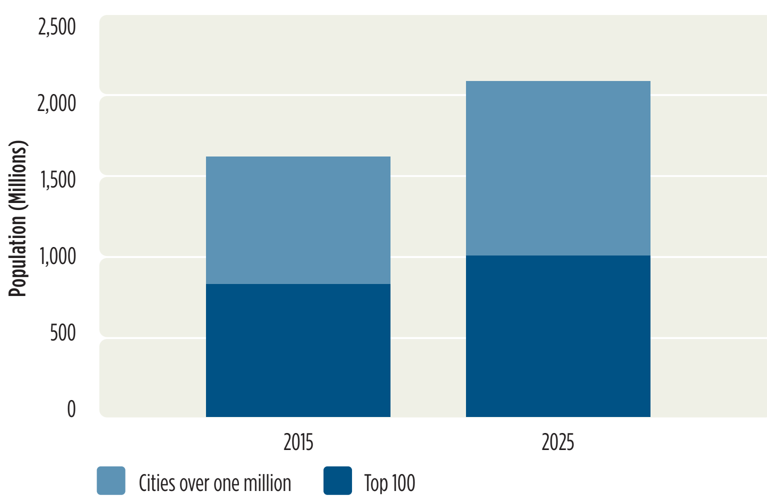
WHERE OUR WATER COMES FROM

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.

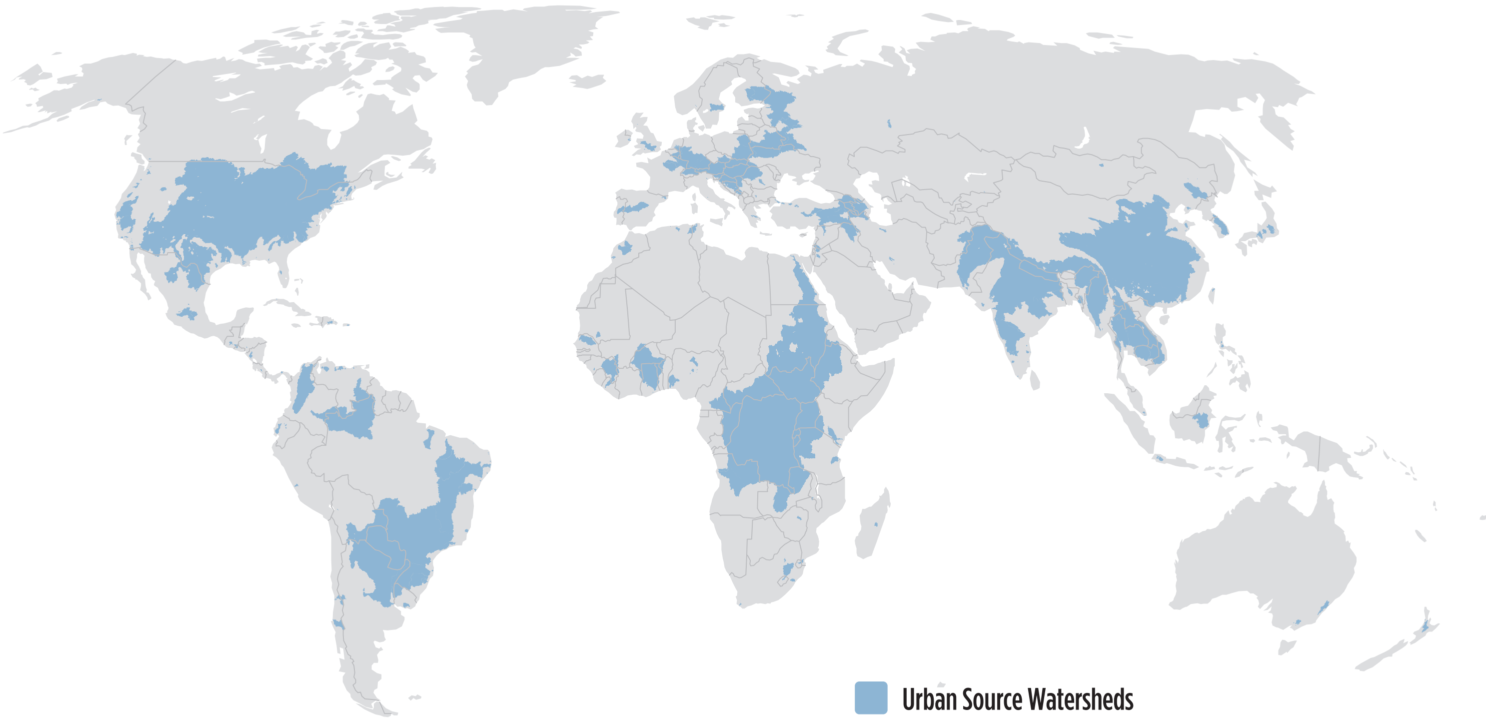
Cities and their water sources

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

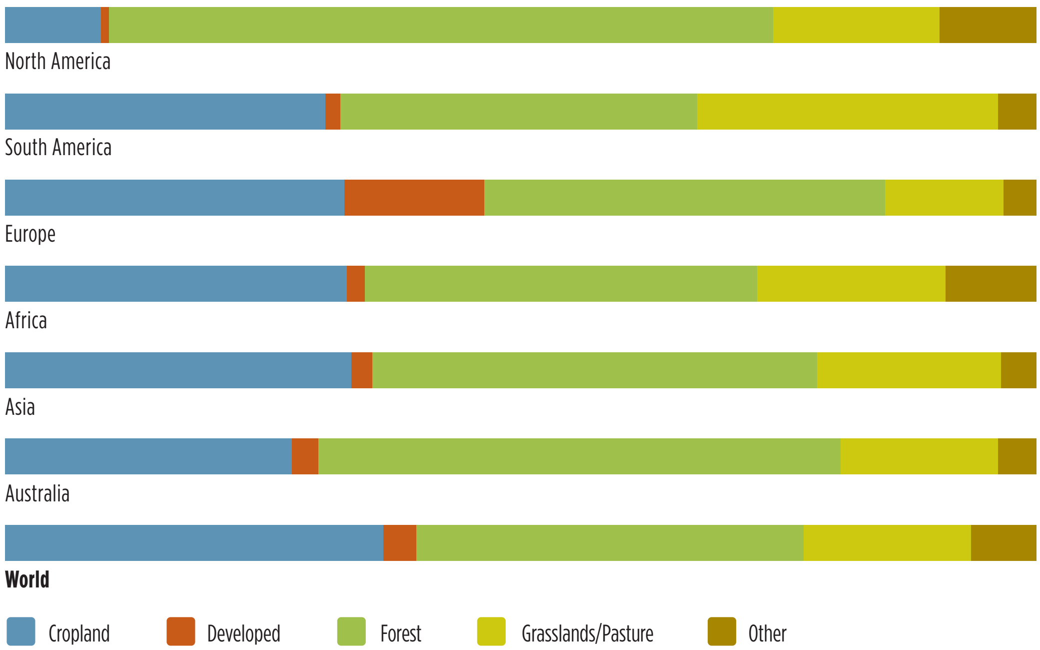


Continent	Top 100 cities (million ha)	All cities mapped (million ha)	Fraction of land serving top 100	Fraction of land serving all cities mapped
North America	161	612	6.0%	22.9%
South America	305	519	19.9%	33.8%
Europe	57	222	5.8%	22.3%
Africa	678	774	22.5%	25.8%
Asia	508	785	11.4%	17.6%
Australia	2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

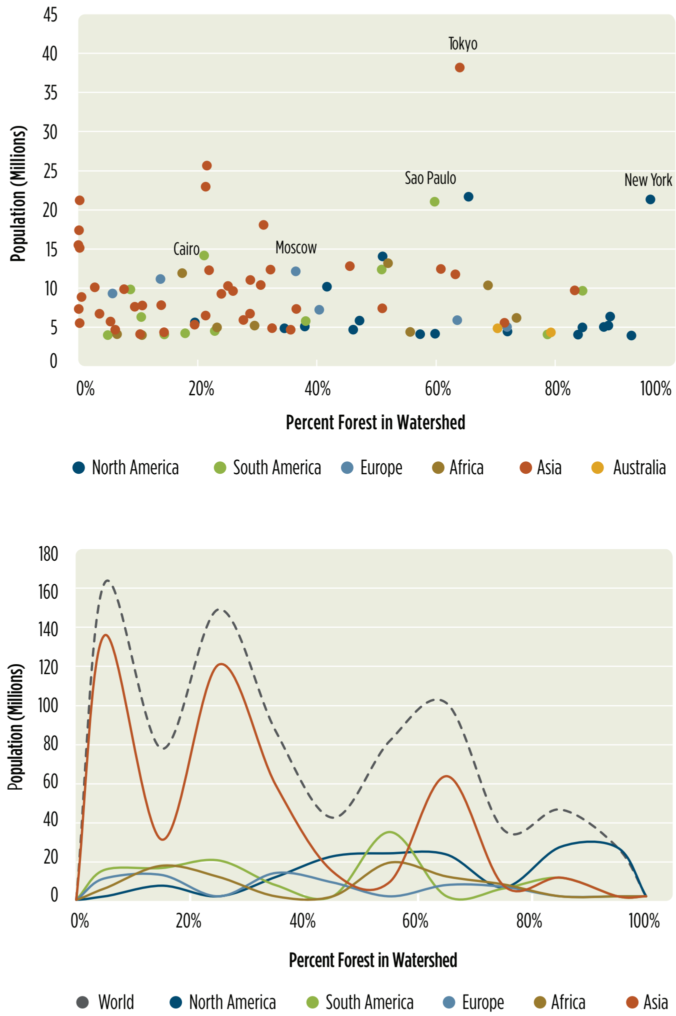


Figure 1-5. Population versus cropland cover

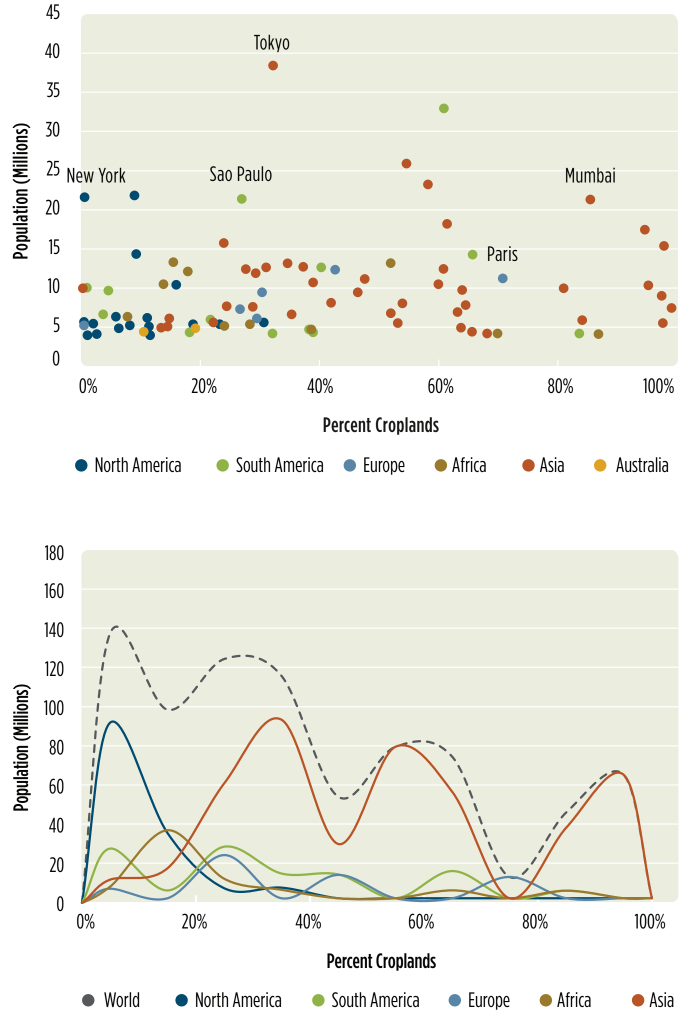
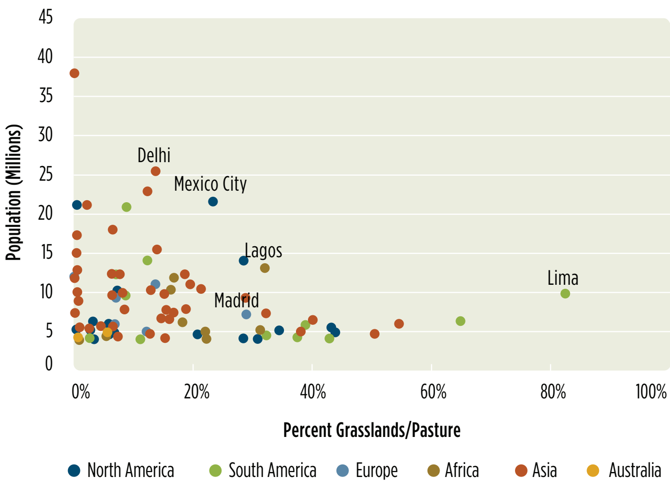
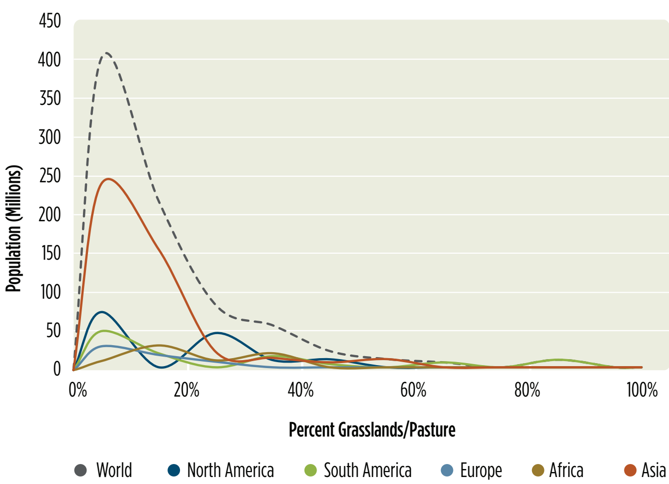


Figure 1-4 shows the scatter plot of forest cover for the top 100 cities as well as the distribution of population by forest cover. Worldwide, 286 million people get their water from watersheds that are more than 50 percent forested, indicating that a forest protection strategy could be very beneficial. 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





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. Chapters 2 and 3 demonstrate how these properties also define the challenges cities face.

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.

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.

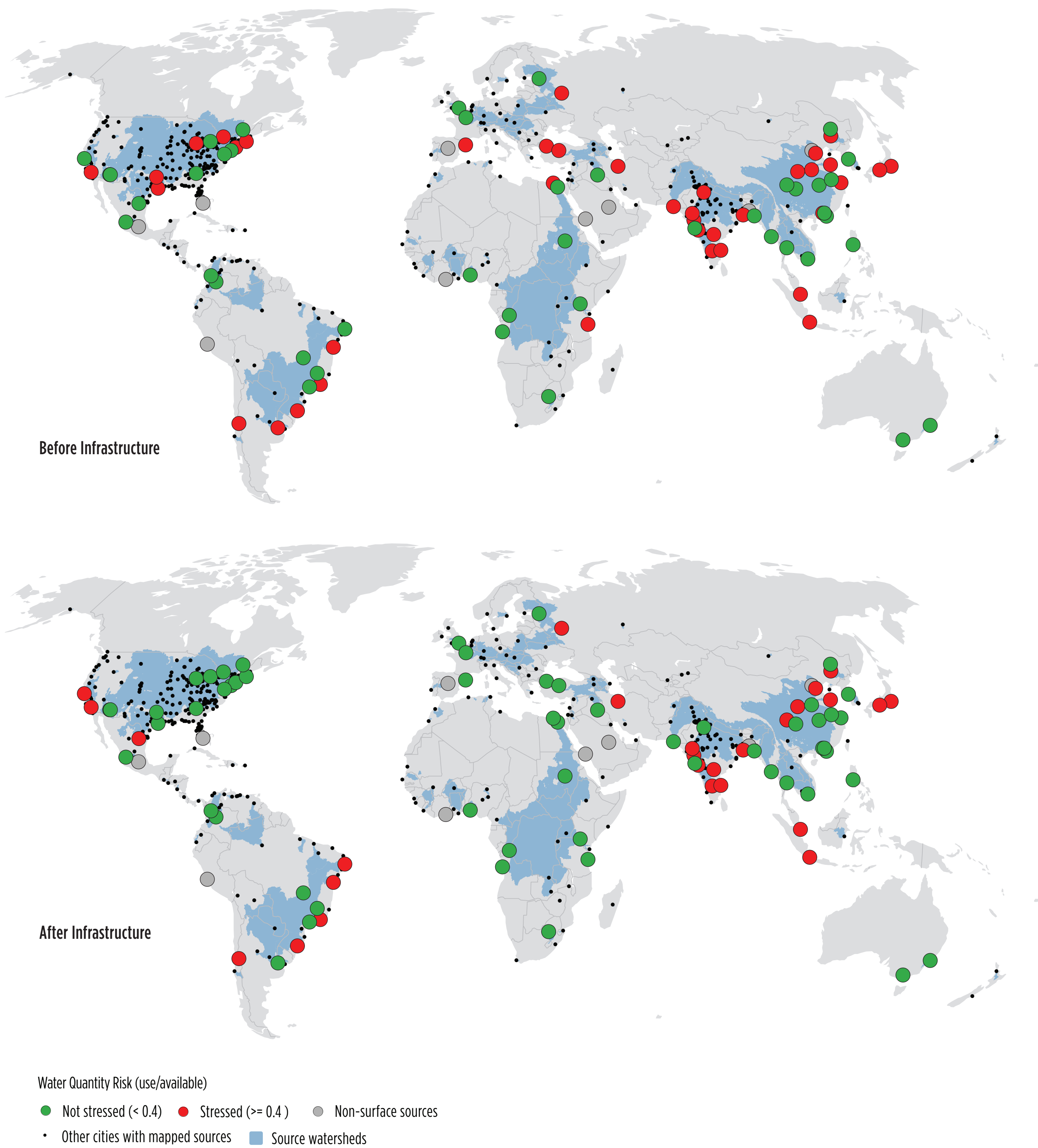
Many cities around the world are located in water stressed watersheds[3]—according to our analysis, more than half of the largest 100. But this fact results in an apparent paradox. If so many cities are located in water stressed areas, why is it that cities from Lima to Las Vegas thrive and their populations 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. Global transfers to secure water for cities



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.

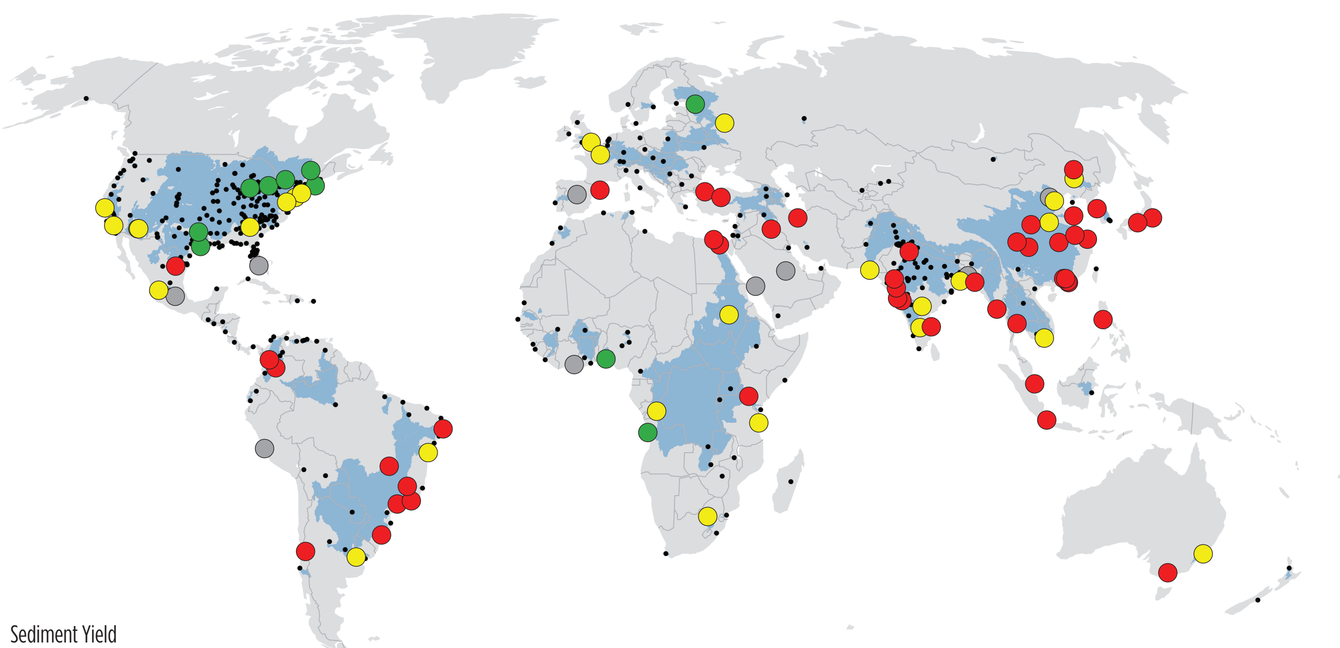
Water quality is also a major motivation behind interbasin transfer. Indeed, several of the world's largest cities have chosen to import relatively clean water from distant sources rather than clean up contaminated local sources. For example, New York gets its water not from the Hudson River but largely 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



Sediment Yield
(tonnes per square kilometer)

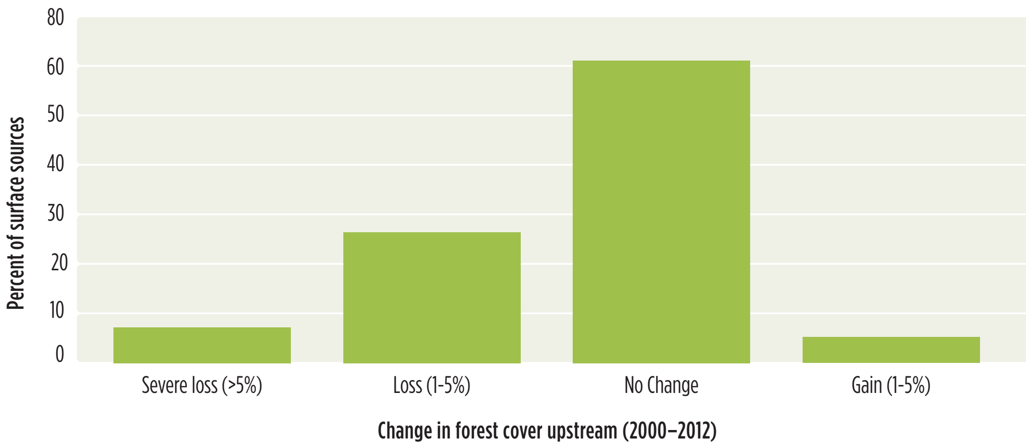
● Low (< 25) ● Medium (25–225) ● High (>225)
● Non-surface sources • Other cities with mapped sources ■ Source watersheds

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.

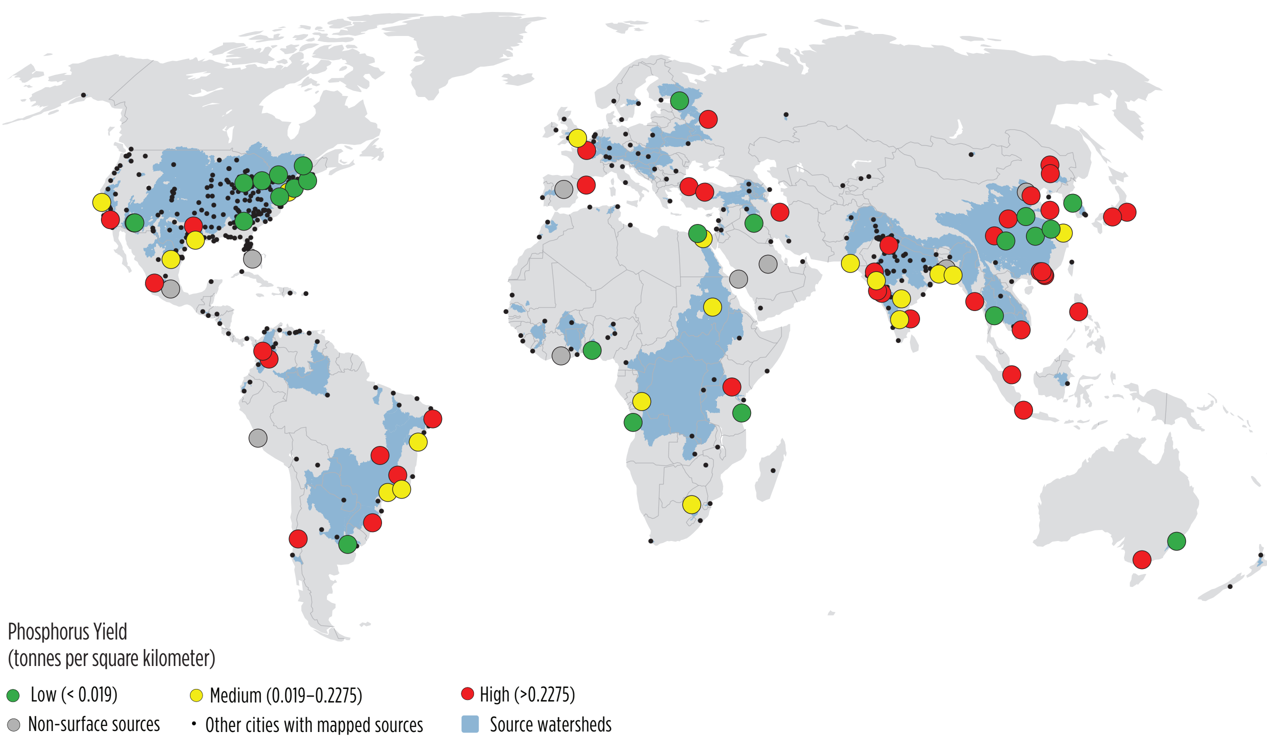
4 See Appendix B for more information on our statistical estimation of the effect of sediment on water treatment costs.

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.

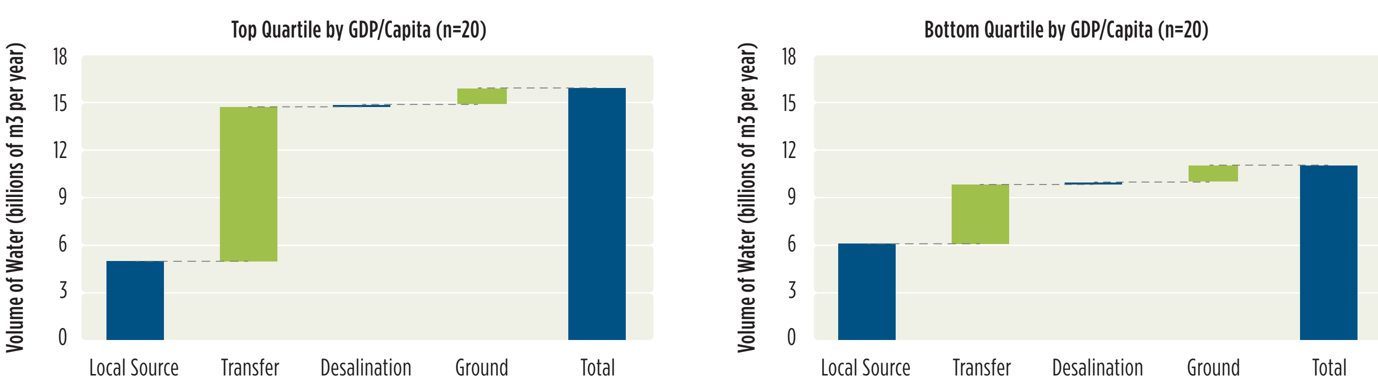
Rich, large cities are able to build their way out of scarcity by transferring water from distant sources. The world's richest cities rely on 9.9 cubic kilometers of water supply from interbasin transfer, almost twice as much as the 5 cubic kilometers of local water source they use. For example, Los 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.

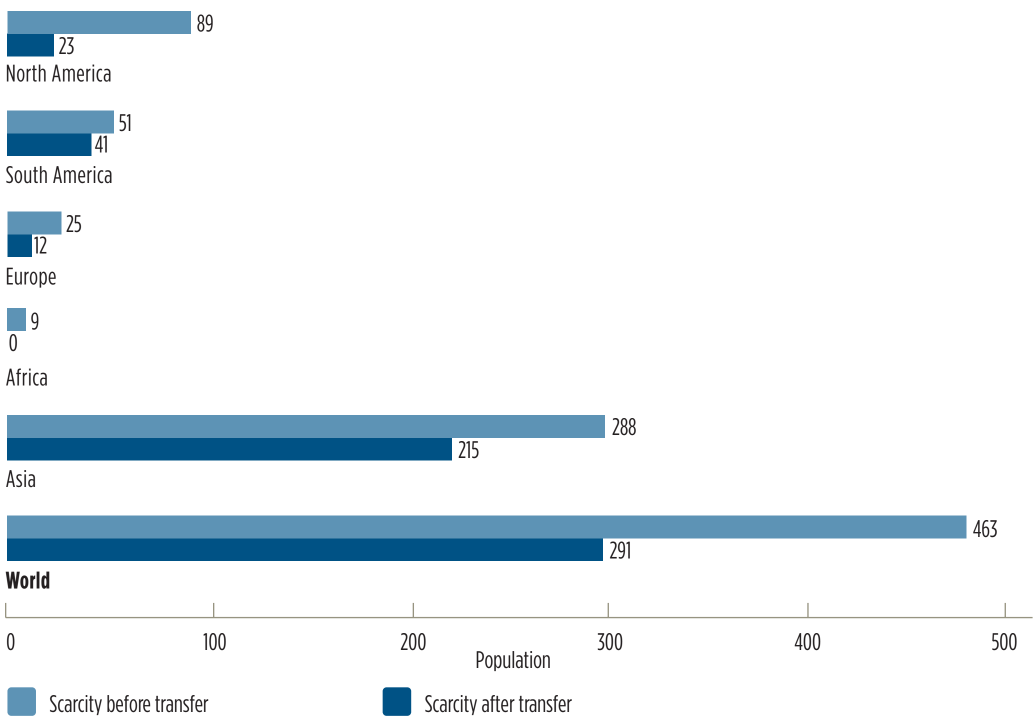
Figure 2-5. Volumes from water sources for top 100 cities (top GDP/capita quartile versus bottom GDP/capita quartile)



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.

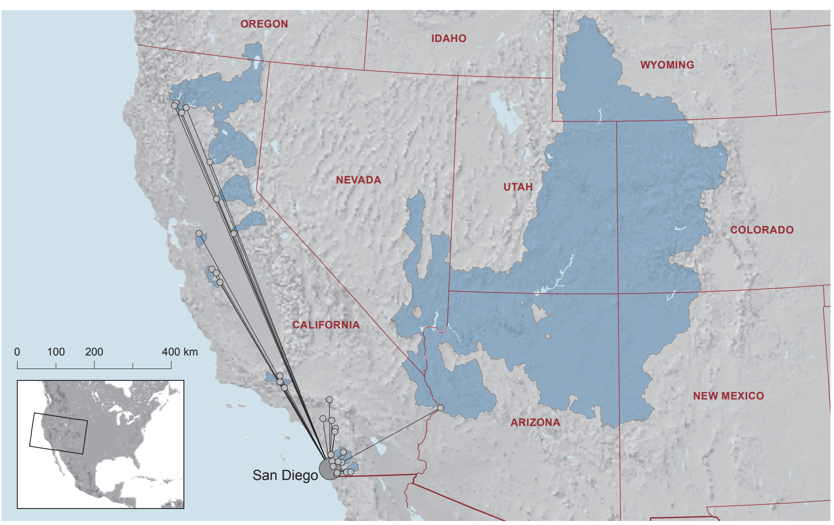
The San Diego story

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

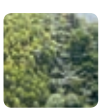
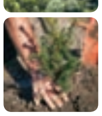
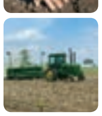
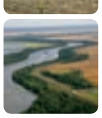
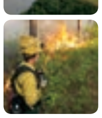
One in three of the largest 100 cities worldwide is currently in water stress, and hundreds of millions of urbanites draw water from sources with low quality, either because of high sediment or nutrient loading. As urbanization and development proceed, the number of high quality source watersheds will 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.

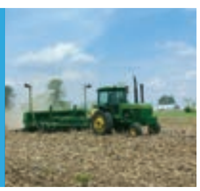
To understand the viability of watershed conservation as a strategy for urban water utilities, we have estimated the potential impact of applying five conservation solutions (Figure 3-1) across 2,000 urban water sources. These strategies were selected for their proven performance and wide applicability 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 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.

CASE STUDIES

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

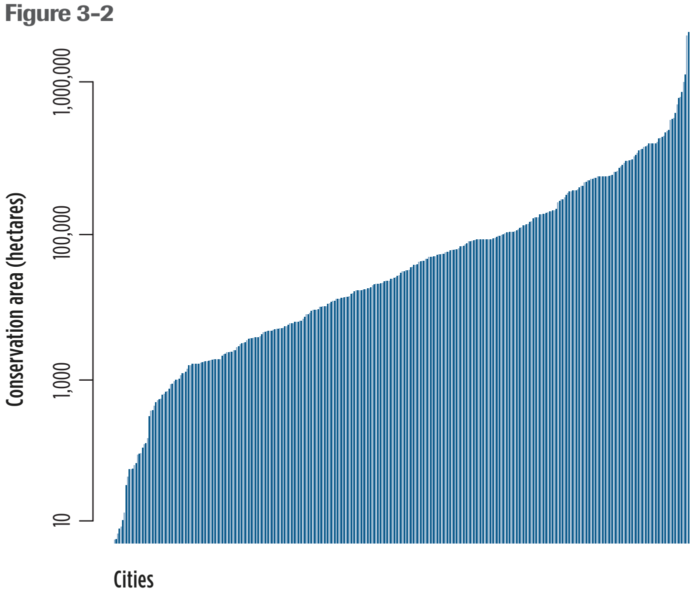


Figure 3-2. Area of Ag. BMPs to get a 10 percent reduction in phosphorus

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

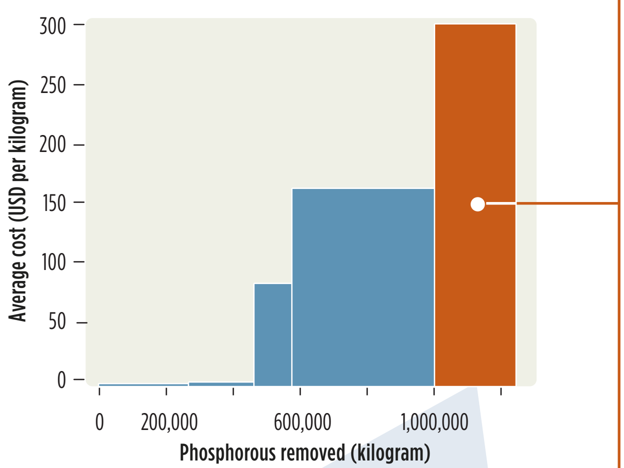


Figure 3-3. Beijing watersheds, Ag. BMPs to remove 10 percent of phosphorus

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

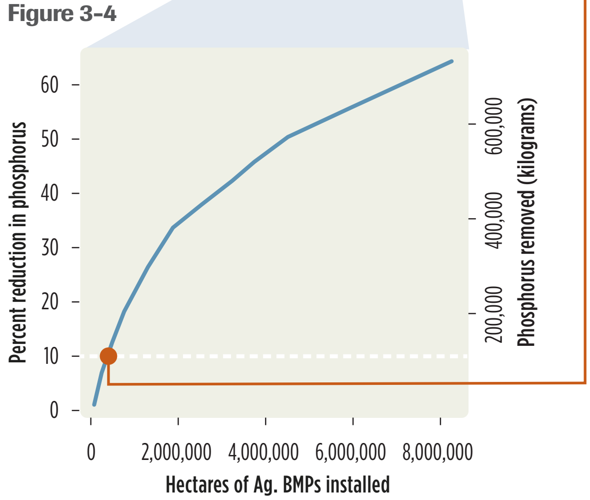
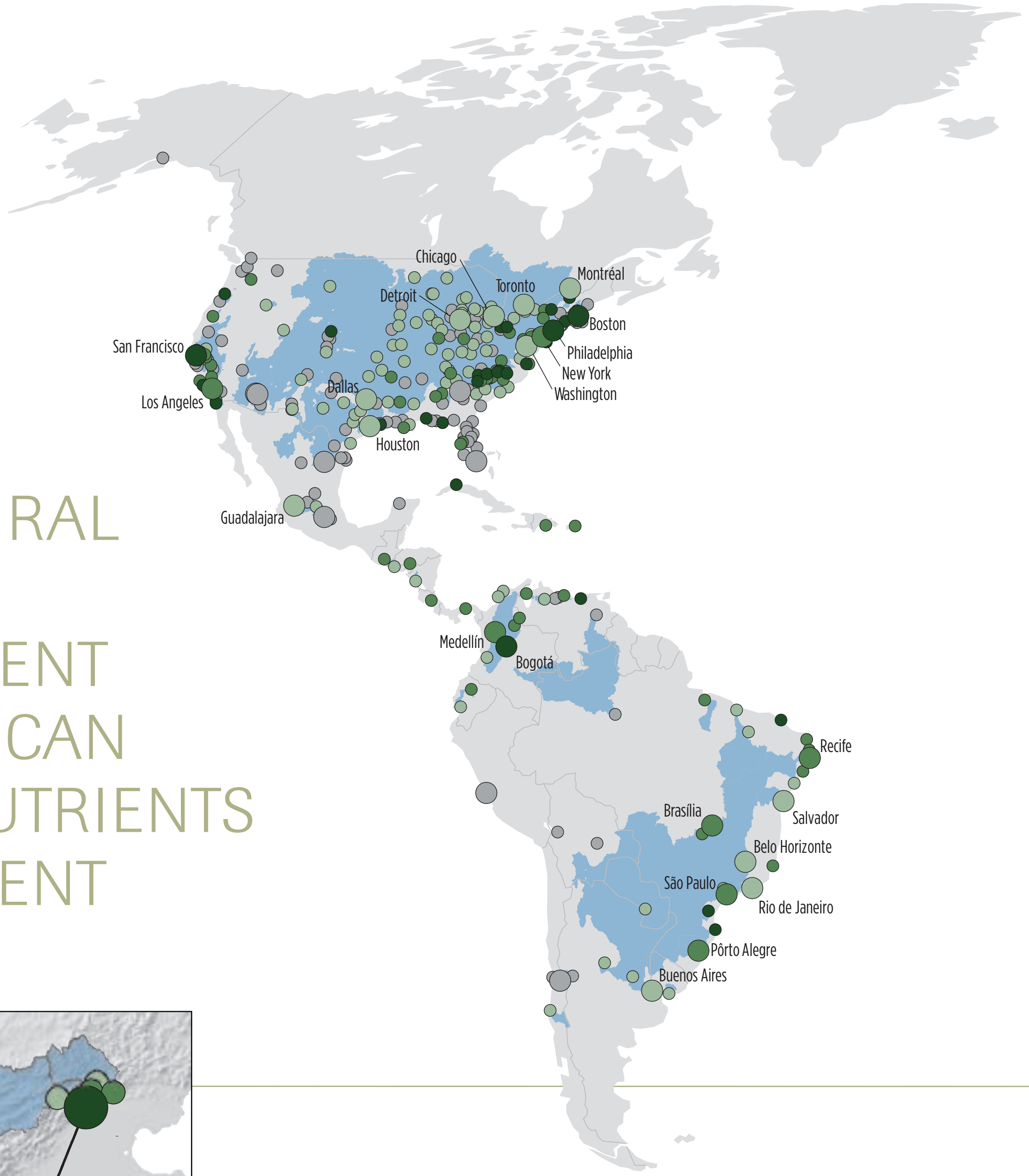


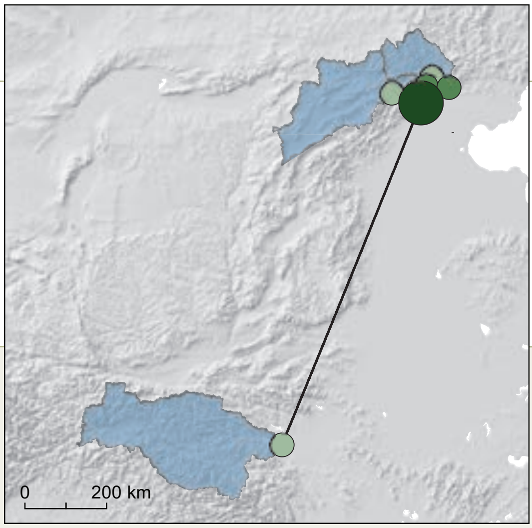
Figure 3-4. Miyun Reservoir, Beijing water system

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

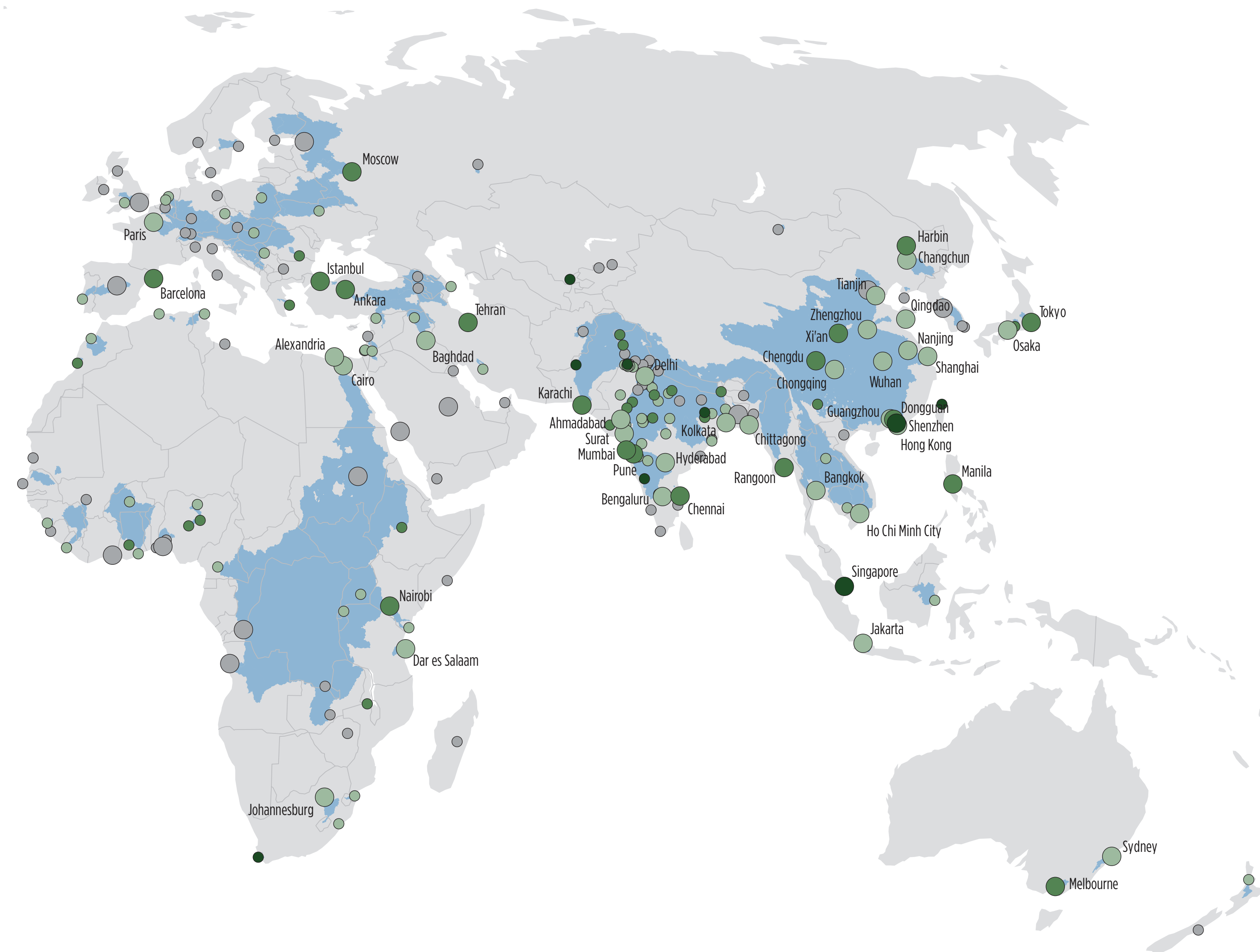
- Miyun reservoir could reduce sediment by 10 percent by implementing agricultural BMPs on 17,000 hectares.

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?

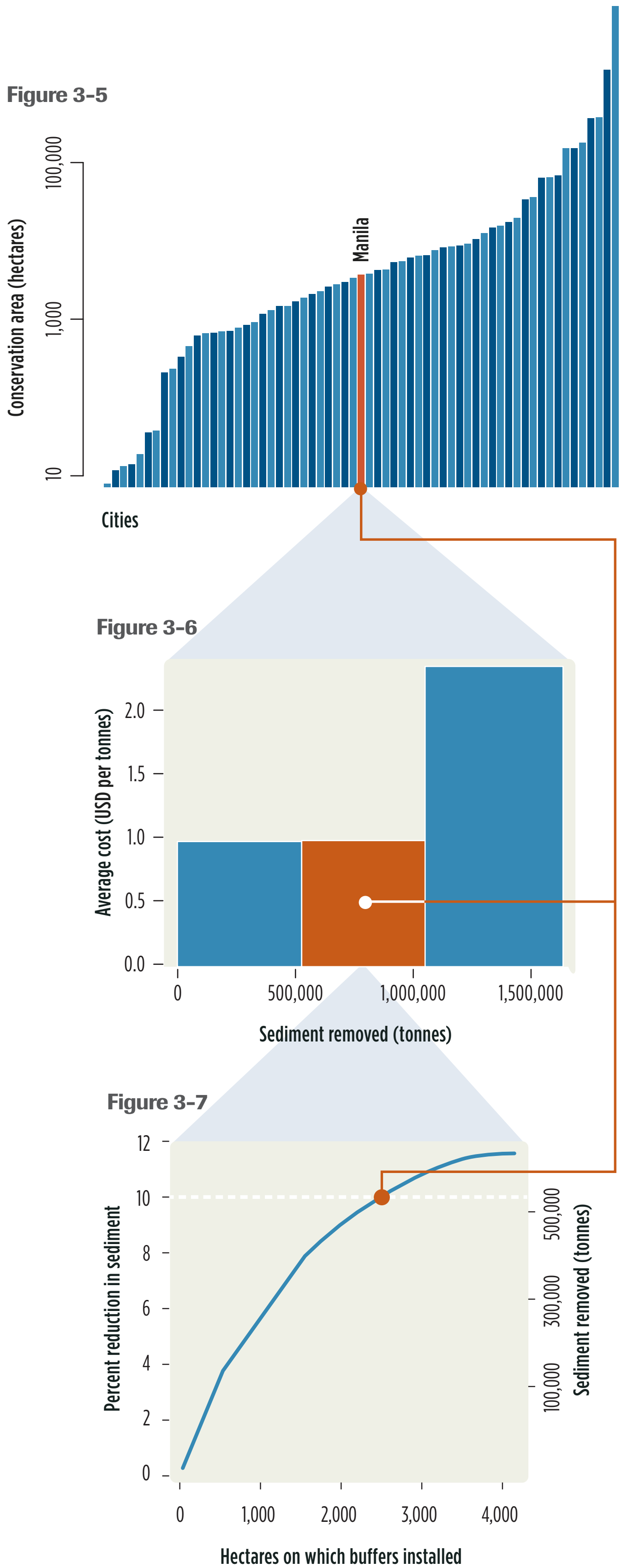


Figure 3-5. Hectares with buffers to get a 10 percent in sediment

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

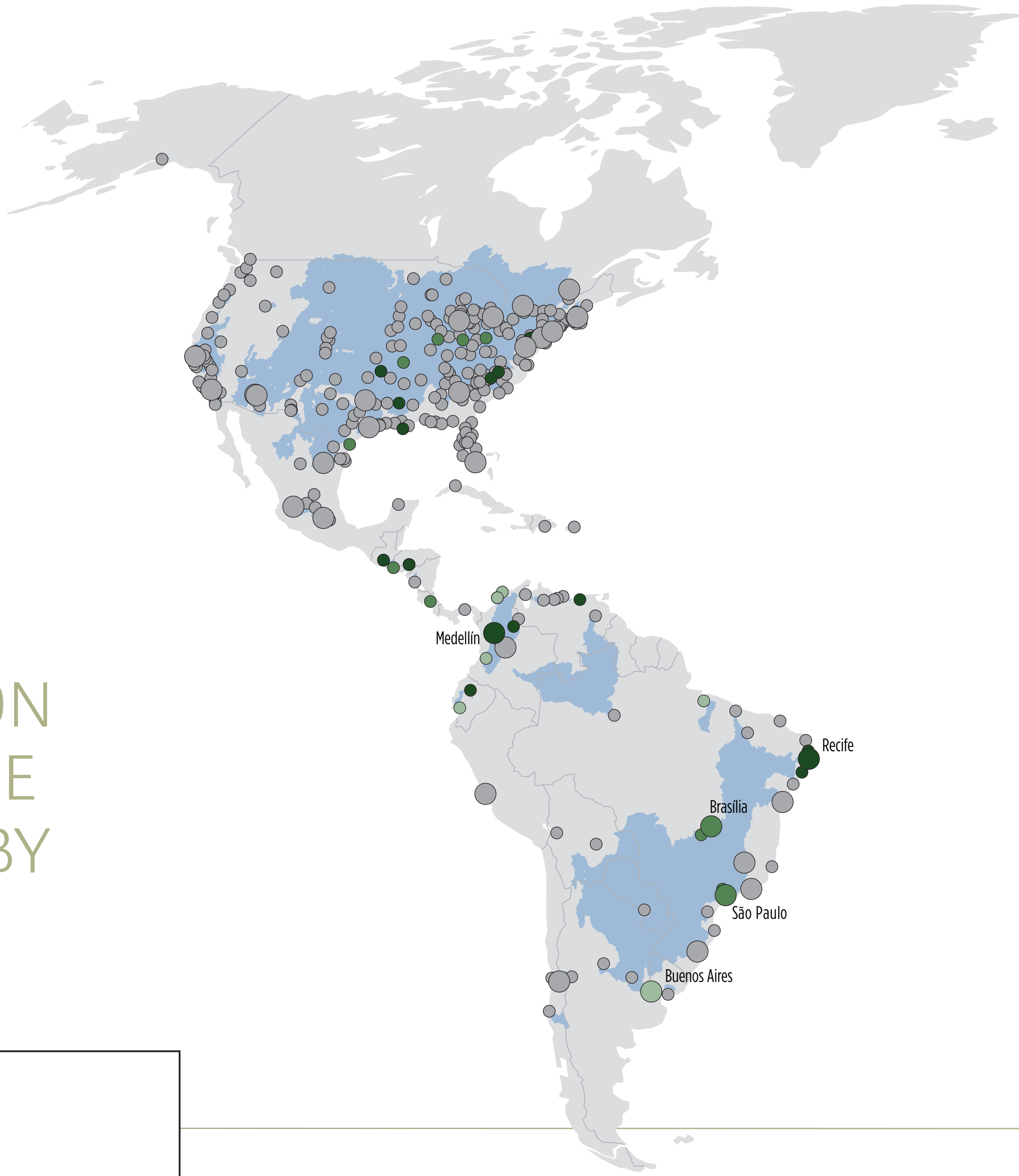
- Manila's three surface sources vary in cost effectiveness for reducing sediment from US $1.0 to US $2.4 per tonne.

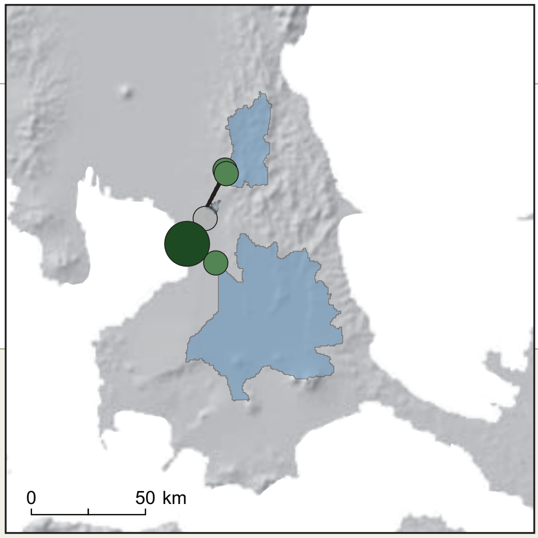
Figure 3-7. Angat Reservoir, Manila

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

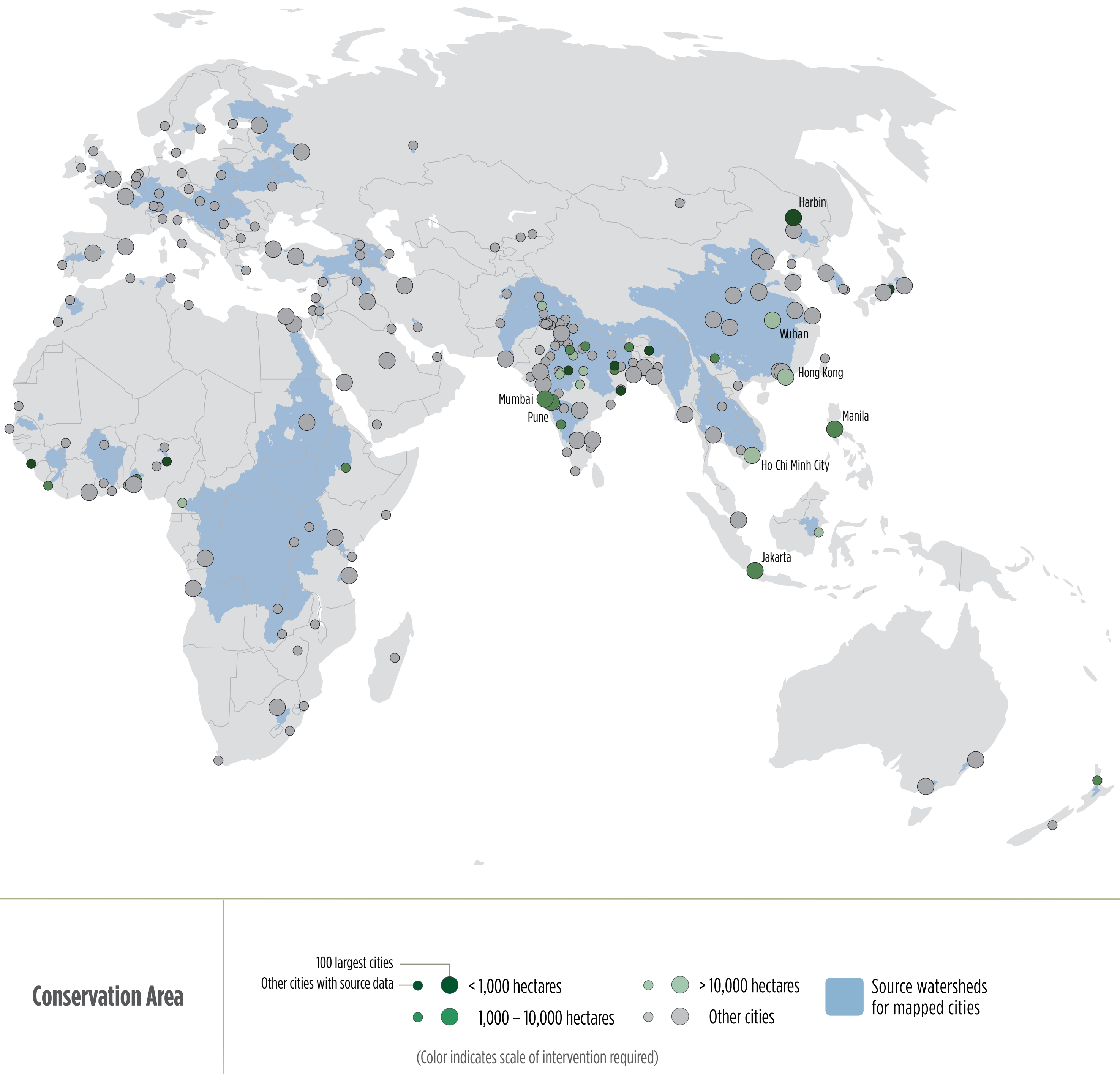
- Angat reservoir could reduce sediment by 10 percent by installing riparian restoration on 2,500 hectares.

WHERE RIPARIAN RESTORATION CAN REDUCE SEDIMENT BY 10 PERCENT





Manila, Philipines



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

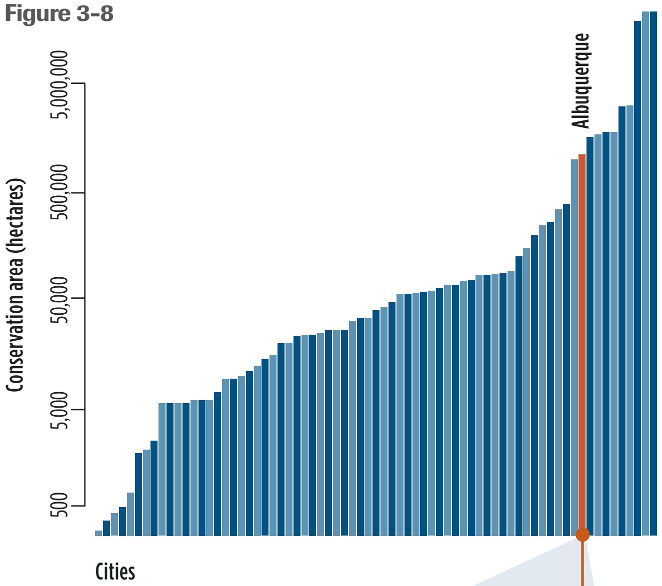


Figure 3-9

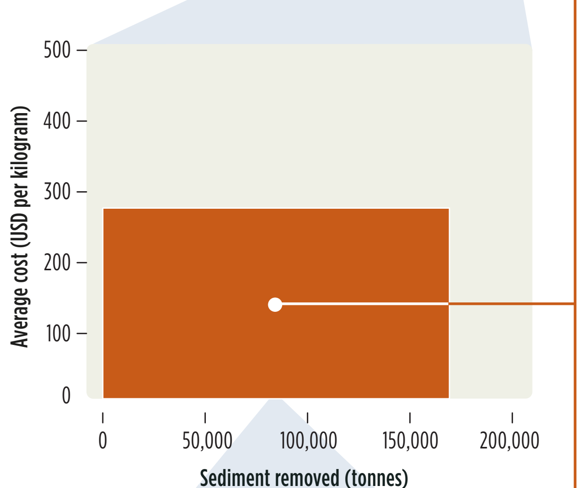


Figure 3-10

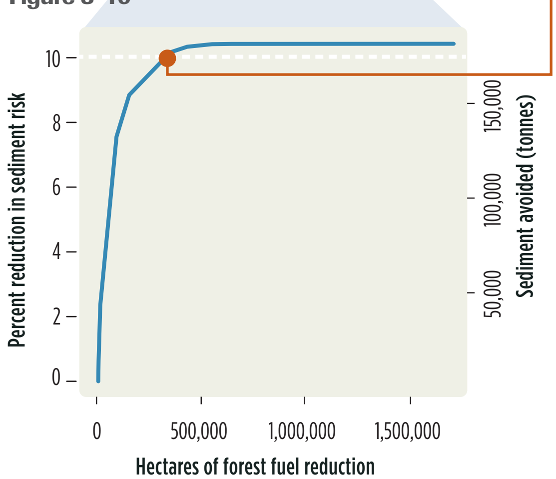


Figure 3-8. Forest fuel reduction to reduce sediment risk 10 percent

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

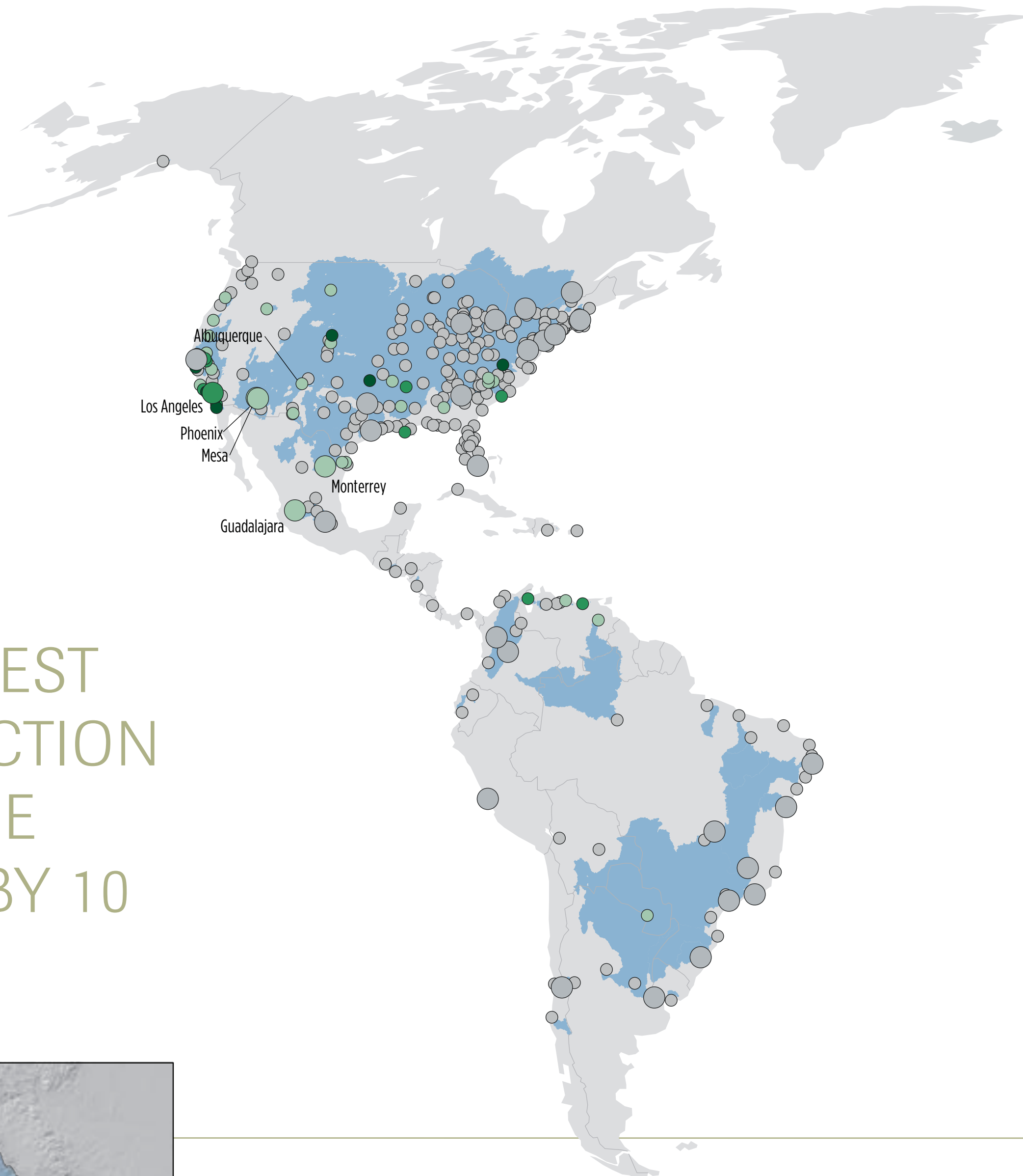
The cost of using forest fuel reduction to reduce sediment risk by 10 percent for Albuquerque's sources.

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

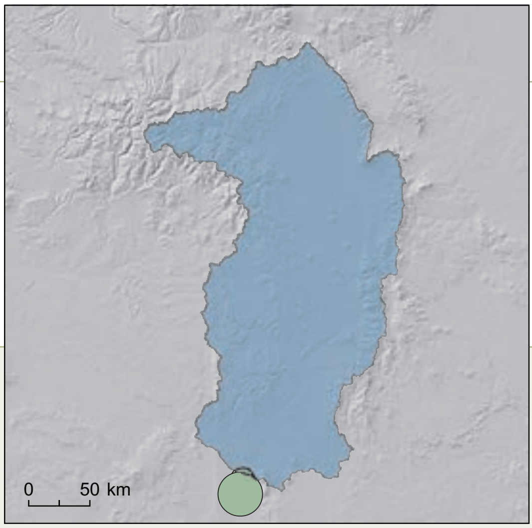
Figure 3-10. Rio Grande, Albuquerque water

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

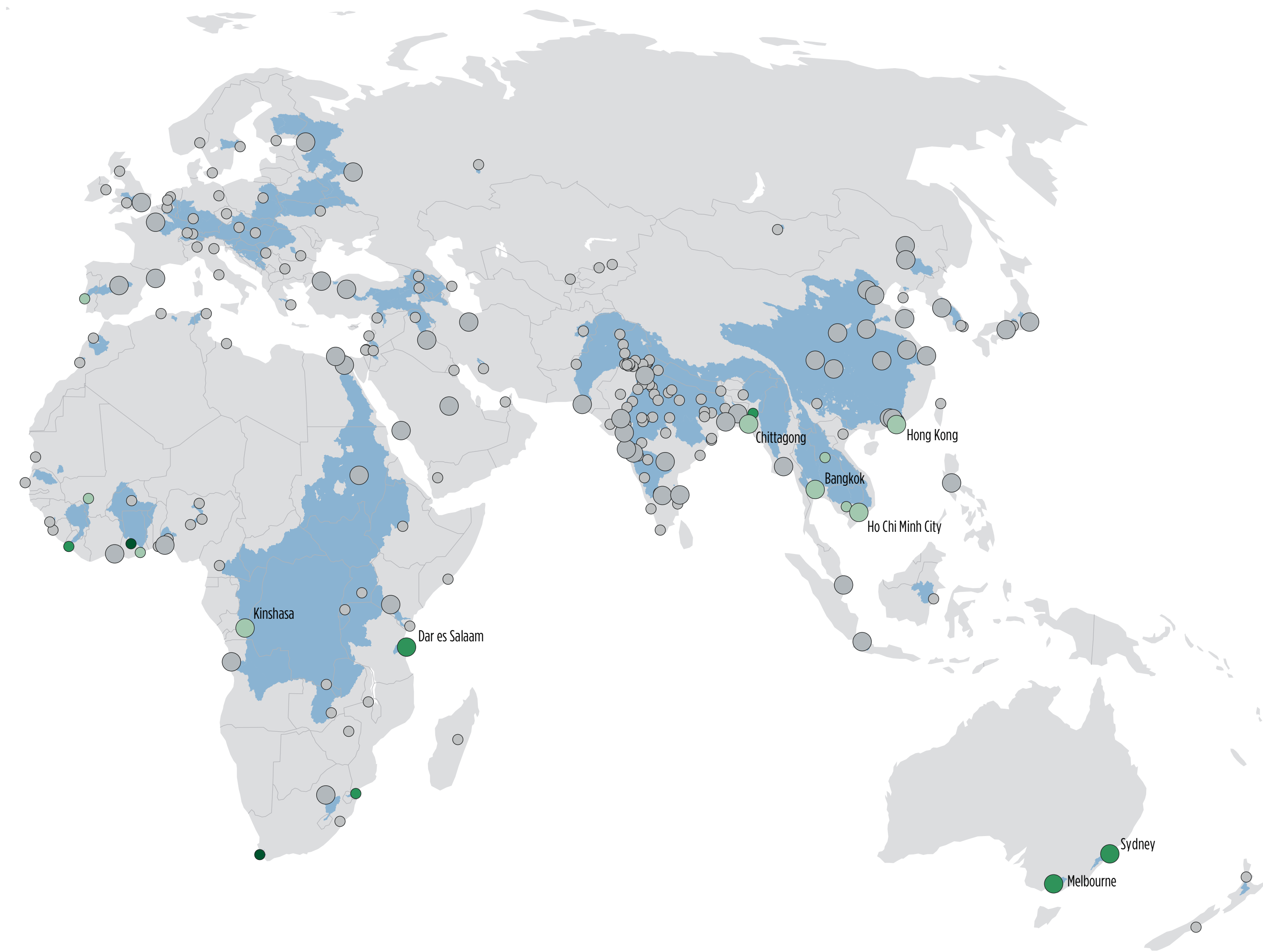
- Albuquerque's intake on the Rio Grande could reduce sediment risk by 10 percent by conducting forest fuel reduction on 350,000 hectares.



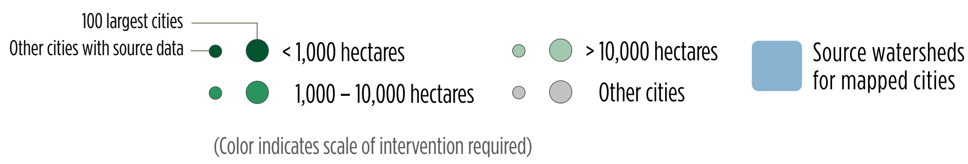
WHERE FOREST FUEL REDUCTION CAN REDUCE SEDIMENT BY 10 PERCENT



Albuquerque, New Mexico



Conservation Area



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 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

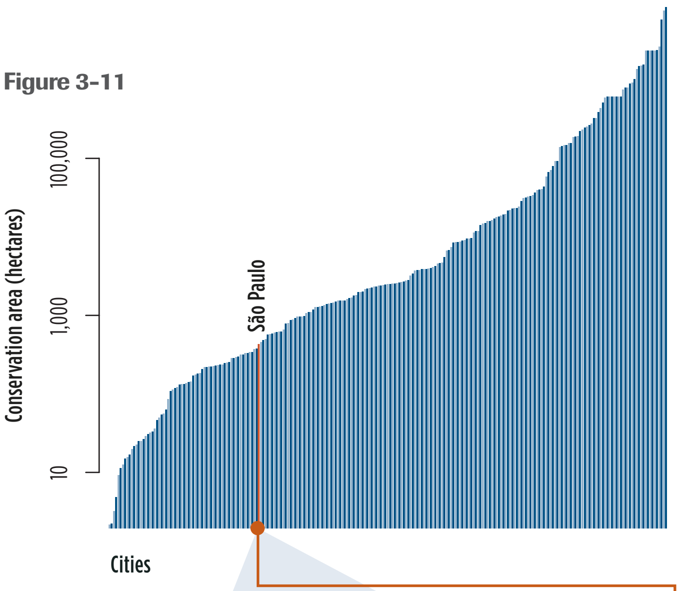


Figure 3-12

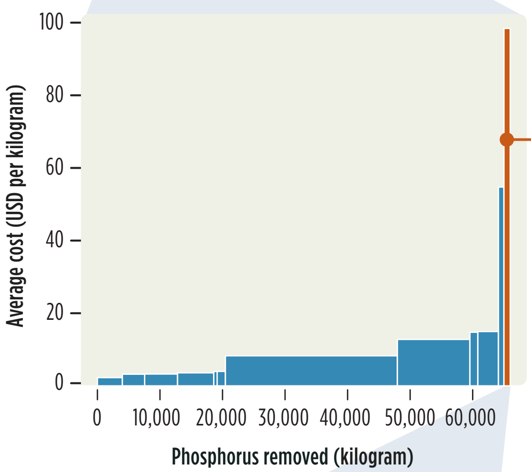


Figure 3-13

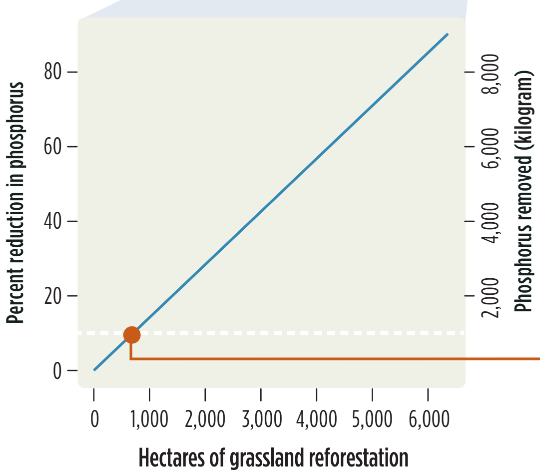


Figure 3-11. Area of reforestation to get a 10 percent reduction in phosphorus

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.