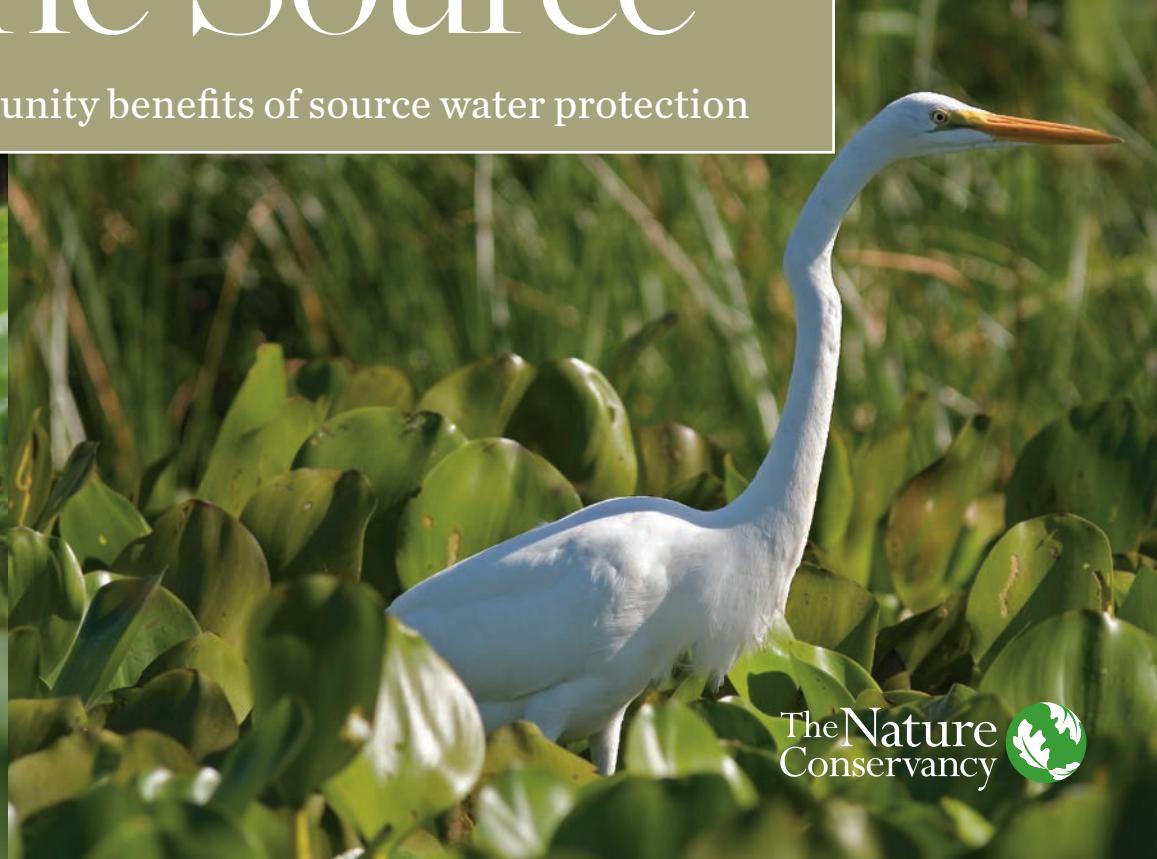
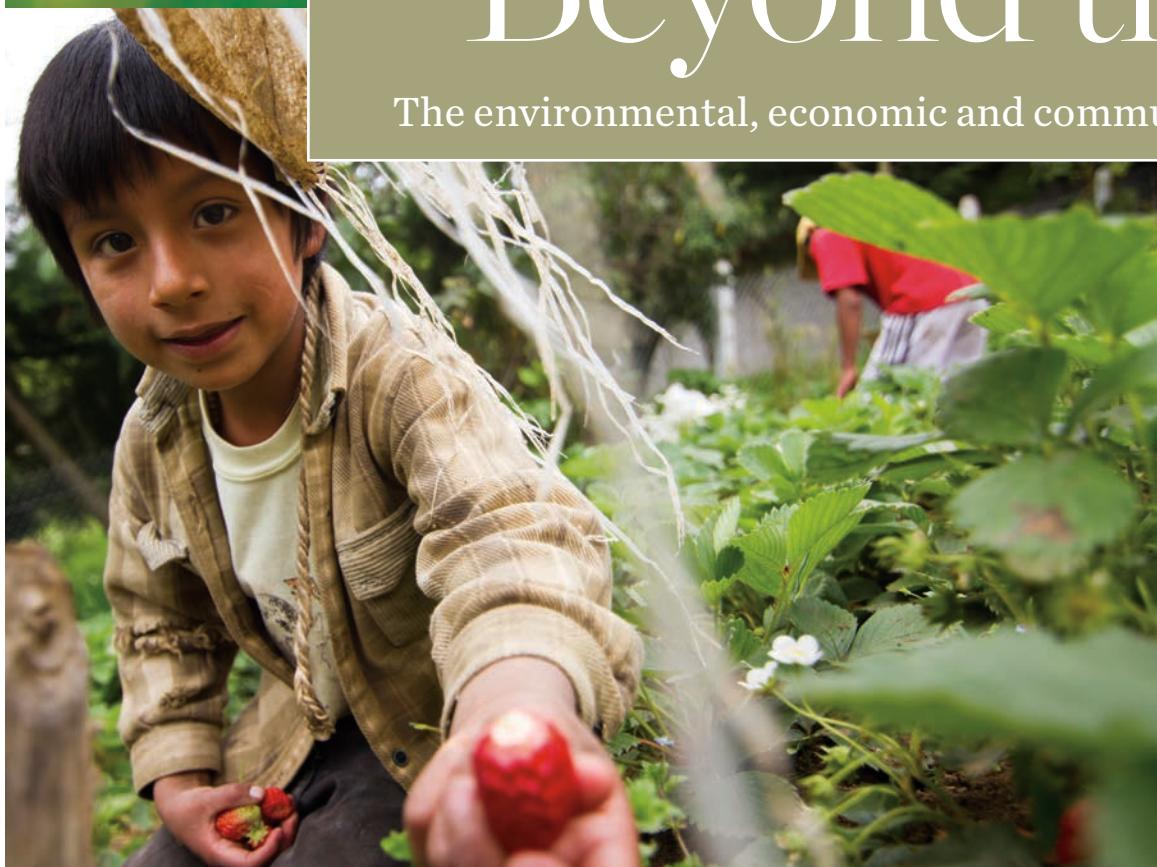




# Beyond the Source

The environmental, economic and community benefits of source water protection



The Nature  
Conservancy



# Acknowledgments



## Co-authors

Robin Abell, Nigel Asquith, Giulio Boccaletti, Leah Bremer, Emily Chapin, Andrea Erickson-Quiroz, Jonathan Higgins, Justin Johnson, Shiteng Kang, Nathan Karres, Bernhard Lehner, Rob McDonald, Justus Raapple, Daniel Shemie, Emily Simmons, Aparna Sridhar, Kari Vigerstøl, Adrian Vogl, Sylvia Wood

## Steering Committee

Pascal Mittermaier, Aurelio Ramos, Heather Tallis

## Advisory Board

Colin Apse, Lisa Wojnarowski Downes, Pipa Elias, Joe Kiesecker, Quan Mu, Fernando Veiga

## Contributors

Contributors to *Beyond the Source* include experts who generously contributed data, analyses, interpretation, and/or guidance. Many contributors also provided report review and case study content.

Eileen Andrea Acosta, Carolina Aguirre Echeverri, Aziza Akhmouch, Samuel Roiphe Barréto, Steven Bassett, Silvia Benitez, Genevieve Bennett, Marilia Borgo, Alejandro Calvache, Rebecca Chaplin-Kramer, Abhishek Chaudhary, Matt Clark, Lorena Coronel, William Darwall, A.P. Dixon, Mauricio Echeverry, Peter W. Ellis, James Famiglietti, Gena Gammie, Carlos García, Edenise Garcia, Jorge Gastelumendi, Maria Margarita Gutierrez, Jay Harrod, Peter L. Hawthorne, Colin Herron, Hilda Hesselbach, Fred Kihara, Timm Kroeger, Eric Krueger, Lisa B. Kushner, Maria Lemke, Jorge Eduardo León Sarmiento, Alejandro López-Serrano, Hendrik Mansur, Gabriel Martone, Yuta J. Masuda, Laura McCarthy, Hana Moidu, Pedro Moreno, Max A. Moritz, Francisco Nuñez, James Oakleaf, Renzo Paladines, Mitzi Parmentier, Paulo Petry, Carolina Patricia Polania Silgado, Edwin Pynegar, Lois Quam, Ana Maria Quintero Caicedo, Katie Reytar, Sasha Richey, Brian Richter, Oriana Romano, Leonardo Sáenz, Lynn Scarlett, Anika Seggel, Lisa Shipley, Ryan Smith, Adriana Soto, Rita Strohmaier, Byron Swift, Gilberto Tiepolo, Stefanie Nicole Tye, Alexandra Tyukavina, Amalia Vargas, Maria Teresa Vargas, Jeff Walk, Stacie Wolny, Charles Wight, Paola Zavala, Chris Zganjar, Cory Zyla

## Reviewers

Justin Adams, Kate Brauman, Bert De Bièvre, Lynne Gaffikin, Josh Goldstein, Bronson Griscom, Gina Hancock, Diego Herrera García, Paul Hicks, Wendy Larson, Nate Matthews, Yiyuan Jasmine Qin, Laura Weintraub, Hazel Wong

## Mapping Site

Zach Ferdaña, Kris Johnson, Casey Schneebeck, Matt Silveira

## Acknowledgments

Brooke Atwell, Maija Bertule, Timothy Boucher, Henrique Bracale, Benjamin Bryant, Jan Cassin, André Targa Cavassani, Caroline Clark, Michael Curley, Randy Curtis, Todd Gartner, James Gerber, Tom Gleeson, Emma Goodyer, Ana Guzmán, Raimond Hafkenscheid, Matthew Hansen, Joerg Hartmann, Krista G. Kirkham, Ken Lay, Erik Lopes, Santiago Martínez, Marcelo Moura, Mark Mulligan, Mauro Nalesso, Licia Maria Nunes de Azevedo, Ben Packard, Milena Ribeiro, Keaton Sandeman, Roger Sayre, Carrie Vollmer-Sanders, David Wilk, Xinying Zeng

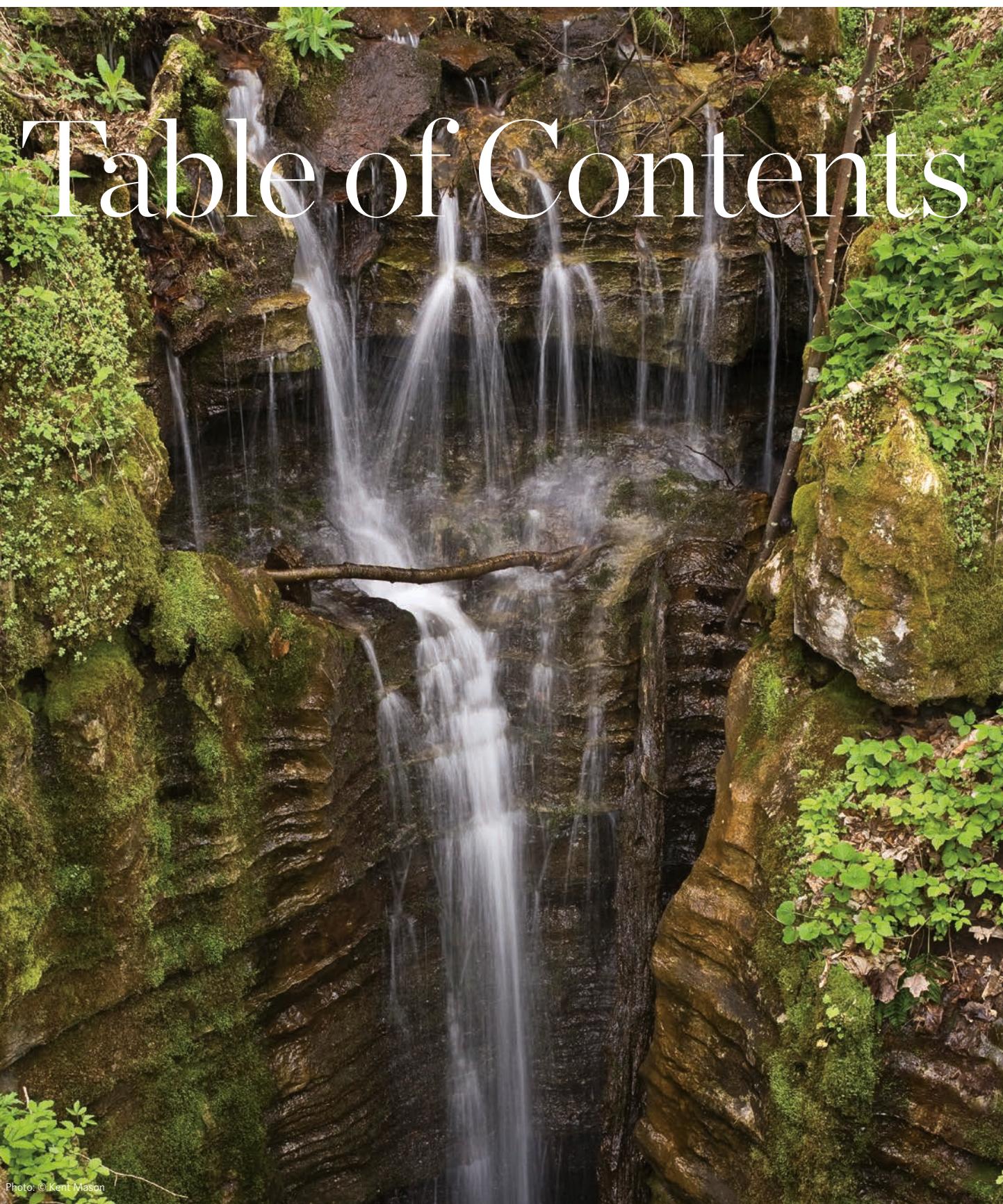
## Editors

Andrew Myers, Meghan Snow

## Designers

Paul Gormont, Lead Designer, Apertures, Inc.  
Kameleon Worldwide, Maya Lim, Vin Design

**Please cite this document as:** Abell, R., et al. (2017). *Beyond the Source: The Environmental, Economic and Community Benefits of Source Water Protection*. The Nature Conservancy, Arlington, VA, USA.



# Table of Contents

<b>Foreword</b>	<b>vii</b>
<b>Executive Summary</b>	<b>1</b>
Healthy source watersheds are vital infrastructure .....	1
Source watersheds are a nexus of value and action.....	4
Capturing the value of source watersheds through water funds .....	8
Scaling source water protection by bridging the gaps.....	11
A call to action .....	15
<b>Chapter 1</b>	<b>17</b>
<b>Water Insecurity: A Central Risk to Global Prosperity</b>	
Water today and tomorrow .....	17
Water security runs through all global goals .....	19
Beyond built infrastructure .....	22
Source watersheds as water infrastructure.....	23
Mapping source watershed areas for 4,000 cities .....	24
Groundwater resources and above-ground impacts.....	27
The way forward .....	27
<i>LOCAL SPOTLIGHT: San Antonio, United States .....</i>	28

<b>Chapter 2</b>	<b>31</b>	<b>Chapter 4</b>	<b>101</b>	<b>Chapter 6</b>	<b>141</b>																																																										
Protecting Natural Infrastructure at its Source		Overcoming Barriers to Change through Water Funds		Scaling by Value Creation through Water Funds																																																											
Water sources face growing threats .....	31	Sharing the value of healthy watersheds .....	101	From what to how with source water protection .....	141																																																										
Water quality threats .....	33	Challenges of scale .....	101	The cost of source water protection at scale .....	141																																																										
Water quantity threats.....	36	Sustainability requires a systems approach .....	102	The funding gap.....	144																																																										
Source water protection is land stewardship.....	38	Defining good governance .....	103	Bridging the gap.....	146																																																										
The potential for reducing sediment and nutrient pollution.....	40	Going from principles to solutions—Water funds .....	104	Making the business case for water fund investments .....	148																																																										
<i>LOCAL SPOTLIGHT: Bloomington, United States</i> .....	42	Water funds provide a platform for overcoming barriers .....	107	Borrowing to bridge the gap .....	153																																																										
<i>LOCAL SPOTLIGHT: Monterrey, Mexico</i> .....	44	Water funds in the real world.....	112	Accelerating impact.....	155																																																										
<i>LOCAL SPOTLIGHT: Rio Grande, United States</i> .....	44	<i>LOCAL SPOTLIGHT: Rio Grande, United States</i> .....	122	Bringing water funds to scale through collective action .....	158																																																										
				Conclusion .....	159																																																										
<b>Chapter 3</b>	<b>47</b>	<b>Chapter 5</b>	<b>125</b>	<b>Online Resources</b>	<b>161</b>																																																										
Opportunities for Source Water Protection to Produce Co-benefits		The Intersection of Multiple Benefits																																																													
Benefits beyond water security .....	47	Building a multi-benefits case.....	125	<b>Appendices</b>	<b>165</b>																																																										
Climate change mitigation.....	47	Stacking benefits for cities.....	125	<i>LOCAL SPOTLIGHT: São Paulo, Brazil</i> .....	54	Optimizing across multiple benefits—		Appendix I: International Policy Processes that Include Water .....	165	Building resilience to climate change through adaptation .....	56	A deep dive in Colombia .....	129	Appendix II: Assessment of Urban Source Watershed Map Accuracy .....	166	<i>LOCAL SPOTLIGHT: Rio Yaque del Norte, Dominican Republic</i> .....	62	<i>LOCAL SPOTLIGHT: Nairobi, Kenya</i> .....	136	Appendix III: Additional Results by Region .....	168	Human health and well-being.....	64			Appendix IV: Foundational Frameworks and Approaches for Water Funds—Supplement to Chapter 4 .....	174	<i>LOCAL SPOTLIGHT: Santa Cruz Valleys, Bolivia</i> .....	74			Appendix V: Methods .....	176	<i>LOCAL SPOTLIGHT: Cauca Valley, Colombia</i> .....	76					Benefits to terrestrial and freshwater biodiversity .....	78					<i>LOCAL SPOTLIGHT: Rio de Janeiro, Brazil</i> .....	92					Nitrogen—A thread from farms to fisheries.....	94									<b>Endnotes</b>	<b>205</b>
<i>LOCAL SPOTLIGHT: São Paulo, Brazil</i> .....	54	Optimizing across multiple benefits—		Appendix I: International Policy Processes that Include Water .....	165																																																										
Building resilience to climate change through adaptation .....	56	A deep dive in Colombia .....	129	Appendix II: Assessment of Urban Source Watershed Map Accuracy .....	166																																																										
<i>LOCAL SPOTLIGHT: Rio Yaque del Norte, Dominican Republic</i> .....	62	<i>LOCAL SPOTLIGHT: Nairobi, Kenya</i> .....	136	Appendix III: Additional Results by Region .....	168																																																										
Human health and well-being.....	64			Appendix IV: Foundational Frameworks and Approaches for Water Funds—Supplement to Chapter 4 .....	174																																																										
<i>LOCAL SPOTLIGHT: Santa Cruz Valleys, Bolivia</i> .....	74			Appendix V: Methods .....	176																																																										
<i>LOCAL SPOTLIGHT: Cauca Valley, Colombia</i> .....	76																																																														
Benefits to terrestrial and freshwater biodiversity .....	78																																																														
<i>LOCAL SPOTLIGHT: Rio de Janeiro, Brazil</i> .....	92																																																														
Nitrogen—A thread from farms to fisheries.....	94																																																														
				<b>Endnotes</b>	<b>205</b>																																																										

# Foreword



# Beyond the Source: From Transactions to Transformation

Conservation has traditionally been an exercise in localism. Trees are planted to restore local forests damaged by human activity, fire or floods. Grasses and shrubs are placed as buffers between agricultural fields and water sources to reduce soil and chemical runoff. These nature-based activities are not typically viewed as critical components to solving global challenges like climate change or poverty alleviation, but they should.

Around the world, cities are growing at an incredible pace, and along with that growth comes the need for more water to address sanitation, food and energy requirements. But 40 percent of the land area around our water sources is degraded by deforestation, poor agricultural practices and development. Investment in nature can help cities and rural communities, companies and farmers, plan for a future where the needs of people and the environment can be balanced, especially when it comes to water.

*Beyond the Source* seeks to illustrate the value of nature to cities looking to secure water supplies while adding a number of benefits that address global challenges we face. By restoring forests and working with farmers and ranchers to improve their land management practices, we can improve water quality and reduce water treatment costs for four out of five downstream cities serving 1.4 billion people. Those same activities can provide millions of rural farmers with new sources of income and food, grow trees that absorb carbon from our atmosphere and provide habitat for pollinators that are critical to our food production. For roughly half of all cities, nature-based activities can be implemented for as little as US\$2 per person annually.

In order to realize the full value of natural infrastructure, we need to move beyond a “one activity for one purpose” mindset. By “stacking” the benefits that each conservation activity provides, the financial case is strong for investing in natural solutions alongside gray infrastructure. In fact, one in six cities could recoup the costs through savings in annual water treatment costs alone.

For utilities, local leaders, industries and policymakers, this will require looking beyond jurisdictional boundaries to form new partnerships and action plans. Water funds, which enable downstream water users to jointly fund upstream land conservation and restoration, are one successful mechanism for securing improved water quality and in some cases more reliable flows. This holistic thinking is already driving source water protection activities in places such as Nairobi, New Mexico and Monterrey.

Water security is the greatest risk to our prosperity. We are making progress, but it is not enough. All those with a stake in water need to come together to address the challenges facing our finite water resources and invest in solutions at the scale and speed needed to tackle these problems. In doing so, we can generate much greater outcomes for people and nature.



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



Healthy source watersheds are vital natural infrastructure for cities around the world.

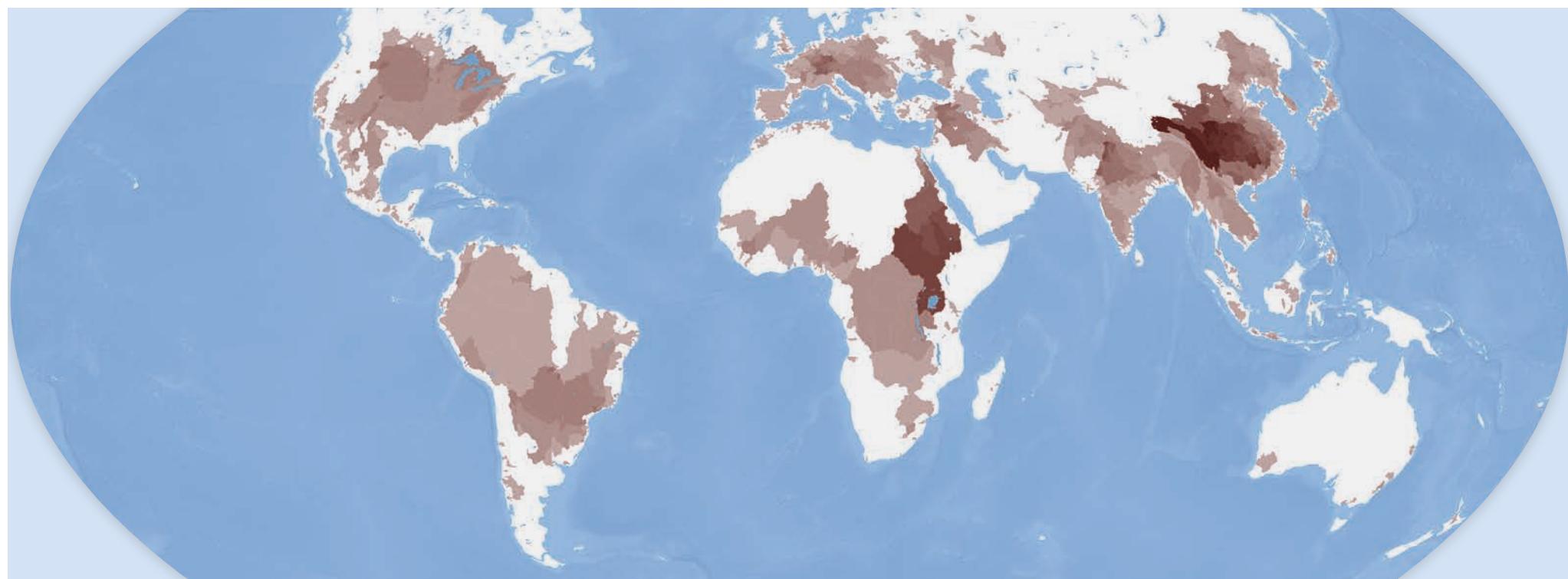
# Executive Summary

## Healthy source watersheds are vital infrastructure

Healthy source watersheds are vital natural infrastructure for nearly all cities around the world. They collect, store and filter water and provide benefits for biodiversity conservation, climate change adaptation and mitigation, food security, and human health and well-being. Today, an estimated 1.7 billion people living in the world's largest cities depend on water flowing from source watersheds sometimes located hundreds, if not thousands, of kilometers away. By 2050, those

urban source watersheds will be tapped by up to two-thirds of the global population though they represent one-third of the Earth's land surface. Cities—as hubs for employment, services and investment—will clearly be the drivers of economic growth. To grow sustainably, cities will need to play an active role in protecting the water sources on which people and nature depend, but they can't do it on their own. Source watersheds are a nexus for action for those working to build resilient cities, improve water security, drive sustainable development and create a stable climate.

Current and potential urban source watersheds



**Figure ES.1.** Watershed areas that currently or could potentially provide surface water supply to cities with populations greater than 100,000 people. Darker colors indicate overlapping watershed areas, where multiple withdrawal points collect surface runoff from the same upstream land areas. (Source: The Nature Conservancy)

Source watershed areas by percent overlap



## Source watersheds are under threat

We find that 40 percent of source watershed areas show high to moderate levels of degradation. The impacts of these changes on water security can be severe. Nutrients and sediment from agricultural and other sources raise the cost of water treatment for municipal and industrial users. Loss of natural vegetation and land degradation can change water flow patterns across the landscape and lead to unreliable water supplies, with implications for both upstream and downstream users. According to the World Bank, some regions could see their growth rates decline by as much as 6 percent of GDP by 2050 as a result of water-related losses in agriculture, health, income and property—sending them into sustained negative growth. Aspirational goals to see livelihoods improve, like those set in the Sustainable Development Goals (SDGs), are beyond reach without a more water-secure world.

## Nature-based solutions can improve water quality and quantity

Protecting and restoring the natural infrastructure of source watersheds can directly enhance water quality and quantity. There are many effective source water protection activities (Table ES.1). In this report, we model forest protection, reforestation and cover crops as one example of agricultural best management practices (BMPs).

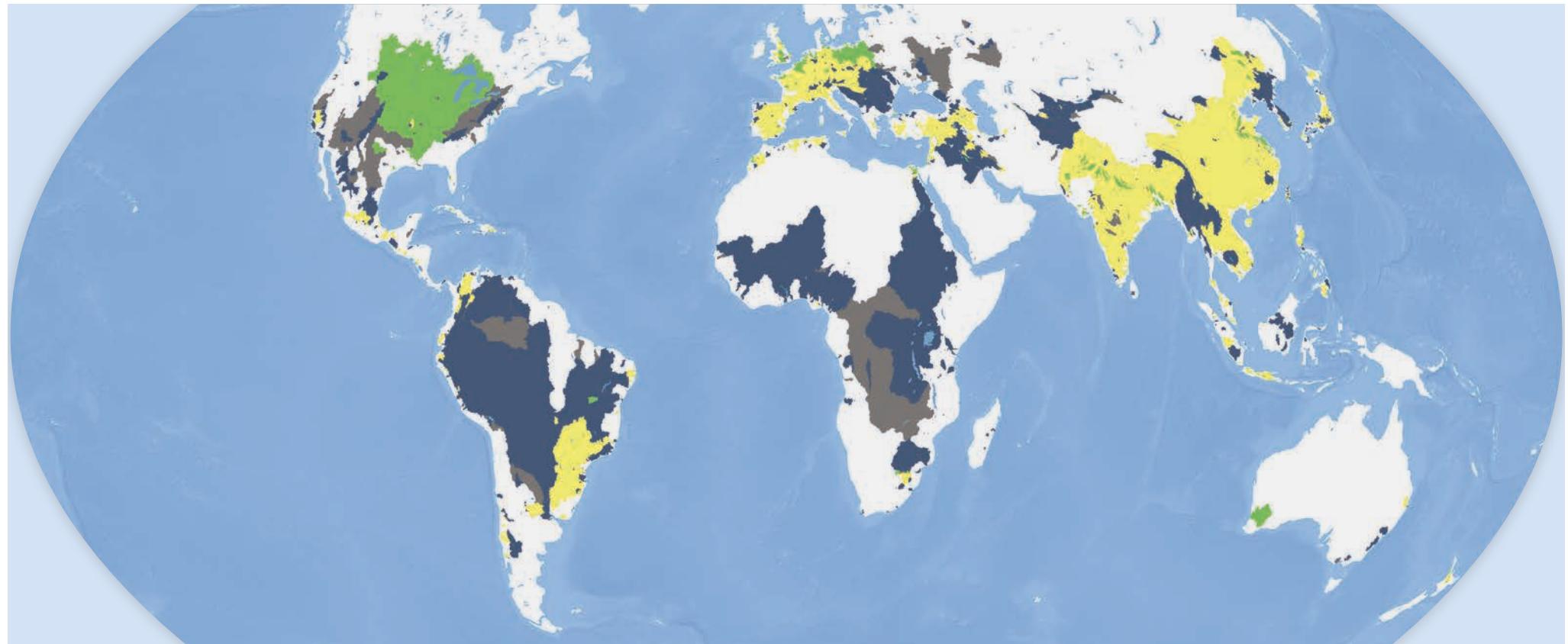
Specifically, in this report we show that:

- Four out of five cities in our analysis (81 percent) can reduce sediment or nutrient pollution by a meaningful amount (at least 10 percent) through forest protection, pastureland reforestation and agricultural BMPs as cover crops.
- Globally, 32 percent of the world's river basins experience seasonal, annual or dry-year water depletion. Source water protection activities could help improve infiltration and increase critical base flows in streams. For example, an analysis of the watersheds supplying water to six of Colombia's largest cities shows that source water protection activities could increase potential base flow up to 11 percent. Activities like these will be especially important in the 26 percent of source watershed areas predicted to experience decreases in annual precipitation by mid-century.
- Source water protection can maintain or improve groundwater resources by targeting aquifer recharge zones or other sensitive areas of the landscape. For example, early results in San Antonio, Texas, suggest that land-based programs that have protected 21 percent of aquifer recharge areas may have already avoided pollution impacts.

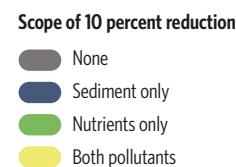
Source water protection activity	Description
	<b>Targeted land protection.</b> Protecting targeted ecosystems, such as forests, grasslands or wetlands.
	<b>Revegetation.</b> Restoring natural forest, grassland or other habitat through planting (direct seeding) or by enabling natural regeneration; includes pastureland reforestation.
	<b>Riparian restoration.</b> Restoring natural habitat that is at the interface between land and water along the banks of a river or stream. These strips are sometimes referred to as riparian buffers.
	<b>Agricultural best management practices (BMPs).</b> Changing agricultural land management to achieve multiple positive environmental outcomes.
	<b>Ranching best management practices (BMPs).</b> Changing land management practices on ranchlands to achieve multiple positive environmental outcomes.
	<b>Fire risk management.</b> Deploying management activities that reduce forest fuels and thereby reduce the risk of catastrophic fire.
	<b>Wetland restoration and creation.</b> Re-establishing the hydrology, plants and soils of former or degraded wetlands that have been drained, farmed or otherwise modified, or installing a new wetland to offset wetland losses or mimic natural wetland functions.
	<b>Road management.</b> Deploying a range of avoidance and mitigation techniques that aim to reduce the environmental impacts of roads, including those impacts related to negative effects on soils, water, species and habitats.

**Table ES.1.** Major categories of source water protection activities considered in this report.

## Potential for pollution reduction in urban source watersheds



**Figure ES.2.** Modeled potential for achieving a 10 percent reduction in sediment or nutrient (phosphorus) pollution through conservation activities (forest protection, pastureland reforestation and agricultural BMPs as cover crops). Legend colors indicate where a 10 percent reduction is possible for one, both or no pollutants. For many watersheds, pollution reduction greater than 10 percent is possible through source water protection activities. (Source: The Nature Conservancy)



Four out of five cities can reduce sediment and nutrient pollution by a meaningful amount through forest protection, pastureland reforestation and improved agricultural practices.

Nature-based solutions used to improve water quality and quantity can also help us reduce our carbon footprint, maintain critical ecosystems and build healthier, more resilient communities in the face of climate change.

## Source watersheds are a nexus of value and action

The value of source water protection goes well beyond water security. For the first time, we provide an in-depth exploration of the co-benefits—including climate change mitigation and adaptation, biodiversity, and human health and well-being—that can result from source water protection investment (Table ES.2). To understand the scale of opportunity, we present the ceiling of what could be achieved if all the source water protection activities we model were implemented.



**Water security.** Maintaining or improving water quality and dry season flows.



**Climate change mitigation.** Avoiding greenhouse gas emissions and increasing carbon sequestration.



**Climate change adaptation.** Using nature to mitigate climate change impacts and build resilient communities.



**Human health and well-being.** Supporting and improving physical and mental health, food security, livelihoods and social cohesion.



**Biodiversity conservation.** Protecting and improving the status of terrestrial and freshwater species and the ecosystems in which they live.

**Table ES.2.** Benefit categories of source water protection explored in this report.



## Climate change mitigation benefits

In December 2015, the Paris COP 21 committed to avoiding further loss of carbon stored in forests, as well as capturing carbon through land-based practices. Article 5 of the Paris Agreement recommends Parties conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases. According to the Food and Agriculture Organization of the United Nations (FAO), agriculture and land use, land-use change and forestry are among the most referenced sectors in mitigation contributions with 86 percent of countries referring to these land-based activities—second only to the energy sector.

- **Carbon storage:** We find that 64 percent (143 gigatonnes) of the total carbon stored in above-ground biomass in all tropical woody vegetation globally was held within urban source watersheds. From 2001 to 2014, more than 6.6 gigatonnes of carbon (24.3 gigatonnes of CO<sub>2</sub>) were emitted as a result of tropical forest loss in the source watersheds, equivalent to 76 percent of all carbon emitted as a result of tropical forest loss over that same time.
- **Climate change mitigation potential:** If reforestation, forest protection and agricultural BMPs were fully implemented across all source watersheds, an additional 10 gigatonnes of CO<sub>2</sub> in climate change mitigation potential could be achieved per year, or 16 percent of the 2050 emissions reduction goal. Between 4 and 11 percent of this ceiling of potential could be realized via city investments in source water protection activities at a level required to achieve meaningful sediment or nutrient reductions. The remaining potential points to opportunities for cities or other actors to capture additional climate change mitigation potential through programs motivated by water security or other co-benefits.

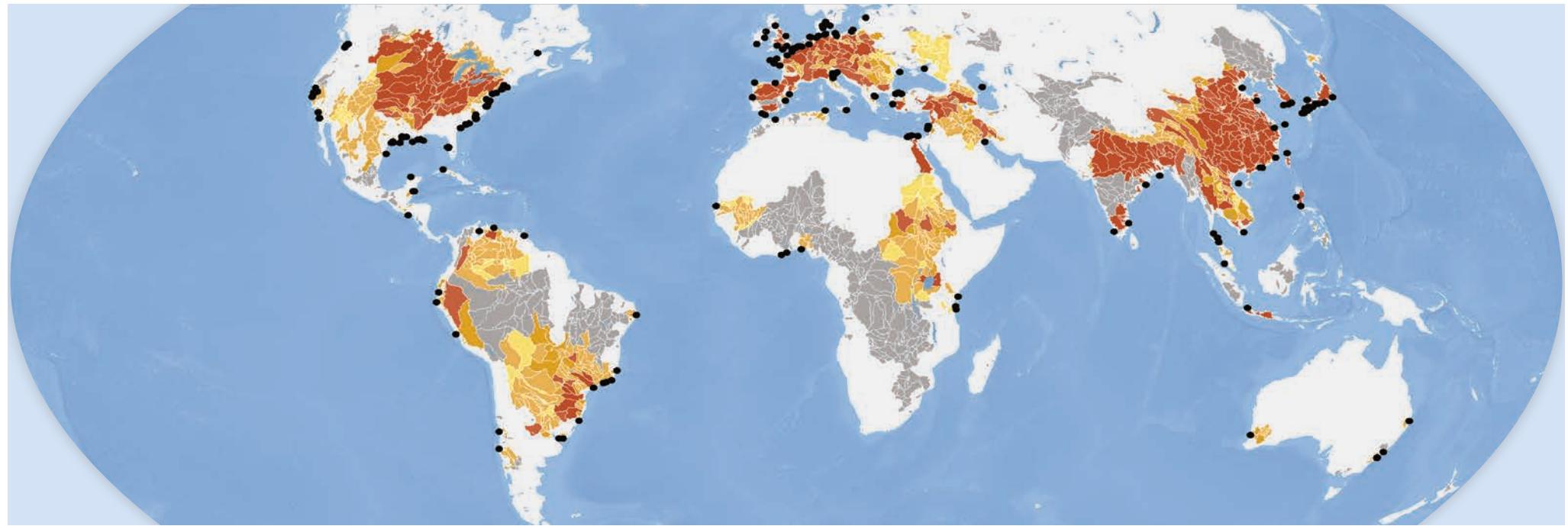
Source water protection activities can reduce the impacts of increased rainfall and other climate-related hazards.

## Climate change adaptation benefits

Climate change impacts will be felt most acutely by vulnerable people. Functioning ecosystems can support resilient communities, consistent with the Sustainable Development Goal 13, Target 1 to: “Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.” While catastrophic climatic events will still bring flood risks, source water protection activities can reduce the impacts of increased rainfall and other climate-related hazards.

- **Regulating fire frequency:** The combination of fire suppression and a drier, hotter climate in some geographies can lead to catastrophic fires, with impacts to communities and downstream water quality. Forest fuel reduction, a source water protection activity, may be an appropriate activity to address this challenge in the 24 percent of urban source watershed areas where fire frequency is predicted to increase by mid-century.
- **Better soil retention:** Source water protection activities, including but not limited to agricultural BMPs and restoration, can help to mitigate soil erosion. These activities will have almost universal relevance, as 83 percent of source watershed areas are predicted to increase in erosivity by mid-century due to climate change. Erosion not only leads to water pollution, but reduces soil productivity and thereby reduces the resiliency of farming communities.

## Excess nitrogen in upstream urban source watersheds linked to downstream eutrophication areas



**Figure ES.3.** Excess nitrogen in urban source watersheds upstream of reported downstream eutrophication problems, including dead zones. Urban source watersheds displayed in gray are not linked to any reported eutrophication problems. HydroBASINS with negative values indicate a deficit balance of nitrogen. (Source data: World Resources Institute eutrophication database 2013 ; EarthStat total fertilizer balance data 2014)

## Human health and well-being benefits

Source water protection activities are important pathways to meeting human health and well-being goals, including food security. Up to 780 million people living in urban source watersheds within countries in the bottom tenth percentile of the Human Development Index could receive direct or indirect health benefits. Up to 28 million farming households could implement agricultural BMPs that aim to reduce sediment runoff by 10 percent globally. In doing so, they are likely to see related benefits, including improvements in crop production and health and well-being. Our findings include:

- Reduced risks to fisheries:** Excess nutrients in source watersheds can make their way via runoff into streams, down river courses and ultimately into coastal zones, where fisheries are often critical resources for local communities. The impacts may be particularly important to the 10 to 12 percent of the global population that depends on fisheries and aquaculture for their livelihoods, 90 percent of whom are small, artisanal fishers, according to the FAO. Source water protection activities could help mitigate nutrient inputs for over 200 of the 762 globally reported coastal eutrophication and dead zones (Figure ES.3).

- Avert micronutrient deficiency:** According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), over 75 percent of the world's crop species depend on pollination by bees, butterflies and other species to produce the foods we consume. The annual value of global crops directly affected by pollinators is US\$235 billion to US\$577 billion. Pollination is vital for fruit and vegetable crops that serve as the source of essential micronutrients (e.g., vitamin A, iron, folate). Approximately 2.6 billion people live in source watershed areas where greater than 10 percent of micronutrient supply would be lost without the benefits of pollination. By avoiding the loss of important pollinator habitat close to agricultural lands, source water protection could avert the loss of 5 percent of agricultural production's economic value globally from pollinator loss alone.



## Biodiversity benefits

Natural ecosystems and biodiversity are fundamental to a sustainable planet, as recognized in the Aichi Biodiversity Targets and the SDGs. In freshwater ecosystems, the trend is negative. WWF's 2016 Global Living Planet Index shows that, on average, the abundance of populations monitored in freshwater systems has declined by 81 percent between 1970 and 2012. More than three-fourths of the urban source watersheds are within regions of high species diversity and endemism. In addition, nearly half of the vulnerable terrestrial mammals, amphibians and birds listed by the International Union for Conservation of Nature (IUCN), and more than half of the vulnerable freshwater fishes as assessed to date by the IUCN, occur within urban source watersheds. Source water protection has enormous potential for biodiversity conservation.

- **Avoided extinction:** The risk of regional extinctions—loss of a species within a given ecoregion—would be reduced for 5,408 terrestrial species, if reforestation opportunities were fully implemented within source watersheds. Forty percent of those regional risk reductions would occur in Africa, suggesting a huge opportunity for biodiversity gains in that region from this one practice.
- **Habitat protection:** Targeted land protection is critical for sustaining both aquatic and terrestrial biodiversity. We find that 44 countries that currently fall short of the Convention on Biodiversity's 17 percent target for protection of lands and inland waters could achieve that target through protection of natural habitat that sits outside existing protected areas. One-quarter of those could reach the target by protecting just 10 percent or less of remaining natural land cover outside protected areas.

For more than 15 years, water funds have successfully enabled downstream water users to invest in upstream habitat protection and land management to improve water quality and quantity.

## Capturing the value of source watersheds through water funds

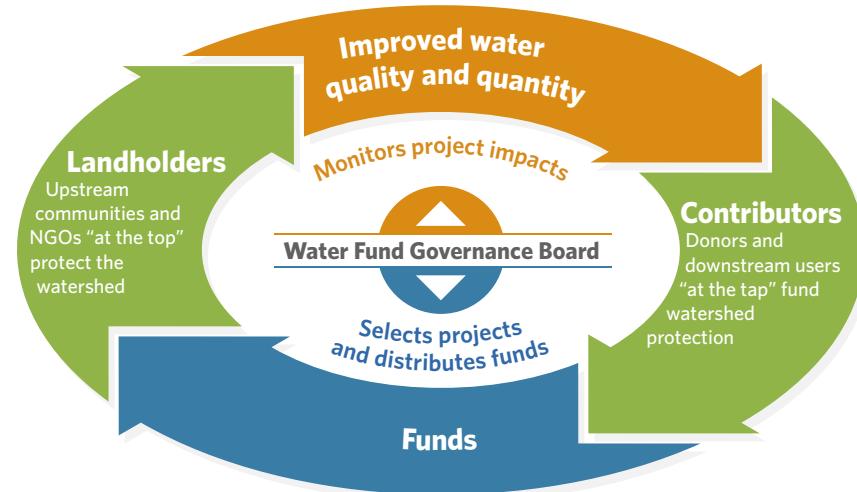
The water security benefits and co-benefits of source water protection are not being captured systematically today. Despite overwhelming benefits to cities, most exert little influence over how sources are managed. The barriers to implementation generally fall into three main areas:

- There is often a mismatch between the jurisdictions of the problem owners and problem solvers. Urban water users, such as municipalities, urban water managers or industries, have limited jurisdiction and cannot easily reach beyond those jurisdictional borders. Rural land stewards are making decisions that affect urban users but have little to no incentive to reduce their impacts.
- Knowledge transfer is lacking on how investments in source water protection can achieve specific water security outcomes or other benefits.
- Replicable mechanisms that allow for a diversity of funding flows, based both on a supportive policy environment and on specific financial structures, are lacking.

### Defining a water fund

The water fund, an institutional platform developed by cities and conservation practitioners including The Nature Conservancy, can help resolve governance issues by bridging science, jurisdictional, financial and implementation gaps. For more than 15 years, water funds have helped communities improve water quality by bringing water users together to collectively invest in upstream habitat protection and land management, and mobilize innovative sources of funding. As a permanent governance, investment and source water protection implementation mechanism, water funds provide the framework for collective action, connecting land stewards in rural areas and water users in urban areas to share in the value of healthy watersheds (Figure ES.4). With a portfolio of 29 funds in operation as of the publication of this report and approximately 30 in design, The Nature Conservancy and its partners are building an understanding of how to reduce the risks associated with source water protection investments (Figure ES.5). Other actors are also developing similar models in a variety of contexts. Taken together, a body of work is emerging that provides solutions to the barriers on the ground.

The major elements and flows of a water fund



**Figure ES.4.** A water fund is designed to cost-effectively harness nature's ability to capture, filter, store and deliver clean and reliable water. Water funds have four common characteristics: science-based plans, a multi-stakeholder approach, a funding mechanism and implementation capacity.

## Water Funds in Action

### Quito, Ecuador

In response to growing water demands and concern over watershed degradation, the municipality of Quito, the water company of Quito and The Nature Conservancy helped create the Fund for the Protection of Water (FONAG) in 2000. FONAG works to mobilize critical watershed actors to exercise their civic responsibility on behalf of nature, especially related to water resources. The multi-stakeholder board—composed of public, private and NGO watershed actors—provides a mechanism for joint investment in watershed protection, including supporting the communities that live there.

FONAG conducts source water protection through a variety of mechanisms. First, it works to protect and restore high Andean grasslands (*páramos*) and Andean forest in critical areas for water provision to Quito, including areas owned by local communities, private landowners and the Quito water company. In addition to direct source water protection activities, FONAG focuses on strengthening watershed alliances, environmental education and communication to mobilize additional watershed actors in watershed protection. FONAG has also established a rigorous hydrologic monitoring program to communicate and improve outcomes of investments in collaboration with several academic institutions.

FONAG has an endowment of more than US\$10 million and an annual budget of more than US\$1.5 million. The largest source of funding (nearly 90 percent) comes from Quito's water company, which by a municipal ordinance is required to contribute 2 percent of the water company's annual budget. Since its inception, FONAG has worked to protect and/or restore more than 40,000 hectares of *páramos* and Andean forests through a variety of strategies, including working with more than 400 local families.

### Nairobi, Kenya

The Upper Tana River Basin is of critical importance to the Kenyan economy. Covering an area of approximately 1.7 million hectares, the Upper Tana supplies 95 percent of Nairobi's drinking water, sustains important aquatic biodiversity, drives agricultural activities that feed millions of Kenyans and provides half of the country's hydropower output. The basin has experienced high population growth and declining sustainability of agriculture, resulting in the conversion of forest to cropland and decreasing land per capita.

Smallholder farms are the largest upstream water user in aggregate of Upper Tana Basin water. Hydropower generation is the second largest upstream user of water, though the water is returned to the river. The unchecked expansion of farming, quarrying and dirt road construction across the Upper Tana over the last 40 years has led to land degradation. Consequently, elevated sediment loads are entering the river system, impacting the delivery of water to Nairobi water users and reducing the

storage capacity of reservoirs. In response to these challenges, the Upper Tana-Nairobi Water Fund was launched to implement a holistic set of source water protection activities with the objectives of increasing water yields, reducing sediment, and promoting sustainable food production and increased household incomes in farming communities across the project areas.

In order to mobilize funding, a comprehensive analysis integrated investment planning techniques with watershed modeling tools to prioritize where to work. Non-monetized benefits, including pollinator habitat and carbon storage, were identified and the overall cost-to-benefit analysis concluded that, even by conservative estimates, the selected watershed interventions could ultimately deliver a two-to-one return on investment over a 30-year timeframe. By recognizing the multiple embedded values of a healthy watershed, and involving the key stakeholder groups, the water fund was able to design a collective action program whereby investing together made the most financial sense. Many of these projected benefits are already being measured through demonstration interventions.

### San Antonio, Texas, United States

As one of the largest artesian aquifers in the world, the Edwards Aquifer serves as the primary source of drinking water for nearly 2 million central Texans, including every resident of San Antonio—the second largest city in Texas—and much of the surrounding Hill Country. Its waters feed springs, rivers and lakes and sustain diverse plant and animal life, including rare and endangered species. The aquifer supports agricultural, industrial and recreational activities that not only sustain the Texas economy, but also contribute immeasurably to the culture and heritage of the Lone Star State.

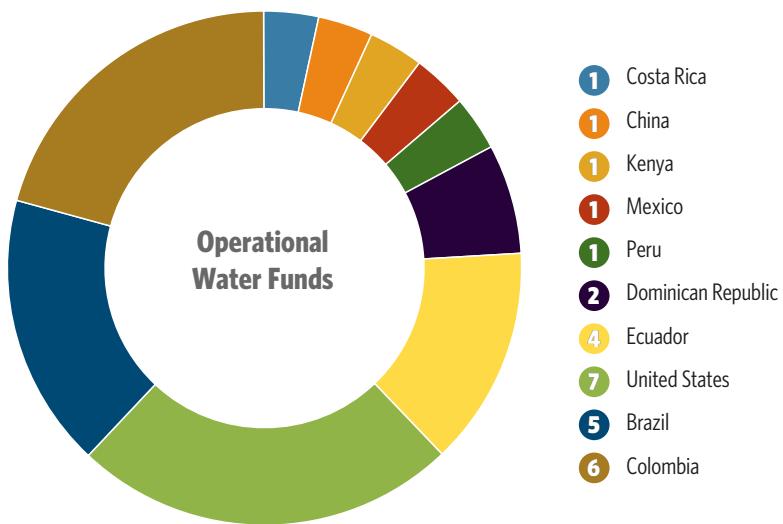
With careful land management, there is the potential to avoid additional impacts to the aquifer and reduce the need to expand water treatment for San Antonio. In 2000, voters approved the city's first publicly-financed water fund measure to protect the Edwards Aquifer. The proposition passed with enthusiastic support and authorized US\$45 million to purchase properties within the aquifer's most sensitive area. San Antonians have since voted three more times not only to continue the program, but to greatly expand it. The ensuing Edwards Aquifer Protection Program raised a total of US\$315 million to protect the Edwards Aquifer in Bexar County, where San Antonio lies, as well as throughout much of the surrounding regions.

Since 2000, The Nature Conservancy has worked alongside city officials in San Antonio and surrounding communities to ensure these water funds have the greatest impact. To date, the efforts have helped local governments invest more than US\$500 million in water protection funds and protect more than 48,560 hectares above the Edwards Aquifer, including 21 percent of the aquifer's recharge zone, its most sensitive area.

Operational water funds within the portfolio of The Nature Conservancy and its partners



**Figure ES.5.** The water fund concept was born in Quito, Ecuador, and the track record of delivery pioneered in Latin America has led to replication in East Africa, China and the United States. There are 20 operating funds in Latin America, seven in the United States, one in Sub-Saharan Africa and one in China.



The Nature Conservancy is  
working on nearly 60 water funds  
around the world.

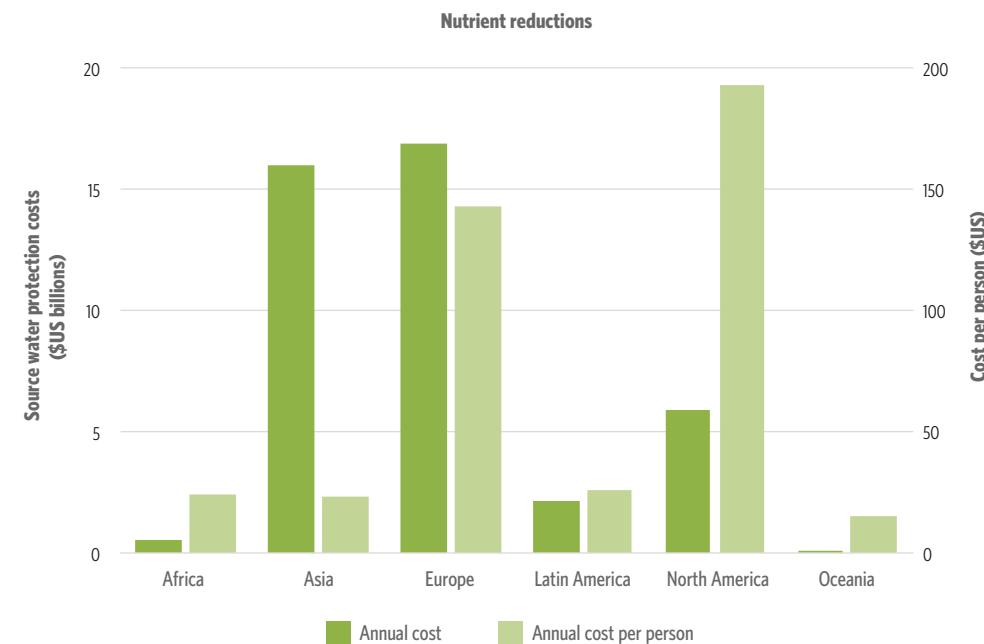
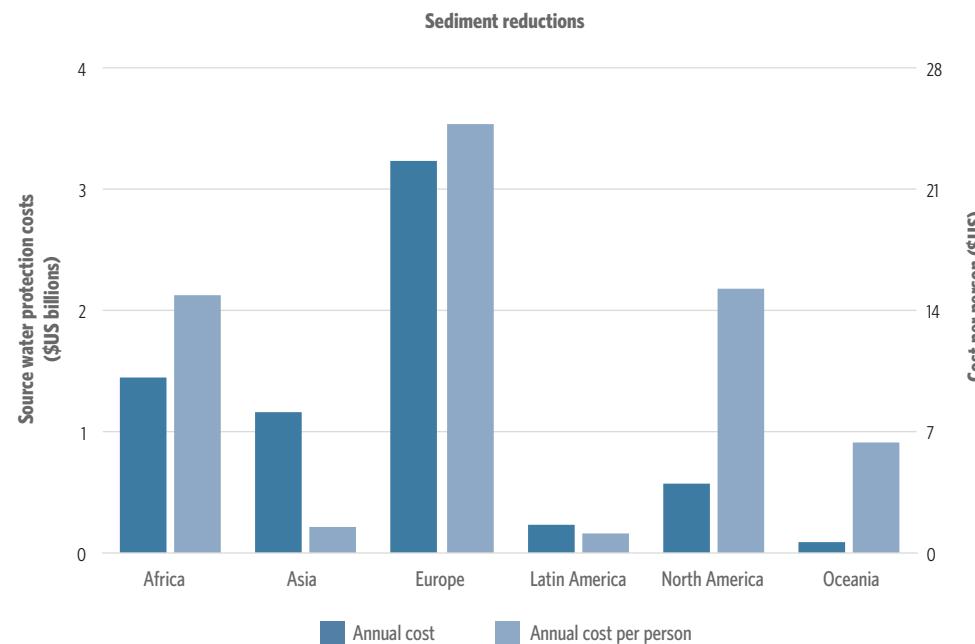
## Scaling source water protection by bridging the gaps

The cost of source water protection could be covered by revealing benefits to diverse payers through the business case for water funds. Forest Trends reports that roughly US\$24.6 billion is spent annually on payments for watershed services programs, an umbrella that includes water funds. We estimate that an increase of US\$42 billion to US\$48 billion annually would be required to achieve an additional 10 percent of sediment and nutrient reductions in 90 percent of our source watersheds. With this level of funding, we could improve water security for at least 1.4 billion people by first focusing on the most cost-effective watersheds for water security purposes. For example, we estimate sediment reduction can be achieved with US\$6.7 billion

annually, improving water security for 1.2 billion people at an average per capita cost of under US\$6 annually (Figure ES.6). For half of cities, source water protection costs could be just US\$2 or less per person per year.

While substantial, this annual increase of US\$42 billion to US\$48 billion represents around 7 to 8 percent on average of the global expenditure on water—estimated to be US\$591 billion per year in 2014—and is commensurate to what cities like New York City are spending on watershed protection as a fraction of their overall water expenditure. Water funds can provide a mechanism to connect the benefits produced by source water protection to potential payers to close the funding gap.

**Annual source water protection costs to achieve a 10 percent reduction in sediment and nutrients in 90 percent of urban source watersheds**



**Figure ES.6.** Estimated annual costs (total and per capita) of source water protection implementation—through forest protection, pastureland reforestation and agricultural BMPs as cover crops—to achieve a 10 percent reduction in sediment (left) or nutrients (right) in source watershed areas. For each region, a subset of watersheds—particularly within very large basins—heavily skew costs upwards. Results reported here remove these outlier watersheds as measured by per capita costs, showing values for the remaining 90 percent of watersheds within each region.

## Integrating reveals more value

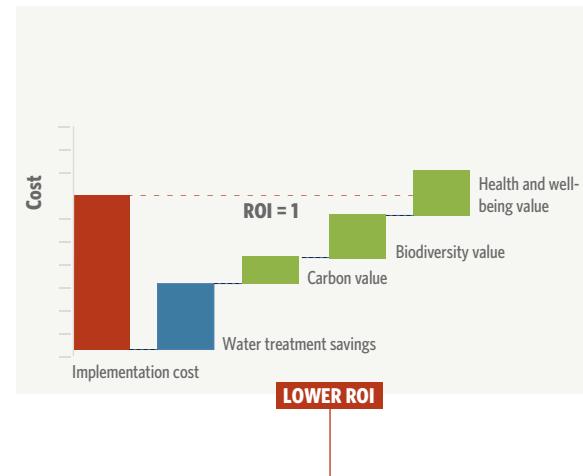
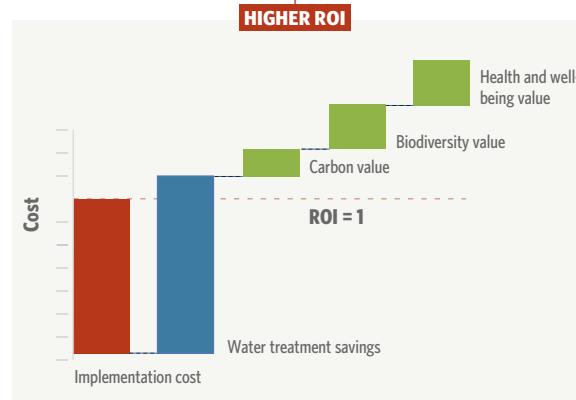
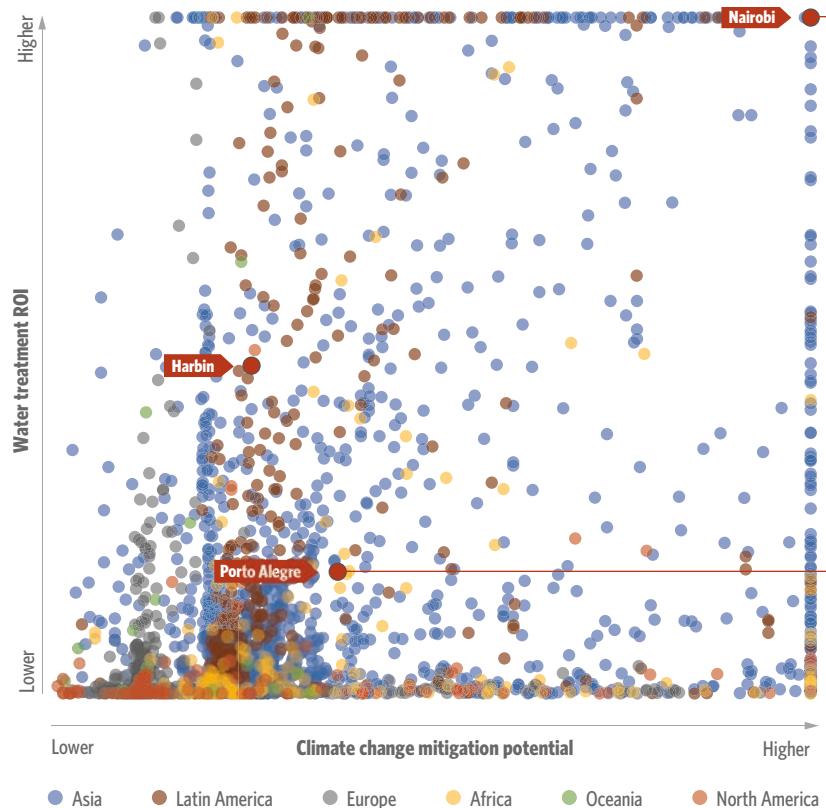
Understanding the value proposition of source water protection to each city is critical to making the business case and pooling resources. We analyzed the relative water treatment return on investment (ROI) for the roughly 4,000 cities in our source watershed model and cross-walked these to relative values of co-benefits such as climate change mitigation, biodiversity, and human health and well-being (Figure ES.7). This analysis allows us to target cities that are the most likely candidates for source water protection based on one or more values. The cost-to-benefit ratio of source water protection falls into three broad categories:

1. We estimate that one in six cities—roughly 690 cities serving more than 433 million people globally—has the potential to fully offset conservation costs through water treatment savings alone.

2. Other cities may have a moderate to low relative ROI for water utilities, but may be able to achieve source water protection by also monetizing their climate change mitigation potential. Cities could intercept payment streams where these exist from national ministries or international actors who have made a strong commitment to a stable climate and are looking for on-the-ground opportunities for mitigation.

3. Other cities may be able to achieve source water protection by combining more than two benefits for which payers—public or private—exist. For example, through an examination of the source watersheds of a set of Colombia's largest cities, we find a range of 13 to 95 percent savings when land uses are optimized to achieve multiple goals (sediment, nutrients and carbon) simultaneously rather than individually, on average representing a 63 percent savings in public investment.

### Demonstration of stacking co-benefits in different city archetypes



**Figure ES.7. Left:** Comparison of indicators of potential co-benefit value (horizontal axis) versus relative water treatment ROI (vertical axis). Climate change mitigation potential estimated from annual sequestration potential from reforestation and cover crops as implemented to reach a 10 percent reduction in sediment or nutrients. **Middle:** Illustrative graph showing cities with a positive ROI based solely on water treatment savings. **Right:** Illustrative graph showing cities whose ROI could be positive with the addition of co-benefit values.

## Using water funds to scale source water protection

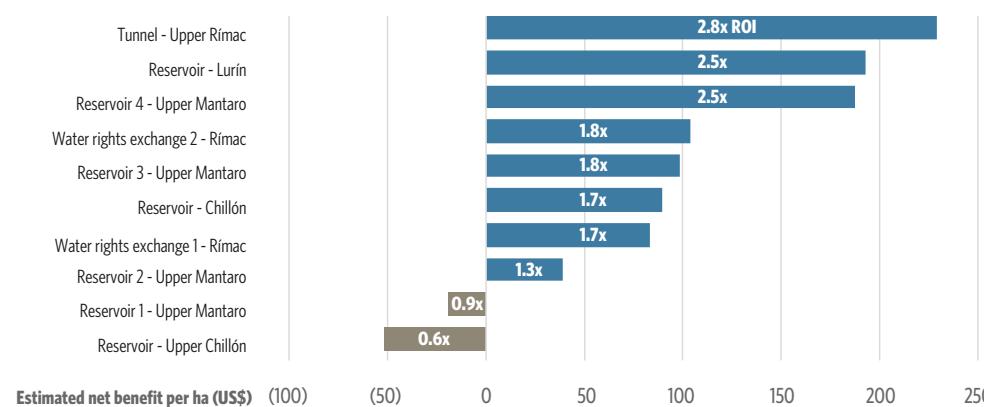
Water funds can scale source water protection by increasing participation based on a solid value proposition. Water funds provide an attractive vehicle for pooling and deploying revenue in watersheds from the diverse beneficiaries of watershed services. Nonetheless, to get to scale, water funds need greater diversity and surety of cash flows. Opportunities to do so include:

- strengthening public funding flows based on a value proposition for water and other values;
- diversifying buyers by bridging into new sectors; and
- positioning source water protection as a smart option for infrastructure investment beyond operations and maintenance (O&M) savings.

Public funding will continue to be critical to source water protection efforts. Water funds with a strong ROI for water treatment or climate adaptation, for example, can pool a percentage of water tariffs, taxes or transfers.

Other sectors could benefit from source water protection but have not entered the market strongly. For example, there is a clear case for the return on investment to hydropower companies. A number of water funds, such as those of Nairobi and Quito, are in operation and on-track to provide direct benefits to hydropower facilities. A detailed cost-benefit analysis predicts a positive return on investment for reforestation efforts upstream of Colombia's Calima Dam.

**Estimated ROI for generating dry season flows to Lima, Peru's metropolitan area via puna/mamanteo restoration**



**Figure ES.8.** A positive ROI is shown with bars extending right of the zero on the X-axis, and represents the ROI of replacing the listed gray infrastructure option on the y-axis with a specific green infrastructure option (restoration of puna/mamanteo system).

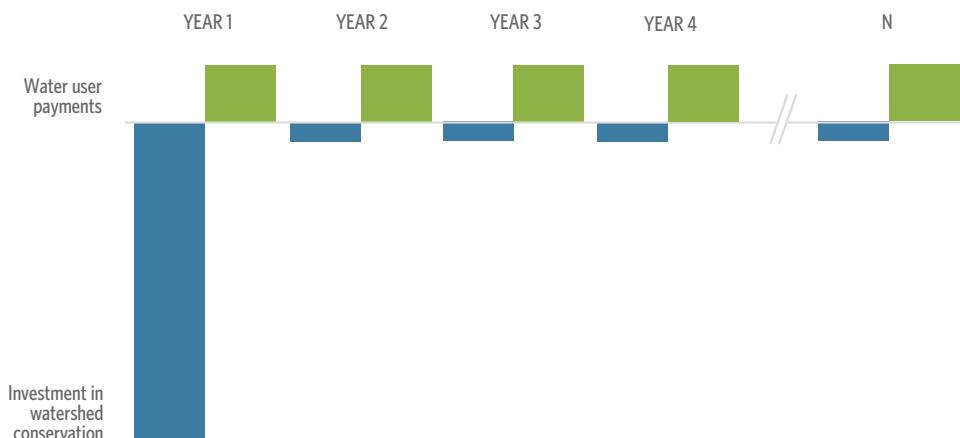
Equally important is the case for source water protection as a complement to gray infrastructure to capture investments into water funds. In the case of Lima, Peru an analysis of anticipated costs and related dry-season flow benefits found source water protection to be preferable to gray infrastructure in eight-of-ten cases (Figure ES.8).

## Enabling upfront financing

If monetized, the benefits will help scale source water protection by enabling upfront financing. With enough diverse and stable payers contributing to water funds, upfront financing becomes possible and could dramatically increase the rate of deployment under the right conditions. For example, in the case of San Antonio, Texas, voters approved four ballot initiatives that authorized bond offerings to fund the Edwards Aquifer Protection Program. The bonds are repaid through tax increases. The capital made available through the bonds made land protection efforts possible in a condensed time frame, critical in an area where urban sprawl was both reducing available protection opportunities and increasing the cost of action over time (Figure ES.9).

In addition to overcoming financial barriers, there are a number of gaps that, if addressed, could accelerate the development and implementation of water funds to help achieve the global impact described here. These include gaps in policy and governance, adequate capacity to deliver, economies of scale in implementation, social acceptance, science and general awareness of source water protection's full potential.

**Proposed cash flow pattern of water funds with upfront investment**



**Figure ES.9.** Upfront investment in upstream watershed conservation commensurate with program goals, with annual repayment by water users. Adapted from Credit Suisse Group AG and McKinsey Center for Business and Environment 2016 with permission.

For half of cities, source water protection could cost just US\$2 or less per person per year.



Photo: © Kevin Arnold

## A call to action

Forward-looking cities, utilities, land stewards, local communities, lawmakers, corporations and philanthropists are taking steps to secure a more sustainable water future and support the development of healthier, more resilient communities. But more is needed.

**Urban leaders** should take a full inventory of the economic benefits that would accrue to the city through source water protection. These would include reduced water supply O&M costs and potential avoidance of capital infrastructure and other co-benefits such as climate change mitigation and the conservation of biodiversity and open spaces that have significant positive impacts. City administrations are the most natural participants in the water fund platform, and through policy design, can help intermediate water tariffs, taxes or transfers into cash flows that could support long-term payments to source water protection and help finance interventions.

**National leaders** should explore how a source water protection portfolio can optimize multiple goals and public investment. In particular, countries may be able to meet a portion of national climate, biodiversity and SDG targets through source water protection efforts that also address regional economic development goals and support water security for municipalities.

**Public and private financers and donors** are critical as we move from innovation to expansion of water funds. Getting the science and tools to a local scale is essential. Investing in landscape assessments and water fund feasibility studies is a key gap. Ultimately, the scale-up of water funds will also require their development as financial vehicles that can connect capital from mainstream capital markets and institutional investors into the watersheds and their benefits. This will require significant innovation and trial to build a reliable track record for what is effectively a new asset class.

**Corporations**, as core beneficiaries of water security, are key champions and leaders in water security efforts. Corporations should explore where they face business risks related to water quality or availability, including indirect use such as the power their operations depend upon, and partner with the civil and government sectors to establish water funds in those locations. Corporations might also explore where their own business operations might be expanded to deliver some of the components required to achieve source water protection.

**The scientific and non-governmental communities** have much to do. This report lays out areas that require more analysis and reflection. These communities should continue efforts to build the understanding of how and when water funds, and more generally source water protection efforts, will be successful, as well as exploring new policy, governance and financial approaches to implementing them.

**Upstream land stewards** should know the value of their land and understand the impacts of their practices on downstream water quality and quantity. By evaluating the benefits that may be offered through the establishment of a water fund, upstream landowners have an opportunity to improve their lives and livelihoods while improving downstream water quality.

**Citizens of the cities that depend on source watersheds** should be advocates for their water. The public should know where their water comes from and what's impacting its long-term security. People can advocate for leadership to protect water at its source through policy changes and programs like water funds that put in place long-term implementation capacity.

Cities are and will be the drivers of economic growth of the future, requiring vast public investment as well as creating impact on the lands and waters that make up the extended natural infrastructure on which their resilience will depend. Cities can and should lead in considering what actions should be taken to improve their water security and resiliency. Their actions can also generate benefits such as climate change mitigation and biodiversity conservation that extend far beyond city borders and reach wide constituencies. Our aspirations for a better world require collective action. We cannot afford to work in jurisdictional, financial or motivational silos. Cities can lead, but they cannot do it alone. All of us have a role to play.

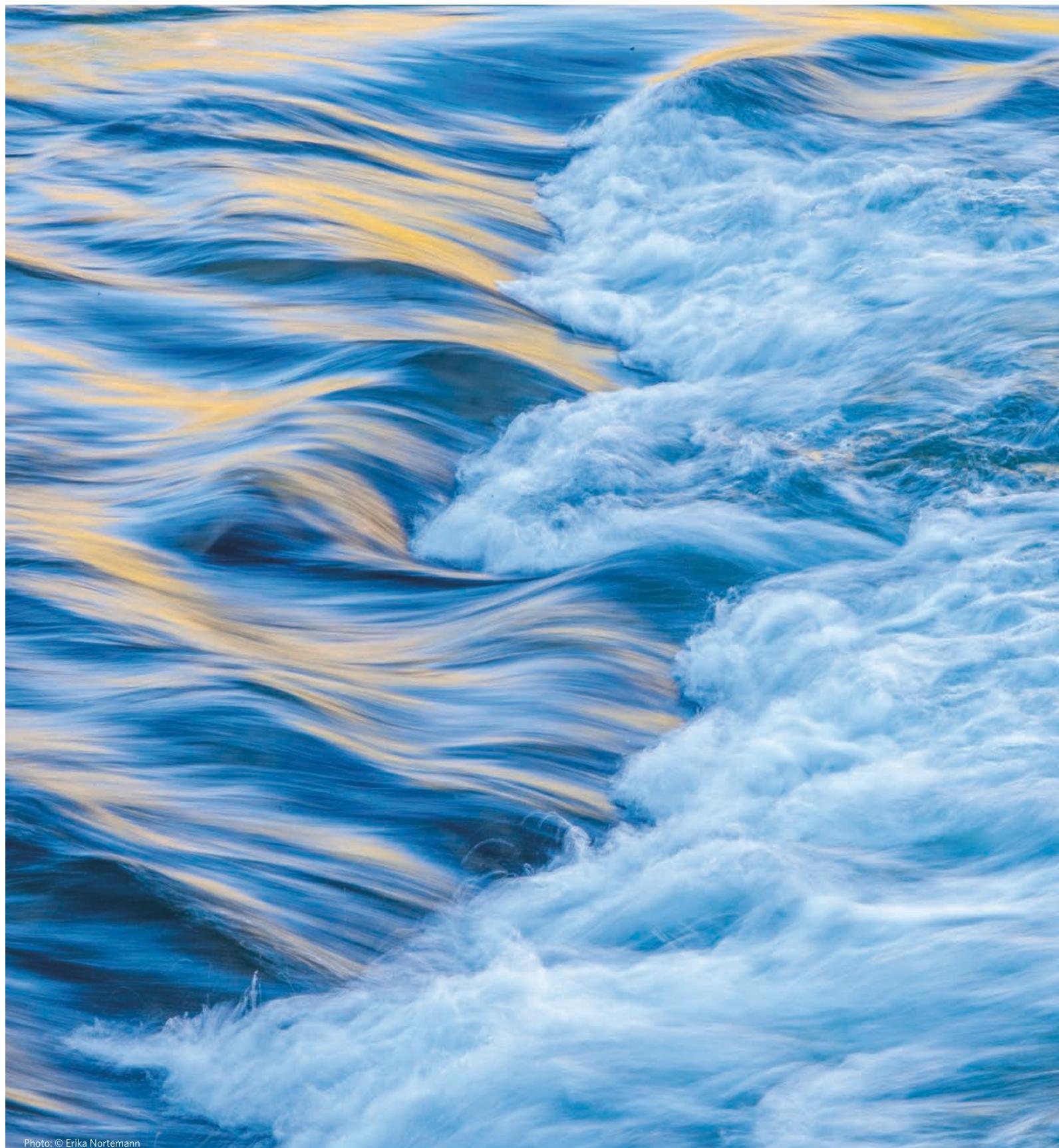


Photo: © Erika Nortemann

## CHAPTER ONE INSIGHTS

Source watersheds are vital natural infrastructure for nearly all cities around the world.

- Global sustainability goals cannot be met without improvements in water security. Natural infrastructure for water security supports other goals simultaneously.
- Natural infrastructure can and must complement gray infrastructure, which by itself will not be a financially- or environmentally-sustainable water security solution for much of the world.
- A new map of the world that models source watersheds for 4,000 cities reveals that roughly 1.7 billion urban dwellers depend on over one-third of the Earth's land surface for water.
- Source water protection can maintain or improve the quality of groundwater resources by targeting aquifer recharge zones or other sensitive areas of the landscape.

# Chapter 1

## Water Insecurity: A Central Risk to Global Prosperity

### Water today and tomorrow

This report is concerned with water security and what we can do about it. In particular, it focuses on the role of ecological conservation to protect the sources of water we depend upon.

The futures of cities and rural communities, industry and agriculture, developed and developing countries and our natural and built environments are inseparable.<sup>1</sup> Ensuring sustainability, human health and well-being, and security requires an integrated approach to governing and managing linked systems.<sup>2,3</sup> Employing an integrated approach increases the complexity of solutions but is the only way to make real progress toward meeting multiple objectives. No issue is more interlinked across the global economy and society at large than water security.

The World Economic Forum identifies water crises—defined as “a significant decline in the available quality and quantity of fresh water resulting in harmful effects on human health and/or economic activity”—as the risk of greatest concern to the global economy over the next 10 years.<sup>4</sup> The effects of these water challenges are already in stark display.<sup>5</sup> For instance, the use of nitrogen and phosphorus in fertilizers has grown by as much as nine times since 1960, with consequences for freshwater and coastal marine systems alike. In the United States alone, the costs associated with nutrient pollution of freshwater systems was estimated to be US\$2.2 billion annually.<sup>6</sup>

It goes without saying that the greater the pollution load in our water, the greater the investment required for cleaning that water so that it is safe to drink. Maintaining clean, reliable supplies of drinking water is a global priority. Despite gains in the 1970s, access to safe drinking water around the world was predicted in a 2009 study to begin declining by 2010 due to lack of sufficient investment. That same report predicted reductions in economic growth by 2050 as a result of reduced access to water.<sup>7</sup> These growth reductions were expected to occur across developed, emerging and developing countries—only at different times.

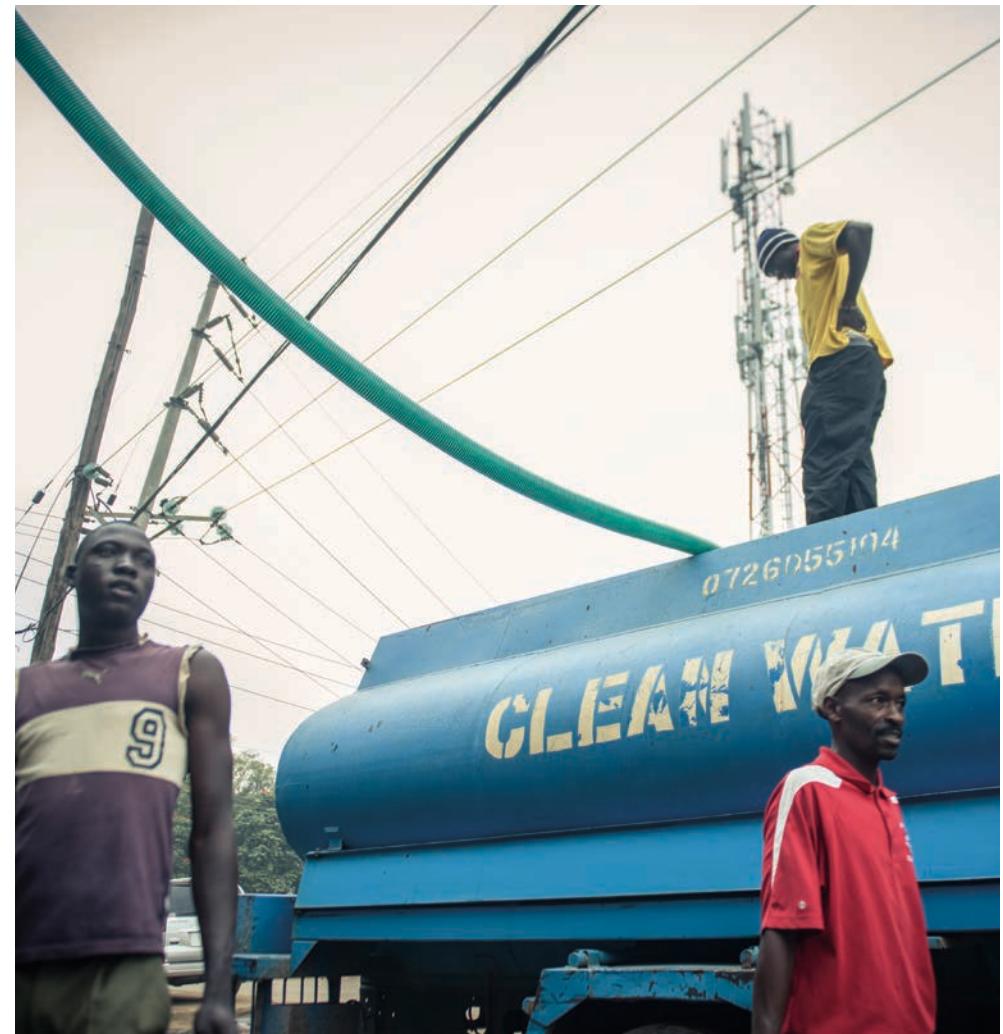


Photo: © Nick Hall

Given the fundamental importance of water to every sector and to everyday life, water crises are linked to over one-third of other global risk categories.<sup>8</sup> Climate change already manifests itself in temperature and precipitation changes, which are linked to the increased frequency and severity of droughts and floods.<sup>9,10</sup> A failure of urban planning in many cities results in untreated waste reaching water supplies through sewer overflows,<sup>11</sup> impacting health and ecosystems in waterways and nearshore marine areas.

The natural and working lands around our water sources serve as vital water infrastructure for cities around the world. These lands collect, store and filter our water, while providing a number of benefits to people and nature.

Water crises are also drivers of other risks. Perhaps most prominent are the impacts of water on food security. Agricultural production is responsible, on average, for around 70 percent of surface and groundwater withdrawals globally and 90 percent on average in water scarce basins.<sup>12</sup> Water demand will almost surely increase with population and economic growth. Adding complexity to the situation is agriculture's impact on water quality. The sector is by far the largest contributor of nonpoint source pollutants in our waterways. The occurrence and severity of these quantity and quality impacts vary considerably across the world's water basins. Addressing them requires balancing food security and water security concerns, along with their many connections to energy as part of the food-water-energy nexus. Linkages between water crises and food crises are complex, encompassing physical, economic and institutional constraints that go beyond the core problem of insufficient water supplies at a given place and time.<sup>13</sup>

Water is also anticipated to be a driver of instability among human communities and even states. The Intergovernmental Panel on Climate Change (IPCC) argues that droughts and coastal flooding could spark large-scale demographic responses like migration, not only directly from those disasters, but from related impacts like land degradation and reduced agricultural production.<sup>14</sup> The U.S. National Intelligence Council has concluded that “water problems—when combined with poverty, social tensions, environmental degradation, ineffectual leadership and weak political institutions—contribute to social disruptions that can result in state failure.”<sup>15</sup>

Many communities experience these linkages every day. Indigenous, rural and lower-income urban communities all have direct experience with how water risks affect their well-being.<sup>16</sup> The Indigenous Peoples Kyoto Water Declaration, in its call for climate change mitigation to reduce water-related climate hazards, states: “The most vulnerable communities to climate change are Indigenous Peoples and impoverished local communities occupying marginal rural and urban environments.”<sup>17</sup> The declaration also makes clear the links between water risks and threats to the natural environment.

Reducing a range of global risks, which are ultimately experienced at the local level, will require progress toward water security. We adopt the United Nations (UN)-Water's definition of water security: the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.<sup>18</sup>

In this report, we present a sustainable path toward achieving many of these water security objectives while simultaneously making progress toward multiple linked global goals. We focus on addressing a central element of water security—the provision of clean, reliable drinking water—and argue that protecting drinking water resources at their source can contribute to conserving biodiversity, mitigating climate change, building resilience to climate impacts and providing a range of health and well-being benefits. Protecting source watersheds can deliver multiple goals at once because: 1) the sustainable management of water resources is a necessary step in achieving multiple objectives of the sustainable development agenda; and 2) the process of source water protection itself contributes to that agenda through engagement with rural communities and stakeholders to improve land management.

This report is designed to reveal the value of source watersheds to municipal leaders who will be responsible for the water security of the majority of people on the planet, and to those global, national and local decision-makers who also have a stake in healthy watersheds because of the multiple benefits they provide. Understanding their value is not enough: our report seeks to illustrate how source water protection can be implemented at a scale that will make a difference in our collective pursuit to create a sustainable world. We explore water funds, an innovative governance and financing mechanism for source water protection that is already uniting stakeholders via a permanent instrument that shares economic benefits with upstream communities. Cities can lead, but this journey will require all of us to act.

## Water security runs through all global goals

Water security is central to sustainable human development efforts: past, present and future. Many parts of the world have progressed toward ensuring access to clean, reliable water for both people and nature, but it cannot be taken for granted amidst evolving pressures. Meeting water goals is not a static achievement, but one that requires continued investment.

In September 2015, 193 countries agreed upon the 2030 Agenda for Sustainable Development, which includes a framework for 17 Sustainable Development Goals (SDGs). This global agreement marks a renewed commitment for global action on improved and sustained well-being for all, recognizing that while many lives are improving, there is still much more to do to reach everyone. The SDGs, also referred to as the “Global Goals,” build on the Millennium Development Goals (MDGs) launched in 2000 with the ambition of mobilizing resources and commitments to halve extreme poverty by 2015 and ensure that the lives of those living in extreme poverty improve.<sup>19</sup>

Water connects multiple SDGs (Figure 1.1). The SDG “water goal” (SDG 6) aims to “ensure availability and sustainable management of water and sanitation for all” and encompasses the need to invest in adequate infrastructure, provide sanitation facilities and encourage hygiene at every level. It also includes the need to protect and restore water-related ecosystems such as forests, mountains, wetlands and rivers to mitigate water scarcity.<sup>20</sup> The goal’s eight targets also have clear links to other goals. For instance, targets relate to the needs of vulnerable women and girls, to pollution and hazardous chemicals, to improving water-use efficiency across all sectors and to implementing integrated water resources management.<sup>21</sup> Meanwhile, several other SDGs tackle water-related issues, such as development of safe, resilient and sustainable cities and the reduction of water-related disasters due to climate change.

These linkages represent a huge opportunity to tackle water-related issues from a multi-dimensional approach, and they highlight the challenge of developing new and adequate tools and approaches to accommodate and leverage those linkages. These interdependencies also underscore that the SDGs will only be achieved with success of the “water goal,” and the success of the water goal will depend on meeting other goals.<sup>22, 23</sup>

Water is the common currency which links nearly every SDG, and it will be a critical determinant of success.

*World Bank, 2016<sup>24</sup>*

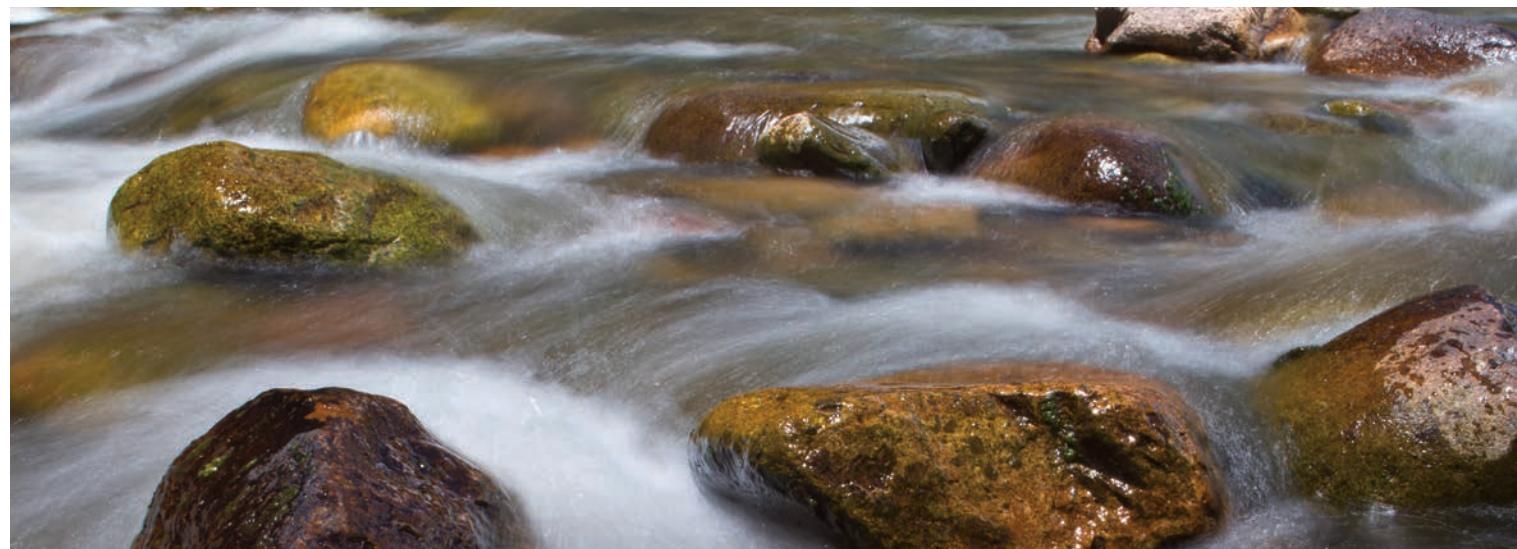


Photo: © Erika Nortemann/TNC

## Sustainable development goals and water

### 6 CLEAN WATER AND SANITATION



#### Goal 6 is also termed the “water goal.”

This goal aims to ensure available and sustainable management of water and sanitation for all.

#### Water security relies on management of natural infrastructure systems.

Natural systems are the building blocks for sustaining ecological systems, and natural infrastructure systems are critical to delivering water to cities and other communities. A changing climate will affect natural systems and can exacerbate water security challenges.



#### Water security is essential to food, shelter, health, energy and income.

Water quantity and quality are critical to daily livelihoods and economic development. The most marginalized face the greatest challenges for meeting these basic needs. Achieving water security will require responsible production and consumption of water-intensive products and services.



#### Achieving water security requires fostering inclusive and empowered populations.

Equitable land and water access and management are critical and dependent on water allocation, availability and sustainability. Participatory, informed, accountable and transparent institutions and partnerships are needed to meet water security goals.



**Figure 1.1.** Water is connected to many of the Sustainable Development Goals (SDGs), including those for mitigating climate change, building more resilient cities through climate change adaptation, and improving human health and well-being.

The achievability of these goals is the key question as many governments, civil society groups, private sector actors and communities begin to plan and implement actions to reach targets by 2030. A pilot study of the 34 OECD countries suggests that at least for some nations, achieving certain water goal targets may be within reach given current baselines due to a degree of progress under the MDGs. However, the distance to targets for other goals, like those related to climate and biodiversity, is far greater.<sup>25</sup> Coarse cost estimates for achieving all SDGs suggest, as one assessment states, “very significant resource implications across the developed and developing world”—on the order of US\$5 trillion to US\$7 trillion per year, or 6 to 9 percent of total global GDP.<sup>26</sup> Estimates for the cost of achieving individual targets, or related global goals, include US\$37.6 billion per year for achieving universal drinking water access (SDG Target 6.1).

Through its partnerships goal (SDG 17), the SDG framework acknowledges that achieving any and all of the goals will require a new level of collaboration across global initiatives.<sup>27</sup> In other words, it will require new partnerships to achieve individual goals and many of those partnerships will require working across goals. The interconnectedness of water security with other goals—climate change mitigation and adaptation, biodiversity conservation, sustainable cities and communities—underscores the opportunities to be gained through integrated approaches, particularly those focused on water security. At the same time, there must be a recognition that achieving one goal may come at the expense of another and not all situations are “win-wins” for all stakeholders and interests. For instance, the substitution of hydropower for coal-fired energy may contribute to climate change mitigation while imperiling freshwater species.<sup>28</sup>

Nevertheless, there is a growing political will for addressing these challenges. Water is core to all of them. Several international and political processes and negotiations now include water as a priority area to address sustainable development, adaptation and climate targets (Appendix I). In November 2015, the French Water Partnership along with the Coalition Eau stated, in a review of integration of water within the Intended Nationally Determined Contributions (INDCs) submitted for the UN Framework Convention on Climate Change Conference of Parties (COP21), that 92 percent of the INDCs cited water as a core priority for adaptation.<sup>29</sup> In addition, the Convention on Biological Diversity (CBD) Aichi Target 14 emphasizes the role that water plays for human communities and users.

A new platform convened by the UN Secretary General and the President of the World Bank has called upon a High Level Panel on Water (HLPW) to present their support for the implementation of SDG 6 and transform the way the world looks

at solving the most dire water issues. The panel was launched during the World Economic Forum (WEF) in Davos in January 2016 and aims to create a more inclusive, comprehensive approach that can lead to stronger collaborations among civil society, private and public sectors. Panel members include Heads of State from 11 countries: Mauritius, Mexico, Australia, Bangladesh, Hungary, Jordan, the Netherlands, South Africa, Senegal, Tajikistan and Peru. The core focus of the Panel over the two years of its mandate will be to ensure the availability and sustainable management of water and sanitation for all (SDG 6), as well as contribute to the achievement of the other SDGs that rely on the development and management of water resources.

The HLPW Action Plan, launched on September 21, 2016, illustrates nine cross-cutting pillars that can elevate the international negotiation processes for water (Figure 1.2).<sup>30</sup> Many of the challenges facing water are rooted in data, valuation and governance. The HLPW has also set forth key action items that build consensus around effective, sustainable and equitable approaches to valuing, pricing and allocating water that coincide with political and social realities across the globe. It seeks to create a holistic and integrated approach to water governance through relevant policy frameworks and to articulate the benefits of establishing and maintaining strong institutions.

#### Pillars of the High Level Panel on Water



Figure 1.2. From High Level Panel on Water Action Plan September 21st, 2016, by HLPW, © 2016 United Nations. Reprinted with the permission of the United Nations.

The HLPW can serve as an external catalyst to international policy processes, such as the United Nations Framework Convention on Climate Change (UNFCCC), to shed more light on water during the climate negotiation process and generate a dialogue to discuss the adaptation opportunities that water brings to the table.<sup>31</sup> Through its motives and calls to action, the HLPW can be used as a political aid for UN-Habitat to further its New Urban Agenda.<sup>32</sup> The panel also has an opportunity to meet Aichi Target 14 by catalyzing strong partnerships and international cooperation through better development planning processes.

Furthermore, the HLPW can advance the global agenda on water from the global and regional levels to local and district levels on a country-by-country basis.

The HLPW does not just serve as an implementation body, but as a platform that enables the review and exchange of information and more opportunities to bring water out of its silo.

Reaching the 2030 Agenda for Sustainable Development targets will require an acceleration of effort through the generation of data that can better inform decision-making from global to national and local scales, implementation through system and landscape-scale planning, and improving financing channels to meet multiple impacts. Even as we take a global view of these challenges and commitments, and

investigate how progress can be made toward these goals at a global accounting level, we recognize that water, in particular, requires solutions implemented at the local level, taking into account biophysical, socioeconomic and cultural conditions.

## Beyond built infrastructure

Many countries have largely built their way out of water insecurity through traditional “gray infrastructure”—dams, reservoirs, pipes, canals, drains and cement-lined streams for moving water and facilities utilizing processes like sedimentation tanks and reverse osmosis for water treatment.

Interbasin water transfers (IBTs), which move water from one watershed to another, have been the gray infrastructure solution of choice for addressing water stress<sup>33</sup> for approximately 12 percent of the world’s largest cities.<sup>34, 35</sup> Plans for IBTs are multiplying. India’s Interlinking of Rivers project is perhaps the most ambitious, with plans to connect 33 rivers across the country at an estimated cost of US\$168 billion.<sup>36</sup> The environmental impacts of IBTs can be marked.<sup>37</sup> Socioeconomic impacts, such as impaired livelihoods of more marginalized upstream communities or even displacement, are additional costs of serious concern.<sup>38, 39, 40</sup>



Photo: © Bridget Besaw

Water quality challenges have also been addressed through engineering solutions coupled with regulations. The progress generated throughout the developed world and many other geographies should not be understated. Investments in sanitation and access to improved water sources,<sup>41</sup> as well as reductions in point sources of pollution such as industrial discharges,<sup>42</sup> have been substantial. However, much of the world has been left behind. An estimated 90 percent of sewage and 70 percent of industrial waste in developing countries is discharged into waterways without any treatment at all.<sup>43, 44</sup>

Downstream, water treatment is essential for removing chemicals, excess sediment and nutrients, bacteria and other pollutants from drinking water. However, even the best systems cannot keep up with all pollutants.<sup>45</sup> Water treatment is expensive and energy-intensive. On average, a 100-megaliter-per-day plant using conventional treatment has an average annual operating cost of US\$1.7 million. Upgrading that plant to meet higher treatment standards could entail an approximate 30 percent increase in capital.<sup>46</sup> A new global study found that in 2010, energy for water accounted for 1.7 to 2.7 percent of total global primary energy consumption, of which 45 percent was for municipal use.<sup>47</sup> Of the total energy used for water, withdrawal from the source and conveyance used 39 percent and water purification used 27 percent.<sup>48</sup> That same study found that the Middle East, India and China have overtaken the United States as consumers of energy for water, with China's growth specifically due to industrial and municipal water use.

Wealthier nations have been able to reduce their water security risks through gray infrastructure, but less developed nations unable to afford expensive engineering solutions remain at high risk.<sup>49</sup> With a combination of growing water demand for agriculture, energy production, domestic and industrial use, and decreased water reliability due to climate change, even developed countries may find that engineering solutions alone are insufficient.<sup>50</sup> As well, water infrastructure has a limited lifespan and many systems built in the first half of the 20th century now require replacement.<sup>51, 52</sup> Developing nations will face even greater challenges as their water needs increase to support population and economic growth.

The global community will need to invest an estimated US\$10 trillion in water infrastructure between 2013 and 2030 merely to keep pace with economic growth.<sup>53</sup> This estimate does not include maintenance backlogs or infrastructure deficiencies. In 2014, the size of the global water market was about US\$591 billion.<sup>54</sup> Clearly, the costs of gray infrastructure alone, putting aside environmental and socioeconomic costs, will stretch the budgets of many countries, especially those less developed. A sustainable water infrastructure solution is not a luxury, but a necessity.

## Source watersheds as water infrastructure

Nearly 20 years after it began, the story of New York City's water system has reached innumerable people who would otherwise be unfamiliar with the concepts of source water protection and healthy watersheds. The city's water supply comes from three watersheds, 75 percent of which is forested area, and most of which is privately owned and managed. New York City invested in a working forests pollution prevention program in addition to their existing agricultural best management practices program, collaborating with landowners to reduce nonpoint source pollution at its source.<sup>55</sup> This program serves as an alternative to building a US\$8 billion to US\$10 billion treatment plant. Today, the New York City water supply remains the largest unfiltered supply in the United States, saving the city more than US\$300 million a year on water treatment operation and maintenance (O&M) costs.<sup>56</sup>

Similar utility watershed management programs have begun to proliferate across the United States, Latin America and beyond.<sup>57</sup> These are in addition to the cities, such as Oslo and Seattle, that long ago had the foresight to preserve much of their source watersheds to ensure high-quality water over the long-term. This has resulted in ongoing cost savings with the avoidance of construction and operation of complex water treatment systems.

For utilities, investing in source water protection can make economic sense. On average globally, a 10 percent reduction in sediment in source water translates to a 2.6 percent reduction in O&M costs in water treatment and a 10 percent reduction in nutrients reduces O&M costs by 2 percent.<sup>58</sup> Both sediment and nutrients can generate additional costs beyond the O&M of existing treatment facilities. High sediment loads produce more wastewater and sludge, which require treatment and transport. Build-up of sediment can ultimately require dredging of sedimentation tanks and can silt up storage infrastructure. High nutrient concentrations require frequent filter cleaning and additional treatment processes that can be extremely expensive.<sup>59</sup> Excess nutrients can also increase the risk of harmful algal blooms, which may temporarily shut down water systems and impact other water uses. There are measureable benefits of reducing these pollutants at their source.

Sustainable water security will require an integration of traditional engineering solutions with nature-based solutions such as those adopted by New York City. Nature-based solutions are, in their essence, the services that well-functioning natural systems can contribute toward solving challenges like water insecurity, climate change and human health issues related to environmental degradation. Nature-based solutions for addressing water-related problems, often referred to as "green infrastructure," can work alongside gray infrastructure. Nature-based solutions can capture, infiltrate, store and filter water for a variety of uses.

The traditional definition of water infrastructure must evolve to embrace a broader, more holistic definition of sustainable water infrastructure that includes both traditional man-made water and wastewater infrastructure and natural watershed systems.

*Bolger, Monsma and Nelson, 2009<sup>64</sup>*

Some promising initial evidence suggests that nature-based solutions can help reduce capital costs and in some cases be more cost-effective than gray infrastructure. For instance, studies of seven U.S. cities that maintain high-quality water due to protection or restoration of their source watersheds have found that the savings from avoided water treatment infrastructure costs could be up to US\$6 billion.<sup>60</sup> A rare econometric study in the developing world found that the value of virgin (unlogged) forests in upstream source watersheds in Malaysia was equivalent, on average, to more than one-third of the country's water treatment plants' aggregate expenditures on priced inputs (labor, energy, chemicals and maintenance).<sup>61</sup> In many cases, the value of green infrastructure assets increases over time—in stark contrast to gray infrastructure—and can help prolong the life of gray infrastructure.<sup>62</sup>

However, despite the opportunity, there are real challenges to implementing nature-based solutions at the scale needed to address water security.<sup>63</sup> These include:

- changing the way water institutions think and operate
- gaps in our knowledge and understanding of the implementation and full range of benefits of nature-based solutions
- the infancy of comparable cost calculations between natural-based solutions and gray infrastructure
- high transaction costs
- the length of time it takes some nature-based solutions to demonstrate their full benefits

We have seen progress in all these challenge areas, as more organizations and institutions incorporate nature-based solutions into their portfolio of solutions and more cases are available for filling knowledge gaps and undertaking cost-benefit analyses.

Nature-based solutions cannot address all water quality problems, and continued progress on improving sanitation, providing universal access to improved water sources and reducing point sources of toxics and other contaminants will be critical. Even if water supply is derived from a protected, pristine watershed, gray infrastructure is necessary to convey that water to users. Meeting the water security challenges for our growing world most cost-effectively will require an integrated combination of nature-based and gray solutions. The most appropriate portfolio of strategies will vary depending on local conditions, but nature-based solutions should be considered alongside conventional gray infrastructure and natural assets should be given their due when valuing all water security assets.

## Mapping source watershed areas for 4,000 cities

We can begin to understand the breadth of opportunities linked to source water protection by analyzing them through the lens of watersheds supplying water to the world's largest cities. For this report, we developed a new map of existing and possible source watershed areas for cities with a population of 100,000 or greater (see Appendices II and V for more information).

Previous efforts by The Nature Conservancy collected data on explicit withdrawal points for more than 500 cities.<sup>65, 66</sup> That foundational work also identified the degree to which cities depend on groundwater and other water sources and identified cities obtaining all or some of their water through IBTs.

To develop a more globally comprehensive map of potential source watershed areas, we modeled surface water sources for more than 3,500 additional cities not already included within our data set. This approach assumes cities generally draw water from the largest river nearby and that larger cities have more capacity to reach further out. Due to lack of data regarding which cities obtain a significant fraction of their water from groundwater and other sources besides surface water supply, the method assumes that all cities have some dependency on surface water sources. Three in every four cities previously assessed get a majority of their supply from surface sources, indicating that surface sources dominate the global water supply landscape. All identified source watersheds were treated equally in our analysis, regardless of the amount of water they may supply to a given city or the number of downstream beneficiaries.

For the purposes of our analyses, we restricted our map to those source watersheds where conservation activities on the landscape are most likely to result in, at a minimum, modest improvements in water quality outcomes. Building from previous modeling efforts, we include those watersheds that can achieve at least a 5 percent reduction in either sediment or nutrients through representative types of conservation activities: forest protection, pastureland reforestation and the agricultural best management practice of cover crops.<sup>67</sup> Due to limitations of global data coverage, particularly for far northern and southern latitudes, some watersheds have been further excluded (parts of Russia and Alaska, for example).

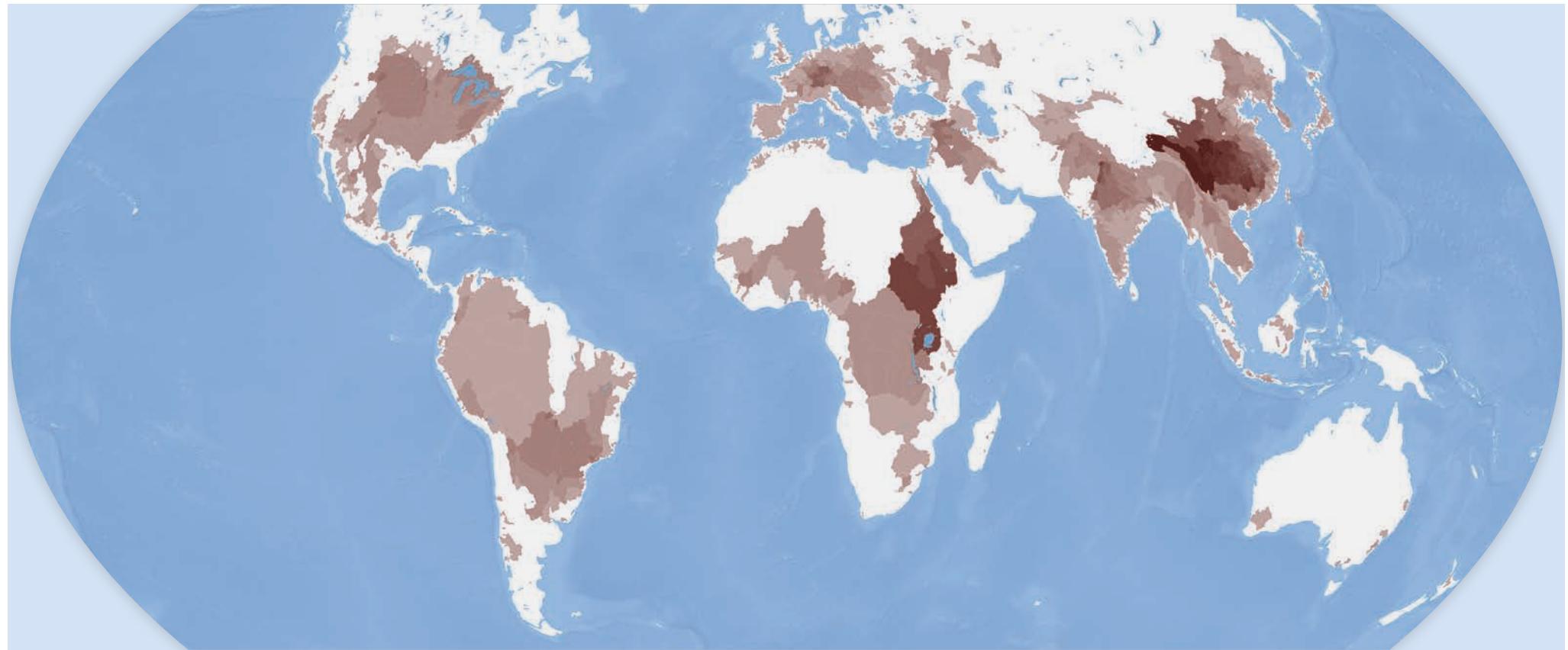
The resulting map (Figure 1.3) represents a global view of the urban source watershed areas likely to play a role in water security for the world's cities. This map is used for all subsequent analyses in this report, making connections between opportunities for urban water security and other benefits. For most analyses where the input data are at adequately high levels of resolution, we visualize the results using sub-watersheds derived from the HydroBASINS dataset.<sup>68</sup> The larger dataset of source watersheds covers more than 37 percent of the surface of the world's ice-free terrestrial surface (4.8 billion hectares) and may provide drinking water for up to 1.7 billion people living in cities—over half of the world's urban population.<sup>69</sup>

Impact on downstream water quality and quantity varies within and between watersheds, but this map nonetheless represents an immense area of influence. Importantly, in many cases watershed areas overlap for several water users. Such areas indicate strategic leverage points where multiple cities and other users can pool resources to support investments in source water protection. These areas of overlap are also indicative of potential hotspots where source water protection activities might be most important.



Photo: © Scott Warren

## Current and potential urban source watersheds



**Figure 1.3.** Watershed areas that currently or could potentially provide surface water supply to cities with populations greater than 100,000 people. Darker colors indicate overlapping watershed areas, where multiple withdrawal points collect surface runoff from the same upstream land areas. (Source: The Nature Conservancy)

**Source watershed areas by percent overlap**



Source watersheds for the world's cities cover more than 37 percent of the world's ice-free land.

## Groundwater resources and above-ground impacts

Until recently, in many places around the world, surface water and groundwater were managed as separate resources. Scientific advances and increasing awareness around the importance of groundwater are changing that paradigm. As a result, freshwater regulators have come to understand that surface and groundwater systems are connected in ways that require integrated management.<sup>70</sup>

Groundwater depletion can affect surface water systems by reducing groundwater contributions to streamflow, thus impacting ecosystems that rely on groundwater during periods with limited rainfall.<sup>71</sup> The same land-use activities that can impair surface waters can also affect groundwater systems, albeit often over longer time scales. By extension, source water protection activities have the potential to maintain or improve groundwater resources, though the results of remediation may be slower to manifest than with surface waters. Activities focused on groundwater can be pinpointed at aquifer recharge zones or other areas of the landscape identified for their vulnerability, to the extent that these are known.

Overall, our knowledge of groundwater—where it is and in what amounts and how its quality and quantity may change over time—is exceedingly poor with estimates of aquifer storage over time varying by orders of magnitude.<sup>72,73</sup> This is concerning, considering that an estimated 1.5 to 3 billion people rely on it as their primary freshwater source<sup>74</sup> without knowing when it may become unusable from, for instance, poor water quality or from the water table dropping to inaccessible depths.<sup>75</sup> We do know that more than half of the world's largest aquifers are already in decline, half of which have negligible natural replenishment.<sup>76</sup>

These information gaps are even more worrisome when we consider how essential groundwater is to the global economy. In addition to providing an estimated 36 percent of all household water supply, it supplies 43 percent of water used for irrigated agriculture and 24 percent of the water supply for manufacturing.<sup>77</sup> Not surprisingly given global population growth, total groundwater abstraction has increased tenfold since 1950, largely to supply expansions in irrigated agriculture.<sup>78</sup>

There is an expectation that groundwater use will accelerate further as climate change reduces the reliability of surface water flows, especially during times of drought<sup>79</sup> when we tend to have an increased reliance on groundwater.<sup>80</sup> At the same time, groundwater systems will be impacted by climate change. Where precipitation is predicted to decline, groundwater recharge may decrease accordingly, and the hardest hit areas may include those already suffering from water stress.<sup>81</sup> As well, for some coastal cities, there is the real risk of groundwater salinization due to sea level rise.<sup>82</sup> Meanwhile, land-use changes affecting surface waters will not spare connected groundwater systems.

## The way forward

This report sets out the case for protecting water at its source as an opportunity to deliver water security for cities. In the process of delivering water security, the protection of source watersheds will also deliver on a number of other related goals that make them integral to the broader sustainable development agenda. The challenge in operationalizing this idea resides in overcoming a number of institutional and practical challenges.

In the next chapters of this report, we will articulate the case for source water protection, as well as the means by which we believe those challenges can be overcome. We focus on four benefit areas in addition to water security, where source water protection can make meaningful contributions: biodiversity conservation, climate change mitigation, building resilience to climate change through adaptation, and human health and well-being. We will introduce the water fund, a structure that The Nature Conservancy and others are increasingly using to deliver source water protection. A water fund, at its core, is an innovative governance and financing mechanism that unites stakeholders in a permanent instrument created for urban source water protection, through sharing economic benefits with upstream communities. We investigate how source water protection, through its generation of multiple benefits, can increase the return on investment for protection activities. Additionally, we explore how optimizing across those benefits can create cost savings. We conclude with an examination of what will be required to take water funds to scale globally so that these many benefits can be realized.

## LOCAL SPOTLIGHT

### Edwards Aquifer, San Antonio, Texas, United States—Protecting groundwater



**Left.** Officials release a benign "tracer dye" into Edwards Aquifer drainage systems to chart flows and track the underground water pathways. **Right.** Hydrogeologist descends into a sinkhole to check on the Edwards Aquifer.

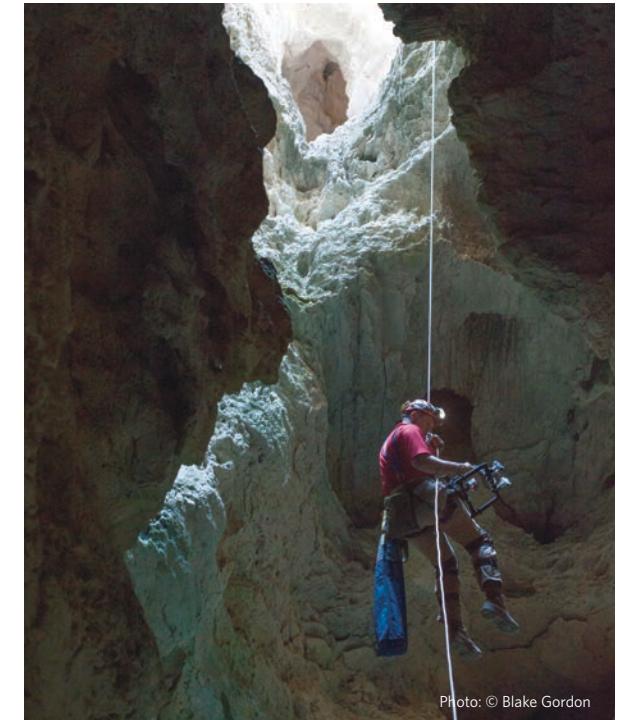
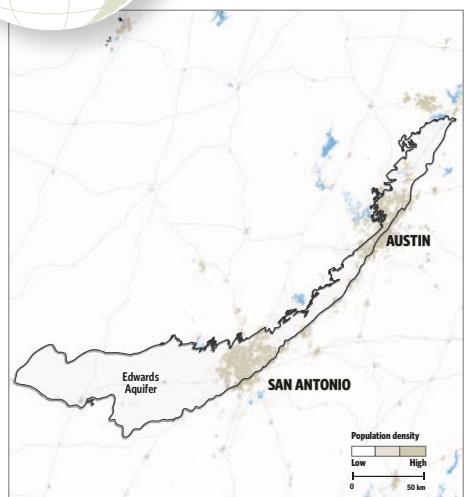


Photo: © Blake Gordon



#### The challenge

As one of the largest, most prolific artesian aquifers in the world, the Edwards Aquifer serves as the primary source of drinking water for nearly 2 million central Texans, including every resident of San Antonio—the second largest city in Texas—and much of the surrounding Hill Country. Its waters feed springs, rivers and lakes and sustain diverse plant and animal life, including rare and endangered species. The aquifer supports agricultural, industrial and recreational activities that not only sustain the Texas economy, but also contribute immeasurably to the culture and heritage of the Lone Star State.

The aquifer stretches beneath 12 Texas counties, and the land above it includes several important hydrological areas. Two areas in particular—the drainage area and the recharge zone—replenish the aquifer by "catching" rainwater, which then seeps through fissures, cracks and sinkholes into the porous limestone that dominates the region. While this natural filtration system helps refill the aquifer with high-quality water, the growing city of San Antonio is expanding into territories of the very sensitive recharge zone, increasing the risk of contamination. In addition to a rising population, the state's water supplies have been impacted by multi-year droughts. By 2060, Texas is projected to be home to approximately 50 million people while the annual available water resources are estimated to decrease by nearly 10 percent.<sup>83</sup>

**Note:** Population data used for all local spotlight locator maps throughout the report are derived from Gridded Population of the World, Version 4 (GPWv4), NASA SEDAC, CIESIN, Columbia University, 2016 and WorldPop data (<http://www.worldpop.org.uk/>), accessed 30 Oct 2016 through Creative Commons Attribution 4.0 International License.



## Action and opportunity

With careful land management, there is the potential to avoid additional degrading impacts to the aquifer and reduce the need to expand water treatment for San Antonio. Being wholly dependent on an aquifer for drinking water, San Antonio has long understood the importance of its protection.<sup>84</sup> In 2000, voters approved the city's first publicly-financed water fund measure to protect the Edwards Aquifer. The proposition passed with enthusiastic support and authorized US\$45 million to purchase properties within the aquifer's most sensitive area. San Antonians have since voted three more times not only to continue the program, but to greatly expand it. The ensuing Edwards Aquifer Protection Program raised a total of US\$315 million to protect the Edwards Aquifer in Bexar County, where San Antonio lies, and throughout much of the surrounding regions.

Since 2000, The Nature Conservancy has worked alongside city officials in San Antonio and surrounding communities to ensure these water funds have the greatest impact. To date, the efforts have helped local governments invest more than US\$500 million dollars in water protection funds and protect more than 48,562 hectares above the Edwards Aquifer. That area includes 21 percent of the aquifer's recharge zone, its most sensitive area.

Source water protection efforts are expected to produce measurable water quality improvements, reducing risks to this critical drinking water supply. Model simulations indicate that landscape protection efforts may have already resulted in the avoidance of bacteria concentration increases of up to 23 percent, on average, in the streams draining into the recharge zone. Additionally, experts anticipate reductions in nitrogen, phosphorus, lead and zinc levels.

## SAN ANTONIO DASHBOARD

Water fund start date	Number of upstream participants to date	Number of potential downstream beneficiaries	Number of partners to date	Primary funding sources	Activities	Anticipated co-benefits
2000	N/A	Between 1,000,000 and 5,000,000	7	Public (User-approved sales tax)		



Photo: © Ami Vitale

## CHAPTER TWO INSIGHTS

The natural and working lands around our water sources serve as vital water infrastructure that can improve water quality and quantity for cities around the world.

- Four of five cities (81 percent) can reduce sediment and nutrient pollution by a meaningful amount (at least 10 percent) through forest protection, pastureland reforestation and/or the agricultural best management practice of cover crops.
- Globally, 32 percent of the world's river basins experience seasonal, annual or dry-year water depletion. Source water protection activities could help improve infiltration and increase critical base flows in streams. This will be especially important for the 26 percent of urban source watershed areas that are expected to receive less annual precipitation in the coming years, and for the many more that may experience seasonal water shortages.

# Chapter 2

## Protecting Natural Infrastructure at its Source

### Water sources face growing threats

Assessing the state of natural infrastructure for water supply requires a landscape perspective. The quality and timing of water flowing across a watershed varies in response to natural landscape conditions—climate, topography, natural vegetation, soil types, geology and other biophysical factors. These factors determine the types and degrees of water security services provided by nature. For example, rich soil laden with layers of organic plant matter in the high altitude páramo grasslands of the Northern Andes can act as a natural “sponge,” storing water for sustained release during the dry season.<sup>85, 86</sup>

Human development has a profound capacity to significantly alter these natural conditions, often negatively impacting the water security benefits derived from these landscapes. Every source watershed will have its own signature in terms of human land-use activities—their type, extent and intensity. Global analyses can provide broad pictures of the current state of these source watersheds and linked impacts in our focal categories of biodiversity, climate change mitigation, building resilience to climate change through adaptation, and human health and well-being. A global perspective can illustrate the scope and scale of challenges and opportunities, ultimately helping to provide a roadmap for how to make smarter investments toward ensuring water security.

For a relatively holistic picture of the potential impact of land-use activities on water security, we use a new measure of human modification that looks at both extent and intensity of human activities.<sup>87</sup> The measure presents an aggregate view of many of the dominant drivers of water quality and quantity outcomes: urban and agricultural expansion, oil and gas, coal, solar, wind, biofuels and mining development. Such development activities can have far-reaching impacts on water security. Agriculture alone is the largest consumer of water supplies around the world and the biggest nonpoint source contributor to nitrogen pollution in the world’s coastal marine ecosystems.<sup>88, 89</sup>

We find that 19 percent of the area within source watersheds experienced a high level of modification and an additional 21 percent experienced a moderate level (Figure 2.1, Table 2.1). As we might expect from its long history of intensive development, Europe accounts for much of the world’s impacted landscapes where

more than 46 percent of land has been highly modified. The area encompassed by source watersheds in Asia has also been impacted by human development where almost one-third of the entire area has been highly modified, including hotspots in South Asia and China.

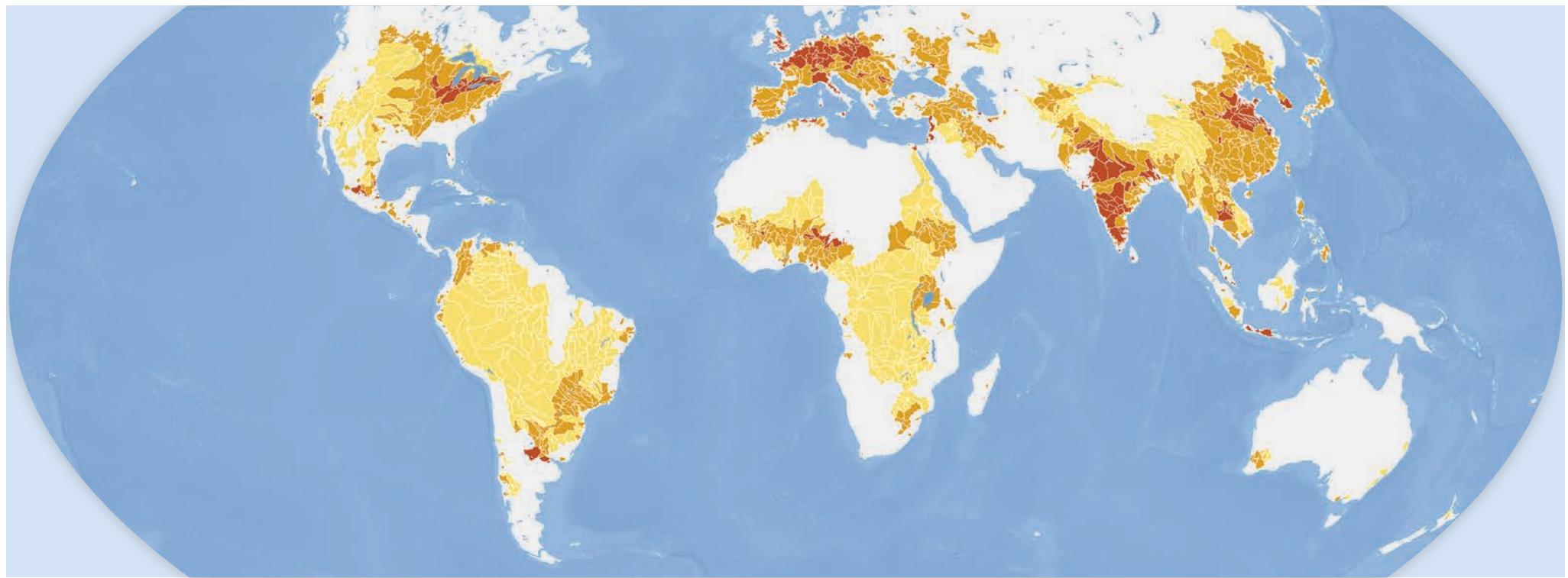
Taken as a whole, the results point to different archetypal landscapes where source water protection activities are particularly relevant. At a broad scale, the results suggest that for more than half of the area in source watersheds, activities focused on land protection and smart development could help maintain landscape integrity for water security and other benefits. For one-quarter of the area in source watersheds, source water protection activities would necessitate approaches that influence practices on working landscapes, such as improved fertilizer and livestock management. Nature-based solutions have broad application across these areas, mitigating future development risk and restoring important ecosystem services.

What the aggregate measure does not highlight, however, are which components of water security might be most threatened by development—or, conversely, which might benefit most from source water protection efforts. The following subsections explore some of the biggest threats to water quality and quantity that could be mitigated at least in part through source water protection.



Photo credit: © Bridget Besaw

## Human impact on the landscape integrity of urban source watersheds



**Figure 2.1.** Average level of human modification on the landscape, by Level 5 HydroBASIN. This analysis uses a new measure of Human Modification (HM) that evaluates 13 types of human impact and intensity. Thresholds for low, medium and high modification were created at equal break points along the range of normalized HM values. (Source data: Oakleaf, 2016<sup>90</sup>)

Average Human Modification value per HydroBASIN

- Low
- Medium
- High

### Levels of human modification across urban source watersheds

GEOGRAPHIC REGION	Low Modification (percent)	Medium Modification (percent)	High Modification (percent)
Europe	20.7	32.7	46.6
Asia	40.6	28.3	31.1
North America	50.9	28.8	20.3
Africa	73.0	16.6	10.4
Latin America and the Caribbean	83.2	11.4	5.4
Oceania	56.5	38.9	4.6
<b>GLOBAL</b>	<b>59.9</b>	<b>21.3</b>	<b>18.8</b>

**Table 2.1.** Levels of human modification across urban source watersheds by region based on a new measure of Human Modification (HM) (Oakleaf 2016<sup>91</sup>)

## Water quality threats

Water pollution sources can be broadly separated into two types: point and nonpoint sources. Point sources derive from discrete discharge points such as pipes and ditches.<sup>92</sup> Although many countries have implemented strong regulations to curb point sources of pollution, with huge progress coming in the last several decades, discharges from manufacturing waste, untreated sewage and other point sources still plague many of the world's waterways.<sup>93, 94, 95</sup> For example, in China, many freshwater bodies are too toxic for swimming, fishing and other human contact uses, and in some cases have been linked to increased cancer rates.<sup>96</sup> In many cases, sound policies and regulation, as well as adequate built infrastructure, are the most viable solutions for addressing point source pollution.<sup>97</sup>

In contrast to point sources, nonpoint pollution often has no discernable discharge point. The sources of pollution are diffuse, spread across large areas and can originate from a large number of contributors.<sup>98</sup> Unlike point source pollution, nonpoint source pollution remains a challenge everywhere around the world.<sup>99, 100</sup> From North America to Southeast Asia, water flowing across modified landscapes can bring changes in water quality that challenge the ability to ensure sufficient and sustainable access to clean water.

Nonpoint pollution includes a wide array of pollutant types: from naturally derived substances such as sediment to manufactured agrochemicals such as organic pesticides. Two pollutants have particular relevance for urban source water protection: sediment and nutrients. Both occur naturally, but elevated levels contribute to higher operating costs for water treatment facilities, sometimes necessitating additional and more complicated treatment technology.<sup>101</sup> For instance, increased sediment can necessitate greater use of chemicals, thus increasing treatment costs. In extreme cases, such as conditions following intense rains in areas with high sediment loadings or catastrophic wildfires, increased sediment in streams can compel the use of alternative water sources with immediate implications for water security. Sediment impacts can extend all the way to the ocean, affecting coral reef communities and other marine life.<sup>102, 103</sup>

Excess nutrients—primarily phosphorus and nitrogen—also pose challenges for urban water supply. Nitrogen in some forms is toxic at high concentrations and is widely regulated. Many freshwater systems are phosphorus-limited, so adding phosphorus to lakes and other slow-moving water bodies can eventually lead to algal blooms, which have many direct and indirect effects on the costs of water treatment.<sup>104</sup>

In altered landscapes, the loading of sediment and nutrients to the hydrologic system increases via several pathways. As vegetation is removed, soil is exposed and experiences a higher risk of erosion. As it rains, water picks up this soil and carries it downstream to lakes and streams, increasing the turbidity of the

waterways. Significant triggers for soil erosion include deforestation, land clearing for agriculture and poor agricultural practices, poor construction methods and extensive fire. Steep slopes pose a greater threat for soil erosion, and in some cases for related landslides. Along the edges of waterways, the removal of riparian vegetation plays a key role in increasing streambank erosion, which can provide a large source of excess sediment.

Nutrients and other nonpoint source pollutants are transported into waterways via runoff generated from precipitation events. Vegetation growing along flow paths can capture these pollutants and reduce the load reaching lakes and streams, but this natural filtration service loses effectiveness as vegetation is removed. Agriculture is the largest contributor of nonpoint source loadings of nutrients on the landscape, as fertilizer is applied to crops to increase productivity. Nutrients also originate in urban and suburban areas due to application of lawn fertilizers, animal waste and other sources. Deposition of air pollution can also contribute nutrients on the landscape, although this source is most often considerably less than that from agricultural fertilizer application.

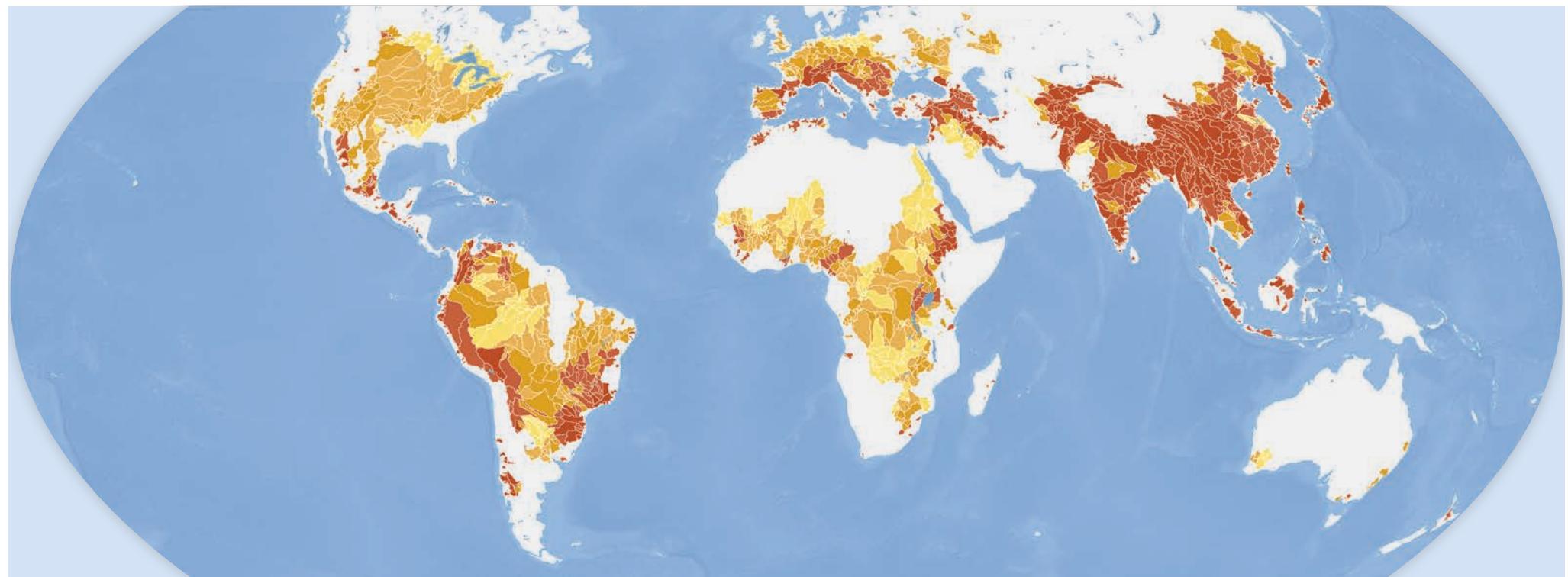
Building from prior efforts, we assess nonpoint sediment and phosphorus levels within urban source watersheds. In practice, phosphorus and nitrogen loading are highly spatially correlated at large scales and the phosphorus results presented here are indicative of similar global spatial patterns for nitrogen loading.

Comparing across regions (Figure 2.2, Table 2.2), areas of higher and lower sediment loading are broadly distributed, aside from in Asia where sediment loading is almost uniformly high. More than 60 percent of the area encompassed by source watersheds in Asia are at risk of high erosion levels. Areas of high sediment loading are in part reflective of human development intensity, but also result from biophysical conditions such as rainfall patterns, topography and slope. Considering the implications for source water protection and water security, we see that sediment pollution spans a range of landscape types and has broad global relevancy.

Unsurprisingly, the distribution of nutrient loading (Figure 2.3, Table 2.3) highlights those areas of the world with the greatest agricultural productivity and widespread use of fertilizers, including North America, Asia and Europe where high nutrient loading areas account for more than 40 percent of the area within source watersheds. Africa, with much lower fertilizer application rates, has fewer areas with elevated nutrient loading.

While loading values are not wholly predictive of actual water quality conditions or impairment—only a fraction of the sediment or nutrient load actually reaches a given water withdrawal point—these maps do provide spatial context for understanding the potential threat of nonpoint pollution for urban water sources. Understanding the spatial variability of both sources and impacts is essential to formulating solutions to address these challenges.

## Estimated sediment loading in urban source watersheds



**Figure 2.2.** Estimated sediment loading per hectare by Level 5 HydroBASIN. These estimates represent potential sediment loads, where the actual sediment contribution to streams will vary based on watershed hydrology. Data are shown by quintiles where the first quintile represents areas with the lowest estimated sediment loading. (Source data: McDonald and Shemie, 2014<sup>105</sup>)

### Sediment load per hectare

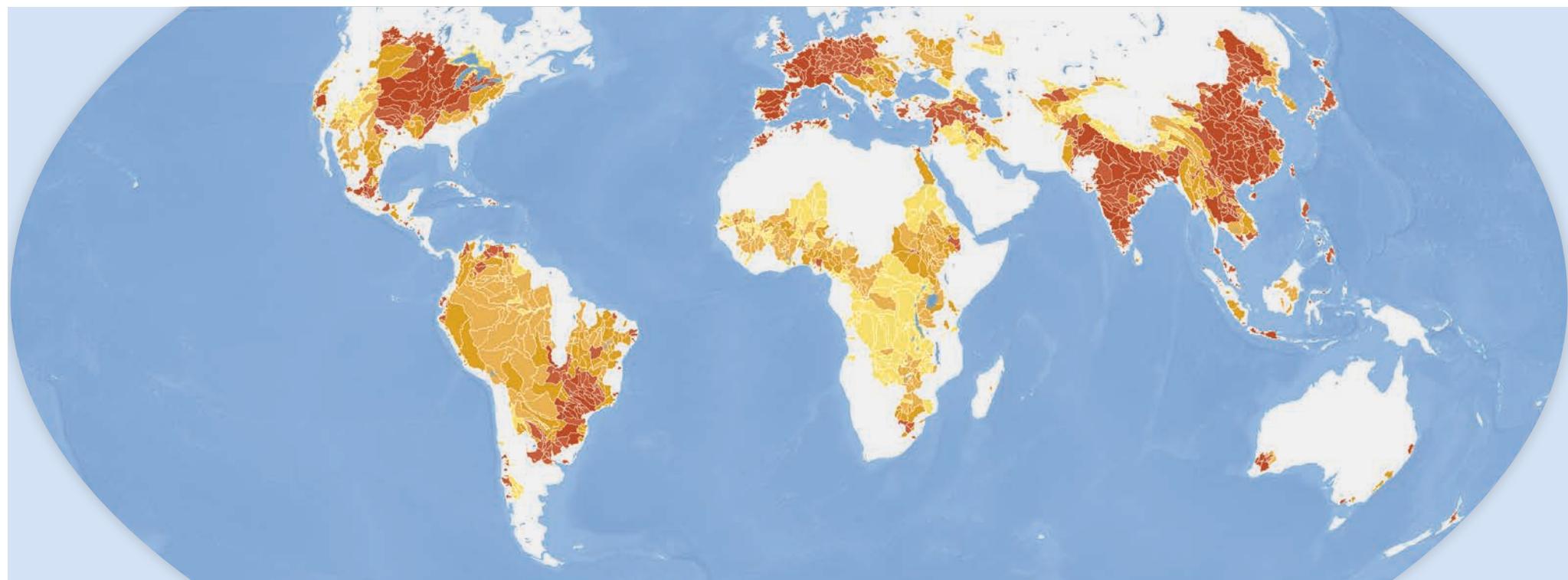
- 1st quintile
- 2nd quintile
- 3rd quintile
- 4th quintile
- 5th quintile

### Sediment loading in urban source watersheds by region

GEOGRAPHIC REGION	Low Pollution (percent)	Medium Pollution (percent)	High Pollution (percent)
Africa	46.7	49.7	3.6
Asia	5.5	30.6	63.9
Europe	11.2	71.8	17.0
Latin America	15.8	66.2	18.0
North America	28.8	71.2	0.0
Oceania	49.2	50.6	0.2

**Table 2.2.** Proportion of area within urban source watersheds by region within low, medium and high sediment loading categories. Low, medium and high categories correspond to the lowest 25 percent, 25-75 percent and the highest 25 percent of the estimated sediment loading, respectively. (Source data: McDonald and Shemie, 2014<sup>106</sup>)

## Estimated excess nutrient loading in urban source watersheds



**Figure 2.3.** Estimated excess phosphorus per hectare by Level 5 HydroBASIN. These estimates represent only the exported fraction of phosphorus from land-based nonpoint sources such as fertilizer application on agricultural land. These estimates represent potential phosphorus loads, where the actual phosphorus contribution to streams will vary based on watershed hydrology. Data are shown by quintiles where the first quintile represents areas with the lowest estimated phosphorus loading. (Source data: McDonald and Shemie, 2014<sup>107</sup>)

### Phosphorus load per hectare

- 1st quintile
- 2nd quintile
- 3rd quintile
- 4th quintile
- 5th quintile

### Excess nutrient loading in urban source watersheds by region

GEOGRAPHIC REGION	Low Modification (percent)	Medium Modification (percent)	High Modification (percent)
Africa	56.8	42.3	0.9
Asia	15.4	36.3	48.3
Europe	4.4	55.6	40.0
Latin America	29.0	62.2	8.8
North America	13.2	46.5	40.3
Oceania	6.4	43.0	50.6

**Table 2.3.** Proportion of the area within urban source watersheds by region within low, medium and high phosphorus loading categories. Low, medium and high categories correspond to the lowest 25 percent, 25-75 percent and the highest 25 percent of the estimated nutrient loading, respectively. (Source data: McDonald and Shemie, 2014<sup>108</sup>)

## Water quantity threats

The primary driver of source water protection efforts has been water quality concerns, but reducing water quantity risks is emerging as an important secondary—and in some cases even primary—benefit.

At a global level, more than 50 percent of the world's cities and 75 percent of all irrigated farms are experiencing water shortages on a recurring basis.<sup>109</sup> Today, more than 90 percent of water consumed in water-scarce regions goes to irrigated agriculture. A major nexus of this problem concerns food security and the importance of protecting the social fabrics of rural communities while co-designing and implementing water scarcity solutions alongside these communities.

Water scarcity is a consequence of allowing too much water to be consumed relative to the renewable supply of water derived from rain and snow.<sup>110</sup> Many hydrologic models quantify water scarcity at the global scale. One of these, WaterGAP3,<sup>111</sup> allows for differentiation between chronic depletion and episodic depletion. A basin is categorized as chronically depleted when more than 75 percent of the renewable

water replenishment is consumptively used on either an annual or seasonal basis. A basin categorized as episodically depleted occurs when the consumptive use exceeds 75 percent of the renewable replenishment only during drier years or droughts. To put this into perspective, approximately 1,700 basins (or 11 percent) globally are categorized as chronically depleted and 3,100 (or 21 percent) additional basins are episodically depleted.

Source watersheds experiencing chronic or episodic depletion can impair the water security of cities and upstream communities, with additional ramifications for ecosystems and wildlife. Droughts challenge the capacity to fulfill water demand, requiring many cities to adapt or invest in alternative sources.<sup>112</sup> Even seasonal depletion during part of the year can affect the ability of cities to provide sufficient supply for urban use, with additional risks in cases where electricity generation coincides with source watershed depletion.<sup>113</sup>

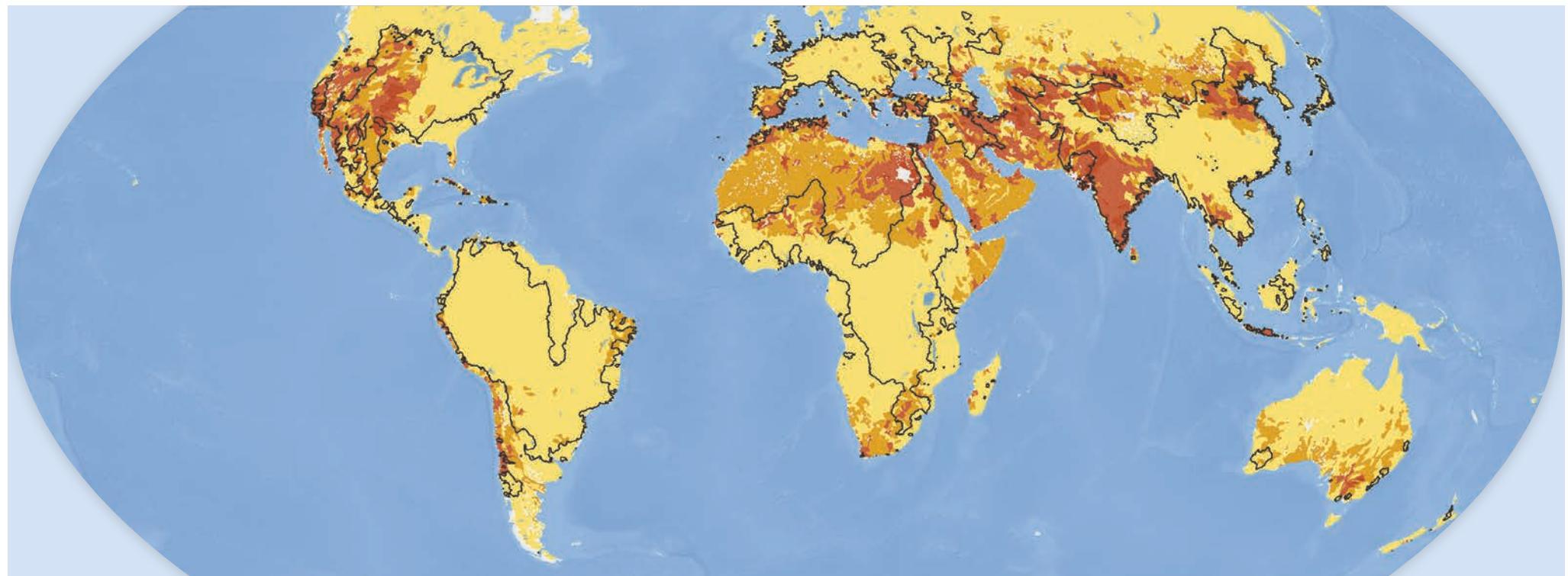
Looking across the modeled basins that intersect potential urban source watersheds, we find that more than one-quarter (27 percent) of source watershed areas experience chronic or episodic depletion (Figure 2.4). High annual depletion (greater than 75

percent annual depletion on average) is not widespread across source watershed areas, but—given the potentially detrimental implications—is an important risk facing cities in North America and Asia (see Appendix III for results by region). Seasonal depletion (where average monthly depletion exceeds 75 percent for at least one month) is more broadly significant for water supply, affecting 11 percent of source watershed areas globally. Episodic dry-year depletion is also notable across basins within source watershed areas, impacting more than one-fifth of the area in North America and a similar proportion of source watershed areas globally.



Photo credit: © Nick Hall

## Water depletion in urban source watersheds



**Figure 2.4.** Water depletion categories for modeled WaterGAP3 basins intersecting urban source watersheds. Water depletion is defined as the ratio of consumptive use to water availability. Basins are annually depleted when average annual depletion is 75 percent or greater. A basin is seasonally depleted when monthly depletion exceeds 75 percent for one or more months per year on average. Dry-year depletion is defined as the occurrence of monthly depletion greater than 75 percent for at least 10 percent of years within the model period (1971–2000). Basins are categorized exclusively, such that a given basin is assigned the highest risk category (in order of precedence following annual, seasonal and then dry-year depletion). Urban source watersheds are outlined in black. (Source data: Brauman et al., 2016<sup>114</sup>)

### Water depletion category

- < 5%
- 5-25%
- Dry-year
- Seasonal
- > 75%

The results imply that source watersheds are broadly—but not uniformly—impacted by heavy water use, with implications for both upstream communities and downstream cities alike. This water scarcity is likely to be exacerbated by increasing food production, growing urban populations and predicted climate change impacts, including increasing temperatures and changes in precipitation patterns (see Chapter 3).<sup>115, 116</sup> Potential solutions must address the different types and varying intensities of predicted water depletion, including strategies that minimize the need for costly investments in procuring new water sources.

Natural ecosystems such as forests, grasslands and wetlands provide a natural regulating function for the hydrologic cycle, from reducing the impact of heavy rainfall on soil erosion to aiding with infiltration of water into soil, regulating high

peaks and base flows. In general, the science is reasonably clear about the benefits of natural land cover for downstream flows, and about the negative impacts of deforestation and land cover conversion in general. For instance, a global-scale meta-analysis has demonstrated that deforestation changes forest hydrology and amplifies flood risks and severity in developing countries.<sup>117</sup> This conclusion agrees with the conventional view that forests support natural flow regimes,<sup>118</sup> including regulating base flow, and can increase net water yield.<sup>119, 120, 121</sup> However, the underlying relationships among forest, land use and land cover (LULC) and hydrologic outcomes are complex, and scientists argue that the factors of soil and surface degradation in forest hydrological change are largely missing from many discussions.<sup>122, 123</sup> In other words, the condition of soils under the plants growing in them may be as important to downstream hydrology as are the plants themselves.



Largely because hydrologic outcomes from changes in land use in a given place are so dependent on local conditions, there remains some debate within environmental and development communities about the potential for reforestation or afforestation to address water scarcity and, at the other end of the quantity spectrum, reduce catastrophic flooding.<sup>124</sup> Reforestation or afforestation in degraded watersheds are often adopted as solutions to restore retention capacity and base flows, and reduce peak flows and stormflows. However, the results are variable and often affected both by biophysical conditions<sup>125, 126, 127, 128</sup> and by factors like poor management, inadequate data or a lack of scientific understanding.<sup>129</sup> Nonetheless, reforestation and soil conservation measures have documented benefits in terms of reducing peak flows and stormflows associated with soil degradation.<sup>130, 131</sup>

Protecting undisturbed forests and other areas of natural land cover will be an effective contribution toward maintaining base flows and reducing downstream overland runoff.<sup>132, 133</sup> A fruitful area of further research will look at the hydrological

dynamics of secondary forests, agroforestry, degraded lands and their restoration. Source water protection efforts offer an opportunity for well-designed monitoring programs to produce useful evidence.

## Source water protection is land stewardship

In essence, source water protection is about land stewardship—a core part of many traditional cultures and a growing priority worldwide. Typical source water protection activities can be grouped into eight categories (Table 2.4). Additional activities, like floodplain or coastal protection and restoration, are common nature-based solutions in projects focused less on drinking water and more on other ecosystem service benefits like flood risk reduction, though in some cases they can also help mitigate excess nutrients. Activities are not exclusive of each other, and many source water protection projects will employ more than one.

Source water protection activity	Description
	<p><b>Targeted land protection</b> is a term that broadly encompasses all of the conservation activities undertaken to protect targeted ecosystems, such as forests, grasslands or wetlands. Agroforests—where trees or shrubs are grown among crops or pastureland—may also be the focus of protection.</p> <p>Targeted land protection is typically undertaken as a preventative measure that reduces the risk of adverse environmental impacts in the future, such as through increased sediment or nutrient loadings that may result from changing land uses. Accordingly, these types of conservation activities differ from those that are focused on reducing the current loading of pollutants.</p>
	<p><b>Revegetation</b> involves the restoration of natural forest, grassland or other habitat through planting (direct seeding) or by enabling natural regeneration; includes pastureland reforestation (active or passive forest restoration on grazing lands).</p> <p>Revegetation restores the ability of nature to: 1) hold soil in place and reduce erosion, 2) naturally filter pollutants from overland flow and 3) help infiltrate runoff water into the soil.</p>
	<p><b>Riparian restoration</b> involves restoring natural habitat that is at the interface between land and water along the banks of a river, stream or lake. These strips are sometimes referred to as riparian buffers.</p> <p>Riparian zones comprise the area where land and a river, stream or lake interface. Riparian restoration seeks to reestablish riparian functions and related physical, chemical and biological linkages between terrestrial and aquatic ecosystems.<sup>134</sup> The key features of healthy riparian areas are native trees with deep, soil-binding roots. Grass and shrubs are also important ground covers and bio-filters. Riparian buffers are especially important as they are the last defense against pollutants flowing into streams. They can provide critical habitat at the water's edge, and through shading, they can help reduce water temperatures. Temperature regulation has important implications for the ability of water to maintain adequate levels of dissolved oxygen, can be critical for the survival of aquatic species and is linked to reduced incidence of algal blooms.<sup>135</sup></p>
	<p><b>Agricultural best management practices (BMPs)</b> are changes in agricultural land management that can be channeled toward achieving multiple positive environmental outcomes.</p> <p>A wide variety of agricultural BMPs exist, including practices such as cover crops, conservation tillage, precision fertilizer application, irrigation efficiency, contour farming and agroforestry. In the context of existing water funds, agricultural BMPs are primarily in reference to modifying land management practices on croplands, specifically those focused on reducing erosion and nutrient runoff. These practices can help protect drinking supplies, as well as help to protect other uses such as recreation, animal habitat, fisheries and agricultural uses such as irrigation and stock watering.</p>
	<p><b>Ranching best management practices (BMPs)</b> are changes in land management practices on ranchlands that can be channeled toward achieving multiple positive environmental outcomes. Silvopasture is the practice of combining trees with forage pasture and livestock.</p> <p>Ranching BMPs are normally implemented to maintain or improve the quality of water and soils through the improvement of grazing management practices, range structures (e.g., access roads, fencing, grade stabilization), or land treatments (e.g., brush management, range seeding, edge of field treatments). These types of improvements typically seek to reduce sediment and nutrient loadings (e.g., phosphorus, nitrogen), as well as potentially harmful pathogens from livestock waste.</p>
	<p><b>Fire risk management</b> involves the deployment of management activities that reduce forest fuels and thereby reduce the risk of catastrophic fire. Also commonly referred to as "forest fuel reduction," fire risk management seeks to achieve fuel reduction goals through mechanical thinning and/or controlled burns.</p> <p>Fire risk management is typically employed in areas where forests are prone to catastrophic wildfires. The abrupt removal of forest cover and damage to ground cover and soils from catastrophic fires can be particularly problematic when the fire is followed by a large rainstorm, as these events can cause large-scale erosion of unsecured hillsides. Accordingly, similar to targeted land protection, fire risk management seeks both to preserve the integrity of healthy forests and reduce the future risk of increased sediment and nutrient transport, which differs from other activities that are aiming to reduce current annual loadings of pollutants.</p>
	<p><b>Wetland restoration and creation</b> involves the re-establishment of the hydrology, plants and soils of former or degraded wetlands that have been drained, farmed or otherwise modified, or the installation of a new wetland to offset wetland losses or mimic natural wetland functions.</p> <p>Wetlands are areas where water covers soil all or part of the time. Wetlands protect and improve water quality, provide fish and wildlife habitat, store floodwaters and maintain surface water flow during dry periods. Accordingly, the holistic nature of wetland restoration, including the reintroduction of animals, is important. Typically, a wetland is created through the excavation of upland soils to elevations that will support the growth of wetland species through the establishment of an appropriate hydrology. Wetlands may be installed or restored via this or other approaches such as removing underground drainage tiles, installing dikes or plugging open ditches.</p>
	<p><b>Road management</b> involves the deployment of a range of avoidance and mitigation techniques that aim to reduce the environmental impacts of roads, including those impacts related to negative effects on soils, water, species and habitats.</p> <p>The environmental effects of roads include displaced and compacted soils; altered conditions that change soil pH, plant growth and the vegetative community structure; reconfigured landforms that can result in changed hydrologic regimes; and/or increased number and extent of landslides and debris flows, which can affect terrestrial and aquatic systems. Mitigation techniques for managing roads may include site-level actions to reduce erosion and improve road-stream crossings, or implementing access management and closing and decommissioning roads.</p>

**Table 2.4.** Categories of common source water protection activities.

## The potential for reducing sediment and nutrient pollution

At the global scale, there is no singular mechanism for assessing the potential leverage of nature-based solutions to mitigate water security threats. Local context and conditions matter a great deal. Still, we can infer the global potential of conservation actions by considering a subset of water security benefits. Previously, The Nature Conservancy developed an approach for assessing the potential for reducing nonpoint pollution through several source water protection activities.<sup>136</sup> We extend this effort to consider the potential for reducing sediment and nutrient pollution across the source watersheds comprising our global map of source watershed areas (see Appendix V for detailed methodology).

We consider three conservation practices representative of source water protection approaches: forest protection, pastureland reforestation and agricultural BMPs as cover crops. For a given watershed, these practices have varying potential to reduce sediment and nutrients. Our model targets implementation to those areas applying those activities where the greatest impact is possible. This results in a unique combination—or “portfolio”—of practices for a given watershed.

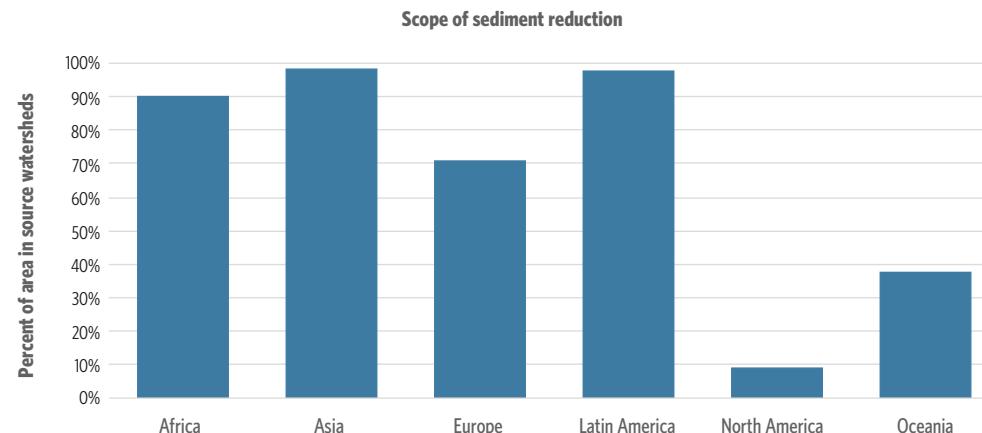
Our model enables inferences about the scale of opportunity for mitigating, through nature-based solutions, risks to urban water supply from nonpoint source pollution. Assuming a reduction target of 10 percent, we see broad global opportunity for addressing sediment or nutrient pollution through conservation actions. Asia in particular has potential for achieving appreciable reductions in both sediment and

nutrients. In North America, nutrient reduction potential dominates due to high agricultural inputs in the Mississippi River Basin, with opportunities for sediment reduction in smaller watersheds.

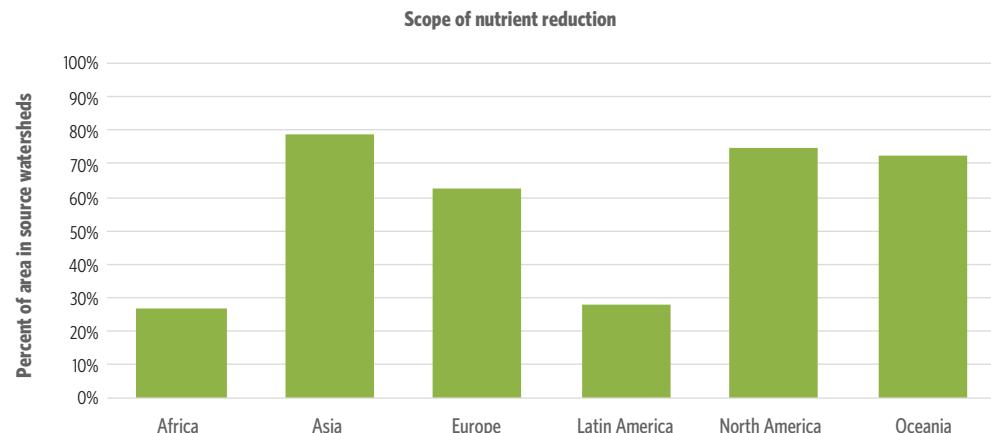
We find that source water protection activities can reduce sediment pollution in at least 70 percent of the area encompassed by source watersheds across Africa, Asia, Latin America and Europe (Figure 2.5 and 2.6). North America is predicted to have more limited scope for reducing sediment, but very large basins like the greater Mississippi affect these results. Still, more than half of the source watersheds in North America could achieve at least a 10 percent reduction in sediment. The potential for nutrient reduction is strong in Asia, Europe, North America and Oceania, where more than 60 percent of watershed areas can benefit from nature-based solutions. In terms of cities, we find that four of five cities (81 percent) in our urban source watershed model can reduce sediment and nutrient pollution by a meaningful amount (at least 10 percent) through forest protection, pastureland reforestation and/or the agricultural BMP of cover crops.

Importantly, this map of conservation potential does not indicate which source watersheds offer the greatest opportunity relative to costs or other feasibility constraints. While a reduction in sediment or nutrients of 10 percent or greater may be achievable, the cost of doing so may be prohibitive or greatly outweigh the value of water security benefits. We explore costs in Chapter 6. Still, these results indicate that source water protection is an important—and potentially impactful—solution for protecting natural water infrastructure areas and improving water security.

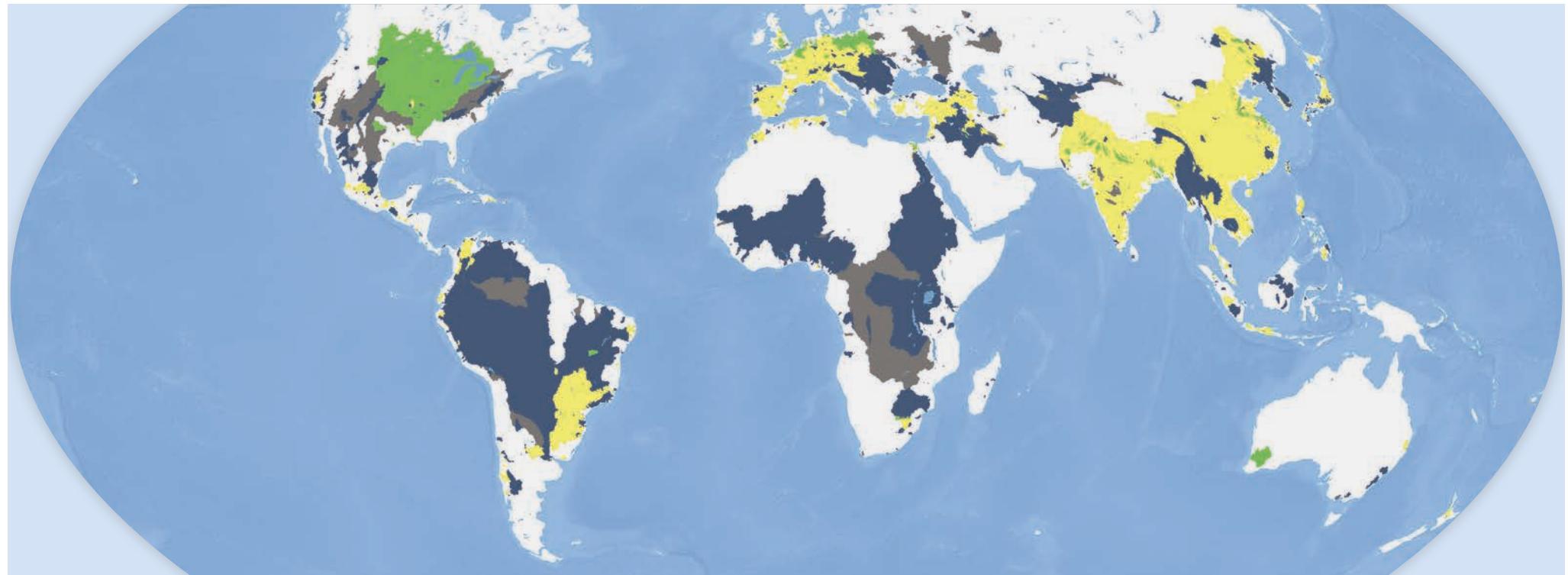
### Scope of pollution reduction potential



**Figure 2.5.** Percent area in urban source watersheds by region that can achieve a 10 percent reduction in sediment or nutrients (phosphorus) through conservation activities (forest protection, pastureland reforestation and agricultural BMPs as cover crops). (Source: The Nature Conservancy)



## Potential for pollution reduction in urban source watersheds



**Figure 2.6.** Modeled potential for achieving a 10 percent reduction in sediment or nutrient (phosphorus) pollution through conservation activities (forest protection, pastureland reforestation and agricultural BMPs as cover crops). Legend colors indicate where a 10 percent reduction is possible for one, both or no pollutants. For many watersheds, pollution reduction greater than 10 percent is possible through source water protection activities. (Source: The Nature Conservancy)

### Scope of 10 percent reduction

- None
- Sediment only
- Nutrients only
- Both pollutants

Source water protection is an important—and potentially impactful—solution for protecting natural water infrastructure areas and improving water security.

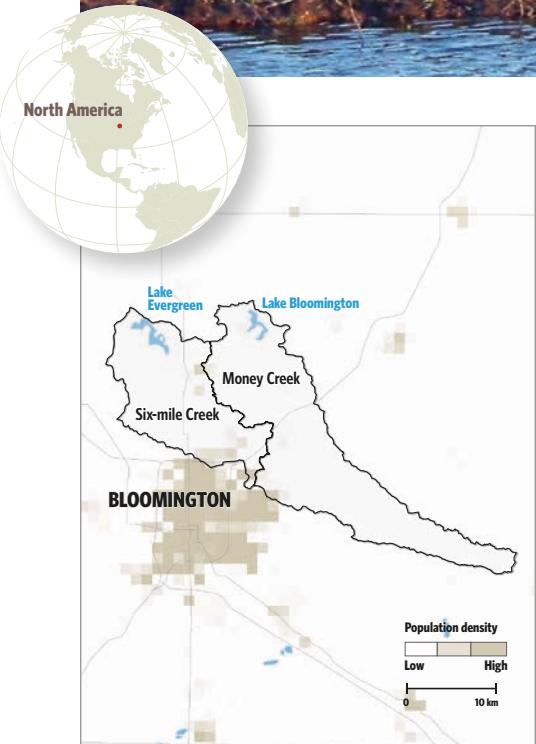
## LOCAL SPOTLIGHT

### Mackinaw River Watershed, Bloomington, Illinois, United States—Creating wetlands to improve water quality



Photo: © Timothy T. Lindenbaum

Constructed wetland at the Franklin demonstration farm in the Mackinaw River watershed.



#### The challenge

The watershed of the Mackinaw River, a tributary to the Illinois River, covers 295,000 hectares and contains some of the most productive agricultural land on Earth.<sup>137</sup> The Nature Conservancy has been working in the watershed since 1994 to protect the river, which remains home to 66 native fish species and nearly 30 species of mussels. The fact that such aquatic diversity has remained in a watershed that has been subjected to over 150 years of intensive row-crop production is extraordinary.

Much of the watershed's land was historically too wet to farm, resulting in the installation of drainage tile systems below the farmland's surface to remove water and reduce soil moisture down to a level that is optimal for crop production.<sup>138</sup> Unfortunately, the excess water that drains away also washes fertilizers and chemicals into adjacent waterways.

Excess fertilizers can generate adverse impacts to local and regional aquatic ecosystems. Nutrients that are common in fertilizers, including nitrogen and phosphorus, have been recognized as a critical source of pollution that is driving water quality problems both near and far. For instance, the state of Illinois has been identified as one of the highest contributors of nitrogen and phosphorus (16.8 percent and 12.9 percent respectively) to the Gulf of Mexico,<sup>139</sup> which has been plagued by hypoxic dead zones for decades that starve marine life of oxygen and coastal fishing communities of livelihoods.

The impacts of agricultural runoff have potential effects on local drinking water supplies that serve the 80,000 people living in the city of Bloomington, Illinois, and several surrounding townships. The city's main water supply comes from Lake Bloomington, a reservoir on a Mackinaw River tributary. Historically, the reservoir experienced periods in which nitrate concentrations exceeded the U.S. Environmental Protection Agency's 10 parts per million drinking water standard, requiring the city to divert water from a secondary reservoir in order to dilute the high concentrations in Lake Bloomington.

"One of my favorite things about this project is to see the number of people that come from all over the world to learn about sustainable farming practices that we're developing right here in Illinois. We've had people from as far as Brazil and Argentina. Water quality is a common issue shared all over the world, anywhere people want to grow food."

—John Franklin, owner of the Franklin Family Research and Demonstration Farm where the wetland studies have occurred

### Action and opportunity

Extensive research conducted by The Nature Conservancy and its partners at the University of Illinois has shown that wetlands, which help to regulate water and filter pollutants, can effectively remove up to 60 percent of inflowing nitrates from subsurface tiles when they are strategically installed alongside agricultural fields. This is significant since other studies have shown that the majority of the nitrate runoff comes from tile drainage of row crops.<sup>140</sup> Using a combination of wetlands and saturated buffers as a natural water treatment solution has the potential to be cost-competitive with traditional ion exchange treatment systems. A multi-practice approach that combines edge-of-field and in-field practices also qualifies for substantial cost-sharing from federal programs like the Conservation Reserve Program.<sup>141</sup> Using economic and watershed mapping, researchers are developing watershed scenarios to identify the optimal places to work that will reduce nutrient pollution from entering Lake Bloomington in the first place.

With these modeled results in hand, the proposed Bloomington Water Fund could include securing public and private funding leveraged with U.S. Farm Bill dollars to help cover watershed conservation costs. The concept of the fund is built on two critical principles:

1) the combination of agricultural best management practices and green infrastructure are an effective approach to address nitrate-nitrogen water quality problems that are persistent across the Mackinaw River watershed; and 2) they can provide meaningful results in an economically efficient way.

Since 2007, The Nature Conservancy and the University of Illinois have been conducting studies at a research and demonstration farm near Bloomington. This multi-practice research is measuring a range of important factors, including: 1) how large wetlands need to be relative to the area drained by tiles to effectively retain tile water long enough to reduce nutrients; and 2) how nitrogen management practices on agricultural landscapes (e.g., cover crops that capture and hold nutrients through the fall and winter) complement wetlands to reduce nitrate loss from the fields.

The future looks promising for the proposed Bloomington Water Fund. The city has developed watershed plans and established a capital fund for watershed practices that include treatment wetlands, nitrogen management and streambank erosion practices. Outreach by the county's Soil and Water Conservation District is increasing awareness and interest among landowners. A group of local producers, landowners and representatives from agribusinesses are serving as an advisory committee to help promote the project and ensure its compatibility with farming operations. Much more work remains, but this high level of collaboration has already led to the creation of seven wetlands in the Mackinaw River watershed that are being carefully monitored.

There is great replication potential for the water fund model across the Midwest. In Illinois alone, there are over 2.4 million hectares of agricultural lands that drain into surface drinking water supplies serving more than 1.6 million people. These water users will hopefully look to Bloomington to learn how they, too, can partner with farmers to protect their local water sources, and in doing so, the habitat of aquatic life.

BLOOMINGTON DASHBOARD						
Water fund start date	Number of upstream participants to date	Number of potential downstream beneficiaries	Number of partners to date	Primary funding sources	Activities	Anticipated co-benefits
N/A*	15	Between 50,000 and 80,000	8	Public (U.S. Farm Bill funds)**	 	 

\*Bloomington, Illinois has titled their budget line for watershed conservation "the water fund" for many years. For the past several years, The Nature Conservancy's strategy has been to grow the project within the existing structure by integrating additional funding mechanisms within the water funds model.

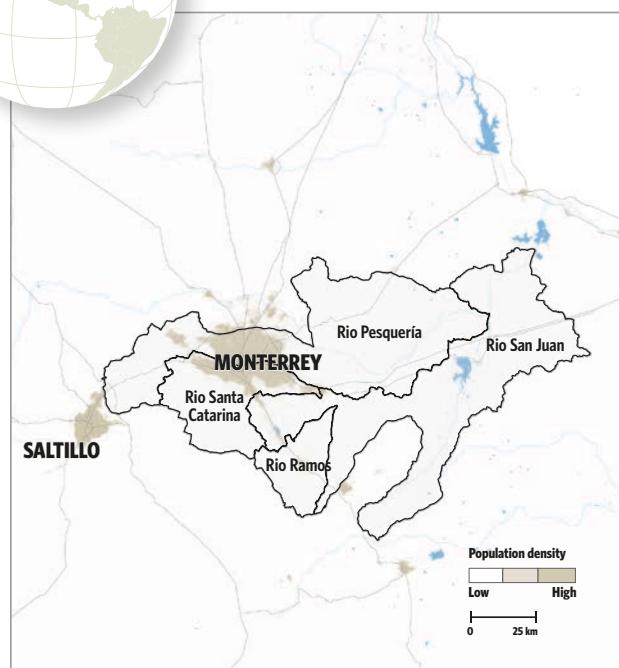
\*\*Also looking into methods of increasing private funding to leverage Farm Bill dollars for watershed conservation.

## LOCAL SPOTLIGHT

### San Juan Watershed, Monterrey, Mexico—Adapting to extreme hydro-meteorological events



Photo: © Juan Ángel Sánchez de Llanos



#### The challenge

Monterrey, Mexico, one of Latin America's industrial capitals with a population of over 4 million, is an important economic center for residents and Mexico alike. Unfortunately, the city is positioned in an area that is naturally prone to intense hydro-meteorological events (floods and droughts). Because most (approximately 60 percent) of Monterrey's drinking water supply comes from upstream areas that have been degraded on a recurring basis from land-use change and phenomena such as forest fires and invasive species, Monterrey is one of the top 25 Latin American cities for water risk.<sup>142</sup>

Climate events can be devastating. In 2010, Hurricane Alex cost the state of Nuevo León US\$1.35 billion.<sup>143</sup> Poor land management cannot be solely blamed for these losses, but it plays a role. Deforestation and erosion in the San Juan watershed, alongside rampant and poorly planned expansion of urban areas, can reduce infiltration in recharge zones that, in turn, exacerbates runoff and can contribute to flooding. Future flood events are projected to intensify in the watershed, potentially exceeding the retention capacity of the existing dam that protects the city from high flows.<sup>144</sup>

The year following Hurricane Alex, Monterrey was hit again, this time by a severe drought. The effects of the drought were made worse by the weakened storage and regulation capacity of upstream areas. The scarcity of water ultimately damaged over 50,000 hectares of crops and killed more than 10,000 livestock.<sup>145</sup> Within the first few months alone this resulted in a loss of US\$3 million for Nuevo León,<sup>146</sup> but the severe drought persisted three years, ending in 2013.

In addition to the cycle of extreme weather events that increases risk for Monterrey's residents and its drinking water supplies, five of the six aquifers in the region are already over-drafted. By 2030, the gap between water supply and demand is expected to increase by 33 percent as the state works to meet the needs of an estimated 1.3 million new residents.<sup>147</sup> Almost all of Monterrey's water originates

in the San Juan watershed, which means there is a lack of alternative sources to use in dry years. Maintaining reliable base flows through revegetation has become a clear priority and one of several strategies to help the state avoid costly interbasin transfers.

## Action and opportunity

The Monterrey Metropolitan Water Fund (FAMM) is a multi-stakeholder platform developed to increase the San Juan watershed's capacity to regulate its water flows. After three years of preparatory work, structural design, feasibility studies and fundraising (mainly through the FEMSA Foundation and The Nature Conservancy), the FAMM recently became Mexico's first legally established water fund.

Over the next 20 years, the water fund will focus its work on a strategically targeted area covering over 124,000 hectares. While this only covers around 5 percent of the San Juan watershed, the areas chosen are highly sensitive and located in parts of the watershed that produce approximately 60 percent of Monterrey's water supply. As such, the water fund activities are expected to help address the water quantity problem for the whole watershed. For example, it is estimated that the water fund's work in the 9,752 hectares of highest sensitivity (8 percent of the potential intervention area) would reduce runoff by 262 cubic meters per hectare per year, whereas if this same landscape were to be continually degraded, runoff would increase by 622 cubic meters per hectare per year (Figure 2.7).<sup>148</sup> Reducing runoff allows more water to infiltrate into the soil, which increases base flows and can reduce moderate flood flows off the landscape.

FAMM already has US\$8 million pledged from the private sector and is currently supported by 60 diverse partners. Four key objectives drive the water fund's work:

- 1. Reduce flooding.** Reduce the amount of water flowing in the Santa Catarina River by up to 750 cubic meters per second during catastrophic rains.
- 2. Improve infiltration.** Contribute to increasing the San Juan watershed's capacity to absorb available water by 20 percent.
- 3. Develop a water culture and raise environmental awareness among the population.** Help the population to understand the relationship between the watershed and the city.
- 4. Develop environmental resources management skills.** Promote an increase in the percentage of federal resources managed that favor the watershed.

These objectives will be achieved through a combination of green and gray infrastructure, including reforestation, firebreaks, erosion barriers, fencing, retaining walls, runoff traps, check-dams, earth dikes and large-scale urban rainwater harvesting areas, along with public awareness campaigns. Although source water protection activities cannot prevent catastrophic flooding or mitigate all impacts from extreme droughts, they have significant potential to reduce the severity of flooding and sustain critical base flows during droughts.

Predicted runoff changes resulting from source water protection activities in the San Juan watershed

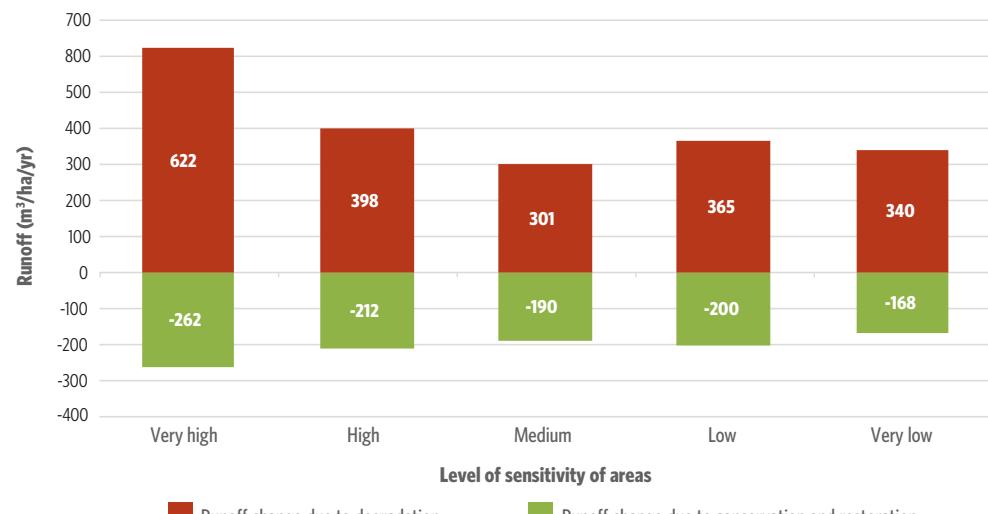


Figure 2.7. Model predictions for how source water protection activities can improve base flows and reduce flooding. Each bar represents runoff change due to passive conservation (red), and reduced runoff due to restoration (green) for areas grouped into five levels of sensitivity.

MONTERREY DASHBOARD							
Water fund start date	Number of upstream participants to date	Number of potential downstream beneficiaries	Number of partners to date	Primary funding sources	Activities	Anticipated co-benefits	
2013	30	Between 1,000,000 and 5,000,000	More than 60	Private NGO/Foundation Bilateral/Multi-lateral Public Utility			

## CHAPTER THREE INSIGHTS

Beyond protecting our water sources, healthy natural and working lands in urban source watersheds...

**...are vital for mitigating climate change through carbon sequestration and avoided emissions.**

- From 2001 to 2014, more than 6.6 gigatonnes of carbon were emitted as a result of tropical forest loss in the source watersheds, equivalent to 76 percent of all carbon emitted as a result of tropical forest loss over that period.
- By taking care of the land in urban source watersheds, we can get 16 percent of the necessary carbon reductions needed in 2050 under the Paris Agreement. Between 4 and 11 percent of this ceiling of potential could be realized via city investments in source water protection activities at a level required to achieve meaningful sediment or nutrient reductions.

**...can reduce the impacts of climate change—such as floods, fire and land erosion—that disproportionately affect the poorest communities.**

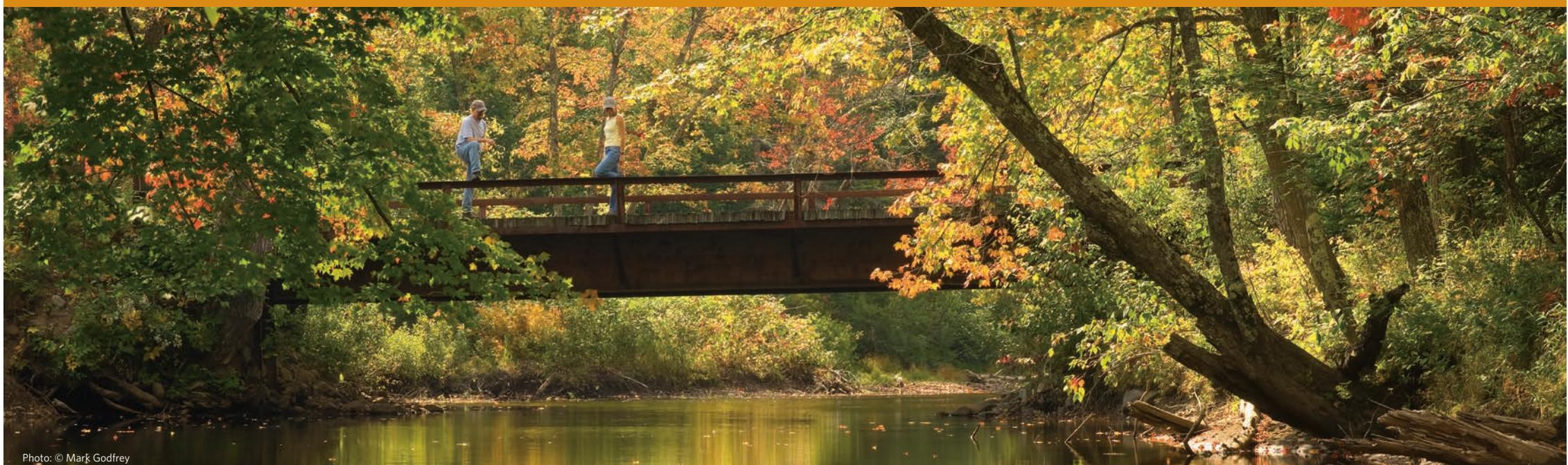
- 24 percent of source watershed areas will likely experience an increase in forest fires. Activities that reduce forest fuels in those regions, where appropriate, could help reduce that risk.
- 83 percent of urban source watershed areas are likely to experience an increase in soil erosion. By protecting natural lands and improving farming practices, we can keep the soil in place, improving water quality and the resilience of farming communities.

**...can build healthier communities by protecting fisheries and providing habitat to pollinators that help us grow nutritious food.**

- Source water protection activities could help mitigate nutrient inputs for over 200 of the 762 globally reported coastal eutrophication and dead zones, many of which support fisheries upon which local communities depend.
- Without pollinators, 2.6 billion people who live in urban source watersheds would see a 10 percent decrease in the amount of micronutrients available through local crops, and global agricultural production's economic value would decline by 5 percent.

**...can protect or restore the habitat for thousands of species, many of which are endangered or threatened.**

- The risk of regional extinctions for 5,408 species would be reduced if reforestation opportunities were fully implemented within source watersheds.
- Through protection of natural habitat that sits outside existing protected areas, 44 countries that currently fall short of the Convention on Biodiversity's 17 percent target for protection of lands and inland waters could achieve that target.



# Chapter 3

## Opportunities for Source Water Protection to Produce Co-benefits

### Benefits beyond water security

We have shown how source water protection addresses water security risks, especially those related to water quality. The benefits of source water protection activities, through their protection and improvement of a watershed's landscape, can go well beyond water security to encompass other benefits. Here we focus on four co-benefit areas:

- Mitigating climate change
- Adapting to climate change and building resilient communities
- Improving human health and well-being
- Conserving biodiversity

In this chapter we describe a range of opportunities in these areas, looking across global urban source watersheds to assess where source water protection activities have the highest potential to deliver benefits. Some of the benefits lend themselves to quantification and mapping, whereas others are tied closely to local conditions and mediating factors and therefore cannot be reliably quantified at the global scale. Our objective is to identify and explore areas of potential improvement rather than provide a definitive and comprehensive assessment of the magnitude and extent of the opportunity. Ultimately, achieving all these co-benefits, as with water security, will require planning, implementation and evaluation in the context of local conditions.

### Climate change mitigation

Safeguarding and restoring natural areas that provide water security services will simultaneously avoid emissions that occur through natural land cover conversion and extensive fires, and contribute to maintaining or increasing carbon sequestration. Land stewardship on working landscapes can provide additional benefits for mitigation, such as through ranching BMPs for cattle grazing and manure management, and agricultural BMPs that include fertilizer methods and applications, tillage and soil structure management, cover crops and crop rotation. The scale of potential benefits that source water protection activities can have on carbon sources and sinks is meaningful for a global community committed to climate change mitigation.

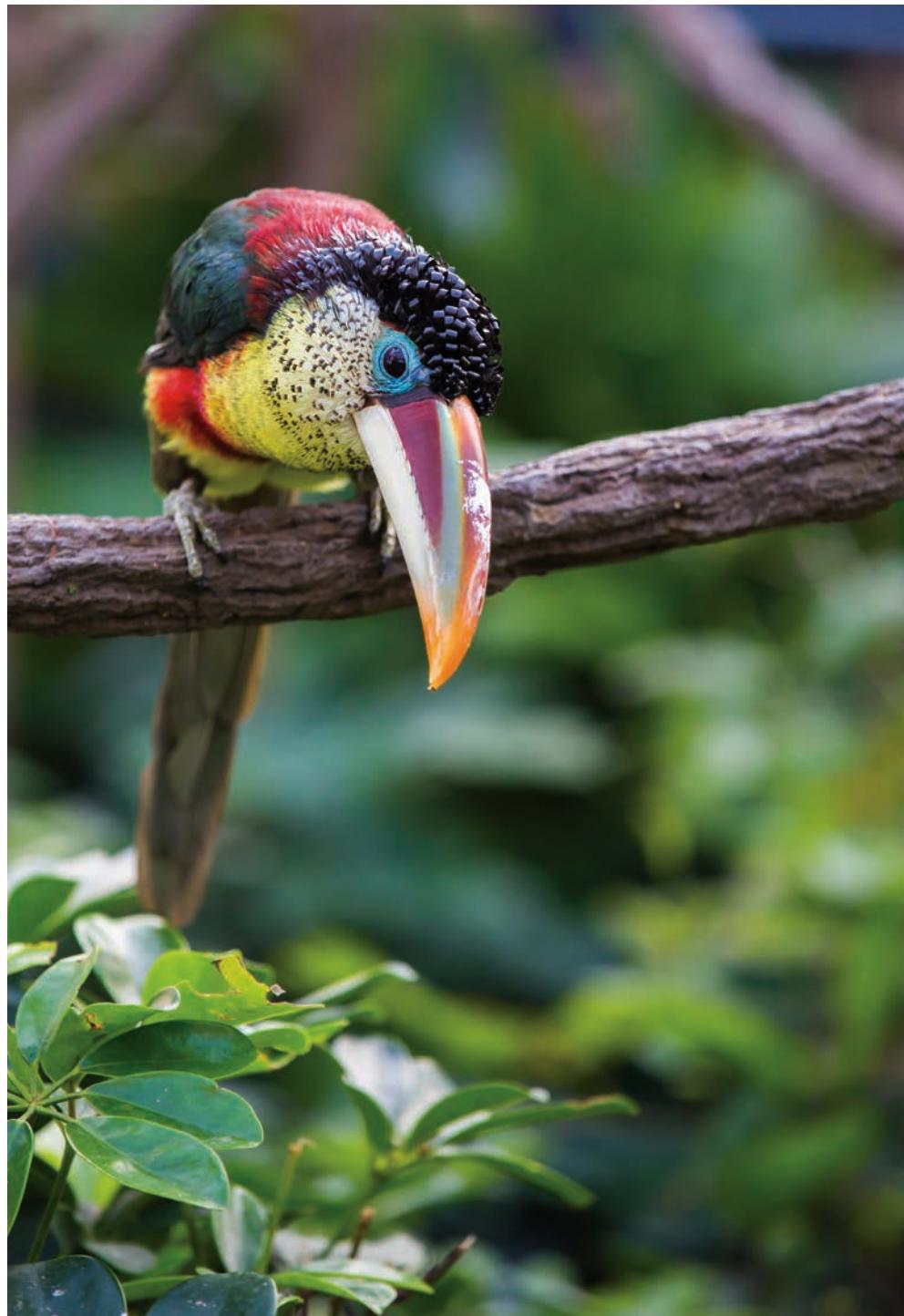


Photo: © Shutterstock/Cuson

## Trade-offs Among Benefits

Because land-based activities can be the source of many co-benefits, there are obvious synergies. For example, protecting forests can contribute to biodiversity conservation while also enhancing climate change mitigation. Where protection extends to the access and rights of Indigenous and other local communities, these actions may also help to reach other goals like food security (e.g. through ensuring the conservation of wild foods).

However, it is also clear that—in some contexts—there will be tradeoffs among source water protection objectives and among groups of people. For example, in some areas, actions taken to conserve terrestrial ecosystems (with benefits for water quality, climate change mitigation and biodiversity) may conflict with the

goals of agricultural production for ensuring food security and reducing poverty. Likewise, climate change mitigation strategies focusing on afforestation and reforestation may result in tradeoffs in water quantity and even in biodiversity in some areas.<sup>149, 150</sup>

Being aware of these tradeoffs and carefully planning to find options that maximize positive outcomes for all parties is critical. That includes having our eyes open to winners and losers in different contexts. Where tradeoffs are apparent (e.g. protecting a forest where a farmer wants to expand cultivation), incentives adopted with free, prior and informed consent can help to level the playing field and move land use toward providing local and broader societal benefits.<sup>151</sup>



Photo: © Ian Shive

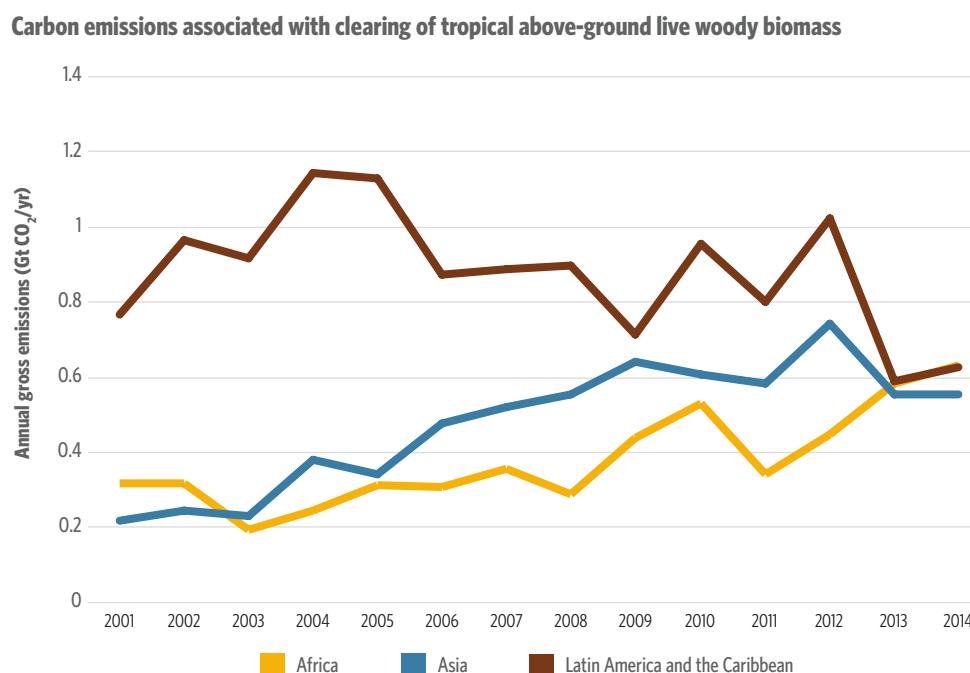
## The carbon challenge

The sources and sinks of carbon from land use and land cover change (LULCC) are significant in the global carbon budget. The contribution of LULCC to anthropogenic carbon emissions was about 33 percent of total emissions over the last 150 years, 20 percent of total emissions in the 1980s and 1990s, and 12.5 percent of total emissions between 2000 and 2009.<sup>152</sup> Overall emissions from LULCC have not declined, but their relative contribution to total emissions has gone down as fossil fuel emissions have risen.<sup>153</sup>

Deforestation—defined as forest cover loss that leads to conversion to other (non-forest) land uses—is the second largest source of anthropogenic carbon emissions globally.<sup>154</sup> Building on a dataset that combines forest loss from 2001 to 2014 with tropical carbon stored in biomass, we find that 24.3 gigatonnes of carbon dioxide (6.62 gigatonnes of carbon)<sup>155</sup> emissions resulted from tropical forest loss in the source watersheds during that period. That translates to an average estimate of annual carbon emissions from gross tropical deforestation equivalent to

1.73 gigatonnes of carbon dioxide (0.47 gigatonnes of carbon) per year. That amount is equivalent to around 76 percent of all carbon emitted as a result of tropical forest loss over that same time. These numbers tell us that the source watersheds have produced a disproportionately larger fraction of the world's carbon emissions than their coverage alone would otherwise suggest (source watersheds cover 55 percent of the Earth's tropical land surface).

The results also indicate those regions where we might expect continued high above-ground carbon losses in the future in the absence of targeted interventions. An examination of aggregate regional carbon loss by year suggests that the amount of carbon loss in Latin America, while high compared to all other regions, demonstrated a statistically significant slight negative trend (Figure 3.1). Conversely, the rate of carbon loss in Asia and Africa demonstrate a statistically significant increase. The results for Africa are perhaps the most concerning. Although the overall carbon losses are lower than those of Latin America and Asia, amounts appear to be increasing over the last years of the assessment period.



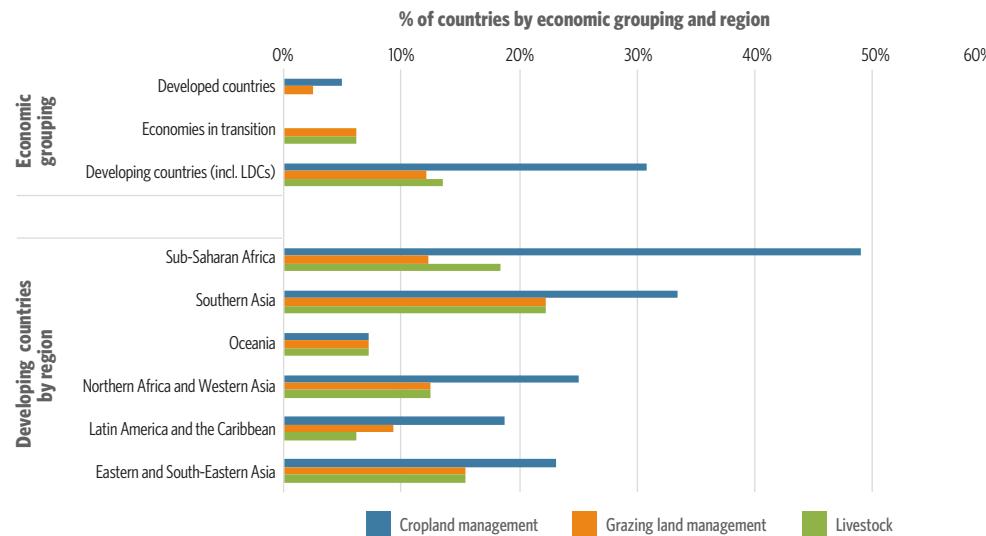
**Figure 3.1.** Annual gross carbon dioxide (CO<sub>2</sub>) emissions to the atmosphere from 2001 to 2014 as a result of clearing above-ground live woody biomass in urban source watersheds across the tropics. North America, Europe and Oceania are omitted due to minimal area in the tropics. Cumulative emissions per year are summarized by region in units of gigatonnes of CO<sub>2</sub>. All above-ground biomass loss is assumed to be committed emissions and reported as gross estimates. (Source data: Zarin, et al., 2016<sup>156</sup>)

## Climate change mitigation opportunities through source water protection

In December 2015, world leaders convened at the Paris Climate Conference and made a commitment to hold the average global temperature rise below 2 degrees Celsius above pre-industrial levels and even pursue efforts that will limit the temperature rise below 1.5 degrees Celsius. Based on historical trends and future growth projections, the world is unlikely to stop global temperature rise below 2 degrees Celsius by fossil fuel reductions alone.<sup>157</sup> Therefore, in order to negate carbon emissions at the end of the century, the Paris Agreement calls great attention and focus to forests as a solution to reducing and offsetting greenhouse gas emissions. Source water protection activities, including land cover protection, vegetative restoration, reduction of forest fuel where appropriate, as well as agriculture and ranching BMPs, could help countries achieve their carbon reduction goals in order to stabilize and reduce concentrations of carbon dioxide in the atmosphere.<sup>158, 159, 160, 161, 162</sup>

As of October 2016, 163 countries had submitted their INDCs to the United Nations Framework Convention on Climate Change (UNFCCC).<sup>163</sup> The Food and Agriculture Organization of the United Nations analyzed the INDCs (and subsequent Nationally

**Percentage of countries that refer to mitigation policies and measures in agriculture, by type of activity and economic grouping/region**



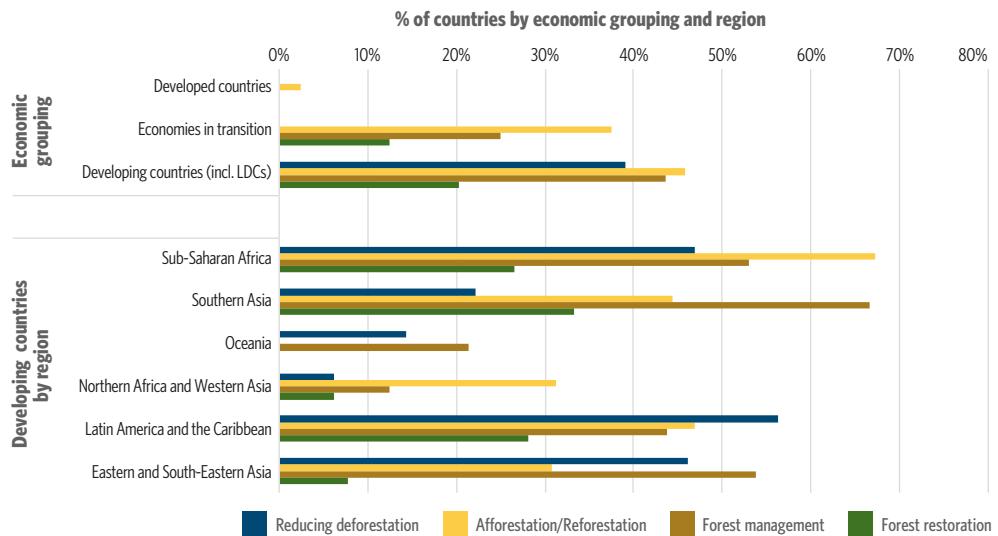
**Figure 3.2.** Some countries separated grazing land management from other livestock management (including feed, breeding and manure) and so the two categories are both presented here. Developing countries, particularly the least-developed countries (LDCs), put a strong emphasis on the agriculture sectors. Source: FAO 2016, The Agriculture Sectors in The Intended Nationally Determined Contributions: Analysis.<sup>165</sup> Reproduced with permission.

Determined Contributions) and found that the agriculture sectors—crops, livestock, fisheries and aquaculture, as well as forestry—feature prominently in meeting national mitigation and adaptation goals provided by countries to meet their negotiated contributions to achieving the COP21 Paris Agreements on climate change.<sup>164</sup> Agriculture and land use, land-use change and forestry (LULUCF) are among the most referenced sectors in countries' mitigation contributions with 86 percent of countries referring to agriculture and/or LULUCF, second only to the energy sector as climate change mitigation actions (Figure 3.2 and 3.3).

### Above-and below-ground carbon

Forests play an important role in the carbon cycle as they are both carbon sources and sinks, meaning they are continuously exchanging carbon dioxide with the atmosphere. Efforts to protect and restore forests around the world are critical to mitigating climate change. While oceans store by far the largest amount of carbon, most above-ground terrestrial carbon is stored in forests, as compared to other vegetation types.<sup>174</sup> The current carbon stock in the world's forests is estimated to be 861 gigatonnes of carbon.<sup>175, 176</sup> By comparison, the atmospheric carbon pool stores about 780 gigatonnes of carbon and is increasing by about 4 gigatonnes of carbon a year.<sup>177</sup>

**Percentage of countries that refer to mitigation policies and measures in LULUCF, by type of activity and economic grouping/region**



**Figure 3.3.** LDCs stands for least-developed countries. Source: FAO 2016, The Agriculture Sectors in The Intended Nationally Determined Contributions: Analysis.<sup>166</sup> Reproduced with permission.

Geographically, 55 percent of forest carbon is stored in tropical forests, 32 percent in boreal forests and 14 percent in temperate forests. There is a fundamental difference in the carbon structures of different forest types: tropical forests have 56 percent of carbon stored in biomass and 32 percent in soil, whereas boreal forests have only 20 percent in biomass and 60 percent in soil.<sup>178</sup>

These ratios have implications for carbon-informed land management. While above-ground biomass in the form of vegetation rightly garners attention, soil carbon is an equally important sink.<sup>179, 180</sup> Estimates of soil carbon vary,<sup>181</sup> but one study concludes that soils contain 5 percent of the world's carbon pool, compared to 1.2 percent in living organisms and 1.5 percent in the atmosphere (the remainder is in fossil fuels and the ocean). Land degradation, largely through land cover conversion for agriculture, has been a primary source of soil carbon emissions. Importantly, agricultural BMPs can help retain soil carbon, with the potential added benefits of improvements in production, increased infiltration of water and reduced impacts on soil biodiversity.<sup>182</sup>



Photo: © Drew Kelly

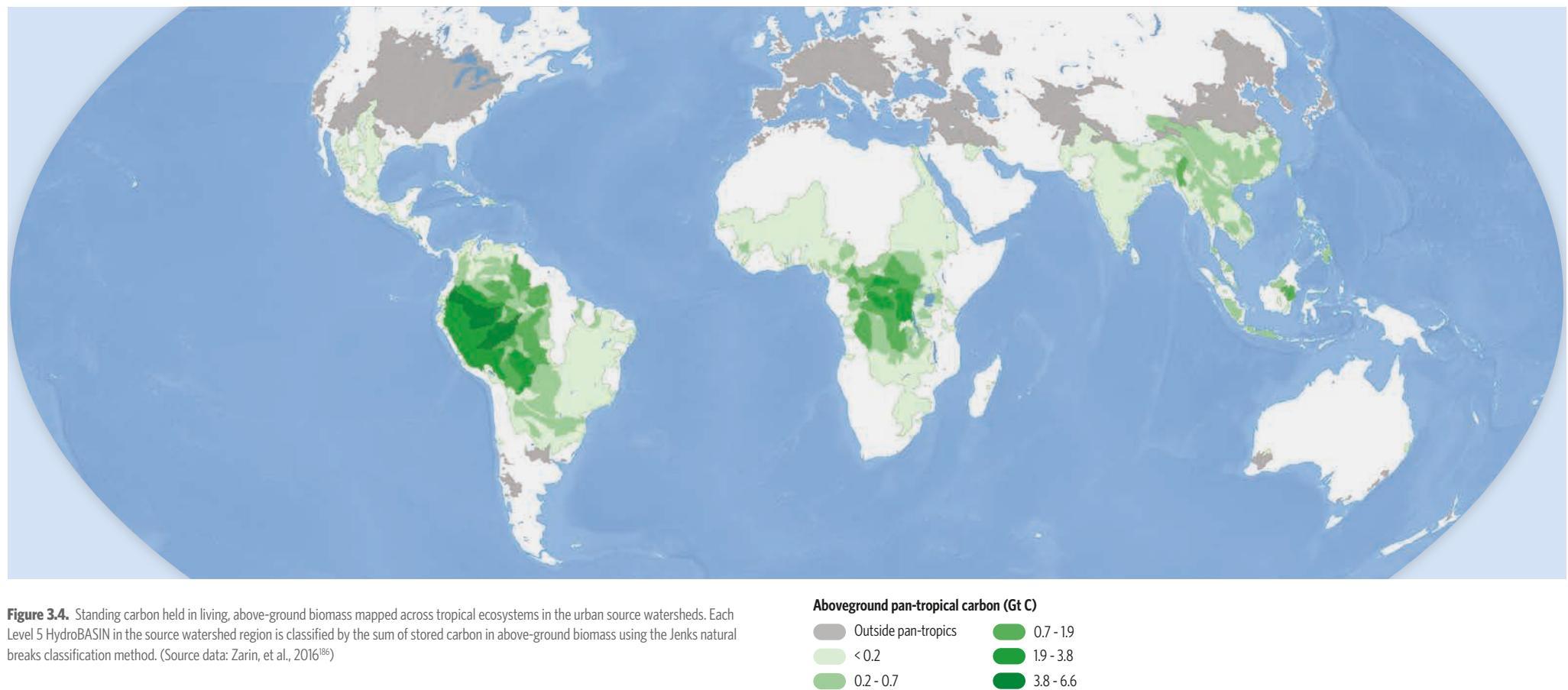
## Wetlands protection and restoration



Wetlands cover 6 percent of the world's land surface and contain about 10 percent of the global terrestrial (vegetation and soil) carbon pool.<sup>167</sup> Peatlands—a type of wetland characterized by substantial peat (organic remains) accumulation at the surface<sup>168</sup>—cover over 400 million hectares worldwide (3 percent of the world's land area) and contain 30 percent of all global soil carbon. They occur in over 180 countries and represent at least one-third of the global wetland resource.<sup>169</sup> Most peatlands (approximately 350 million hectares) are in the northern hemisphere, covering large areas in North America, Russia and Europe. Tropical peatlands occur in mainland East Asia, Southeast Asia, the Caribbean, Central America, South America and southern Africa. Indonesia alone holds 65 percent of the global peatland carbon pool.<sup>170</sup>

A current estimate of global undisturbed peatland is 30 million to 45 million hectares or 10 to 12 percent of the global peatland area.<sup>171</sup> Peatland draining and burning are estimated to contribute 2 to 3 gigatonnes of carbon annually, equivalent to 10 percent of annual fossil fuel emissions.<sup>172</sup> Peatland restoration can contribute significantly to carbon sequestration, though restored peatlands will contribute less to climate change mitigation than intact peatlands.<sup>173</sup>

## Amount of standing carbon held in above-ground tropical biomass in urban source watersheds



**Figure 3.4.** Standing carbon held in living, above-ground biomass mapped across tropical ecosystems in the urban source watersheds. Each Level 5 HydroBASIN in the source watershed region is classified by the sum of stored carbon in above-ground biomass using the Jenks natural breaks classification method. (Source data: Zarin, et al., 2016<sup>186</sup>)

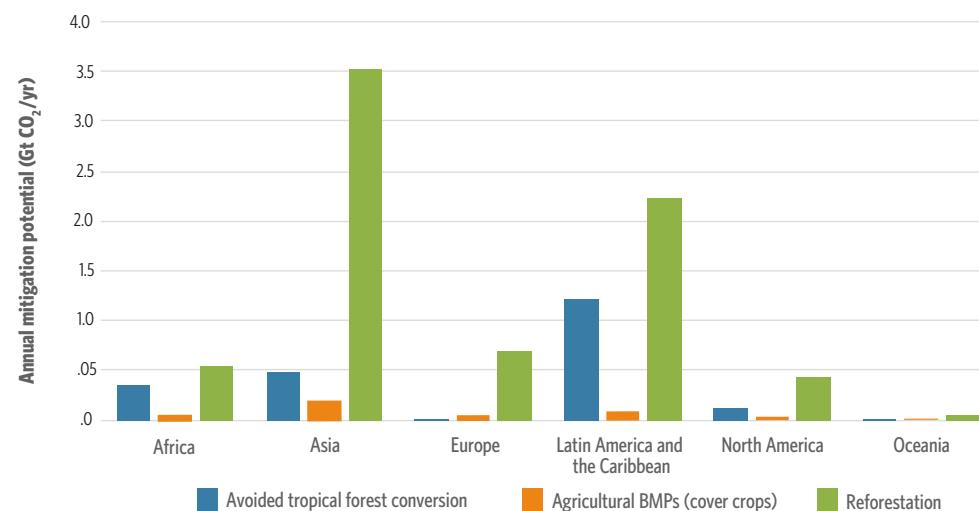
Due to data considerations, we focus our analysis on standing carbon held in above-ground tropical biomass. Research suggests that programs to reduce the emissions from deforestation and forest degradation are cost-effective ways to mitigate climate change,<sup>183</sup> so we assume that carbon in above-ground biomass represents an opportunity for carbon storage through protection.<sup>184</sup> Across all urban source watersheds in tropical ecosystems, we find a total of 143 gigatonnes of carbon stored in above-ground biomass as of the year 2000 (Figure 3.4). This represents 64 percent of the total above-ground carbon in all tropical woody vegetation (in the area delimited by Zarin, et al., 2016<sup>185</sup>). Not unexpectedly, given the size and relative intactness of the Amazon River Basin, the vast majority of standing carbon occurs in South America (69 percent), followed by central Africa with the Congo River Basin (32 percent) (see Appendix III for results by region).

Source water protection is about more than forest protection, so we take our analysis one step further to calculate the ceiling of additional climate change mitigation through three land-based mitigation activities: avoided tropical forest conversion (targeted land protection), reforestation and cover crops (agricultural BMPs). We calculate a total mitigation potential of 10.17 gigatonnes of carbon dioxide per year (equivalent to 2,771 million metric tonnes of carbon per year, using a conversion factor of 3.67 to convert carbon to carbon dioxide). Reforestation comprises the vast majority of this potential (Figure 3.5, see Appendix III for results by region). This is equal to slightly more than one-quarter of the total global carbon dioxide emissions from fossil fuel use and industry in 2015.<sup>187</sup>

To put this number in perspective, we compare the potential climate change mitigation of these source water protection activities to the reduction in carbon dioxide emissions that is needed in the year 2050 to drop from a baseline emission scenario (characterized by no additional efforts to constrain emissions) to an emission scenario that aims to limit global temperature rise to 2 degrees Celsius above pre-industrial levels. We estimate that if land-based mitigation activities are fully implemented in urban source watersheds they could provide 16 percent of the total mitigation needed in the year 2050 across all sectors for a likely chance of limiting warming to 2 degrees Celsius (Figure 3.6).<sup>191</sup> While we consider this estimate to be the ceiling of climate change mitigation across source watersheds for three types of activities, it does not consider other agricultural BMP activities like improved application of nitrogen and manure or planting trees in croplands, which also have climate change mitigation benefits.

We also calculated the climate change mitigation potential produced by applying the same three activities—forest protection, pastureland reforestation and agricultural BMPs as cover crops—to achieve a 10 percent reduction in sediment and nutrients. Across urban source watersheds where reduction in sediment by 10 percent is possible, we estimate a mitigation potential of 0.41 gigatonnes of carbon dioxide

**Ceiling of annual climate change mitigation potential in urban source watersheds, by activity and region**

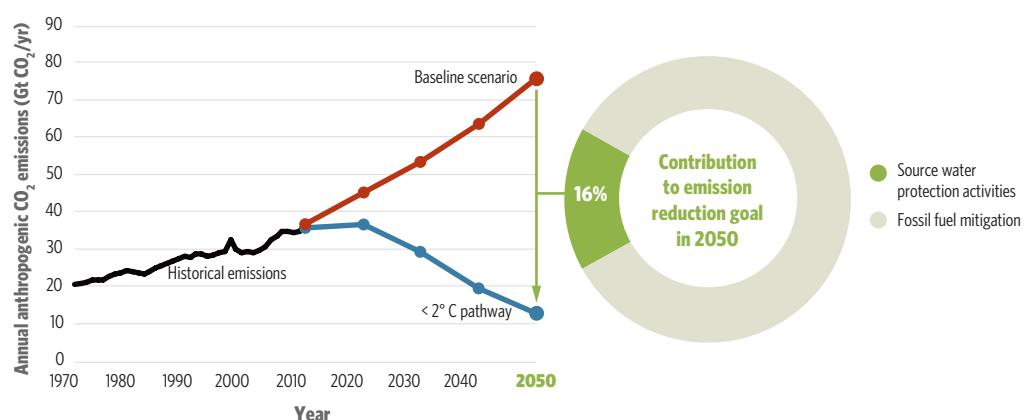


**Figure 3.5.** The ceiling of annual climate change mitigation potential (measured in units of gigatonnes of CO<sub>2</sub> per year) in urban source watersheds by geographic regions based on three source water protection activities: avoided tropical forest conversion, cover crops and reforestation. (Source data: Hansen, et al. 2013<sup>188</sup>; WRI, 2014<sup>189</sup>; ESA 2010 and UCLouvain (GlobCover)<sup>190</sup>)

per year. We also estimate that a 10 percent reduction in nutrients, where possible, across urban source watersheds would result in 1.11 gigatonnes of carbon dioxide per year of mitigation potential (see Appendix III for results by region). Our results suggest that cities investing in source water protection activities at a level required to achieve meaningful reductions in sediment or nutrients might contribute 4 to 11 percent of the maximum (ceiling) mitigation potential. The remaining potential points to opportunities for cities or other actors to capture more mitigation potential as a co-benefit to water security.

Not all above-ground and soil carbon will remain stored in urban source watersheds, even with the most ambitious source water protection efforts. Nonetheless, results on above-ground carbon, combined with data on recent forest loss, indicate relative areas of high potential for retaining carbon. Maps of reforestation and restoration potential<sup>194</sup> can suggest opportunities for additional carbon sequestration, and working landscapes amenable to various best management practices can make important contributions to climate change mitigation, especially but not only through better soil management. In large part, nature-based solutions for water security are nature-based solutions for climate change mitigation and vice versa.

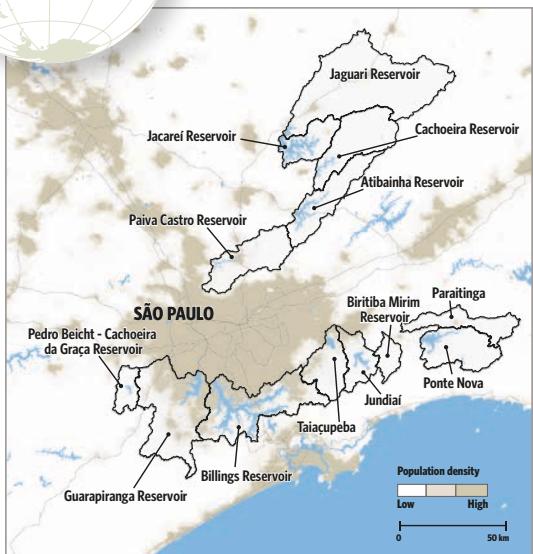
**Ceiling of potential contribution of land-based mitigation activities in urban source watersheds toward a 2050 emission reduction goal**



**Figure 3.6.** The graph on the left depicts historical data up to 2010, and two possible future scenarios: a so-called baseline scenario (RCP 8.5) and a scenario that aims to limit global temperature rise to 2 degrees Celsius above pre-industrial levels (RCP 2.6). The pie chart on the right shows that if three source water protection activities (avoided tropical forest conversion, reforestation and cover crops) were implemented to their full potential across urban source watersheds, they could account for 16 percent of the total mitigation needed to reduce emissions across all sectors in the year 2050. The remaining emission reductions would likely come from other sectors, primarily fossil fuel reductions. (Source: historical CO<sub>2</sub> emissions (fossil fuel combustion, cement production, and land-use change) from Le Quere, et al., 2015<sup>192</sup>; Emissions for future RCP projections (fossil fuels, other industrial sources, and agriculture, forestry and other land use) come from Annex II: Climate System Scenario Tables (IPCC 2013)<sup>193</sup>)

## LOCAL SPOTLIGHT

### Cantareira System, São Paulo, Brazil—Reforestation for water security mitigates climate change



**Above:** Brazil's first forest conserved through Payments for Environmental Services in São Paulo's Cantareira System. **Left:** Preparing tree seedlings for planting.

#### The challenge

With a population of around 20 million people, São Paulo is the most populated metropolitan region in Brazil and the sixth largest on the planet.<sup>195</sup> The city is the center of Brazil's financial, service and industrial sectors, making up more than 20 percent of the country's GDP. Unfortunately, it is also one of the top water-stressed cities in Latin America.<sup>196</sup>

For decades São Paulo's most important watersheds—that of the Piracicaba, Capivari and Jundiaí rivers (PCJ) and Upper Tietê River—have experienced severe deforestation, which impacts water availability and contributes to climate change. Already, São Paulo consumes 4 percent more water than is available in its rivers (a deficit of 3,000 liters per second), and by 2025 this is expected to increase by 16 percent if immediate large-scale actions are not taken to address the root causes of the crisis.<sup>197</sup> While investments in traditional gray infrastructure are critical, they are costly and will be more effective with parallel efforts to reduce water use and waste and restore watershed landscapes.

Approximately 46 percent of the water consumed by the São Paulo metropolitan area comes from the Cantareira System, which encompasses four sub watersheds of the Piracicaba River (Jaguari, Jacareí, Cachoeira, Atibainha) and one from the Alto Tietê River (Juqueri), and is one of the largest water supply systems in the world. Comprised of six reservoirs, it sits in the biodiverse and highly threatened Atlantic Forest. The Cantareira System's watersheds have already lost over 70 percent of their original forest as a result of land-use changes to support agriculture, pasture lands and urban expansion.<sup>198</sup> Restoring natural vegetation in critical areas of the watersheds will not only help filter out sediments and pollutants to improve water quality, but it is expected to contribute to natural flow regulation and improve water availability during the dry season.

## Action and opportunity

Brazil's water funds—in some cases known as water producer projects—are focused on implementing or maintaining natural infrastructure to ensure water provision for water users. The Nature Conservancy and its partners are promoting this scheme to improve water security for 12 urban centers in the country. One of these sites is São Paulo and its metropolitan area, where early projects started as pilots in 2005. The first pilot project was in Extrema, a municipality that encompasses many of the PCJ headwaters and became a broadly recognized case.

The priority of the São Paulo Water Fund has been to recover the natural functions of the watersheds to improve water security and conserve biodiversity. With the goal of decreasing sedimentation by 50 percent in the Cantareira system, approximately 13,000 hectares were identified for reforestation and natural regeneration, specifically in riparian zones, water recharge areas and steep slopes—all of which would be protected by law for their importance to water quality and for delivering a multitude of other benefits.

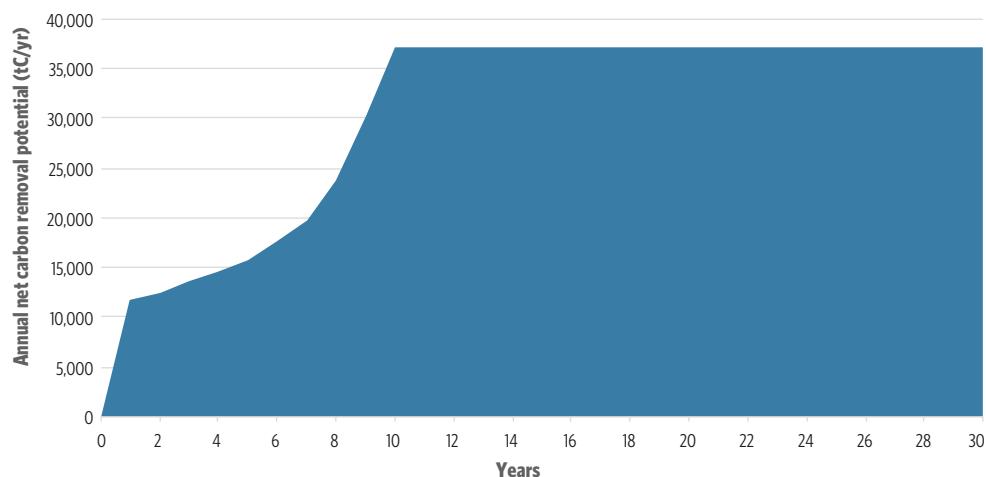
The scale at which forests would be restored and protected was substantial enough to explore the addition of climate change mitigation as a co-benefit of the projects in São Paulo. In 2008, the Dow Chemical Company and Foundation supported The Nature Conservancy in a 3-year pilot project with two main goals: to restore 350 hectares in the watershed of the Cachoeira Reservoir, one of the six reservoirs of the Cantareira System; and to develop a forest carbon project that could enable the inclusion of other carbon initiatives throughout the Cantareira system.

In 2012, a contract for Payment for Ecosystem Services for Carbon (PES-Carbon) was signed with a landowner participating in the Extrema Water Conservation Project. This was a pilot and pioneer experience for The Nature Conservancy. The agreement compensated the farmer for both water production and carbon storage. By following the Verified Carbon Standard (VCS) methodology, The Nature Conservancy was able to identify the carbon sequestration rates for reforestation in that particular region: each reforested hectare in the Cantareira System would be able to store around 102 metric tonnes of carbon over 30 years (375 tonnes of carbon dioxide ( $\text{CO}_2$ ) equivalent) (Figure 3.7). Considering these parameters and the plan to scale the São Paulo Water Fund (a target of restoring around 14,200 hectares by 2025), expected additional benefits

for climate change mitigation generated by the restoration activities are around 942,500 tonnes of carbon (or 3.46 million tonnes of  $\text{CO}_2$  equivalent). In the case of the Extrema Water Conserver Project, the carbon sequestration benefits are also being used to engage new partners, such as companies looking to have a sustainable supply chain.

The development of the carbon project was an important step in identifying opportunities to adapt and implement this co-benefit for other water producer projects in Brazil. The benefits of water funds go beyond water security and working with partners reinforces that natural infrastructure can provide benefits for climate change mitigation, biodiversity conservation and local communities.

**Estimated annual net carbon removal potential through forest restoration for the São Paulo Water Fund over 30 years**



**Figure 3.7.** Net carbon removal data within planned restoration sites estimated based on parameters from Borgo and Tiepolo (2012).<sup>199</sup>

SÃO PAULO DASHBOARD						
Water fund start date	Number of upstream participants to date	Number of potential downstream beneficiaries	Number of partners to date	Primary funding sources	Activities	Anticipated co-benefits
2005*	221	More than 5,000,000	17	Private Public	 	 

\*2005 is when the first Extrema Conservador das Aguas project started.



Photo: © Jason Houston

## Building resilience to climate change through adaptation

### The climate change challenge

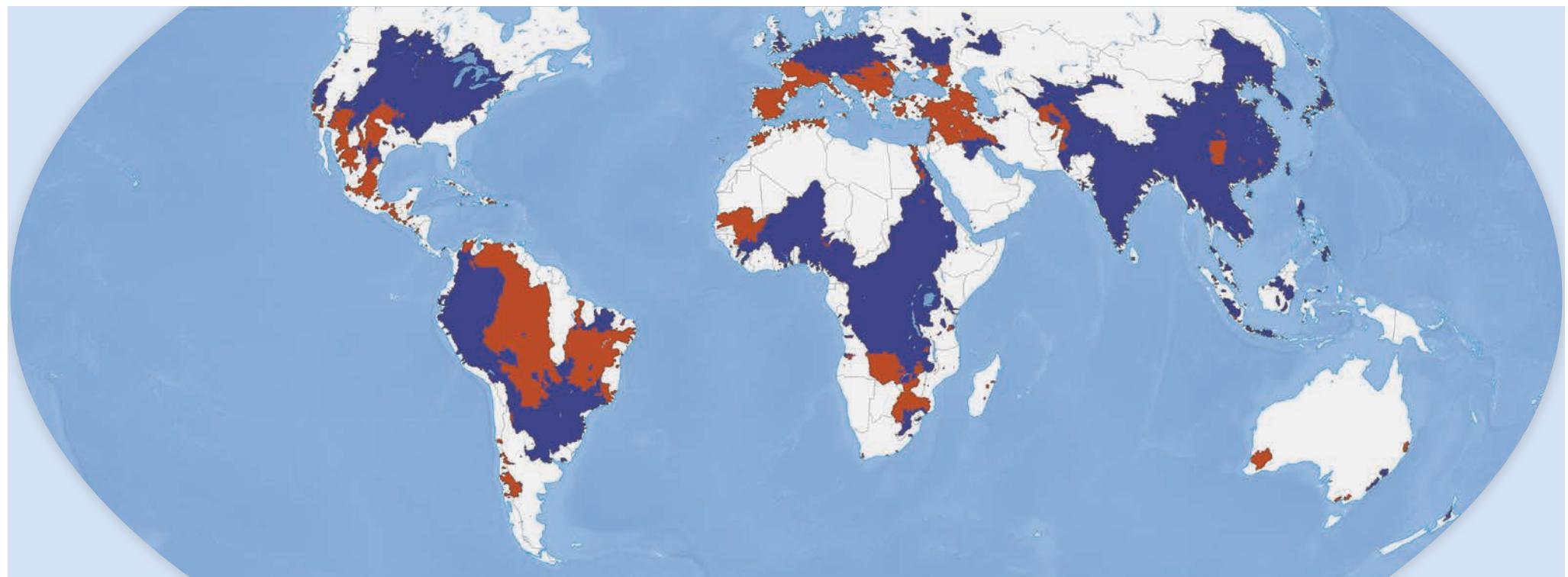
From floods to drought, a large number of the impacts related to climate change are directly linked to water resources. Many of the communities that will be hardest hit are also the least prepared to adapt to these challenges.<sup>200</sup>

Water-related risks increase with greenhouse gas concentrations. Climate change over the present century will reduce the availability of surface and groundwater resources in many regions, resulting in inter-sectoral competition over this natural resource.<sup>201</sup> Increases in temperature are already affecting the intensity and frequency of heat waves, storms and extreme precipitation events, and in some

areas, increasing the rate of major inland flooding.<sup>202</sup> Floods further affect water quality through increases in sediment and other pollutants and disruptions in water treatment.<sup>203</sup> Some arid areas are becoming drier, increasing the probability of drought and more intense and longer-burning wildfires.<sup>204</sup> A consequence of the loss of vegetation from mountain forest wildfires is an increase in the risk of devastating flash floods in lower-lying areas.<sup>205</sup> Some predicted changes will be less visible, yet no less important, such as the spread of vector- and water-related diseases.<sup>206</sup>

Current and past land-use activities in source watersheds, through their conversion and fragmentation of habitat and impairment of downstream freshwater systems, have already made terrestrial and aquatic species more vulnerable to the impacts of climate change.<sup>207, 208</sup> For instance, species whose populations have been severely reduced due to habitat loss may have lost the capacity to adapt to new climate conditions.<sup>209</sup>

## Predicted change in precipitation across urban source watersheds at mid-century



**Figure 3.8.** Change in annual precipitation between 2046 and 2065 in urban source watersheds. Nine General Circulation Models (GCMs) were used to calculate change in precipitation and the predicted direction of change for a given area was determined by 50 percent or more agreement among GCMs. (Source data: <http://ClimateWizard.org><sup>20</sup>)

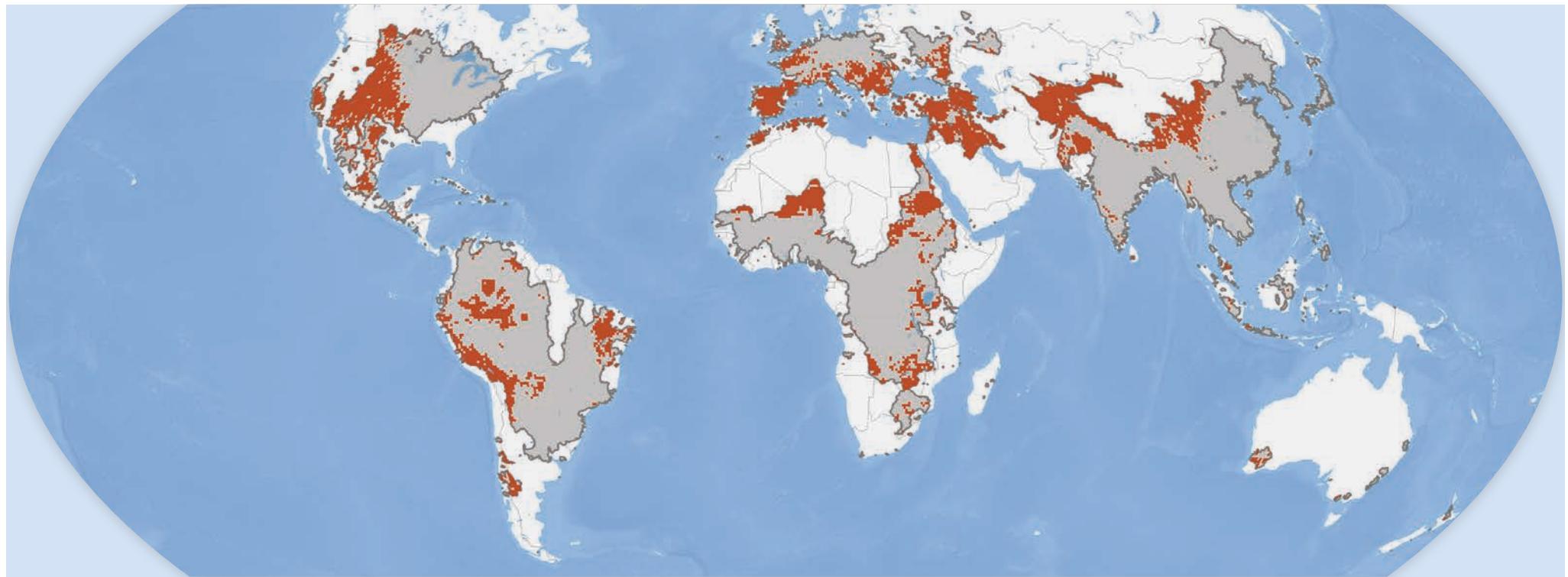
### Direction of change

- Decrease
- Increase

Although global models of future climate conditions resist downscaling to fine-scale geographies, broad patterns are discernable. Changes in precipitation are more difficult to model than changes in temperature, but are highly relevant to considerations of water and freshwater systems. Analysis of precipitation model agreements indicate that, globally, 74 percent of the area within source watersheds will experience increases in annual precipitation and the remaining 26 percent will experience decreases (Figure 3.8, see Appendix III for results by region). Regional numbers tell a different story in some cases. For instance, in Oceania the numbers are flipped, with 74 percent in decreasing precipitation and 25 percent in increasing precipitation.

The uncertainty embedded in these predictions, combined with the coarse model outputs, argues for a cautious interpretation of results. We do not have precise information about when these increases or decreases will occur, or by how much. The answers could have markedly different outcomes. Precipitation increases, for instance, may occur as intense storms resulting in flooding with negative consequences for water security, or those increases may be spread across time more gradually. What we can say is that water supplies, and water flows, will almost certainly change everywhere, with likely but uncertain ramifications for the human and natural communities adapted to historic conditions.

## Predicted increase in fire probability across urban source watersheds



**Figure 3.9.** Areas predicted to increase in fire probability between 2010 and 2039 across urban source watersheds. Calculations were based on the predictions of 16 General Circulation Models (GCMs). The map includes only those areas where at least two-thirds of GCMs agreed that fire probability would increase, shown in red; other areas are shown in gray. (Source data: Moritz, et al., 2012<sup>213</sup>)

● Increase in fire probability

Future precipitation and temperature changes have additional ramifications for fire intensity and frequency worldwide. Wildfires, especially large and high-intensity fires, can have a substantial impact on water quality. Primary water quality concerns following a wildfire include the introduction of organic debris, sediment, nitrate and phosphorus, heavy metals and fire retardant chemicals.<sup>211</sup> The loss of forest canopy and litter layer caused by a fire also reduces the absorption capacity of rainwater and snowmelt, accelerating runoff and erosion.<sup>212</sup> In some cases, landslides are a concern.

We find that 24 percent of the total source watershed area is predicted to have increased fire frequency by 2039 (Figure 3.9, see Appendix III for results by region). These findings are especially concerning for those regions that are already prone to high-intensity fires. In some forests, historic and continued fire suppression contribute to the severity of fires observed today or expected in the future. While these results should not be used to identify specific watersheds where fuel reduction would be an appropriate strategy for reducing the risk of catastrophic fires, they are an indication of where adaptation planning for fire and its impacts may be most critical.

## Opportunities for building resilience to climate change

Adaptation to climate change seeks to reduce the risks and vulnerabilities of social and biological systems to the effects of climate change. It goes hand-in-hand with building resiliency, or strengthening and reorganizing underlying capacities to better absorb future stresses and impacts.

The United Nations reports that climate change adaptation is primarily about water—and that adaptation is, therefore, about better water management practices.<sup>214</sup> We suggest that it is also about better watershed management practices.

In its 2014 report to policymakers, the IPCC includes ecosystem management and physical approaches as essential for reducing vulnerability and exposure to the risks of climate change—and many of these actions form the backbone of source water protection.<sup>215</sup> Source water protection activities such as targeted land protection and revegetation, agricultural and ranching BMPs, and forest fuel reduction have the potential to become key parts of an adaptation and resiliency toolkit with benefits that cascade beyond preventing and adapting to climate effects.

Specifically, by improving water quality, increasing the reliability of downstream water flows and contributing to food security, source water protection activities can move communities to a less vulnerable place. Furthermore, a science-based, adaptation-focused source water protection plan can identify priorities for future protection, restoration and management based on climate models. These future implementation areas may be different from those on the ground today.

The need and opportunity for building resiliency through management of land and water is increasingly obvious to many governments. Of the 130 signatories to the Paris Agreement that include an adaptation section in their INDCs, 115 countries mention the water sector and 127 refer to improvements in the agricultural sector as key concerns when it comes to their nations' capacity to adapt to climate change.<sup>216</sup> Moreover, many countries, especially those from the Global South, link adaptation measures to the eradication of poverty and the movement of those countries toward middle-income levels of development.<sup>217</sup> Integrated approaches to adaptation—of which agroforestry is a part—are mentioned by almost one-third of countries that submitted adaptation measures to the Paris Agreement.<sup>218</sup>

In addition to building resilience for human communities, source water protection can build resilience within aquatic and terrestrial biotic communities, sometimes in indirect ways. For instance, protecting or restoring riparian zones with native vegetation helps provide linear habitat connectivity, links different ecosystems, moderates temperature through shade and creates microclimates for local wildlife through provision of thermal refugia.<sup>219</sup> The high water content of riparian zones also means they are able to absorb heat and buffer organisms against extreme temperatures. At the same time, riparian zones facilitate the infusion of cold groundwater into warmer surface waters, thus allowing for cool water aquatic refugia.<sup>220</sup> Meanwhile, adaptation benefits to biodiversity also benefit people. UNEP reports evidence suggesting that adaptation strategies that benefit native species and habitat can simultaneously build the resiliency of poor communities that rely on linked ecosystem goods and services.<sup>221</sup>

### Resilience:

The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. In essence, the ability to "spring back from" a shock.

*Definition from the UN Terminology on Disaster Risk Reduction<sup>222</sup>*

## Wetlands as adaptation allies



One collection of source water protection strategies of particular relevance to adaptation is wetland

protection, restoration or creation. Wetlands can regulate water flow volume, velocity and floodplain flow rates, thereby reducing flood and drought risk.<sup>223</sup> Cost savings from flood reduction have been reported. For instance, in the Mississippi River Basin, the Wetlands Initiative completed a study showing that the restoration of the 100-year flood zone of the Upper Mississippi five-state watershed could store 48 billion cubic feet (about 1,359,208,600 cubic meters) of floodwater while saving over US\$16 billion in projected flood damage costs.<sup>224</sup>

## Adapting to the unpredictable: Precipitation change

Especially, but not solely, in the 26 percent of the area within source watersheds predicted to experience decreases in precipitation by mid-century, source water protection activities may contribute to maintaining the reliability of base flows. Protecting intact forests is a proactive strategy for buffering against future precipitation declines, along with reforestation and agricultural BMPs. Areas of the landscape where revegetation or agricultural BMPs have a disproportionately large infiltration benefit due to soil conditions and other factors should be prioritized. Furthermore, to the extent that forest corridors along rivers and streams can be prioritized for restoration or protection, thermal benefits to native species may be maximized.

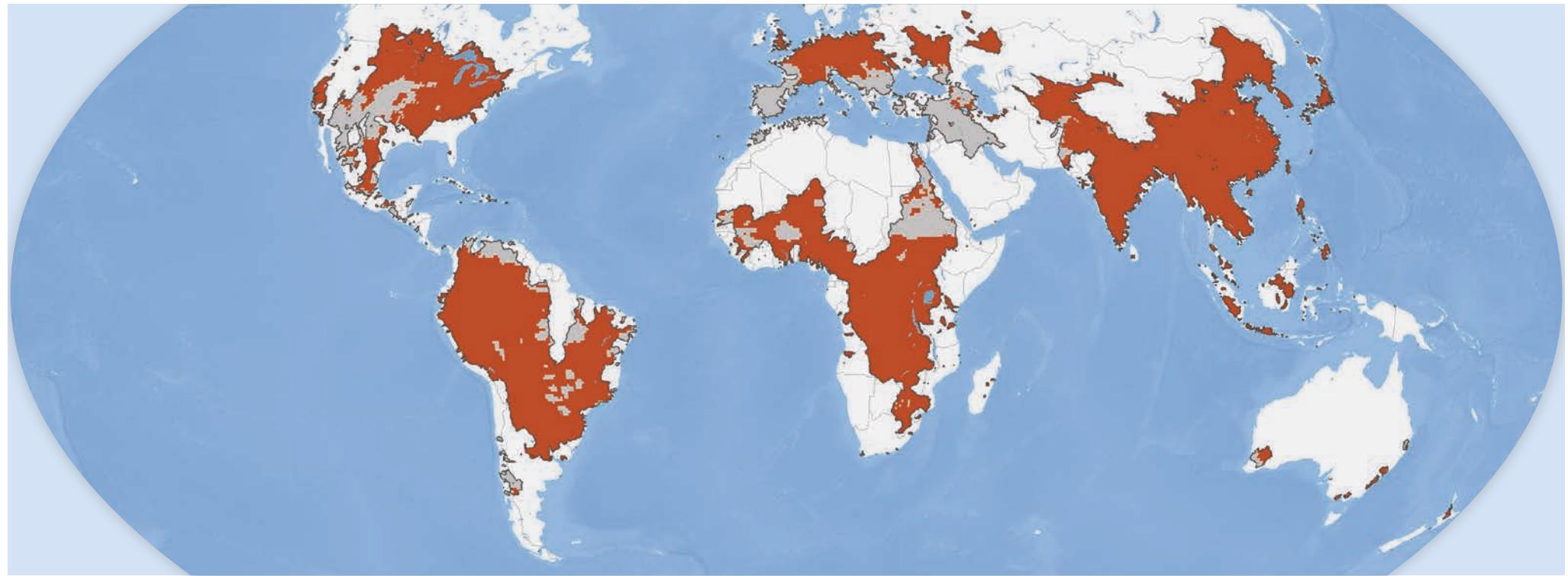
Future flooding resulting from changes in the timing and volume of precipitation are of equal concern in many geographies. By and large, the same activities that can improve base flow also have the potential to moderate the levels of less intense and more frequent storm events because they promote infiltration over runoff. Adaptation to catastrophic flooding will require investments beyond source water protection, especially within cities and other communities in downstream and coastal areas, but natural infrastructure can provide a strong base to mitigate against more common floods.

Even without droughts or floods, a new climate reality will likely still require adaptation by both upstream and downstream communities. For instance, farmers may need to adjust their application of fertilizer to account for new precipitation patterns so that more fertilizer stays on fields and less nutrients run off into streams. These “smaller” forms of adaptation align well with source water protection, which will have limits in terms of mitigating impacts from major climate events but can lead to measurable improvements for more everyday climate challenges.



Photo: © Mark Godfrey

Predicted increase in erosivity at mid-century across urban source watersheds



**Figure 3.10.** Areas predicted to increase in erosivity between 2046 and 2065 across urban source watersheds. Nine General Circulation Models (GCMs) were used to calculate change in erosivity. Only areas where at least half of the GCMs agree that erosivity will increase are shown in red on the map; other areas are shown in gray. (Source data: <http://ClimateWizard.org><sup>227</sup>)

### The near certainty of increased erosion and adaptation options

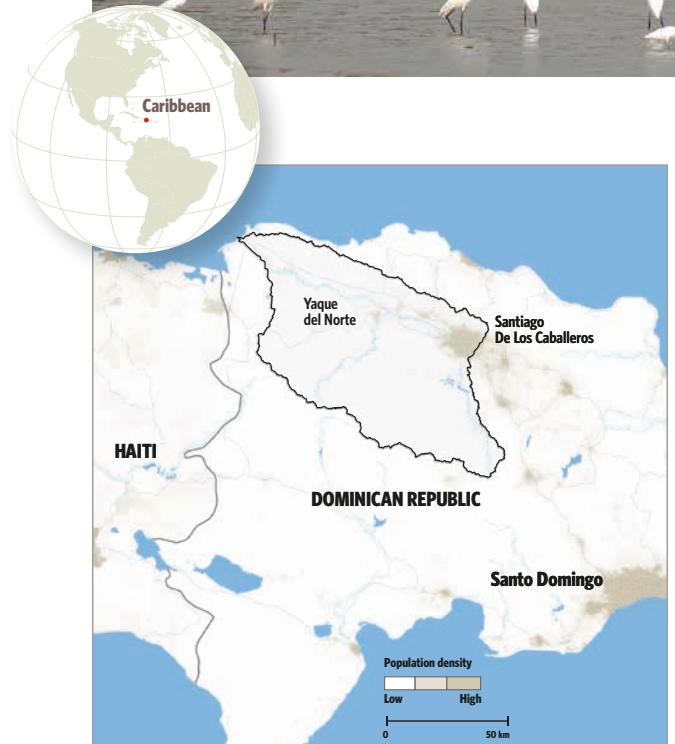
Conventional agriculture is one of the main contributors to climate change.<sup>225</sup> At the same time, unsustainable agricultural practices—monoculture, short rotations and intensive tillage—directly expose soil to the erosive effects of wind and rain.<sup>226</sup> Where climate change is predicted to bring increased precipitation, storms and flooding will heighten erosive processes. Erosion not only leads to water pollution but reduces soil productivity and thereby reduces the resiliency of farming communities.

Erosivity increase

There are clear benefits to both human and aquatic communities from focusing source water protection practices in areas that are prone to erosion today and likely to experience increased erosion in the future. Activities like agricultural BMPs will be important across nearly the entire extent of urban source watersheds as 83 percent of their entire area is predicted to increase in erosivity by mid-century (Figure 3.10). The highest proportions are in Asia, Africa, Latin America and the Caribbean, but the wide extent of predicted change, coupled with the additional co-benefits of erosion control (e.g., reduced water treatment and hydropower generation costs, reduced stresses on aquatic species) argue strongly for implementation of these activities wherever possible.

## LOCAL SPOTLIGHT

### Rio Yaque del Norte, Dominican Republic—Preparing for a climate-changed future



#### The challenge

As nations around the world commit to addressing the drivers of climate change, individual countries and the communities within them are confronted with the need to adapt today. The Dominican Republic in the Caribbean is becoming increasingly concerned with how climate change will affect its watersheds' natural hydrological services given the precipitation, temperature and extreme weather events that have been projected for the country. The projected increase in intense storms and hotter conditions are likely to disproportionately affect residents who are already vulnerable (e.g., people living in poverty, lacking infrastructure).<sup>228</sup> Of high concern to decision-makers is the effect land use and climate change could have on reducing both water quality through sedimentation and the reliability of water supplies through changes in flow.

The Yaque del Norte River has the largest basin of any in the Dominican Republic, covering almost 15 percent of the country (about 705,300 hectares). Sub-watersheds within the basin are critical for delivering the urban populations' drinking supplies, meeting the needs of agricultural and industrial sectors, providing a source for hydropower development and housing a broad diversity of aquatic life. Agriculture is the most water-intensive of all sectors, using 80 percent of the basin's water and covering 20 percent of its land area. The remaining basin area is covered by forests, scrub and grasslands, mangroves, other vegetation types and populated areas.<sup>229</sup> Urban areas use about 12 percent of the basin's water which goes to a combination of domestic, commercial and industrial sectors.

Given the importance of the Yaque del Norte Basin to the Dominican Republic's residents, economy and biodiversity, the projection that precipitation in the basin will experience a slight decrease in the future while extreme hydro-meteorological events will intensify, calls for increased investment in adaptation measures.<sup>230</sup>

## Action and opportunity

The Nature Conservancy and its partners designed the Yaque del Norte Water Fund explicitly with climate change in mind. Its activities will contribute to regulating base flow and reducing soil erosion –with the aim of reducing future water security risk – and helping communities build resilience to other climate change impacts like sea level rise.

With support from the United States Agency for International Development (USAID), The Nature Conservancy worked with Riverside Technology to assess the long-term impacts of climate change when combined with different land use and land cover projections. Researchers used SWAT (Soil and Water Assessment Tool) to develop scenarios out to 2055, the results of which inform what conservation activities the water fund should specifically include to produce the greatest contribution to base flow and lowest sediment loads for present and future conditions.

While multiple climate change scenarios were used in this study, all projections supported the notion that the average annual temperature would increase by 1 to 3.5 degrees Celsius with respect to the historical mean. Mean annual precipitation projections, however, range from about -40 percent to +20 percent, representative of weather in a climate-changed future where variations of total rain from year-to-year can become intensified.<sup>231</sup> Urban population growth and GDP projections were used to estimate the urban land cover in 2055, while changes in farmland from 2002 to 2011 were used to estimate the future extent and types of cropland.

A series of future land use and land cover scenarios was developed to compare possible outcomes of different management actions within the watershed. Urban and crop expansion were simulated for the business-as-usual, development and combination scenarios, whereas forest expansion and reduction of crops were simulated for the conservation scenario.

A combination of reforestation, agroforestry and silvopasture practices were simulated under the best management practice scenario.<sup>232</sup>

While this study identified a range of outcomes for each scenario, it found that the best management practice scenario would produce the best outcome, with the largest water yield in terms of base flow alongside the lowest sediment yield.<sup>233</sup>

That scenario included:

- reforestation in areas where slopes are greater than 60 percent;
- reforestation of a 30-meter buffer along main rivers;
- reforestation of a 250-meter buffer around reservoirs;
- agroforestry practice in areas with slopes less than 60 percent, as well as within protected areas; and
- silvopasture practice in forested areas with slopes between 10 percent and 25 percent, as well as outside protected areas.

Scientific results such as these have been directly applied to guide decision-making under the Yaque del Norte Water Fund's approach to adapting to climate change. The climate change adaptation strategies for the water fund now include:

- conservation and restoration of riparian corridors to diminish the impacts of floods;
- targeted conservation of forests to avoid an increase in sediments during heavier rainfall periods;
- conservation and restoration of mangroves and coastal wetlands to diminish the impact of sea level rise; and
- analysis of connectivity routes to develop private and community-managed biological corridors.<sup>234</sup>

These adaptation-focused activities will complement others, including forest restoration for both ecological and hydrologic benefits, the implementation of BMPs on coffee and cacao plantations and livestock pastures, training and environmental education programs, and facilitation of participatory governance processes. All told, the water fund is expected to generate a range of benefits for more than 1.7 million people living and working in the basin, for companies using bulk water systems in production and processing, and for power companies for whom reducing sedimentation of hydroelectric reservoirs is a priority.<sup>235</sup>

RIO YAQUE DEL NORTE DASHBOARD						
Water fund start date	Number of upstream participants to date	Number of potential downstream beneficiaries	Number of partners to date	Primary funding sources	Activities	Anticipated co-benefits
2015	475	Between 1,000,000 and 5,000,000	14	Multi-lateral Private NGO/Foundation	   	    

## Human health and well-being

Human well-being, of which health is a key part, depends in no small part on the health of the environment.<sup>236</sup> Communities around the world have long recognized and valued the inseparability of human and natural systems through the lens of health. For example, access to clean water, secured in part through well-managed watersheds, underpins and enhances human health far beyond mere survival. Clean, ample water supplies are inextricably linked to vibrant physical and mental well-being, cultural and spiritual fulfillment, and social connections.<sup>237</sup> The scientific and medical communities have understood the cause-and-effect relationship of sewage-contaminated water and diseases like cholera since the mid-1800s,<sup>238</sup> and studies of the broader health effects of environmental change date as far back as the time of Hippocrates in fifth century B.C.<sup>239</sup>

However, the multiple links between watershed management and human health are only now beginning to be explored in full.<sup>240, 241, 242</sup> Robust evidence for this dependence is emerging from a rapidly growing and fascinating research frontier that is highlighting the importance of well-managed watersheds for a number of positive human health outcomes.<sup>243, 244, 245</sup> Some of these linkages are related to how land management affects water pollution (e.g., bacteria and nutrients) and the retention of those pollutants, whereas others relate to changes in ecosystem function and services not directly related to water supplies (e.g., crop pollination and disease regulation). These relationships are complex, as health outcomes also depend on cultural, socio-economic and political mediating factors.<sup>246, 247</sup> However, based on existing evidence, source water protection, particularly when situated as part of a systemic approach to water management, has a strong potential to be a “strategic health care partner.”<sup>248</sup>

## Source Water Protection and Human Health

The relationships between source water protection activities and positive health outcomes are complex. Watershed conservation is just one of many factors that influence human health, and it interacts with a suite of mediating factors that underlie positive health outcomes. For example, the degree to which riparian restoration (a source water protection activity) will influence pathogen loads and water quality (an ecosystem service) will depend on mediating factors such as

precipitation and broader land-use planning and management (e.g., surrounding livestock waste management practices). Secondly, the influence of the resulting change in water quality in reducing diarrhea rates and resulting morbidity or mortality (a positive health outcome) will in turn depend on a suite of mediating factors like whether or not people have access to improved water sources and access to health care.<sup>249, 250</sup>



Photo credit: © Amy Deputy

Here we elaborate on four principle pathways that demonstrate how source water protection can lead to positive health outcomes for both upstream and downstream communities, understanding that more pathways are likely to be elucidated in the future. We focus primarily on physical health outcomes because these pathways are more amenable to mapping than other aspects of well-being, but mental health and social and cultural connections are equally important dimensions of human health and broader well-being.

### Improving water quality for reduced diarrheal disease

Approximately 80 percent of diarrheal disease—the second leading global cause of death of children under the age of five—is attributable to unsafe water and insufficient hygiene and sanitation.<sup>251</sup> This diarrheal disease burden is disproportionately experienced by low- to middle-income countries, particularly in sub-Saharan Africa, Southeast Asia, Latin America and the western Pacific.<sup>252</sup> Addressing this problem requires a systemic approach focused on improving sanitation, hygiene and water access while also decreasing pollution from land management practices.<sup>253</sup> Interventions at the household level (e.g., point-of-use water filters, safe water storage and hygiene) and the community level (e.g., improved access to high-quality pipe water and sewer connections) have led to significant progress in addressing this issue.<sup>254, 255</sup> However, there is also an important need for a broader focus on source watershed planning initiatives that address the problem at the source and reduce pathogen contamination of water supplies.

Source watershed planning includes managing human settlements and waste, as well as the spatial location and management practices of agricultural and ranching activities. Livestock production, which occurs on approximately 30 percent of the ice-free terrestrial surface of the Earth,<sup>256</sup> is of particular concern because livestock waste can contain the pathogen cryptosporidium<sup>257</sup>—the second leading cause of moderate to severe diarrhea in infants in the developing world.<sup>258, 259</sup>

Ranching often holds a central position in the livelihoods of local farmers and communities around the world. Livestock rearing produces well-being benefits in the form of protein production and household income, and often has important social and cultural benefits. On-farm best management practices (e.g., riparian buffers and spatial planning of livestock activities) can reduce the occurrence of cryptosporidium and other pathogens entering water systems, providing an important means to securing on-farm and downstream benefits through clean water. Many of these water quality benefits can likely be achieved without reducing production value, providing win-wins for livestock production and water quality.

However, in cases where source water protection does involve reducing livestock numbers or removing certain lands from grazing, tradeoffs in production and water quality merit careful consideration. Whether rates of diarrheal disease are reduced in a given place will depend on local mediating factors such as the availability of water filtration and good hygiene practices. The greatest benefits will likely be seen in areas where livestock are important contributors to pathogen contamination of water sources and where water treatment is limited, which is the case in many rural and marginalized areas in the developing world.<sup>260, 261</sup>

Protection and restoration of forest and other ecosystems—when strategically located as a buffer between livestock and water bodies—can also help to keep pathogens from reaching water sources, mitigating the effect of livestock and human waste on water quality.<sup>262, 263</sup> The effects of vegetation on water quality and human health are complex and heterogeneous, but emerging research suggests a clear link between forest cover and water quality. For example, a recent study of the watersheds of 40 Canadian rivers found clear relationships between land use and water quality, though the spatial scales over which urban, agricultural and forested land uses affected different water quality parameters varied. The bacterium *Escherichia coli*, for instance, was associated primarily with land use at local (5 to 10 kilometer) scales, underscoring the importance of targeting source water protection activities where they can make the greatest difference.<sup>264</sup>

Another dimension of the relationship between source water protection and diarrhea relates to water quantity. Having sufficient water for both household activities (cooking, cleaning) and personal hygiene is closely related to health outcomes.<sup>265</sup> Insufficient availability of water can lead to poor hygiene practices that increase the chances of bacterial infections, resulting in diarrheal diseases and sometimes even death. The relationship between source water protection and water quantity is complex, but conservation of natural vegetation cover may maintain the reliability of dry season base flows in some regions.<sup>266</sup> For example, a study from Indonesia found a positive relationship between forest cover and base flow, as well as a link between base flow and lower diarrhea rates.<sup>267</sup>

Interventions focused specifically on improved sanitation, hygiene and point-of-use treatment systems are likely the most effective ways to decrease diarrhea.<sup>268</sup> However, ranching BMPs and activities that promote the conservation of natural vegetation cover are important components of a systemic approach to water management that combines source water protection with other technical and social interventions.

## Vector-borne disease

Disease ecology is a dynamic frontier of research that is evaluating the links between ecosystem change and the emergence and transmission of zoonotic diseases—those that can be spread between animals and humans.<sup>269</sup> The Millennium Ecosystem Assessment recognizes regulation of infectious disease as a critical ecosystem service, given mounting evidence that ecosystem degradation increases disease risk.<sup>270</sup> There is a growing list of zoonotic diseases that are expanding due to changing interactions with people and animals, both domestic and wild, as a result of agricultural expansion and encroachment into natural habitats (Table 3.1). These include, but are not limited to, West Nile virus and Lyme disease in North America, Japanese encephalitis in Southeast Asia, trypanosomiasis in eastern Zambia and a variety of bat-transmitted viruses in Australia.<sup>271</sup>

In general, the effect of ecosystem alteration on infection risk is complex. When natural habitats are fragmented or otherwise altered, the interactions among pathogens, vectors and hosts can change, but the direction of change may be highly context-specific.<sup>272</sup> A key element is how local human populations' presence and/or behaviors influence exposure to increase or reduce disease transmission.<sup>273</sup>

The case of malaria, in which the predominant strain *Plasmodium falciparum* is carried by over 40 species of the *Anopheles* mosquito, offers an example of the complexity of the relationships that predict disease burden. Depending on which species of *Anopheles* is present in a landscape, land-use change can have very different impacts on rates and transmission risks of malaria to local human populations.<sup>275</sup>

It is generally expected that deforestation in the Neotropics and Central Africa will increase malaria risk because there are few known deep-forest mosquito vectors, but one or more dominant near-forest species.<sup>276</sup> Deforestation in these areas creates more amenable habitats for mosquitoes and draws people into direct contact with vectors, for instance, by offering new farming opportunities. This phenomenon has led to what is known as "frontier malaria," especially in Latin America.<sup>277</sup> Maintaining intact blocks of forest, as opposed to creating extensive forest edges, may help to reduce malaria exposure in these areas.<sup>278</sup>

In contrast to the frontier malaria situation in the Americas and Africa, in Southeast Asia there are many forest-dwelling malaria vectors.<sup>279</sup> Deforestation and clearing in the region have mostly been associated with decreasing rates of malaria.<sup>280, 281</sup> Conservation activities to protect and restore forests in these areas will need to be cognizant of these dynamics when working with local communities.

Agents and infectious diseases with suspected or known links to landscape change

Vector-borne and/or zoonotic	Soil	Water	Human	Other
Malaria	Melioidosis	Schistosomiasis	Asthma	Hemorrhagic fevers
Dengue	Anthrax	Cholera	Tuberculosis	Foot and mouth
Lyme disease	Hookworm	Shigellosis	Influenza	Rice blast
Yellow fever	Coccidioidomycosis	Rotavirus		Trachoma
Rift Valley fever		Salmonellosis		
Japanese encephalitis		Leptospirosis		
Onchocerciasis		Cryptosporidiosis		
Trypanosomiasis				
Plague				
Filariasis				
Meningitis				
Rabies				
Leishmaniasis				
Kyasanur Forest fever				
Hantavirus				
Nipah virus				

Table 3.1. Reprinted from Patz et al., 2004<sup>274</sup> with permission.

Understanding the local social and economic context, and pairing interventions with public health education programs focused on shifting people's behaviors, will be critical to ensuring that exposure to the disease is diminished through source water protection activities. Such planning is especially important where current rates of malaria are unstable or low. In these areas, human populations are often naïve to the disease and outbreaks can be devastating.<sup>282, 283</sup>

With these caveats as to the complexities of predicting disease transmission, we find that:

- 25.1 percent of the area within source watersheds is classified as having unstable or low risk of endemic malaria transmission (Southern Amazon basin, Nepal and South East Asia);
- 4.8 percent of the area within watersheds area is classified as having a stable moderate risk of endemic malaria transmission (Nile basin and Great Lakes Area of East Africa, Northern India and Western Amazon); and
- 12.9 percent of the area within watersheds is classified as having a stable high risk of endemic malaria transmission (Central and West Africa).

Thoughtful protection of remaining intact forest resources and improved agricultural practices, particularly irrigation practices, can prevent further increases in the prevalence of malaria by reducing vector breeding habitats and human exposure to mosquitos. However, to more fully address disease risk, such efforts must be paired with control and prevention measures that encourage people to reduce areas of still water near houses where mosquitos breed, spray their houses and screen windows, use bed nets and wear long garments to help prevent mosquito bites.<sup>284</sup>

### Hidden hunger

As we have seen, healthy watersheds are the source of ecosystem services that go well beyond water security. Pollination is one such critical service. Over 75 percent of the world's crop species depend on pollination by bees, butterflies and other insects to produce the foods we consume. These crops represent approximately 35 percent of global annual food production, and the annual value of global crops directly affected by pollinators is US\$235 billion to US\$577 billion.<sup>285</sup> Equally important is the role of pollination for the production of essential micronutrients (e.g., vitamin A, iron and folate) in fruit and vegetable crops like pumpkins, melons and tropical fruits.<sup>286, 287</sup>

Deficiencies in these essential micronutrients have been termed "the hidden hunger" for their role as the major nutrition crisis of our time. While nearly 800 million people suffer from malnutrition due to insufficient caloric intake, even more—upwards of 2 billion people—lack sufficient micronutrients in their diet for a healthy and productive life.<sup>288</sup> Micronutrient deficiency is on the rise in many parts of the world<sup>289, 290</sup> with serious consequences, especially for children and pregnant women.<sup>291, 292</sup>

In many low-income countries, local nutritional diversity of national food supply (as measured in per capita availability), alongside consumption choices, is highly associated with key human health outcomes.<sup>293</sup> This suggests that in those low-income countries where micronutrient deficiencies are highest, the per capita

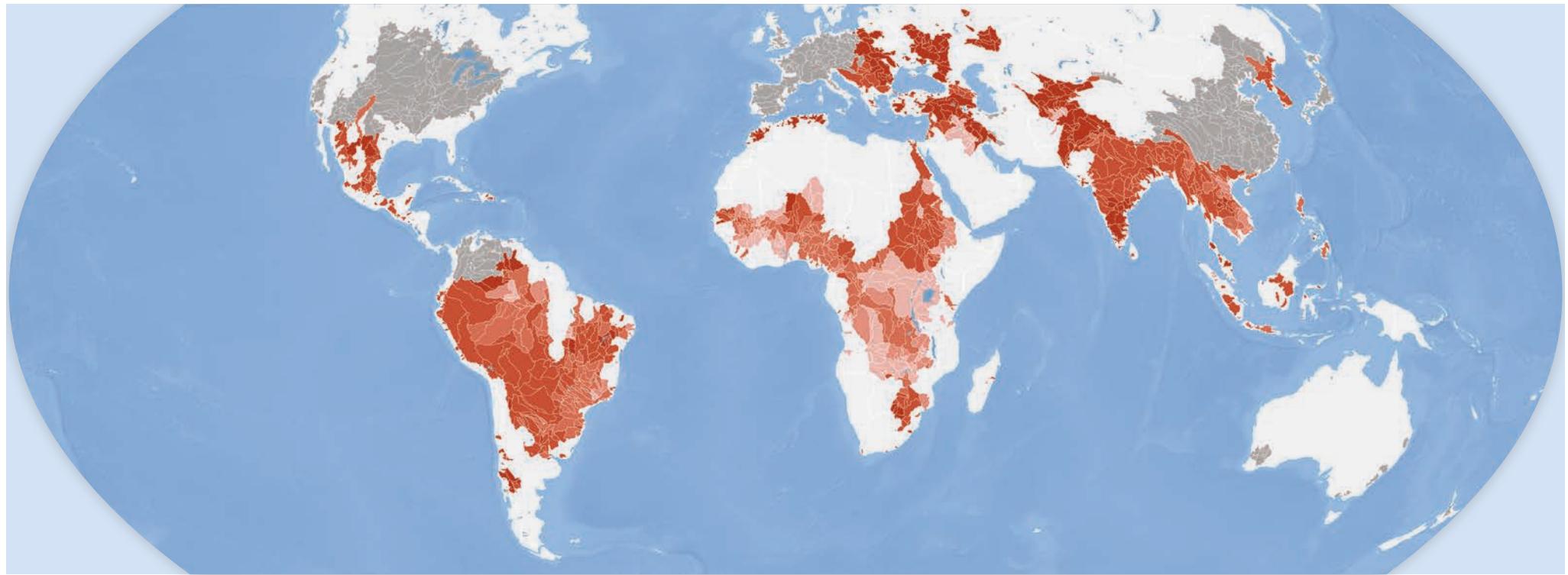
production of micronutrient-rich, pollinator-dependent crops can influence local health outcomes. In middle- and high-income countries,<sup>294</sup> trade flows are more likely to fill potential nutritional production gaps.

People, then, depend on certain crops as a source of essential micronutrients, and these crops in turn depend upon bees and other animal pollinators for fruit set or seed production. Pollinators, in turn, depend on healthy natural and agricultural ecosystems for foraging and nesting success.<sup>295, 296, 297</sup> Land use and management practices that threaten pollinator populations (e.g., pesticide use and vegetation loss), therefore, may have serious implications for human nutrition and health.

Globally, pollinator populations (including wild and domestic populations) are already in massive decline. More than 40 percent of invertebrate species—particularly bees and butterflies—face extinction,<sup>298</sup> a trend incredibly concerning for both ecosystem and human health. This decline is attributable to multiple synergistic stressors including pesticide use, disease, on-farm habitat loss in simplified agricultural landscapes (loss of hedgerows, grass strips and wildflowers), surrounding area habitat loss and climate change.<sup>299, 300</sup>

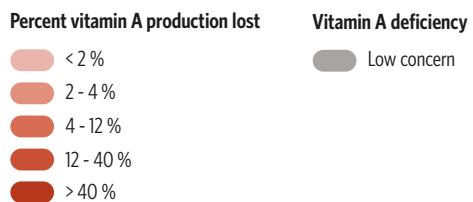


## Percent vitamin A production reduction within urban source watersheds in “no pollination” scenario



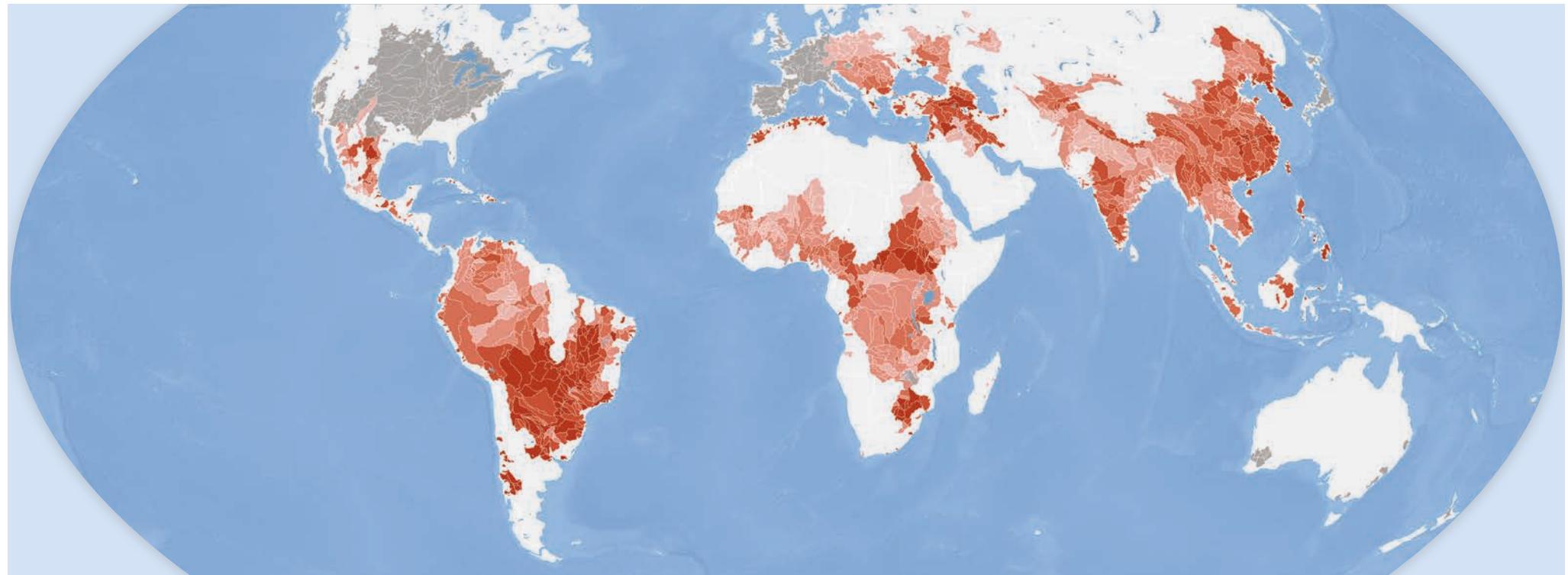
**Figure 3.11.** Percent reduced vitamin A production within urban source watersheds without pollination for areas currently experiencing moderate or severe vitamin A deficiency based on country-wide statistics (Source data for country-level statistics: WHO 2009<sup>307</sup>). Watersheds in gray are of low concern for vitamin A deficiency. (Source data: Klein, et al., 2007; Monfreda, et al., 2008; FAO food composition databases)

A general rule of thumb suggests that at least 30 percent of an area surrounding or within agricultural lands needs to remain as forests, shrublands, grasslands and/or agroforests in order to provide adequate habitat for pollinator species populations.<sup>301, 302, 303</sup> As we see in a subsequent section, within urban source watersheds 4.7 percent of forests that were present in 2000 were gone by 2014, and more losses are expected in the future in many regions without conservation interventions. Further habitat losses and unsustainable management practices will likely result in continued pollinator declines and falling crop yields, which may limit access to micronutrient-rich foods in vulnerable regions.<sup>304</sup> Actions to protect and restore forests, agroforests and other ecosystems for water-related benefits could, therefore, simultaneously protect pollination services.



Following a recently developed methodology (see Appendix V),<sup>305</sup> we evaluated what the impact of the full loss of all pollinators would be in terms of crop and micronutrient production. Although complete loss of pollination habitat is an unlikely scenario, evidence shows that the total loss of pollination is not tremendously far from observed pollination loss, particularly in cases where natural vegetation cover drops below the 30 percent threshold within a radius of 1 to 3 kilometers surrounding croplands. Using global food composition tables, we compare a baseline scenario of current crop and micronutrient yield to a “no pollination” scenario where crop yield and its associated micronutrients were reduced by their respective pollination dependence.<sup>306</sup> We show the calculated percent loss in crop-based vitamin A and iron production associated with the loss of local pollinators for each source watershed (Figure 3.11 and 3.12).

## Percent iron production reduction within urban source watersheds in “no pollination” scenario



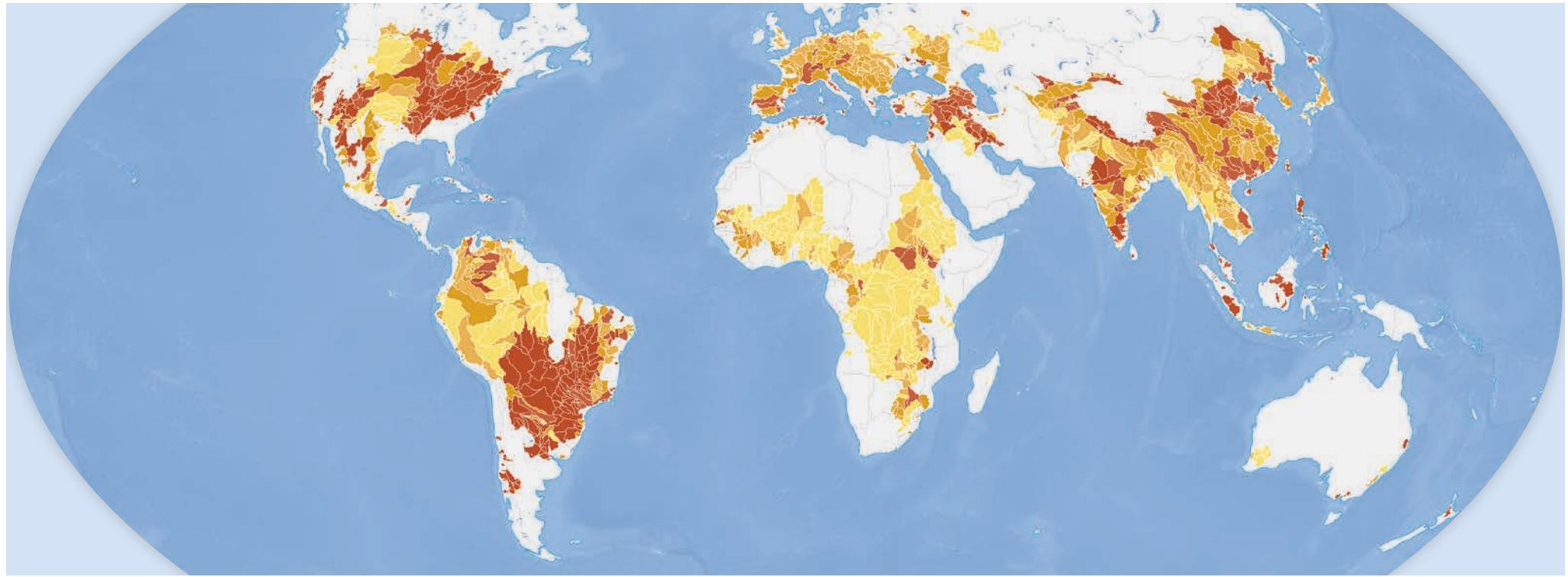
**Figure 3.12.** Percent reduction in iron production within urban source watersheds without pollination for areas currently experiencing moderate or severe iron deficiency based on country-wide statistics (Source data for country-level statistics: WHO 2008<sup>309</sup>). Watersheds in gray are of low concern for iron deficiency. (Source data: Klein, et al., 2007; Monfreda, et al., 2008; FAO food composition databases)



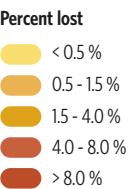
The impacts of lost pollination on micronutrient production are striking. Of the two micronutrients we considered, vitamin A tends to have the largest percent loss when pollination services are removed, in some places by as much as 40 percent or more (see Appendix III for results by region). The regions most affected include Mexico, Central Asia, parts of the Middle East and Eastern Europe where losses of vitamin A would be greater than 40 percent. These changes overlap areas where vitamin A deficiencies are already moderate or severe (>20 percent).<sup>308</sup> Even in Africa, where the expected declines are more moderate (on the order of 2 to 12 percent), the high background level of vitamin A deficiency suggests that additional loss of this micronutrient from local food supply could place these populations at even higher risk.

Losses in iron production are more heterogeneously distributed through the source watersheds (see Appendix III for results by region). Some areas, notably Eastern Europe, would have nearly no reduction in iron production, while parts of South America would experience large losses. Without pollination, the Cerrado of Brazil and the Chaco of Argentina, where there are already moderate iron deficiencies, would both suffer losses greater than 12 percent in iron production. The upper parts of the Nile River Basin would also experience significant declines in iron production, which could critically impact a local population where 40 percent of people already experience severe iron deficiency.<sup>310</sup>

## Percent agricultural economic value lost



**Figure 3.13.** The estimated percent of total agricultural economic value lost in the absence of pollination services. Calculations of agricultural economic value were based on spatially explicit crop data compiled by Monfreda, et al., 2008<sup>311</sup> and FAO trade data on crop-specific pricing.<sup>312</sup>



Overall, approximately 2.6 billion people live in source watershed areas where greater than 10 percent of micronutrient supply would be lost without the benefits of pollination. Another 3.8 billion people live where 5 percent or more of micronutrient supply would be lost.

Because the loss of pollinators would also affect overall crop yields, farming economies around the world would be affected. Looking at where these reductions in yields would have the greatest economic impact, we see that South America would experience the largest losses. The United States, China and Europe would also see considerable losses (Figure 3.13). Yields are not expected to change dramatically in Africa and Southeast Asia, which also correlates with the proportionally smaller declines in vitamin A and iron in these regions. The differences between our

micronutrient findings and these on lost economic value underscore that economic output alone may underestimate the full effect on human health.

Within urban source watersheds, forest protection and restoration adjacent to agricultural lands, agricultural BMPs (including reduced pesticide use, which has the added benefit of reducing direct human health impacts) and agro-ecological systems, such as agroforestry, could help avert the total global loss of 11 percent of vitamin A production, 6 percent of iron production and 5 percent of agricultural production's economic value.

The actual impact of these decreases in crop and micronutrient availability will depend on mitigating factors in each region, including the availability of

## Mental and Physical Health Benefits of Natural and Semi-natural “Green Spaces”

A growing body of research links time spent in natural and semi-natural areas to improved mental and physical health and well-being.<sup>313, 314, 315</sup> This link has long been recognized intuitively and is now supported by scientific studies. In varied contexts, nature-based experiences have been linked to decreased depression, enhanced cognitive functioning and reduced stress.<sup>316, 317</sup> For example, the Japanese practice of *Shirin Yoku* (literally “forest bathing”) draws on research showing that spending time in the forest reduces stress, improves mood and concentration, reduces blood glucose levels among diabetic patients and boosts immune functioning.<sup>318, 319, 320, 321</sup>

Caring for and stewarding land and marine resources can be a source of joy and relational values in many communities.<sup>322</sup> This is particularly the case among

communities with deep cultural connections to place and social cohesion tied to interacting with, caring for, and sharing natural resources. For example, in indigenous Hawaiian culture, the values of *kuleana* (stewardship and responsibility), *malama āina* (caring for the land) and *aloha āina* (love of the land) underpin healthy and resilient communities. These psychological, cultural and social benefits of ecosystem stewardship are experienced in a variety of contexts. Globally, a suite of cultural “services” including spiritual fulfillment, recreation and social cohesion are considered critical human well-being benefits of nature.<sup>323</sup> Source water protection activities that engage communities in stewardship and maintain access to natural and semi-natural environments can have positive psychological, physical, cultural and community health benefits.

supplements, people’s dietary behavior and prices of nutritious local foods. Regardless of these factors, the health of pollinators—which are intricately linked to how we manage land—clearly plays a role. Implemented at a large scale, these activities may help to reduce or even reverse the rapid decline of pollinators around the world and support healthy, local diets. Within source watersheds, optimized location of natural land cover protection in close proximity to agricultural lands will be important to maintaining pollination services.

### Beneficiaries of source water protection

The potential well-being benefits of source water protection described here accrue to both the local, rural communities where the source water protection activities are carried out, and also to non-targeted urban and rural populations throughout the watershed.

Across urban source watersheds, source water protection activities have the potential to provide well-being benefits to 4.4 billion people who live in these watersheds. This includes 780 million people who live in watersheds located in countries in the bottom-tenth percentile of the Human Development Index (as of 2014).<sup>324</sup> The poorest people may have the most to gain from water quality and quantity improvements and other health benefits, especially where they lack access to improved water sources and are food insecure.

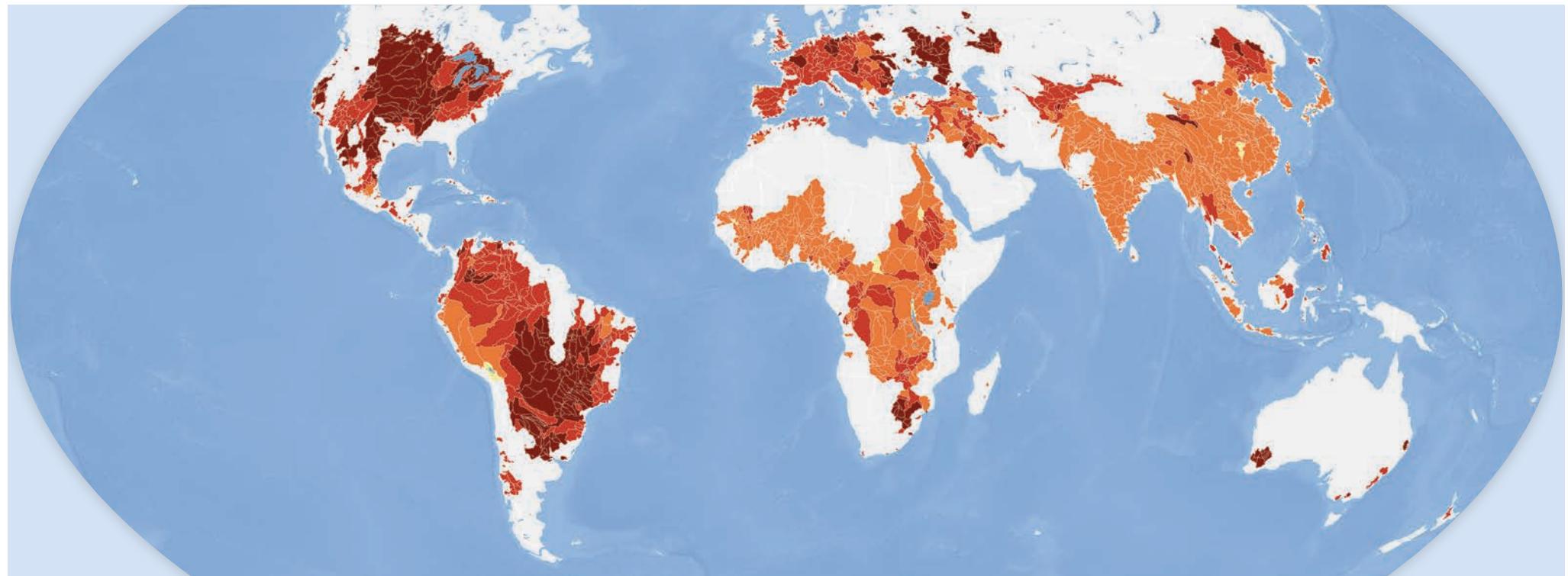
If source water protection were to go to scale to achieve 10 percent sediment and/or nutrient reductions, we also estimate that up to 28 million farming households (for sediment) and 89 million households (for nutrients) would have the

opportunity to participate in agricultural BMPs, with potential for benefits from improvements in crop production, reduced farming costs, increased community resilience and other well-being benefits.

Of these potential farmers, 92 percent (for the sediment reduction target) and 96 percent (for nutrients) would be smallholder farmers—those with less than 2 hectares of land—primarily in Africa and Asia (Figure 3.14). In total, across all urban source watersheds, 53 and 79 percent of cropland targeted with agricultural BMPs for sediment and nutrient reduction respectively is managed and owned by smallholder farmers. Working with these farmers will require building trust and designing incentives and activities that increase productivity while providing broader societal benefits. Although these farmers will unlikely be able or willing to set aside land for conservation or forest restoration, they would benefit from soil conservation, silvopasture, agroforestry and other agricultural BMPs that can help ensure the sustainability and resilience of their production systems over time.

In contrast, mostly large landholders would be engaged in North America and South America, where a single farming household can own and manage up to 600 hectares of land. In these areas, due to their smaller number, the transaction costs of working and coordinating with farmers would be much reduced, with the potential for large gains because a significant portion of the total nutrient pollution comes from these industrially-managed systems. In this way, there is a trade-off between reduced transaction costs and number of people in the watershed benefiting from source water protection, although transactions costs can be reduced through a variety of approaches described in Chapter 6.

Distribution of median field and farm sizes within urban source watersheds



**Figure 3.14.** The estimated median field and farm size across urban source watersheds. (Source data: Fritz, et al., 2015<sup>325</sup>)

**Median field size (ha)**

- < 0.5
- 0.5 - 2
- 2 - 20
- > 20

The poorest people may have the most to gain from water quality and quantity improvements and other health benefits, especially where they lack access to improved water sources and lack food security.

## Source Water Protection and Sustainable Agriculture

Source water protection programs can offer an attractive benefit to land stewards through incorporation of “working landscapes” – or landscapes that provide both environmental and livelihood benefits. While the concept of working landscapes and their component agricultural BMPs may be relatively new, some of the practices have a long history in traditional (as opposed to conventional) agriculture.

Agroforestry—or crops with trees—is an increasingly prominent example of a working landscape practice that can provide multiple economic, cultural and ecological benefits.<sup>326, 327</sup> Agroforestry’s diversified cropping systems mimicking natural forests form an important part of indigenous food production systems around the world and are also being used as a contemporary agricultural BMP in non-traditional contexts. These systems tend to be resilient, productive, pest-resistant, nutrient-conserving and biodiverse, providing multiple economic, cultural and ecological benefits.<sup>328</sup> For example, they can provide fuelwood, cultivated foods, timber and medicinal plants for local communities,<sup>329, 330</sup> while also supporting high levels of “natural” biodiversity.<sup>331, 332, 333</sup> These systems have also been shown to reduce sediment and nutrient runoff into adjacent watercourses and enhance carbon sequestration and storage.<sup>334, 335</sup> Agroforestry systems also support a diversity of wild foods and provide pollinator habitat, both of which can help to combat malnutrition and micronutrient deficiencies.<sup>336, 337, 338, 339, 340</sup> A subset of agroforestry, “silvopasture” integrates trees with pasture with the intention of increasing pasture quality and producing fodder while also protecting soils and vegetation.

Another type of agricultural BMP, conservation agriculture (defined by a combination of conservation tillage, crop rotations, and cover crops) has gained traction in many parts of the world. In some regions, variations on the principles

of conservation agriculture have been part of traditional agricultural systems for generations. As of 2011, conservation agriculture had been implemented on approximately 125 million hectares, with the greatest concentrations by far in United States, Brazil, Argentina, Australia and Canada.<sup>341</sup> The broad extent of this adoption has been cited as evidence of its implicit benefits for farmers.<sup>342</sup>

There is clear evidence that conservation agriculture increases soil organic matter and a range of associated processes including improved sediment retention. However, crop yield outcomes vary based on practices employed, climate, crop type and biophysical conditions.<sup>343</sup> Available evidence on actual changes in crop yields suggests that conservation agriculture has the greatest potential to increase crop yields when implemented as a set of integrated practices in rainfed systems in water-limited or water-stressed regions, including potentially on millions of hectares in Sub-Saharan Africa and South Asia.<sup>344, 345</sup> Decisions to adopt conservation agriculture practices can go beyond immediate changes in crop yield, though. For example, a recent review of farmer adoption of conservation agriculture identified reduction in farm operation costs, nutrient use and efficiency, water savings and crop yield stability as additional factors that motivated adoption beyond increased crop yield.<sup>346</sup>

Source water protection programs that work with BMPs, including agroforestry and conservation agriculture, will need to adapt practices and strategies to the local biophysical, economic and socio-cultural context and work to integrate local knowledge for the greatest results. Where they do so, existing sustainable agricultural systems can be supported and less sustainable practices shifted toward mutually beneficial outcomes for farmers and broader society.



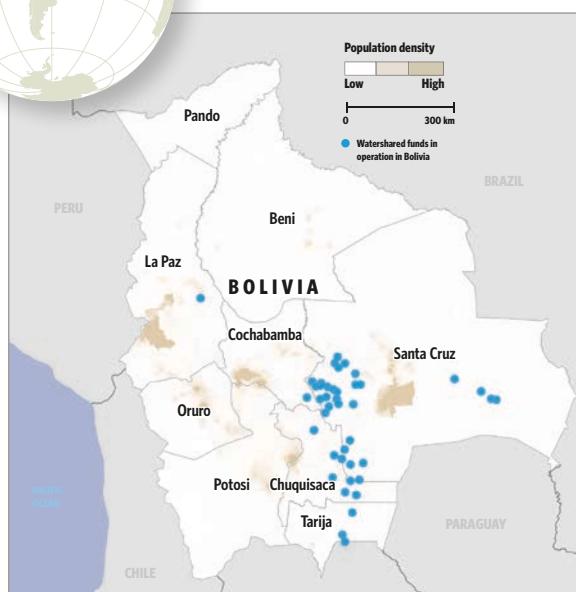
Photo: © Ian Shive

## LOCAL SPOTLIGHT

### Santa Cruz Valleys, Bolivia—Promoting health through Watershared Funds



Photo: © Steffen Reichle



#### The challenge

The Santa Cruz valleys of eastern Bolivia are among the most biodiverse regions on Earth, spanning an altitudinal range of nearly 3,000 meters and lying at the intersection of three major ecosystems: Amazonia, the Andes and the dry forests of central South America. The forests of this area are home to numerous species, including conservation icons such as the Andean spectacled bear (*Tremarctos ornatus*) and the endangered endemic red-fronted macaw (*Ara rubrogenys*). However, pressure from agriculture in the region has led to forest degradation and fragmentation, as well as contamination and pollution of the aquatic environment, with implications for aquatic species, forest animals and local communities.

Communities in the area obtain water for drinking, cooking, washing, sanitation and irrigation from water bodies in the forest near settlements. While this makes them independent and largely self-sufficient in terms of water supply, it also means that water quality in those communities is dependent upon land use in the surrounding area upstream of water sources as chemical water treatment in the area is extremely rare.

Farmers in the area allow their cattle to roam freely through the forest during a large part of the year. During this period, cattle have direct access to these water bodies for drinking, but they also contaminate them with their feces, which contain pathogenic viruses, bacteria and protozoa. The consequence of this is a public health crisis in many of the communities: widespread diarrhea, often affecting babies, young children and the elderly.

One case, from the village of Pucará, demonstrates the problem. Almost immediately after the village relocated its drinking source to a larger mountain stream, incidences of gastrointestinal disease increased dramatically (Figure 3.15). The source of the contamination was easy to identify: the new water source was situated in a catchment of 116 hectares used as rough grazing for cattle. None of the watercourses upstream of the outtake were protected and there was little conserved forestland within the catchment. Unsurprisingly, monitoring found heavy *E. coli* contamination.<sup>347</sup>

#### Cases of diarrhea attended at the Pucará Health Centre, Bolivia

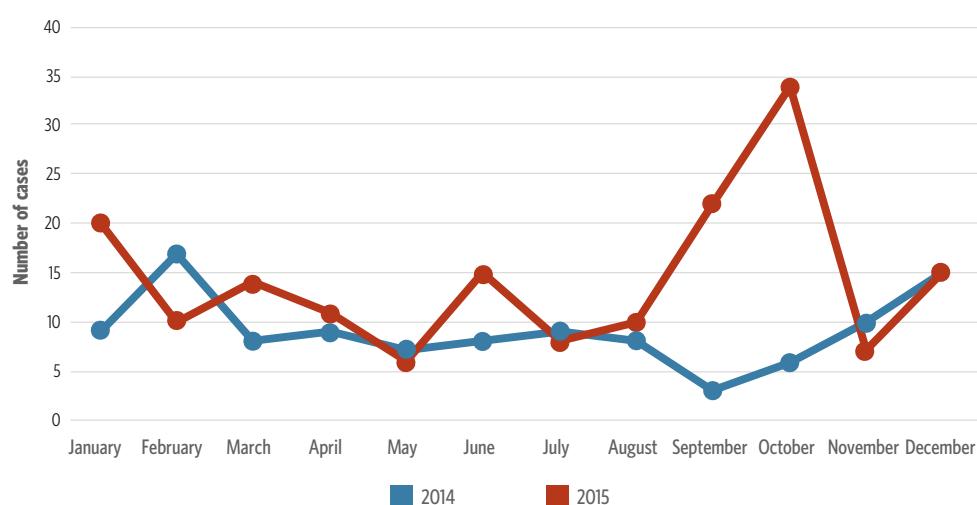


Figure 3.15. Cases of diarrhea attended at the Pucará Health Centre. The new water system was connected in August 2015.

#### Action and opportunity

As in many other communities in the region, the mayor of Pucará is working with a Watershared Fund, as well as landowners and the local water committee, to determine how to remove cattle from the watershed and to protect the watercourses from intrusion. Watershared is an initiative of more than 125 municipal and regional governments across the Andes to protect their upstream water sources by conserving their forests. Municipal water funds are one of the initiative's primary mechanisms. In Bolivian Watershared Funds, farmers who protect lands and streams receive compensation with a value of US\$10 per hectare per year if they comply with their contract, and in the form of productive goods such as beehives, fruit trees, irrigation tubing and cement for construction of irrigation systems and water troughs for cattle. Conserved land is monitored yearly for compliance to ensure that cattle continue to stay out of forests and watercourses. Municipal Watershared Funds, made possible by contributions from local governments, water user associations and Fundación Natura Bolivia (a conservation NGO), pay for program implementation, compensation and monitoring.

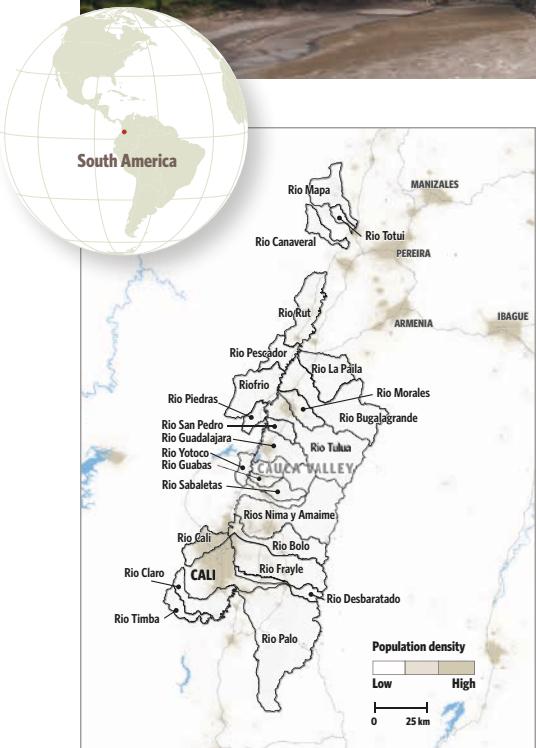
Researchers from Fundación Natura Bolivia and collaborating universities have conducted water quality studies in the community to monitor changing levels of *E. coli*, an indicator of fecal contamination. In the worst cases, levels of *E. coli* at water outtakes can reach 30,000 colony-forming units per liter, greatly increasing the risk of infection by people consuming this water. Colonies are enumerated using a field-friendly technology, Coliscan™ Easygel, that allows bacteriological work in contexts without laboratory equipment.

Monitoring is showing that real improvements in health outcomes can be achieved through investment in both upstream conservation and water infrastructure, of which there are many examples.<sup>348</sup> Experiences of the Watershared Funds suggest that delivering water of high quality, sustainably and through locally appropriate technology, is achievable and requires creating and/or strengthening local institutions.<sup>349</sup>

SANTA CRUZ VALLEYS DASHBOARD						
Water fund start date	Number of upstream participants to date	Number of potential downstream beneficiaries	Number of partners to date	Primary funding sources	Activities	Anticipated co-benefits
2003	6,560	300,000	70	Utility Public  Water user associations NGO		

## LOCAL SPOTLIGHT

### Cauca Valley, Colombia—A range of well-being benefits



#### The challenge

Nearly 2,750 family-run sugar plantations and 13 sugar mills fill the narrow fertile flatlands of Colombia's high valley of the Río Cauca (Cauca Valley). These sugar plantations—stretching some 230,000 hectares—represent a major portion of Colombia's essential sugarcane industry. Agriculture, including sugar and other crops, requires clean and abundant water supplies throughout the year. However, increasing water demand for irrigation and for a growing population, in combination with climate change, has led to water scarcity, particularly between June and September. Deforestation and agricultural expansion in the upper watersheds is additionally thought to exacerbate this dry season water shortage while also reducing water quality.

The sugarcane growers have long believed that the amount and quality of their water depends on how the upper watersheds are managed, which, in turn, depends on the well-being of local farmers and communities. For almost 30 years, the sugarcane growers and sugar mills have supported the work of 13 community-based river associations and five NGOs, to work with local communities and farmers to protect the watershed while also improving rural livelihoods and well-being. These river associations have worked tirelessly to establish relationships and trust with landowners and communities in a region plagued by instability and conflict. For example, in the Bolo watershed a river association, Asobolo, has worked with over 700 landowners since 1993 to protect 212 springs, fence 100 hectares of stream, protect 1,500 hectares of forest and improve agricultural production in 30 hectares. The leader of Asobolo, Amalia Vargas, fundamentally believes that achieving long-lasting conservation requires a combination of projects focused on environmental and social outcomes.

From 1989 to 2009, 15 river associations and NGOs, like Asobolo, have protected watersheds and improved local livelihoods. However, they largely did so in a context of insufficient resources and lacked a coordinating network to be able to strategically invest in new watershed areas and activities. It soon became clear that a new funding and governance institution was needed to connect and amplify the work of river associations in protecting watersheds and improving well-being.

"The water fund helped me by giving me trees. They educated us on how the trees aided preservation of water. Avocado trees have been good for the soil, and also to feed ourselves, to sell and to support my family. Water gives us life, because without water there is no life."

Maria Esmeralda Marcillo, local farmer

## Action and opportunity

The need became a reality in 2009, nearly 30 years after river associations like Asobolo first began working in the upper watersheds of Valle del Cauca. The sugarcane industry, 18 river user associations and NGOs, The Nature Conservancy, Bavaria (a beer company), EcoPetro (oil company of Colombia), Mexichem (a production company), EPSA (an electric power generation company) and the Colombian government environment authority united to form the water fund, Fondo Agua por La Vida y La Sostenibilidad ("Water for Life and Sustainability").

Reflecting the diversity of its stakeholders, the water fund has multiple goals, including reducing dry season water shortages, reducing erosion for water quality, improving rural livelihoods and protecting biodiversity. For the last seven years the water fund has been strategically building upon and amplifying the work that river associations have been doing for many years. In addition to traditional source water protection activities (riparian buffers, forest protection, etc.), the water fund focuses on building environmental awareness and capacity around the sustainable management of natural resources. For example, Asobolo, with new funding and capacity supported by the water fund, carries out environmental education activities in seven schools with over 2,000 children, has conducted 40 workshops related to protecting critical water sources and has helped strengthen 10 community organizations focused on watershed management. While many of the farmers they work with immediately see the benefit of protecting their water sources (e.g., for drinking, irrigation and trout production), the water fund also provides incentives in the form of capacity and materials for agroforestry and silvopastoral systems (including home gardens), which contribute to food security and household well-being. In an Indigenous community in another watershed where the water fund works, silvopasture techniques, including fodder banks, have doubled milk production, allowing for substantial increases in cheese production.

To date, over 1,500 families participate in Agua por La Vida activities through river associations like Asobolo, and an estimated 18,000 families may experience indirect benefits from improved

watershed management. The water fund has worked on more than 10,170 hectares, including protecting 795 freshwater springs and fencing more than 802 kilometers of riparian forest. It has also supported nearly 400 home gardens, 610 hectares of agroforestry (coffee, banana and avocado), 1,500 hectares of silvopastoral systems, provided educational programs in 66 schools and supported over 25 local organizations dedicated to sustainable agriculture. Growing numbers of neighboring families and farmers are eager to join—a clear testament to the benefits the water fund provides to its upstream participants.

In 2014, Asobolo, Agua por La Vida, The Natural Capital Project and The Nature Conservancy carried out a pilot social monitoring project to document program outcomes from the perspective of water fund participants. Their first step was mapping out the perceived environmental and social benefits associated with each of the water fund's activities. A range of benefits were expected, including reduced erosion and improved water quality, improved agricultural production, enhanced nutrition (from agroforestry systems and home gardens) and reduced social conflict.

Many of these expected benefits will take years to manifest, but interviews, household surveys and focus groups carried out in a pilot study (of 27 participants) demonstrate that participants already perceive benefits from the water fund. For example, in the Agua Clara River area, after just three years of the program, over one-quarter of respondents thought there had already been improvements in agricultural production and over three-quarters said they thought that water fund activities increased land value through protecting water supplies. It turns out that, in this area, environmental actions to protect water sources, like fencing and reforestation, increase the value of the land—both from a natural heritage standpoint and from an economic standpoint. Almost all (96 percent) said they had participated in environmental workshops and engaged in a conservation/environmental action (e.g., reforestation, proper waste disposal) as a result of training, which they fundamentally see as beneficial for both the environment and for people.

FONDO AGUA POR LA VIDA DASHBOARD						
Water fund start date	Number of upstream participants to date	Number of potential downstream beneficiaries	Number of partners to date	Primary funding sources	Activities	Anticipated co-benefits
2009	2,165	Between 1,000,000 and 5,000,000	22, including 16 watershed associations	Private NGO Regional environmental authority	    	  

## Indigenous Communities and Biodiversity Conservation



Although human activity has resulted in significant land-use changes and associated biodiversity

losses, human activity can also be beneficial for species and habitats. Within Central America, for example, more than 40 percent of lands and waters are home to over 80 Indigenous groups who are recognized as guardians of the most biologically diverse lands on the isthmus.<sup>375</sup> In many cases maintaining cultural and biological diversity are intricately connected, necessitating a bio-cultural approach.

## Benefits to terrestrial and freshwater biodiversity

A large number and proportion of urban source watersheds are situated within areas supporting significant biodiversity values. Given the range of impacts to terrestrial and freshwater species and ecosystems from habitat conversion—the elimination of natural habitat caused by a major, long-term change in land or water use—source water protection strategies that conserve existing native forests, grasslands and wetlands and restore or rehabilitate converted areas where possible through active or passive revegetation, all contribute to biodiversity conservation. Additionally, working landscapes can reduce stresses on freshwater habitats and species through improvements in water quality and flow reliability.

### Losses on the landscape

Current rates of species extinction are about 1,000 times the background rate of extinction—the rate that would occur in the absence of human activity.<sup>350</sup> Of those vertebrate species groups whose status has been comprehensively assessed, the results are sobering: estimates for species threatened with extinction are 26 percent for mammals, 13 percent for birds and 41 percent for amphibians.<sup>351</sup> Another measure is the Living Planet Index (LPI), which tracks a sample of species populations around the world; it finds an average decline of 38 percent for monitored populations of terrestrial vertebrates from 1970 to 2012.<sup>352</sup>

Changes in land use are implicated as a major source of recent extinctions,<sup>353</sup> and if left unchecked, are projected to be the most influential source of impact to ecosystem function and biodiversity change by 2100.<sup>354</sup> Studies have confirmed that areas subject to high human disturbances generally have less biological diversity, reduced biological integrity<sup>355</sup> and higher probabilities of species extirpations—the loss of species from discrete parts of their ranges.<sup>356</sup> However, land uses vary in their intensity, scale and impact, and it is important to recognize that many communities have been stewards of biodiversity for generations, protecting and caring for the world's forests and maintaining bio-cultural diversity in agroforests and other agro-ecological systems.<sup>357, 358</sup>

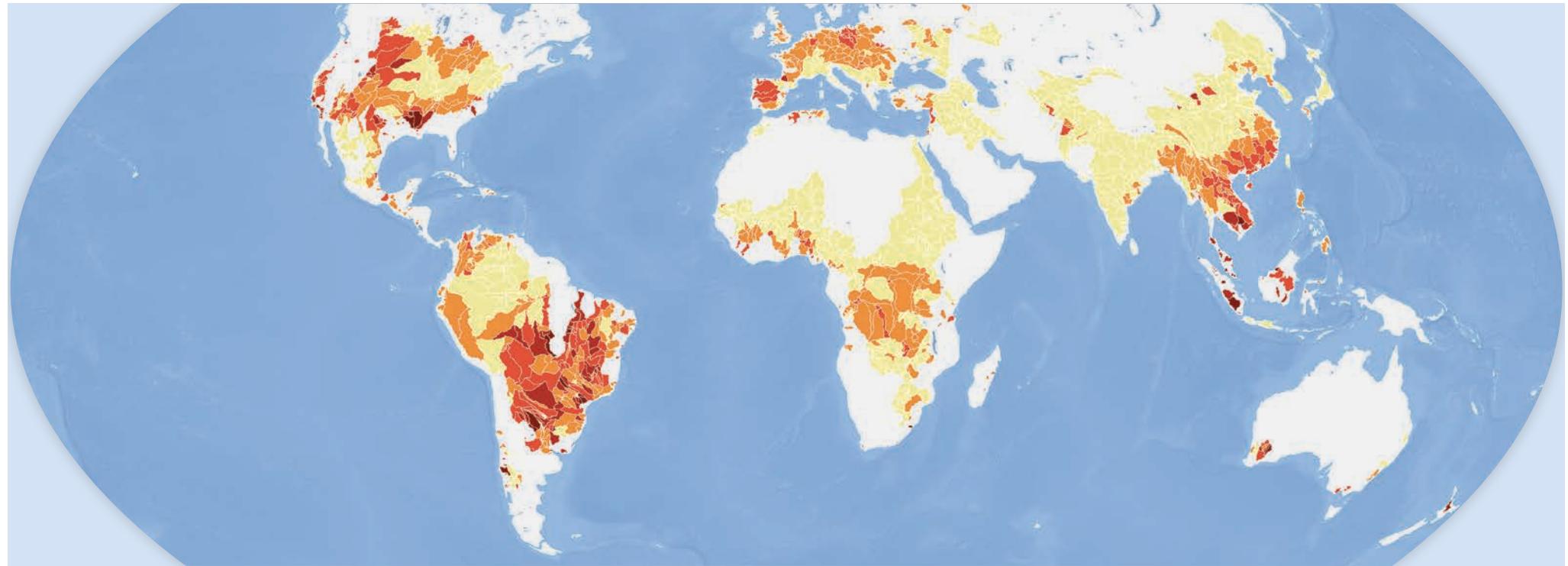
Over 30 percent of the Earth's pre-industrial land cover—the biophysical cover of the Earth's surface—has been converted, with the greatest losses by area occurring in forests and grasslands.<sup>359</sup> The most rapid current and future projected forest losses are in the tropics, driven by agriculture expansion, wood extraction, and extension of roads and other infrastructure into forest habitats.<sup>360</sup> Grasslands have been converted primarily for agriculture and livestock, with the greatest losses occurring in temperate grasslands, savannas and shrublands.<sup>361, 362</sup> Wetlands are also highly imperiled by conversion and other threats.<sup>363</sup>

Forests provide habitat for at least half of known terrestrial plant and animal species.<sup>364</sup> Estimates by the International Union for Conservation of Nature (IUCN) suggest that 12.5 percent of the world's species of plants, 44 percent of birds, 57 percent of amphibians, 75 percent of mammals and 87 percent of reptiles are threatened by forest decline.<sup>365</sup> Over the past three centuries, approximately 40 percent of global forest area has been lost.<sup>366</sup>

Using a widely adopted global map of forest cover change,<sup>367</sup> we find an average forest loss across all source watersheds of 4,873,900 hectares per year from 2001 to 2014 (Figure 3.18). This rate of forest loss results in an aggregate area of 68,185,702 hectares, roughly equivalent to the size of Myanmar, and represents 4.7 percent of the forest area that was present in 2000 (see Appendix III for results by region). Forest loss in source watersheds constituted one-fourth of the total global forest loss recorded in a different dataset from 2001 to 2012.<sup>368</sup> While the absolute amount of forest lost may not seem exceptionally large, it covers only a fourteen-year time span and as such is important for highlighting areas of recent forest loss and a probable trend for future loss, as well.

We do not consider gains in forest cover, but we recognize that there are some places around the world that are experiencing increases in forests due to passive and active reforestation. Between 1990 and 2015, the extent of forest has increased in parts of

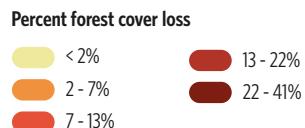
## Percent forest cover loss across urban source watersheds (2001 - 2014)



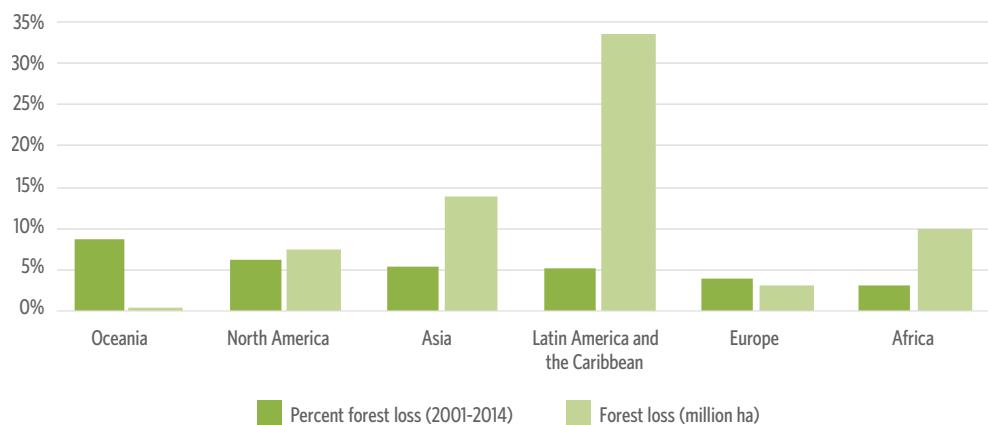
**Figure 3.16.** Percent of forest loss in urban source watersheds between 2001 and 2014, relative to the standing forest in the year 2000. The percent of loss is summarized for each Level 5 HydroBASIN in the urban source watersheds and uses the Jenks natural breaks classification method. (Source data: Hansen, et al., 2013<sup>376</sup>)

East Asia, Europe, North America and South and Southeast Asia, but in these regions the gains have largely been the result of planted forests,<sup>369, 370</sup> which may not have the same biodiversity benefits as natural forest.<sup>371, 372</sup>

As with most global numbers, our global forest loss finding masks high variability across regions, and percent loss and absolute loss tell different stories (Figure 3.16 and 3.17). Latin America, for example, has a slightly lower percent loss than Oceania, North America and Asia, but its total extent of loss dwarfs that of those other regions. Areas with the highest spatial extent of forest loss correspond in part to areas with the largest extent of forests overall, such as the Amazon River Basin in South America and the Congo River Basin in central Africa. Larger swaths of South America, along with Southeast Asia, parts of the western United States, Indonesia, and southwestern Australia stand out for their percent forest loss from 2001 to 2014. Many of these regions are notable for their terrestrial and freshwater biodiversity, so these high rates of forest loss are particularly concerning from a conservation perspective.<sup>373, 374</sup>



### Percent and extent of forest loss within urban source watersheds, by region (2001-2014)



**Figure 3.17.** Extent and percent of forest loss for urban source watersheds by region from 2000-2014. (Source data: Hansen, et al., 2013<sup>377</sup>)

## Compounded threats to freshwater systems and species

Based on an assumption that the recent past can be an indicator of the near future, forest loss findings can complement the Human Modification results (Chapter 2) by indicating regions of high immediate concern, especially for terrestrial species. However, these same datasets are not entirely sufficient for comprehensively assessing threats to the biodiversity of freshwater systems—sometimes called inland waters or inland wetlands—because freshwater systems integrate the impacts of activities across their upstream catchments and are subject to a wide range of additional threats such as water withdrawals and dams.

The potential for source water protection activities to benefit freshwater systems is exciting, given that freshwater systems are both disproportionately diverse and threatened. They cover less than 2 percent of the Earth, yet they contain over 100,000—or 6 percent—of all described species on Earth. This includes approximately one-third of all vertebrate species.<sup>378</sup> Among these species are fish that serve as critical protein and livelihood sources for millions of people, many of whom are among the poorest on Earth.<sup>379, 380</sup>

On the threat side, The Living Planet Index shows an average decline of 81 percent in population levels of monitored freshwater organisms from 1970 to 2012.<sup>381, 382</sup> The current version of The IUCN Red List of Threatened Species<sup>383</sup> suggests that 27.8 percent of species dependent on freshwater systems are imperiled and threatened with extinction.<sup>384</sup> In North America, freshwater animal species are expected to disappear at a rate five times that of terrestrial animals and three times that of marine species.<sup>385</sup>

To understand the broad distribution of threats to freshwater species and systems within urban source watersheds, we use the freshwater-focused Incident Biodiversity Threat Index, which combines 23 drivers of current stress and charts their impacts downstream (Figure 3.18).<sup>386</sup> In essence, the freshwater index includes nearly all factors included in the Human Modification Index, plus many more specific to freshwaters. For instance, polluted waters will typically have a more direct and serious impact on aquatic species than on terrestrial ones. The freshwater index also incorporates gray infrastructure, like dams, that block migratory routes for aquatic species and normally change the timing and amount of water flows to which those species are adapted.

Using the Incident Biodiversity Threat Index, we find that 48 percent of the area of source watersheds has high threat levels and only 6 percent has low threat levels (see Appendix III for results by region). Index data were unavailable for some source watershed areas, but we would expect the global number for high threat areas to be



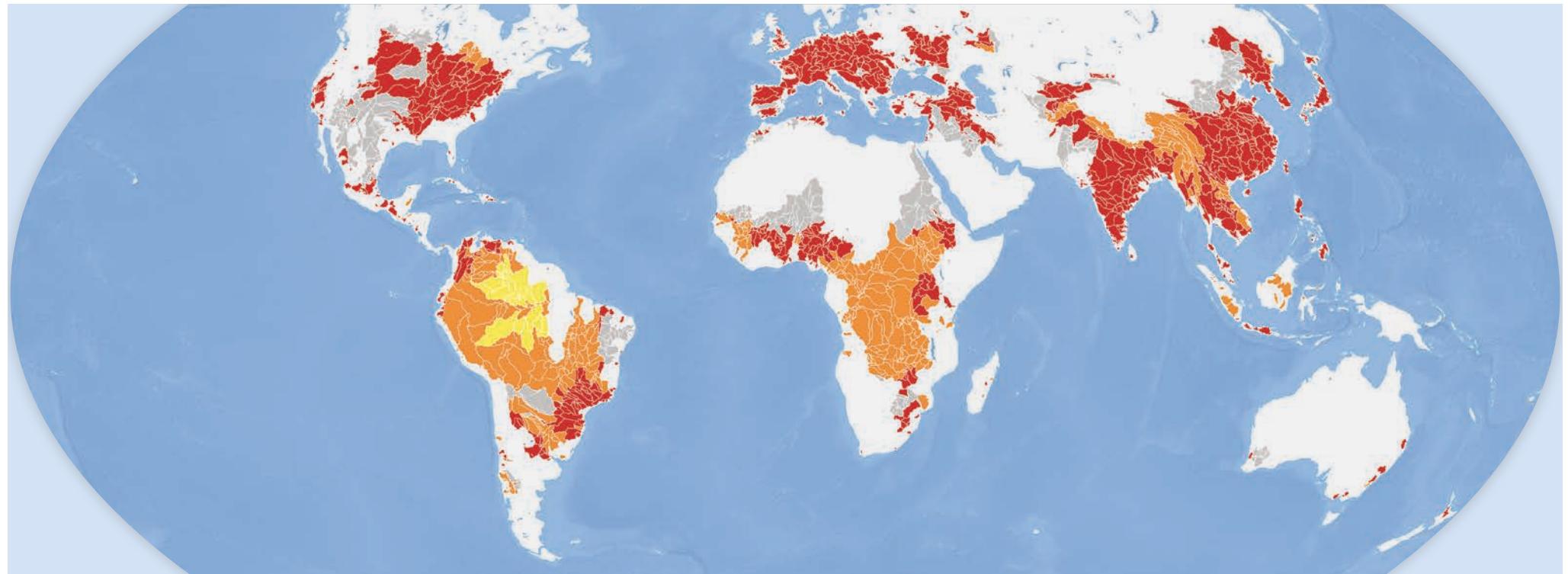
Photo credit: © Michelle Kalantari

even greater if all areas were included. Europe, Asia and North America all show extensive areas of high freshwater biodiversity threat, which makes sense given the high level of catchment disturbance, pollution and water resource development—three of the four stressor themes—across all three regions.<sup>387</sup>

Nutrient and sediment loadings are inputs to the freshwater threat index, and we see a high degree of overlap between the composite index results and our loadings maps (with greater overlap for nutrients) (see Chapter 2). However, the differences are perhaps more informative than the similarities, as they point to threats that go beyond poor land management and over-fertilization. Some of these threats, such as hydropower dams, may not be squarely within the wheelhouse of source water protection activities. Others, however, including over-abstraction of water for irrigated agriculture, could be mitigated by agricultural BMPs in some places.

Overall, the two indexes—Human Modification and Incident Biodiversity Threat—tell us that broad areas within urban source watersheds suffer from landscape change and disturbance along with other threats, with implications for native species and their habitats. The silver lining is that source water protection activities have the potential to help mitigate a number of those threats. Freshwater species arguably face a greater range of threats than terrestrial species, but they may also benefit more from source water protection due to water quality and quantity improvements.

## Human threat to freshwater biodiversity across urban source watersheds



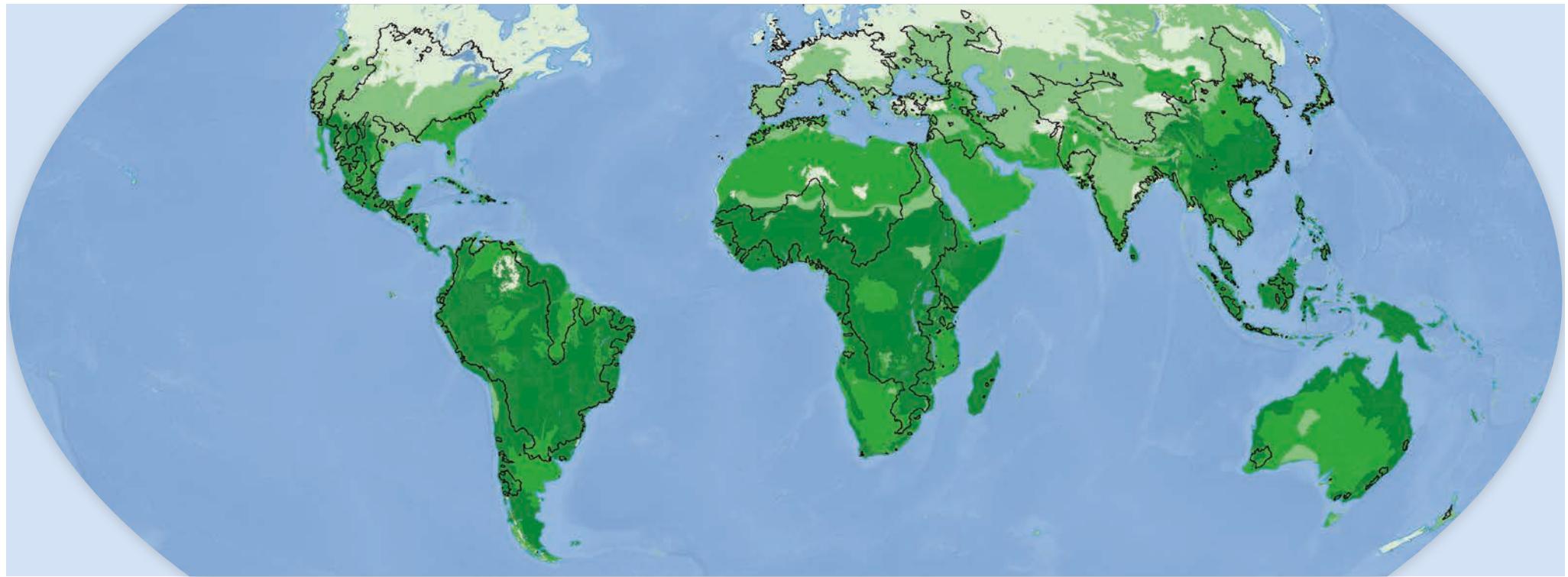
**Figure 3.18.** The Incident Biodiversity Threat Index is used to summarize levels of human threat to freshwater biodiversity for each Level 5 HydroBASIN that intersects with urban source watersheds. The thresholds for low, medium and high biodiversity threat are determined at equal breaks between the range of index values, which were normalized and standardized between zero and one. Some basins do not have average threat values because there is insufficient coverage of the index data in places that do not meet a minimum threshold of average annual runoff. (Source data: Vörösmarty, et al., 2010<sup>388</sup>)

### Average index value per HydroBASIN

- Low
- Medium
- High
- Limited data

Nearly half of all source watershed areas have high levels of threat to freshwater species and systems.

## Biodiversity value levels of terrestrial ecoregions intersecting with urban source watersheds



**Figure 3.19.** Terrestrial ecoregions characterized by levels of rarity-weighted richness. Rarity-weighted richness values are calculated as a combination of number of species and relative rarity of those species. The urban source watersheds are mapped on ecoregions to show variability of rarity-weighted richness within their bounds and to highlight areas of high terrestrial biodiversity value. Values for terrestrial ecoregions are based on terrestrial vertebrate species. Highest biodiversity values are in the first quartile and lowest are in the fourth. (Source data: Abell, et al., 2011<sup>390</sup>)

### Rarity-weighted richness

- 1st quartile
- 2nd quartile
- 3rd quartile
- 4th quartile

## From biodiversity threat to opportunity

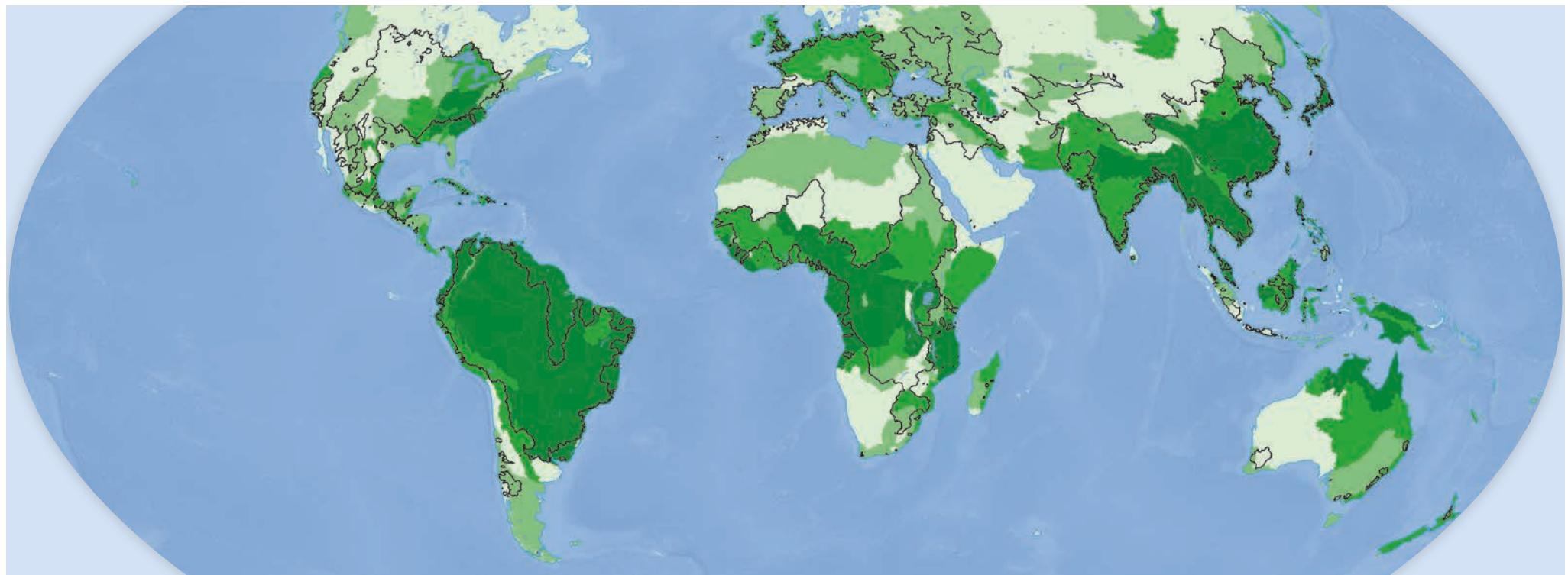
Analyses and corresponding maps of threats to terrestrial and freshwater species identify regions of high concern, but they can also suggest places of high urgency for action. Coupling information on threat with data on where high biodiversity values are concentrated can help guide source water protection investment.

Biodiversity refers simply to the variety of life on Earth, but in practice, species often underpin biodiversity measures. A typical measure is species richness—the number of species in a given place. A common companion measure is species endemism—the number of species that are found in that place and nowhere else. An area with high richness is one where conservation measures might target and

protect a large number of species. An area with high endemism is one where, without conservation measures, some number of species could potentially be lost from the planet forever. Neither measure is objectively more important than the other.

To understand where concentrations of biodiversity overlap with urban source watersheds, we use a measure that, in effect, combines species richness and endemism. The combined measure—called rarity-weighted richness—identifies areas with both many species overall and some proportion that are found in fewer rather than greater numbers of places.<sup>389</sup> For data availability reasons, we apply the measure at the ecoregion scale. Ecoregions are large units of land or water containing geographically distinct assemblages of species, natural communities and environmental conditions. They have been defined separately for terrestrial,

## Biodiversity value levels of freshwater ecoregions intersecting with urban source watersheds



**Figure 3.20.** Freshwater ecoregions characterized by levels of rarity-weighted richness. Rarity-weighted richness values are calculated as a combination of number of species and relative rarity of those species. The urban source watersheds are mapped on ecoregions to show variability of rarity-weighted richness within their bounds and to highlight areas of high freshwater biodiversity value. Values for freshwater ecoregions are based on freshwater fish species. Highest biodiversity values are in the first quartile and lowest are in the fourth. (Source data: Abell, et al., 2011<sup>39</sup>)

### Rarity-weighted richness

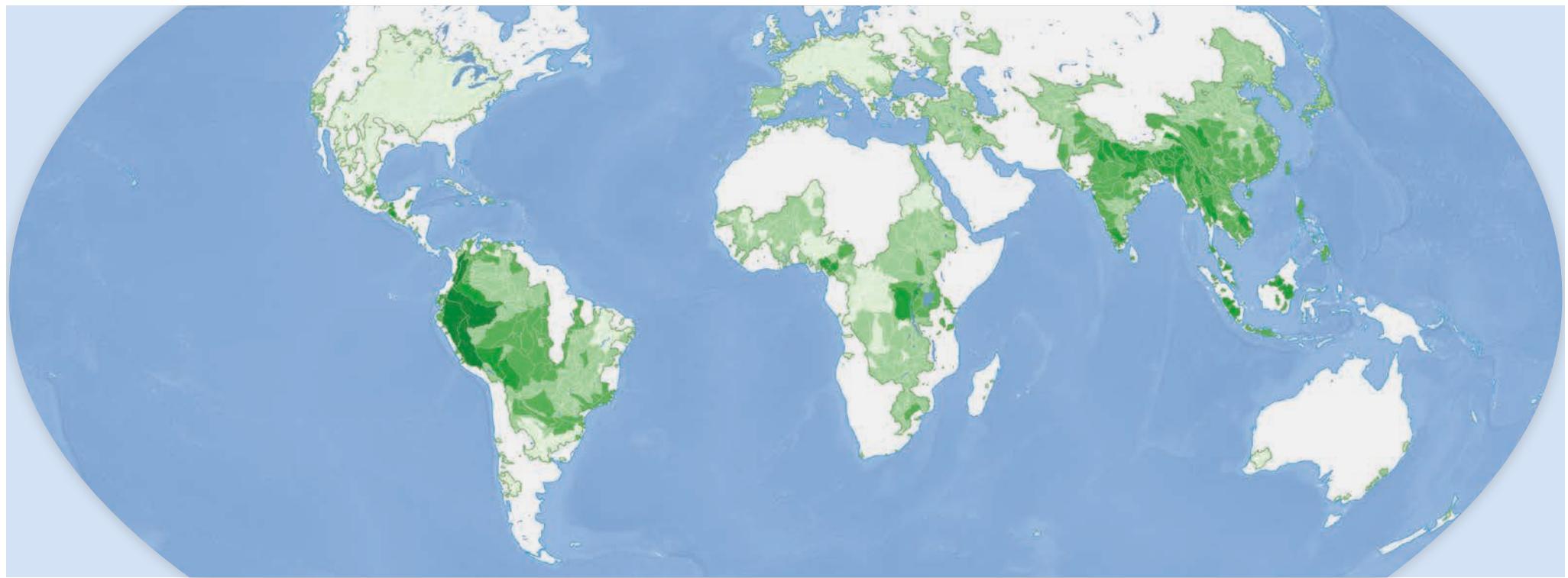
- 1st quartile
- 2nd quartile
- 3rd quartile
- 4th quartile

freshwater and marine systems. We refer to ecoregions with high rarity-weighted richness values as “high biodiversity value ecoregions,” with the caveat that biodiversity can be measured in any number of ways, and we use data only from a small number of species groups.

Areas of overlapping high terrestrial and freshwater biodiversity values are well-known hotspots like the Amazon, the Congo and the Mekong river basins. Larger areas of South America, Africa and Oceania are covered by high biodiversity value terrestrial ecoregions (based on terrestrial vertebrates), whereas high biodiversity value freshwater ecoregions (based on freshwater fish species) are found in larger portions of South Asia, eastern tributary basins of the Mississippi and in western Europe.

The relevance of these hotspots comes into focus when high biodiversity value ecoregions are overlaid with urban source watersheds (Figure 3.19 and 3.20, see Appendix III for results by region). We find that outside of Oceania (with very little area in our source watersheds) and Europe (where there are no high biodiversity value terrestrial ecoregions), the degree of overlap is high; 85 percent of the area of source watersheds overlaps with high biodiversity value freshwater ecoregions and 79 percent with terrestrial ones. The significance of these findings is that, if source water protection activities are well-designed for mitigating and minimizing threats to native species, there is strong potential for contributing to the conservation of large numbers of species, some number of which may represent critical conservation opportunities.

## Imperiled terrestrial species within urban source watersheds



**Figure 3.21.** Number of imperiled terrestrial species, including mammals, birds and amphibians, per Level 5 HydroBASIN within urban source watersheds, restricted to where source water protection activities could benefit them. Imperiled species are those classified by the IUCN Red List as critically endangered, endangered or vulnerable. Data classified using Jenks natural breaks. (Source data: BirdLife International and NatureServe 2015; IUCN 2016<sup>394</sup>)

### Number of species

- 3 - 12
- 13 - 25
- 26 - 46
- 47 - 91
- 92 - 219

## Targeted species and site conservation

Certain species groups have been scrutinized well enough that we have a relatively complete idea of which are most at risk and where they occur. We find that urban source watersheds contain a disproportionately large number of imperiled species and areas identified as critical for sustaining species at high risk.

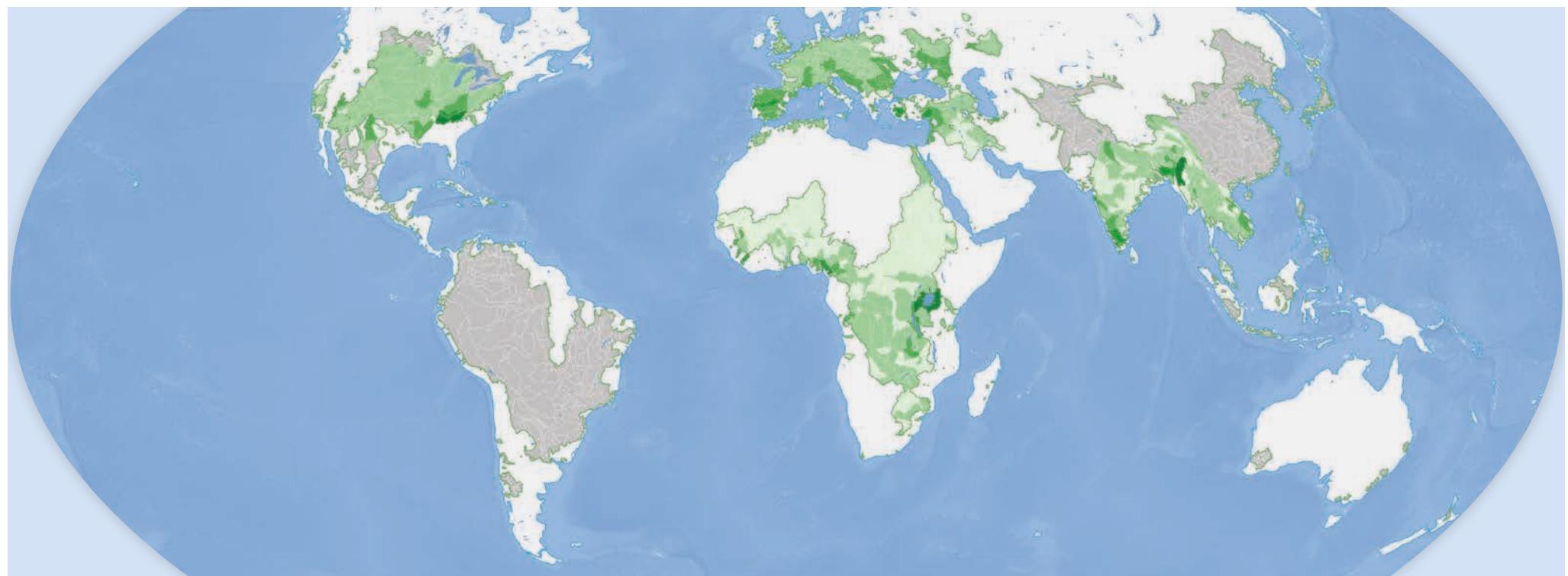
### Imperiled species

The conservation organization IUCN oversees and leads assessments of risks to species groups worldwide, resulting in categorizations of imperiled species as

critically endangered, endangered or vulnerable. For several species groups those assessments have attained a level of comprehensiveness and detail that allow analyses and mapping of imperiled species within source watersheds.

We find that 51 percent of the IUCN red-listed terrestrial species are found within urban source watersheds. That number includes 1,047 imperiled amphibian species, 537 mammals and 650 birds (54, 47 and 50 percent of all imperiled species in those groups, respectively). The source watersheds are also home to 680 imperiled freshwater fish species, representing 59 percent of those species evaluated as imperiled by IUCN, but comprehensive assessments of freshwater

## Imperiled fish species within urban source watersheds



**Figure 3.22.** Number of imperiled freshwater fish per Level 5 HydroBASIN within urban source watersheds. Imperiled species are those classified by the IUCN Red List as critically endangered, endangered, or vulnerable. Only those regions that have been comprehensively assessed are shown. Data classified using Jenks natural breaks. (Source data: IUCN 2016<sup>395</sup>)

fish species have only been completed for some regions. We would expect far higher numbers once assessments have been completed for South America, much of Asia and Oceania.

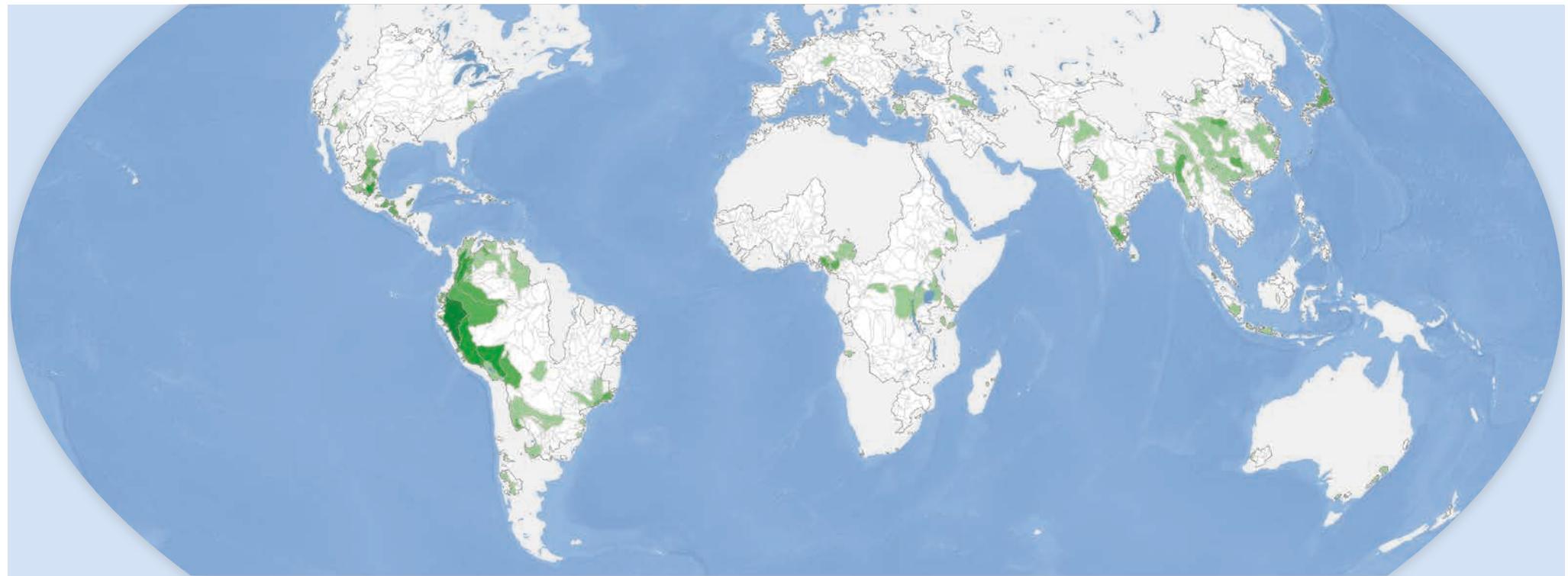
Looking at the terrestrial species results by region, numbers are generally consistently high across taxonomic groups in Asia, Latin America, the Caribbean and Africa (Figure 3.21, see Appendix III for results by region). Latin America and the Caribbean stand out for the exceptional number of imperiled amphibians

### Number of species

- 0
- 1-6
- 7-13
- 14-23
- 24-41
- Limited Data

in source watersheds. Frogs in particular are extremely imperiled in that region, largely due to habitat loss, pathogenic fungal disease and climate change.<sup>392, 393</sup> For freshwater species, eastern tributaries to the Mississippi Basin, the East African Great Lakes, parts of western Europe and the Irrawaddy River Basin in Southeast Asia stand out (Figure 3.22, see Appendix III for results by region). Threats in these areas encompass point and nonpoint source pollution, dams and invasive species, among others.

## Alliance for Zero Extinction sites within urban source watersheds



**Figure 3.23.** Number of Alliance for Zero Extinction (AZE) sites per Level 5 HydroBASIN within urban source watersheds. Data classified using Jenks natural breaks. (Source data: AZE 2010<sup>398</sup>)

### Number of AZE sites

0
1-2
3-6
7-14
15-29

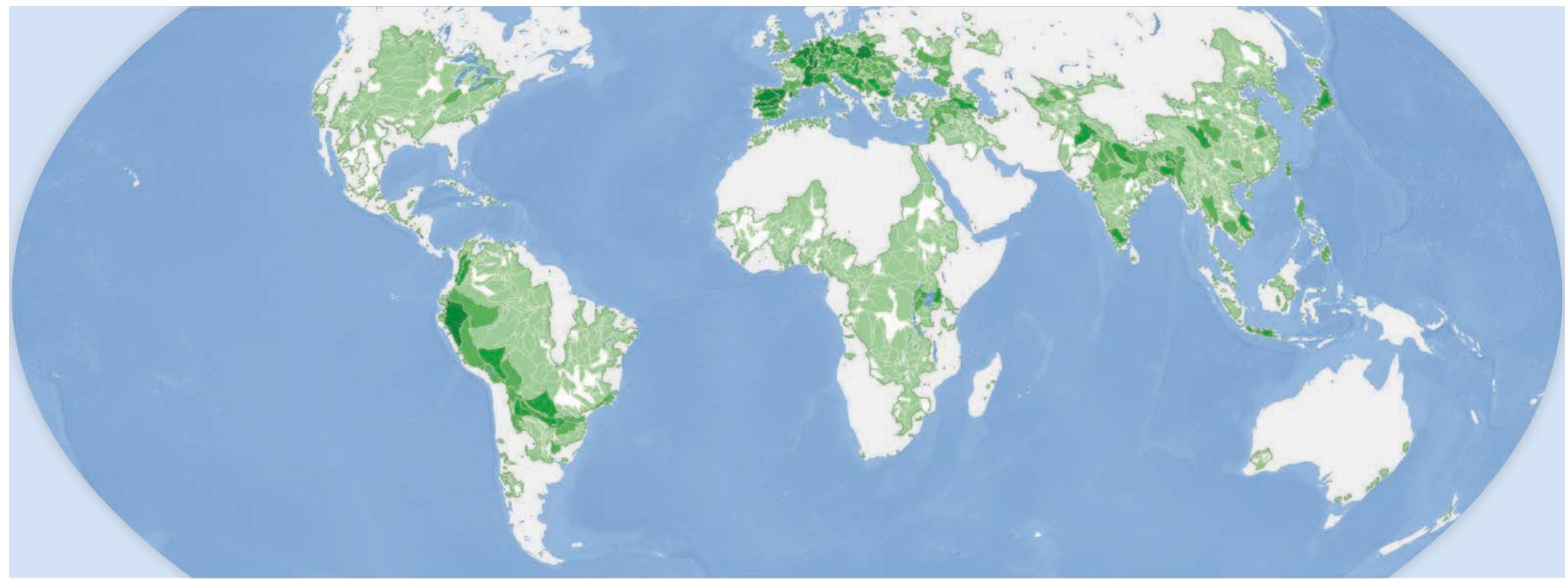
## Pinpointing protection for at-risk species

Many of the world's species at greatest risk have been assessed as imperiled and occupy discrete sites. Loss of a site would likely translate to the species' extinction. The Alliance for Zero Extinction (AZE) has identified 587 sites globally that support 920 species of mammals, birds, amphibians, reptiles, conifers and reef-building corals that are both categorized as endangered or critically endangered, and greater than 95 percent of the known resident or a life history segment of the population is restricted to single sites.<sup>396</sup> Nearly half of all AZE sites occur within urban source watersheds and these sites are home to 431 AZE species (Figure 3.23, see Appendix III for results by region). High

concentrations of AZE sites within source watersheds occur in Central America, the Andean region of South America and southeastern Australia.

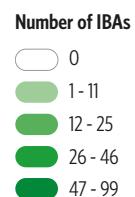
AZE sites are discrete by definition and tend to be relatively small, so it makes sense that only a small fraction—less than 1 percent—of all source watershed areas are home to AZE sites. However, where those sites do occur, source water protection activities could potentially make a real difference. In particular, targeted land protection could make a strong contribution toward safeguarding these high-risk species.<sup>397</sup>

## Important Bird and Biodiversity Areas (IBAs) within urban source watersheds



**Figure 3.24.** Number of Important Bird and Biodiversity Areas (IBAs) per Level 5 HydroBASIN within urban source watersheds. Data classified using Jenks natural breaks. (Source data: BirdLife International 2015<sup>401</sup>)

Birdlife International's Important Bird and Biodiversity Areas (IBAs) are a complement to AZE sites. IBAs are key areas identified for bird conservation and include areas that contain globally threatened species, species that are biome- and range-restricted, and/or that hold congregations of birds, often migratory species, for breeding and overwintering purposes at different times of the year.<sup>399</sup> Over 12,000 IBAs have been identified worldwide. Of these, 422 are identified as IBAs in danger—under most immediate risk from damage or destruction.<sup>400</sup> More than one-third of all IBAs, and more than one-third of those under most immediate danger, intersect with urban source watersheds (Figure 3.24, see Appendix III for results by region). Wetlands protection or restoration would be



especially relevant source water protection activities for safeguarding the many IBAs identified for their wetland-dependent bird species.

Reducing species extinction risk through reforestation—an example of potential impact through a specific activity

Restoration or rehabilitation of native habitats, through active or passive revegetation, may be an important strategy in watersheds with medium and high levels of human modification. The World Resources Institute (WRI) estimates that there are more than 2 billion hectares of forest landscape restoration

## Riparian Zones



Protecting and restoring riparian zones are critical source water protection activities, both for providing

clean, reliable water and for conserving functional ecosystems and the species they sustain. Natural riparian corridors—the strips of trees or other vegetation that run along the edges of streams and other freshwater systems—are the most diverse, dynamic and complex biophysical terrestrial habitats on Earth.<sup>413</sup> Riparian corridors capture sediment and nutrient runoff from adjacent lands and reduce impacts to water quality.<sup>414, 415</sup> In addition, they provide critical habitats to aquatic, semi-aquatic and terrestrial species, are sources of energy and woody materials for headwater ecosystems, and provide shade to moderate water temperature. Countries around the world mandate the protection of riparian zones<sup>416</sup>, though enforcement of those laws varies.



Photo: © walkinglessa.com

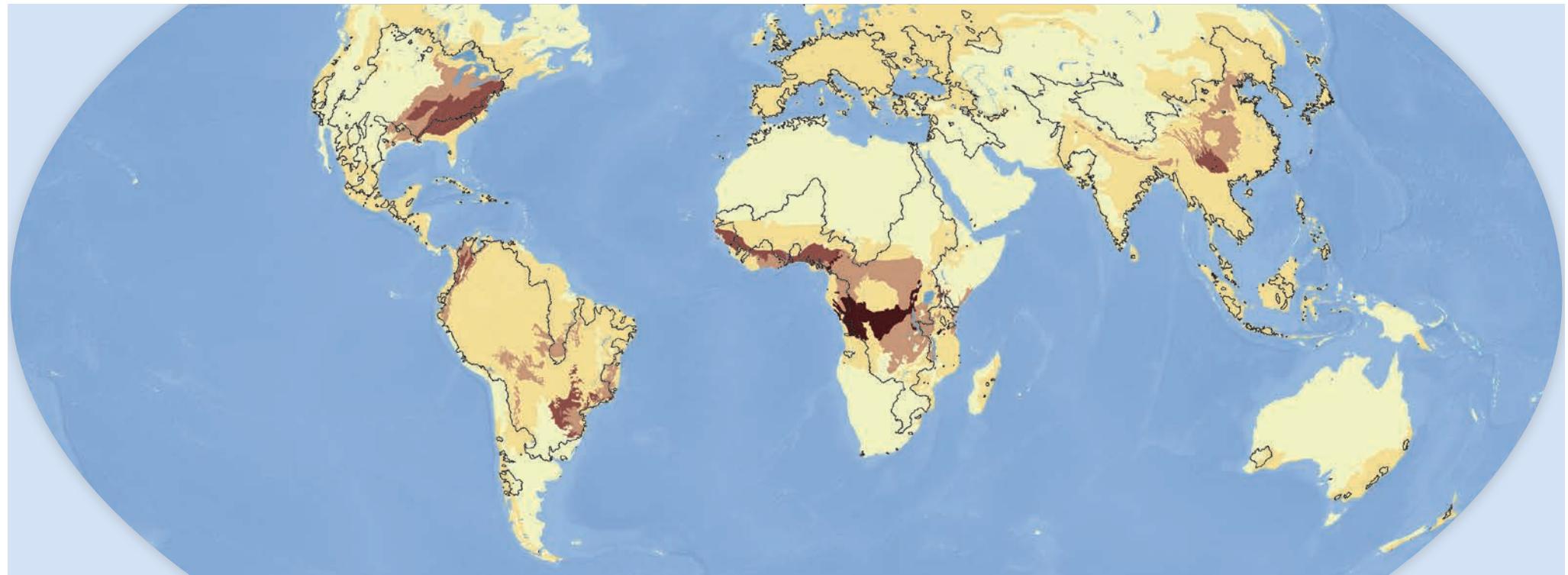
opportunity worldwide.<sup>402</sup> Of this area, nearly 700 million hectares are considered reforestation opportunities.<sup>403</sup> Terrestrial ecosystem restoration and rehabilitation provides benefits to biodiversity and ecosystem services, with the greatest potential for ecosystem services and terrestrial biodiversity co-benefits occurring in tropical terrestrial ecosystems.<sup>404</sup>

To estimate the biodiversity benefit of restoration and rehabilitation across source watersheds, we used a new approach<sup>405</sup> in which global and regional species extinctions due to human land use are projected using a countryside species-area relationship (SAR) model. Subtracting species extinctions projected by the model using the future land-use mix (i.e., after implementing forest landscape restoration opportunities worldwide) from those projected using the current land-use mix, we estimate the potential reductions in terrestrial mammal, amphibian and bird species extinctions from implementing wide-scale and remote reforestation<sup>406</sup> within source watersheds. If these forest restoration opportunities were fully implemented within source watersheds (excluding current agricultural and urban land uses), the risk of global extinction—the complete loss of a given species worldwide—would be reduced for 52 species. The risk of regional extinctions—loss of a species within a given ecoregion—would be reduced for 5,408 species. Forty percent of those regional risk reductions would occur in Africa, suggesting the opportunity of reforestation in that region is a potential high priority (Figure 3.25, see Appendix III for results by region).

### The scale of species and ecosystem conservation opportunities

All of our analyses of imperiled species and critical conservation areas indicate a benefits ceiling for source water protection activities. Realistically, all source watersheds will not have source water protection activities implemented comprehensively across the watershed, and all species and areas within those watersheds would not benefit equally from all activities. To increase the likelihood that source water protection activities achieve their biodiversity conservation potential, the best information on species' locations, habitat requirements and threats should be brought to bear on activity planning, alongside information on where water security benefits can best be achieved.

## Potential for reforestation and restoration opportunities to avoid regional extinctions



**Figure 3.25.** Number of projected avoided regional species extinctions by terrestrial ecoregion. Species-area relationship models predict reduced risk of species extinctions based on changes in land use through reforestation and restoration opportunities that intersect urban source watersheds within a terrestrial ecoregion. (Source data: WRI 2014<sup>407</sup>; Hoskins, et al., 2016<sup>408</sup>; Chaudhary, et al., 2015<sup>409</sup>; BirdLife International and NatureServe 2015; IUCN 2016<sup>410</sup>)

If forest restoration opportunities were fully implemented within source watersheds, the risk of global extinction would be reduced for 52 terrestrial species.



Photo: © Kent Mason

## Protecting intact habitats

An established tool for stemming land cover conversion to agricultural and other uses is a protected area, sometimes called a reserve or refuge. Conversations about how to work with local communities within and beyond the borders of protected areas are ongoing, and there is a growing recognition of the value of lands outside protected areas for biodiversity.<sup>411</sup> Nonetheless, the Convention on Biological Diversity (CBD), to which 196 countries are party and 168 are signatories, has set a target for protected areas that those countries are working toward: By 2020, at least 17 percent of terrestrial and inland water areas and 10 percent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascapes.<sup>412</sup>

There are debates about the utility of a fixed percentage target for protection, about the appropriate units of analysis and about how to measure that protection, especially for freshwater systems.<sup>417, 418, 419</sup> Using countries as our unit of analysis, we find that with merely four years to go, only 38 percent of all countries worldwide currently meet or exceed CBD's 17 percent protection target for land area. This includes 177 countries that have less than 10 percent protected as of mid-2016 (see Appendix III for results by region).

Of the 173 countries intersecting with source watersheds, 73 have already reached the 17 percent target. Within source watersheds, if all existing areas of natural land cover that currently sit outside designated protected areas (PAs) were protected – the ceiling of potential – we find that 44 additional countries intersecting with

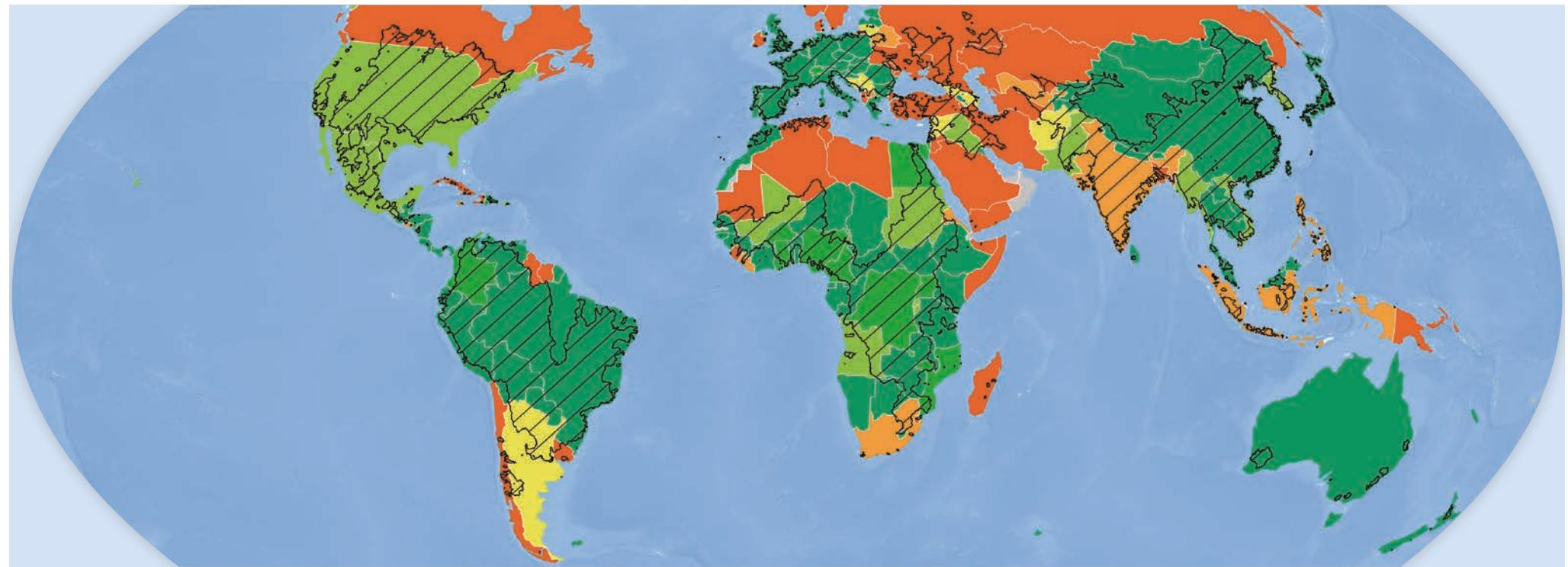
source watersheds could reach the CBD's 17 percent target (Figure 3.26, see Appendix III for results by region). One-quarter of those countries could reach the 17 percent target by protecting 10 percent or less of the natural land cover that currently sits outside their PAs.

Regionally, we see that Africa and Asia have the highest representation of countries that could meet the CBD target through new land protection, with 16 countries in Africa and 14 in Asia. It is noteworthy that the proportion of remaining natural land cover currently outside PAs that would need to be protected varies substantially; in Africa, it is 16 percent, while in Asia it is 40 percent. Those findings are reflective of the fact that far less natural land cover remains outside PAs in Asia than in Africa.

As with our species results, these findings are suggestive of the full magnitude of benefit from source water protection activities, and specifically targeted land protection. For many countries, the creation of new PAs covering even just 10 percent of currently ‘unprotected’ natural land cover may be an ambitious goal. However, there is strong evidence that official databases of PAs undercount the contribution of Indigenous and community-managed PAs, a problem that may be addressed over time.<sup>420</sup> This suggests both that “true” PA gaps may be smaller than these findings suggest, and that Indigenous and community-based land protection already is and can continue to be an important contributor to meeting countries’ protection targets.

Effective and equitable management of existing protected areas may be as important as the creation of new protected areas, whether they are formally designated or not. There is ample evidence that many existing protected areas lack effective management, failing to meet their full potential for biodiversity conservation and downstream water provision alike.<sup>423</sup> Source water protection activities bolster

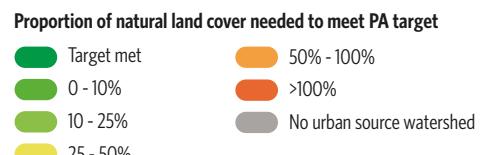
## Potential for source water protection to help countries reach 17 percent protection target



**Figure 3.26.** Countries that could meet Aichi Biodiversity Target 11 (at least 17 percent of lands and inland waters protected) if augmented with land protection as a source water protection activity. It was determined that a country had the potential to reach the target if the area of natural land cover in urban source watersheds, but outside of existing protected areas, was greater than a country's protected areas deficit. Following the approach of the Biodiversity Indicators Partnership,<sup>421</sup> all designated protected areas recorded in the World Database on Protected Areas (WDPA) with a known size were included, except for marine and coastal protected areas. The different levels indicate the percentage of unprotected natural land cover within urban source watersheds, by country, that would need protection to meet the goal. Those countries in which over 100 percent of natural land cover is needed could not meet the goal with source water protection; however, many of these countries have very low coverage of urban source watersheds. Countries in gray contain no source watersheds. (Source data: IUCN and UNEP-WCMC 2016<sup>422</sup>).

the services provided by protected areas by strengthening protection mechanisms and working with communities to minimize external threats, where possible. Community management of protected areas has been shown to strengthen their effectiveness,<sup>424</sup> and new management and funding models have potential to expand protected networks further.<sup>425</sup> For instance, in Ecuador, the Quito water utility's surcharge has funded management of Cajas National Park for water protection.<sup>426</sup>

Considering source water protection through the lens of a biodiversity co-benefit may help to narrow the places where targeted land protection might be most important. Prioritizing ecologically representative areas under threat would support



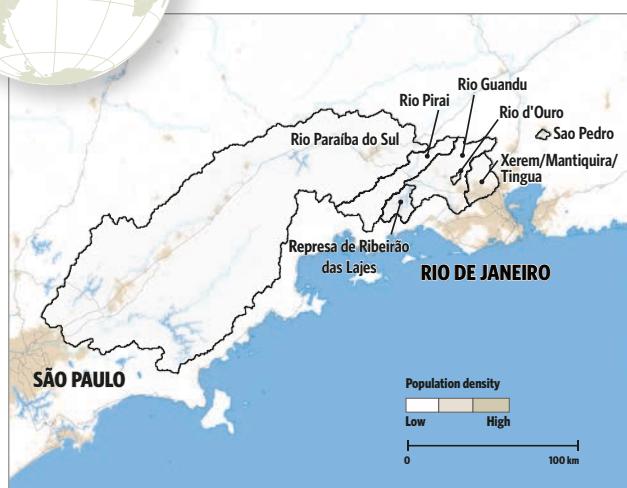
regionally characteristic species, as well as imperiled species dependent on linked habitats and ecosystem functions. Intact forest landscapes—unbroken expanses of natural ecosystems within the zone of current forest extent that show no signs of significant human activity and are large enough that all native biodiversity could be maintained—deserve special attention.<sup>427</sup> Urban source watersheds contain 36 percent of the world's intact forest landscapes, with the vast majority (28 percent) in the Latin America and Caribbean region (see Appendix III for results by region). These intact forest landscapes are important, among other reasons, for providing sufficient terrestrial habitat to support viable populations of wide-ranging species, as well as many natural processes that sustain freshwater ecosystems.

## LOCAL SPOTLIGHT

### Rio de Janeiro, Brazil—Measuring biodiversity and ecological integrity benefits



Photo credit: © iStock/EduLeite



#### The challenge

As the most visited city in the southern hemisphere, Rio de Janeiro (Rio) is known around the world for its majestic coastline, vibrant culture and the exceptional biodiversity that surrounds it. Such attractions are important drivers of tourism, which can produce a wide range of economic benefits at local, regional and national scales. However, tourism can also make an already thirsty city even thirstier. In Rio, 10 million urban residents each consume almost 300 liters of water each day—well over the national and global averages.

The increasing demand for water plays an important role for an already stressed water source. About 80 percent of the water used in Rio is supplied by the Guandu River System, but more than 50 percent of this is lost to leakages and other faults in the transfer system.<sup>428</sup>

The Guandu River watershed's importance as a water source is matched by its importance for sustaining globally significant biodiversity. Rio is surrounded by remnants of the Atlantic Forest, one of the most biologically diverse ecoregions of the world with more than 20,000 species of plants and 2,200 species of mammals, birds, reptiles, amphibians and freshwater fishes (hundreds of which are endemic to the area).<sup>429</sup> Forest loss threatens these species and their habitat. Centuries of agriculture, cattle ranching and urban development have led to the deforestation of almost 90 percent of this ecoregion and have caused intensive sedimentation of water sources.<sup>430</sup> The urgent need for forest protection in the Atlantic Forest is underscored by the current status of the country's endangered species. Approximately 60 percent of all threatened animals in Brazil reside within this ecoregion.<sup>431, 432</sup>

Brazil's challenges are daunting, but the opportunity is clear: the downstream demand for the water services that the upstream watersheds provide can direct financial investments to those areas to reduce water risk, while also protecting the ecological integrity of these biologically diverse regions.

## Action and opportunity

While extensive deforestation continues to degrade the Atlantic Forest habitat that supports many endangered species and further threatens Rio's water security, there is a strategic opportunity that can address both risks. The Upper Piraí watershed, where natural vegetation remains relatively intact, directly contributes to the Guandu system and ultimately supplies the city of Rio with 12 percent of its water. To maintain reliable supplies of clean water from this source, The Nature Conservancy and its partners supported the Brazilian National Water Agency and the Guandu Watershed Committee in creating a water fund to compensate local landowners for conserving and restoring forests in the headwater catchments.<sup>433</sup> Over the course of about seven years, the Rio de Janeiro water fund (Water and Forest Producer Project) has distributed US\$110,000 to 62 landowners for reforesting almost 500 hectares of degraded land and for protecting an additional 3,000 hectares of existing forest.<sup>434</sup>

While maintaining base flows and reducing sediment loads were priority objectives for the water fund's stakeholders, the fund's managers also recognized the importance of investing in a robust biodiversity monitoring program. Surveys indicated the high biological value of these watersheds and the significant benefits that could be achieved through source water protection. Monitoring to date has focused on describing baseline conditions at the start of the water fund's activity implementation.

## Endangered fish species

The National Museum of Rio de Janeiro has conducted baseline surveys to inventory fish species at 15 sites across the upper Piraí watershed. Among the survey findings were several species found only in the region and a thriving population of an endangered fish species.

## Threatened bird species

The National Museum has also been conducting bird surveys in the watershed. A total of 291 bird species have been documented, including 10 that are globally threatened and 38 that had never been observed previously in the region. Importantly, the survey also documented 32 bird species in forest corridors that had been restored, 11 of which were forest-restricted birds and six being typical understory species. These findings indicate the potential for biodiversity conservation as a result of restoration interventions.<sup>435</sup> Part of that success is linked to the presence of intact forest remnants that are able to serve as seed sources for the recolonization of restored tracts.

## Terrestrial plant species

Monitoring of plant species in remnant native forest and restoration plots has recorded a total of 374 species representing 64 families of trees and shrubs, of which two are rare species and one is a potentially new undescribed species. A comparison of satellite imagery from 2004 and 2009 has shown an initial increase in the extent of secondary stage vegetation, signaling movement toward forest ecosystems able to support native forest-adapted species.<sup>436</sup>

Investments in monitoring are critical to measuring the impacts of source water protection activities and to learning how to improve the design and implementation of those activities in the future. Future monitoring in the Guandu watershed will benefit the water fund as it adaptively manages its program, and it should generate findings of relevance to other forest restoration efforts in the region and elsewhere in the world.

RIO DE JANEIRO DASHBOARD						
Water fund start date	Number of upstream participants to date	Number of potential downstream beneficiaries	Number of partners to date	Primary funding sources	Activities	Anticipated co-benefits
2009	46	Between 1,000,000 and 5,000,000	6	Private NGO/Foundation National Water Agency Public (Charging for use of water and other sources)	   	    

## Nitrogen—A thread from farms to fisheries

The impacts of excess nutrients—both nitrogen and phosphorus—in freshwater systems is a well-studied problem and illustrates the integrated nature of land management practices, water quality, ecosystem function, biodiversity, and human health and well-being. We focus on nitrogen here due to its direct impacts on human health, recognizing that addressing nitrogen loading sources will also address phosphorous loadings in many instances.

### Upstream and downstream tradeoffs

While the Earth's atmosphere is made up of 78 percent nitrogen, little is available to plants for growth. Rather, plants depend on nitrogen that is in bioavailable forms such as nitrates, nitrites and ammonium. One of the largest sources of these forms of nitrogen comes from the application of mineral and organic fertilizers to croplands. Low to moderate fertilizer use improves food production with positive economic and health implications for direct beneficiaries of this production. Over 40 percent of the increase in global agricultural yield achieved since the middle of the twentieth century has come from the use of fertilizers, along with increased irrigation and high quality crop seed,<sup>437</sup> lifting many out of hunger.<sup>438</sup> Fertilizer use has also nearly doubled the amount of bioavailable nitrogen in the environment during the past century, though rates of growth vary regionally.<sup>439, 440</sup>

As the amount of bioavailable nitrogen increases in our ecosystems there are major tradeoffs that emerge between crop production and downstream water quality, with human and ecological health outcomes. Source water protection activities aim to reduce fertilizer use, optimize the timing of fertilizer application and trap bioavailable nitrogen before it enters water courses.<sup>441</sup> Crops require specific nutrients at different phases of their growth cycles and are taken up less at other times. Targeted application of fertilizers at these critical growth points reduces the application of excess fertilizers, saving farmers money and ensuring good crop yields. As well, careful attention to weather forecasts, such as large rainfall events, can prevent the loss of newly applied fertilizers to streams, which can significantly impact downstream water quality. Riparian restoration is another critical tool for watersheds exporting high amounts of nitrogen per year. Riparian vegetation, which slows overland water flow and helps increase infiltration, can also capture nutrients before they enter streams and has additional benefits for terrestrial and freshwater species.

In the following sections we trace the causes and consequences of excess nitrogen in our lands and waterscapes and describe how source water protection, paired with strong legal frameworks, can provide an effective means of reducing nitrogen levels for downstream populations, with implications that stretch all the way to the ocean.

### Where and why excess nitrogen is a problem

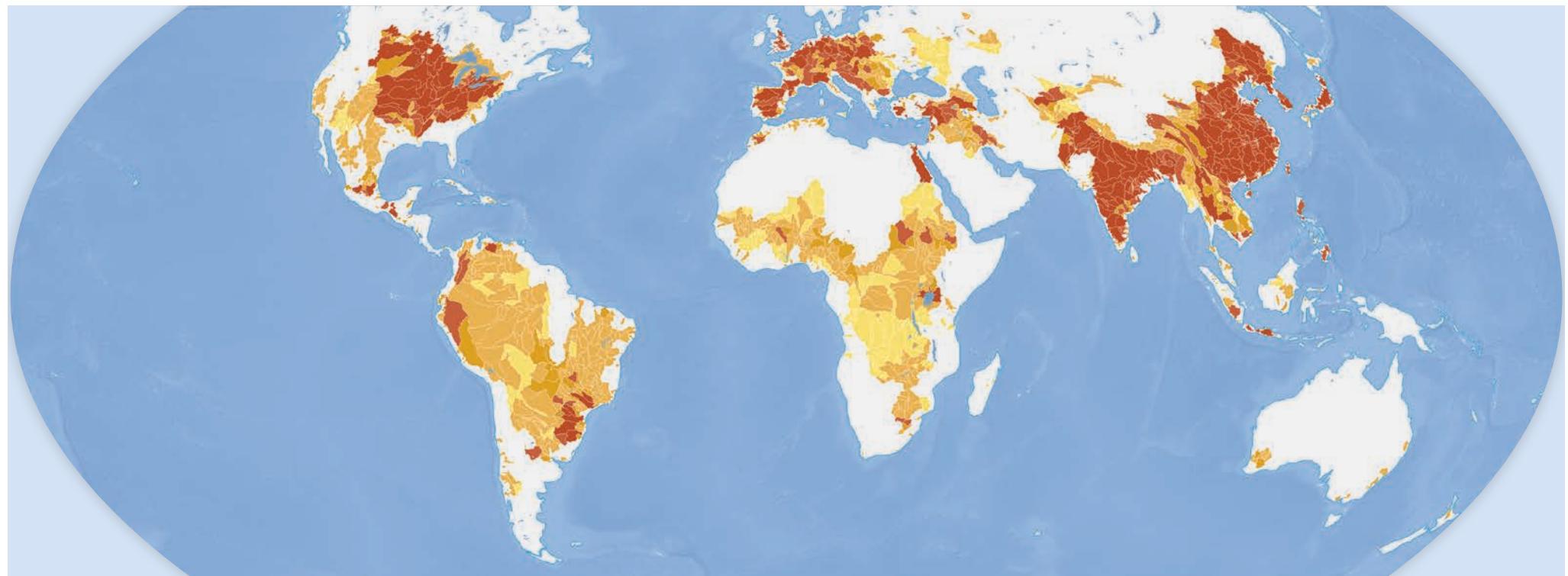
Nitrogen is an important element in ecosystem functioning. However, large influxes of nitrogen into aquatic systems, especially at particular times of the year that coincide with algal growth (e.g. spring and summer), can disrupt the nitrogen cycle and lead to ecosystem degradation with impacts for human health. Excessive levels of nutrients in water courses, known as eutrophication, often leads to high levels of aquatic plant and algal growth which can impair those water courses' use for drinking water, recreation or habitat for fish and other aquatic species upon which communities may depend.



Photo credit: © Kili Yuwan

Algal bloom in salt marsh resulting from agricultural effluents.

## Total annual excess nitrogen application



**Figure 3.27.** Areas of excess nitrogen application per year across urban source watersheds. HydroBASINS with negative values indicate a deficit balance of nitrogen. (Source data: EarthStat total fertilizer balance data<sup>448</sup>)

### Total excess nitrogen (tonnes)

Yellow	< 0
Orange	0 - 10,000
Dark Orange	10,000 - 20,000
Red	20,000 - 40,000
Dark Red	> 40,000

We use a global nitrogen balance dataset<sup>442</sup> to identify the source watersheds where nitrogen input levels are higher than can be taken up by soils and vegetation (including crops) and may pose a threat to local water quality. These nitrogen sources come primarily from fertilizer application, as well as nitrogen fixation from the atmosphere, animal wastes and deposition of industrial pollutants, which each vary regionally.<sup>443</sup> We find that 76 percent of the area across urban source watersheds experience excess nitrogen application over the course of a year. Together these watersheds receive an excess of 38 megatonnes (Mt) of nitrogen a year, much of which makes its way into aquatic systems through

leaching and runoff from agricultural areas (Figure 3.27). Based on estimates of global nitrogen sources, that could be equal to an additional 19 to 42 percent of the naturally-created nitrogen fixed on land each year.<sup>444, 445, 446</sup> It is worth noting that downstream wastewater treatment plants themselves can also be a significant source of nitrogen pollution.<sup>447</sup>

Most of the source watersheds with large excess nitrogen loads are in areas with intensive farming practices, such as Europe, Asia and North America. For example, source watersheds in Asia contribute 71 percent of the total nitrogen excess load

across all source watersheds (see Appendix III for results by region). Although dominated by smallholder farmers, large swaths of China and India practice high-fertilizer input agriculture for rice and wheat, with China applying three times more fertilizer per hectare than in the United States.<sup>449</sup> In North America, the corn belt of the Midwest, typified by industrialized and input-intensive monoculture, is also an area of high excess nitrogen, which finds its way almost exclusively into the Mississippi River. These areas have also experienced increasing reported water quality problems, especially at the outflow of the Mississippi into the Gulf of Mexico.<sup>450</sup> In contrast, source watersheds in the Amazon and Africa have some of the lowest levels of excess nitrogen, likely due to low agricultural development and low fertilizer use, respectively.

### Invisible impacts of excess nitrogen in water

As nitrates from agriculture run off the land, they enter our drinking water systems. High levels of nitrates in drinking water are most common in rainy seasons, when heavy rains wash soils and recently applied fertilizers from fields into local streams. Excessive levels of nitrates in drinking water have been linked to blue baby syndrome (methemoglobinemia), when a baby's blood cannot carry sufficient oxygen, leading to blue-ish skin, as well as to scattered reports of increased incidence of bladder and ovarian cancers,<sup>451</sup> although these connections have yet to be reliably confirmed.<sup>452, 453</sup> In the United States and elsewhere, a maximum level of 10 milligrams of nitrates per liter has been set for safe drinking water,<sup>454</sup> with slightly higher levels globally set by the World Health Organization (WHO).<sup>455</sup> In recent years, this level has been an increasing challenge for some municipalities to achieve in their public water supply system.<sup>456</sup>

### A recent bloom in nutrient-related problems

Many people may be largely unaware of tasteless and odorless nitrates in their drinking water, but nutrient over-enrichment of freshwater and coastal ecosystems from anthropogenic inputs is a rapidly growing—and often visible—environmental and public health crisis.<sup>457</sup> One of the first and most noticeable outcomes of eutrophication are large, nutrient-fueled algal blooms in lakes, rivers and oceans. Both nitrogen and phosphorus runoff from fertilizers and industrial sources can drive eutrophication, although the relative importance of phosphorus and nitrogen in different freshwater system types, and in marine versus freshwater systems, is complex.<sup>458, 459, 460</sup>

In 2008, there were over 700 reported coastal areas around the world experiencing eutrophication problems.<sup>461</sup> In China, a combination of seaweed farming and nutrient inputs are believed to be behind an 2,590,000-hectare algal bloom that in 2008 blanketed the coast of Qingdao,<sup>462</sup> a tourist destination, resulting in clean-up costs of US\$30 million and more than US\$100 million in losses to abalone and sea cucumber industries. The following year's bloom in the same location was even larger in extent.<sup>463</sup> In the United States alone, 20 states experienced serious algal outbreaks in 2016, encompassing both inland and coastal occurrences.<sup>464</sup> For example, large algal blooms, primarily driven by phosphorus loads from agriculture and industry, have become a recurring summer phenomena in Lake Erie, shared by the United States and Canada, stimulating large government investment in improving both agricultural management practices and water treatment.<sup>465</sup>

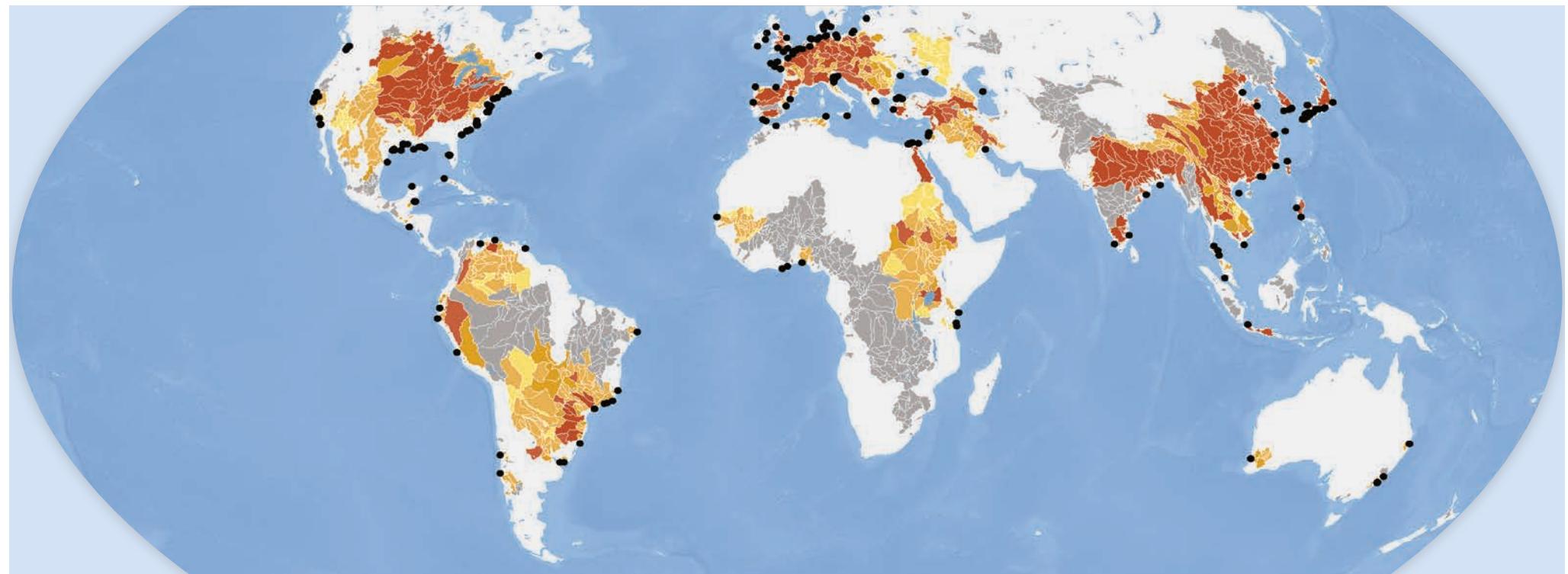
Some algal blooms are not only unpleasant but toxic.<sup>466</sup> Certain species of algae, including golden and red algae, and some types of cyanobacteria, produce toxins that can cause adverse health effects in wildlife and humans—damage to the liver and nervous system among them.<sup>467, 468</sup> Many coastal seafood farms, including producers of oysters and shellfish, have been periodically closed due to large “red tides,” an algal bloom that renders filter feeders (mussels, clams, oysters, etc.) toxic to humans and other mammals as they bioaccumulate toxins up the food chain.<sup>469</sup>

### Dead zones, an extreme impact of nitrogen pollution on biodiversity

When large algal blooms occur, oxygen in the water is consumed as the algae decompose, creating what are known as dead zones where there is little (“hypoxic”) to no oxygen (“anoxic”) left for fish and other aquatic life. These can result in large fish kills or avoidance of these areas by marine species.<sup>470</sup> Between 1995 and 2011, the number of known dead zones rose from 195 to over 515 worldwide.<sup>471</sup> While dead zones have most often been reported along coastlines of North America, Europe and parts of Asia, they are increasingly reported from coastal areas in South America, Australia and Africa, although reporting from these regions is patchy.

Dead zones tend to occur at the mouths and deltas of rivers where land-based nutrients enter the marine system and manifest impacts on local species. The impacts can be long-lived. A recent study showed that ocean floors can take over 1,000 years to recover from low-oxygen events.<sup>472</sup> These events are expected to become more widespread as farming and ranching practices continue to expand and as global ocean temperatures rise due to climate change, fueling larger algal blooms.<sup>473</sup>

## Excess nitrogen in upstream urban source watersheds linked to downstream eutrophication areas



**Figure 3.28.** Excess nitrogen in urban source watersheds upstream of reported downstream eutrophication problems, including dead zones. Urban source watersheds displayed in gray are not linked to any reported eutrophication problems. HydroBASINS with negative values indicate a deficit balance of nitrogen. (Source data: World Resources Institute eutrophication database 2013<sup>476</sup>; EarthStat total fertilizer balance data 2014)

### From land to sea

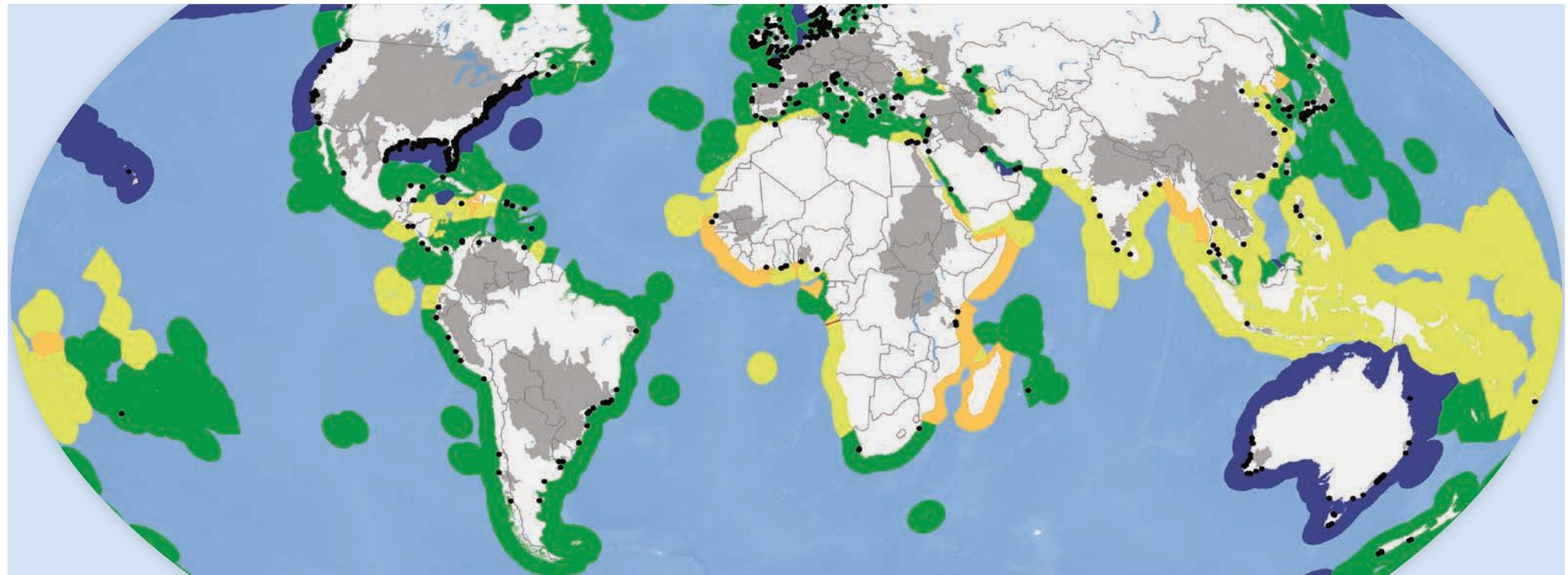
Tracing the paths of nutrients in rivers and streams to coastal zones, we find that urban source watersheds feed into 200 of the 762 (26 percent) globally reported coastal eutrophication and dead zones (Figure 3.28). Areas reporting higher numbers of eutrophication problems and dead zones tend to occur downstream of areas with rates of high excess nitrogen and are primarily concentrated around the east coast of North America, Northern Europe, eastern China and Japan.

One of the challenges of nitrogen is that excess nutrient application tends to be concentrated regionally, with multiple high-application watersheds draining into

the same rivers. As a result, nutrients applied across many watersheds in a country may end up accumulating into a single or small number of rivers, which then deliver very high nutrient loads into coastal zones.

For example, in the United States, much of the Corn Belt drains into the Mississippi River and later into the Gulf of Mexico, creating the largest dead zone in the world.<sup>474</sup> Dead zones in the Gulf of Mexico can grow to 2,000,000 hectares in size. Likewise, in China, the central agricultural zones mostly drain into the Yellow and the Yangtze Rivers, which flow into the East China Sea, another region that has been plagued by large number of algal blooms and dead zones.<sup>475</sup>

## National dependence on coastal artisanal fisheries



**Figure 3.29.** Dependence on artisanal fisheries, as determined by the Ocean Health Index based on the log-normalized per capita GDP adjusted for purchasing power parity.<sup>481</sup> Lower PPPpcGDP areas are expected to depend more on small-scale artisanal fisheries for a source of protein and livelihoods than counties with higher scores. Urban source watersheds contributing to existing eutrophication problems are displayed in gray. (Source data: World Resources Institute eutrophication database 2013<sup>482</sup>; Halpern, et al., 2012<sup>483</sup>; World Bank GDP per capita data)

### Links to human well-being

The impacts of algal blooms and dead zones may be particularly important for the 10 to 12 percent of the global population that depends on fisheries and aquaculture for their livelihoods, 90 percent of whom are small, artisanal fishers.<sup>477</sup> Coastal fisheries are an important livelihood strategy for millions of people living on or near marine shorelines globally. Together, artisanal fishing by individuals, households and small cooperatives contributes over half of the world's marine and inland fish catch, nearly all of which is for direct human consumption.<sup>478</sup> In addition to the world's 56.6 million people engaged in the primary sector of capture fisheries and aquaculture, another 140 million people are employed in fish processing, distribution and marketing.<sup>479</sup>

Based on data collected by the Ocean Health Index,<sup>480</sup> the highest dependencies are along the shores of Sub-Saharan Africa and Southeast Asia, with moderate



dependence through the small island nations of Oceania where local poverty levels are high and dependence on wild-caught fish is important. In these areas, protection of coastal environments and fisheries will be especially important for sustaining local livelihoods and diets (Figure 3.29).

The linkages from upstream catchments to coastal areas, and from farms to fisheries, exemplify the 'ridges to reefs' concept that is garnering increased attention as a result of the coastal impacts described above. Ridges to reefs programs are largely driven by concerns related to coastal ecology and fisheries, but as we have shown, there is high overlap with source water protection efforts catalyzed by concerns related to urban drinking water. This overlap underscores the need for systemic approaches to watershed management. In the following chapter, we focus on how water funds—a source water protection mechanism—actualize that systemic approach.



The value of source water protection goes beyond water security.



Photo: © Erika Nortemann

## CHAPTER FOUR INSIGHTS

The water fund, an institutional platform developed by cities and conservation practitioners including The Nature Conservancy, can help resolve water and watershed governance issues by bridging science, jurisdictional, financial and implementation gaps.

- Good water governance includes effectiveness, efficiency, trust and engagement.
- Barriers to effective governance across a watershed include lack of incentives for stakeholders; institutional fragmentation; lack of political will and leadership; high transaction costs of involving multiple stakeholders in the governance process; and lack of financial vehicles that allow for major funding flows.
- Water funds help overcome barriers and deliver on good water governance.
- For more than 15 years, water funds have helped communities improve water quality by bringing water users together to collectively invest in upstream habitat protection and land management, and mobilize innovative sources of funding.
- Water funds share common characteristics: a funding vehicle, a multi-stakeholder governance mechanism, science-based planning and implementation capacity that works to provide a sustainable framework for delivering source water protection at scale.

# Chapter 4

## Overcoming Barriers to Change through Water Funds

### Sharing the value of healthy watersheds

If source water protection activities were implemented around the world, the magnitude of potential benefits could be substantial. Source water protection, however, is simply a toolbox of land-based activities (as laid out in Chapter 2). How do we put those tools to work in an effective, equitable and sustainable way?

There are multiple answers to the ‘how’ question, but not all answers are optimal or just. For instance, a provincial government focused on the needs of a populous and comparatively wealthy downstream city could mandate that upstream farmers or ranchers take land out of production without providing fair compensation for the loss of their livelihoods. Source water protection for the downstream municipality might be achieved, but at a cost to upstream communities.

The challenge of managing the equitable, optimal distribution of tangible values over the long term has been the focus of water governance discussions during the last 40 years. Water governance has evolved from a simple concept of designing and maintaining water infrastructure systems to one that focuses on participatory governance at multiple scales, the management and delivery of water to different users<sup>484</sup> and the protection of water resources.<sup>485</sup>

This chapter discusses governance and other barriers to source water protection and presents how one approach—water funds—may help move us past these challenges.

### Challenges of scale

The trend of decentralization has brought water management down to units more aligned with hydrological and local political boundaries such as river basins or municipal water authorities. Governing at a watershed scale matters because it recognizes the biophysical reality of water resources, and it can better achieve positive outcomes for all water users and ecosystems within the watershed boundaries. While this has allowed for more locally-relevant decision-making, it comes with institutional complexity. It becomes complex because land and water use decisions within a watershed are driven by different actors, with goals and jurisdictions that can be at odds with each other.



Photo: © David Sanger

"The 'water crisis' is largely a governance crisis"

OECD, 2011<sup>486</sup>

For example, in most Latin American countries, decentralization of water policies has resulted in complex relationships among public institutions and the public they serve at all levels of government, where these stakeholders often have conflicting priorities and interests.<sup>487</sup> In the United States, for instance, management of the Colorado River poses complex governance challenges given the multitude of local, state and federal actors with varied levels of jurisdictional authority involved in managing the river landscape for food, energy and drinking water.<sup>488</sup> The challenge is in governing at the right scale and designing institutions to meet desired objectives among all relevant actors at this scale.

## Sustainability requires a systems approach

A growing awareness around the interconnections among the needs and desires of diverse stakeholders within watersheds drives demand for a systems approach to watershed governance and management.<sup>489, 490</sup> A systems approach can be defined simply as evaluating and managing multiple objectives collectively rather than individually (see Appendix IV for more information).

A systems approach offers an opportunity to address, more equitably and effectively, the complexity that characterizes the linked social and ecological systems in watersheds that include multiple sectors and stakeholder interests.<sup>491</sup> A key component of a systems approach is governance, as noted by the U.S. National Research Council: "sustainable management of connected systems calls for governance that effectively links across domains, as well as across geographic and temporal scales."<sup>492</sup>



Photo: © Adriano Gambarini

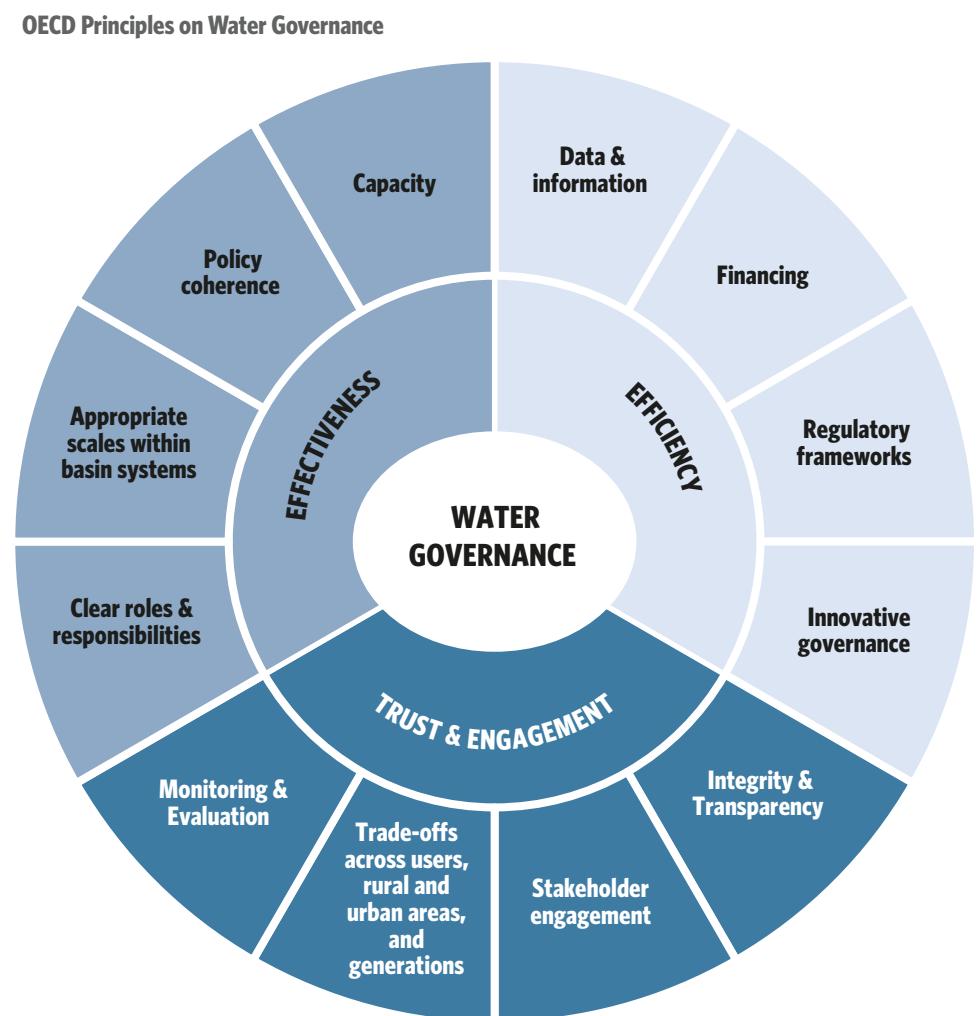
## Defining good governance

The Organization of Economic Cooperation and Development Water Governance Initiative (OECD WGI), an international network of 100-plus public, private and not-for-profit stakeholders, developed principles for good water governance through a multi-stakeholder process (see Appendix IV for more information). Its 12 Principles are grouped into three clusters that form the core of a water governance framework (Figure 4.1).<sup>493</sup>

- **Effectiveness:** Outlines the need for defined roles and responsibilities and coordination across multiple levels of authority. Should be applied at the appropriate scales within basin systems and encourage cross-sectoral coordination and policy coherence.
- **Efficiency:** Identifies components to maximize benefits at the least cost to society through sharing of appropriate and timely data and information, mobilizing financial resources and establishing well-designed regulatory frameworks.
- **Trust and Engagement:** Outlines the need for building public confidence and ensuring inclusiveness of stakeholders through promoting integrity and transparency practices, stakeholder engagement, assessment of trade-offs across users and designing monitoring and evaluation systems.

All 12 Principles are rooted in broader principles of good governance: legitimacy, transparency, accountability, human rights, rule of law and inclusiveness.<sup>494</sup>

The OECD Principles were designed to be applicable to all water management functions and are well-suited for governance of both land and water across a watershed. For source water protection, the principles provide a starting point for understanding how governance around source water protection could be designed to be equitable and empowering in such a way as to achieve multiple benefits that are usually managed separately.



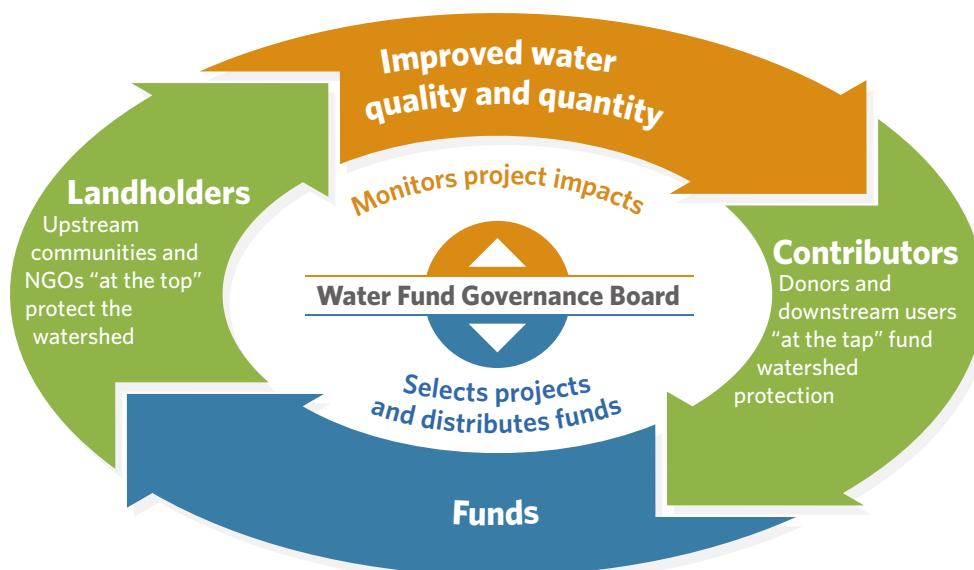
**Figure 4.1.** At the core of the OECD Principles on water governance are effectiveness, efficiency and trust and engagement. Reprinted from OECD, 2015, OECD Principles on Water Governance<sup>495</sup> with permission.

## Going from principles to solutions—Water funds

One governance mechanism for source water protection explicitly designed to address trust and engagement, effectiveness and efficiency is a water fund. Water funds are a finance and governance mechanism that links downstream water users to upstream land stewards around a common goal of sustainable watershed management.<sup>496, 497</sup> They come in a variety of forms and can be adapted to the local socio-cultural, political, economic and environmental context, but they share four primary organizational components.

First, water funds are a governance mechanism for building trust and engagement among multiple watershed stakeholders for transparent project planning and decision-making. This governance process is partly characterized by a multi-stakeholder board or a project management unit composed of water users and, sometimes, other watershed actors, including upstream communities. Second, given the need to meet multiple stakeholder goals in a transparent way, water funds have also been characterized by efforts to include science and local knowledge in water fund planning and prioritization.<sup>498, 499</sup> In addition, water funds are a funding vehicle where multiple stakeholders—including water users, government agencies and non-governmental organizations (NGOs)—come together to provide long-term resources for source water protection. Finally, there is a watershed conservation program, which facilitates the implementation of activities on the ground.<sup>500</sup>

Schematic of the transfer of services and funding within a water fund



Water funds have also been referred to as “collective action funds,” characterized by their pooling of “resources from multiple water users (and sometimes NGOs or government acting in the public interest) to financially incentivize coordinated interventions across a landscape.”<sup>502, 503</sup> A water fund’s success fundamentally depends on this pooled downstream support, but also on the pooled support and engagement of local land stewards who feel that they benefit from water fund activities in a meaningful way. Water funds can create a virtuous cycle whereby well-designed, equitable programs provide opportunities and support for land stewards who then manage their land in a way that provides watershed services important for their own communities as well as for downstream water users. Recognizing the benefits of watershed services, downstream users provide political and economic support that ensures continued benefits to all actors in the landscape (Figure 4.2).

By connecting downstream and upstream communities, water funds can be seen as promoting a more systemic approach to watershed management that involves, connects and gives voice to a broad range of stakeholders. The water fund model builds on lessons learned from experiences and evolution in water management, including integrated water resources management (IWRM), that have helped illuminate strengths and challenges around integration at appropriate scales and with context-relevant tools and approaches.

**Figure 4.2.** A water fund is designed to cost-effectively harness nature's ability to capture, filter, store and deliver clean and reliable water. Water funds have four common characteristics: science-based plans, a multi-stakeholder approach, a funding mechanism and implementation capacity.

The water fund model is not one-size-fits-all. Each water fund needs to be tailored to the local socio-cultural, ecological and economic context.<sup>504, 505, 506</sup> In practice, water funds display a wide diversity of funding, governance and implementation strategies related to the objectives of organizing and mobilizing resources and supporting watershed protection (see Table 4.1).<sup>507, 508, 509, 510</sup>

#### Examples of governance, funding and implementation models for water funds

Governance models	Funding models/sources	Implementation models/strategies
<ul style="list-style-type: none"> <li>▪ Multi-stakeholder governance board or project management unit (mix of public, private, multi-lateral and civil society institutions and, in some cases, representation by upstream water providers)</li> <li>▪ Project management unit composed of watershed committee, public agencies and civil society</li> <li>▪ Board of people elected by various watershed stakeholders</li> <li>▪ Three-way agreement among municipalities, water providers and facilitating NGO, day-to-day management by independent water user associations in each municipality</li> <li>▪ Umbrella organization among municipalities</li> <li>▪ Government agency in charge with no board, but many partners</li> </ul>	<ul style="list-style-type: none"> <li>▪ Voluntary contributions by board/project management unit members</li> <li>▪ Donations outside board</li> <li>▪ Watershed committees required by law to invest fees from large water users in watershed health</li> <li>▪ Legal regulations create conditions for establishment of PES schemes through public resources</li> <li>▪ Municipal block grants</li> <li>▪ Municipal taxes and water user fees</li> <li>▪ Water companies apply a water tariff that includes the costs of watershed conservation</li> <li>▪ Percentage of water company income established by municipal ordinance</li> <li>▪ Water companies (utilities) invest part of general budget</li> <li>▪ Environmental compensation/offsets</li> <li>▪ Interest generated by endowment</li> </ul>	<ul style="list-style-type: none"> <li>▪ Payment for ecosystem services</li> <li>▪ In-kind contributions for habitat conservation/restoration (e.g., home gardens, inputs for alternative income generating activities, materials for improved agricultural productivity)</li> <li>▪ Protected area creation</li> <li>▪ Land purchases</li> <li>▪ Easements</li> <li>▪ Forest certification</li> <li>▪ Social marketing/education</li> <li>▪ Direct investment in agricultural practices that reduce sediment or nutrient run-off, such as buffer strips, terracing, cover crops, etc.</li> <li>▪ Direct investment in restoration of ecosystems, like wetlands, grasslands and forests to improve watershed health</li> <li>▪ Public land management practices, such as fire management or enforcement infrastructure</li> <li>▪ Targeted investments to reduce the impact of other sources of water impairment, like road surfaces</li> </ul>

Table 4.1. Derived from existing and in-development programs around the world.

By connecting downstream and upstream communities, water funds can be seen as promoting a more systemic approach to watershed management that involves, connects and gives voice to a broad range of stakeholders.

## Water Funds Toolbox

In an effort to capture over 15 years of experience in water fund development and operation, and to meet a growing need of practitioners who want to learn how to implement a water fund, The Nature Conservancy is iteratively developing an online Water Funds Toolbox.<sup>501</sup> In developing the Toolbox, a wide variety of approaches and experiences were condensed down to four common components across five typical phases of a water fund, as shown in Figure 4.3. The water fund exploration, development and operational phases run across the top of this figure, while the components (multi-stakeholder governance, science-based decision-making, finance and deployment) cut across each of these phases.

Even as water funds are applied uniquely in each location to adapt to local conditions, partners and challenges, these four components serve as the common foundation upon which each water fund is built. These components ensure transparency, engagement, effective operation, efficient implementation and sustainability of the fund into the maturation phase.

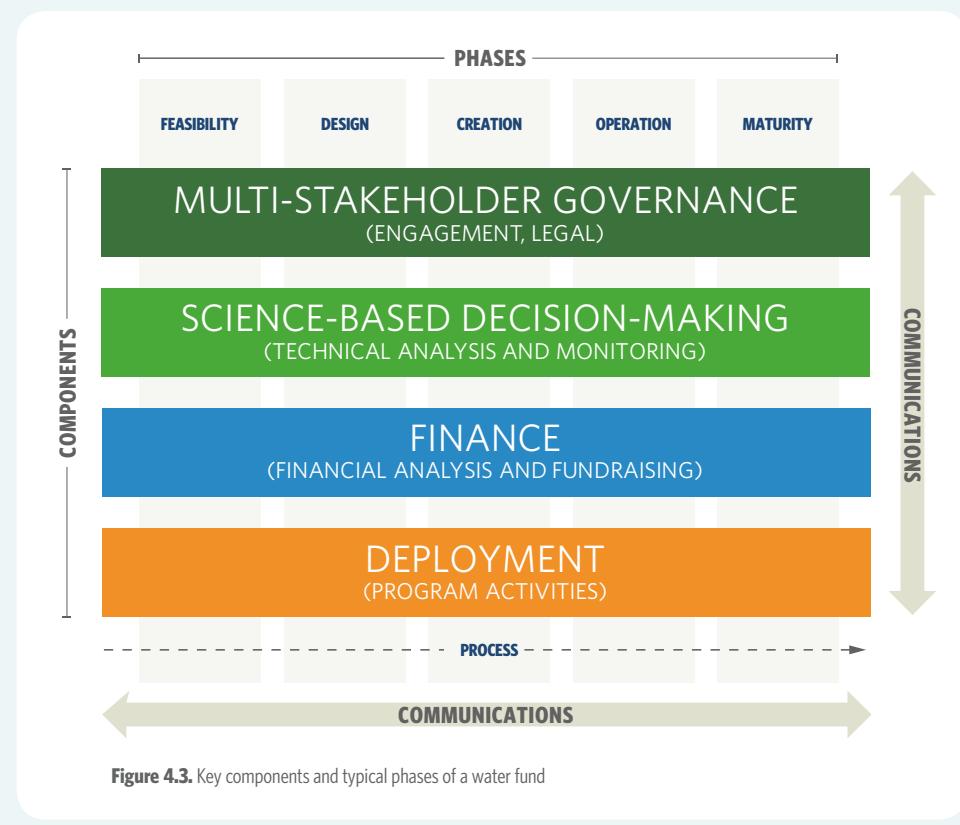


Photo: © Carlton Ward Jr.

## Water funds provide a platform for overcoming barriers

Governing connected systems—land and water—within a watershed requires a combination of elements: clear rules, appropriate actors, effective participation, common visions, multisector and multi-level strategic planning, strong relationships, accountability and conflict management. Many of these components are difficult to achieve.

Barriers to effective governance across a watershed include:

- lack of incentives for stakeholders to improve the condition of a watershed for one or more objectives;
- institutional fragmentation that hinders decision-making and management enforcement;
- lack of political will and leadership; and
- lack of investment in the processes and transaction costs of involving multiple stakeholders in the governance process.<sup>511, 512, 513</sup>

It has also been noted that many financial vehicles for source water protection are not structured in a way that allows for or encourages major investment flows (see Chapter 6).

Water funds address the core components of good governance as described by OECD (effectiveness, efficiency, trust and engagement). In doing so, they help overcome the barriers to sustainable source water protection at the scale needed to help secure water sources.

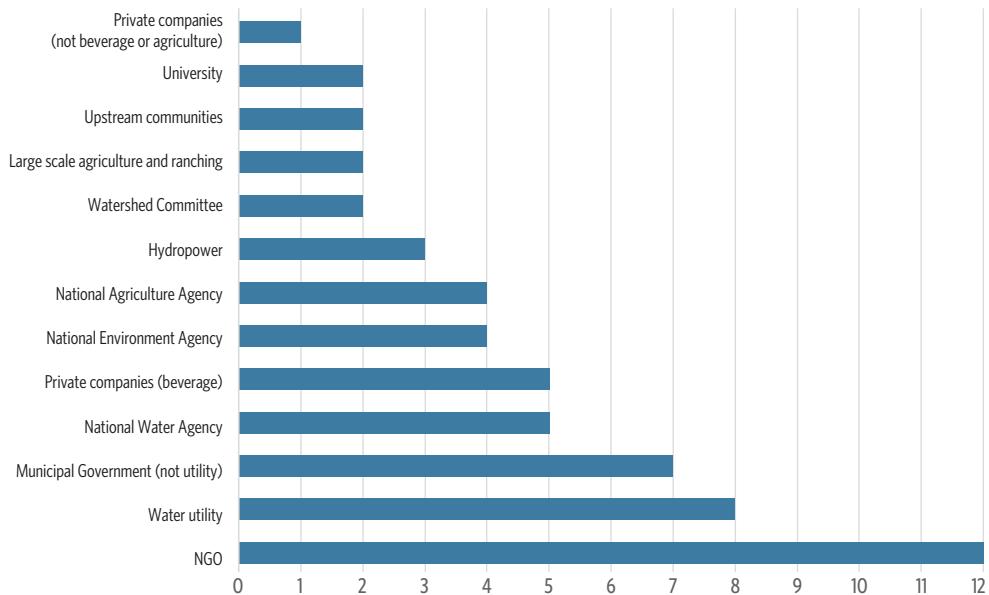
### Effectiveness

Working at a watershed or basin scale requires bringing together multiple government agencies, communities and other stakeholders. Institutional fragmentation that hinders decision-making and management enforcement, lack of political will, lack of political leadership and conflicting interests often stand in the way of effective governance. Water funds provide a way to link upstream and downstream actors—who would otherwise remain dispersed and disconnected—around a common goal of protecting watersheds for the social good.

A key element of this bridging process is bringing together financial, political and social capital in the form of a multi-stakeholder board or project management unit. These decision-making bodies include diverse watershed actors who decide what, where and how to invest resources. The composition and decision-making structure of these boards vary based on the local context, but water funds to-date have successfully engaged a wide range of actors. NGOs, water utilities, municipal governments, national water authorities, private companies and hydropower are the most commonly represented (Figure 4.4). Some of the most successful water funds in terms of number of participants and land area influenced have included local communities on the governance boards, demonstrating the value of including these voices from both an equity and an effectiveness standpoint.<sup>514</sup>

The water fund development process is often the first time diverse watershed actors come together to pool resources (including financial, social and political capital) and make decisions around common goals. This mobilizing process, essentially creating or at least strengthening watershed governance, represents both a key enabling factor and major benefit of a successful water fund.

### Representation of stakeholder groups on boards and project management units among water funds in the Latin American Water Funds Partnership



**Figure 4.4.** Latin American Water Funds Partnership programs represent a subset of all water funds. Bars represent number of funds with representation of a given stakeholder group. Reprinted from Bremer, et al. (2016) with permission.<sup>515</sup>



## Efficiency

Barriers to efficiency include lack of common objectives, lack of data and information framed to support science-based decision-making, and lack of a credible track record to support public and private investments. Science-based decision-making using biophysical and socioeconomic data and models along with local knowledge can create a shared understanding of challenges and opportunities. Transparent funding mechanisms that allow for the flow of payments from downstream users and other contributing stakeholders to upstream land managers can begin to build a solid track record.

### Science-based decision-making

Water funds can move land-based activities from one-off projects to a portfolio of targeted source water protection activities that, in sum, can produce impacts at the necessary scale. Local data and sound science are the foundation of this strategic portfolio. Scientific data can provide a strong starting point of agreement for stakeholders who have not previously collaborated. Using these data to develop a plan of action helps ground decision-making about where specific types of activities

should be implemented. The types of data needed for science-based decision-making in a water fund include data on land-use type and practices, topography, soil and vegetation types, historic precipitation, expected climate change impacts, stream flows, groundwater levels (if applicable) and water quality. Incorporating co-benefits into water fund portfolio planning requires additional data sets, including information on terrestrial and freshwater ecosystems, current and potential carbon storage, as well as socioeconomic data. In cases where not all of these data are available locally, decision-making can be informed by regional or even global data.

Ecosystem services tools (such as InVEST<sup>516</sup> and RiOS<sup>517</sup>) or more traditional water resources tools (such as SWAT<sup>518</sup>), which model how proposed water fund activities might impact downstream water quality or flow regulation, can help water fund stakeholders make transparent, informed decisions about which activities are needed and over what geographic extent to meet the shared water fund objectives. These models, coupled with local knowledge about the potential for engaging land owners on specific parcels of land and about potential positive and negative socioeconomic impacts of proposed activities, provide the building blocks for development of the shared water fund portfolio of activities.

### Transparent, sustainable funding mechanism

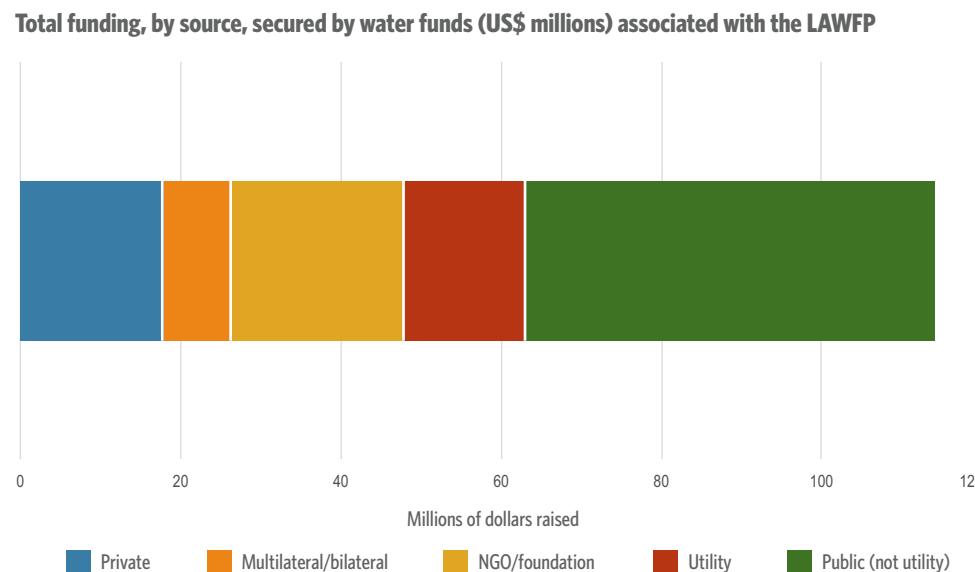
To support the portfolio of activities, a water fund must address the challenge of obtaining, maintaining and scaling the political and financial support of downstream water users and other funders (e.g., governments and NGOs interested in supporting programs focused on social and environmental well-being). This is critical for the effectiveness and efficiency of the water fund as a governance mechanism. Without this support, water funds lack the means to carry out source water protection activities in a scaled and sustained way. Existing water funds have been successful in mobilizing a range of downstream actors including water utilities, hydropower, municipalities, NGOs and private companies, which provide diverse and innovative funding streams. Much of this funding comes from voluntary or legally-mandated contributions from the multiple water users and government agencies that constitute governance boards or project management units. Start-up funding from NGOs, corporations and multi-lateral institutions are also important.<sup>519</sup>

Water funds employ a variety of often-concurrent strategies to ensure that these funding sources are sustainable over the long-term. Some are structured with endowments while the majority rely on other models of sustainable financing sources.<sup>520</sup>

This includes municipal ordinances that require that water utilities invest a portion of their profits in watershed management; national laws that funnel environmental offsets to water funds; and laws requiring that water user fees (collected from water utilities, large companies and/or from citizens) be invested in conservation.<sup>521, 522</sup>

The Latin American Water Funds Partnership (LAWFP) (a partnership among The Nature Conservancy, the FEMSA Foundation, the Inter-American Development Bank and the Global Environment Facility), currently provides support for 19 operational water funds across six countries, with many more funds in development.<sup>523</sup> Among LAWFP water funds in operation, public funding sources, which include rate-payer fees, are dominant, with about 10 percent of funding coming from municipal utilities and another 50 percent from other public sources, including governments and watershed committees (Figure 4.5).

Water funds in Africa and North America have also been financed primarily by public sources, including public utilities, municipal governments, the federal government and the forest services. Rural municipal funds in the Andes known as “Watershared agreements” (see Chapter 3) are also funded dominantly by local governments and public utilities (who often include a water tax on local water users).



**Figure 4.5.** Note: private foundation funding is included in the “NGO/foundation” category, not in the “Private” category.  
(Source: The Nature Conservancy).

Ecosystem services models, coupled with local knowledge, can provide the building blocks for development of the shared water fund portfolio of activities.



## Trust and Engagement

A key barrier to building trust and engagement is an insufficient investment in involving all stakeholders in water governance processes. This is often due to the high transaction costs.

Multi-stakeholder governance mechanisms in water funds support inclusiveness, transparency, equity and engagement. Science-based decision-making addresses issues of trade-offs across users and, in planning for the projects, encourages appropriate engagement. Targeted engagement of women in water fund committees and planning of source water protection activities can help to ensure that women's voices are part of the decision-making process and that the prioritized activities benefit women. Finally, implementation of a monitoring system to track short-term, medium-term and long-term impacts of the funds allows for adaptive management and demonstration that the fund activities are meeting shared objectives.

## Deployment: Partnering with upstream actors

Water funds require the support of households, local communities and/or institutions that manage, own and/or steward land in the watershed for long-term social and ecological sustainability. Without this support, there is no way to actually carry out and scale source water protection activities. Water funds that have successfully implemented source water protection activities have worked with NGOs, Indigenous and other local community organizations or other intermediaries who have long histories building trust with communities, farmers and other land stewards.<sup>524, 525, 526, 527</sup>

Upstream communities are unlikely to start or continue working with the water fund unless they feel they are meaningfully benefitting, so sharing the values derived from healthy watersheds in a fair and equitable way is critical for both social and ecological sustainability (see Appendix IV on the importance of a rights-based approach).

Successful water funds will work with local communities and intermediaries who have strong relationships with local land stewards to understand the amount and type of compensation required as well as how, when and to whom this incentive should be distributed. In addition, water funds need to work with government agencies that may also steward land within the watershed to ensure that collaborative roles and responsibilities are sustained across the landscape (See Rio Grande case study, this chapter).

Engagement and incentive strategies with local land stewards may look different depending on local contexts:

- In some cases, support provided in the form of technical and financial capacity to implement a source water protection activity (e.g., agroforestry or agricultural BMPs) may already create enough benefit to motivate and sustain participation.
- In other cases, additional incentives may be required, particularly where land needs to be set aside or used differently and/or where the water fund aims to improve livelihoods as part of its overall goals or strategy. Incentives can include direct payments or in-kind compensation through assistance with activities like ecotourism, micro-enterprise, beekeeping and home gardens, which strive to provide benefits in the form of increased or stabilized household income and enhanced food production.<sup>528, 529, 530, 531</sup>
- Water funds also commonly provide education and capacity-building activities related to sustainable agricultural production and water management.<sup>532</sup>

## Sharing the Wealth: The potential monetary and non-monetary benefits from water fund participation

One potential benefit of water funds—particularly where direct payments are used—comes in the form of increased household income. However, because water funds are relatively young, the little evidence that exists on changes to income comes from more established payment for ecosystem services (PES) programs that rely on similar approaches. A rigorous study of change in income and/or material living standards as a result of participation in PES programs would consider both opportunity costs and ‘business-as-usual’ counterfactuals (i.e., what would have happened without the program), but few studies to date have taken this approach (among the few, one study in Bolivia serves as an example<sup>534</sup>). Overall, the limited available evidence suggests moderate, positive impacts on household incomes resulting from participation in PES programs that use direct payments.<sup>535, 536, 537</sup>

Among the most rigorous evaluations of the impacts of watershed-focused PES programs on household income come from China’s Sloping Lands Conservation Program (SLCP), which pays farmers to convert agriculture on steep slopes to forestry in order to reduce erosion and protect water supplies. The majority of studies suggest that the SLCP has increased rural incomes for participants compared with non-participants by about 10 percent through payments and by stimulating off-farm labor.<sup>538, 539, 540, 541</sup> Moreover, researchers conclude that low-income households have experienced the greatest relative increases and that the program has generally decreased inequality.<sup>542, 543</sup>

Studies of other PES programs underscore the context-specific nature of program benefits. Similar to the SLCP, Mozambique’s Nhambita PES program generated cash income increases of 10 percent.<sup>544</sup> In contrast, an evaluation of Costa Rica’s PES program found no detectable net benefits in terms of assets and self-perceptions of well-being, most likely because cash transfers were accompanied by decreased on-farm inputs (cattle and labor). However, that study’s authors concluded that financial benefits do not capture the full suite of benefits that motivate participation and that non-financial values (e.g., environmental protection, land tenure security and social networks) spur participation and overall satisfaction with the programs.<sup>545</sup>

Existing studies of water funds, as well as the broader PES literature, underscore this point: non-monetary values—improved land tenure security, environmental protection, greater opportunities for political and social engagement, as well as access to training and capacity building—can be better motivators and improve perceived shared benefit of participation than money.<sup>546, 547, 548, 549</sup> For example, in Brazil, compliance with the national Forest Code is an important motivator for participation in water funds.<sup>550</sup> In Colombia, participants have cited source water

protection benefits as a major goal of participation.<sup>551</sup> The most important impact of a Bolivian Watershared program that diversified the productive systems of 108 households to include beekeeping and fruit production was that these new activities helped enhance general resilience and reduced exposure to market and climate risks.<sup>552</sup> Likewise, another study of Bolivian programs found that the conservation activities themselves add economic value to landholders through improved water quality.<sup>553</sup>



Many water funds have been designed explicitly around social goals and to encourage broad participation of local land stewards. For instance, in Tungurahua, Ecuador, the water fund “Fondo de Páramos de Tungurahua y Lucha Contra la Pobreza” (water fund for Tungurahua’s páramos and fight against poverty) was established and mobilized by Indigenous community organizations with explicit goals of alleviating poverty and protecting the environment.<sup>533</sup> Other funds support improvements in gender equity. For example, Watershared agreements target women through a focus on honey production, which is traditionally a female activity. Social institutions established or strengthened by water funds can help improve women’s access to land, provide a voice in decision-making processes and ensure that the design of activities lessens, rather than increases, the burdens of water insecurity.

Monitoring and evaluation programs create credibility, transparency and trust. Accountability of investment by downstream users and upstream actors is an important component to ensure integrity and transparency. For water funds to endure and scale in a meaningful way, they need to learn by doing, tracking progress toward intended outcomes and gathering evidence on what works and what doesn’t for upstream land stewards, downstream beneficiaries and the governance institution itself.

The success of water funds rests in large part on developing an evidence-based culture that evaluates and demonstrates success around the right metrics, while providing opportunities to “fail fast” and reorient resources to better achieve intended goals. Well-designed hydrologic monitoring programs can be used to improve prioritization tools<sup>554, 555</sup> and can also refine projected outcomes through improving calibration and validation of ecosystem service models. Likewise, well-designed social monitoring programs can be used to avoid unintended negative impacts and risks and ensure that the water fund provides the best possible outcomes for upstream communities. Community-based monitoring, informed by local knowledge and observation, also contributes in major ways to understanding the social and biophysical impacts of water fund activities.

Monitoring and evaluation have become an increasingly important part of water fund models.<sup>556, 557</sup> Many water funds have begun collecting hydrologic and socio-economic monitoring data to assess the outcomes of water fund activities on the amount and quality of water and on human well-being.<sup>558, 559</sup> Using these data to meaningfully evaluate effectiveness of the type, location and current scale of source water protection activities is critical to improving program outcomes and increasing support. For example, within the LAWFP, at least eight water funds have established

hydrological monitoring programs and four have done some form of social monitoring, with additional programs planning these designs.<sup>560, 561</sup> Hydrological and socio-economic monitoring has also been implemented in several Watershared agreements<sup>562</sup> and a comprehensive baseline social monitoring study is complete for the Upper Tana-Nairobi Water Fund.<sup>563</sup> These monitoring programs are generally run by or work in close collaboration with NGOs and other academic and research institutions. Many have also been developed in close participation with local communities, too. Ongoing efforts continue to evaluate data and link findings to water fund adaptive management and effective communication of impacts.

## Water funds in the real world

The spread of water funds around the world is a testament to their high potential and success (Figure 4.6). In its 2014 survey of investment in watershed services programs, Forest Trends found that over the previous two years, water funds (“collective action funds”) were the fastest growing type of program in terms of number of programs, making up one of every three new programs.<sup>564</sup> In its 2016 survey, Forest Trends documented 95 active, pilot and in-development water funds around the world, with a proliferation in Asia and North America, where previously most had been concentrated in Latin America.<sup>565</sup> Those 95 programs represented a total investment of over US\$563.9 million and covered nearly 9 million hectares.

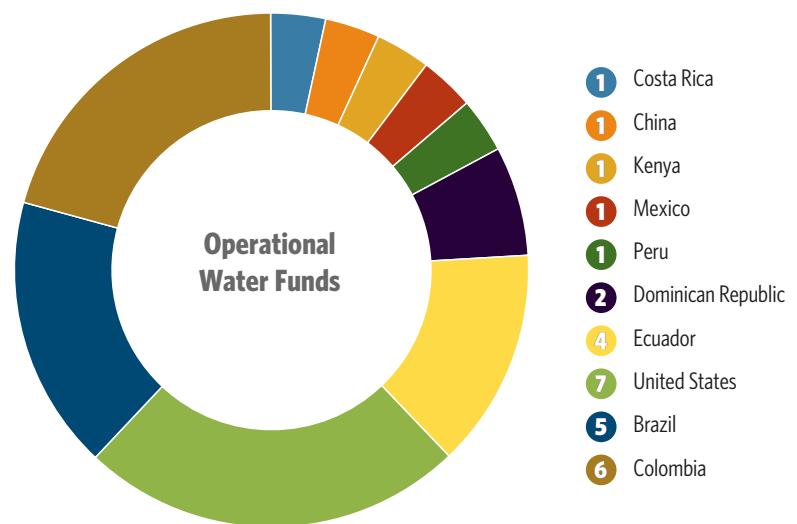
As expected, not all locations where water funds have been explored have resulted in sustainably operated programs.<sup>566</sup> There are a number of reasons why a water fund may not move from a feasibility study to full, sustained operation, including an inability to find long-term financing sources, legal or social barriers and the lack of a robust business case. However, as the number of water funds grows and lessons are shared through peer networks on how to overcome common barriers, the likelihood of success should increase. Likewise, as water funds implement monitoring and linked adaptive management practices to track actual impacts, the trial-and-error period of new funds should decline.

Here we discuss several examples of water funds around the world that have emerged and the different forms they have taken. We focus on the pillars of funding, governance and implementation. In addition to these three pillars, almost all of these water funds rely on science-based decision-making to develop a robust portfolio of activities that will deliver on shared objectives. As water funds expand into new contexts, additional models may emerge and specific combinations may prove to be more or less viable.

## Operational water funds within the portfolio of The Nature Conservancy and its partners



**Figure 4.6.** The water fund concept was born in Quito, Ecuador, and the track record of delivery pioneered in Latin America has led to replication in East Africa, China and the United States. There are 20 operating funds in Latin America, seven in the United States, one in Sub-Saharan Africa and one in China.



- 1 Costa Rica
- 1 China
- 1 Kenya
- 1 Mexico
- 1 Peru
- 2 Dominican Republic
- 4 Ecuador
- 7 United States
- 5 Brazil
- 6 Colombia



### The central Andes as a hotspot for diverse water fund models

Over 20 million people living in Andean cities and towns rely on drinking water from highland páramo or puna grasslands and Andean forests. These water sources are also critical for hydropower, irrigation and cultural values. The Andes have become a hotspot for water funds, including 11 funds in operation associated with the Latin American Water Funds Partnership, several dozen rural municipality funds and an umbrella fund (FORAGUA).<sup>567</sup> Here we describe three representative water funds from the region.

### Quito, Ecuador: Fondo para la protección del Agua (FONAG)

*Description:* In response to growing water demands and concern over watershed degradation, coupled with a lack of resources to protect watersheds, the municipality of Quito, the water company of Quito and The Nature Conservancy helped to create FONAG (Fund for the protection of water) in 2000. Soon after, other public and private organizations joined the water fund, bringing membership to six organizations (EPMAPS- Empresa Pública Metropolitana de Agua Potable y Saneamiento (Quito's water company), The Nature Conservancy, Empresa Eléctrica Quito, Cervecería Nacional, Tesalia-CBC and CAMAREN).

FONAG has an endowment of more than US\$10 million and an annual budget of more than US\$1.5 million. As the oldest official water fund, FONAG has been successful in protecting and restoring over 40,000 hectares of páramo and Andean forests through a variety of strategies, including working with more than 400 local families.

*Governance:* FONAG's vision is to mobilize all watershed actors to exercise their civic responsibility on behalf of nature, especially related to water resources. The multi-stakeholder board composed of public, private and NGO watershed actors provides a mechanism for joint investment in watershed protection. FONAG works on prioritized areas important for water provision for the Metropolitan District of Quito, which includes working with rural communities and private land owners, as well as managing areas owned by the water company and FONAG. FONAG provides a mechanism to link downstream financial support to the upper watershed areas, including the communities who live there.

*Funding:* FONAG obtains funding from its board members and from other organizations interested in supporting the water fund. The majority of these funders are part of FONAG's governance board, where decision-making power is linked to monetary contribution. The largest source of funding (nearly 90 percent) comes from Quito's water company, which by a municipal ordinance is required to contribute 2 percent of the water company's annual budget. This, and the interest from its independently-run endowment, provide long-term financial sustainability. In addition, bilateral and multilateral institutions such as United States Agency for International Development (USAID) and Inter-American Development Bank (IDB) have been important supporters of the fund, providing key funding through grant agreements. The Environmental Department of Quito Municipality, private foundations and private companies are also important contributors to FONAG.

*Implementation:* FONAG conducts source water protection through a variety of mechanisms. First, it works to protect and restore high Andean grasslands (páramos) and Andean forest in critical areas for water provision to Quito, including areas owned by local communities, private landowners and the Quito water company. It does this through active and passive restoration of native ecosystems and through a community guarda páramo (páramo park guard) program that employs local community members to protect these areas from outside use. In areas owned by communal or private landowners, FONAG develops conservation agreements with the owners to ensure protection and restoration of the areas, providing different types of incentives to the owners. Rather than make direct payments for conservation, restoration and sustainable agriculture, the water fund utilizes in-kind compensation like home gardens and support for community projects. In addition to direct source water protection activities, FONAG focuses on

strengthening watershed alliances, environmental education and communication to mobilize additional watershed actors in watershed protection.<sup>568</sup> FONAG has also established a rigorous hydrologic monitoring program to communicate and improve outcomes of investments in collaboration with several academic institutions.

#### Bolivia, Colombia, Ecuador and Peru: Watershared agreements

*Description:* The "Watershared" model was first developed in 2003 in the Bolivian village of Los Negros when six downstream irrigators negotiated a first-of-its-kind deal with their upstream counterparts. Upstream forests were protected from cattle incursion by landowners who were compensated for their conservation efforts. Downstream water users provided alternative development tools, such as beehives, fruit tree seedlings and irrigation tubes.<sup>569</sup> There are now 40 Watershared funds in three Bolivian states (Departments) largely operating in small rural municipalities. Within Bolivia, almost 5,000 upstream landowners collectively participate in these Watershared agreements that now protect 250,000 hectares. In addition, Watershared programs in nine municipalities have supported the creation of 1 million hectares of newly protected Water Sanctuaries. The underlying philosophy of Watershared is the same everywhere—“people who produce water, share it; people who use water, share the benefits”—but local details vary significantly.



Photo: © Nigel Aspinth

*Governance:* There are a number of defining characteristics of Watershared governance. The municipal government drives the process, first issuing a watershed conservation decree and then allocating funds to finance the decree. At the same time, the water provider commits funds, either in a fixed amount or via a tariff increase. These two institutions, along with a catalyzing entity, usually an NGO, then create the water fund institution. This institution leads the creation of a board (one representative from each institution), the development of statutes and operating regulations and the opening of a bank account (usually housed within the legal structure of the water provider). The board makes major decisions, while day-to-day operations are coordinated by the water provider with technical support from the NGO.

Watershared funds are designed primarily to reduce conflicts and bureaucracy. In Cuenca, Ecuador, for example, the city water provider, Empresa de Telecomunicaciones, Agua Potable, Alcantarillado y saneamiento de Cuenca (ETAPA), had for decades been working to protect the upper Yanuncay watershed. However, in upstream Soldados, villagers were viscerally opposed to ETAPA, going as far as to kidnap company staff. Downstream, demand was exceeding supply in the dry season, but city users were wasting water. A two-pronged public awareness campaign calmed tensions upstream and promoted a “shorter showers” initiative downstream, thereby resolving both of ETAPA’s major problems. With the conflicts resolved, and a clear local mechanism of cooperation visible to all, ETAPA was then able to contract 22 Watershared agreements in the middle watershed, conserving 1,341 hectares.<sup>570</sup>

*Funding:* Watershared programs are, on average, about 70 percent funded by local water users and/or their municipal governments, with the rest coming from outside donations, including NGOs. Accordingly, resources come primarily from local governments and 195,000 downstream water users, who annually invest roughly US\$500,000 across the 40 funds. The Watershared model requires and facilitates a local, long-term financial commitment to conservation: municipal governments and water users’ associations must commit funds before the facilitating NGOs provide start-up funding. Given that a local financial commitment requiring public money is required for program initiation, local officials take great interest in designing the schemes, resulting in a sense of local ownership and the potential for long-term sustainability.

*Implementation:* Watershared agreements are implemented through a tool known as reciprocal watershed agreements, as well as through land purchases. The provision of alternative development tools to upstream landowners provides a quick and low-cost route to forest conservation. Landowners choose what compensation packages they prefer from a menu of options, including improved cattle management, irrigation systems, and honey and fruit production. They also receive technical support to help maximize economic improvements. Community members recognize that the

program provides not just economic benefits, but also downstream recognition of communities’ key role in the management of water resources and hence increased visibility of the communities in the local political arena.<sup>571</sup>

Watershared programs do not rely on extensive hydrological and economic studies to define the correct payment levels, nor do they focus on the opportunity cost of conservation as the primary driver of levels and types of compensation. Rather, they attempt to strengthen and formalize pro-conservation social norms, by publicly recognizing individuals who contribute to the common good by conserving their “water factories.” They respond to one of the key findings of behavioral economic experiments, that “money ... is the most expensive way to motivate people. Social norms are not only cheaper, but often more effective as well.”<sup>572</sup> Watershared compensations are thus tokens of appreciation rather than economic transactions and can comprise much lower amounts than neoclassical economic theory would predict.

### Southern Ecuador: FORAGUA

*Description:* Rapid population growth is causing water shortages in many of southern Ecuador’s cities and towns. Expanding land uses such as farming and livestock grazing have resulted in significant deforestation, reducing water quantity and quality. To address this problem, in 2009 a group of municipalities joined together with Nature and Culture International’s support to form a single integrated water fund called the Regional Water Fund of Southern Ecuador (FORAGUA). By the end of 2014, the 15 municipal government members of FORAGUA had created over 70,000 hectares of municipal reserves, protecting and restoring watershed ecosystems that supply water for over 432,000 people.<sup>573</sup>

In addition to clean water benefits, many of these watershed reserves protect Andean cloud forests, which are among the richest, most diverse ecosystems on Earth, harboring one-sixth of all the world’s vascular plant species in less than 1 percent of the world’s land area. Other FORAGUA municipalities are protecting the extremely biodiverse and highly threatened seasonal dry forests on the western slope of the Andes with the watershed reserves they have created.

*Governance:* FORAGUA is a story of governance within and between watersheds. Water fees collected by each municipality are deposited in FORAGUA, with 90 percent going to a dedicated account for watershed protection in the municipality where the funds originated. The remaining 10 percent is used to support FORAGUA’s Technical Secretariat and other operating costs. This allows smaller municipalities and rural populations to participate since they can access a greater level of technical assistance and administrative support from the Technical Secretariat than their individual fees would be able to cover. The Technical

Secretariat currently comprises three professionals (an executive director, a forester and an accountant) whose primary functions are recruitment of new member municipalities, funds oversight, outside fundraising and technical assistance.<sup>574</sup> FORAGUA is structured as a public trust fund governed by its constituent municipalities, which elect representative members to a constituent assembly. Each member of the constituent assembly gets one vote at an annual meeting where they also elect a five-member board of directors. This shared governance structure provides added certainty that the funds entrusted to FORAGUA are used according to agreed-upon budgets and watershed conservation plans.

**Funding:** FORAGUA is funded primarily with resources from citizens living within the watersheds, thus building both local capacity and sustainability. One of the requirements of FORAGUA is that member municipalities implement a special fee on water users that will generate revenues for the FORAGUA trust fund. These fees vary from two to 15 cents per cubic meter of water used per month, depending on the municipality and the user type (domestic, commercial, industrial or government). This represents 20 to 25 percent of the total monthly bill paid by users for clean water, or about a dollar per user per month. One factor in building public support has been a decrease in water treatment costs. The Municipality of Loja, for example, saved over US\$56,700 from 2008 to 2010 in reduced chemical use for potable water treatment following cattle removal from city source watersheds.<sup>575</sup>

An independent public financial entity ensures that revenues from the water fees collected by each municipality are invested effectively and spent to manage watersheds and water resources of southern Ecuador. FORAGUA is composed of separate accounts or sub-funds for each participating municipality.

**Implementation:** A requirement of FORAGUA is that municipalities must declare reserves to protect both watersheds and other high conservation value areas. Funds collected are allocated “to the development of programs and/or projects for the conservation, protection and recovery of the environmental services and biodiversity of fragile and threatened ecosystems.”<sup>576</sup> FORAGUA’s statutes further establish that the funds can be only invested in “land purchases, payments or compensation for environmental services, control and protection of natural vegetation, prevention and control of forest fires, reforestation and restoration of habitats, reserve management (basic infrastructure, trails, fencing, signage), environmental education, support to conservation processes in rural areas and the monitoring of water quality and quantity.” Virtually all of the municipalities have adopted land purchase as their primary conservation tool and have collectively purchased 15,249 hectares to date. FORAGUA municipalities have also invested in fencing to keep livestock out of streams, infiltration ponds to enhance groundwater recharge, tree plantings with high school Eco Clubs and various environmental education activities.

## Water funds in a Brazilian context

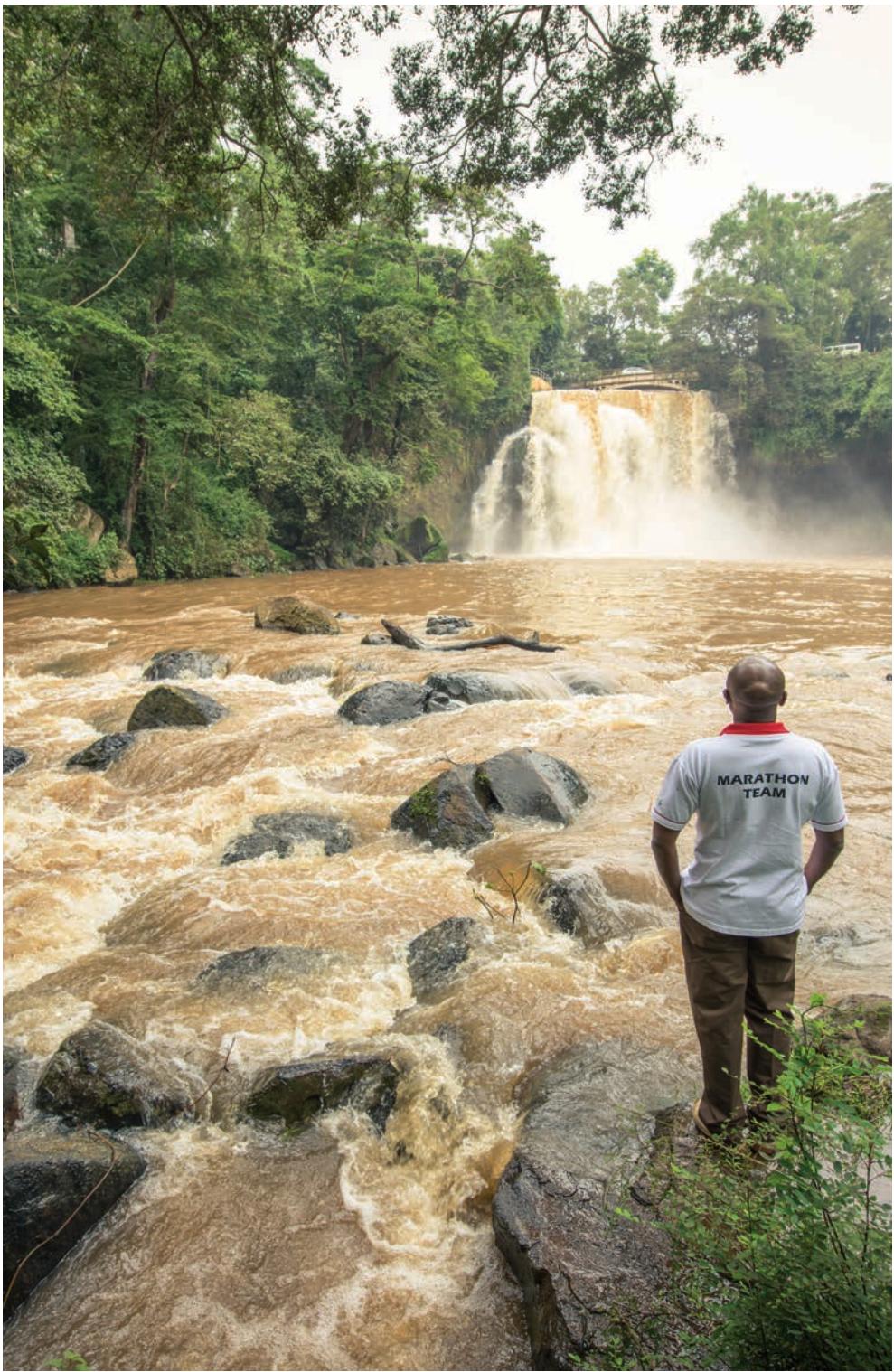
Brazilian cities, including Rio de Janeiro and São Paulo, faced a historic drought in 2014, likely exacerbated by deforestation.<sup>577</sup> In response to this and other water stress events, Brazil put forward a variety of models of source water protection that sit under and outside the umbrella of the LAWFP. Brazil water funds have taken three general approaches: 1) watershed committees gather and redirect investments from companies, water-dependent industries and government agencies into source water protection; 2) laws allow for public funds to be utilized in watershed PES schemes; and 3) utilities apply water tariffs to support conservation.

### Extrema, Brazil: Conservador das Águas program, Mina Gerais

**Description:** Many of the Brazilian water funds are part of the Water Producer Program initially started by Brazil’s National Water Agency. There are now over 30 of these programs in the country, all with mechanisms to financially compensate farmers for source water protection with water users’ fees. Here we describe the first of these projects, Conservador das Águas program in Extrema, a city within the Atlantic Forest of Brazil linked to the Cantareira system—the water source for over 10 million people living in São Paulo.<sup>578</sup> Extrema is also considered part of the broader Piracicaba-Capivari-Jundiaí (PCJ) Water Producer project.



Photo credit: © Adriano Gambarini



*Governance:* While Conservador das Águas is different than other water funds in that it does not have a multi-stakeholder board or project management unit, the program has established long-term collaborations among government agencies, civil society and landowners. This has been instrumental in its success to date. These multiple partnerships have provided the municipality with additional funding streams, as well as skilled labor for activity implementation and monitoring. These partnerships have also helped solidify trust with the landowners as the municipality works to implement activities.

*Funding:* Funding for Conservador das Águas initially came exclusively from the Extrema municipality, due to a 2005 law authorizing the use of municipal funds for payment for ecosystem services and forest restoration. In 2009, the municipal council passed additional legislation, which created the Municipal Public and Private Fund for PES (Fundo Municipal para Pagamentos por Serviços Ambientais—FMPSA), allowing Conservador das Águas to pool additional resources from the PCJ (Piracicaba, Capivari and Jundiaí basins) watershed committee's water-user fees and other national and international institutions. Municipal sources remain dominant, but the additional funding is key to the expansion and sustainability of the program. Hydrologic monitoring supported by the University of São Paulo, The Nature Conservancy and others has been instrumental in communicating success of watershed interventions to water users whose fees support the program.

*Implementation:* Conservador das Águas has attracted the support of rural farmers through direct cash payments (which were based on opportunity costs), as well as offering a way to feasibly comply with the national Forest Code. Program developers worked closely with rural associations and key farmers to spread the news of the program by word-of-mouth and to increase uptake by other landowners. Activities include soil conservation agricultural BMPs, water sanitation systems and forest restoration and conservation to comply with the Forest Code.

### Establishing water funds in Africa

There is a huge potential for water funds in Africa to help secure reliable, high-quality water for growing populations and improve agricultural productivity, particularly for the large number of smallholder farmers. As land conversion for agriculture and other economic development pursuits continues, it is critical to develop cost-effective ways to maintain or improve water sources for communities and downstream cities. Water funds can play an important role in securing water not only for large cities, which have the ability to pay for watershed investments, but even more importantly perhaps for communities that depend on the same water sources and do not have access to water treatment.

### Nairobi, Kenya: Upper Tana-Nairobi Water Fund

*Description:* A coalition of Kenyan businesses, government agencies, conservation groups and utilities launched The Upper-Tana Nairobi Water Fund—Africa’s first water fund—in March 2015. The fund is designed to provide a sustained, high-quality water supply to a system that delivers water to over 9.3 million people and to generate US\$21.5 million in long-term benefits to Kenyan citizens including farmers and businesses. The Tana River is a critical component of the Kenyan economy, supplying 95 percent of Nairobi’s water and 65 percent of Kenya’s hydropower supply.<sup>579</sup>

In Kenya, pollution and catchment degradation are estimated to cost at least 0.5 percent of GDP each year, equaling US\$32 million.<sup>580</sup> The Upper Tana-Nairobi Water Fund provides Nairobi water users with the opportunity to mitigate some of these threats by investing in upstream watershed conservation efforts for the benefit of farmers, businesses and millions of Kenyans who depend on the Tana River for their fresh water. The fund was set up with multiple objectives, including improving agricultural livelihoods and securing Nairobi’s water supplies through reducing erosion leading to suspended sediment and maintaining dry season flow in priority watersheds.

*Governance:* The Upper Tana-Nairobi Water Fund puts nature-based solutions into action by bringing together multiple stakeholders. This includes a management board consisting of the county government, the water resource authority, the forest service, the regional council of governors, the Nairobi water utility, a leading beverage company, Kenya’s leading energy generation company and distinguished private sector leaders. The idea of nature-based solutions was not new to Kenya, but previous to the water fund, Nairobi lacked a strategy to plan for, invest in and implement interventions in a targeted manner that meets multiple objectives and brings together the key actors and financing needed to make it happen. The fund seeks to link downstream water users to the communities that manage source watersheds by investing in activities that cost-effectively reduce erosion and improve livelihoods (i.e., through agricultural BMPs that prevent soil loss and increase agricultural productivity).

*Funding:* The Upper Tana-Nairobi Water Fund, similar to FONAG and others, is a public-private partnership registered as an independent charitable trust that has obtained funding from a variety of sources. In the first four years of development, it was able to mobilize US\$4 million through voluntary contributions. Board members are not required to provide funding, although the majority do. For example, Nairobi City Water and Sewerage Company, which collects water tariffs in the city, is an

important contributor. There are also important multilateral funders, including the Global Environment Facility (GEF), which has committed over US\$7 million in funding to ensure the water fund is successful as it expands conservation work to the watershed scale. The project aims for a US\$15 million endowment that will provide sustainable funding over the long-term.

*Implementation:* Similar to the Andean funds, the Upper Tana-Nairobi Water Fund uses in-kind compensation mechanisms to encourage farmers to adopt agricultural BMPs, restore riparian buffers, install efficient irrigation and reforest. These in-kind compensation packages include water pans, capacity building and training around agricultural production, seeds, equipment and livestock such as dairy goats. The water fund also focuses on reducing sediment from rural unpaved roads. To date, the water fund has worked with over 15,000 farmers by collaborating with local partners, including the Green Belt Movement and the Kenya National Farmers Federation. The target, by 2025, is to work with 300,000 farmers, a tremendous number that is only possible through the social capital that this partnership has built over many years.

### Water funds in North America

The growing number of innovative approaches to developing water funds across the United States is representative of the flexibility and wide applicability of the water fund concept. Within the United States, The Nature Conservancy currently leads seven operational water funds and has more than 10 in development. Funding for these projects has been secured through a range of strategies, including: voter-approved measures that set aside a percentage of public revenue into a central fund to proactively protect lands that determine the quantity and quality of water available to them (Edwards Aquifer Protection Program in Texas, Chapter 1<sup>581</sup>); revenue-sharing agreements to reduce the risk of catastrophic fire through forest fuel reduction programs (Rio Grande Water Fund in New Mexico, this chapter<sup>582</sup>); and the allocation of a percentage of utility revenue toward conservation projects (Savannah River Clean Water Fund in South Carolina<sup>583</sup>).

The momentum behind water funds in the United States is rapidly increasing as the concept and the tools continue to take root and be shared. More broadly than water funds, there are several initiatives that seek to leverage local contributions to larger source water protection efforts that combine with state and federal level investments. For example, the U.S. Forest Service is partnering with the Coca-Cola Company, the U.S. Department of Agriculture and the National Forest Foundation to invest in watershed improvements that benefit urban drinking water sources.<sup>584</sup>

## South Carolina and Georgia, United States: Savannah River Clean Water Fund

**Description:** The Savannah River flows over 301 miles connecting the Blue Ridge Mountains to the Atlantic Ocean with a contributing watershed split between South Carolina and Georgia. The Savannah River Clean Water Fund focuses on the lower 220 river miles of this basin, which has a contributing area of 1.13 million hectares. Savannah River water is critical for hydropower, drinking water, recreation and some of the best bass fishing in the world. The watershed remains highly forested, much of it as “working forest.” However, the threat of urban expansion is real, posing serious threats to the river in the form of nutrient and bacteria pollution. Local people are also concerned about the threat of emerging contaminants, including the chemicals in household products (e.g. cleaners) that would come with encroaching development. In response, the Savannah River Clean Water Fund was formed with the goal of retaining at least 60 percent of existing forest cover, to protect the river and its many benefits. This water fund is still in a pilot phase and represents an innovative and exciting case of the water fund approach in a North American context.

**Governance:** Forming the Savannah River Clean Water Fund has been an exercise in governance-building and the power of local champions. This is much broader than a one-utility approach seen in some other cases and represents a true effort to work together at the watershed scale. By forming a new non-profit organization, the water fund has brought together diverse watershed actors including utilities, forestry groups, conservation organizations and business representatives. In the case of the Savannah River Clean Water Fund, a well-connected and talented local land trust leader helped facilitate connections among relevant actors.

Unlike water funds in Latin America, the board of the Savannah River Clean Water is composed of individuals nominated by the utilities (n=6) and by other partners (n=6) on the steering committee. The science community, including university researchers and The Nature Conservancy, are actively collaborating to prioritize and evaluate the outcomes of the project and demonstrate successes.

**Funding:** The Savannah River watershed has a long history of land protection, but funding for easements based on biodiversity value has never met demand. In response, five public water utilities in the watershed have collectively and voluntarily agreed to fund the project for a minimum of US\$1 million per year for three years. This funding comes from the utilities’ general budgets, rather than rate increases. The water fund also obtained a challenge grant to provide US\$300,000 in operational funding. In total, the Steering Committee estimates that it will require US\$150 million to reach the project goal of maintaining 60 percent forest cover. The Steering Committee has proposed that half of this amount come from water users and the other half from public and philanthropic funding sources.

**Implementation:** The South Carolina side of the Savannah River watershed has a long history of conservation through easements. This is less so the case in Georgia. People living in both sides have a strong desire to conserve the natural heritage of the area, but have often lacked the means to take advantage of available conservation easement options. The water fund will work strategically with existing conservation NGOs (including The Nature Conservancy, Ducks Unlimited and several land trusts) that already have strong relationships with people in the area. These organizations can apply to work in priority areas defined by the water fund as critical for watershed protection goals. While the main focus of the water fund is on forest easements, they are also exploring how to incorporate agricultural BMPs as part of their strategy. Using a Watershed Priority Management Index, the steering committee proposed focusing on land purchases and conservation easements for 85,000 hectares of the most critical areas for water quality. An additional 388,000 hectares could be kept in forest cover using more creative and less expensive mechanisms including forest certification, term easements and land stewardship.

## Exploring water funds in China

Given the popularity of PES programs and the critical role that local governments play across China, recent analyses conducted by The Nature Conservancy and its partners suggest that collective action water funds offer an untapped financial and governance mechanism to implement conservation at scale. These investments provide water users with a cost-effective approach to achieving water security while further securing a wide range of socioeconomic and ecological benefits. In response to this potential, The Nature Conservancy in China is currently scoping and designing water funds with local partners. One water fund, Longwu, is currently in operation.

### Longwu Water Fund

**Description:** Longwu Reservoir is located northeast of Huanghu town, Yuhang district, Zhejiang Province and supplies drinking water to two villages of approximately 3,000 people. Total nitrogen and total phosphorus levels have been rising in the drinking water, while dissolved oxygen has been dropping. The nutrient pollution is largely the result of over-application of fertilizer and pesticides for bamboo planting in the catchment. The Longwu Water Fund was established on November 1, 2015 to reduce this nonpoint source pollution and improve farmers’ livelihoods. Although this water fund is small, it represents the first of its kind as an innovative collective action case in the China context.<sup>585</sup>



**Funding:** One unique feature of the funding source in Longwu is that it comes mainly from business profits produced by transitioning the conventional bamboo industry to a more environmentally-friendly one. With an initial investment of US\$50,000 from partner donations, the water fund earns its ongoing funding from organic bamboo shoots, eco-tourism and educational activities. It is expected that this eco-friendly business venture will allow the water fund to be financially self-sustaining.

**Governance:** Similar to water funds in Latin American and other countries, the Longwu Water Fund is governed by a multi-stakeholder advisory board, which includes The Nature Conservancy, a farmer representative and a food company. Farmers can enter into a five-year contract for the fund to manage their forest land via a property right trust. Wanxiang Trust serves as the legal trustee and the main management body of the water fund. The Nature Conservancy serves as an advisor for trust execution and provides watershed conservation model design, forest land management planning, conservation impacts assessment and coordination of public resources.

**Implementation:** An operating company under the water trust fund implements most of the environmentally-friendly projects. For example, the company is responsible for producing and selling organic bamboo shoots online. It also is in charge of designing and operating nature education and eco-tourism. In late 2015, the water trust fund project began a pilot project on more than 6.5 hectares of forest land with organically grown bamboo shoots. The monitoring data show great improvements in total phosphorus and dissolved oxygen in the downstream reservoir. Following the pilot project, in late 2016, the water fund will continue to expand in the reservoir catchment area. It plans to include more than 70 percent of the bamboo forest of the catchment area in integrated management by the water trust fund to address the challenges related to fertilizer and herbicide application. While the fund is modest in scale, it is an important step toward demonstrating how transparent, science-based, collective-action water funds can achieve water security for people and protect the integrity of ecosystems across China.

## LOCAL SPOTLIGHT

### Rio Grande, New Mexico, United States—Collaborating to reach scale



Panorama of burned ridge above Valles Caldera National Preserve in New Mexico.

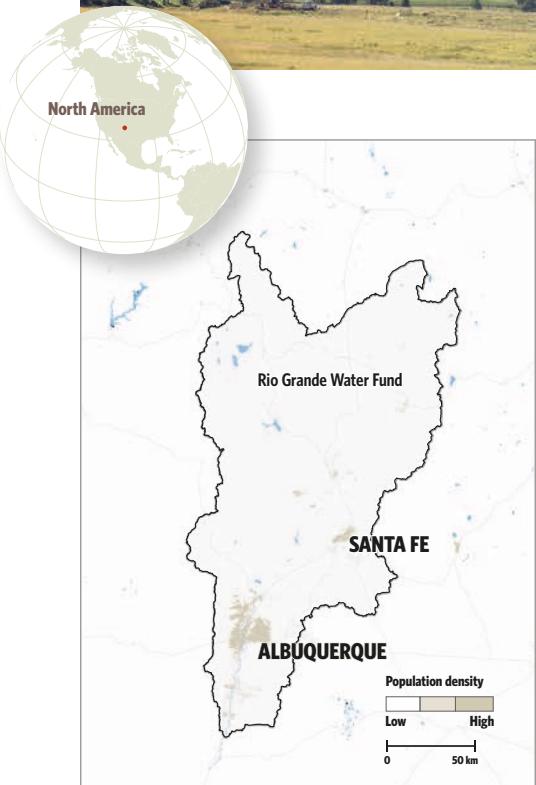
#### The challenge

In the summer of 2011, a severe wildfire struck the state of New Mexico and began to spread at a rate of 0.4 hectares per second, ultimately burning more than 63,000 hectares in just one week. The fire destroyed dozens of houses and buildings and 60 percent of Bandelier National Monument. In some areas where the fire's heat reached an extreme level of intensity, even the soil was vaporized.<sup>586</sup> This wildfire became known as "Las Conchas"—the largest wildfire that New Mexico had ever encountered up to that date.

The Las Conchas fire was ignited by a tree falling onto a power line. The reason it reached such an unprecedented scale, however, is rooted in much more complex problems than electrical infrastructure. First were policies involving the suppression and prevention of naturally occurring (low-intensity) fires for the purpose of safety and forest reserves.<sup>587</sup> The second catalyst is climate change. Since the late 1990s, New Mexico's western landscapes have experienced an average temperature rise of 2 degrees Celsius; some areas have seen an increase of 4 degrees Celsius. By 2005, these pressures caused the now high-density forests to dry out and die. What was once a robust supply of timber for the region became a devastating source of fuel.

Reducing the risk of wildfires has become ever more important for New Mexico not only to prevent catastrophic burns, but also to protect water sources. Shortly after the Las Conchas fire, New Mexico experienced downpours that quickly washed all the wildfire debris and ash into the Rio Grande. This resulted in a 21-meter sediment plug in one of the Rio Grande's tributaries, and sediment loads in the river far beyond what the downstream city of Albuquerque, New Mexico could reasonably process at the water treatment plant. The ash-laden water ultimately prevented Albuquerque from receiving its supply of water from the Rio Grande for 40 days.<sup>588</sup> Under such extreme circumstances, this flooding event was declared a federal disaster. The Las Conchas is neither the first nor the last extreme event New Mexico has experienced in this fire-prone region and climate change impacts are projected to exacerbate incendiary conditions.<sup>589</sup>

In addition to municipal water supplies, other important values—such as homes, property, community and business infrastructure, terrestrial and aquatic biodiversity, agricultural and rural economies, tourism and outdoor recreation—are also at risk when forested watersheds are severely damaged by wildfire.<sup>590</sup>



While these risks are known among key actors across New Mexico, collaborating to address them—principally though not exclusively through managing forest fuels—has been challenging given the range of mandates, goals and desired outcomes each actor holds. It has been estimated that fire suppression activities cost New Mexico as much as US\$1.5 billion dollars from 2009 to 2012.<sup>591</sup> These recurring costs directly affect the state's economy with extensive financial implications for property owners, businesses and residents.<sup>592</sup>

Restoration activities have clear benefits. Through an economic lens, the impact of wildfire on just one acre (0.4 hectares) can have a price tag of up to US\$2,150, while thinning one acre as a preventative measure is only US\$700 on average.<sup>593</sup> It is expected that this cost would also decrease over time as thinning practices become more efficient. Based on these estimates, it is more cost-effective to invest in prevention than suffer damaging wildfires.

## Action and opportunity

In order to protect the water supply for the cities of Albuquerque and Santa Fe, tribal lands, surrounding communities and other water users, The Nature Conservancy began developing the Rio Grande Water Fund in 2013. Initially gaining traction from the water and energy subcommittee of the Greater Albuquerque Chamber of Commerce, it wasn't long before the fund started accumulating a variety of new partners such as businesses, water utilities and government forest managers. It was clear enough to New Mexico that healthy watersheds are a necessity to secure livelihoods that the fund gained enough funding and support to officially launch in 2014. While this initiative is focused on tangible activities such as tree thinning, stream restoration, flood control and wildfire management,<sup>594</sup> the scale of natural ecosystems restoration requires direct collaboration among stakeholders. The fund is expected to restore 688,000 hectares of fire-prone ponderosa pine and mixed conifer forest across the Rio Grande watershed stretching some 320 kilometers from Belen all the way to the Colorado border.<sup>595</sup>

By April 2016, the water fund had an impressive 49 signatories including local governments (federal entities, counties, cities and districts), nonprofits, agencies and private businesses. Signatories bring their various mandates, as well as expertise, to the table. For example, in recognition of the need to manage a diverse landscape, the fund includes the four local county governments; federal actors such as the USDA Forest Service, Bureau of Land Management and the U.S. Fish and Wildlife Service; state level counterparts; local community associations such as Chama Peak Land Alliance and Rocky Mountain Youth Corps; Native American tribal

communities; and the private sector such as the New Mexico Forest Industry Association. Other water service delivery and infrastructure actors at local and national scales such as the water utility, the Flood Control Authority and the Army Corps of Engineers are also frequently engaged. Collectively, these partners represent the diverse set of land ownership and water users found in the fund's area who commit to working together to secure clean water for communities in the watershed and downstream.

While federal and state funding comprises the majority of the contributions to the fund, the first US\$2 million came from private foundations and was the most crucial component to the water fund's formation. The funding goes to planning, restoration treatments, education, outreach and a monitoring program. While The Nature Conservancy administers the private investments, the executive committee of diverse stakeholders decides which projects in the focal areas receive funding. These specific locations are determined by the following five criteria:

1. Wildfire risk
2. Water quality and supply
3. Economic opportunity
4. Forest health (including ecosystem integrity versus harmful insects and disease)
5. Fish and wildlife habitat

The fund offers an excellent example of how investing in a collaborative platform for city, local and national agencies and stakeholders can provide significant economic, political and environmental benefits. Bringing together multiple water users under the water fund model has helped to:

- harmonize mandates across diverse stakeholders and overcome jurisdictional accountability challenges, aiming to improve the effectiveness;
- leverage funding sources to allow for efficiency in terms of resources and capacity, as well as complementary investments such as US\$6.2 million allocated by the state legislature to fund watershed restoration improvements across the state (Work New Mexico Act) and nearly US\$4 million of federal funding available through competitive grants; and,
- mobilize a collaborative, multi-partner approach to protect watersheds and water supply across a landscape of almost 700,000 hectares through inclusive priority setting and coordinated capacity building in forest management.

RIO GRANDE DASHBOARD							
Water fund start date	Number of upstream participants to date	Number of potential downstream beneficiaries	Number of partners to date	Primary funding sources	Activities	Anticipated co-benefits	
2014	N/A	Between 500,000 and 1,000,000	53	Public (federal and state agencies) NGO/Foundation Private Utility	   	    	



## CHAPTER FIVE INSIGHTS

The cost of source water protection could be covered by revealing benefits to diverse payers through the business case for water funds.

- We estimate that one in six cities—roughly 690 cities serving more than 433 million people globally—has the potential to fully offset conservation costs through operations and maintenance (O&M) savings alone.
- Other cities may be able to achieve source water protection by combining water security with other benefits for which payers—public or private—exist. We offer an approach that can help identify which cities have relatively high biodiversity value, climate change mitigation potential or agricultural values that could combine with water security to increase return on investment.
- Through an examination of the source watersheds of a set of Colombia's largest cities, we find a range of 13 to 95 percent savings when land uses are optimized to achieve multiple goals (sediment, nutrients and carbon) simultaneously rather than individually, on average representing a 63 percent savings in public investment.

# Chapter 5

## The Intersection of Multiple Benefits

### Building a multi-benefits case

We have elucidated how source water protection has the potential to generate a range of co-benefits in the areas of climate change mitigation, climate adaptation, human health and well-being, and biodiversity conservation. The magnitude of these co-benefits is in some cases substantial and additional to the core benefits of improved water quality or sustained water supplies. What does it look like when multiple benefits can be achieved simultaneously in the same watershed, and how might the co-occurrence of benefits catalyze investment in source water protection via a mechanism like a water fund?

Here we approach this question in two ways and at two different scales. Looking globally, we illustrate the degree to which multiple benefits could be realized through source water protection for cities around the world. At a national scale in Colombia, we examine how conservation planning for multiple benefits can produce cost savings over single-benefit approaches. These assessments demonstrate the broad global significance of a multi-benefits approach to source water protection and how cities and other actors might use such information to unlock the value of multiple services provided by healthy watersheds.

### Stacking benefits for cities

As described in the previous chapter, water funds have traditionally been driven by a recognition from cities—and particularly city water utilities—that addressing water problems at their source can provide water security benefits. In particular, reductions in nonpoint pollution can lead to lower operations and maintenance (O&M) costs, including reduced material and energy inputs for water treatment plants. The Nature Conservancy previously estimated that a 10 percent reduction in sediment could on average result in a 2.6 percent reduction in O&M costs.<sup>596</sup>

By comparing the estimated conservation costs for achieving a 10 percent reduction in sediment or nutrients against potential savings from avoided water treatment, we can assess the ability of cities and their water providers to help offset the costs of watershed protection. In this report, we calculate return on investment (ROI) as estimated potential O&M cost savings and other benefits relative to the estimated costs for source water protection activities, where a value of one or greater indicates



Photo: © Arni Vitale



Aerial view of the water purification plant, part of the Cantareira system which provides fifty percent of São Paulo's drinking water. Some of the São Paulo urban area can be seen beyond the water treatment facility.

a positive ROI. For one in six cities across our expanded dataset, it is possible to achieve a positive ROI from reduced treatment costs alone. The factors that determine a positive ROI include a wide range of biophysical, socioeconomic and technical features.<sup>597</sup> By integrating across value chains, there is potential to broaden allies and investors where water treatment savings alone won't be enough. In effect, the "stacking" of multiple benefits achieved through source water protection in a given watershed may be enough to make those watershed activities an attractive investment.

Building from the results shown in Chapter 3, and utilizing a small selection of co-benefit measures, we illustrate the potential for stacking multiple benefits and increasing the value of source water protection relative to costs. These data are not

intended to represent economic valuations. Rather, they are suggestive of relative changes and regional patterns that result from a more holistic picture of source water protection benefits.

Figure 5.1 presents data representative of co-benefits for biodiversity, climate change mitigation and agricultural productivity. For each co-benefit category, we compare avoided treatment ROI against measures indicative of potential co-benefit value. Each point on the graph represents average values across the source watersheds for a single city. With the exception of climate change mitigation potential, these measures are not attributable to a defined scale of conservation implementation. Instead, these measures suggest opportunities where conservation actions may be coincident with areas of higher co-benefit value.

## Reading the Scatterplots: Nairobi, Harbin and Porto Alegre

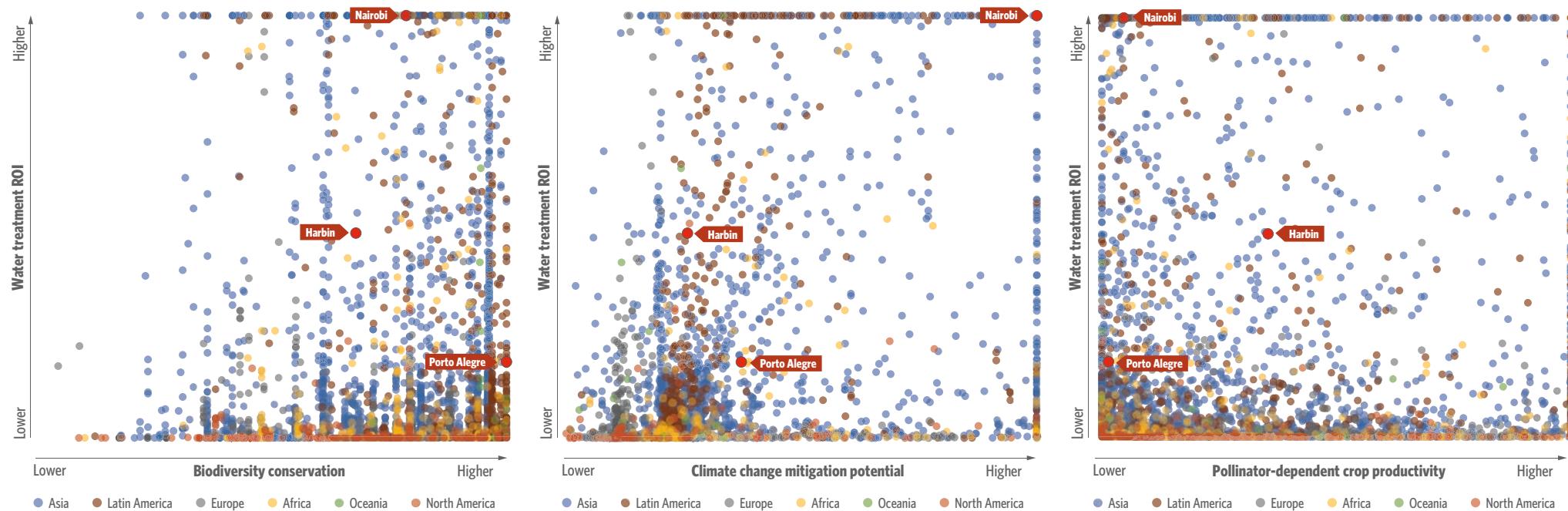
The city of Nairobi, Kenya, is situated high in all three charts, indicative of the strong potential for O&M savings relative to conservation costs. Unsurprisingly, with headwaters in Aberdare National Park, the source watersheds for Nairobi also coincide with areas important for biodiversity, as shown by its high position on the far right on left-most panel. Activities that support the protection of these areas would provide added value beyond cost savings from avoided treatment O&M. Further benefits for climate change mitigation potential could also be significant, as indicated by Nairobi's position on the middle panel. In effect, water treatment savings alone could pay for these added benefits.

For the city of Harbin in northeastern China, potential treatment O&M returns are also relatively high, though lower than Nairobi. This suggests that, while source

water protection activities in Harbin could significantly drive investment, a more integrated approach could bring additional partners and resources. Leveraging the potential synergies across water security, biodiversity and crop productivity outcomes could help ensure adequate funding for conservation activities.

In terms of potential water treatment O&M returns, Porto Alegre, Brazil, exhibits lower cost-recovery potential. For Port Alegre, these results suggest that a multi-partner, multi-benefit approach would be necessary components of any source water protection effort. The biodiversity value of such investments could be very high, as indicated in the left-most plot. Climate change mitigation potential relative to conservation costs suggests further added value from investments to reduce sediment and nutrient pollution.

**Comparison of indicators of potential co-benefit value versus water treatment ROI**



**Figure 5.1.** Comparison of indicators of potential co-benefit value (horizontal axis) against water treatment ROI (vertical axis). Biodiversity value (**left panel**) derived from ecoregions coincident with watershed areas, measured as rarity-weighted richness normalized by habitat type. Climate change mitigation potential (**middle panel**) estimated from annual sequestration potential from reforestation and cover crops as implemented to reach a 10 percent reduction in sediment or nutrients. Pollinator-dependent crop productivity (**right panel**) estimated as the average potential reduction in crop productivity for pollinator-dependent crop types in the absence of natural pollinators, resulting from natural land cover conversion. See text and Appendix V-1.24 for additional discussion and details.

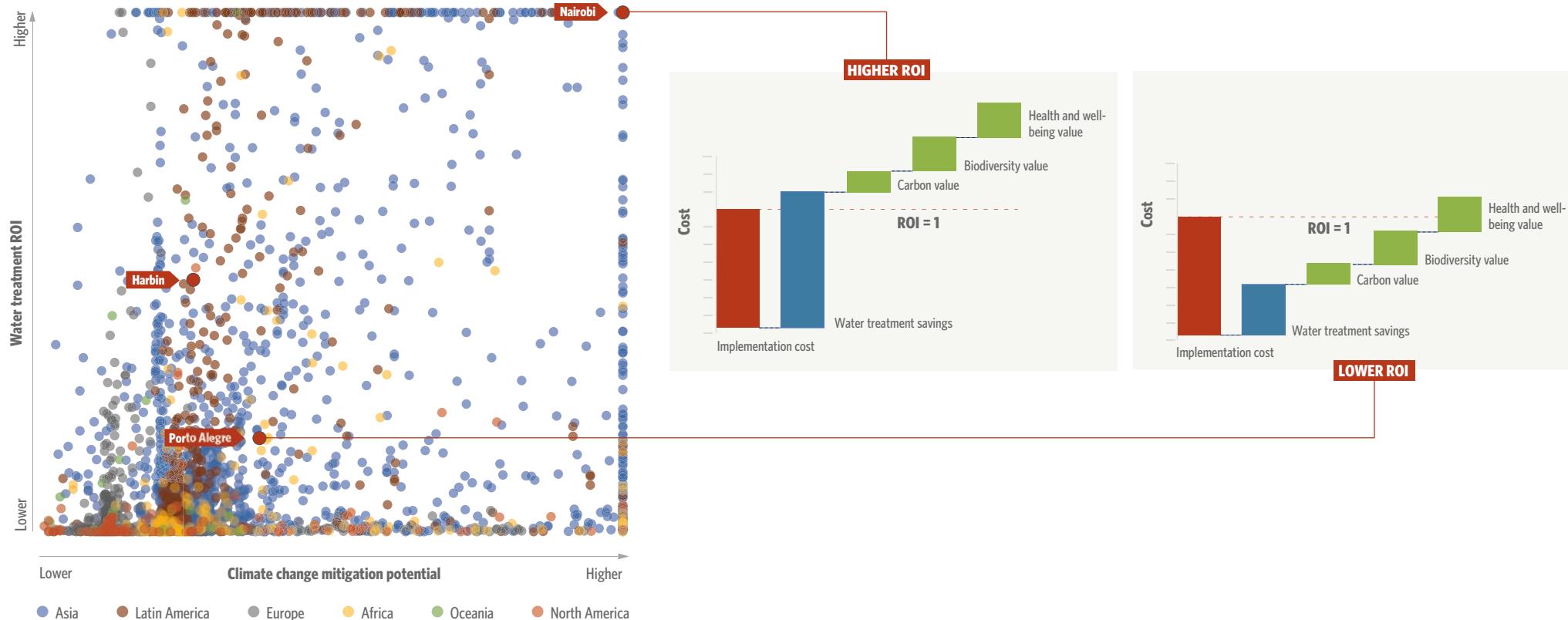
The results suggest different city archetypes related to the potential benefits from source water protection (Figure 5.2). For cities with relatively high ROI based on water treatment costs, the impetus for source water protection can largely be driven by water treatment savings alone. For other cities, where treatment ROI appears lower, consideration of a broader selection of source water protection activities could lead to lower costs and more favorable returns. Similarly, an assessment of other potential savings, such as avoided capital expenditures for additional treatment equipment and facilities, might move a city significantly up the ROI axis. For some cities, though, water treatment savings may never be enough to justify investment in source water protection on its own.

Wherever a city sits along the ROI axis, but especially for those with lower values, considering benefits in addition to water treatment savings can open up the potential for a higher comprehensive ROI, presenting the possibility of other allies or investors.

While our results at the global scale provide a suggestive appraisal of source water protection value for cities, these results highlight two fundamental lessons: 1) given the distribution of points across co-benefit axes, we see that the multiple benefits framework is relevant to many cities around the world; and 2) by comparing these potential co-benefit values against treatment ROI, we can identify different source water protection archetypes that can provide a starting point for cities to engage additional partners. The cities identified here illustrate these narratives.

A global assessment of such co-benefit values is inherently challenging as issues of scale and complexity preclude definitive appraisals. The actual ROI values for a city would rely on locally available data and additional information on compounding factors. Nonetheless, Figure 5.2 illustrates that it is possible to identify groups of cities where further analysis is warranted. Understanding these opportunities is vital to broadening the reach of natural infrastructure as a global solution.

#### Demonstration of stacking co-benefits in different city archetypes



**Figure 5.2. Left:** Comparison of indicators of potential co-benefit value (horizontal axis) versus relative water treatment ROI (vertical axis). Climate change mitigation potential estimated from annual sequestration potential from reforestation and cover crops as implemented to reach a 10 percent reduction in sediment or nutrients. **Middle:** Illustrative graph showing cities with a positive ROI based solely on water treatment savings. **Right:** Illustrative graph showing cities whose ROI could be positive with the addition of co-benefit values.

## Optimizing across multiple benefits— A deep dive in Colombia

Global-level analyses provide a big picture of potential benefits of source water protection, but they lack the granularity needed to understand how optimizing across those benefits may provide cost savings and even create value. In other words, can we generate multiple benefits simultaneously and do so for less cost than if those benefits were achieved individually?

To begin to answer this question and to understand better the scale of benefits for actual cities and their source watersheds, we analyzed the water security and carbon co-benefits of source water protection activities in watersheds of one country. We selected Colombia for our focused analyses because of the country's demonstrated investment toward watershed management and payment for ecosystem services programs, as well as for the emerging political, social and economic factors that have propelled the country to lead on sustainable development goals and green growth agendas. Some of these factors and enabling conditions include:

- **Increasing water and land management challenges:** Colombia faces pressures from flooding, drought, deforestation, land degradation and contamination of water systems across the country, as well as increasing land-use change affecting natural ecosystems. Levels of natural habitat conversion are high. As of 2009, 19 of 32 Colombian Departamentos (equivalent to states) had over 50 percent of their terrestrial ecosystems completely converted to non-natural land uses.<sup>598</sup> In the Magdalena Cauca Basin, the number has reached at least 62 percent of natural habitats. In 2015, 124,035 hectares were deforested nationally—a substantial area, but a reduction of 12 percent from the previous year.<sup>599</sup>

- **Vulnerability to climate change:** Extreme climate events in Colombia are increasingly frequent and severe. In 2010 and 2011, an intense La Niña season resulted in flooding and landslides that damaged or destroyed infrastructure and productive areas. Economic damages soared to around US\$7.8 billion.<sup>600</sup> In 2015 and 2016, extreme drought conditions due to an El Niño season brought streamflow levels in the Magdalena River Basin to historic lows. Cities such as Cali and Santa Marta experienced serious water shortages. The country faced potential energy cuts as the hydropower sector struggled to meet demand. Livelihoods of millions of people who depend on agriculture and fisheries were also affected by the prolonged droughts. Colombia's Second National Communication submitted to United Nations Framework Convention of Climate Change (UNFCCC) estimated that between 2011 and 2040 over 70 percent of High Andean ecosystems will potentially suffer “very high” and



Photo: © Erika Nortemann

“high” impacts of climate change, which will affect environmental goods and services, along with the growing population and expanding production systems that depend on those ecosystems.<sup>602</sup>

- **The need for a green growth agenda:** Colombia is facing rapid urbanization and the challenge of delivering services to a growing population of whom 27.8 percent remain in poverty.<sup>603</sup> Current estimates project that by 2050 nearly 84 percent of Colombians will be living in urban areas.<sup>604</sup> This projected concentrated growth in cities will require continued investments in infrastructure to ensure sustainable incomes, food, water, energy and shelter for all citizens. Given this need, Colombia has focused its National Development Plan on a green growth agenda that includes comprehensive goals for the energy, housing and agricultural sectors requiring them to incorporate substantial sustainable development approaches. In 2015, along with 41 other countries, Colombia signed OECD's Declaration on Green Growth.

- **Political will on implementing climate change goals and SDGs 2030 Agenda:**

The Ministry of Environment and Sustainable Development leads national efforts to mobilize Colombian agencies in complying with the country's commitments on emissions reduction and climate adaptation. To rapidly advance toward SDG implementation, the Colombian Government created a cross-sectoral, multi-agency, high-level commission to align efforts and monitor progress from multiple ministries and agencies at the national level. The government is also building a national-level statistical database for monitoring progress toward SDGs.<sup>605</sup>

- **Innovative policy instruments for watershed management investment:**

Leadership in Colombia enacted legislative and institutional mandates that promote investment in watershed management services through local and regional environmental authorities called Corporación Autónoma Regional (CARs—Regional Autonomous Corporations). These investments include annual revenues directed either toward payments to landowners for ecosystem services or direct land acquisition in source watershed areas. Since 1993, hydropower companies must transfer a percentage of their earnings from energy production to municipalities and CARs for watershed protection. Several public agencies in Colombia, including CARs, water utilities, municipalities and private companies have worked together to create and operate six water funds in the country. These actors have invested over US\$9 million in watershed conservation strategies.

The Colombian government is currently designing crucial policy instruments to secure financial sustainability of water management action, including a bill and a national policy (Conpes document) for payment for ecosystem services as mandated in its 2014-2018 National Development Plan.<sup>606</sup> The government also committed to reviewing existing economic and financial instruments for conservation and sustainable biodiversity use, and to adjust them or create new ones if necessary. The OECD has also made recommendations to Colombia on effective investments in watershed protection, including a revision of the national water tariffs scheme to incorporate the cost of protecting watersheds and ecosystem services. The latter has been highlighted by some actors as a necessary effort to secure progress on water conservation.

- **Efforts to protect and restore key ecosystems:** The 2014-2018 National Development Plan mandated the prompt and efficient implementation of the National Plan for Ecological Restoration, Rehabilitation and Recuperation of Degraded Landscapes,<sup>607</sup> launched in 2015. Aligned with its national efforts, Colombia also committed at UNFCCC's COP 20 in 2014 to restore 1 million hectares of degraded landscapes by 2020. Prioritization of highly critical páramos (alpine tundra ecosystems) is essential to provide ecosystem services to water-dependent sectors in the country such as energy and agriculture.

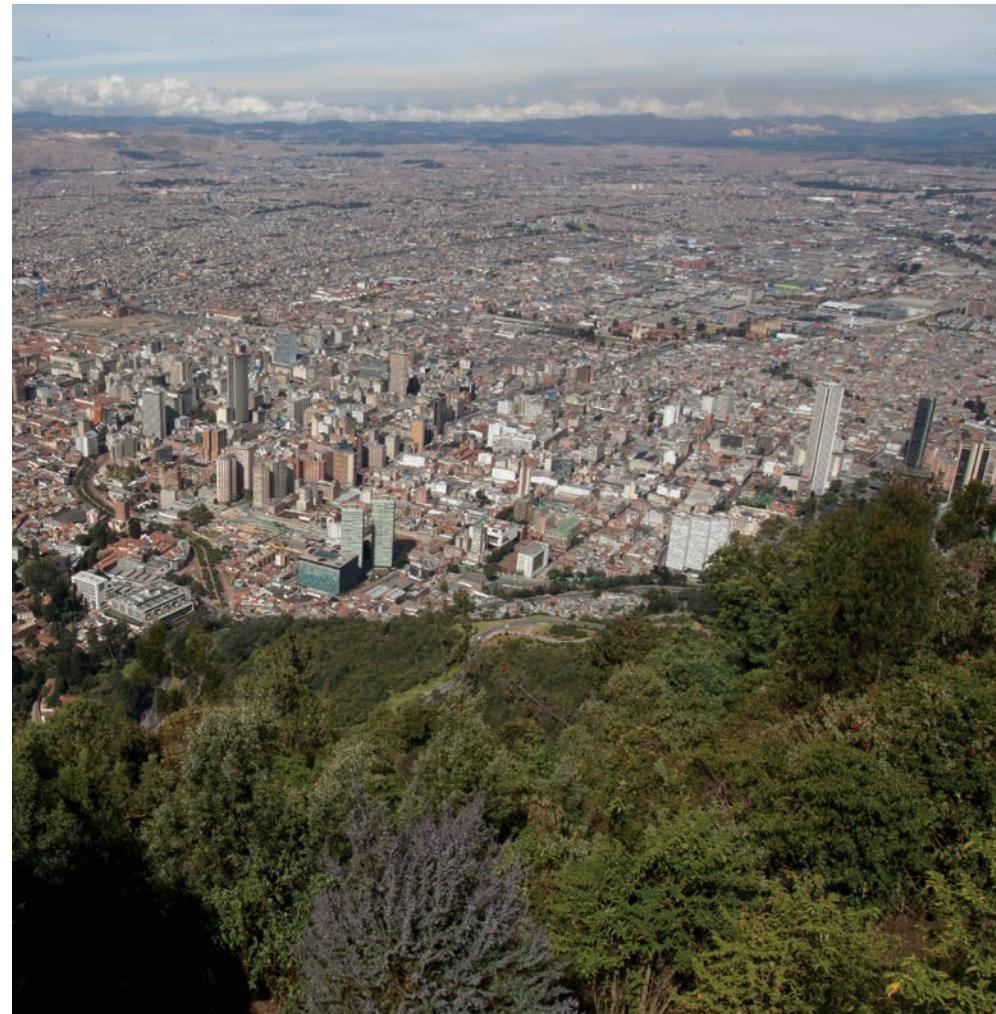


Photo: © Carlos Villalon

Within Colombia, we analyzed the watersheds supplying water to six of the country's largest cities: Bogotá, Medellín, Cali, Cartagena, Cúcuta and Bucaramanga (Figure 5.3). These cities have a combined population of over 13 million people (about 27 percent of the population of the country). We began with cities because they have been the primary drivers of water funds in Colombia and abroad, while recognizing that source water protection can also be implemented via other governance and financing mechanisms. The source watersheds of these cities are threatened by expanding urbanization, mining, ranching and other agriculture.

With the exception of Cartagena, whose water supply is a wetlands complex around the Canal del Dique (a canal connected to the Magdalena River near its outlet at the Caribbean Sea), all of these cities rely on páramos and High Andean forest to

secure water for their populations. Páramos are crucial to regulate flows as they store water during rainy seasons and slowly release it during dry seasons, which reduces extreme downstream flow events and helps maintain base flows. However, the páramos represent only 2.4 percent by area of the terrestrial ecosystems in the country.<sup>608</sup> Pressures on these areas mean an increased risk related to disturbed flows and water quality deterioration. Only 36 percent (709,849 hectares) of páramos in Colombia are within protected areas. Outside the protected areas, there is a risk from large-scale agriculture currently competing with páramo areas.

## Optimization

Using a combination of the Natural Capital Project's InVEST modeling tools and state-of-the-art optimization, we generated portfolios of optimal activities within the source watersheds of these six cities (see Appendix V for more detail on methods). We chose the source watershed areas based on the locations of water intake points for the cities, although we excluded the basins of the very large Cauca and Magdalena rivers, which supply water to Cali and Cartagena, respectively. While source water protection could potentially have a significant impact on ecosystem services provided by these basins, we focused on source watersheds at a scale deemed feasible for water fund implementation in the near term (Figure 5.3).



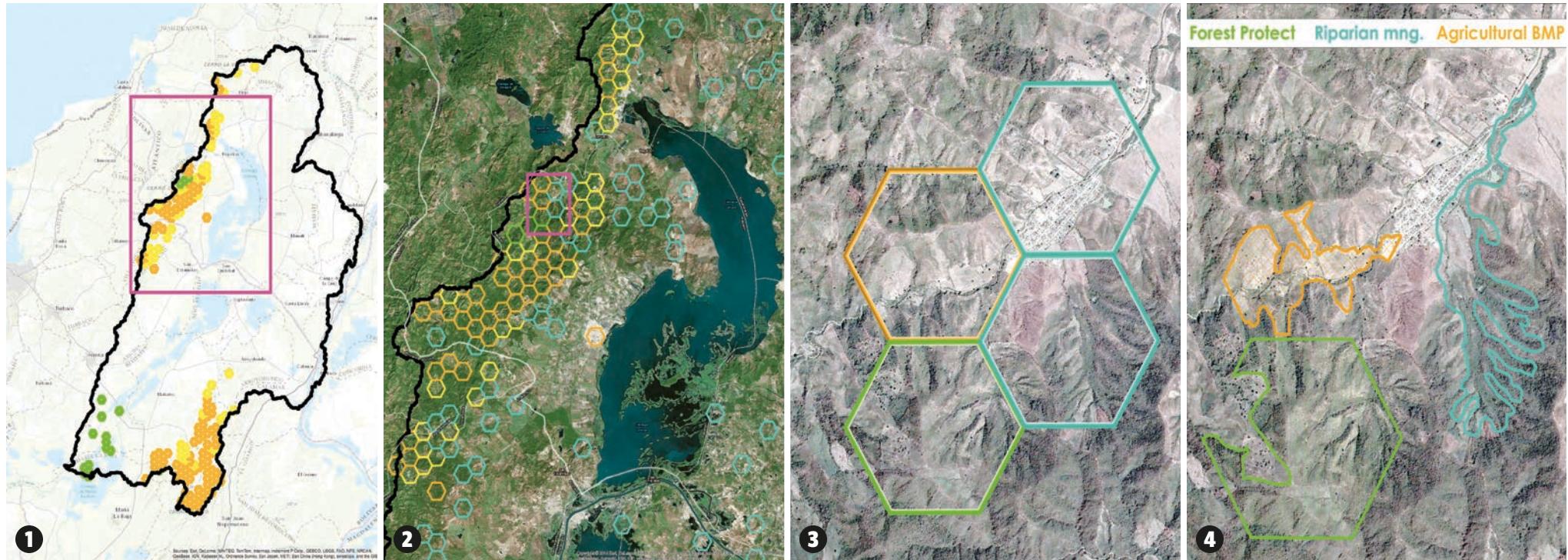
**Figure 5.3.** The six analyzed Colombian cities and their source watersheds.

Our goal was not to generate a definitive plan for action in these watersheds, but to illustrate the types and locations of conservation investments that water funds might implement to achieve targets for multiple ecosystem services (sediment retention, nutrient retention and climate change mitigation). We used a national-level land cover map for consistency across our watershed analyses, whereas a detailed and actionable plan for a given watershed would employ the most recent high-resolution data available for that particular location.

Similar to our global approach, the three source water protection activities that we modeled were forest protection, forest/páramo/riparian restoration and agricultural BMPs (Chapter 2). Ecosystem service indicators we calculated included average annual sediment load (in tons per year), average annual nitrogen load (in kilograms per year) and total carbon stored on the landscape (in metric tons). We set minimum targets of 10 percent reduction in sediment and nutrients, as well as a 10 percent increase in carbon storage. Following the CBD's Aichi Target 11 of 17 percent protection for lands and inland waters, we also set a land protection target of avoiding 17 percent of damages to these three services from future land degradation, which we assumed would result from converting natural vegetation to pasture. As with the national-level datasets, we used the same targets across all watersheds, although we recognize that designing and implementing water funds in these locations would have to include considerations of where activities are feasible based on socioeconomic factors and land tenure.

We used InVEST models to estimate the change in ecosystem services that could result from implementation of each of the possible activities, taking into account the topography, climate, soil, vegetation and landscape context. Our optimization model incorporated these estimates of activity effectiveness along with restrictions on where they are feasible and produced the most effective portfolio of activities (in terms of simultaneously meeting or exceeding all targets) for the lowest cost. We assumed that forest/páramo restoration would not be implemented on more than 10 percent of a landholder's property. In our model, riparian restoration is possible only up to 90 meters on either side of stream banks.

## Optimization analysis results and the relation between portfolios and field activities



**Figure 5.4.** **Map 1** shows the optimization results for Cartagena's source watershed. **Map 2** shows the hexagonal units that comprise the portfolio in the area surrounding the Guájaro reservoir.

**Map 3** shows the analysis units and the selected activity within each. **Map 4** shows how actual implementation areas were evaluated and how programs might be designed for the three activities in each source watershed landscape. These results should be considered illustrative only. An actionable conservation plan for these source watersheds would likely use higher-resolution input data and targets tailored to local circumstances. Nonetheless, the results show that a relatively small area under a combination of forest protection, restoration and agricultural BMPs can achieve meaningful water security and carbon benefits.

We used average costs per hectare for our three activities—forest protection, forest/páramo/riparian restoration and agricultural BMPs—derived from the experience of The Nature Conservancy working in water funds across Colombia. These include both direct and program administration costs. Actual costs will vary with the scale of the project and the local context, but the relative values and implementation areas will be generally consistent across watersheds. Agricultural BMPs are the least expensive to implement per hectare, on average, followed by restoration and forest protection, which are more expensive. The costs for protection did not include any direct payments to landholders, which can be highly variable and are typically negotiated on a case-by-case basis, making the final cost of land protection potentially higher than our results suggest.

The results of our optimization exercise confirm that multiple benefits can be achieved through activities on fewer hectares than if those benefits were generated individually. Achieving one minimum target often resulted in overshooting others, which we can interpret as getting even more value than required for a given investment. For instance, in Cartagena's source watersheds (Table 5.1, Figure 5.4), restoration activities to achieve a 10 percent reduction in nitrogen export generates a 34 percent reduction in sediment export and a 26 percent increase in carbon storage.

Although we did not create a water quantity target for these watersheds, we did analyze water regulation co-benefits using a new module of the InVEST tool (“seasonal water yield”). Specifically, we modeled how infiltration of water into the soil, and consequent contributions to dry season base flows in streams, could change if forest restoration, riparian restoration and agricultural BMPs were implemented in the locations identified through our optimization models. We found increases in potential

### Optimization portfolio results for six Colombian cities and their source watersheds

City source watershed	Hectares in portfolio	Percent of total watershed area	Percent improvement from baseline (through restoration and agricultural BMPs)			Percent future degradation avoided (through protection)		
			Carbon storage	Nitrogen reduction	Sediment reduction	Carbon loss mitigated	Nitrogen increase mitigated	Sediment increase mitigated
Cartagena	17,832	7	26	-10	-34	15	20	24
Medellín	12,032	10	15	-10	-14	16	20	20
Cali	2,491	14	9	-11	-12	15	22	27
Bogotá	21,888	8	10	-10	-15	20	19	35
Bucaramanga	11,831	16	9	-10	-14	18	19	22
Cúcuta	41,642	17	10	-10	-15	16	19	22

**Table 5.1.** Results based on restoration targets of 10 percent reduction for sediment and nutrient loads and a 10 percent increase in carbon storage (with results reported as percent change). Protection targets were 17 percent avoided damages to these services (with results reported as percent of future degradation avoided). Results are based on InVEST models using national-level datasets.

### Contribution of land use and management to base flow in six Colombia cities and their source watersheds, under current conditions and with optimized source water protection implemented

City	Baseline contribution to baseflow (millions of cubic meters)	Additional contribution of restoration/protection to baseflow (millions of cubic meters)	Percent increase
Cartagena	210.6	23	10.9
Medellín	1199.3	26.4	2.2
Cali	108.2	3.8	3.5
Bogotá	905.3	28.2	3.1
Bucaramanga	249.8	11.8	4.7
Cúcuta	906.2	47.4	5.2

**Table 5.2.** Water regulation co-benefits of forest restoration, riparian restoration and agricultural BMPs. Results are based on a new “seasonal water yield” module of the InVEST tool.

base flow contribution (in cubic meters per year) from 2 to 11 percent, with most increases around 3 to 5 percent (Table 5.2). These estimates suggest additional water available in these source watersheds that could translate to improved dry season water availability. Improved water availability benefits freshwater species, as well as the upstream communities that rely on these water sources for their basic needs during dry seasons and drought.

While these findings should be considered estimates only, to be refined through more detailed analyses and ground-truthing, they suggest that through smart, data-driven planning there is high potential to realize multiple benefits through source water protection activities.

## Cost savings

Our optimization results enable us to compare the costs of achieving sediment, nutrient and carbon benefits simultaneously with the costs of doing so individually. We used the same method described previously to develop separate optimal activity portfolios to reach each ecosystem service target one-by-one to represent what implementation would look like if different actors focused only on their individual mandates. Most important for this analysis is our comparison of costs within a given watershed for the multiple-versus-individual benefits portfolios.

We find that cost savings via multiple benefit optimization range from 13 to 95 percent across the six cities and their source watersheds (Table 5.3). Put differently, in some watersheds, achieving equivalent nutrient, sediment and carbon improvements would cost nearly double if investments in achieving those benefits were made individually. These findings clearly show the cost savings of collective planning and implementation. It is important to note that by working individually, the portfolios often resulted in even greater overshooting of some targets. While this might be beneficial in some cases, it represents additional inefficiencies in implementation that could be minimized through designing collaborative programs. In reality, independent efforts to address different benefits—especially water quality and climate change mitigation—would likely be taken via separate policy and planning processes. The inefficiencies of multiple efforts should be considered as additional costs.

**Estimated percent increase in cost per city from implementation of land-based activities to achieve sediment, nutrient and carbon targets one-by-one versus through an optimized, multi-objective portfolio**

City source watershed	Percent increase in cost for single objective vs. multi-objective
Cartagena	13
Medellín	41
Cali	90
Bogotá	44
Bucaramanga	94
Cúcuta	95

**Table 5.3.** In other words, results show the estimated cost savings via optimized multiple-benefit portfolios.

## Implications for Colombia and beyond

Our results do not represent the total benefits that source water protection might deliver across Colombia, whether via water funds or other mechanisms. The source watersheds included in this analysis cover less than 1 percent of the country's total area. Source water protection may very well be an important strategy well beyond these geographies, both for downstream beneficiaries and for upstream communities that depend on local water sources.

Nonetheless, looking at these results suggests the considerable magnitude of benefits that source water protection might achieve at a country scale. For instance, despite the small coverage area of these source watersheds, the carbon storage potential from restoration activities across all six sets of source watersheds is over 7.8 million tons of carbon and the avoided carbon loss from protection is estimated at another 6.1 million tons of carbon.

Colombia's INDC outlines strategies to limit emissions resulting from land-use change, including limiting deforestation.<sup>609</sup> The source watersheds' contribution toward these goals demonstrates the dual benefits that multi-objective planning—climate change mitigation and water delivery—could have in meeting local and national goals.

Among adaptation goals included in Colombia's INDC, the government has prioritized increasing water resource management tools that are in place for the country's priority water basins. Watershed protection through water funds can contribute to achieving this objective as they provide an innovative mechanism to work in a specific conservation portfolio with clear and quantifiable goals, measured by a tracking system.

Our approach is also aligned with the government's commitment to invest in transformative measures to ensure the SDGs are integrated rather than viewed separately.<sup>610</sup> Our findings show watershed protection through water funds can contribute to progress toward achieving targets for SDG 6 (access to water and sanitation for all)<sup>611</sup> as described below:

- “Ensuring sustainable withdrawals and supply of fresh water to address water scarcity and substantially reduce the number of people suffering from water scarcity.” Restoration activities analyzed here contribute to this goal by increasing the contribution to base flows by an average of 5 percent, with potential benefits for over 3.3 million people<sup>612</sup> living within the source watersheds of our six major cities.
- “Implement integrated water resources management at all levels.” Our results demonstrate the economic value of collective action by reducing the overall cost of reaching water security targets.

- “Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.” A total of 82,408 hectares of critical ecosystems are restored and 25,307 hectares are preserved by implementing the source water protection activities recommended for these six cities.
- “Support the participation of local communities in improving water and sanitation management.” Water funds provide a mechanism for local upstream communities to engage with and receive support from downstream communities whose vital water sources depend on land management.

These tools and approaches can also contribute to advancing targets for SDG 13 on increasing resilience to climate change and for SDG 15 on life on land (to protect terrestrial and freshwater ecosystems).<sup>613</sup>

While every country and perhaps every source watershed within each country will be different in terms of its biophysical, socioeconomic, cultural and political contexts, this analysis suggests the kinds of results we might hypothesize would apply in other geographies—that optimized portfolios can generate multiple benefits at less cost than if they were pursued individually.

Testing that hypothesis is an important next step, along with adding in additional benefits like biodiversity conservation. Applying a similar approach to source watersheds in other parts of the world would begin to produce a set of estimates that could be compared to see how relationships among benefits and cost savings change in different contexts. Ultimately, the approach used here can be modified for use in individual source watersheds to develop data-driven action plans. Impacts on the ground from the long-term implementation of those plans can and should be measured to determine the actual scale of benefits achieved.

The case of Colombia, where six water funds are currently in operation and three are in development, exemplifies how a combination of national and local political will, global platforms and commitments, environmental need and economic efficiencies can come together to set the stage for source water protection that can be replicated at a global scale. In the following chapter, we examine what will be required to take water funds to scale globally, with a focus on business models for matching investment with need, and on the diversity of partners who might come together with cities to catalyze those investments in the service of progress toward multiple global goals.

Photo: © Paul Smith



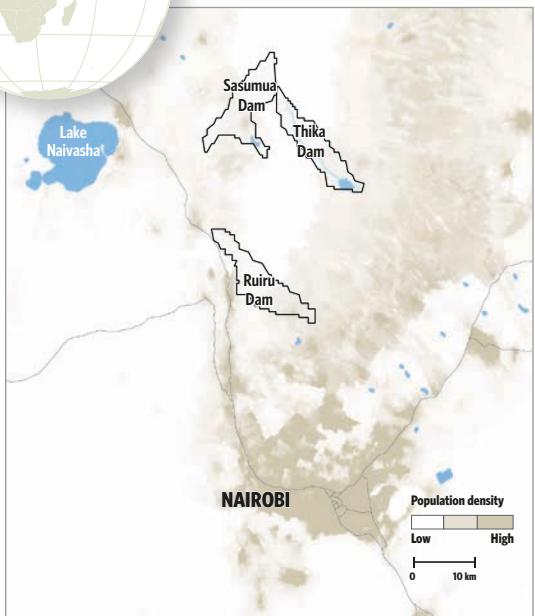
**The Dique Canal runs between the Magdalena River and the port city of Cartagena. Villages around the canal have suffered severe flooding in the past year. At nearly 1,000 miles long, the Magdalena River covers 24% of the national territory and is an economic life-force for the more than 30 million Colombians that live throughout the basin. With the help of the Ministry of Environment and the river's environmental authority, Cormagdalena, the Conservancy is implementing conservation strategies throughout the basin.**

## LOCAL SPOTLIGHT

### Upper Tana Watershed, Nairobi, Kenya—Economic benefits of protecting source watersheds



Photo credit: © Nick Hall



#### The challenge

The Upper Tana River Basin is of critical importance to the Kenyan economy. Covering an area of about 1.7 million hectares, the Upper Tana supplies 95 percent of Nairobi's drinking water, sustains important aquatic biodiversity, drives agricultural activities that feed millions of Kenyans and provides half of the country's hydropower output.<sup>614</sup> The basin has experienced high population growth, resulting in the conversion of forest to cropland and decreasing land per capita.<sup>615</sup>

Smallholder farms are the largest upstream users in aggregate of Upper Tana Basin water above the river's Masinga Reservoir. While economic prosperity in the Upper Tana is closely linked to a range of ecosystem services, natural resources and off-farm employment,<sup>616</sup> the agricultural sector (including crops and pastureland) forms the dominant source of livelihood and labor employment. Unfortunately, the sustainability of small- and large-scale agricultural practices is under growing pressure due to over-cultivation, poor nutrient management, low productivity of livestock in the lower reaches of the basin and persistent encroachment of cropland into forested riparian and high slope areas.<sup>617</sup>

Hydropower generation is the second largest user of water, and threats facing the main hydropower reservoirs, Masinga and Kamburu, encapsulate larger water security risks in the basin.<sup>618</sup> The unchecked expansion of farming, quarrying and dirt road construction across the Upper Tana over the last 40 years has led to land degradation. Consequently, elevated sediment loads are entering the river system, impacting the delivery of water to Nairobi water users and reducing the efficiency and lifespan of reservoirs. For instance, by 2001, the Masinga reservoir had already lost an estimated 158 million cubic meters of storage volume due to siltation rates, twice as high as the reservoir was designed to accommodate.<sup>619</sup> Reservoir function has been further compromised by reduced dry season flows resulting from increased demand for irrigation water and encroachment on natural wetlands that once stored runoff water and recharged aquifers.

## Action and opportunity

In response to these challenges, the Upper Tana-Nairobi Water Fund was launched to implement a holistic set of conservation activities with the objectives of increasing water yields, reducing sediment loadings, promoting sustainable food production and increasing household incomes in farming communities across the project areas.<sup>620</sup>

In order to mobilize funding, a comprehensive analysis integrated investment-planning techniques with watershed modeling tools to prioritize where to work. Non-monetized benefits, including increased pollinator habitat and carbon storage, were identified (Table 5.4), and cumulative costs and benefits were modeled and assigned to stakeholder groups (Table 5.5). The final analysis concluded that even by conservative estimates the selected watershed interventions could deliver a two-to-one ROI on average over a 30-year timeframe (Figure 5.5).<sup>621</sup> Importantly, the value of co-benefits is estimated to be far greater than the water treatment

savings. By recognizing the multiple embedded values of a healthy watershed, and involving key stakeholder groups, the water fund was able to design a collective action program whereby investing together makes the most financial sense.

Many of these projected benefits are already being measured through demonstration interventions. More than 600 smallholder farmers have received support in implementing soil and water conservation structures on their farms in the Thika-Chania sub-watershed. More than 1,000 small-scale farmers are adopting water harvesting structures in the Maragua sub-watershed. An additional 7,000 coffee farmers have been recruited to adopt soil and watershed conservation practices in the Sagana-Gura sub-watershed, equipping them with the skills to apply for certification by the Rainforest Alliance. As the Upper Tana-Nairobi Water Fund grows and evolves, monitoring the range of benefits will enable adaptive management of the fund and will provide valuable learnings for other programs embarking on developing their own business cases.

### List of non-monetized benefits

Stakeholder	Benefit
Nairobi City Water and Sewerage Company (NCWSC)	Reduction in wet sludge disposal
NCWSC	Avoided service interruptions
NCWSC	Increased dry season flows
Other water suppliers	Lowered sediment levels
Municipal water processors	More reliable water supply
Kenya Electricity Generation Company (KenGen)	Reduction in reservoir sedimentation
KenGen	Avoided turbine intake maintenance costs
Upstream farmers	Increased fodder for livestock
Upstream farmers	Additional income and employment opportunities
Urban private sector processors	Improved water supply
Local communities	Cleaner drinking water
General: Ecosystem services	More habitat for pollinators
General: Ecosystem services	Increased carbon storage in new trees planted

**Table 5.4.** Anticipated benefits of source water protection in the Upper Tana River Basin and recipient stakeholder groups. Adapted from The Nature Conservancy 2015.<sup>623</sup>

### Cumulative benefits across benefit streams

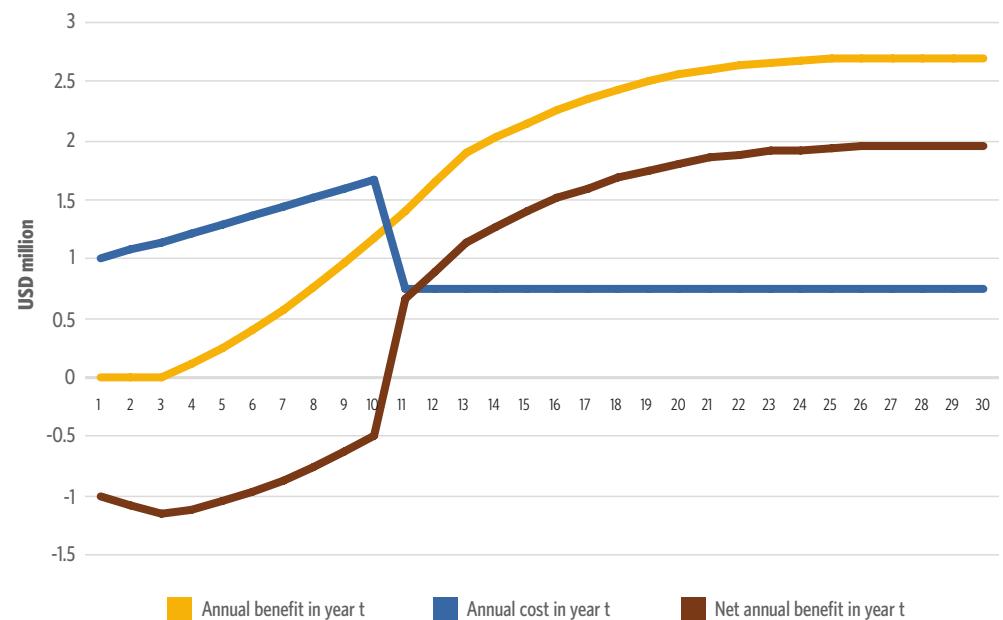
Stakeholder	Benefit or (Cost)	Present Value (US\$)
Water Fund	Investment cost	(7,110,000)
Ag producers	Net additional cost, e.g., maintenance	(8,520,000)
Ag producers	Increased agricultural productivity	12,000,000
NCWSC	Avoided flocculants costs	394,000
NCWSC	Avoided electricity costs	36,700
NCWSC	Net revenue from saved process water	2,090,000
NCWSC	Benefits of above, applied to demand met in future	870,000
NCWSC	<b>Total NCWSC benefits with scale-up</b>	<b>3,390,000</b>
KenGen	Avoided interruptions	281,000
KenGen	Increased generation from increased water yield	5,870,000
KenGen	<b>Total KenGen benefits</b>	<b>6,150,000</b>
	<b>Present value of benefits</b>	<b>21,500,000</b>
	<b>Present value of costs</b>	<b>(15,600,000)</b>
	<b>Net present value</b>	<b>5,900,000</b>

**Table 5.5.** Predicted benefits are over a 30-year time frame. Figures are rounded to three significant digits within each row, while sums are based on exact values. Adapted from Vogl, et al., 2016.<sup>624</sup>



Stanley, fruit and vegetable farmer on his farm in the Upper Tana Watershed, Kenya. The Nature Conservancy is working to protect the Upper Tana Watershed in Kenya and provide cleaner, more reliable water for Nairobi.

**Total annual benefits and costs over a 30-year timeframe including continued maintenance after 10 years (in US\$ million)**



**Figure 5.5.** The cost-benefit analysis of the water fund based on a 30-year time horizon, with the investment of US\$10 million being disbursed at a rate of US\$1 million per year for 10 years. This figure shows how costs and benefits are anticipated to be realized over time. Adapted from The Nature Conservancy 2015.<sup>622</sup>

## NAIROBI DASHBOARD

Water fund start date	Number of upstream participants to date	Number of potential downstream beneficiaries	Number of partners to date	Primary funding sources	Activities	Anticipated co-benefits
2015	15,000	More than 5,000,000	10	Private NGO/Foundation Bilateral/Multi-lateral donor agencies Public Utility	    	    



One in six large cities can pay for natural solutions through savings in annual water treatment costs alone.



## CHAPTER SIX INSIGHTS

**Water funds can scale source water protection by increasing participation based on a solid value proposition.**

- We estimate that an increase of US\$42-\$48 billion annually would be required to achieve an additional 10 percent of sediment and nutrient reductions in 90 percent of our source watersheds. For half of cities, all annual source water protection activity costs could be just US\$2 or less per person.
- We estimate that sediment reduction alone can be achieved with US\$6.7 billion annually, improving water security for 1.2 billion people at a per capita cost of under US\$6 per person per year on average.
- Water funds at scale require augmenting funding in three ways: strengthening public funding; making the case for other sectors, like hydropower, that could participate in water funds; and making the case for natural infrastructure as a supplement or complement to gray infrastructure.
- Water funds with robust stable funding can accelerate source water protection by being the vehicle for financing. Other barriers exist for scaling water funds. We provide a call to action to address these barriers and bring source water protection to scale.

# Chapter 6

## Scaling by Value Creation through Water Funds

### From what to how with source water protection

Through the lens of source watersheds for the world's large cities, we have assessed the types, scale and potential benefits of source water protection activities, including water security and other sustainability goals. We have then explored a mechanism—water funds—that helps overcome the fundamental governance challenges of linking downstream cities and their urban users with upstream land stewards. To make this point tangible, we have demonstrated how integrating co-benefits for cities brings forth significant new values. For six cities in Colombia, source water protection achieves multiple goals simultaneously at less cost than if they were pursued individually, demonstrating that collective investment in natural infrastructure can make financial sense.

We now return to the question of scale. In this final chapter, we estimate what resources would need to be mobilized at scale, identify some of the monetizable benefits for which downstream users are willing to pay and propose examples of how this turns the challenge of scaling water funds into a solvable financing and delivery problem.

As the influence of cities increases worldwide, we return to cities as a driving force behind the creation of water funds. Nonetheless, our final recommendations encompass and look beyond cities, laying out a pathway of action that includes upstream communities, businesses, governments and civil society.

### The cost of source water protection at scale

As we have seen, source water protection has broad geographic relevance for reducing land-based sources of nonpoint pollution (see Figure 2.5 and 2.6): more than 1.7 billion people living in cities could potentially benefit from improved water quality. This represents more than half of the world's urban population that could benefit from improved water security as a result of natural solutions.<sup>625</sup> Four out of five cities in our analysis (81 percent) can reduce sediment or nutrient pollution by a meaningful amount through three representative practices: forest protection, pastureland reforestation and agricultural BMPs as cover crops.



Photo credit: © Samantha Pinkham

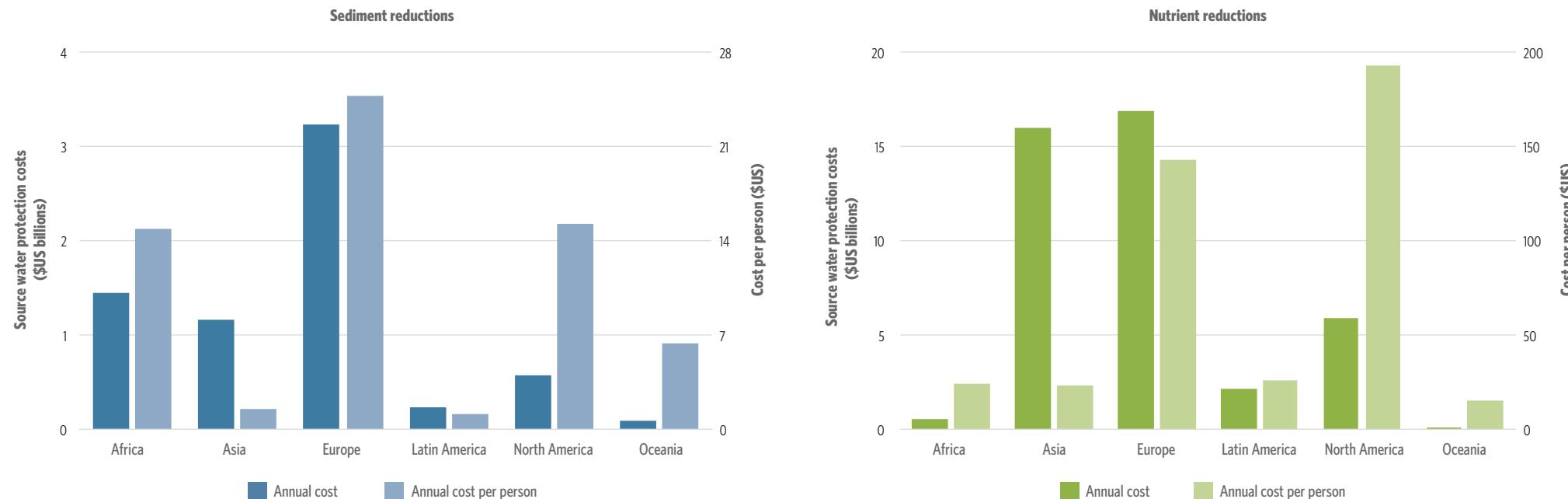
If implemented across all watersheds where a meaningful pollution reduction is possible (defined herein after as 10 percent reduction), we estimate that annual costs could total US\$40 billion for sediment reduction and up to US\$190 billion per year for nutrient reduction. As outlined in Chapter 2, we base these gross estimates on implementation of the three practices listed above, targeted to the highest pollution-contributing areas within watersheds. Aggregate costs are derived using regional estimates as described previously (Appendix V).<sup>626</sup> Because the same activities implemented in the same locations would in many cases contribute to both reduction targets simultaneously, as we have seen in the Colombia city examples (Chapter 5), the total cost to achieve sediment and nutrient targets would be less than the sum of the costs to achieve these targets separately.

We acknowledge the high price tag for implementation, especially to reduce nutrients, and observe that aggregate costs can be driven in part by a small number of watersheds where a meaningful reduction is achievable but exceptionally costly. Therefore, we remove from consideration the top 10 percent of watersheds in terms

of cost per person by region (Figure 6.1, left and right, for sediment and phosphorus, respectively). We find that aggregate costs decline dramatically, to US\$6.7 billion annually for sediment and US\$41 billion annually for nutrients. And while total annual costs decrease significantly, the total population that could benefit remains high: an estimated 1.2 billion people potentially benefitting from sediment reduction and 930 million people from nutrient reduction. Taking the overlapping areas into consideration, we estimate that at least 1.4 billion people could benefit from either sediment or nutrient reduction.

Though aggregate implementation costs can be substantial, the large number of potential beneficiaries living in cities can translate into comparatively modest per capita costs (Figure 6.1). For half of cities, annual source water protection activity costs could be just US\$2 or less per person. While regional differences in income would play a significant role in assessing affordability, these results indicate that the cost of conservation is likely within reach for many cities and watersheds around the world.

**Annual source water protection costs to achieve a 10 percent reduction in sediment and nutrients in 90 percent of urban source watersheds**



**Figure 6.1.** Estimated annual costs (total and per capita) of source water protection implementation—through forest protection, pastureland reforestation and agricultural BMPs as cover crops—to achieve a 10 percent reduction in sediment (left) or nutrients (right) in source watershed areas. For each region, a subset of watersheds—particularly within very large basins—heavily skew costs upwards. Results reported here remove these outlier watersheds as measured by per capita costs, showing values for the remaining 90 percent of watersheds within each region.



Photo credit: © Kevin Arnold

For sediment loading, annual costs per person appear favorable for many regions and watersheds. In Asia, meaningful sediment reduction could be achieved at an estimated cost of just US\$1.50 per person per year. By contrast, annual costs for Africa are more than US\$14 per person, an amount that may be a burden for rate-payers in a region with GDP of just US\$1,571 per person per year.<sup>627</sup> These cost estimates highlight the necessity of bringing more payers to the table. Indeed, the Upper Tana-Nairobi Water Fund (Chapter 5) is an excellent example of how other stakeholders—including businesses and multilaterals—have helped start the fund and create the financial stability needed through endowments.

In considering the costs of reducing nutrients, we generally see that more source water protection activity—and therefore greater costs—is needed as compared to sediment reduction. This relationship is in part reflective of pollutant loads across the landscape, but also the limitations of our modeling. While we consider three important

strategies for reducing nutrient runoff, there are several additional strategies that could be deployed for further reductions and potentially with greater cost efficiency (see Chapter 2 for more discussion of the conservation activities relevant to source water protection). Even with greater overall costs, we see differences between and within regions that indicate global potential. In Asia, we estimate the overall annual cost per person for reducing nutrients is US\$24, approximately 0.2 percent of the regional per capita GDP (US\$10,866).<sup>628</sup> Per capita cost estimates for North America are much higher (\$193 per person) due in part to inclusion of very large basins with comparatively smaller city populations (e.g., Mississippi Basin). However, when compared to the regional per capita GDP (US\$54,580) these costs are affordable across much of the region at 0.35 percent of the per capita GDP. Such per capita comparisons do not imply that city residents alone can or should pay for source water protection, but they do provide a simple means of appraising relative feasibility.

## The funding gap

Today, roughly US\$24.6 billion is spent annually on watershed conservation programs that incorporate payments for ecosystem services (PES).<sup>629, 630</sup> Water funds, also called collective action funds, are a type of PES program.

Closing the gap between what has been currently mobilized (US\$24.6 billion) and the cost of additional implementation in 90 percent of our watershed areas necessary to achieve 10 percent sediment and nutrient reduction (estimated to be an additional US\$42 billion to US\$48 billion per year) is a challenge as great as closing the broader financing gap that has plagued water infrastructure in both developed and developing countries.<sup>631</sup> However, it is worth noting that increases in expenditures in source water protection of that magnitude, while certainly daunting, are not inconceivable. These increases represent around 7 to 8 percent on average of global expenditure on water, estimated to be US\$591 billion in 2014,<sup>632</sup> and together with current spending are commensurate to what cities like New York City are spending on watershed protection as a fraction of their overall water expenditure.

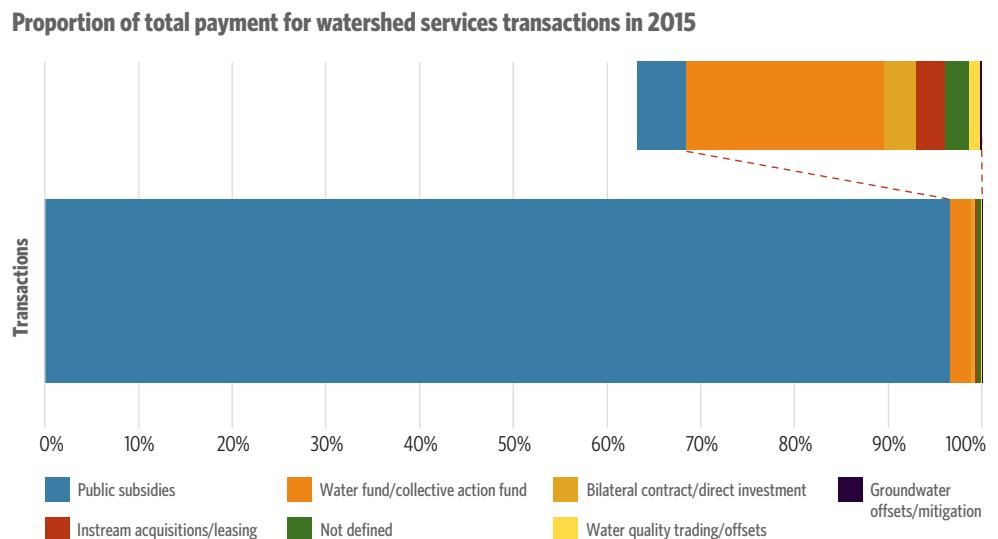
The full cost of implementing watershed conservation at scale requires not only more funding but also a financially sustainable model that takes advantage of the full value created by source water protection. At present, public subsidies by national

governments make up 94 percent of the overall global investment in watershed payment for ecosystem services programs (Figure 6.2).<sup>633</sup> China alone constitutes over half that amount. Given the current fiscal challenges of most countries, growing this revenue stream will be difficult. Furthermore, much of this funding could be considered ephemeral. Only about US\$6 billion has been committed to watersheds in future years.<sup>634</sup>

The challenge is that no single source of value can be reliably and consistently mobilized around the world to pay for source water protection. While there will be some cases where the changes in water quality and supply alone can motivate water users to pay for actions at sufficient scales, in general, finding diverse sources of value for diverse payers who can consistently pay for watershed conservation will be required to achieve the desired scale.

By resolving the watershed governance issue between upstream land stewards and potential downstream payers for multiple benefits, water funds offer an opportunity to overcome this critical stumbling block for source water protection. In fact, one in five watershed payments for ecosystem services projects is already delivered through collective action funds, like water funds, which bring together payments from a wide variety of actors such as private businesses, utilities and civil society organizations to cover the cost.<sup>637</sup>

For half of cities, annual source water protection activity costs could be just US\$2 or less per person.



**Figure 6.2.** Proportion of total payment for watershed services transactions for collective action funds and other project types.<sup>635</sup> The total value of watershed conservation-focused PES transactions was US\$24.6 billion in 2015. Adapted from Bennett and Ruef, 2016<sup>636</sup> with permission.

## Water Funds and Reducing Water Risk for the Private Sector

With its proclivity for innovation, the private sector has been an important leader in the establishment of water funds around the world. The role of the private sector includes contributing seed money in early phases of water fund development, serving on water fund governing boards, using existing relationships to bring other actors to the water fund and contributing to the water fund over the long-term as a water user.

The private sector's role in water funds is linked to its increasing focus on water security. Companies assess and address water security risk to their operations, product ingredients and product sales, or services to consumers. The organization CDP tracks water risk and water stewardship for 617 investors representing US\$63 trillion in assets. Their 2015 report revealed that nearly two-thirds of responding companies reported exposure to water risk, with financial impacts of these risks at more than US\$2.5 billion.<sup>638</sup> Global companies with high dependence on agriculture supply chains, such as food and beverage companies,

have led the way in responding to physical, regulatory and reputational water risks through water stewardship programs.

The Alliance for Water Stewardship (AWS), a voluntary certification body, is emblematic of a growing interest within the private sector for reducing water risk. The AWS provides guidance for companies wishing to identify and address water stewardship concerns in the places where they operate and bestows AWS certification on those companies meeting its standard.<sup>639</sup> That standard is also available for public or private utility certification and is applicable to any water use including, for example, small shareholder farmers or producer collectives. Finally, the United Nations has recognized the growing interest and need for private sector involvement in improving water management through the establishment of the CEO Water Mandate, which activates the private sector to lead in advancing water stewardship, sanitation and the SDGs through collaborative efforts.<sup>640</sup>



Photo credit: © Carlos Villalon

## Bridging the gap

The growth in water funds with the express purpose of driving more investment into source water protection is impressive. What started with New York City and then moved to Latin America with Quito, Ecuador's water fund, has now become a global network (Figure 4.6). The Nature Conservancy alone has 29 operating water funds and another 30 in design as of this date.

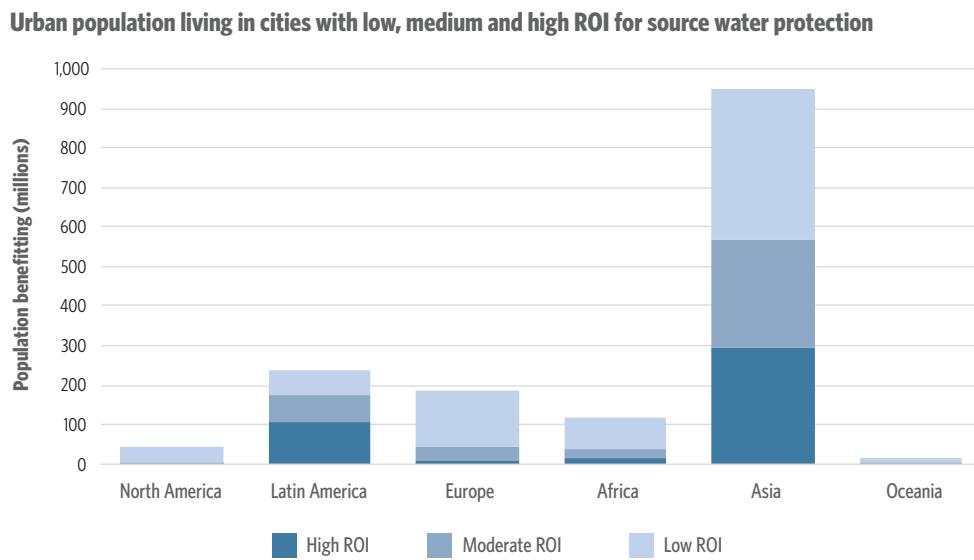
### The case for water users

In many cases, water funds are developed because municipalities, corporations and local businesses share a specific water-related risk and have no easy solution at hand. Partnering with civil-society organizations and public entities enables them to learn about how source water protection programs may reduce treatment costs or supply risks and how to make this happen.

Using an expanded dataset and models improved since our first publication on this topic,<sup>64)</sup> we estimate that one in six cities—serving more than 433 million people globally—has the potential to fully offset source water protection activity costs through water treatment savings alone (Figure 6.3). Agricultural BMPs in the form of cover crops are the most cost-effective of the three strategies that we modeled, and

are most likely to result in a positive ROI. The positive return is in the form of reduced water treatment O&M costs through reduction in chemical and energy inputs. As we saw in Chapter 5, such cities represent strategic opportunities, particularly for driving investment in source water protection, where a single stakeholder (cities) can derive economic value commensurate with the costs of conservation implementation. An additional one in four cities could offset a smaller-but-still-meaningful proportion (at least 10 percent) of source water protection costs through treatment savings. For these cities, the savings from reduced treatment costs could help fund source water protection, although additional funding sources would be necessary.

We consider the one in six cities to be a conservative estimate. O&M provides an incomplete picture of water treatment benefits, as it does not include savings from avoided capital costs. Moreover, these findings capture only costs and savings from the three source water protection activities (forest protection, reforestation and use of cover crops) that we used in this global analysis, which means that practices that would be designed locally to most cost-effectively meet local resource challenges are not considered. This gap reveals itself in the results for North America, where the ROI seems the lowest and therefore shows a relatively low level of benefiting population. Practices like forest thinning, riparian restoration and wetland restoration that are most prevalent in U.S. water funds were not modeled by this global analysis. Nonetheless, those cities with a higher ROI represent strategic opportunities to move forward with water fund feasibility assessments. Asia, with its high population, represents the best opportunity to impact the lives of the greatest number of people.



**Figure 6.3.** Number of people within cities who could benefit from reductions in sediment or nutrient pollution, as shown by categories of potential ROI. ROI here represents estimated cost savings from avoided water treatment O&M relative to estimated source water protection costs to reach a 10 percent reduction in sediment or nutrients. ROI categories correspond to values greater than 1 (high), between 0.1 and 1 (moderate) and less than 0.1 (low). Numbers are relative (not definitive) for any one city.

Agricultural BMPs in the form of cover crops are the most cost-effective of the three strategies modeled.

## Stacking co-benefits

Although water security is almost always the catalyst for the creation of a water fund, we know that most water funds include activities designed explicitly to generate co-benefits beyond this primary outcome. Data from Forest Trends' 2016 survey of payments for watershed services programs, of which water funds are one type, confirm the prevalence of co-benefits among program objectives. Of 155 programs responding, 82 listed biodiversity benefits, 80 listed direct community benefits, 58 listed climate adaptation and 18 climate change mitigation.<sup>642</sup>

Existing water funds provide further support for the assertion that co-benefits are a programmatic focus rather than an afterthought.

- In São Paulo, Brazil (Chapter 3), the water fund is working to motivate land owners to participate in forest protection and restoration by paying them for the carbon ecosystem services their lands provide.
- In the Rio Yaque del Norte, Dominican Republic (Chapter 3), the water fund is using the best available scientific data and models to prioritize lands where source water protection can enhance water infiltration and help build resilience in the face of predicted climate-related droughts.
- In the Santa Cruz Valleys in Bolivia (Chapter 3), multiple programs are focused on providing safe drinking water to upstream communities whose health has been compromised by water contaminated by livestock waste.
- In the Rio Grande Basin in the United States (Chapter 4), the water fund is expected to create 300 to 600 seasonal forest worker jobs each year and help sustain the high tourism value of the region.<sup>643</sup>
- In Nairobi, Kenya (Chapter 5), supporting the livelihoods of smallholder farmers is a primary objective alongside reducing the water pollution that has proven costly to the water and energy sectors.

As we have argued, source water protection, almost by definition, generates co-benefits. These and other cases demonstrate that water funds are being designed with those co-benefits in mind to maximize the generated values.



Photo credit: © Devan King

## Making the business case for water fund investments

To get to scale, water funds need more predictable cash flows. In this section, we lay out tangible opportunities for cash flow growth. We suggest that the opportunities consist in strengthening public funding flows, diversifying buyers by bridging into new sectors and positioning natural infrastructure as a smart option for infrastructure investment (beyond O&M).

### Long-term public funding flows

According to the OECD, the core financial sources of investment for the water sector are the “3Ts”<sup>644</sup>: tariffs, taxes and transfers, including official development assistance. These long-term public funding flows are critical for the water sector and form the vast majority of PES programs to date. They need to be sufficient and reliable in order to assure desired results and to attract external sources of finance.

The case for continued public investments is clear: some regions could see their growth rates decline by as much as 6 percent of GDP by 2050 as a result of water-related losses in agriculture, health, income and property—sending them into sustained negative growth.<sup>645</sup> Aspirational goals to see livelihoods improve, like those set in the Sustainable Development Goals, are beyond reach without a more water-secure world. More work is needed to make current and future public payments targeted to create the highest value for the public and to make them more stable in nature.

There are positive signs from local governments and the utility sector that there is willingness to dedicate a portion of tariffs to natural infrastructure, as discussed in Chapter 4. In the case of the Edwards Aquifer Protection Program (Chapter 1), local citizens have supported measures in the form of taxes and tariffs of over US\$300 million to date to fund source water protection. More work is needed to increase local government and utility sector tariffs and taxes to provide a secure cash flow.

### Other sector opportunities

To date, buyers have been largely motivated by water quality issues, while other sectors have not yet participated at the same level in source water protection programs (Figure 6.4). In the following section, we highlight “cash flow archetypes” that suggest potential for a favorable return on investment for additional beneficiaries beyond urban water users.

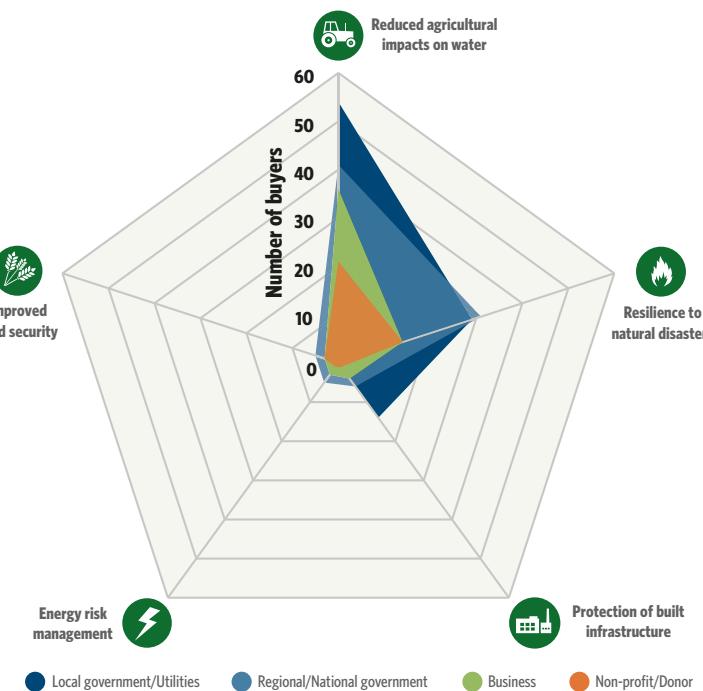
These cash flow archetypes represent an opportunity to reveal the value of specific natural infrastructure solutions in new sectors. The track record generated from

interventions in one geography can reliably build a learning base to improve the likelihood of success in other geographies where similar conditions and ecosystems are found. Moreover, if the ROI track record is considered favorable and robust in multiple locations, it can motivate scalable, private-market participation through pay-for-success and pay-for-performance participation models. Lastly, such intervention track records can also strengthen traditional water funds as they can motivate additional contributions from new and existing payees who will have a clarified value proposition in situations where these cash flow archetype relationships are present.

### Hydropower generation via cloud forest restoration

Cloud forests are unique tropical montane ecosystems featuring persistent ground-level clouds. They provide significant hydrological services downstream from the tropical mountain headwaters where these ecosystems are found.<sup>647</sup> Their watershed benefits include stream flow regulation, additional precipitation inputs from fog- and wind-driven rain capture and significant avoided sedimentation potential.<sup>648</sup>

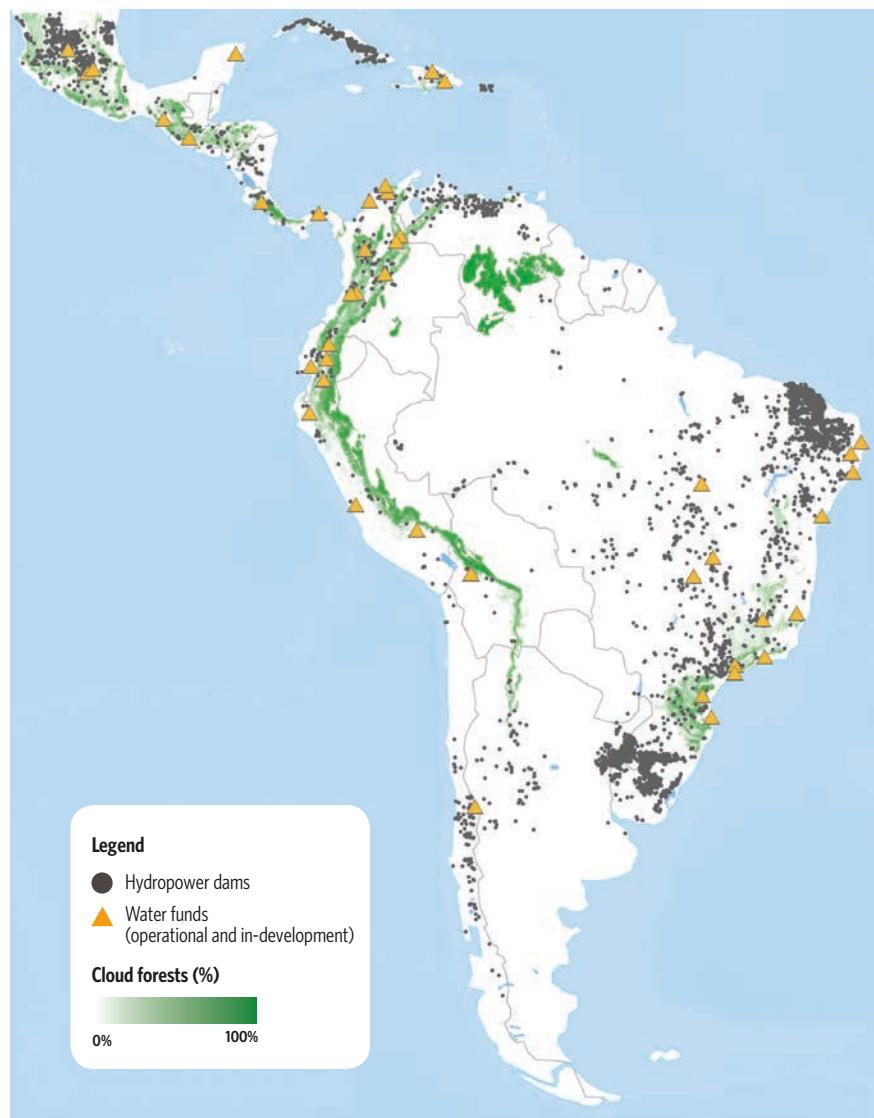
### Water-energy-food drivers for payments for watershed services projects, by buyer and motivation



**Figure 6.4.** While a value proposition can be made for delivering other outcomes beyond improved water quality, such as energy risk management or protection of built infrastructure, buyers with these motivations are not yet participating strongly in the market. Adapted from Forest Trends 2014<sup>646</sup> with permission.

These benefits help downstream hydropower operators who stand to gain increased revenues through the optimization of reservoir operations resulting from cleaner, more regular and often additional water inputs to reservoirs, as well as likely significant decreased costs from a reduction in sediment management expenses. Approximately 55 percent of hydropower-contributing watersheds in Latin America contain cloud forests, and these include an estimated 60 million hectares of degraded

#### Intersection of cloud forests, hydropower installations and water funds in Latin America

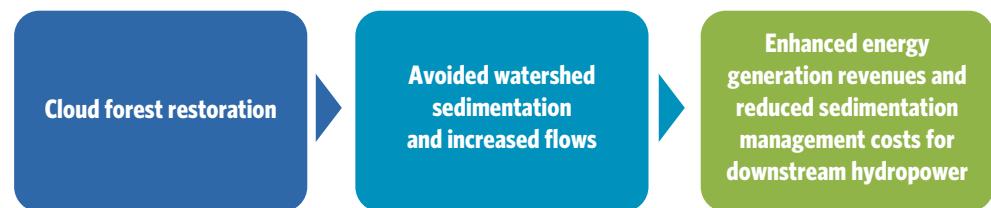


**Figure 6.5.** Broad areas of overlap exist among cloud forests, hydropower locations and existing and in-development water funds, which could theoretically act as implementing agents for the required cloud forest protection and restoration efforts.

forests (Figure 6.5).<sup>649</sup> This overlap generates a unique hydropower–cloud forest nexus for cloud forest restoration and more sustainable hydropower generation both across Latin America and globally in areas such as Laos, China and Rwanda where hydropower plants also rely on headwaters covered with cloud forests.

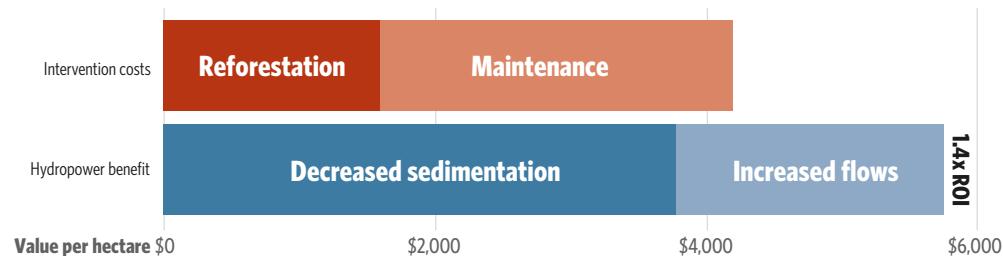
Given that roughly 60 percent of cloud forests in Latin America have been lost due to factors such as agriculture and forest conversion to pasture, linking hydropower generation to cloud forest restoration provides a potentially meaningful and scalable restoration platform.

A new integrated set of modeling methodologies can estimate the ecosystem benefits derived from cloud forest restoration and then plug these benefits into the operating models of downstream hydropower users. In one example, the value of avoided sedimentation (reduced cost) and increased hydrological flow (increased revenue) to the Calima Dam in the Valle de Cauca, Colombia, indicates a positive ROI for Energia del Pacifico S.A., Calima's owner to pay for cloud forest restoration practices (Figure 6.7).<sup>650</sup>



**Figure 6.6.** Cloud forest restoration/hydropower generation value chain

#### ROI for Calima Hydropower Dam based on targeted cloud forest restoration interventions



**Figure 6.7.** Adapted with permission from Leonardo Sáenz (Sáenz, et al., 2014).<sup>651</sup>

## Fire risk reduction via forest thinning

Logging practices and fire suppression efforts have created large swaths of forested area in the western United States that are overly dense with brush and small trees. When paired with ongoing drought conditions, higher temperatures and longer fire seasons, this combination leads to increased risk of catastrophic fires—large and severe wildfires that spread within the forest canopy and lead to more lasting damages. While ecosystems can quickly bounce back from moderate burns, catastrophic fires can create lasting ecosystem changes as post-fire altered soil conditions favor different plant species to move in, a dynamic that can require millennia to unwind. Catastrophic fires also have significant negative impacts on watershed flow quality and sedimentation dynamics. Where appropriate, fuel reduction through selective thinning of unnaturally dense forests can reduce the severity of wildfires and break this cycle, meaningfully reducing the risk of property loss and disruption to water services. Communities and industries that face higher fire-related risk, or their insurers, may be keenly interested in the benefits of the water fund.

The Rio Grande Water Fund (Chapter 4) is designed to prevent catastrophic fires that create financial losses for land owners and create sedimentation issues for

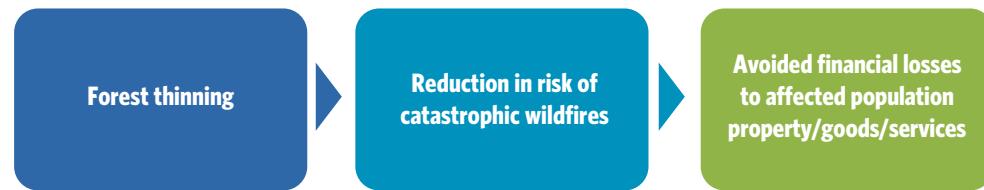


Figure 6.8. Forest fuel reduction value chain

downstream water utilities. We examine two representative fire scenarios impacting 21,000 and 62,700 hectares (representing respectively 4 percent and 11 percent of acreage) in Taos County, New Mexico. The fires were simulated using weather conditions observed during recent large fires in the region. These conditions, once rare, are becoming more common. The ROIs presented below contrast the forest thinning costs associated with the avoided costs of wildfire with market goods and services important to the affected watershed community. The analysis indicates a positive return on investment for the Taos County community in the event that either representative fire occurs (Figure 6.9).<sup>652</sup>

## Capturing infrastructure investment by making the right case

Lastly, one of the important ways to improve water security efforts and gain support for natural solutions is to place it side-by-side with gray infrastructure as an option while those infrastructure investment decisions are being made. In an effort to add to the growing body of work on evaluating gray versus green infrastructure ROI, we offer a third example of how to increase the funding pool by accessing capital expenditures where appropriate.

Taos County ROI for conducting forest thinning treatment compared with benefits provided by two representative fire scenarios

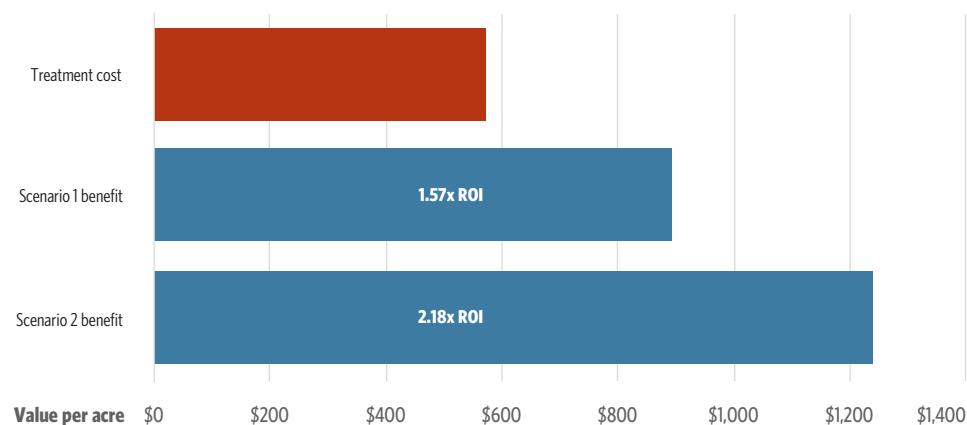


Figure 6.9. Adapted from Kruse, et al., 2016.

### Dry season flows via puna/mamanteo restoration

Small Central Andean communities for centuries depended on an ancient stream diversion system, mamanteo, to improve water regulation. These systems move a portion of wet season flows in the highest reaches of their watersheds to trenches built laterally across mountainsides to facilitate soil infiltration. Several weeks to months later, some of the water resurfaces downslope in micro-pools where it is used by the community for dry season crop and pasture irrigation. Part of the infiltrated water travels further downslope where a portion of it eventually reenters streams, increasing scarce dry season streamflow that supports large reservoirs and agricultural production.

Mamanteo systems are found in puna—high-altitude grassland ecosystems occurring from Bolivia to Ecuador—whose soils provide water regulation capacity, banking rainy season flows into the extended dry season. In many areas, puna grasslands have been heavily degraded by livestock overgrazing, resulting in reduced flow regulation. As well, many mamanteo systems are insufficiently maintained. By restoring these interdependent mamanteo and puna systems it is possible to improve the dry season flows for both high Andean communities and downstream water users. For instance, if implemented across Lima's three Pacific source watersheds, the two interventions are expected to generate additional dry season flows equivalent to 29 to 170 percent of the current combined 34 million cubic meter dry season volumetric streamflow deficit (based on how much water demand outstrips supply) in the three watersheds.<sup>653</sup>



Figure 6.10. Puna/mamanteo restoration value chain

Even without cost sharing with upstream communities operating mamanteo systems—expected to be feasible given the large projected agricultural production and net welfare gains for these communities—each dollar invested in joint mamanteo and puna restoration instead of 8 of 10 future gray infrastructure alternatives (for increasing dry season water availability in the middle and lower portions of Lima's three Pacific source watersheds) is estimated to have an ROI ranging from 1.3 to 2.8 dollars. Most of these gray infrastructure projects are expected to be implemented within the next two decades (Figure 6.11).<sup>654</sup> The interventions proposed under this framework would both lead to enhanced farmer income and restoration of these rich and sensitive puna landscapes.

### Expanding the business case

Increasing cash flow from all water users and beneficiaries of watershed protection is an important area of continued development. Making the case for increased public investments and more diverse private beneficiaries is critical. Further development of carbon, biodiversity, health and agricultural investment business models provide an interesting next step. With a robust set of identified payers, new opportunities for financing source water protection through an established mechanism like water funds emerges.

### Estimated ROI for generating dry season flows to Lima, Peru's metropolitan area via puna/mamanteo restoration

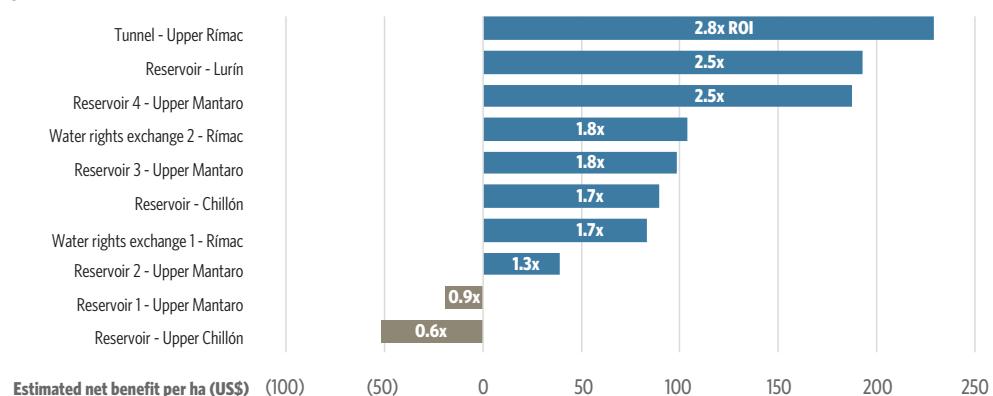


Figure 6.11. A positive ROI is shown with bars extending right of the zero on the X-axis, and represents the ROI of replacing the listed gray infrastructure option on the y-axis with a specific green infrastructure option (restoration of puna/mamanteo system).

## Reducing Transaction Costs to Increase Financial Feasibility

The ROI of a water fund is based on two components: the total cost of implementing the fund, including administrative, implementation and monitoring costs; and the delivery of benefits to investors. Barriers that can reduce the financial feasibility of a water fund include the high transaction costs of engaging multiple stakeholders, difficulty translating outcomes into measurable financial returns where these are required and unwillingness of the beneficiaries to pay for the program design costs.

Transaction costs in a water fund context include those expenses incurred in developing contractual relationships between investors and service providers. These costs are influenced in part by the number of land owners or managers

with whom the water fund contracts to implement activities. In general, the greater number of parties involved, the more time and resources it will take to complete contracting and to monitor that activities are being implemented.

Transaction costs can be decreased where smaller landowners already belong to a watershed committee, communal land agreement, agricultural cooperative, or where a trusted civil society partner can represent them, so that investors can contract with a single or smaller number of counterparts. These arrangements have been implemented in the Upper Tana-Nairobi Water Fund (Chapter 5) and the Agua por La Vida Water Fund (Chapter 3) in Colombia, among others.



Photo credit: © Erika Nortemann

Along the banks of the Río Tabacay in Ecuador's Cañar Province, there are 15 family farms involved in the Asociación de productores agroecológicos de la microcuenca del río Tabacay (Association of organic producers of the Tabacay River basin). The Association is a pilot program promoting sustainable and organic farming practices. This program was created by FONAPA, the Water Fund for the Conservation of the Paute River Watershed, whose members include The Nature Conservancy and other private and public entities. The Río Tabacay is a tributary to the Río Paute.

## Borrowing to bridge the gap

Water funds provide an attractive vehicle for pooling and deploying investments in watersheds from the diverse beneficiaries of watershed services. Under the right conditions, return-seeking investors can securitize these cash flows to help accelerate implementation to a meaningful scale.<sup>655</sup>

To date, few water funds have reached their full implementation potential at a watershed scale due to a lack of funding sources needed for large-scale impact. In addition, even where more modest-but-predictable funding exists from water users, funding structures generally rely on a year-by-year cash flow.

The typical cash flow of water funds (Figure 6.12) can work well, but in some cases, such as where buying land is identified as a high-priority source water protection activity, frontloading the cost of conservation can make more sense. There are multiple benefits to borrowing against future cash flows to implement conservation at greater scales. Most public works, like water treatment plants, are financed this way, often through tariffs or taxation.

The benefits of frontloading investments may include accelerated implementation, which helps meet regulatory requirements where compliance timelines are

important. It may also help in avoiding or postponing treatment costs. Frontloading may provide access to private financing unavailable to incremental implementation and afford economies of scale in implementation (Figure 6.13).<sup>657</sup>

Several criteria must be met to securitize cash flows:<sup>658</sup>

- **Size:** Must be large enough—US\$15 million to US\$30 million range
- **Diversification:** Must offer diversification of credit and operating risk
- **Absorption capacity:** Must be able to manage accelerated implementation
- **Credit quality:** Must have rated counterparties
- **Auditing:** Must be audited by a regionally or internationally recognized firm

Only a tiny share of watershed payment programs are currently “investment-ready.” Those looking to tap traditional and impact capital markets<sup>659</sup> will need to make progress toward meeting investment criteria. Perhaps most pressing is absorption capacity, or the ability of programs to accelerate implementation when funding becomes available. As discussed, high transaction costs associated with establishing contractual arrangements with land owners can limit a program’s ability to accelerate conservation. Water funds that prioritize the integrated participation of upstream communities will likely be those best positioned to attract investors.

Common cash flow pattern for watershed protection programs

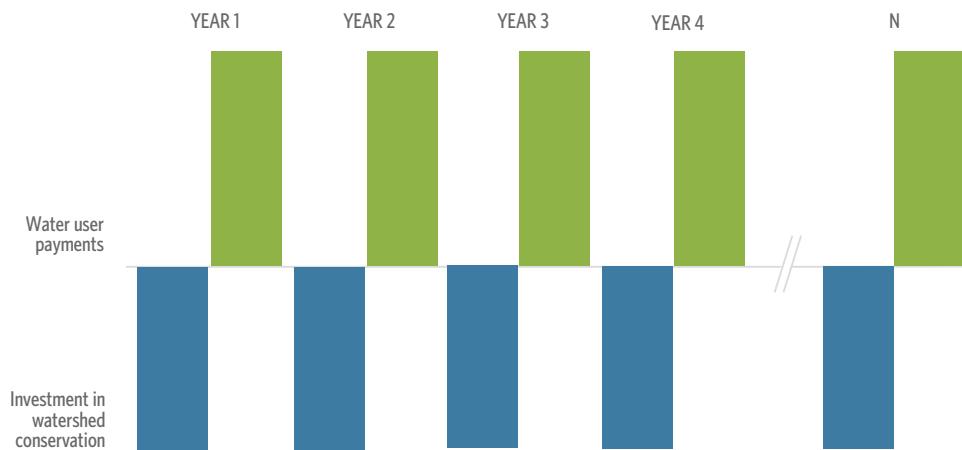


Figure 6.12. Incremental investments in upstream watershed conservation commensurate with annual payment by downstream water users. Adapted from Credit Suisse Group AG and McKinsey Center for Business and Environment 2016<sup>656</sup> with permission.

Proposed cash flow pattern of water funds

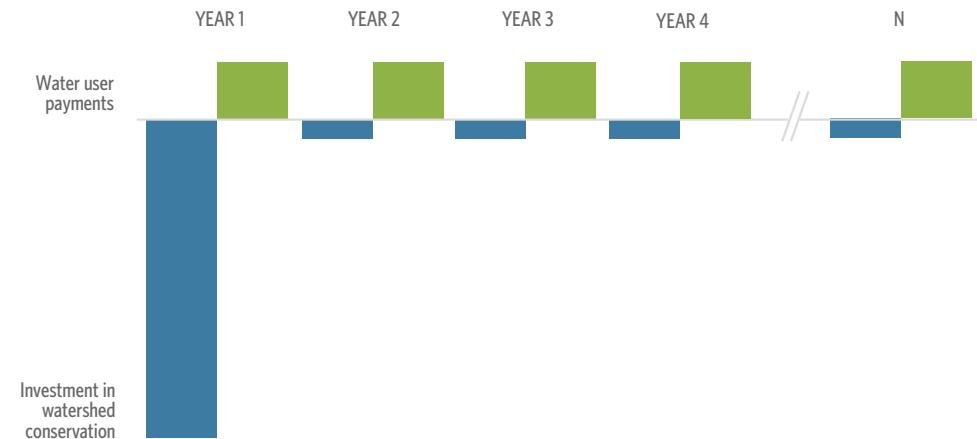


Figure 6.13. Upfront investment in upstream watershed conservation commensurate with program goals, with annual repayment by water users. Adapted from Credit Suisse Group AG and McKinsey Center for Business and Environment 2016<sup>658</sup> with permission.

## Matching cash flows to financing mechanisms

Adequate secure cash flows, including the 3Ts, can attract additional sources of finance—such as bonds, loans and private investors. Sources of finance are important for making large, upfront investments, but they need to be repaid by some combination of the 3Ts and other secure funding. We offer here a few examples of how water funds can provide a mechanism for upfront investment, early implementation and repayment over time.

### Taxation and private bonds

Persuading voters to tax themselves offers one way to increase funding. The Nature Conservancy and its partners have a long track record of delivering voluntary tax increases for conservation purposes across the United States. By conducting political and public advocacy campaigns, the Conservancy has generated funding outcomes that help conserve water sources.

- **San Antonio, Texas (Chapter 1):** City voters approved four ballot initiatives (in 2000, 2005, 2010 and 2015) that authorized bond offerings to fund the Edwards Aquifer Protection Program. The bonds are repaid through a one-eighth-cent sales tax increase.<sup>661</sup>

### Transfers and private bridge capital

Providing bridge capital offers a way to mitigate risk in a watershed investment. By covering upfront expenditures and making repayment conditional on agreed-upon outcomes, bridge capital opens the door for a pay-for-results/performance model of repayment.

- **Bloomington, Illinois (Chapter 2):** The Nature Conservancy and its partners are exploring a funding structure that would provide capital for practices such as creating wetlands. Some funds would be repaid through assignment of federal cost share and other incentives.<sup>662</sup>

### Tariffs and private securitized payments

Securitized tariffs offer a way to accelerate implementation. Water-use tariffs are commonly used to repay large investments in the water sector, like water treatment and distribution works. They can also be used to repay large, upfront investments in watersheds, like the purchase of land.

- **Camboriú, Brazil:** The local water provider, EMASA, may be eligible to invest more quickly in watershed conservation using tariffs as a repayment mechanism if the benefits of upfront investing can be shown to outweigh the cost of capital. Preliminary analysis suggests that when benefits to all downstream users are considered, ROI is positive. Currently, only EMASA bears the costs—suggesting there is potential for collective action.<sup>663</sup>

Regardless of the funding source, the step change in watershed conservation financing will most likely occur first in programs that exert discipline around a single financial closure<sup>664</sup> whereby investment in the watershed is conditional upon an agreed plan, the establishment of preconditions for the plan to succeed and the commitment of all needed funds. Criteria related to a single closure include: agreement on what impact is meaningful for investors (e.g., reduction in sediment as measured in total suspended solids); analysis of how much conservation is required to achieve a meaningful impact on ecosystem function (e.g., 12,000 hectares of riparian buffers); agreement with a minimum number of landowners required to participate (e.g., 200 signed contracts); monitoring capacity (e.g., monitoring equipment installed); implementation capacity and track record (e.g., vendors identified); and, full cost of the program accounted for (e.g., financial model).

Accelerating the pace and scale of implementation would frontload the benefits on source water protection for nature and people. Where appropriate monitoring takes place, implementation at scale would also increase our ability to attribute these benefits to conservation. While not always the case, some conservation benefits may only be measurable when large-scale land-use change occurs. In China, to augment the groundwater table and quantity of surface water in Beijing's Miyun and Guanting reservoirs, some 12,200 hectares of rice paddies were converted to corn and other dryland crops.<sup>665</sup> Where implementation at scale nears the timetables of traditional infrastructure projects, namely three to seven years, such investments will also be buffered somewhat from political interference and changes in leadership. China's same 'Paddy to Dryland' program occurred within a timeframe of five years.<sup>666</sup> Perhaps most importantly from a global vantage point, however, accelerating implementation creates the track record of predictable costs and attributable impacts commonly demanded by buyers and lenders in other geographies.



Photo credit: © Blake Gordon

## Accelerating impact

In addition to overcoming financial barriers, there are a number of gaps that, if addressed, could help accelerate the development and implementation of water funds to achieve the global impact described here. These include gaps in policy, capacity, science and general awareness of the full potential of source water protection. The following describes these gaps and offers recommendations on the most critical steps that can be taken to fill them.

### Policy, regulatory environment and supportive governance

The regulations regarding payments for ecosystem services vary across countries and may prevent, allow or encourage water fund mechanisms. Like other multi-stakeholder programs, having certain legal and institutional characteristics in place will enable creation and management of a water fund. Some countries or states supportive of source water protection, such as Peru,<sup>667</sup> encourage the establishment of water fund-type mechanisms by requiring utilities to invest a portion of their user fees in source water protection or by recognizing source watersheds as part of water supply infrastructure, as recently passed in California.<sup>668</sup> As these types of mechanisms become more common across the globe, it is likely that regulations will adapt to meet the demand for source water protection and better support mechanisms like water funds.

Conflict, corruption, lack of transparency, lack of jurisdictional powers, lack of clear property rights, lack of information and other governance gaps present challenges to development and operation of a water fund. However, as described in Chapter 4,

the water fund model can increase transparency, strengthen collaboration and bridge some of the water resource governance gaps where they exist.

Some specific recommendations on the types of policies and regulatory changes that can help support the development of water funds include:

- Develop stricter regulations for water quality, but allow flexibility about how to reach those water quality targets
- Allow payment for ecosystem services without restrictions related to jurisdictions, providing cities or utilities with the legal means to invest in areas outside of their jurisdiction
- Mandate that a certain portion of water-user fees are spent on source water protection activities, embedding the true cost of water in water-user tariffs
- Recognize that green infrastructure is part of the water supply system, equal to gray infrastructure
- Encourage transparency and enforcement of land tenure laws to reduce uncertainty for buyers, improve participation of producers and reduce the inequity of compensation
- Support additional policies that encourage source water protection programs and/or a systems approach to water management
- Include watershed conservation within engineering and procurement standards to assure consideration of natural solutions alongside traditional built solutions

## Building out capacity and economies of scale

Today, conservation practices in water funds are designed and implemented largely by NGOs or public entities. As the scale of practices increases, conservation work can be contracted out to dedicated firms who seek to reduce costs over time (Figure 6.14). For example, food and agribusiness companies are likely better equipped to increase crop yield with less water and fertilizer use within their supply chain of smallholder farmers, as is the case in the Guanajuato Water Fund in Mexico.<sup>669</sup> Likewise, the forest industry is likely better equipped to deliver and maintain large-scale forest restoration at a lower cost than NGOs. This represents another corollary benefit—businesses and jobs in the private sector may grow to meet this demand. In New Mexico’s Rio Grande Fund (Chapter 4), an estimated 300 to 600 seasonal forest worker jobs will become available each year.<sup>670</sup>

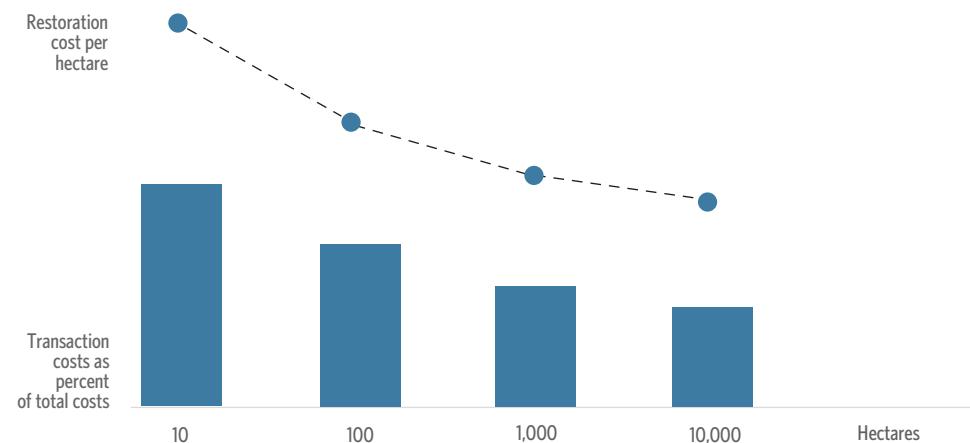
Additionally, water funds are set up to reflect idiosyncratic, site-specific conditions and a unique set of local actors. This leads to reinventing the wheel, increased costs and delayed implementation. Standardizing the process to establish a water fund represents an important opportunity to save time and resources in the project design stage (Figure 6.15). Several organizations (The Nature Conservancy, Forest Trends, Fundación Natura Bolivia, U.S. Agency for International Development, CEO Water Mandate, RARE, Alliance for Water Stewardship and EcoDecision) are already investing in capacity building through knowledge capture and dissemination via reports, online toolboxes and training programs. There is a vibrant community

of on-the-ground practitioners who have experience establishing collective action programs. Capturing and disseminating this knowledge to train others will help new programs leapfrog and increase the quality of existing water funds. Other for-profit companies are developing the skills to deliver effectively on different steps of a water fund. These efforts are starting to accelerate the pace of water fund implementation and help ensure effectiveness across funds.

Specific recommendations include:

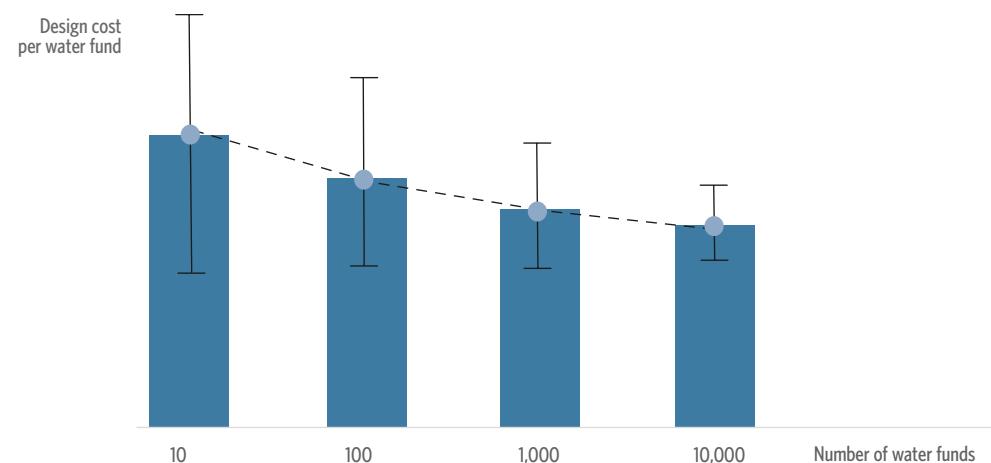
- Gather water fund how-to knowledge from experienced practitioners and disseminate via online resources, reports, webinars and training
- Build networks of practitioners to encourage peer-to-peer learning
- Create standardization of water fund development, design and operation to help increase efficiency of development and effectiveness of implementation
- Enlist individuals and companies to specialize in water fund delivery (or aspects of its delivery) to increase efficiency
- Develop design standards for specific buyer-practice arrangements (see previous section), reducing design costs while increasing the likelihood of success
- Develop design standards for corporate water actors looking to promote collective action water funds in multiple locations within their value chains

**Expected economies of scale for watershed restoration**



**Figure 6.14.** As more hectares are restored, the per hectare cost declines by reducing transaction costs that at first can account for half of total costs.

**Predictability of water fund design costs**



**Figure 6.15.** As more water funds are set up locally, knowledge transfer and standards are expected to bring costs down. While each watershed faces different challenges, the cost to design and establish new water funds should also become more predictable.

## Social acceptance and participation

Even in a favorable regulatory setting, social acceptance of a water fund-type mechanism may stand in the way of successful implementation.

There are at least three major elements that can determine how accepted a water fund might be in a specific place: trust, timing and strong leadership. Trust among stakeholders who wish to engage in a water fund is critical to its success, especially in the early stages of development when parties who have never before collaborated begin to work together. Sometimes this can be overcome with the involvement of a trusted third-party such as a civil society organization or a common leader, or it must be built over time through an honest sharing of desired outcomes and involvement of all relevant stakeholders, including upstream communities. Timing can be a critical factor in determining the success of a water fund. In some cases, a catastrophic event like Monterrey, Mexico's massive flood or New Mexico's extreme wildfire followed by landslides and flooding can trigger interest in a water fund. In other situations, the case for a water fund must be built over time through pilot projects, ongoing information sharing and building of trusted relationships. Finally, a strong, charismatic leader can provide the critical catalyst that ignites passion for the idea of a water fund, brings a wide network of stakeholders on board and provides the sustained energy for water fund development through to full operation.

Some ways that organizations and institutions can help maintain this momentum include:

- Develop strong local leaders who can move water funds forward and champion adoption by others
- Work to build connections to organized associations of land stewards—farmer unions, cooperatives, river basin associations—that could radically reduce the transaction costs of engaging a large number of owners, while safeguarding land steward interests
- Develop safeguards and guidelines to ensure a multi-stakeholder approach that ensures an equitable sharing of value
- Develop social impact assessments that help plan, evaluate and adapt programs in a participatory manner with local communities

## Science

As described in Chapter 4, a core element of a successful water fund is science-based decision-making. The science of source water protection is already robust and can inform the design of on-the-ground activities. As illustrated in Chapter 5, new modeling tools can assist in optimizing for multiple benefits. Science is also critical for advancing the evidence for natural infrastructure and building the business case in specific watersheds. It is in these areas where a greater investment in science is most needed.

More specifically, the following actions will help close this science gap:

- Increase investments in water fund monitoring to determine baseline (starting) conditions and measure change over short-, medium- and long-terms
- Improve analysis and dissemination of results
- Integrate monitoring results with existing scientific knowledge to develop a clear connection between specific activities and outcomes over a range of conditions
- Continue to improve tools used in water fund feasibility studies and in planning portfolios in the development phase
- Standardize the biophysical and socioeconomic elements of a business case to make it easier to develop water funds in new geographies

## Awareness

There is a huge need to increase awareness of and interest in the potential for source water protection via water funds or other mechanisms to provide the full range of benefits described in this report. Our vision is that the majority of urban water utility managers, mayors, major water users, national governments and international institutions concerned with water, carbon, biodiversity, or human health and well-being are aware of the embedded values of healthy watersheds and of the potential of water funds to generate and share benefits. We have a long way to go to reach this vision.

Some specific targets for increasing awareness to move water funds from an early adopter concept to a more mainstream approach to managing water supply sources include:

- Increase awareness of source water protection/water funds with decision-makers who have the capacity to support policies and funding to encourage water funds
- Broaden the awareness of water funds as a cost-effective solution to water security among urban water utility managers and mayors (through existing peer networks and targeted outreach)
- Grow the public awareness of where their water comes from and the need to support source water protection/water funds (via marketing and education)
- Incorporate green infrastructure into standard educational curriculum for water resource engineers, water utility managers and other related fields

## Bringing water funds to scale through collective action

The opportunity to use water funds as a way to help cost-effectively secure water, mitigate and respond to climate change, protect biodiversity, and support human health and well-being is immense. In fact, the global value of this opportunity, and the consequences if we fail to act, are too massive to ignore. However, it will take the combined efforts of many different actors working in collaboration to carry out this vision of a water-secure world through source water protection. In particular, we call on the leadership of the following groups to do their part to set this local-to-global movement in motion:

**Mayors and Municipal Administrators:** Find out if your community is one of the cities that will see positive economic benefits from source water protection through reduced water treatment O&M costs and potential avoidance of capital infrastructure. A water fund feasibility study is a good starting place. Consider how the multiple benefits presented by source water protection may support other goals you have for creating resilient cities and mitigating and adapting to climate change. Support changes in water tariffs, taxes or transfers that will provide long-term financing to source water protection. Consider how the co-benefits you provide to other stakeholders may open up additional investment or attract allies to help solve your municipal-level challenges.

**National Ministry Leaders:** Explore how a source water protection portfolio can optimize multiple goals and public investment. For example, a portion of your national climate goals might be met through source water protection efforts

that also address regional food security goals and support water security for municipalities. Support legal or regulatory changes that encourage long-term financing of source water protection, such as allowing for water-user fees to be directed to natural infrastructure solutions. Support policies that strengthen the governance of water management to the benefit of nature and people.

### **International Financing Institutions and Development Agencies:**

Include natural water infrastructure in development-focused feasibility studies to consider how natural solutions generally—and source water protection specifically—can increase sustainability of investments and be cost-effective over the long-term. Consider how source water protection can integrate multiple agency funding goals, like climate adaptation, climate change mitigation, biodiversity conservation and food security. Water funds are proven implementation mechanisms that can deliver on the goals and aspirations outlined in global frameworks such as the Sustainable Development Goals, the Paris Agreement, the New Urban Agenda and Aichi biodiversity protection targets.

**Corporations:** Explore where your corporation has a business risk related to water quality or availability, including indirect use, and how you might partner with civil and government sectors to develop water funds across this high-risk portfolio. Consider how you can meet multiple company-wide commitments such as water stewardship, climate change and human health and well-being through investment in water funds. Advocate for policy changes that support long-term implementation and financing of source water protection. Explore where your own business operations might be expanded to deliver some of the components required to achieve source water protection.

**Private Investors and Donors:** Explore how and where there are investment opportunities to accelerate deployment of natural solutions to enhance long-term water security investments. Support the development of science-based feasibility studies to understand the values of source water protection in your community of interest. Invest in building the knowledge and capacities needed to replicate innovations like water funds that work.

**Urban Water Managers:** Consider how natural infrastructure solutions may enhance the sustainability of your water security investments or reduce your costs. Educate city leaders on how changes in the investment of limited public funding may be the best technical, social and economic solution given long-term trends. Consider partnering with NGOs and other actors to start a water fund built on a feasibility study that determines its specific values to your resource management needs.



"We recognize that cities and human settlements face unprecedented threats from unsustainable consumption and production patterns, loss of biodiversity, pressure on ecosystems, pollution, natural and human-made disasters, and climate change and its related risks, undermining the efforts to end poverty in all its forms and dimensions and to achieve sustainable development. Given cities' demographic trends and their central role in the global economy, in the mitigation and adaptation efforts related to climate change, and in the use of resources and ecosystems, the way they are planned, financed, developed, built, governed and managed has a direct impact on sustainability and resilience well beyond urban boundaries."

- New Urban Agenda<sup>671</sup>

**NGOs:** Continue investing in science-based efforts to build understanding of how and when water funds and, more generally, source water protection efforts will meet local resource needs. Work together to build capacity to design and deliver water funds globally and share lessons learned in the journey. Educate and promote natural infrastructure solutions with political leaders and advocate for policy changes that will support financing and implementation of source water protection efforts. Serve as conveners among stakeholders who may have never collaborated previously, but who could jointly benefit from a water fund mechanism. Ensure best practices are adhered to in the development and implementation of water funds.

**Upstream Land Stewards:** Know the value of your land and what you bring to the table. Understand the impacts you can make to improve water quality and quantity. Evaluate how a water fund might support you in your own livelihood and management goals. Be an active participant in the development and implementation of water funds.

**Communities and Public at Large:** Know where your water comes from and what is impacting your long-term water security. Advocate for leadership in your community to investigate how protecting water at its source may be in your best interests and those of future generations. Advocate for policy changes that support long-term implementation and financing of source water protection.

## Conclusion

This report lays out a compelling and robust case for source watersheds as a key nexus for action by the variety of players who care about enhancing water security, building more resilient cities, developing more sustainable agriculture, stabilizing the climate and protecting biodiversity.

Understanding the value of healthy source watersheds is not enough: our report seeks to illustrate how source water protection can be implemented at a scale that will make a difference in our collective pursuit of a sustainable world. Water funds are an innovative mechanism already uniting stakeholders in communities around the world, connecting actors upstream and downstream. The results are clear: collective action is contributing to water security for millions of people and bringing a multitude of other valuable benefits. More is needed, however. Cities can lead, but this journey will require all of us to act.



Photo credit: © Erika Nortemann

# Online Resources

## Interact with the data

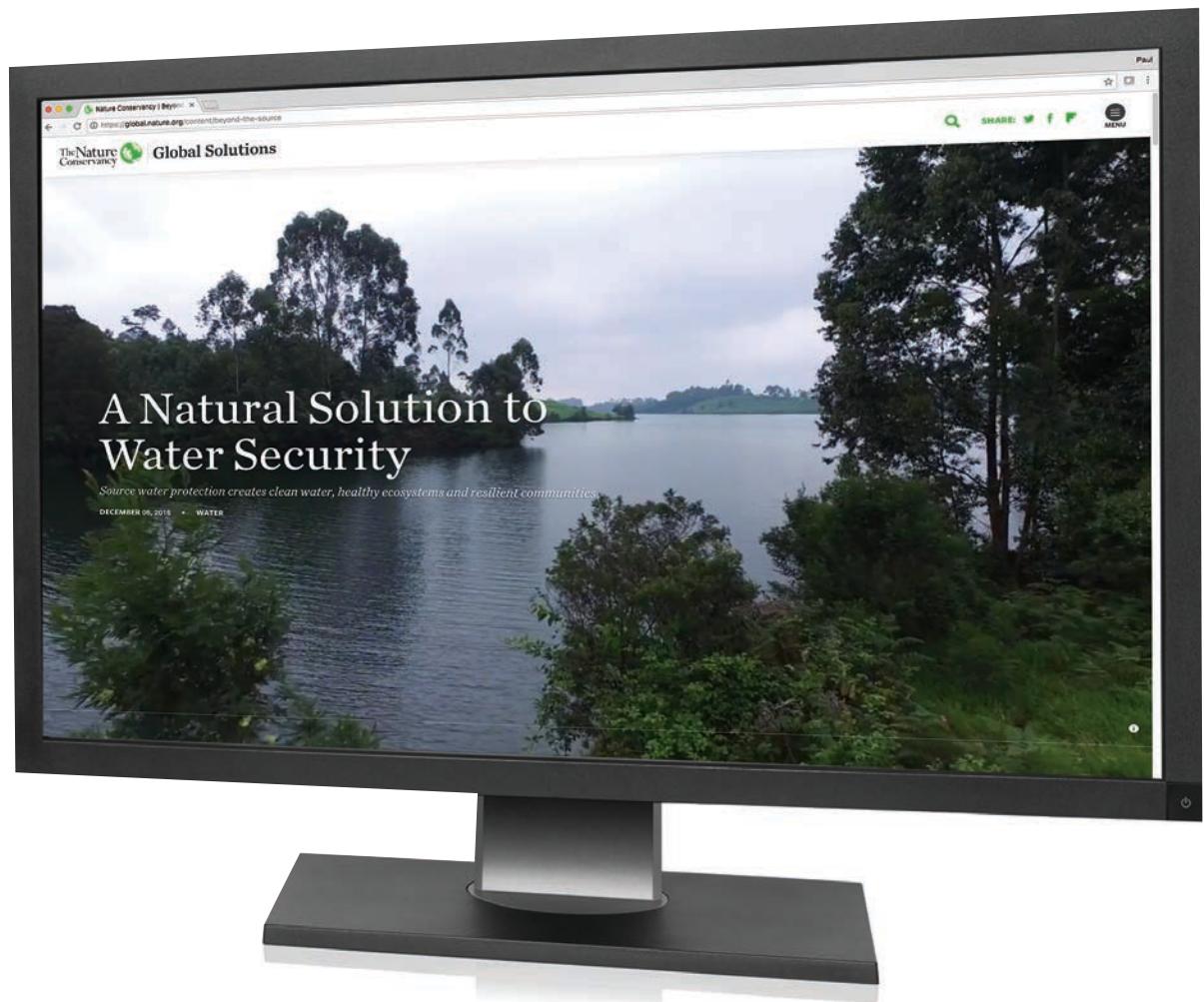
The maps and underlying data used in *Beyond the Source* represent a rich set of resources that lend themselves to further exploration. The Nature Conservancy has developed an online companion to the report, accessed via [www.protectingwater.org](http://www.protectingwater.org), that features an interactive map and enables users to explore our data. Users will be able to quickly learn more about the potential for pollution reduction through source water protection around the world, areas of synergy among co-benefits of source water protection, and existing water fund programs and their attributes. Visitors to the site can also gain entry to The Nature Conservancy's Water Funds Toolbox, which provides support to those seeking to establish a water fund, as well as access information and resources on addressing water scarcity around the world.

The interactive site is one of a large and growing family of spatial decision tools supported through the Natural Solutions Toolkit, accessed via <http://naturalsolutionstoolkit.org>. The Toolkit connects and coordinates multiple related programs and decision support tools that all advance the use of natural solutions that can reduce risk, advance climate change adaptation and mitigation, and support other conservation objectives.

## Dig deeper into the stories

The page developed on The Nature Conservancy's Global Solutions site for the *Beyond the Source* report digs deeper into the stories of the people whose lives were positively impacted by source water protection and features videos, infographics and photos that further explain the value of conserving nature for the protection of our water resources. This page also offers options to download the report and executive summary.

To explore the page, visit [www.nature.org/beyondthesource](http://www.nature.org/beyondthesource).



# Nature's solution to a sustainable water future

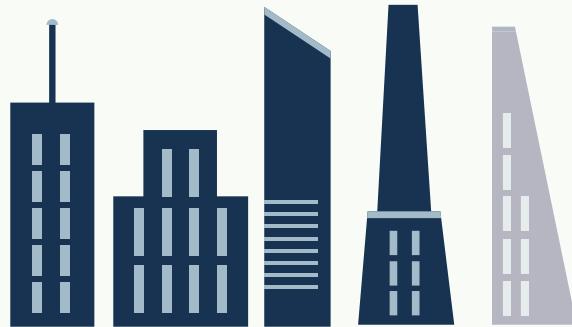


## How can nature help?

The lands around our water sources serve as vital infrastructure that can meaningfully improve water quality and quantity for cities worldwide

**4/5**

**LARGE CITIES\***



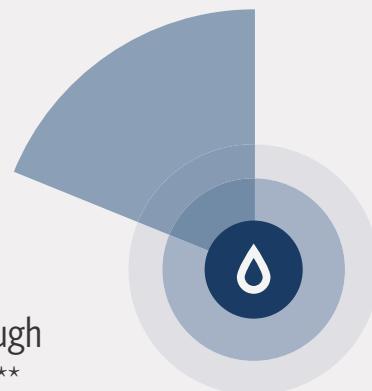
can improve water quality through upstream forest protection, reforestation and improved agricultural practices.

\*Large cities includes the data set of 4,000 cities with populations greater than 100,000 that were part of The Nature Conservancy's research conducted for the Beyond the Source report. \*\*This result represents only operating and maintenance costs.

**1/6**

**LARGE CITIES\***

can pay for natural solutions through savings in water treatment alone.\*\*



\*Large cities includes the data set of 4,000 cities with populations greater than 100,000 that were part of The Nature Conservancy's research conducted for the Beyond the Source report. \*\*This result represents only operating and maintenance costs.

If we could fully protect and restore urban water sources, we could also generate benefits beyond water quality improvements, such as:

Improving the health and well-being of

**>1 billion people**



Reducing the impacts of climate change - such as floods, fire and erosion



Restoring forests that could help reduce the risk of regional extinctions for

**5,400 animal species**



Storing or capturing

**10 gigatonnes of CO<sub>2</sub>** each year



Water funds enable downstream water users—like cities, businesses and utilities—to invest in upstream land management to improve water quality and quantity and generate benefits for people and nature. You can be part of the solution.



Visit [www.nature.org/beyondthesource](http://www.nature.org/beyondthesource) to learn more

©The Nature Conservancy, 2016



Our aspirations for a better world require  
collective action. All of us have a role to play.



Photo: © Erika Nortemann

# Appendices

## Appendix I: International Policy Processes that Include Water

### The Paris Agreement

There is no direct reference to water in the Paris Agreement. However, given water's key role for mitigation and adaptation, the climate policy architecture underpinning it, including COP-decisions, should relate to water where relevant. The adaptation component of the Nationally Determined Contributions (NDCs) provides an opportunity for countries to outline current and future actions to improve water security. Water is at the forefront of the NDCs; 92 percent of them include water as a priority.

*For more information:*

<http://www.endwaterpoverty.org/blog/paris-agreement-and-cop-21-what-are-outcomes-water>

### Nairobi Work Programme (NWP)

The Subsidiary Body for Science and Technological Advice (SBSTA) gave the Nairobi Work Programme (NWP) the mandate to investigate ecosystems and interrelated areas such as water resources and adaptation (Mandate on Water Resources and Adaptation). It serves as a submission platform where parties, NWP partners and other relevant organizations will submit recent activities and research, including good practices, lessons learned, available tools and methods before January 25, 2017.

*For more information:*

<http://www4.unfccc.int/sites/NWP/Pages/water-page.aspx>

### UN-Habitat

With a mandate to promote socially and environmentally sustainable towns and cities, UN-Habitat provides both policy, technical and financial support to governments and local authorities through its high priority water and sanitation (WATSAN) programme. Now under the responsibility of its Urban Basic Services Branch, the programme was set up to help the UN member states attain the water and sanitation targets set by the MDGs and World Summit on Sustainable Development (WSSD). It has also

established the Water and Sanitation Trust Fund (WSTF) which currently supports water and sanitation projects in 27 countries (as of 2012) involving a wide range of partners, including families, communities, governments and like-minded organizations. Nearly 70 percent of the world's population will be urban by 2050.<sup>672</sup> Recognizing this societal shift, 2016's UN HABITAT brought governments, corporations and civil society together to embark on a vision for a new urban agenda to ensure that cities will become and are designed with inclusivity, sustainability and resiliency in mind.

*For more information:*

<http://unhabitat.org/urban-themes/water-and-sanitation-2/>

### UN-Water

Formalized in 2003 by the United Nations High Level Committee on Programmes, UN-Water is the United Nations inter-agency coordination mechanism for all freshwater-related issues, including sanitation. It provides a platform to address the cross-cutting nature of water and maximize system-wide coordinated action and coherence. UN-Water is an advocate for water security investment as a long-term payoff for human development and economic growth, with immediate visible short-term gains.

*For more information:*

<http://www.unwater.org/home/en/>

### Convention on Biological Diversity (CBD)

The UN Convention of Biological Diversity Strategic Plan for Biodiversity (2011-2020) includes 20 targets, known as Aichi Targets. Aichi Target 14 calls for action to ensure "ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded." A recent study noted that, globally, 80 percent of the downstream human community users receive water from upstream protected areas under high threat.<sup>673</sup> Meeting Aichi target 14 will require strengthened coordination among protected area management systems, development planning processes in large landscapes with multiple water users and financing to sustain the essential services a biodiverse landscape provides.

# Appendix II: Assessment of Urban Source Watershed Map Accuracy

## Preamble

The following assessment is an attempt to judge the accuracy and adequacy of the modeling approach to derive urban watersheds that represent actual water source areas of cities. It is important to note, however, that the modeled urban watershed map is not intended to predict true and precise locations of where each city of the world gets its water. Achieving this would be an arduous task, as every city is unique in its decision of how to supply its water. Some cities have ample choices, such as surplus water from multiple nearby rivers and watersheds, and they only select a subset. Others may have developed water provisioning systems tapping into groundwater aquifers to ensure higher quality water. Yet others may have opted for the construction of reservoirs and/or long-distance water transfers or mixed systems. These individual choices cannot be modeled with the presented, physically-based approach but would require manual supervision in identifying each city's unique information such as done in the Urban Water Blueprint (UWB) project for the largest global cities.<sup>674, 675</sup>

Instead, the modeled urban watershed map should be interpreted as an attempt to estimate where surface water resources exist in close vicinity to cities. These locations are easily accessible (in terms of distance) and thus suitable options for cities to get at least a certain proportion of their water, if required. Even if they are not used at this time, some of the identified watersheds may present options for future development. For example, Vancouver, Canada, is currently providing its water from several small local watersheds, but discussions exist about adding the much larger source of the Fraser River Basin to cope with possible future increases in demand. Considering all these caveats, the modeled urban watershed map should not be interpreted as predictive, but rather as a probability map of easily available water. Also, it should be noted that wherever UWB watersheds exist, they were used instead of modeled watersheds, thus the global urban watershed map only contains modeled results for smaller cities.

Notwithstanding the arguments above, in order to judge the general predictive ability of the modeled urban watershed map, a comparison was conducted between the manually allocated UWB watersheds and watersheds that would be derived using the urban watershed methodology (see Appendix V for methods). The UWB watersheds are assumed to be correct and exhaustive for the purpose of this comparison, which

is not warranted in every single instance. Also, a proper interpretation of UWB watershed outlines remains difficult in some cases. For example, Yangon, Myanmar, draws most of its water from several nearby reservoirs, which are correctly mapped in UWB, but also draws a small amount of its water supply from locations within the very large "Ayeyarwady River Basin" (also known as the Irrawaddy River Basin). As these locations are not clearly specified, UWB reports a very large overall water source area for Yangon although the vast majority of its water is supplied from the small watershed areas of its reservoirs.

## Snapping distances

A first source of uncertainty when modeling most-likely urban watershed areas is the requirement to snap the provided city point locations (from the Global Rural-Urban Mapping Project, or GRUMP) to representative locations on the river network (HydroSHEDS). For this step, it was postulated (see above) that cities generally draw water from the largest river nearby and that larger cities have more capacity (and size) to reach further out. The snapping distances—ranging from 10 kilometers for cities below 500,000 people to 20 kilometers for cities larger than 1 million people—were chosen to reflect reasonable city diameters and were informed by findings of the UWB project,<sup>676</sup> which investigated the geographical limitations of obtaining water for different city sizes and income levels. McDonald, et al., (2014) found that 80 percent of large cities travel 22 kilometers to reach an unstressed water source of at least 1,000 million liters per day (MLD) which is a common volume for a city of several million people. They also showed that 80 percent of large cities would have to travel 10 kilometers to reach a source of 100 MLD. The chosen snapping distances are thus considered reasonable estimates for the given task.<sup>677</sup>

## Quantitative comparison of watershed extents between UWB and model results

To judge the reliability of the new watershed delineation method, a quantitative comparison was conducted between the existing city watersheds provided by UWB and those derived with the new modeling approach. A total of 391 UWB cities were identified for which corresponding GRUMP data existed (the remaining UWB cities were below the 100,000 population threshold used in the GRUMP city selection). For these 391 cities, the same watershed modeling method was applied as outlined in the methods (see Appendix V). Some of these cities had multiple watersheds, either due to multiple water intake locations in the UWB, or due to multiple suburbs belonging to one city in GRUMP. In case of multiple watersheds, the watershed polygons were merged to form one water source area per city.

The total urban watershed area according to UWB for the 391 cities is 67.7 million square kilometers, while the modeled watersheds resulted in 50 million square kilometers. The underestimation of 26 percent can largely be attributed to cities with water transfer systems that reach beyond 20 kilometers. It should be noted, however, that GRUMP also represents 15 percent less total urban population in these 391 cities (697 vs. 819 million), possibly indicating that fewer city suburbs were included in the modeling approach than in UWB.

When analyzing all 391 cities, 92 of them (24 percent) showed watersheds with at least 90 percent matching areas, indicating a very high agreement. Another 81 cities (21 percent) showed modeled watershed areas that matched within a factor of two (i.e., more than half and less than double the extent) from UWB watersheds, revealing some larger discrepancies, yet still reasonable overall spatial alignment. Finally, another 88 cities (23 percent) showed watersheds that differed within one order of magnitude (one-tenth to 10-fold) from the UWB values, indicating some severe spatial mismatches, yet still at similar scales. The remaining 130 cities (one-third of all tested cities) showed discrepancies of more than one order of magnitude, including entirely different watersheds such as those where water transfers reach beyond 20 kilometers.

In order to find further patterns in the quality of the modeled watersheds, the sample was restricted to only those 80 cities that have a population of less than 1 million (as larger cities are more likely to reach far to get their water) and that have only one water intake location according to UWB (in order to remove the

more complex urban water systems). This restriction increased the percentage of cities with watershed areas that matched within a factor of 2 to 54 percent. Finally, if those cities with watersheds smaller than 10,000 square kilometers are removed (as smaller watersheds are more prone to large percentage errors), the sample size is reduced to 45 cities. Of these, 64 percent match with UWB watersheds within a factor of two, and 73 percent match within an order of magnitude.

In conclusion, it is difficult to provide a precise interpretation of the findings given the multitude of possible causes for the discrepancies. It is clear that a modeled urban source watershed map cannot predict all unique city water sources, transfer schemes, or outliers. Nevertheless, the modeling approach produced a large amount of very good and reasonable estimates of watershed areas, with two-thirds of tested cities agreeing at least within an order of magnitude. Also, the developed method performed increasingly well in identifying the less complex water provisioning systems of smaller cities. This is an important observation as the larger and more complex water supply systems are covered by the UWB in the global urban watershed map. Finally, it could be argued that mismatches between modeled and UWB watersheds may suggest likely alternative and/or future options for a given city.

## Appendix III: Additional Results by Region

Water depletion: Percent of area in WaterGAP basins that intersect with source watersheds				
Geographic Region	>75% Average Annual Depletion	Seasonal Depletion	Dry-Year Depletion	>75% Average Annual, Seasonal, and Dry-Year Depletion
Africa	1%	6%	17%	25%
Asia	5%	24%	14%	43%
Europe	0%	6%	7%	13%
Latin America and the Caribbean	0%	1%	7%	9%
North America	5%	17%	20%	43%
Oceania	0%	0%	22%	22%
<b>Global</b>	<b>2%</b>	<b>11%</b>	<b>13%</b>	<b>27%</b>

**Table AIII.1.** Water depletion across urban source watersheds (Chapter 2; Appendix V – 1.4)

Geographic Region	Carbon stored in above-ground tropical biomass (Gt C)
Africa	43.83
Asia	28.92
Latin America and the Caribbean	70.43
<b>Pan-tropical</b>	<b>143.18</b>

**Table AIII.2.** Standing carbon held in above-ground tropical biomass in urban source watersheds (Chapter 3; Appendix V – 1.7)

Geographic Region	Avoided Tropical Carbon Emissions (Mt C yr <sup>-1</sup> )			Additional Soil Carbon Sequestration (Mt C yr <sup>-1</sup> )			Additional Forest Carbon Sequestration (Mt C yr <sup>-1</sup> )		
	10% reduction sediment yield	10% reduction phosphorus yield	Maximum potential	10% reduction sediment yield	10% reduction phosphorus yield	Maximum potential	10% reduction sediment yield	10% reduction phosphorus yield	Maximum potential
Africa	55.40	0.50	97.21	7.42	2.64	17.87	9.33	11.51	148.11
Asia	0.58	5.68	131.11	1.93	30.00	55.56	3.87	115.43	960.55
Europe	0.25	0.06	4.64	2.85	10.58	14.25	5.32	29.39	189.50
Latin America and the Caribbean	2.65	3.39	331.98	3.69	20.67	24.74	13.70	32.26	609.00
North America	0.48	4.13	35.83	0.37	17.43	10.44	2.71	18.60	120.65
Oceania	0.04	0.00	2.10	0.03	0.20	0.64	0.35	0.57	16.94
<b>Global</b>	<b>59.40</b>	<b>13.77</b>	<b>602.87</b>	<b>16.28</b>	<b>81.52</b>	<b>123.51</b>	<b>35.28</b>	<b>207.76</b>	<b>2,044.75</b>

**Table AIII.3.** Climate change mitigation potential (Chapter 3; Appendix V - 1.8)

Geographic Region	Precipitation (2046-2065)		Erosivity (2046-2065)	Fire Probability (2010-2039)
	Predicted increase (percent of area within source watershed)	Predicted decrease (percent)	Predicted increase (percent)	Predicted increase (percent)
Africa	84	15	83	19
Asia	88	12	89	27
Europe	57	43	69	38
Latin America and the Caribbean	48	51	85	19
North America	89	11	78	31
Oceania	25	74	69	23
<b>Global</b>	<b>74</b>	<b>26</b>	<b>83</b>	<b>24</b>

**Table AIII.4.** Predicted changes in fire risk, precipitation and erosivity across urban source watersheds (Chapter 3; Appendix V - 1.9-1.11)

<b>Geographic Region</b>	<b>Average percent of vitamin A demand satisfaction lost</b>	<b>Average percent of iron demand satisfaction lost</b>	<b>Percent of agricultural value lost</b>
Africa	21%	8%	3%
Asia	23%	8%	5%
Europe	44%	6%	3%
Latin America and the Caribbean	23%	10%	7%
North America	26%	14%	13%
Oceania	43%	8%	13%
<b>Global</b>	<b>26%</b>	<b>8%</b>	<b>5%</b>

**Table AIII.5.** Average percent of vitamin A production, iron production, and agricultural economic value lost in the absence of pollination service (Chapter 3; Appendix V – 1.13)

<b>Geographic Region</b>	<b>Freshwater Biodiversity Threat</b>			<b>Forest Loss</b>		
	<b>Low threat (Percent of area within source watershed)</b>	<b>Medium threat (percent)</b>	<b>High threat (percent)</b>	<b>Percent forest loss (2001 – 2014)</b>	<b>Forest loss (ha)</b>	<b>Average annual percent loss</b>
Africa	1	55	26	2.99	9,844,053	0.22
Asia	20	51	22	5.14	33,649,273	0.38
Europe	0	5	76	6.15	7,456,006	0.45
Latin America and the Caribbean	0	20	68	5.41	13,795,318	0.40
North America	0	1	96	3.83	3,142,303	0.28
Oceania	0	10	36	8.71	298,749	0.65
<b>Global</b>	<b>5</b>	<b>34</b>	<b>48</b>	<b>4.72</b>	<b>68,185,702</b>	<b>0.34</b>

**Table AIII.6.** Freshwater biodiversity threat and forest loss (Chapter 3; Appendix V – 1.15, 1.16)

Rarety-weighted richness		
Geographic Region	Percent of freshwater ecoregions with high levels of species diversity (first quartile) in source watersheds	Percent of terrestrial ecoregions with high levels of species diversity (first quartile) in source watersheds
Africa	80 (24/30)	78 (35/45)
Asia	91 (32/35)	91 (52/57)
Europe	Not applicable—(0/0)	Not applicable - (0/0)
Latin America and the Caribbean	84 (27/32)	78 (73/93)
North America	85 (11/13)	100 (1/1)
Oceania	Not applicable—(0/0)	11 (1/9)
<b>Global</b>	<b>85 (94/111)</b>	<b>79 (161/204)</b>

**Table AIII.7 (A).** Biodiversity value levels (rarity-weighted richness) of freshwater and terrestrial ecoregions in urban source watersheds (Chapter 3; Appendix V – 1.17)

Imperiled Mammals			Imperiled Birds		Imperiled Amphibians		AZE Sites			IBAs		
Geographic Region	Number of species	Percent of all imperiled species in region	Number of species	Percent of all imperiled species in region	Number of species	Percent of all imperiled species in region	Number of AZE Sites	Percent of all AZE sites in region	Number of endangered species within AZE sites	Number of IBAs	Percent of all IBAs in region	Percent of IBAs in danger
Africa	108	36	83	38	108	38	49	30	49	421	35	47
Asia	220	56	221	61	279	69	80	57	80	1,510	49	44
Europe	13	65	1	20	6	32	2	33	2	1,878	40	43
Latin America and the Caribbean	178	58	325	67	610	54	293	58	293	756	45	38
North America	11	44	10	22	29	56	3	15	3	213	22	10
Oceania	7	7	10	5	15	24	4	7	4	24	5	4
<b>Global</b>	<b>537</b>	<b>47</b>	<b>650</b>	<b>50</b>	<b>1,047</b>	<b>54</b>	<b>431</b>	<b>47</b>	<b>431</b>	<b>4,777</b>	<b>39</b>	<b>39</b>

**Table AIII.7 (B).** Imperiled terrestrial species, Alliance for Zero Extinction Sites and Important Bird and Biodiversity Areas in urban source watersheds (Chapter 3; Appendix V – 1.18—1.20)

Imperiled Freshwater Fish		
Comprehensively Assessed Region	Number of species	Percent of all imperiled species in region
Africa	274	52
Eastern Mediterranean and Arabia	71	65
Europe	83	44
India, Eastern Himalayas and Indo-Burma	159	92
New Zealand and South Pacific Islands	0	0
The United States	106	67
<b>Global</b>	<b>680</b>	<b>59</b>

**Table AIII.7 (C).** Imperiled freshwater species in urban source watersheds (Chapter 3; Appendix V - 1.18)

Number of species		
Geographic Region	Regional savings	Global savings
Africa	2,167	23
Asia	833	4
Europe	115	0
Latin America and the Caribbean	1,336	17
North America	948	8
Oceania	9	0
<b>Global</b>	<b>5,408</b>	<b>52</b>

**Table AIII.8.** Potential for reforestation and landscape restoration to avoid regional and global extinctions (Chapter 3; Appendix V - 1.21)

Geographic Region	Country count	Number of countries that reach 17% PA target	Percent of countries that reach 17% PA target	Number of countries that overlap with source watersheds	Area of PAs (hectares)	Number of overlapping countries that currently reach the PA target	Number of additional overlapping countries that could meet PA target	Percent of remaining natural cover outside PAs required for the 44 countries to meet PA target	Number of countries under each bin representing the percent of natural land in urban source watersheds needed to meet 17% PA target						No overlap with source watersheds
									>0 - 10%	>10 - 25%	>25 - 50%	>50 - 100%	>100%		
Africa	58	26	45%	46	467,309,221	22	16	16%	8	5	0	3	8	8	
Asia	56	19	34%	40	354,798,459	15	15	40%	0	6	4	5	10	12	
Europe	51	26	51%	37	284,415,061	21	7	34%	2	0	3	2	9	9	
Latin America and the Caribbean	51	20	39%	25	547,196,330	13	5	20%	1	1	1	2	7	19	
North America	6	0	0%	2	224,986,147	0	1	12%	0	1	0	0	1	4	
Oceania	25	3	12%	3	145,214,917	2	0	0%	0	0	0	0	1	21	
<b>Global</b>	<b>247</b>	<b>94</b>	<b>38%</b>	<b>153</b>	<b>2,023,920,135</b>	<b>73</b>	<b>44</b>	<b>20%</b>	<b>11</b>	<b>13</b>	<b>8</b>	<b>12</b>	<b>36</b>	<b>73</b>	

Table AIII.9 (A). Present levels of protected area by country (Chapter 3; Appendix V – 1.22)

Geographic Region	Percent of global Intact Forest Landscape that falls within region's source watersheds
Africa	6.4
Asia	1.4
Europe	0.0
Latin America and the Caribbean	27.8
North America	0.4
Oceania	0.0
<b>Global</b>	<b>36.0</b>

Table AIII.9 (B). Percent of current Intact Forest Landscape within source watersheds by region (Chapter 3)

Geographic Region	Annual excess nitrogen application in source watersheds (megatonnes)	Percentage of total nitrogen export from source watersheds
Africa	1.12	2.98
Asia	26.73	71.03
Europe	2.77	7.36
Latin America and the Caribbean	2.01	5.34
North America	4.95	13.15
Oceania	0.054	0.14
<b>Global</b>	<b>37.63</b>	<b>100</b>

Table AIII.10. Total annual excess nitrogen application (Chapter 3; Appendix V – 1.23)

# Appendix IV: Foundational Frameworks and Approaches for Water Funds— Supplement to Chapter 4

## OECD Principles on Water Governance

The OECD Principles on Water Governance provide an overarching framework to enhance water governance systems that help manage “too much,” “too little” and “too polluted” water in a sustainable, integrated and inclusive way, at an acceptable cost and in a reasonable time-frame. The 12 Principles set standards for more effective, efficient and inclusive design and implementation of water policies. These Principles were developed through a bottom-up approach and multi-stakeholder process within the OECD Water Governance Initiative (WGI), an international network of 100-plus public, private and not-for-profit stakeholders gathering twice a year in a Policy Forum to share experiences on water reforms, peer-review analytical work on water governance and guidance on water governance reforms. Since their adoption, the OECD Principles on Water Governance have been backed by OECD and non-OECD countries and over 140 stakeholder groups,<sup>65</sup> of which gathered through the Daegu Multi-stakeholder Declaration on the OECD Principles, released at the 7th World Water Forum (Daegu & Gyeongbuk, Republic of Korea, 2015).<sup>678</sup> All of these stakeholders are now part of the Global Coalition for Good Water Governance. Moving forward, the WGI will support the implementation of the Principles through the collection of best practices and the development of Water Governance Indicators to measure whether framework conditions are in place, as well as to measure progress and impacts.<sup>679</sup>

## A systems approach to water security

Simply defined, a system is “a group of related parts that move or work together.”<sup>680</sup> Scholars have argued that a systems approach to sustainable development includes consideration of ecological, economic or industrial, social, and political factors as “parts” that impact and interact with one another.<sup>681, 682</sup> By following a systems approach, no single factor is viewed or addressed in isolation. Instead, the interconnectedness, risk, uncertainty and resilience of the system are explicitly considered when managing the system.

Here we put key elements of a systems approach in the context of water security:

- **Interconnectedness** is a recognition of how the multiple components of a system interact and have one or more feedback loops among other parts of the system.<sup>683, 684, 685</sup> Beyond recognition of the dynamic biophysical connections between land-based activities and downstream water quality and quantity, achieving water security will require investments in water management both in infrastructure and in institutions and communities that manage water across various needs and goals.<sup>686</sup>
- **Resilience** can be defined as the ability of a social-ecological system’s capacity to absorb disturbances, self-organize, learn and adapt in the face of environmental and other forms of shocks or change.<sup>687</sup> Responsive and adaptive water management will be critical to reaching and sustaining multiple objectives in the future.<sup>688</sup>
- **Risk and uncertainty** is a component of complex systems given continual dynamic changes by parts and the system as a whole through time and space. Good data and information are needed to help understand these dynamic processes in order to better predict and manage change. Currently, most watershed managers lack the basic information necessary for monitoring water system changes and there is a need for better data monitoring in order to effectively manage these systems.<sup>689</sup>

## Adopting a rights-based approach

Source water protection and human rights are intricately linked. On the one hand, conserving and restoring watershed services and other ecosystem benefits is important to ensuring social, cultural and economic rights—such as the right to health and the right to clean water—for both upstream and downstream actors. However, history has shown that conservation efforts that exclude local people from their lands and natural resources can undermine basic human, civil and political rights.<sup>690, 691</sup> At the same time, these inequitable policies and programs often fail to achieve conservation objectives as conservation efforts are most likely to succeed when supported and co-designed by local people who feel that their rights are being protected and that they are benefitting in a meaningful way.<sup>692</sup> Water funds as governance mechanisms that seek to protect source watersheds for people and nature in an effective, efficient and equitable manner are in a unique position to move forward thinking and practice on integrating human rights and conservation.

In response to growing awareness of both the ethical and practical importance of protecting biodiversity, ecosystem services and human rights in an integrated way, development, business, forestry and conservation sectors are increasingly seeking to adopt a Right’s Based Approach (RBA).<sup>693</sup> Implementing this approach in a complex world is no easy task and projects from around the world are working toward

improving these approaches and learning from each other. In a recent review by IUCN and CIFOR of efforts to implement an RBA, they conclude that, while there is no one-size-fits-all approach, sound governance systems that outline procedures for upholding rights and duties is of central importance to these efforts.<sup>694</sup> It is widely agreed that RBAs should not just respect rights, but should “support their further realization where possible.”<sup>695</sup> This would include, for example, incentive structures that help local communities secure tenure and resource access rights.

Respecting and supporting the use and perpetuation of traditional knowledge, access and practice by Indigenous and other local communities is central to a rights-based approach. Protecting land, access and use rights is a water fund’s ethical responsibility, but also can make these programs more successful and sustainable. Indigenous and

other local communities have taken care of their lands and waters for generations and traditional knowledge and practices can offer place-based watershed protection mechanisms that provide socio-cultural, economic and ecological values. Traditional water conservation mechanisms like the mamanteo system in the highlands of Lima, which regulate water supplies, are common throughout the world and can be usefully combined with other source watershed protection activities.<sup>696</sup> Ultimately, water funds should aim to empower and amplify the rights of Indigenous and other rural land stewards to protect and tend to their lands—using traditional and new management strategies—for multiple socio-cultural, economic and environmental benefits. Social impact assessments that plan, evaluate and adapt programs in a participatory manner with local communities should be central to designing, implementing and evaluating a water fund’s progress.<sup>697</sup>

# Appendix V: Methods

In the following section, we document the methods for all the analyses completed for this report. All the analyses documented in this appendix were completed using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. The sources of key publications are listed under each section below. All maps are made with Natural Earth. Free vector and raster map data @ [natural-earth-data.com](http://natural-earth-data.com).

## 1.1 Global map of urban source watersheds

### Data

There are four main data sources used to identify source watershed areas: hydrological data, global city data, surface water withdrawal locations for cities and HydroBASIN-derived modeling data.

Hydrological data comprises the flow direction, flow accumulation (i.e., watershed size) and discharge grids provided by the HydroSHEDS database at 15 arc-second (approx. 500 meters at the equator) pixel resolution (Lehner and Grill, 2013). All watershed boundaries were calculated from this data.

The second data source comprises the global city locations and population numbers taken from the Global Rural-Urban Mapping Project (GRUMP), obtained from the Center for International Earth Science Information Network (CIESIN, et al., 2011). The original vector data contains 67,935 points representing cities recorded with various attributes, including population estimates, valid as of the year 2000.

The third data source comprises the water intake locations for cities obtained from The Nature Conservancy's Urban Water Blueprint (UWB) project and its underpinning City Water Map (CWM) (McDonald, et al., 2014). This dataset originally contained 471 global cities with 1,505 unique intake locations.

The final data source comprises information on HydroBASIN-derived watersheds from source watershed protection models. The Watershed Conservation Screening Tool models non-atmospheric nonpoint sediment and nutrient (phosphorus) yields, and the potential for selected conservation practices to reduce these yields. This dataset includes more than 1 million watersheds with at least partial coverage across all continents (excluding Antarctica).

Importantly, these data sources focus only on potential surface water sources for cities. These data and related analyses do not consider implications of other water sources, most notably groundwater.

### Methodology

#### City selection criteria

All cities of the world with a reported population of at least 100,000 people in the GRUMP database were used. Additionally, we used all CWM cities with surface water intakes and their intake locations.

#### City Water Map cities

The database of the City Water Map (CWM) originally contained 471 cities with 1,505 intake locations. The point locations of CWM intake points represent manually assigned withdrawal points that were snapped to the HydroSHEDS river network. However, 12 locations did not have data on withdrawal points or city names and were thus removed, resulting in 1,493 unique withdrawal locations.

#### GRUMP cities

The global GRUMP data used in this project also contained the same cities and suburbs of the urban agglomerations included in the CWM. These duplicated cities were manually identified and removed in order to eliminate double-counting of cities. After applying the 100,000-population threshold and removing the duplicate cities, 3,724 cities remained.

For all GRUMP cities, the precise water intake location was not known. In order to estimate most likely locations, two criteria were postulated: 1) that cities generally draw water from the largest river nearby; and 2) that larger cities have more capacity and size to reach further out. In order to simulate these criteria, the GRUMP cities were separated into three groups based on population size and then snapped to the highest flow accumulation value (i.e., the largest watershed size as given in the HydroSHEDS database) within a size-dependent distance (see Table AV.1). The snapped points were then assumed to represent the water intake locations of the GRUMP cities.

Population	Snapping Distance (decimal degrees)
100,000 - 500,000	0.10 (~10 km)
500,000 - 1,000,000	0.15 (~15 km)
>1,000,000	0.20 (~20 km)

**Table AV1.** Snapping distances for the GRUMP city locations

#### Combined CWM and GRUMP intakes

The snapped GRUMP points (3,724) and UWB withdrawal points (1,493) were then combined to create the final combined layer of potential intakes, containing 5,217 points. If two points were located within the same pixel of the HydroSHEDS flow direction grid, the point with the higher identifier was shifted one pixel downstream.

#### Final watershed layer

Each intake point was then mapped to its enclosing Level 12 HydroBASIN unit. For each of these HydroBASIN units, the Watershed Conservation Screening Tool has a corresponding polygon which includes all upstream HydroBASIN units. In this manner, each intake point is then associated with a corresponding polygon representing the entire upstream contributing area or watershed for that intake point. For all intake points, this HydroBASIN derived watershed differs in spatial extent from a watershed that might be derived using the precise intake point in conjunction with elevation data. These discrepancies are usually minor, but can be significant for smaller watersheds. Cities outside the spatial extent of the Screening Tool data set were excluded from subsequent analyses. The final watershed layer includes a total of 4,546 watersheds representing surface water sources for 4,138 cities.

#### References

Center for International Earth Science Information Network (CIESIN), Columbia University; International Food Policy Research Institute (IFPRI), the World Bank; and Centro Internacional de Agricultura Tropical (CIAT). (2011). Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Settlement Points. Socioeconomic Data and Applications Center (SEDAC), Columbia University, Palisades, New York. Available from <http://sedac.ciesin.columbia.edu/data/dataset/grump-v1-settlement-points>.

Lehner, B. and Grill, G. (2013). Global River Hydrography and Network Routing: Baseline Data and New Approaches to Study the World's Large River Systems. *Hydrological Processes* **27**: 2171–2186.

McDonald, R.I. (2016). EcoLogic--The Watershed Conservation Screening Tool: A Resource for Large Water Users. *Journal-American Water Works Association* **108**: 18-20.

McDonald, R.I., Weber, K., Padowski, J., et al., (2014). Water on an Urban Planet: Urbanization and the Reach of Urban Water Infrastructure. *Global Environmental Change* **27**: 96-105.

## 1.2 Human Modification (HM)

We examined the extent to which humans have modified the landscape within the source watershed regions. This analysis aims to evaluate how much of the source watershed area has been highly, moderately or lightly impacted by humans. The extent to which the landscapes within the source watersheds have been modified by humans leads to differences in how the land should be managed to either protect or restore the quality of water resources in the region.

Oakleaf (2016) created a global dataset of Human Modification (HM) using methods that are similar to Theobald's (2013) U.S.-continental human modification index. First, Oakleaf estimated the degree of impact associated with 13 different indicators of human modification. Second, he multiplied each indicator by its respective intensity value. Lastly, he produced a cumulative measure of human modification by combining individual human modification values for each indicator using a fuzzy-sum algorithm (Theobald, 2013). The impacts evaluated in this measure fall under various categories, including human settlement, agriculture, transportation and service corridors, mining, energy production and other types of infrastructure development. The final HM product is a global dataset with continuous coverage and values scaled between zero and one with higher values indicating more human modification relative to lower values.

In order to classify the HM into categories of high, medium and low modification, we use two equally distributed breakpoints (0.66 and 0.33, respectively) because the HM values are already normalized between zero and one. We calculate the percent of the source watershed with high, medium and low modification within each continental region. The human modification data are visualized with the source watersheds by summarizing the average HM values for each Level 5 HydroBASIN that lies within the source watershed region.

## References

- Oakleaf, J.R. (2016). Human Modification. Unpublished data. Retrieved from Jim Oakleaf, The Nature Conservancy (accessed July 2016).
- Theobald, D. M. (2013). A General Model to Quantify Ecological Integrity for Landscape Assessments and US Application. *Landscape Ecology* **28**:1859–1874. doi: 10.1007/s10980-013-9941-6

## 1.3 Sediment and nutrient loading in source watershed areas

Information on sediment and nutrient loading was adapted from data developed previously by the Conservancy (McDonald and Shemie, 2014). Briefly, sediment loading is estimated using the Universal Soil Loss Equation (USLE). Data sources, input factors and approach follow those reported previously (McDonald and Shemie, 2014). Nutrient loading was estimated using an export coefficient approach, where each land-cover type exports a certain amount of nitrogen or phosphorus from a given pixel. In practice, nitrogen and phosphorus export are highly correlated at large scales and we report here values for phosphorus. Comparing our phosphorus results with nitrogen values derived as part of other analyses (Appendix V – 1.23) similar patterns emerge across watersheds and regions. The approach for export coefficient and nutrient application rates follow those reported previously (McDonald and Shemie, 2014).

In Chapter 2 of this report, we present sediment and phosphorus loading values as estimated at the level of individual land cover pixels (15 arc-seconds). Area normalized loading values (metric tons per hectare and kilograms per hectare for sediment and phosphorus, respectively) are presented in aggregate at the scale of Level 5 HydroBASIN units. Importantly, these values represent estimated sediment and nutrient loads that could be exported from a given pixel. For any given pixel, only a fraction of the exported sediment or nutrient would be predicted to enter the stream network. Information on such predicted sediment or nutrient yields is utilized for the portfolio analysis reported elsewhere.

Note that these loading estimates are for non-atmospheric, landscape-based nonpoint sources only and do not include other point and nonpoint sources of pollution, which can be significantly greater in some locations.

## References

- McDonald, R.I. and Shemie, D. (2014). Urban Water Blueprint: Mapping Conservation Solutions to the Global Water Challenge. The Nature Conservancy, Washington, D.C., USA. <http://water.nature.org/waterblueprint>

## 1.4 Water depletion

At the regional and global levels, we determined the number, area and percent of WaterGAP basins (CESR) occurring within source watersheds that are over 75-percent depleted on an average annual basis, or are depleted by more than 75 percent seasonally or in dry-years.

The data used in the analysis are a product of the Brauman, et al., (2016) study. This study created a water scarcity metric called water depletion, which is a measure of the fraction of renewable water availability that is consumed for uses such as irrigation, livestock, energy, domestic, etc. The metric is different from other measures of water scarcity in that it considers not just an annual average, but inter- and intra-annual variation in the availability-to-consumption ratio. The metric integrates monthly and yearly variations into the scale by adding dry-year and seasonal water depletion categories (Table AV.2) to a scale based on annual averages. The study classified a global dataset of water basins (WaterGAP3) according to availability and consumption model outputs. Watersheds were placed into six categories as displayed in the table below.

Category	Description
<5%	Watersheds that experience an annual average depletion of less than 5%
5-25%	Watersheds that experience an annual average depletion of between 5-25%
Dry-Year	Watersheds that experience an annual average depletion of less than 75%, however, at least one month in the year experiences over 75% depletion in at least 10% of years
Seasonal	Watersheds that experience an annual average depletion of less than 75%, however, at least one month in the year experiences over 75% depletion
75-100%	Watersheds that experience an annual average depletion of 75-100%
>100%	Watersheds that experience an annual average depletion of greater than 100% (when groundwater is accessed or water is imported)

Table AV.2. Description of water depletion categories derived from Brauman, et al., 2016

Categories 25 to 50 percent and 50 to 75 percent average annual water depletion do not exist because all watersheds falling into these categories demonstrated either dry-year or seasonal water depletion. For the purposes of our analysis, we combined the 75 to 100 percent and >100 percent categories (based on the 75-percent threshold used for the dry-year and seasonal depletion categories) into one category called annual depletion. We calculated statistics for the following water scarcity categories: >75 percent average annual depletion, seasonal depletion and dry-year depletion.

First, we identified WaterGAP3 basins whose centroid falls within the source watersheds. We then determined the number and area of selected basins for each water scarcity category within each region. For each region, the percent of the source watershed area that falls into each of these categories was also calculated by dividing the area of WaterGAP3 basins that intersect source watersheds within each depletion category by the total area of all WaterGAP3 basins that intersect source watersheds for that region. Because no basin was placed into more than one region, we were able to sum the regional numbers to calculate the same statistics at the global level.

In total, the Brauman, et al., (2016) study categorized 15,091 waterGAP3 basins that covered 90 percent of land globally. They eliminated polar regions and Greenland for data reliability reasons, and watersheds smaller than 1,000 square kilometers, mostly small coastal basins, were also excluded from the database. Therefore, where WaterGAP3 data did not exist, corresponding source watersheds were left without water-depletion information. This affects Oceania results more than any other region, because it is made up of many islands and has a high proportion of small coastal basins. However, even in Oceania, the proportion of source watersheds along the coast is negligible. Moreover, most of the smaller islands of Oceania fall into the <5 percent annual depletion category, thus it is unlikely that, where data are missing, a watershed would have been classified in one of the three water scarcity categories.

## References

Brauman, K. A., Richter, B. D., Postel, S., Malsy, M., and Flörke, M. (2016). Water Depletion: An Improved Metric for Incorporating Seasonal and Dry-Year Water Scarcity into Water Risk Assessments. *Elementa: Science of the Anthropocene* **4**: 000083. doi: 10.12952/journal.elementa.000083

Center for Environmental Systems Research (CESR). WaterGAP. CESR, University of Kassel, Germany. Available from <http://www.uni-kassel.de/einrichtungen/en/cesr/research/projects/active/watergap.html> (accessed March 2016).

EarthStat. Water Depletion and WaterGAP3 Basins. EarthStat.org, Global Landscapes Initiative, University of Minnesota and Ramankutty Lab, The University of British Columbia, Vancouver. Data available online from <http://www.earthstat.org/data-download/>

## 1.5 Sediment and phosphorus reduction–portfolio analysis

To assess the potential for realizing water quality benefits resulting from source watershed protection activities, we use an approach similar to that described previously (McDonald and Shemie, 2014). For each watershed in our dataset, we identify the cost-optimal conservation area required to achieve a given pollution reduction target (e.g., the cost of achieving a 10 percent reduction in sediment). Then, we aggregate these watershed-level results to obtain global estimates of the total conservation action required to achieve these targets.

### Modeling conservation activities

Previously, the Conservancy reported on the potential for certain types of source water protection activities to reduce the sediment and phosphorus pollution in watersheds (McDonald and Shemie, 2014). Here, we extend this approach to consider the potential for a subset of activities to reduce sediment or phosphorus concurrently. We consider the reduction potential for three categories of land-based conservation activities: forest protection, pastureland reforestation and agricultural BMPs (modeled as cover crops).

### Estimating pollution loading

Estimates of sediment and phosphorus loading, and the change or reduction in loading resulting from source water protection activities, follow the approach described previously (McDonald and Shemie, 2014). Importantly, forest protection concerns mitigation of future risk. In order to facilitate comparative equivalency of reduction potential across all three activity types, we utilized a single modified estimate of baseline sediment and nutrient loading that incorporates estimates of the future risk of forest loss. Briefly, future loading for forest cover land types is assumed to be a function of both loading and the probability of forest loss, where deforestation probabilities were estimated from changes in forest cover at the scale of biomes (using the time-incremented, land-cover datasets GlobCover from the European Space Agency). In all cases, the deforestation pathway is assumed to result in a transition to pastureland.

## Calculating pollution yields and reduction potential

Using these loading estimates for each watershed within our global map of urban source watersheds, the predicted yields of sediment and phosphorus are derived at the watershed outlet. Predicted yields are obtained from the Watershed Conservation Screening Tool which uses an approach adapted from McDonald and Shemie (2014). The data utilized here in this analysis incorporate revisions that were later used in the Watershed Conservation Screening Tool ([www.watershedtool.org](http://www.watershedtool.org)), which include additional model refinements to further improve the calculation of predicted yields. In addition to accounting for overland attenuation of pollutants as done previously, the Screening Tool further accounts for instream attenuation of pollutants. This modification is expected to further improve predictive accuracy, particularly for large watersheds where instream attenuation can be significant. Model parameters were calibrated against measured water quality data collected for watersheds in the United States, as described in the Screening Tool documentation.

With estimates of predicted yields under baseline conditions and under implementation of the three source water protection activity types, we calculate the reduction potential for all relevant pixels for each practice type across a given watershed. This results in a curvilinear range of reduction values across a given watershed, with some pixels holding greater potential to reduce sediment or nutrient yields per unit area. We subsequently convert these curves to marginal cost curves using information obtained previously on estimated implementation costs across activity types and regions. Finally, we use simple one-dimensional optimization to identify the optimal marginal cost at which a given reduction target can be achieved.

## Analysis outputs

The primary output of this analysis is an estimate for each source watershed within our data set of the conservation implementation area needed to achieve a given pollution reduction target. For each watershed and each reduction target (e.g., 10 percent reduction in sediment), we derive values for the total area of implementation under forest protection, reforestation and agricultural BMPs. For some watersheds, the specified reduction target may not be achievable. In these instances, we do not record implementation area values, but we do include the spatial extent of these watersheds when determining the scope of potential.

For subsequent analyses, these activity area estimates are used to define possible implementation scenarios. For example, we estimate city-level costs and cost savings for achieving a 10 percent reduction in sediment or nutrients in Chapter 5. It is important to note that such scenarios are necessarily limited in scope. Here, we optimize for a single parameter (implementation costs) alone. A more robust – and more socially relevant – optimization approach would consider multiple parameters, as exemplified by the analysis of Colombia (Appendix V – 1.25). For this and other reasons, these results should be interpreted with discretion.

It is also important to note that this optimization is performed at the scale of watersheds. To derive global-level approximations from these watershed-level implementation scenarios, we incorporate conditional assumptions regarding implementation across these watersheds. Namely, given the non-spatial nature of our pollution yield estimates, we assume an equal probability of activity implementation across all relevant pixels for a given activity type. Where overlapping areas occur, we further assume implementation at the maximum area required for that overlapping area. This results in an approximated global view of conservation activity implementation in order to reach or exceed the specified reduction target.

## References

- Arino, O., Ramos Perez, J.J., Kalogirou, V., Bontemps, S., Defourny, P., Van Bogaert, E. (2012). Global Land Cover Map for 2009 (GlobCover 2009). European Space Agency (ESA) and Université catholique de Louvain (UCL). Available from [http://due.esrin.esa.int/page\\_globcover.php](http://due.esrin.esa.int/page_globcover.php) (accessed July 2016).
- McDonald, R.I. (2016). EcoLogic—The Watershed Conservation Screening Tool: A Resource for Large Water Users. *Journal-American Water Works Association* **108**: 18-20.
- McDonald, R.I. and Shemie, D. (2014). Urban Water Blueprint: Mapping Conservation Solutions to the Global Water Challenge. The Nature Conservancy, Washington, D.C., USA. <http://water.nature.org/waterblueprint>

## 1.6 Carbon emissions associated with clearing of above-ground live woody biomass

We estimated the annual carbon dioxide emissions to the atmosphere within our source watersheds across the tropics as a result of above-ground biomass loss, using tree biomass. The primary data source comes from 30-meter resolution biomass loss data (Zarin, et al., 2016), which was retrieved from the Global Forest Watch (GFW) Climate website ([climate.globalforestwatch.org](http://climate.globalforestwatch.org)).

Zarin, et al., (2016) calculated the annual rate of carbon emissions from gross deforestation between 2001 and 2014 by multiplying an estimate of the area of gross deforestation for each year by an estimate of the above-ground carbon content in the year 2000. The data combine gross deforestation estimates from Hansen, et al., (2013) with estimates of above-ground live woody biomass density derived using a methodology similar to Baccini, et al., (2012), but applied to 30-meter resolution Landsat data. By clipping the source watersheds to the tropical coverage of the Zarin, et al., data, we quantified the total amount of carbon dioxide emissions in the source watersheds for each year between 2001 and 2014.

The dataset makes several significant assumptions, which are outlined on the GFW Climate Website and by Zarin, et al., (2016). Briefly, the emissions estimates are considered “gross” estimates because the carbon value of the land is not assessed after clearing. Furthermore, the emissions estimates are considered “committed,” meaning that all the above-ground carbon is emitted to the atmosphere upon clearing.

### References

Baccini, A.G., Goetz, S.J., Walker, W.S., et al., (2012). Estimated Carbon Dioxide Emissions from Tropical Deforestation Improved by Carbon-Density Maps. *Nature Climate Change* **2**: 182-185. doi:10.1038/nclimate1354

Hansen, M.C., Potapov, P.V., Moore, R., et al., (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* **342**: 850-853. doi: 10.1126/science.1244693

Zarin, D.J., Harris, N.L., Baccini, A., et al., (2016). Can Carbon Emissions from Tropical Deforestation Drop by 50% in 5 Years? *Global Change Biology* **22**: 1336-1347. doi: 10.1111/gcb.13153

## 1.7 Standing forest carbon

We estimated the total pan-tropical, above-ground biomass stored in live woody vegetation within our urban source watersheds. The primary data used to quantify above-ground biomass comes from a high resolution product that expands upon the methodology presented in Baccini, et al., (2012) in order to generate a pan-tropical map of above-ground live woody biomass density at 30-meter resolution for the year 2000 (Baccini, et al., *in review*; Zarin, et al., 2016).

First, we calculated the total amount of above-ground biomass in live woody vegetation within the boundary of source watersheds that intersects with the tropical extent of the biomass data. We then converted the total estimate of above-ground biomass in our source watersheds into above-ground carbon using a conversion factor of 0.5 (IPCC, 2003), since about 50 percent of plant biomass consists of carbon.

To visualize the distribution of pan-tropical, above-ground biomass stored in live woody vegetation, we summarized the total amount of above-ground carbon stored in all Level 5 HydroBASINS that intersect with source watersheds.

### References

Baccini, A., Goetz, S.J., Walker, W.S., et al., (2012). Estimated Carbon Dioxide Emissions from Tropical Deforestation Improved by Carbon-Density Maps. *Nature Climate Change* **2**: 182-185.

Baccini A., Walker, W., Carvahlo, L., Farina, M., Sulla-Menashe, D., and Houghton, R. (2015). Tropical Forests are a Net Carbon Source Based on New Measurements of Gain and Loss. In review. Accessed through *Global Forest Watch Climate: Summary of Methods and Data* on July 22nd, 2016. [climate.globalforestwatch.org](http://climate.globalforestwatch.org).

Intergovernmental Panel on Climate Change (IPCC). (2003). Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC National Greenhouse Gas Inventories Programme, Hayama, Kanagawa, Japan. Available from [http://www.ipcc-nppgiges.or.jp/public/gpglulucf/gpglulucf\\_files/GPG\\_LULUCF\\_FULL.pdf](http://www.ipcc-nppgiges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf) (accessed July 2016).

Zarin, D.J., Harris, N.L., Baccini, A., et al., (2016). Can Carbon Emissions from Tropical Deforestation Drop by 50% in 5 Years? *Global Change Biology* **22**: 1336-1347. doi: 10.1111/gcb.13153

## 1.8 Climate change mitigation potential for ceiling and portfolio analyses

We evaluated the potential for source water protection activities to generate climate change mitigation benefits in addition to providing water security benefits. We measure the climate change mitigation potential for the following three source water protection activities: 1) forest protection; 2) reforestation; and 3) agricultural BMPs (implemented as cover crops). For each of the three activities we estimated the following:

- Climate change mitigation potential for the ceiling of maximum potential across urban source watersheds.
- Climate change mitigation potential that could be achieved based on the cost-optimal conservation area of the three activities required to reduce sediment and phosphorus yields by 10 percent across urban source watersheds (Appendix V – Section 1.5).

Broadly, the climate change mitigation potential for each source water protection activity is estimated by multiplying the area extent of the activity by the carbon flux for each unit of activity area. For reforestation and cover crops, the flux of carbon is quantified as additional sequestration while the flux of carbon is quantified as avoided emissions from targeted land protection to avoid forest conversion.

Below, we reference various literature sources where we retrieved and synthesized estimates for the carbon flux provided by each land-based activity.

To estimate the climate change mitigation potential for each source water protection activity, the area encompassing urban source watersheds was broken into non-overlapping units (sub-units) to sum the climate change mitigation potential globally and avoid double counting climate benefits where the original urban source watersheds overlap. For the ceiling of climate change mitigation potential, the non-overlapping sub-unit corresponds to Level 5 HydroBASINS clipped to the source watersheds. For the target-driven reductions in sediment and phosphorus, the sub-unit polygons correspond to the non-overlapping units that were used in the global level approximation to estimate conservation areas needed to achieve pollution reduction targets (Appendix V – Section 1.5). We identified source watershed sub-units in tropical, subtropical and temperate zones using the Food and Agriculture Organization's (FAO, 2002) dataset for global ecological zones. In the event that a source watershed sub-unit overlapped with more than one ecological zone, it was classified according to the zone with the greatest area of overlap.

### Forest protection (avoided forest conversion)

We determined an estimate for the amount of avoided tropical carbon emissions for every hectare of avoided forest conversion in our source watersheds using results from a study by Tyukavina, et al., (2015). We divide their estimate of annual gross biomass loss from tropical forests between 2001 and 2012 by the annual forest cover loss for the same years (138.3 tC ha<sup>-1</sup>). In the study, Tyukavina, et al., quantify both above-ground and below-ground biomass loss in the tropical forests. Our estimate of avoided forest loss also assumes a constant rate of forest loss based on historical data. Due to data constraints, we are limited to estimating the avoided carbon emissions from tropical and subtropical forests and do not consider emissions from other forests, such as temperate or boreal forests. While the avoided emissions from preventing temperate forest conversion might be comparatively less than tropical forests, the avoidance of temperate forest conversion could still provide a significant climate change mitigation potential that is not considered by this analysis.

The following two equations were used to measure the avoided carbon emissions that could be achieved through avoided tropical forest conversion in urban source watersheds by implementing forest protection at the two implementation levels. Equation 1 corresponds to the ceiling of mitigation potential, while Equation 2 corresponds to the mitigation potential determined by the cost-optimal conservation areas for sediment and nutrient reductions.

$$\sum_{i=1}^n \frac{L_i}{A_i} \times F_a \times P_i \quad (1)$$

$$\sum_{i=1}^n L_i \times F_a \quad (2)$$

Where i denotes each sub-unit of source watershed,  $L_i$  is the yearly average number of forest hectares that were lost between 2001 and 2014 (calculated in Google Earth Engine with data from Hansen, et al., 2013),  $A_i$  is the total number of forest hectares in the year 2000,  $F_a$  is the avoidable tropical carbon emission per hectare (tC ha<sup>-1</sup>), and  $P_i$  is the number of hectares under forest protection.

### Reforestation

To identify rates of additional carbon sequestration from reforestation, we used results from Bonner, et al., (2013) for accumulation rates of above-ground biomass in tropical forests and IPCC (2003) for accumulation rates of above-ground biomass in temperate forests. Both these studies identify rates of forest carbon sequestration for above-ground biomass, so we also apply a root-to-shoot ratio of biomass justified by Mokany, et al., (2006) to account for additional sequestration from below-ground biomass.

In order to measure the additional sequestration from tropical and temperate reforestation activities, we multiplied the number of reforestation hectares in each watershed sub-unit by their respective additional sequestration factor provided by temperate and tropical forests. Tropical forests have a larger flux factor because they sequester more carbon than temperate forests. We used the following equation to measure the climate change mitigation potential achieved through reforestation:

$$\sum_{i=1}^n F_{r,t} \times R_i \quad (3)$$

where  $i$  denotes each sub-unit of source watershed,  $F_r$  is equal to the additional carbon sequestration (temperate: 1.98 tC ha<sup>-1</sup> yr<sup>-1</sup>; tropical: 4.46 tC ha<sup>-1</sup> yr<sup>-1</sup>) achieved through reforestation in its respective temperate or tropical zone and  $R_i$  is equal to the number of reforested hectares.

For the estimates of climate change mitigation potential determined by 10 percent reductions in phosphorus and sediment, the reforested area ( $R$ ) is determined by the optimization exercise across all three activities described in Appendix V – Section 1.5. To measure the ceiling of climate change mitigation potential from reforestation in the urban source watersheds, we used data derived from WRI's Atlas of Forest and Landscape Restoration Opportunities (WRI, 2014) to determine a reasonable estimate for the maximum area of reforestation opportunity. Since our estimate for the additional amount of carbon sequestration is limited to reforestation in temperate and tropical forests, we applied two additional steps to extract only reforestation opportunities from WRI's data. First, we removed grassland ecosystems using a spatially explicit dataset of global grassland types (Dixon, et al., 2014). Then, we removed pixels of data that would not transition from a non-forested status to a forested status (here we define the transition from less than 25 percent tree cover to greater than 25 percent tree cover) (WRI, 2014).

### Cover crops (Agricultural BMPs)

When cover crops are introduced in agricultural crop rotations, they offer a climate change mitigation benefit by sequestering carbon in agricultural soils. We cite a meta-analysis by Poeplau and Don (2015) that finds that cover crops introduced into crop rotation results can increase the soil organic carbon by a mean annual carbon sequestration rate of 0.32 (tC ha<sup>-1</sup> yr<sup>-1</sup>).

For both the ceiling of mitigation potential and the mitigation potential based on the optimization of sediment and phosphorus reductions in source watersheds, our approach was to multiply the area of cover crops (hectares) by the mean annual additional rate of soil carbon sequestration in agricultural soils (Equation 4). The climate change mitigation potential of cover crops was calculated across the

entire source watershed area and was not limited to temperate and tropical zones as in the previous two land-based mitigation activities.

$$\sum_{i=1}^n F_c \times C_i \quad (4)$$

Where  $i$  denotes each sub-unit of source watershed,  $F_c$  is the additional amount of soil carbon sequestration (tC ha<sup>-1</sup> yr<sup>-1</sup>) and  $C_i$  is hectares of cover crops.

For the cover crop ceiling analysis, we calculated  $C_i$  using results from two studies, Siebert, et al., (2010) and Poeplau and Don (2015), to inform our methodology. First, we quantified the amount of cropland in source watersheds using GlobCover (using the following classes: 11: post-flooding or irrigated croplands, 14: rain-fed croplands and 20: mosaic cropland (50-70 percent) / vegetation (grassland/shrubland/forest) (20-50 percent)). In a global, spatial analysis, Siebert, et al., (2010) calculated the mean crop duration ratios for all continents (0.41 for Africa, 0.47 for the Americas, 0.5 for Asia, 0.56 for Europe and 0.42 for Oceania). Using these results, we assume the same, respective ratios of winter or off-season fallows in our urban source watersheds across each continent. Furthermore, we assume that half of the area of off-season fallows within the source watersheds is actually suitable for cover crops based on an assumption made by Poeplau and Don (2015), since some crops are either located in places where climate conditions are not suitable for cover crops or the crop is harvested too late in the season.

For the climate change mitigation benefit provided by cover crops under the optimization analysis,  $C_i$  was determined by the optimization exercise across all three activities described in Appendix V – Section 1.5. Similar to the ceiling analysis, we applied the same off-season, fallow-to-cover crop ratio identified by Poeplau and Don (2015) by multiplying the optimized area of agricultural BMPs by 0.5 to estimate the total area suitable for cover crops. Like Poeplau and Don, we consider this to be a conservative assumption.

### References

- Arino, O., Ramos Perez, J.J., Kalogirou, V., Bontemps, S., Defourny, P., Van Bogaert, E. (2012). Global Land Cover Map for 2009 (GlobCover 2009). European Space Agency (ESA) and Universite catholique de Louvain (UCL). Available from [http://due.esrin.esa.int/page\\_globcover.php](http://due.esrin.esa.int/page_globcover.php) (accessed July 2016).
- Bonner, M.T., Schmidt, S., and Shoo, L.P. (2013). A Meta-Analytical Global Comparison of Aboveground Biomass Accumulation between Tropical Secondary Forests and Monoculture Plantations. *Forest Ecology and Management* **291**: 73-86. doi: [10.1016/j.foreco.2012.11.024](https://doi.org/10.1016/j.foreco.2012.11.024)

Dixon, A.P., Faber-Langendoen, D., Josse, C., Morrison, J., and Loucks, C.J. (2014). Distribution Mapping of World Grassland Types. *Journal of Biogeography* **41**: 2003-2019. doi: 10.1111/jbi.12381

Food and Agriculture Organization of the United Nations (FAO). (2002). FAO GeoNetwork: Global Ecological Zones. FAO, Rome, Italy. Available from <http://www.fao.org/geonetwork/srv/en/main.home> (accessed August 2016).

Hansen, M.C., Potapov, P.V., Moore, R., et al., (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* **342**: 850-853. doi: 10.1126/science.1244693

Intergovernmental Panel on Climate Change (IPCC). (2003). Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC National Greenhouse Gas Inventories Programme, Hayama, Kanagawa, Japan. Available from [http://www.ipcc-nccc.iges.or.jp/public/gpglulucf/gpglulucf\\_files/GPG\\_LULUCF\\_FULL.pdf](http://www.ipcc-nccc.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf) (accessed October 2016).

Mokany, K., Raison, R., and Prokushkin, A.S. (2006). Critical Analysis of Root: Shoot Ratios in Terrestrial Biomes. *Global Change Biology* **12**: 84-96. doi: 10.1111/j.1365-2486.2005.001043.x

Poeplau, C. and Don, A. (2015). Carbon Sequestration in Agricultural Soils via Cultivation of Cover Crops-A Meta-Analysis. *Agriculture, Ecosystems & Environment* **200**: 33-41. doi: [10.1016/j.agee.2014.10.024](https://doi.org/10.1016/j.agee.2014.10.024)

Siebert, S., Portmann, F.T., and Döll, P. (2010). Global Patterns of Cropland Use Intensity. *Remote Sensing* **2**: 1625-1643. doi: [10.3390/rs2071625](https://doi.org/10.3390/rs2071625)

Tyukavina, A., Baccini, A., Hansen, M.C., Potapov, P.V., Stehman, S.V., Houghton, R.A., Krylov, A.M., Turubanova, S., and Goetz, S.J. (2015). Aboveground Carbon Loss in Natural and Managed Tropical Forests from 2000 to 2012. *Environmental Research Letters* **10**: 074002. doi: 10.1088/1748-9326/10/7/074002

World Resources Institute (WRI). (2014). Atlas of Forest Landscape Restoration Opportunities. World Resources Institute, Washington, D.C., USA. Available from [www.wri.org/forest-restoration-atlas](http://www.wri.org/forest-restoration-atlas).

## 1.9 Predicted changes in annual precipitation

Data for this analysis was provided by the web-based mapping tool, Climate Wizard (2016), which projects climate change data and statistics for different time periods (Girvetz, et al., 2009). The precipitation predictions of 20 General Circulation Models (GCMs) from the IPCC 5th assessment and run using Representative Concentration Pathway (RCP) 8.5 (a high-emission scenario) were compared to historical climate data to create ensemble change in precipitation grids for mid-century (2046-2065). Climate Wizard produces quantile grids that give the range of GCM climate projections at each grid cell. The 50th (median) percentile grid identified areas where at least 50 percent of the General Circulation Models agreed in the direction of change in precipitation (either increase or decrease) for a given cell. For mid-century, 50th percentile ensemble change in precipitation grid was acquired for the globe. These grids do not include predictions for Antarctica or large water bodies.

## References

ClimateWizard. Available from <http://climatewizard.org/> (accessed July 2016).

Girvetz, E.H., Zganjar, C., Raber, G.T., Maurer, E.P., Kareiva, P., and Lawler, J.J. (2009). Applied Climate-Change Analysis: The Climate Wizard Tool. *PLOS ONE* **4**: e8320. doi:10.1371/journal.pone.0008320

## 1.10 Increased risk of fire frequency

This analysis highlights areas across our urban source watersheds that could be impacted by climate-induced disruptions on fire activity. We used data from Moritz, et al., (2012), a study that identifies consensus of areas of increase or decrease in fire activity based on spatial statistical models that predict fire probability and are driven by multiple General Circulation Models (GCMs).

To project changes in fire activity for a given region, it is important to understand the processes that currently limit fire occurrences in that location. An important starting point for conceptualizing fire occurrence is the “fire regime triangle” which identifies important factors that control fire activity over broad scales of space and time (Moritz, et al., 2005; Parisien and Moritz, 2009; Krawchuk, et al., 2009). The triangle of factors explains that fire occurrence requires enough accumulation of biomass to support periodic fires, a seasonal window in which that biomass is dry enough to burn and fire ignitions. At broad scales, such as those employed in the analysis by Moritz, et al., (2012), fire activity is often seen as either being fuel-

limited (i.e., low productivity, constrained by periodic pulses in precipitation) or flammability-limited (i.e., more abundant fuel, constrained by drought or dry hot and dry winds that enhance combustion).

To project how climate change will affect fire activity, Moritz, et al., (2012) calculated mean change in fire probability using spatial statistical models that integrate global fire datasets and General Circulation Models (GCMs) in addition to key environmental covariates affecting fire occurrence. For each of the 16 GCM models used in the study, the change in future fire probability was calculated by subtracting the model outputs of future probability of fire from those of baseline models. An ensemble mean change was then calculated by averaging each GCM change estimate. Moritz, et al., calculated ensemble mean change in fire probability for the globe (excluding Antarctica) for two time periods: 2010 – 2039 (mid-century) and 2070 – 2099 (end-of-century).

The authors evaluate the agreement among models by mapping the areas where at least two-thirds (i.e., 66.7 percent or 11 or more out of 16) and nine-tenths (i.e., 90 percent or 15 or more out of 16) of the GCMs agreed on the direction of change (increase or decrease in fire probability). The remaining areas were those with high disagreement among GCMs in the direction of change.

Our analysis extracted only the areas where at least two-thirds of the GCM models agreed that there would be an increase in fire probability for mid- and end-of-century. We then tabulated this area within the greater source watershed region, at both time periods and produced regional area statistics.

Note that fire projections such as these are based on long-term climate norms at coarse spatial scales (i.e., 100 square kilometer grid cells), so they will omit the influence of several factors that may be important in specific locations. For example, places like rainforests and deserts are sensitive to drivers like inter-annual precipitation, but this driver is not considered by these models.

More local drivers (e.g., land-use change, ignition patterns and invasive species) that may increase or decrease a location's flammability are also omitted from these fire risk models. In particular, fine-scale management activities that might ameliorate fire behavior, such as fuel treatments to reduce flame lengths or rates of spread, will also not be considered in these projections because they are focused on long-term fire probabilities. Therefore, these projections may not provide a good basis for targeting fuel reduction efforts. Furthermore, we do not know how well the past acts as an indicator for future resilience and restoration efforts (Moritz, et al., 2014).

Caveats aside, the models provide a unique and consistent picture of whether future areas may be more or less fire-prone based on fire patterns for over a decade across the world's environments and a suite of complex variables known to drive

fire activity (Moritz, et al., 2012). Significantly, the overlay of fire risk with urban source watersheds highlights areas where water supplies are likely to be impacted, requiring adaptation planning that integrates fire, water, habitat and other ecosystems services.

## References

- Krawchuk, M.A., Moritz, M.A., Parisien, M.A., Van Dorn, J., and Hayhoe, K. (2009). Global Pyrogeography: The Current and Future Distribution of Wildfire. *PLOS ONE* **4**: e5102. doi: 10.1371/journal.pone.0005102
- Moritz, M.A., Morais, M.E., Summerell, L.A., Carlson, J.M., and Doyle, J. (2005). Wildfires, Complexity, and Highly Optimized Tolerance. *Proceedings of the National Academy of Sciences* **102**: 17912-17917. doi: 10.1073/pnas.0508985102
- Moritz, M.A., Parisien, M.A., Batllori, E., Krawchuk, M.A., Van Dorn, J., Ganz, D.J., and Hayhoe, K. (2012). Climate Change and Disruptions to Global Fire Activity. *Ecosphere* **3**: 1-22. doi: 10.1890/ES11-00345.1
- Parisien, M.A. and Moritz, M.A. (2009). Environmental Controls on the Distribution of Wildfire at Multiple Spatial Scales. *Ecological Monographs* **79**: 127-154. doi: 10.1890/07-1289.1

## 1.11 Predicted changes in erosivity

Data for this analysis was provided by the web-based mapping tool, Climate Wizard (Girvetz, et al., 2009), which provides projected climate change data and statistics for different time periods. The erosivity predictions of nine General Circulation Models (GCMs) and run under emissions scenario A2 were compared to historic erosivity data to create an ensemble change in erosivity grid at mid-century (2046–2065). Climate Wizard produces quantile grids that give the range of GCM erosivity projections at each grid cell. The 50th (median) percentile grid identified areas where at least 50 percent of the General Circulation Models agreed in the direction of change in erosivity (either increase or decrease) for a given cell. All positive cells indicate predicted increase and negative cells indicate areas of predicted decrease. For mid- and end-of-century, 50th-percentile ensemble change in erosivity grids were acquired for the globe, but did not include predictions for Antarctica.

The area of all positive cells from the 50<sup>th</sup>-percentile grid was calculated within source watersheds and within each geographic region at mid-century. Area predicted to increase in erosivity globally at mid-century was calculated by summing regional area statistics.

## References

- ClimateWizard. Available from <http://climatemizard.org/> (accessed July 2016).
- Girvetz, E.H., Zganjar, C., Raber, G.T., Maurer, E.P., Kareiva, P., and Lawler, J.J. (2009). Applied Climate-Change Analysis: The Climate Wizard Tool. *PLOS ONE* **4**: e8320. doi:10.1371/journal.pone.0008320

## 1.12 Vector-borne disease – Malaria

To evaluate which source watersheds are most vulnerable to an increase in malaria occurrence due to potential land use changes, we used the Gething, et al., (2011) global dataset on *Plasmodium falciparum* (Pf) endemicity levels in 2010. We first used data on the annual parasite incidence (API) to identify stable and unstable transmission zones. These regions are delimited based on Pf API where values  $< 0.1\%$  per annum are considered unstable and Pf API values  $\geq 0.1\%$  per annum are stable.

Within stable transmission zones we estimated the area across source watersheds which have high, moderate, or low transmission (i.e., risk) of malaria using the pixel level *P. falciparum* parasite rate (PfPR) estimated by Gething, et al., (2011). According to Gething, et al., (2011) PfPR represents the average number of people in a population carrying the disease at any one time where PfPR  $< 0.05$  corresponds to low risk, 0.05-0.40 corresponds to intermediate risk, and values  $> 0.4$  are high-risk areas of transmission. Reclassifying the PfPR into separate classes based on these ranges, we sum the total number of pixels across all source watershed areas classified as high, moderate and low. We also calculated the source watershed area experiencing unstable malaria transmission by summing the number of pixels with a Pf API  $< 0.1\%$  per annum as unstable. We note the watersheds in areas of low or unstable risk where malaria transmission is seasonal or intermittent. In these areas, local human populations are naïve to the disease and land-use changes that create new habitats for vectors or increase exposure of local populations to mosquitos may increase the risk of transmission.

## Reference

- Gething, P.W., Patil, A.P., Smith, D.L., Guerra, C.A., Elyazar, I.R., Johnston, G.L., Tatem, A.J., and Hay, S.I. (2011). A New World Malaria Map: Plasmodium falciparum Endemicity in 2010. *Malaria Journal* **10**: 378. doi: 10.1186/1475-2875-10-378

## 1.13 Impact of pollination loss on crop and micronutrient production and the agricultural opportunity cost

To characterize the impact of pollination services on agricultural value and micronutrient production, we used spatially explicit estimates of crop yield, hectares cultivated and country-specific prices. We used datasets on hectares in cultivation from Ramankutty, et al., (2008) and crop yield from Monfreda, et al., (2008). These datasets combined three sources of remotely-sensed land-cover data with a wide array of country- or county-specific agricultural census information to identify production and yield of 175 different crops for each 10-by-10 kilometer grid cell globally for the year 2000.

We combined the production and yield data with price information from the Food and Agricultural Organization of the United Nations (FAO, 2016), multiplying the yield of each of the 175 crops by crop-specific prices for each of 250 national administrative units, measured in 2013 US dollars. When price information for 2013 was not available, we used the average price from all prior years that had price information for that crop in that country (inflation adjusted to 2013), or, failing that, the world average price for the crop.

Lack of pollinator habitat has a detrimental effect on the yield of pollination-dependent crops. We used data from Klein, et al., (2007) to specify the proportion of yield that would be lost (calculated in dry-weight tons, at the farm gate) if pollination services were not available to agricultural production on each grid cell. The effect of pollination services on yield exhibits spatially heterogeneous effects with very localized impacts. As a result, we did not identify the relationship between specific source water protection activities and agricultural yield loss (the marginal value of protection); instead, we characterized the total effect that pollination services offer. We summarized agricultural production with two scenarios: 1) a “baseline scenario” based on observed yields; and 2) a “reduced-pollination scenario” where crop yield was reduced by the respective pollination dependence.

To translate yield losses in these scenarios into nutritional effects, we followed the methodology of Chaplin-Kramer, et al., (2014) to assign nutritional content information from the United States Department of Agriculture (2015) to each crop. We calculated the production of calories, vitamin A, iron and folate under the baseline and reduced-pollination scenarios. We reported the average proportion of nutrient production that was lost for each source watershed and for each of the nutrients.

It is important to consider more than just caloric yield when assessing the impact of reduced pollination services. In general, micronutrients will be more severely impacted

by loss of pollination services than will caloric production, as most staple crops are not pollination-dependent. Moreover, micronutrients tend to be produced in locations with lower average socioeconomic status and are more likely to play a direct, subsistence role in individual health. Our results confirm these generalizations, whereby vitamin A, iron and folate production experienced losses two- to four-times greater than for calories. Loss of nutrient production would need to be offset by relying on a larger degree of food importation. Given the large degree of spatial heterogeneity on the size of production losses, this will raise important and challenging questions of international equity.

To estimate the total agricultural economic value lost in the absence of pollination services, which we use as a proxy for the opportunity cost, we combined the high-resolution data (10-kilometer resolution) on crop production for 175 different crops (Monfreda, et al., 2008) with 2014 price information from the FAO for each crop. The prices used were specific to each FAO country to account for spatial heterogeneity of prices available. The total agricultural value in each grid cell of data is defined by the following equation:

$$\pi(h_{xy}) = \sum_{j=1}^J \sum_{i=1}^I p_{ij} * y_{i,xy} \quad (1)$$

where  $p_{ij}$  is the crop- and country-specific price and  $y_{i,xy}$  is the yield in dry-weight metric tons produced of crop  $i$  in the  $xy^{th}$  grid cell. If 2014 prices were not available for a country or crop, we used the average price from 2000 to 2013. If prices were not available at all for this time period, we used the continent average price.

## References

- Chaplin-Kramer R., Dombeck E., Gerber J., Knuth K.A., Mueller N.D., Mueller M., Ziv G., Klein A.-M. (2014). Global Malnutrition Overlaps with Pollinator-Dependent Micronutrient Production. *Proceedings of the Royal Society B Biological Sciences* **281**: p.20141799. doi: 10.1098/rspb.2014.1799
- EarthStat. Cropland and Pasture Area in 2000. EarthStat.org, Global Landscapes Initiative, University of Minnesota and Ramankutty Lab, The University of British Columbia, Vancouver. Data available online from <http://www.earthstat.org/data-download/>
- EarthStat. Harvested Area and Yield for 175 Crops. EarthStat.org, Global Landscapes Initiative, University of Minnesota and Ramankutty Lab, The University of British Columbia, Vancouver. Data available online from <http://www.earthstat.org/data-download/>
- Food and Agriculture Organization of the United Nations (FAO). FAO/INFOODS Food Composition Databases. Available from <http://www.fao.org/infooods/infoods/tables-and-databases/faoinfoods-databases/en/>
- Food and Agriculture Organization of the United Nations (FAO). FAOSTAT. Available from <http://faostat3.fao.org/home/E>
- Klein, A.M., Vaissiere, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., and Tscharntke, T. (2007). Importance of Pollinators in Changing Landscapes for World Crops. *Proceedings of the Royal Society B Biological Sciences* **274**:303-313. doi: 10.1098/rspb.2006.3721
- Monfreda, C., Ramankutty, N., and Foley, J.A. (2008). Farming the Planet: 2. Geographic Distribution of Crop Areas, Yields, Physiological Types, and Net Primary Production in the Year 2000. *Global Biogeochemical Cycles* **22**. doi: 10.1029/2007GB002947
- Ramankutty, N., Evan, A.T., Monfreda, C. and Foley, J.A., 2008. Farming the Planet: 1. Geographic Distribution of Global Agricultural Lands in the Year 2000. *Global Biogeochemical Cycles* **22**. doi:10.1029/2007GB002952
- USDA Nutrient Data Laboratory. USDA National Nutrient Database for Standard Reference (Release 28, released September 2015, slightly revised May 2016). Available from <http://ndb.nal.usda.gov/> (accessed July 2016).

## 1.14 Distribution of field and farm sizes and beneficiaries of agricultural BMPs

To estimate the number of potential farmers that would be engaged in agriculture BMPs we used the Fritz, et al., (2015) global dataset on field size (1 square kilometer resolution) to estimate the median field/farm size in source watershed areas. Continuous values in the original Fritz, et al., (2015) dataset were reclassified into four field-size classes based on communication with the author. Class 1 included values 10 to 19 representing fields <0.5 hectares, Class 2 included values 20 to 29 representing fields 0.5 to 2 hectares, Class 3 included values 30 to 39 representing fields 2 to 20 hectares, and Class 4 included values equal to or greater than 40 representing all fields larger than 20 hectares. Using the Level 5 HydroBASIN units, we summarized the median field size across all classified pixels in each polygon. For a small subset of polygons, there was no overlapping data on field size. For these polygons, we assigned the median field size class of adjacent watersheds.

To estimate the potential number of farmers engaged in targeted water fund activities on cropland we undertook the same exercise to estimate the median size of fields/farms in non-overlapping source watershed polygons that are used in the analysis to estimate the cost-optimal conservation area required to achieve a 10 percent reduction in sediment and nutrient yield. Based on guidance from the author, we estimated the number of fields/farmers represented by a pixel of each size class. To be conservative in our estimate (and recognizing that a single farmer could own more than one field) we used the upper boundary value of the field size range in each class (i.e., 0.5, 2, 20 and 400 hectares) to calculate the approximate number of fields within a one square kilometer pixel (100, 50, 5, 0.25 farmers per pixel respectively). For Class 4 where there was no upper boundary (i.e., >20 hectares) we used a field size of 400 hectares to account for extremely large farms that occur in many developed countries where most of the pixels in this class occur.

For each non-overlapping component of the source watershed polygon, we multiplied the area planned for agricultural best management practices on existing cropland (in square kilometers) by the expected number of fields per square kilometer estimated based on the median field size class. These numbers were summed across all source watershed polygons for a final number of farmer beneficiaries. In this non-overlapping source watershed dataset there were 740 polygons for which no activities on cropland where planned (only reforestation and forest protection) and an additional 13 polygons for which there was no overlap with the Fritz, et al., dataset. These source watershed areas were excluded from the calculation.

Additional calculation of the mean and standard deviation of pixel-level class values for each polygon suggested that the greatest amount of variation in field size occurred in those polygons whose median value field size was class 1 (0.5 hectares; CV = 22 percent). Variability in pixel-level field size within polygons decreased as the median field size increased to class 4 (>20 hectares, CV = 4 percent). This suggests that our assumption of field size in polygons with a median field size of the smallest class (<0.5 hectares) mostly in sub-Saharan Africa, India and China may overestimate the number of individual fields on targeted agricultural cropland since parts of the landscape had larger reported field sizes. As well, in the largest field size class (4), the assumed field size of 200 hectares may also overestimate the number of fields/farms in landscapes where large monoculture cereal and soy cultivation dominate. Class 4 lands occur predominantly across the United States, Australia, New Zealand, Ukraine, Russia, Kazakhstan, Argentina, Uruguay and the Cerrado of Brazil where field/farm sizes have been reported to span from 200 to 1,200 hectares (MacDonald, et al., 2013; Lowder, et al., 2016). Lastly, in many farming systems an individual farmer may own multiple fields that could not be accurately reflected in this analysis. Factoring this in would reduce again the number of farmers expected to participate in water fund activities.

## References

- Fritz, S., See, L., McCallum, I., et al., (2015). Mapping Global Cropland and Field Size. *Global Change Biology* **21**: 1980-1992. doi: 10.1111/gcb.12838
- Lowder, S.K., Skoet, J., and Raney, T. (2016). The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. *World Development* **87**: 16-29. doi: 10.1016/j.worlddev.2015.10.041
- MacDonald, J.M., Korb, P., and Hoppe, R.A. (2013). Farm Size and the Organization of U.S. Crop Farming. Economic Research Service, U.S. Department of Agriculture, Washington, D.C., USA. Available from [https://www.ers.usda.gov/webdocs/publications/err152/39359\\_err152.pdf](https://www.ers.usda.gov/webdocs/publications/err152/39359_err152.pdf) (accessed December 2016)

## 1.15 Forest loss

We quantified the rate and extent of forest loss in urban source watersheds using global-scale data from Hansen, et al., (2013). We retrieved the global forest cover loss data from Google Earth Engine (GEE) and modified a Java-Script code by Tracewski, et al., (2016) to conduct the analysis in GEE. Another website, ShapeEscape, was used to convert urban source watershed data into a format that is compatible with GEE. Using the data, we estimated tree cover in the year 2000 and tree cover loss between 2001 and 2014 with 30-meter cells from Landsat imagery. The original Hansen, et al., (2013) data has been updated with years 2013 and 2014 on GEE using updated methodology.

For each Level 5 HydroBASIN unit that intersects with the urban source watersheds, we analyzed tree cover from the year 2000 and then calculated the area of forest loss each subsequent year based on the year of loss. These years were summed to provide total loss between 2001 and 2014. We calculated the percent loss for each year between 2001 and 2014 by dividing the area lost in each year by the total area of forest in the year prior to loss.

These calculations assume that all original tree cover (based on the tree cover in the year 2000) within the pixel was lost. If the pixel's tree cover value in the year 2000 was 70 percent, then it was assumed that 70 percent of the pixel area lost forest in the year of forest loss (Tracewski, et al., 2016). Each year of forest loss is mutually exclusive, meaning that forest loss can only occur in one pixel during one year.

In interpreting the results of this analysis, it is important to understand the definition of tree cover loss as it is defined by the algorithm used by Hansen, et al., (2013) and that "loss" does not always equate to deforestation. Tree cover

loss is identified by Hansen, et al., in such a way that it includes anthropogenic causes of forest loss, including timber harvesting and deforestation, as well as natural causes such as disease. The dataset also identifies forest loss from fires that can start from both natural and human sources. Our analysis does not report forest cover gain, even though forests across source watersheds do experience variable rates of tree cover gain.

## References

- Google Earth Engine Team. (2015). Google Earth Engine: A Planetary-Scale Geospatial Analysis Platform. <https://earthengine.google.com>
- Hansen, M.C., Potapov, P.V., Moore, R., et al., (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* **342**: 850-853. doi: 10.1126/science.1244693
- Tracewski, L., Butchart, S.H., Donald, P.F., Evans, M., Fishpool, L.D., and Graeme, M. (2016). Patterns of Twenty-First Century Forest Loss Across a Global Network of Important Sites for Biodiversity. *Remote Sensing in Ecology and Conservation* **2**: 37-44. doi: 10.1002/rse.213.

## 1.16 Human threat to freshwater biodiversity

We used data from Vörösmarty, et al., (2010) ([www.riverthreat.net](http://www.riverthreat.net)) to examine levels of threat to freshwater biodiversity across the urban source watersheds. Vörösmarty, et al., (2010) developed an incident index of freshwater biodiversity threat by combining various themes of impact, including catchment disturbance, pollution, water resource development and biotic factors. The incident values for the index of freshwater biodiversity threat are standardized and normalized between values 0 and 1. In this analysis, we set the breakpoints between low, medium and high biodiversity threat at 0.33 and 0.66, respectively. We quantified the areas within our source watersheds (at the global and regional level) that are classified with high, medium and low levels of freshwater biodiversity threat. Vörösmarty, et al., (2010) removed pixel values from the original data if they did not meet a minimum threshold of average annual runoff. If 20 percent of the HydroBASIN's area had insufficient data due to the minimum threshold of average annual runoff, we did not calculate the average index value of threat.

## Reference

- Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R., and Davies, P.M. (2010). Global Threats to Human Water Security and River Biodiversity. *Nature* **467**: 555-561. doi:10.1038/nature09440

## 1.17 Rarity-weighted richness of ecoregions

Data on rarity-weighted richness (RWR) for terrestrial and freshwater ecoregions were obtained from the analysis completed by Abell, et al., (2010). RWR is defined by the number of species in a given ecoregion, weighting each species by the inverse of the number of different ecoregions it occupies. Thus, the RWR measure considers two common metrics of biodiversity importance: 1) the number of unique species; and 2) the rarity of each species based on the extent of its range (Abell, et al., 2010).

For the purposes of this analysis, we identified ecoregions with high RWR as those that fall in the global top quartile of RWR for freshwater ecoregions and for terrestrial ecoregions, considered separately. We then measured the intersection between the urban source watershed boundary and the terrestrial and freshwater ecoregion maps. Only ecoregions with at least 10 percent of their total area overlapping with the source watersheds were counted towards the percent-overlapping statistic. The following equation was used to calculate the percent of global high RWR ecoregions that overlap with source watersheds within each continental region:

$$X_i = \left( \frac{S_i}{N_i} \right) * 100 \quad (1)$$

where  $S_i$  is the number of high RWR ecoregions with at least 10 percent of their area intersecting the source watershed in region  $i$  and  $N_i$  is the total number of high RWR ecoregions in region  $i$ .

## Reference

- Abell, R., Thieme, M., Ricketts, T. H., Olwero, N., Ng, R., Petry, P., Dinerstein, E., Revenga, C., and Hoekstra, J. (2011). Concordance of Freshwater and Terrestrial Biodiversity. *Conservation Letters* **4**: 127–136. doi:10.1111/j.1755-263X.2010.00153.x

## 1.18 Imperiled terrestrial and freshwater species

The objective of this analysis was to quantify the number and percent of imperiled terrestrial and freshwater species that could benefit from source water protection activities. We used the spatial database for the IUCN Red List of Threatened Species to quantify the number of imperiled species that occur within urban source watersheds (BirdLife International and NatureServe, 2015; IUCN, 2016). For both freshwater and terrestrial species, only species with an IUCN code of critically endangered, endangered or vulnerable were selected for the analysis. Additional selection criteria were also used so that only imperiled species that are native or reintroduced and extant to the region were considered in the analysis.

The spatial data for IUCN freshwater fish is limited. Comprehensive assessments have been collected and published to the Red List for only certain regions: continental Africa, Europe, eastern Mediterranean and Arabia, India, eastern Himalayas and Indo-Burma, New Zealand and South Pacific Islands, and the United States. In order to count the number of imperiled fish falling within source watersheds, a 10 percent overlap threshold was set. If less than 10 percent of a species' range fell within source watersheds, then it was not included in the count. Selected fish whose ranges exceeded this threshold were counted within each region for a total number of imperiled fish intersecting source watersheds. The regional counts do not sum to global numbers because many species exist in multiple regions. While the IUCN Red List dataset contains information on fish outside of the comprehensively assessed regions, our global count did not include these fish.

We incorporated birds, amphibians and terrestrial mammals into our analysis of terrestrial species. For terrestrial species, additional criteria were applied to identify imperiled terrestrial species that could benefit from source water protection activities. We developed an approach that combined WRI's Atlas of Restoration Opportunities (WRI, 2014) with Oakleaf's (2016) Human Modification, with the intention of restricting the count of species to places within urban source watersheds where source water protection activities could more realistically support their survival. We classified places within the urban source watershed region that have high human modification (HM values > 0.66) and that are not classified by WRI as reforestation or restoration opportunities as unsuitable habitat for source water protection activities to support their survival. We assume that source water protection activities only support terrestrial species at the actual site of activity implementation (a similar masking approach was not applied for freshwater fish species because source water protection activities can provide positive water security benefits downstream of the activity site). For terrestrial species we also applied a 10 percent overlap threshold. For an imperiled terrestrial

species to get counted within the source watersheds, at least 10 percent of its range had to intersect with the suitable habitat mask. For migratory birds, the BirdLife data includes migration distributions that are mapped across oceans. In the event that a bird migrates across the ocean, the 10-percent threshold only considered the species' terrestrial range.

## References

- BirdLife International and NatureServe. (2015). Bird Species Distribution Maps of the World. Version 5.0. BirdLife International, Cambridge, UK and NatureServe, Arlington, USA.
- International Union for Conservation of Nature (IUCN) 2016. The IUCN Red List of Threatened Species. Version 2016-2. <http://www.iucnredlist.org>. Downloaded on 01 July 2016.
- Oakleaf, J.R. (2016). Human Modification. Unpublished data. Retrieved from Jim Oakleaf, The Nature Conservancy (accessed July 2016).
- World Resources Institute (WRI). (2014). Atlas of Forest Landscape Restoration Opportunities. World Resources Institute, Washington, D.C., USA. Available from [www.wri.org/forest-restoration-atlas](http://www.wri.org/forest-restoration-atlas).

## 1.19 Alliance for Zero Extinction sites

The objective of this analysis was to determine the number of Alliance for Zero Extinction (AZE) sites, and what percent of endangered species triggering AZE sites, that fall within source watersheds. The Alliance for Zero Extinction is a conservation initiative that aims to protect the last remaining populations of endangered or critically endangered species (Alliance for Zero Extinction, 2010). Sites have been identified globally where at least one species is on the brink of extinction and requires special protection. These endangered species belong only to those taxonomic groups that have been globally assessed: mammals, birds, some reptiles, amphibians, conifers and reef-building corals. So far, 588 sites have been identified, triggered by 919 species. All taxonomic groups, including the corals, were included in this analysis.

To determine the number of AZE sites and percent of endangered species found within AZE sites that occur within source watersheds, we ensured that sites with minimal overlap with the source watersheds were not included in the count. We assume source watershed protection would do little to protect a site if less than 10 percent of that site fell within source watersheds. The area of overlap was calculated and those sites surpassing the 10-percent threshold were counted for each geographic

region, and the number of trigger species belonging to those sites was tabulated. Both terrestrial (including the conifers) and marine trigger species were included in the total count. All AZE sites and their corresponding trigger species were assigned to a geographic region and the total number of AZE sites and species were determined for each region. Finally, the percent of AZE sites and trigger species that could be supported by source watershed protection activities was calculated for each region.

## Reference

Alliance for Zero Extinction. (2010). 2010 AZE Update. [www.zeroextinction.org](http://www.zeroextinction.org).

## 1.20 Important Bird and Biodiversity Areas

The goal of this analysis was to calculate the following summary statistics at the regional and global level:

- The percent of all Important Bird and Biodiversity Areas that occur within source watersheds
- The percent of all Important Bird and Biodiversity Areas that are in danger that occur within source watersheds

Important Bird and Biodiversity Areas (IBAs) are a network of more than 12,000 sites around the world that are important contributors of bird diversity. Sites have been identified by BirdLife International based on criteria of threat level, population size and species distribution. These sites also tend to support an array of other plant and animal species, broadening the potential biodiversity conservation impact. About 3 percent of these sites are in imminent danger due to development activities in the surrounding area (BirdLife International, 2014).

Spatial IBA data were obtained directly from BirdLife International (2014). Those IBAs that have at least 10 percent of their area within source watersheds were identified as intersecting source watersheds. For each geographic region, the total number of IBAs, the total number of IBAs in danger, the number of IBAs intersecting source watersheds and the number of IBAs in danger and intersecting source watersheds were collected. From these numbers, percent of IBAs that intersect source watersheds and percent of IBAs that are in danger that intersect source watersheds were calculated.

Because some IBAs are so small, some polygons from the IBA dataset did not overlap the Global Administrative Areas (GADM 2012) country dataset that was used (these were usually on small islands). Therefore, 1.5 percent (181) of IBAs were

not assigned to a geographic region, but were included in global statistics. IBAs belonging in Antarctica (85 IBAs total) were also included in the global IBA sum.

## References

BirdLife International. (2014). Important Bird and Biodiversity Areas: A Global Network for Conserving Nature and Benefiting People. BirdLife International, Cambridge, UK. Available from <http://www.birdlife.org/datazone/userfiles/file/IBAs/pubs/SOWIBAs2014.pdf> (accessed July 2016).

BirdLife International. (2015). Important Bird and Biodiversity Area (IBA) digital boundaries. January 2016 version. BirdLife International, Cambridge, UK. Available through request on <http://datazone.birdlife.org/site/requestgis> (downloaded January 2016).

Global Administrative Areas. (2012). GADM database of Global Administrative Areas, version 2.0. Available from <http://www.gadm.org/about> (accessed March 2016)

## 1.21 Reducing species extinction risk through reforestation and landscape restoration

To assess the potential avoidance of extinctions (potential species savings) due to reforestation and restoration opportunities, we first quantified the number of species within each of 804 terrestrial ecoregions for three taxonomic groups (terrestrial mammals, amphibians and birds). Spatial data for all species ranges were obtained from the IUCN Red List of Threatened Species assessment (BirdLife International and NatureServe, 2015; IUCN, 2016). We also calculated the number of endemic species within each terrestrial ecoregion in addition to the total number of species. A species was considered to be endemic if 95 percent of its range was located within one particular ecoregion.

Next, we obtained spatial data for global forest landscape restoration opportunities (Minnemeyer, et al., 2011) from WRI's Atlas of Forest Landscape Restoration Opportunities (WRI, 2014). Only wide-scale and remote restoration opportunities were used in this analysis (hereafter collectively referred to as "reforestation opportunities"). Mosaic restoration opportunities were removed from the analysis because they are located in more densely populated regions and were defined in such a way that they are suitable places for multiple land uses, including agroforestry, smallholder agriculture and settlements. Any of the reforestation and restoration opportunities that were not located within the boundaries of the urban source watersheds were removed from the analysis.

To measure the change in land-use mix before and after implementing potential reforestation and restoration opportunities, we used a global map of land-use types (approximately 1 x 1 kilometers resolution) for the year 2005 (Hoskins, et al., 2015). This data set was generated through the statistical downscaling of the Land-Use Harmonization dataset (Hurt, et al., 2011). Five different land-use types were considered: 1) primary habitat; 2) secondary habitat; 3) pasture; 4) crop; and 5) urban. We first calculated the area of each land-use type within each ecoregion prior to reforestation activities (i.e., current land-use mix). Next, we converted locations of reforestation and restoration opportunities to primary habitat and recalculated the area of each land-use type within each terrestrial ecoregion (i.e., future land-use mix). In the event that the wide-scale and remote reforestation opportunities overlapped with land-use pixels of cropland or urban land use, we did not apply any conversion of land use to primary habitat. Thus, it was assumed that only the areas of secondary habitat and pasture could be restored and converted to primary habitat.

For predicting species extinctions due to human land use within a region, models describing species-area relationships (SARs) have often been employed. Recent studies have shown that a countryside SAR model outperforms other forms of SARs in predicting extinctions in heterogeneous landscapes (Pereira, et al., 2014). Unlike classic SAR, countryside SAR accounts for the fact that species adapted to human-modified habitats also survive in the absence of their natural habitat (Pereira, et al., 2014).

Using the current land-use mix, the SARs project the number of species expected to go extinct compared to those occurring naturally prior to human intervention in a region (Wearn, et al., 2012). Note that SARs only provide an estimate of final, equilibrium level of species loss but do not tell which particular species will go extinct. Following land-use changes or habitat degradation, species do not go extinct immediately. Instead, a process of time-delayed community “relaxation” usually occurs, where species progressively disappear over time (Brooks, et al., 1999). This time delay offers a window of conservation opportunity, during which it is possible to restore habitat or implement alternative measures such as reforestation to safeguard the persistence of species that are otherwise committed to extinction.

In order to calculate potential species savings due to reforestation activities, we subtracted the total species extinctions projected by countryside SAR using the future land-use mix ( $S_{lost,g,j}^{future}$ ) from those projected using current land-use mix ( $S_{lost,g,j}^{current}$ ).

Countryside SAR projects the total species loss ( $S_{lost,g,j}$ ) per taxonomic group  $g$  due to current land-use mix in an ecoregion  $j$  by (for details see Chaudhary *et al.*, 2015).

$$S_{lost,g,j}^{current} = S_{org,g,j} - S_{org,g,j} * \left( \frac{A_{new,j}^{current} + \sum_{i=1}^n h_{g,i,j} \cdot A_{i,j}^{current}}{A_{org,j}} \right)^{z_j} \quad (1)$$

where  $S_{org,g,j}$  is the original number of species occurring in the original natural forest area  $A_{org,j}$ ,  $A_{new,j}$  is the remaining natural (primary) habitat area in the region,  $A_{i,j}$  is the current area of land-use type  $i$ ,  $h_{g,i,j}$  is the affinity of the taxonomic group to the land-use type  $i$  and  $z_j$  is the exponent for the SAR model. If the converted land-use type is completely hostile and cannot host any species of the taxon, the  $h_i$  value equals to 0. On the other hand, if the converted land use is as benign as the natural undisturbed habitat,  $h_i=1$  (Pereira *et al.*, 2014).

Equation 1 above provides *projected regional extinctions*, producing the number of species expected to go extinct from a particular ecoregion only. However, if the species are endemic to the ecoregion, then their loss translates into global species loss. Avoiding global extinctions is necessary to preserve the genetic diversity of life on Earth (Mace *et al.*, 2003). We also project *global extinctions* per ecoregion by using the number of endemic species per ecoregion ( $S_{end,g,j}$ ) instead of total species ( $S_{org,g,j}$ ) as an input to the SAR in Eq. 1 above (Chaudhary & Kastner, 2016).

We considered four land-use types ( $i = 4$ : secondary forests, agriculture, pasture and urban) for each ecoregion. Rather than country or pixel-level resolution, terrestrial ecoregions were chosen as spatial units to calculate species extinctions because they contain distinct communities of species and their boundaries approximate the original extent of natural ecosystems prior to major land-use change (Olson *et al.*, 2001). As stated above, we obtained species richness per ecoregion ( $S_{org,g,j}$  and  $S_{end,g,j}$ ) from the IUCN database (IUCN, 2016), area estimates per ecoregion ( $A_{new,j}$ ,  $A_{org,j}$  and  $A_{i,j}$ ) from the global land use map of Hoskins, et al., (2016), the taxa affinities ( $h_{g,i,j}$ ) from a global literature review (Chaudhary *et al.*, 2015), and z-values ( $z_j$ ) from Drakare, et al., (2006).

Next, the number of projected extinctions given the future land-use mix (i.e., once all areas identified with reforestation opportunities have been converted to primary forests) is given by:

$$S_{lost,g,j}^{future} = S_{org,g,j} - S_{org,g,j} * \left( \frac{A_{new,j}^{future} + \sum_{i=1}^n h_{g,i,j} \cdot A_{i,j}^{future}}{A_{org,j}} \right)^{z_j} \quad (2)$$

Finally, the potential species savings are calculated as:

$$S_{savings,g,j} = S_{lost,g,j}^{current} - S_{lost,g,j}^{future} \quad (3)$$

## References

- BirdLife International and NatureServe. (2015). Bird Species Distribution Maps of the World. Version 5.0. BirdLife International, Cambridge, UK and NatureServe, Arlington, USA.
- Brooks, T.M., Pimm, S.L., and Oyugi, J.O. (1999). Time Lag Between Deforestation and Bird Extinction in Tropical Forest Fragments. *Conservation Biology* **13**: 1140-1150. doi: 10.1046/j.1523-1739.1999.98341.x
- Chaudhary, A., Verones, F., de Baan, L., and Hellweg, S. (2015). Quantifying Land Use Impacts on Biodiversity: Combining Species-Area Models and Vulnerability Indicators. *Environmental Science & Technology* **49**: 9987-9995. doi: 10.1021/acs.est.5b02507
- Drakare, S., Lennon, J.J., and Hillebrand, H. (2006). The Imprint of the Geographical, Evolutionary and Ecological Context on Species-Area Relationships. *Ecology Letters* **9**: 215-227. doi: 10.1111/j.1461-0248.2005.00848.x
- Hoskins, A.J., Bush, A., Gilmore, J., Harwood, T., Hudson, L.N., Ware, C., Williams, K.J., and Ferrier, S. (2016). Downscaling Land-Use Data to Provide Global 30" Estimates of Five Land-Use Classes. *Ecology and Evolution* **6**: 3040-3055. doi: 10.1002/ece3.2104
- International Union for Conservation of Nature (IUCN) 2016. The IUCN Red List of Threatened Species. Version 2016-2. Available from <http://www.iucnredlist.org> (accessed July 2016).
- Minnemeyer, S., Laestadius, L., Sizer, N., Saint-Laurent, C., and Potapov, P. (2011). A World of Opportunity for Forest and Landscape Restoration. Brochure for *Atlas of Forest and Landscape Restoration Opportunities*. World Resources Institute, Washington, D.C., USA. Available from [http://www.wri.org/sites/default/files/world\\_of\\_opportunity\\_brochure\\_2011-09.pdf](http://www.wri.org/sites/default/files/world_of_opportunity_brochure_2011-09.pdf). Also see [www.wri.org/forest-restoration-atlas](http://www.wri.org/forest-restoration-atlas) (accessed September 2016)
- Olson, D.M., Dinerstein, E., Wikramanayake, E.D., et al., (2001). Terrestrial Ecoregions of the World: A New Map of Life on Earth. *BioScience* **51**: 933-938. doi: 10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2
- Pereira, H.M., Ziv, G., and Miranda, M. (2014). Countryside Species-Area Relationship as a Valid Alternative to the Matrix Calibrated Species-Area Model. *Conservation Biology* **28**: 874-876. doi: 10.1111/cobi.12289
- Wearn, O.R., Reuman, D.C., and Ewers, R.M. (2012). Extinction Debt and Windows of Conservation Opportunity in the Brazilian Amazon. *Science* **337**: 228-232. doi: 10.1126/science.1219013
- World Resources Institute (WRI). (2014). Atlas of Forest Landscape Restoration Opportunities. World Resources Institute, Washington, D.C., USA. Available from [www.wri.org/forest-restoration-atlas](http://www.wri.org/forest-restoration-atlas).

## 1.22 Present levels of protected area by country

In this analysis, we took a country-level approach to evaluating how source water protection activities could help to achieve the Convention on Biodiversity's Aichi Biodiversity Target 11, which states that at least 17 percent of terrestrial and inland water areas should be conserved through managed protected areas (PAs) by the year 2020. The following statistics were calculated:

- The area and percent of each country that is protected
- The PA area and percent deficit of those countries that do not meet Aichi Biodiversity Target 11
- The area of natural land cover in source watersheds but outside of existing PAs
- Natural land cover as a percent of the protection deficit
- The percent of PAs that fall within source watersheds

PA data were gathered from the 2016 World Database on Protected Areas (WDPA) (IUCN and UNEP-WCMC, 2016) produced by United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) in collaboration with International Union for Conservation of Nature (IUCN). It is the largest global protected areas dataset, including both marine and terrestrial PAs. Because the 17-percent target addresses protection of terrestrial and inland water areas specifically, we excluded marine and coastal areas from the analysis. PAs falling into all management categories and all designations were used. Some PA location data were provided as points rather than polygons, and we included those with size information in the analysis by creating a circular buffer around the points. This approach follows that outlined by the Biodiversity Indicators Partnership ([www.bipindicators.net](http://www.bipindicators.net)) for measuring progress toward Aichi Target 11.

To calculate the percent area of each country that is under protection, all protected areas were converted to a raster grid with a 150-meter by 150-meter cell size. Protected areas smaller than a single cell (0.0225 square kilometer) were excluded from the analysis. Globally, this resulted in the loss of 296 square kilometers, or 0.0006 percent of PAs. The area of all PAs was summed for each country. Then the percent and area deficit were calculated for those countries that did not meet the 17 percent protection target.

Next, we evaluated whether the protection of natural land within source watersheds could help countries overcome their PA deficit. Data for natural land came from the 2009 GlobCover project's global land cover dataset, processed by the European Space Agency and the Université catholique de Louvain (ESA and UCL, 2009). We identified land-cover classes that are considered predominantly natural by excluding cropland and urban areas. The area of natural land within watersheds but outside of already existing PAs was summed. Then natural area as a percentage of total additional area required to reach the Aichi Biodiversity Target 11 was calculated to determine which countries could reach the target with targeted land protection as a source water protection activity. As it is unrealistic that source water protection would protect 100 percent of natural land within source watersheds, we also calculated how many countries could meet the target if 10 percent, 25 percent and 50 percent of natural land within each country's source watershed area were protected.

Inaccuracies in the results may stem from the original WDPA dataset, such as misreporting of information by providers or complete lack of size information for PA points, preventing such PAs from being included in the analysis all together. Additionally, incorporating point data into the analysis can give rise to errors given the incorrect shape of the points' buffers. Buffers that hug country or regional boundary lines may be incorrectly distributed between them. Or, where buffers overlap with other PA polygons, the area of overlap may be over or underestimated, affecting how much area outside of the overlap is included in the total.

## References

Arino, O., Ramos Perez, J.J., Kalogirou, V., Bontemps, S., Defourny, P., Van Bogaert, E. (2012). Global Land Cover Map for 2009 (GlobCover 2009). European Space Agency (ESA) and Universite catholique de Louvain (UCL). Available from [http://due.esrin.esa.int/page\\_globcover.php](http://due.esrin.esa.int/page_globcover.php) (accessed July 2016).

Bontemps, S., Defourny, P., Van Bogaert, E., Arino, O., Kalogirou, V., and Ramos Perez, J.J. (2011). GLOBCOVER 2009: Products Description and Validation Report. Available from [http://due.esrin.esa.int/files/GLOBCOVER2009\\_Validation\\_Report\\_2.2.pdf](http://due.esrin.esa.int/files/GLOBCOVER2009_Validation_Report_2.2.pdf)

IUCN and UNEP-WCMC. (2016). World Database on Protected Areas (WDPA) [Online]. UNEP-WCMC, Cambridge, UK. Available from <https://www.protectedplanet.net/> (accessed July 2016).

UNEP-WCMC. (2016). World Database on Protected Areas User Manual 1.3. UNEP-WCMC, Cambridge, UK. Available from [http://wcmc.io/WDPA\\_Manual](http://wcmc.io/WDPA_Manual)

## 1.23 Impacts of excess nitrogen in water

To estimate the total global excess nitrogen loads from source watersheds we use the Global Nitrogen Balance dataset from West, et al., (2014) at a five-minute arc grid (~10 square kilometers) resolution. We summed pixel-level nitrogen balance values for each of the Level 5 HydroBASIN units intersecting source watersheds. Polygons with positive nitrogen balances were summed to estimate total global potential excess nitrogen loading into adjacent waterbodies (~38 megatonnes). HydroBASINS with N-deficits or balanced N-budgets were not included in this global estimation.

We also overlaid the map of nitrogen-contributing source watersheds with a dataset of global reported coastal eutrophication and dead zone areas (WRI, 2013). Using the 15-arc-second HydroSHEDS global river network datasets for each continent, we manually determined whether each coastal eutrophication point was situated downstream of a targeted source watershed area. We classified each watershed as contributing or not to a downstream eutrophication point and each dead zone point as downstream or not of targeted source watersheds and then mapped these categories. For those watersheds contributing to a eutrophication point we display their estimated nitrogen export level.

To consider the potential impact of nitrogen eutrophication on downstream coastal waters and local communities, we use data from the Ocean Health Index, which quantifies Coastal Artisanal Fisheries Dependence for each country's Exclusive Economic Zone. We combine data provided from OHI (Halpern, et al., 2012) with the world marine EEZ boundary v8 layer from Virginia Institute of Marine Science to map these values. Dependence is reported as adjusted per capita GDP Purchasing Power Parity (PPPpcGDP) where lower PPPpcGDP areas are expected to have greater dependence on small-scale artisanal fisheries for a source of protein and livelihoods than counties with higher scores.

An important caveat is that point source pollution from sewage and industry activities can be a (more) important source of nutrient pollution into waterways and the cause of eutrophication events or dead zones. However, nonpoint source pollution from agriculture is widely acknowledged to also be a major contributor of nutrient pollution. Actual nutrient export into water systems is also highly

dependent on timing of fertilizer application, storm events and riparian vegetation and can vary significantly from year to year. There is a strong reporting bias in eutrophication and dead zones in North America and Europe, which have strong institutional monitoring systems in place. Additional eutrophication points are likely underreported across Africa, South America and Asia, leading to an underestimation of the actual number of eutrophication points to which urban source watersheds contribute. Eutrophication points were linked to upstream source watersheds based on reasonable judgment considering proximity to river outflow point and potential ocean circulation effects. Many eutrophication points are in bays and estuaries with multiple discharging rivers; therefore, identified upstream source watersheds are often not the only source of nutrient pollution.

## References

- Claus S., De Hauwere, N., Vanhoorne, B., Souza Dias, F., Oset García, P., Hernandez, F., and Mees, J. (2016). MarineRegions.org. Flanders Marine Institute. Available from <http://www.marineregions.org> (accessed May 2016).
- EarthStat. Total Fertilizer Balance for 140 Crops. EarthStat.org, Global Landscapes Initiative, University of Minnesota and Ramankutty Lab, The University of British Columbia, Vancouver. Data available online from <http://www.earthstat.org/data-download/>
- Halpern, B.S., Frazier, M., Potapenko, J., et al., (2015). Spatial and Temporal Changes in Cumulative Human Impacts on the World's Ocean. *Nature Communications* **6**. doi:10.1038/ncomms8615
- Halpern, B.S., Longo, C., Hardy, D., et al., (2012). An Index to Assess the Health and Benefits of the Global Ocean. *Nature* **488**: 615-620. doi:10.1038/nature11397
- Lehner, B., Verdin, K., and Jarvis, A. (2008). New Global Hydrography Derived from Spaceborne Elevation Data. *Eos* **89**: 93-94. doi: 10.1029/2008EO100001
- West, P.C., Gerber, J.S., Engstrom, P.M., et al., (2014). Leverage Points for Improving Global Food Security and the Environment. *Science* **345**: 325-328. doi: 10.1126/science.1246067
- World Resources Institute (WRI). (2013). Eutrophication & Hypoxia Map Data Set. Available from <http://www.wri.org/resources/data-sets/eutrophication-hypoxia-map-data-set> (accessed May 2016).

## 1.24 Return on investment (ROI) and valuing multiple benefits

### Aggregating watershed results to cities

Cities within the City Water Map (CWM) data set can be associated with one or more source watersheds. Because watersheds may be nested, it is not possible to take the simple sum of watershed-level values for a given city. Instead, for cities that source from multiple watersheds, we present the weighted average of watershed values. Watershed values are weighted by log-transformed estimates of watershed discharge as modeled by the global water balance model, WaterGAP. This weighting scheme assumes that a given city depends more significantly on watersheds with greater total discharge. Accordingly, city-level results should be interpreted as representative rather than cumulative values.

As stressed previously (Appendix V – 1.1), the focus of this report is surface water sources. However, for many cities, dependency on groundwater and other non-surface sources can be significant. So, although pollution reduction from source watershed protection may be achievable, the value of water quality improvement may be insignificant for some cities relative to total water supply.

### Costs of conservation implementation

We estimate costs of conservation implementation utilizing regional estimates reported previously (McDonald and Shemie, 2014). Using our estimates of implementation area for each conservation practice type (Appendix V – 1.5), we estimate total annual costs to achieve a 10 percent reduction in sediment or nutrients for each watershed in our data set. For GRUMP cities and CWM cities with a single source watershed, we associate these watershed-level costs with the respective sourcing cities. For CWM cities with multiple source watersheds, we first calculate the average implementation area for each practice type using the approach described previously. These average implementation area values are then used to derive representative cost values at the city level. For city-level results where we report a single consolidated value, we report data for the lowest cost pollutant in cases where a 10 percent reduction is achievable for both sediment and phosphorus.

To derive global cost estimates, it is not possible to take the simple sum of watershed-level cost values given the nested nature of these source watersheds (doing so would result in significant double counting where watershed areas overlap). In order to estimate implementation costs globally, we apply the regional cost estimates above to the global-level implementation scenarios derived previously (see “Analysis outputs”

in Appendix V – 1.5). These results are summarized by region as aggregate costs and overall per capita costs (total costs divided by the total city population that could benefit). For both costs and per capita costs, we observe non-normal distribution of data at the watershed scale (Shapiro-Wilk test values of 0.034 and 0.057 for sediment and phosphorus per capita costs, respectively). As such, a comparatively small subset of watersheds can account for a significant proportion of estimated global costs. In order to present aggregate global values more representative of a cost-feasible set of watersheds, we further restrict our global cost estimates to watersheds below the 90<sup>th</sup> percentile in terms of per capita costs by region. In general, this results in the exclusion of larger watersheds within each region, where cost-beneficiary ratios tend to be the least favorable (correlation coefficient for per capita costs and watershed area of  $r = 0.38 \pm 0.03$  and  $r = 0.44 \pm 0.04$  for sediment and phosphorus, respectively).

### Estimating cost savings

To estimate potential cost savings from avoided drinking water treatment operations and maintenance (O&M), we first estimate total urban water use for each city. We obtain country-level data on total annual urban water withdrawals from the UN Food and Agriculture Organization (FAO) AQUASTAT database. We then estimate per capita urban water withdrawals using population data from the UN World Urbanization Prospects (WUP) 2014 database. For each country, we use the most recent available data on urban water withdrawals in conjunction with the national urban population estimate that corresponds to the nearest five-year increment (per WUP reporting increments). We then divide total urban withdrawals by total urban population to estimate average annual per capita urban water withdrawals at the country level.

Using these country-level values, we estimate total annual withdrawals for each city by multiplying per capita withdrawals by the estimated city population. For CWM cities, city population estimates were derived from UN WUP for the year 2005 as previously reported (McDonald and Shemie, 2014). For GRUMP cities, we utilize population estimates for the year 2000 as calculated by the Center for International Earth Science Information Network (CIESIN) and reported within the GRUMP dataset. Additionally, these same population values are used to estimate per capita implementation costs. With estimates of total city water withdrawals, we then estimate potential costs savings using the approach previously reported, assuming a 5 percent savings in O&M costs for a 10 percent reduction in sediment or nutrients (McDonald and Shemie, 2014).

We stress that these costs and cost savings are rough estimates intended to indicate orders of magnitude, illustrate global and regional trends, or enable relative comparisons for screening purposes.

### Water treatment return on investment (ROI)

We calculate ROI with respect only to estimated potential operations and maintenance (O&M) savings. Valuing additional impacts, such as avoided capital expenses, could provide further cost savings for cities and their water providers. We calculate water treatment ROI as estimated potential O&M cost savings relative to the estimated costs for source water protection activities, where a value of one or greater indicates a positive return on investment. Such ROI estimates are both narrow in scope and limited in predictive accuracy given the significant assumptions regarding costs, water withdrawals and cost savings.

We stress again that these water treatment ROI values represent rough approximations of potential economic returns, where more detailed city-level analyses could produce divergent results. Detailed city-level analysis would be needed to more fully evaluate the ROI of source water protection investment. Note also that it is a city-level ranking where many cities depend on more than one source watershed, and individual source watersheds may have high investment potential even if the overall city ranking is low.

### Biodiversity returns as rarity-weighted richness

To assess relative potential for biodiversity returns resulting from conservation implementation, we conduct a simple overlay analysis using data on terrestrial and freshwater biodiversity. Using information on rarity-weighted species richness described previously (Appendix V – 1.17), we first associate each source watershed with representative ecoregions as defined by maximum overlap (by percent area) for both terrestrial and freshwater ecoregions. In this way, ecoregional values for terrestrial and freshwater rarity-weighted richness are ascribed to each watershed. We then determine the percentile rank for each watershed by biome type. Ranking by biome provides a better assessment of the regional or sub-regional importance of particular ecoregions in terms of species diversity as compared to analysis of diversity values directly—where areas of particularly high species diversity (e.g., Amazon) would heavily skew results. For each watershed, we then determine the maximum percentile rank between terrestrial and freshwater values. These watershed-level results are then aggregated to the city level as described previously.

Importantly, these biodiversity rankings indicate potential benefits irrespective of conservation implementation extent. In other words, these results assess the value of biodiversity that may be coincident with source water protection activities, but they do not indicate the magnitude of benefits resulting from source water protection implementation.

## Climate change mitigation returns as potential carbon sequestration

Using the approach previously described (Appendix V – 1.8), we assess climate change mitigation potential resulting from conservation implementation necessary to reduce sediment or nutrients by 10 percent. For each source watershed, we estimate potential sequestered carbon that could result from implementation of two of the three modeled practices: pastureland reforestation and agricultural BMPs as cover crops. Forest protection is not included due to a paucity of data outside of tropical regions. These watershed-level results are then aggregated to the city level for a single pollutant type as described previously, resulting in estimates of potential sequestered carbon (in metric tons) for each city. See Appendix V – 1.8 for more information regarding the methodology to measure climate change mitigation benefits from source water protection activities.

As a general rule, larger watersheds require greater conservation implementation—and greater implementation costs—for the same relative reduction in sediment or nutrients. Similarly, larger watersheds exhibit greater potential for carbon sequestration. However, carbon sequestration potential is also highly correlated with conservation costs. In order to assess the relative value of carbon sequestration potential, we normalize these values relative to estimated conservation implementation costs (to achieve a 10 percent reduction in sediment or nutrients).

## Agricultural returns as avoided pollinator-dependent productivity loss

As described previously (Appendix VI – 1.13), the loss of natural habitat can be associated with decreased yields for pollination-dependent crops. We utilize this previously generated data on the proportion of yield that would be lost (calculated in dry-weight tons at the farm gate) if pollination services were not available to agricultural production on each grid cell. For each source watershed, we estimate the average yield loss proportion across all grid cells, weighted by cropland area (with cropland extent calculated from Ramankutty, et al., 2008). Watershed-level yield loss proportions are then aggregated to city-level values as described previously.

It is important to note that these results represent potential returns and do not reflect outcomes from any specific implementation scenario. For example, the cost-optimal conservation implementation area needed for a 10 percent reduction in sediment or phosphorus may exclusively suggest implementation of agricultural BMPs (without forest protection or restoration) and therefore imply minimal benefit for the protection of natural pollinator habitat.

## Comparing water quality and co-benefit returns

In Chapter 5, we use scatter plots to compare potential treatment ROI against the co-benefit returns described above. Each point on the plot represents a single city where it is possible to achieve a 10 percent reduction in sediment and/or nutrients. All city-level values are calculated by the approaches, and presented in the units, described above. For treatment ROI and co-benefit values, we observe values that span one or more orders of magnitude. Thus, to better facilitate figure readability (providing adequate data-point resolution within the coordinate plane, while also maintaining linear axes values), we truncate values exceeding the 90<sup>th</sup> percentile and set axis limits to these truncation values. These truncated values can be identified by points at either axis limit. Note that such points may represent ROI or co-benefit values significantly greater than those implied by the scatterplot.

As cautioned previously, these comparisons and the underlying data are primarily intended to be illustrative in form, supporting appraisal of broad trends and highlighting the potential for more rigorous analyses at a sub-global scale. We consider any individual point to be limited in interpretative value, and highlight three representative cities (Nairobi, Harbin and Porto Alegre) primarily to facilitate interpretation of broader trends.

## References

- Alcamo, J., Döll, P., Henrichs, T., Kaspar, F., Lehner, B., Rösch, T., and Siebert, S. (2003). Development and Testing of the WaterGAP 2 Global Model of Water Use and Availability. *Hydrological Sciences Journal* **48**: 317-337. doi: 10.1623/hysj.48.3.317.45290
- Center for International Earth Science Information Network (CIESIN), Columbia University; International Food Policy Research Institute (IFPRI), the World Bank; and Centro Internacional de Agricultura Tropical (CIAT). (2011). Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Settlement Points. Socioeconomic Data and Applications Center (SEDAC), Columbia University, Palisades, New York. Available from <http://sedac.ciesin.columbia.edu/data/dataset/grump-v1-settlement-points>.
- Food and Agriculture Organization of the United Nations (FAO). (2016). AQUASTAT. Available from [http://www.fao.org/nr/water/aquastat/main/index\\_stm](http://www.fao.org/nr/water/aquastat/main/index_stm) (accessed August 2016).
- Ramankutty, N., Evan, A.T., Monfreda, C. and Foley, J.A., 2008. Farming the Planet: 1. Geographic Distribution of Global Agricultural Lands in the Year 2000. *Global Biogeochemical Cycles* **22**. doi:10.1029/2007GB002952

## 1.25 Colombia deep dive

### City selection criteria

Seven major cities in Colombia were initially selected whose population exceeded 500,000 per the 2005 national census: Bogotá (pop. 6,840,116), Medellín (pop. 2,214,494), Cali (pop. 2,119,908), Barranquilla (pop. 1,146,359), Cartagena (pop. 892,545), Cúcuta (pop. 587,676) and Bucaramanga (pop. 516,512). The Nature Conservancy, along with numerous local partners, have been working on developing conservation plans and scoping water funds in each of these cities, providing a rich history of experience and data there to inform our deep-dive analysis.

### Source watershed delineation

Source watershed delineation was done using the DelicateIT tool from InVEST and the 90-meter DEM (Sharp, et al., 2016). Water intake locations for cities were obtained from The Nature Conservancy's Urban Water Blueprint project (McDonald and Shemie, 2014) and its underpinning City Water Map, and were used as outlet points for the initial source watersheds. The resulting source watersheds were then reviewed by The Nature Conservancy Colombia and, in some cases, modified based on additional data on water intake locations. Based on this feedback, we restricted the eventual analysis to a subset of our original source watersheds and cities:

- Cali: We eliminated the Cauca River Basin, which supplies a portion of water to the city, and focused instead on the western tributary that has been identified by The Nature Conservancy as the most likely place to begin water fund implementation.
- Cartagena: We eliminated the Magdalena River Basin, which supplies a portion of water to the city, and focused instead on the watersheds to the north of the water intake on the Dique Canal, as more feasible areas for initial water fund implementation.
- Barranquilla: The source watershed for this city is the very large Magdalena River Basin, which is not at a scale feasible for short-term water fund implementation, so this city was eliminated from the final analysis.

The source watersheds for each of the six final cities were merged and analyzed together as a single study area, so while there are more than six source watersheds, results are reported for the aggregated source areas per city.

### Ecosystem services modeling

We applied the InVEST suite of models (Sharp, et al., 2016; version 3.3.1) to calculate ecosystem service delivery in each of the source watersheds under baseline (2007) conditions and with activities implemented. Models included the sediment delivery ratio model (sediment), nutrient delivery ratio model (nutrient), forest carbon edge effect (carbon) and seasonal water yield. Ecosystem services are expressed as the total for each city's source watersheds in terms of mean annual sediment export (tons per year), mean annual nitrogen export (kilograms per year) and total carbon stored in above-ground and below-ground biomass, soil carbon and litter (tonnes).

We estimated the benefits of implementing activities by running the InVEST service models for each activity one at a time, using a set of input land cover rasters where the activity was implemented in every possible location. We restricted activities only to feasible locations: forest/páramo protection was restricted to natural forests, páramo and mangroves; agricultural BMPs were restricted to croplands and pasture; restoration was restricted to shrublands, croplands, secondary vegetation, pasture, degraded/bare areas and other highly impacted areas; riparian restoration was additionally restricted to within 90-meter buffers on both sides of streams.

Marginal values for each activity in each location were then calculated based on the degree to which the activity helps to reach the target change in each ecosystem service. We applied two types of targets for each study area and ecosystem service: 1) for restoration activities (forest/páramo restoration, riparian restoration and agricultural BMPs), the target was defined as a 10 percent improvement (-10 percent for sediment and nitrogen and +10 percent for carbon storage); and 2) for protection, the target was set to avoid 17 percent of potential future degradation.

For agricultural BMPs, forest restoration and riparian restoration, the differences between the baseline scenario and full implementation in all possible locations were used to calculate marginal benefits. Protection was calculated by changing all possible natural land covers to a degraded state, in this case pasture. The marginal benefit of protection (avoided degradation) is the proportion of the change in service on a protected landscape, relative to the total change on a fully degraded landscape:

$$\text{Avoided degradation} = (\text{degraded} - \text{protected}) / (\text{degraded} - \text{baseline}) * 100$$

Final marginal values were expressed as a proportion of the change from each activity relative to the total city-level target change in each service, and were used to generate optimal portfolios in the next step.

## Generating optimal portfolios

The input data to our optimization process is a series of tables summarizing the marginal value of each activity within each spatial decision unit (SDU). SDUs are spatial regions representing the smallest area on which an activity will be implemented. Here, we used a hexagonal grid of 120 hectares based on input from The Nature Conservancy's Colombia staff. For each of the potential management options the table contains the value to each service for each SDU (calculated as the sum of pixel-level marginal values within each SDU).

The optimization problem was to find the cost-minimizing management activity in each SDU that would hit watershed-level environmental targets. We ran the optimization for nitrogen and sediment loading and carbon storage targets individually, and for all three together.

We implemented the optimization using binary integer programming. Formally, the problem is to find the optimal  $\vec{x}_{ij}$ , where the value of each  $x_{ij}$  is 1 if management option  $j$  is chosen for SDU  $i$  and 0 if it is not. We constrained the choice of activity to a single option per SDU by setting  $\sum_j x_{ij} \leq 1$  for each  $i$ . If all the  $x_{ij}$ 's are zero for a given SDU, then the choice is to maintain current (baseline) management.

The optimization problem is

$$\min_{\vec{x}_{ij}} C(\vec{x}_{ij}) \quad (1)$$

$$\text{such that } V_s(\vec{x}_{ij}) > T_s \quad (2)$$

where:

$C(\vec{x}_{ij})$  is the total cost of the selected management options.

$V_s(\vec{x}_{ij})$  is the value to service  $s$  of the SDU management choices. For nitrogen and sediment, this represents the amount that is retained by the landscape. For carbon, this represents increase in carbon storage.

$T_s$  is the target value for each service  $s$ . For nitrogen and sediment this is the target for increased retention. For carbon, it is the target for tons of carbon restored. In each case, the constraint is set up to ensure that the total benefits meet or exceed the goals.

For the optimization with all three targets, we included constraints (2) for all three  $s$  values.

## Ecosystem service return on investment

We applied the InVEST models on the optimal scenarios to calculate the total change in ecosystem services from implementation. To do this, we created new land cover input data by applying the selected activities to all possible land covers within each SDU selected for that activity, based on the same feasibility restrictions outlined above in "Ecosystem services modeling."

We also applied the InVEST seasonal water yield model at this stage to estimate the change in contribution to dry season flow (index of slow flow contribution to streams). These results represent the co-benefit that portfolio implementation might have for water security. Change in the contribution to baseflow ( $Q_b$ , mm) was calculated as the difference between  $Q_b$  from the baseline to the optimal portfolio. The benefit of forest and riparian restoration, agricultural BMPs and the avoided loss in  $Q_b$  from protection were summed to give the total benefit to baseflow contribution. This total is expressed as percent change from the baseline  $Q_b$ .

## Data used

The modeling approach and all data sources were developed and compiled in close collaboration with the technical staff in the office of The Nature Conservancy Colombia. While some local datasets of higher quality were available (e.g., 30-meter resolution DEM for some areas, updated land cover maps for others), we chose to apply national-level datasets, ensuring consistent results across the country that would be comparable in aggregate.

Data type	Source	Model application
Digital elevation model (DEM)	SRTM (Jarvis, et al., 2008)	Sediment, nutrient, seasonal water yield
Precipitation	WorldClim (Hijmans, et al., 2005)	Sediment, nutrient, seasonal water yield
Minimum/maximum monthly temperature	WorldClim (Hijmans, et al., 2005)	Seasonal water yield
Climate zones	Koeppen-Geiger climate zones (Kottek, et al., 2006)	Seasonal water yield
Number of rain events per month	IWMI's Online Climate Summary Service Portal (IWMI, 2009)	Seasonal water yield
Soils	Soils map of Colombia (IGAC, 2003)	Sediment, nutrient, seasonal water yield
Hydrologic soil group	FutureWater HiHydro dataset. (De Boer, 2015)	Seasonal water yield
Land cover and management	Map of continental, marine and coastal ecosystems of Colombia (IDEAM, et al., 2007)	Carbon, sediment, nutrient, seasonal water yield
Land cover-based parameters: USLE C factor, USLE P factor	Peralvo and Coello, 2008	Sediment
Land cover-based parameters: Nitrogen load and nitrogen retention efficiency	Peralvo and Coello, 2008	Nutrient
Land cover-based parameters: above-ground, below-ground, soil and dead carbon pools	Peralvo and Coello, 2008	Carbon
Land cover-based parameters: evapotranspiration coefficient	Peralvo and Coello, 2008	Seasonal water yield

**Table AV.3.** Data used for ecosystem services modeling and optimization

## Biophysical data

Annual precipitation data from Hijmans, et al., (2005) were used in the nutrient model and these data were converted to erosivity (used in the sediment model) based on the empirical formula in Pérez and Mesa (2002). Monthly precipitation events and minimum/maximum monthly temperatures (used in the seasonal water yield model) were also derived from Hijmans, et al., (2005), and potential evapotranspiration was calculated based on the Modified Hargreaves method as described in Droogers and Allen (2002). Number of rain events per month (used in the seasonal water yield model) were obtained from International Water Management Institute (IWMI) Online Climate Summary Service Portal (IWMI, 2009).

Soil erodibility (used in the sediment model) was calculated from soil texture (IGAC, 2003) based on the procedure in Stone and Hilborn (2012).

Land cover data were obtained from the latest national ecosystems map of Colombia (IDEAM, et al., 2007). This map is used most frequently by government agencies for national-scale planning and provides consistent classification across the entire study region. Biophysical parameters associated with land cover and management were derived from Peralvo and Coello (2008).

## Activity costs

Per-hectare costs for activities were obtained from The Nature Conservancy Colombia staff based on historical data for implementing water fund programs in Bogotá, Cali and Medellín. Because we lacked location-specific data for all the study areas, we applied average per-hectare costs for each activity to all source watersheds. We did not have separate cost data for upland versus riparian restoration, so we used the same cost for both activities. Agricultural BMPs in our data set ranged from silvopastoral systems to agroforestry to pasture improvement. We averaged these costs assuming that, when implemented, the water fund would choose the appropriate practice given local conditions.

We found that using average costs resulted in more conservative cost assumptions overall; however, costs can vary widely across the country due to factors such as labor and transportation costs, differing processes for negotiating compensation, landholder expectations and opportunity costs. In addition, land protection typically involves some additional compensation to landholders, negotiated on a case-by-case basis, that was not included in our portfolio costs due to issues of sensitivity around publishing this information. These variations mean that total portfolio budgets should be considered representative rather than definitive.

## Activity effectiveness

Activity implementation results in changes to land cover and associated parameters. The following assumptions were made about parameter changes in areas where activities were implemented:

- Forest protection: without protection, the alternative (avoided degraded state) is conversion to pasture.
- Restoration: we assume restoration is implemented on only 10 percent of the land areas chosen for implementation, based on the experience of The Nature Conservancy Colombia staff in negotiating restoration with landholders. We assume that restored areas are converted to natural forests.
- Riparian restoration: we assume that areas within a 90-meter buffer on both sides of streams are converted to natural forest.
- Agricultural BMPs on croplands: we assume an average reduction in nitrogen load of 61 percent (McDonald and Shemie, 2014; USEPA, 2009); average reduction in USLE\_C of 72 percent (McDonald and Shemie, 2014); USLE\_P was set to the same value as mixed agriculture (Peralvo and Coello, 2008); above-ground, below-ground and dead carbon were unchanged, but soil carbon was increased to match natural forest value.
- Agricultural BMPs on pasture: we applied parameters from Peralvo and Coello (2008) for “silvopastoral systems” where available; others were set to equal natural grassland.

## Limitations

Field data on sediment, nitrogen loads and carbon stocks were not available for the study areas and selected water intake points. While data are available in some rivers that could enable calibration and model validation, most locations would require use of proxy data and other interpolation methods that were outside the scope of this study. For this reason, targets are expressed only in relative terms. Depending on model performance and parameter calibration, the absolute improvement in services may vary, but we assume that our method adequately captures the relative distribution of marginal values—and therefore the optimal locations for activities and the cost needed to reach targets.

The results for avoided degradation assume that all possible areas are degraded equally. More detailed land cover change modeling would enable us to incorporate risk of conversion into the calculation of degradation; however, such modeling

was outside the scope of this study. While we ignore the risk of conversion in our degradation estimates, our approach allows the water funds to target their protection efforts to places where the cost of inaction is highest.

Further, total costs of portfolio implementation should be considered illustrative, as we did not vary ecosystem parameters, costs and targets across the source watersheds of the six cities. In reality, water fund implementation and costs would necessarily incorporate more detailed local and site-based data, and be subject to varying implementation, labor and opportunity costs.

Finally, our results report changes in carbon storage (expressed as mass), not carbon sequestration (typically expressed as a rate over time), which limits the direct comparisons that can be made to Colombia’s national climate change mitigation commitments. Further work to develop estimates of sequestration rates (in combination with land change modeling over time) would help to clarify this contribution.

## References

- De Boer, F. (2016). HiHydroSoil: A High Resolution Soil Map of Hydraulic Properties. Version 1.2. Report FutureWater 134. FutureWater, Wageningen, The Netherlands. Available from <http://www.futurewater.nl/wp-content/uploads/2015/05/HiHydroSoil-A-high-resolution-soil-map-of-hydraulic-properties.pdf>.
- Droogers P. and Allen, R.G. (2002). Estimating Reference Evapotranspiration Under Inaccurate Data Conditions. *Irrigation and Drainage Systems* **16**: 33-45. doi: 10.1023/A:1015508322413
- Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., and Jarvis, A. (2005). Very High Resolution Interpolated Climate Surfaces for Global Land Areas. *International Journal of Climatology* **25**: 1965-1978. doi: 10.1002/joc.1276
- IDEAM, IAvH, IGAC, IIAP, INVEMAR, SINCHI. (2007). Mapa de Ecosistemas Continentales, Costeros y Marinos de Colombia. Escala 1:500.000. Bogotá: Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), Instituto de Investigaciones de Recursos Biológicos Alexander von Humboldt (IAvH), Instituto Geográfico Agustín Codazzi (IGAC), Instituto de Investigaciones Ambientales del Pacífico John von Neumann (IIAP), Instituto de Investigaciones Marinas y Costeras José Benito Vives De Andréis (INVEMAR) e Instituto Amazónico de Investigaciones Científicas (SINCHI).

- Instituto Geográfico Agustín Codazzi (IGAC). (2003). Mapa de Suelos de Colombia, Escala 1:500.000 Bogotá: Instituto Geográfico Agustín Codazzi.
- International Water Management Institute (IWMI). (2009). Online Climate Summary Service Portal: <http://wcatlas.iwmi.org/Default.asp>
- Jarvis, A., Reuter, H.I., Nelson, A., and Guevara, E. (2008). Hole-Filled SRTM for the Globe Version 4. Available from the CGIAR-CSIRO SRTM 90m Database <http://srtm.csi.cgiar.org>.
- Kottek, M., Grieser, J., Beck, C., Rudolf, B., and Rubel, F. (2006). World Map of the Köppen-Geiger Climate Classification Updated. *Meteorologische Zeitschrift* **15**: 259-263. doi: 10.1127/0941-2948/2006/0130.
- McDonald, R.I. and Shemie, D. (2014). Urban Water Blueprint: Mapping Conservation Solutions to the Global Water Challenge. The Nature Conservancy, Washington, D.C., USA. <http://water.nature.org/waterblueprint>
- Peralvo, M. and Coello, X. (2008). Implementación de modelos de funciones hidrológicas para Ecuador y Colombia. Report. Seearth Consulting Group.
- Pérez J. and Mesa, O. (2002). Estimación del Factor de Erosividad de la Lluvia en Colombia: Simposio Latinoamericano de Control de Erosión.
- Sharp, R., Tallis, H.T., Ricketts, T., et al., (2016) InVEST +VERSION+ User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund. Available from <http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/>
- Stone, R.P. and Hilborn, D. (2012). Universal Soil Loss Equation (USLE) Fact Sheet. OMAFRA 12-051. Available from <http://www.omafra.gov.on.ca/english/engineer/facts/12-051.htm>.
- U.S. Environmental Protection Agency (EPA). (2009). STEPL BMP Efficiency Rates. “Reduced Tillage Systems.”



Four out of five large cities can improve water quality through upstream forest protection, reforestation and improved agricultural practices.



Photo: © Bridget Besaw  
[www.bridgetbesaw.com](http://www.bridgetbesaw.com)

# Endnotes

- 1 Matthews, N. (2016). People and Fresh Water Ecosystems: Pressures, Responses and Resilience. *Aquatic Procedia* **6**: 99-105.
- 2 Steffen, W., Richardson, K., Rockström, J., et al. (2015). Planetary Boundaries: Guiding Human Development on a Changing Planet. *Science* **347**: 1259855
- 3 National Research Council of the National Academies. (2013). Sustainability for the Nation: Resource Connection and Governance Linkages. The National Academies Press, Washington, D.C. USA.
- 4 World Economic Forum (WEF). (2016). The Global Risks Report 2016, 11th Edition. World Economic Forum, Geneva, Switzerland.
- 5 Some examples of current water security concerns, especially related to water quantity:
  - Water stress currently affects 2 billion people worldwide, and one in four cities (United Nations, 2016: *The Sustainable Development Goals Report 2016*; United Nations, 2011: *2011 Global Assessment Report on Disaster Risk Reduction: Revealing Risk, Redefining Development*)
  - In internationally reported droughts since 1900, more than 11 million people have died with over 2 billion affected, though many of those deaths occurred during periods of conflict (United Nations, 2011: *2011 Global Assessment Report on Disaster Risk Reduction: Revealing Risk, Redefining Development*).
  - Water-related natural hazards – which include floods, mudslides, storms and related ocean storm surges, heat waves, cold spells, droughts and waterborne diseases – account for 90 percent of all natural hazards (UNESCO 2012: *The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*).
  - OECD estimates 4 billion people living in water scarce areas by 2050, and global water requirements are predicted to be pushed 40 percent beyond sustainable water supplies by 2030 (OECD 2012: *OECD Environmental Outlook to 2050: The Consequences of Inaction*).
  - By 2035, water consumption for energy production is predicted to increase by 85 percent (International Energy Agency 2012: *World Energy Outlook 2012*). The World Bank estimates that GDP growth rates in some regions could decline by up to 6 percent by 2050 as a result of water-related losses in agriculture, income, property, and reductions in health (World Bank 2016: *High and Dry: Climate Change, Water, and the Economy*).
- 6 Sutton M.A., Bleeker A., Howard C.M., et al. (2013). Our Nutrient World: The Challenge to Produce More Food and Energy with Less Pollution. Global Overview of Nutrient Management. Centre for Ecology and Hydrology, on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative. Edinburgh, UK.
- 7 Fogden, J. (2009). Access to Safe Drinking Water and Its Impact on Global Economic Growth. HaloSource, Inc., Washington, USA.
- 8 See note 4.
- 9 World Bank. (2016). High and Dry: Climate Change, Water, and the Economy. World Bank, Washington, D.C., USA.
- 10 World Water Assessment Programme. United Nations Educational, Scientific and Cultural Organization (UNESCO). (2012). The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. UNESCO, Paris, France.
- 11 Butler, D. and Davies, J.W. (2010). Urban Drainage, 3rd Edition. Spon Press, London & New York.
- 12 Richter, B. (2016). Water Share: Using Water Markets and Impact Investment to Drive Sustainability. The Nature Conservancy, Washington, D.C., USA.
- 13 Molden, D., De Fraiture, C., and Rijsberman, F. (2007). Water Scarcity: The Food Factor. *Issues in Science and Technology* **23**: 39-48.
- 14 McCarthy, J.J, Canziani, O.F., Leary, N.A., et al. (2001). Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.
- 15 National Intelligence Council. (2012). Intelligence Community Assessment on Global Water Security. National Intelligence Council, U.S. Department of State, USA.
- 16 Christian-Smith, J., Gleick, P.H., Cooley, H., Allen, L., Vanderwarker, A., and Berry, K.A. (2012). A Twenty-First Century U.S. Water Policy. Oxford University Press, New York, USA.
- 17 Indigenous Peoples Kyoto Water Declaration. (2003). Formulated by indigenous participants at the Third World Water Forum in Kyoto, Japan. Available from [http://portal.unesco.org/science/en/ev.php-URL\\_ID=3886&URL\\_DO=DO\\_TOPIC&URL\\_SECTION=201.html](http://portal.unesco.org/science/en/ev.php-URL_ID=3886&URL_DO=DO_TOPIC&URL_SECTION=201.html) (accessed October 2016).

- 18 United Nations-Water Task Force on Water Security. (2013). Water Security & the Global Water Agenda: A UN-Water Analytical Brief. United Nations University, Ontario, Canada.
- 19 The MDGs and SDGs can be viewed as recent milestones along the journey toward sustainable development. The goals illustrate an evolution over time to appropriately reflect growing challenges around equity, quality of life, and financing. Precursors to these frameworks include the 1987 Brundtland Commission report, which formally recognized the three pillars of sustainable development (environment, social, and economic), and the 1992 Rio Earth Summit, which supported the creation of a global institutional architecture for achieving sustainable development.
- 20 United Nations Development Programme (UNEP). Sustainable Development Goals – Goal 6 Clean Water and Sanitation. Available from <http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-6-clean-water-and-sanitation.html> (accessed October 2016).
- 21 For more information and details on SDG 6, refer to:  
<https://sustainabledevelopment.un.org/sdg6>
- 22 Shah, T. (2016). Increasing Water Security: The Key to Implementing the Sustainable Development Goal. Global Water Partnership Technical Committee. Global Water Partnership, Stockholm, Sweden.
- 23 See note 9.
- 24 See note 9.
- 25 Organisation for Economic Co-operation and Development (OECD). (2016). Measuring Distance to the SDGs Targets: A Pilot Assessment of where OECD Countries Stand. OECD Publishing. Available from <http://www.oecd.org/std/OECD-Measuring-Distance-to-SDGs-Targets-Pilot-Study.pdf> (accessed September 2016).
- 26 United Nations Conference on Trade and Development (UNCTAD). (2014). World Investment Report 2014 Investing in the SDGs: An Action Plan. United Nations, New York and Geneva.
- 27 United Nations (UN). Sustainable Development Goals – Goal 17 Revitalize the global partnership for sustainable development. Available from <http://www.un.org/sustainabledevelopment/globalpartnerships/> (accessed October 2016).
- 28 Matthews, N. and Ringler, C. (2016). Trade-offs and synergies: ICSU's draft framework for understanding the SDGs. CGIAR Research Program on Water, Land and Ecosystems. Available from <https://wle.cgiar.org/thrive/2016/06/28/trade-offs-and-synergies-icsus-draft-framework-understanding-sdgs> (accessed October 2016).
- 29 Cran, M. and Durand, V. (2015). Review of the Integration of Water within the Intended National Determined Contributions (INDCs) for COP21. French Water Partnership and Coalition Eau. Available from [http://www.iwa-network.org/downloads/1448965142-2015%2011%2029\\_Review%20of%20Water%20integration%20in%20INDC\\_VF.pdf](http://www.iwa-network.org/downloads/1448965142-2015%2011%2029_Review%20of%20Water%20integration%20in%20INDC_VF.pdf) (accessed October 2016).
- 30 United Nations. (2016). High Level Panel on Water—Action Plan. Available from [https://sustainabledevelopment.un.org/content/documents/11280HLPW\\_Action\\_Plan\\_DEF\\_11-1.pdf](https://sustainabledevelopment.un.org/content/documents/11280HLPW_Action_Plan_DEF_11-1.pdf) (accessed October 2016).
- 31 Specifically, the Panel calls upon the UNFCCC process to “increase the attention to water in the climate action plan as a key measure to achieve national climate commitments by improving water governance, management and infrastructure for enhanced water security and increased resilience against floods and droughts” (Joint Statement of High Level Panel on Water 2016).
- 32 United Nations (UN). The New Urban Agenda. Available from <https://habitat3.org/the-new-urban-agenda/> (accessed October 2016).
- 33 Water stress is defined as the inability to meet human and ecological demand for water.
- 34 McDonald, R.I. and Shemie, D. (2014). Urban Water Blueprint: Mapping Conservation Solutions to the Global Water Challenge. The Nature Conservancy, Washington, D.C., USA.
- 35 WWF. (2007). Pipedreams? Interbasin Water Transfers and Water Shortages. WWF Global Freshwater Programme, Zeist, Netherlands.
- 36 Ramachandran, S. (2016). The Cost of Interlinking India's Rivers. The Diplomat. Available from <http://thediplomat.com/2016/07/the-cost-of-interlinking-indias-rivers/> (accessed July 2016).
- 37 For the donor basin, a loss of water can lead to drought conditions during dry years. Water transfers, usually accomplished through the construction of one or more dams, can also impair native aquatic wildlife through habitat destruction and barriers to migration (WWF, 2007: *Pipedreams? Interbasin Water Transfers and Water Shortages*). Non-native invasive species as well as disease vectors may be transferred among basins (Gichuki and McCormick, 2008: *International Experiences of Water Transfers: Relevance to India*).
- 38 Gichuki, F. and McCormick, P.G. (2008). International Experiences of Water Transfers: Relevance to India. Strategic Analyses of the National River Linking Project (NRLP) of India Series 2—Proceedings of the Workshop on Analyses of Hydrological, Social and Ecological Issues of the NRLP: 345-371.

- 39 Matthews, N. (2012). Water Grabbing in the Mekong Basin-An Analysis of the Winners and Losers of Thailand's Hydropower Development in Lao PDR. *Water Alternatives* **5**: 392-411.
- 40 See note 15.
- 41 In 2015, the proportion of the world's population with access to improved water sources had increased to 91 percent from 82 percent in 2000 (United Nations, 2016: *The Sustainable Development Goals Report 2016*). However, the United Nations has underscored that not all improved water sources are safely managed, and access is highly variable within countries (Bain, et al. (2014). Fecal Contamination of Drinking-Water in Low- and Middle-Income Countries: A Systematic Review and Meta-Analysis. *PLOS Med* **11**: e1001644). Improved water sources are those that, by the nature of their construction and when properly used, adequately protect the source from outside contamination (WHO/UNICEF Joint Monitoring Programme, see <http://www.wssinfo.org/definitions-methods/watsan-categories/>).
- 42 Magat, W.A. and Viscusi, W.K. (1990). Effectiveness of the EPA's Regulatory Enforcement: The Case of Industrial Effluent Standards. *The Journal of Law & Economics* **33**: 331-360.
- 43 Cooley, H., Ajami, N., Ha, M.-L., Srinivasan, V., Morrison, J., Donnelly, K., and Christian-Smith, J. (2013). Global Water Governance in the 21<sup>st</sup> Century. Pacific Institute, Oakland, California, USA. Available from <http://www.pacinst.org/publication/global-water-governance-in-the-21st-century/> (accessed October 2016).
- 44 Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D., and Savelli H. (eds). (2010). Sick Water? The Central Role of Wastewater Management in Sustainable Development. A Rapid Response Assessment. United Nations Environment Programme, UN-HABITAT, GRID-Arendal. Kenya and Norway.
- 45 Sunday Review Editorial Board. (2016). Fixing Our Broken Water Systems. The New York Times, February 13, 2016. Available from [http://www.nytimes.com/2016/02/14/opinion/sunday/fixing-our-broken-water-systems.html?rref=collection%2Ftimestopic%2FWater%20Pollution&action=click&contentCollection=timestopics&region=stream&module=stream\\_unit&version=latest&contentPlacement=71&pgtype=collection&r=2](http://www.nytimes.com/2016/02/14/opinion/sunday/fixing-our-broken-water-systems.html?rref=collection%2Ftimestopic%2FWater%20Pollution&action=click&contentCollection=timestopics&region=stream&module=stream_unit&version=latest&contentPlacement=71&pgtype=collection&r=2) (accessed October 2016).
- 46 See note 34.
- 47 Liu, Y., Hejazi, M., Kyle, P., Kim, S.H., Davies, E., Miralles, D.G., Teuling, A.J., He, Y., and Niyogi, D. (2016). Global and Regional Evaluation of Energy for Water. *Environmental Science & Technology* **50**: 9736-9745.
- 48 See note 47.
- 49 Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., et al. (2010). Global Threats to Human Water Security and River Biodiversity. *Nature* **467**: 555-561.
- 50 International Energy Agency (IEA). (2012). World Energy Outlook 2012. OECD/IEA, Paris, France.
- 51 Miller, K., Costa, K., and Cooper, D. (2012). How to Upgrade and Maintain Our Nation's Wastewater and Drinking-Water Infrastructure. Center for American Progress, Washington, D.C., USA.
- 52 In 2013, the American Society of Civil Engineers gave the United States a grade of D (Poor) for its wastewater infrastructure, noting the challenge of replacing aging pipes and impacts related to sewer overflows (American Society of Civil Engineers, 2013: *2013 Report Card for America's Infrastructure*).
- 53 Dobbs, R., Pohl, H., Lin, D.Y., Mischke, J., Garemo, N., Hexter, J., Matzinger, S., Palter, R. and Nanavatty, R. (2013). Infrastructure Productivity: How to Save \$1 trillion a Year. McKinsey Global Institute. McKinsey & Company.
- 54 These numbers are broken down as follows: 34.35 percent from municipal capital expenditure, 53.64 percent from municipal operating expenditure, 0.17 percent from industrial capital expenditure, 6.26 percent from industrial operating expenditure, 2.03 percent from point of use treatment, and 0.63 percent from irrigation (RobecoSAM, 2015: *RobecoSAM Study Water: The Market of the Future*).
- 55 Brunette, V. and Germain, R.H. (2003). Forest Management in the New York City Watershed. Paper submitted to the XII World Forestry Congress 2003 in Québec City, Canada. Available from <http://www.fao.org/docrep/article/wfc/xii/0649-b3.htm> (accessed September 2016).
- 56 New York State Department of Environmental Conservation. New York City Water Supply. Available from <http://www.dec.ny.gov/lands/25599.html> (accessed September 2016).
- 57 Gartner, T., Mulligan, J., Schmidt, R., and Gunn, J. (eds). (2013). Natural Infrastructure: Investing in Forested Landscapes for Source Water Protection in the United States. World Resources Institute, Washington, D.C., USA.
- 58 See note 34.
- 59 Eller, D. (2015). Des Moines Water Quality Suit Slated for Trial in 2016. The Des Moines Register, July 15, 2015. Available from <http://www.desmoinesregister.com/story/money/agriculture/2015/07/15/des-moines-water-works-lawsuit-buena-vista-calhoun-sac-counties-water-quality/30191169/> (accessed September 2016).

- 60 See note 57.
- 61 Vincent, J.R., Ahmad, I., Adnan, N., Burwell III, W.B., Pattanayak, S.K., Tan-Soo, J.S., and Thomas, K. (2016). Valuing Water Purification by Forests: An Analysis of Malaysian Panel Data. *Environmental and Resource Economics* **64**: 59-80.
- 62 Ozment, S., DiFrancesco, K., and Gartner, T. (2015). The Role of Natural Infrastructure in the Water, Energy and Food Nexus. Nexus Dialogue Synthesis Papers. IUCN, Gland, Switzerland.
- 63 See note 62.
- 64 Bolger, R., D. Monsma, R. Nelson. (2009). Sustainable Water Systems: Step One—Redefining the Nation’s Infrastructure Challenge. A report of the Aspen Institute’s Dialogue on Sustainable Water Infrastructure in the U.S. The Aspen Institute, Washington, D.C., USA.
- 65 See note 34.
- 66 Shemie, D., Vigerstøl, K., Mu, Q., Karres, N, and Wang, L. (2016). China’s Urban Water Blueprint. The Nature Conservancy, Beijing, China.
- 67 See note 34.
- 68 Lehner, B. and Grill, G. (2013). Global River Hydrography and Network Routing: Baseline Data and New Approaches to Study the World’s Large River Systems. *Hydrological Processes* **27**: 2171–2186. Data available at [www.hydrosheds.org/page/hydrobasins/](http://www.hydrosheds.org/page/hydrobasins/).
- 69 United Nations, Department of Economic and Social Affairs, Population Division. (2015). World Urbanization Prospects: The 2014 Revision. United Nations, New York, USA.
- 70 McNutt, M. (2014). The Drought You Can’t See. *Science* **345**:1543-1543.
- 71 Stromberg, J.C., Tiller, R., and Richter, B. (1996). Effects of Groundwater Decline on Riparian Vegetation of Semiarid Regions: The San Pedro, Arizona. *Ecological Applications* **6**:113-131.
- 72 Kundzewicz, Z.W. and Doell, P. (2009). Will Groundwater Ease Freshwater Stress under Climate Change?. *Hydrological Sciences Journal* **54**: 665-675.
- 73 Richey, A.S., Thomas, B.F., Lo, M.H., Famiglietti, J.S., Swenson, S., and Rodell, M. (2015). Uncertainty in Global Groundwater Storage Estimates in a Total Groundwater Stress Framework. *Water Resources Research* **51**: 5198-5216.
- 74 Foster, S.S.D. and Chilton, P.J. (2003). Groundwater: The Processes and Global Significance of Aquifer Degradation. *Philosophical Transactions of the Royal Society B: Biological Sciences* **358**: 1957-1972.
- 75 See note 73.
- 76 Richey, A.S., Thomas, B.F., Lo, M.H., Reager, J.T., Famiglietti, J.S., Voss, K., Swenson, S., and Rodell, M. (2015). Quantifying Renewable Groundwater Stress with GRACE. *Water Resources Research* **51**: 5217-5238.
- 77 Döll, P., Hoffmann-Dobrev, H., Portmann, F.T., Siebert, S., Eicker, A., Rodell, M., Strassberg, G., and Scanlon, B.R. (2012). Impact of Water Withdrawals from Groundwater and Surface Water on Continental Water Storage Variations. *Journal of Geodynamics* **59**: 143-156.
- 78 Shah, T., Burke, J., Villholth, K., et al. (2007). Groundwater: A Global Assessment of Scale and Significance. Pages 395-423 in Molden, D. (ed.). *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. Earthscan, London, UK & International Water Management Institute (IWMI), Colombo, Sri Lanka.
- 79 See note 72.
- 80 Famiglietti, J.S. (2014). The Global Groundwater Crisis. *Nature Climate Change* **4**: 945-948.
- 81 Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Döll, P., Kabat, P., Jiménez, B., Miller, K.A., Oki, T., Sen, Z., and Shiklomanov, I.A. (2007). Freshwater Resources and Their Management. Pages 173-210 in Parry, M.L., et al. (eds). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.
- 82 See note 72.
- 83 The Nature Conservancy. Texas Freshwater Fact Sheet. Available from <http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/texas/texas-freshwater-fact-sheet.pdf> (accessed October 2016).
- 84 Save Our Springs Alliance. Edwards Aquifer. Available from <http://www.sosalliance.org/28-education.html> (accessed October 2016).
- 85 Goldman, R.L., Benitez, S., Calvache, A., and Ramos, A. (2010). Water Funds: Protecting Watersheds for Nature and People. The Nature Conservancy, Arlington, Virginia, USA.
- 86 Buytaert, W., Wyseure, G., De Bièvre, B., and Deckers, J. (2005). The Effect of Land-Use Changes on the Hydrological Behaviour of Histic Andosols in South Ecuador. *Hydrologic Processes* **19**: 3985–3997.

- 87 Oakleaf, J.R., Kennedy, C.M., Baruch-Mordo, S., West, P.C., Gerber, J.S., Jarvis, L., and Kiesecker, J. (2015). A World at Risk: Aggregating Development Trends to Forecast Global Habitat Conversion. *PLOS ONE* **10**: e0138334.
- 88 Brauman, K. A., Richter, B. D., Postel, S., Malsy, M., and Flörke, M. (2016). Water Depletion: An Improved Metric for Incorporating Seasonal and Dry-Year Water Scarcity into Water Risk Assessments. *Elementa: Science of the Anthropocene* **4**: 000083.
- 89 Howarth, R. W. (2008). Coastal Nitrogen Pollution: A Review of Sources and Trends Globally and Regionally. *Harmful Algae* **8**: 14–20.
- 90 Oakleaf, J.R. (2016). Human Modification. Unpublished data. Retrieved from Jim Oakleaf, The Nature Conservancy (accessed July 2016).
- 91 See note 90.
- 92 National Oceanic and Atmospheric Administration (NOAA). Categories of Pollution: Point Source. Available from <http://oceanservice.noaa.gov/education/kits/pollution/03pointsource.html> (accessed October 2016).
- 93 United Nations Environment Programme (UNEP). (2010). Clearing the Waters: A Focus on Water Quality Solutions. UNEP, Nairobi, Kenya.
- 94 United Nations. (2015). Wasterwater Management: A UN-Water Analytical Brief. Available from [http://www.unwater.org/fileadmin/user\\_upload/unwater\\_new/docs/UN-Water\\_Analytical\\_Brief\\_Wastewater\\_Management.pdf](http://www.unwater.org/fileadmin/user_upload/unwater_new/docs/UN-Water_Analytical_Brief_Wastewater_Management.pdf) (access October 2016).
- 95 Lall, U., Heikkila, T., Brown, C., and Siegfried, T. (2008). Water in the 21st Century: Defining the Elements of Global Crises and Potential Solutions. *Journal of International Affairs* **61**: 1-17.
- 96 Wu, C., Maurer, C., Wang, Y., Xue, S., and Davis, D.L. (1999). Water Pollution and Human Health in China. *Environmental Health Perspectives* **107**: 251-256.
- 97 See note 93.
- 98 U.S. Environmental Protection Agency (EPA). What is Nonpoint Source?. Available from <https://www.epa.gov/polluted-runoff-nonpoint-source-pollution/what-nonpoint-source> (accessed October 2016).
- 99 Rissman, A.R. and Carpenter, S.R. (2015). Progress on Nonpoint Pollution: Barriers & Opportunities. *Daedalus* **144**: 35-47.
- 100 See note 95.
- 101 See note 34.
- 102 Restrepo, J.D., Park, E., Aquino, S., and Latrubesse, E.M. (2016). Coral Reefs Chronically Exposed to River Sediment Plumes in the Southwestern Caribbean: Rosario Islands, Colombia. *Science of the Total Environment* **553**: 316-329.
- 103 International Society for Reef Studies (ISRS). (2004). The Effects of Terrestrial Runoff of Sediments, Nutrients and Other Pollutants on Coral Reefs. Briefing Paper 3. International Society for Reef Studies, pp: 18. Available from <http://coralreefs.org/wp-content/uploads/2014/05/ISRS-Briefing-Paper-3-Water-Quality.pdf> (accessed October 2016).
- 104 U.S. Environmental Protection Agency (EPA). (2015). A Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution. EPA Office of Water. Available from <https://www.epa.gov/sites/production/files/2015-04/documents/nutrient-economics-report-2015.pdf> (accessed October 2016).
- 105 See note 34.
- 106 See note 34.
- 107 See note 34.
- 108 See note 34.
- 109 See note 12.
- 110 Water consumption refers to water removed for use and not returned to its source. Water withdrawal refers to the total volume removed from a water source such as a lake or river. A portion of this water may be returned to the source where it would become available to be used again. See “Withdrawal vs. Consumption,” available from <http://sustainabilityreport.duke-energy.com/2008/water/withdrawal.asp>.
- 111 See note 88.
- 112 See note 34.
- 113 See note 88.
- 114 See note 88.
- 115 See note 34.
- 116 See note 88.
- 117 Bradshaw, C.J., Sodhi, N.S., Peh, K.S.H., and Brook, B.W. (2007). Global Evidence that Deforestation Amplifies Flood Risk and Severity in the Developing World. *Global Change Biology* **13**: 2379-2395.

- 118 A river or stream's flow regime is variability in its water flow throughout the course of a year in response to precipitation, temperature, evapotranspiration, and watershed characteristics.
- 119 Base flow is the portion of stream flow that results from seepage of water from the ground into a channel slowly over time. It is the primary source of running water in a stream during dry weather.
- 120 Bruijnzeel, L.A. (2004). Hydrological Functions of Tropical Forests: Not Seeing the Soil for the Trees?. *Agriculture, Ecosystems & Environment* **104**: 185-228.
- 121 Dudley, N. and Stolton, S. (2003). Running Pure: The Importance of Forest Protected Areas to Drinking Water. World Bank/WWF Alliance for Forest Conservation and Sustainable Use.
- 122 See note 120.
- 123 Bruijnzeel, L.A. (2016). Hydrological Impacts of Tropical Land Degradation, Natural Regeneration and Reforestation. Presentation on AGU Chapman Conference: *Emerging Issues in Tropical Ecohydrology*. Cuenca, Ecuador, 09 June 2016.
- 124 Lacombe, G., Ribolzi, O., de Rouw, A., et al. (2016). Contradictory Hydrological Impacts of Afforestation in the Humid Tropics Evidenced by Long-Term Field Monitoring and Simulation Modelling. *Hydrology and Earth Systems Sciences* **20**: 2691-2704.
- 125 Nunes, A.N., De Almeida, A.C., and Coelho, C.O. (2011). Impacts of Land Use and Cover Type on Runoff and Soil Erosion in a Marginal Area of Portugal. *Applied Geography* **31**: 687-699.
- 126 Sharma, R.D., Sarkar, R., and Dutta, S. (2013). Run-Off Generation from Fields with Different Land Use and Land Covers Under Extreme Storm Events. *Current Science(Bangalore)* **104**: 1046-1053.
- 127 Chen, X., Zhang, Z., Chen, X., and Shi, P. (2009). The Impact of Land Use and Land Cover Changes on Soil Moisture and Hydraulic Conductivity Along the Karst Hillslopes of Southwest China. *Environmental Earth Sciences* **59**: 811-820.
- 128 Krishnaswamy, J., Bonell, M., Venkatesh, B., Purandara, B.K., Rakesh, K.N., Lele, S., Kiran, M.C., Reddy, V., and Badiger, S. (2013). The Groundwater Recharge Response and Hydrologic Services of Tropical Humid Forest Ecosystems to Use and Reforestation: Support for the "Infiltration-Evapotranspiration Trade-Off Hypothesis." *Journal of Hydrology* **498**: 191-209.
- 129 Kaimowitz, D. (2005). Useful Myths and Intractable Truths: The Politics of the Link Between Forests and Water in Central America. Pages 86-98 in Bonell, M. and Bruijnzeel, L.A. (eds). *Forest, Water and People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water Management*. Cambridge University Press, Cambridge, UK.
- 130 See note 120.
- 131 Ogden, F.L., Crouch, T.D., Stallard, R.F., and Hall, J.S. (2013). Effect of Land Cover and Use on Dry Season River Runoff, Runoff Efficiency, and Peak Storm Runoff in the Seasonal Tropics of Central Panama. *Water Resources Research* **49**: 1-20.
- 132 See note 121.
- 133 See note 123.
- 134 Beschta, R. L. and Kauffman, J.B. (2000). Restoration of Riparian Systems—Taking a Broader View. Pages 323–328 in Wigington, J.P.J., Jr., and Beschta, R.L. (eds.). *Riparian Ecology and Management in Multi-Land Use Watersheds*. American Water Resources Association. Middleburg, VA, USA.
- 135 Halliday, S.J., Skeffington, R.A., Wade, A.J., Bowes, M.J., Read, D.S., Jarvie, H.P., and Loewenthal, M. (2016). Riparian Shading Controls Instream Spring Phytoplankton and Benthic Algal Growth. *Environmental Science: Processes & Impacts* **18**: 677-689.
- 136 See note 34.
- 137 Approximately 70 percent of the Mackinaw watershed is agricultural land, mostly growing corn and soybeans.
- 138 Illinois is one of the most highly drained states in the Upper Mississippi River Basin, with 4.7 million hectares currently estimated as drained by tiles.
- 139 Alexander, R., Smith, R., Schwarz, G., Boyer, E., Nolan, J., and Brakebill, J. (2008). Differences in Phosphorus and Nitrogen Delivery to the Gulf of Mexico from the Mississippi River Basin. *Environmental Science & Technology* **42**: 822-830.
- 140 Smiciklas, K.D., Moore, A.S., and Adams, J.C. (2008). Fertilizer Nitrogen Practices and Nitrate Levels in Surface Water within an Illinois Watershed. *Journal of Natural Resources & Life Sciences Education* **37**:14-19.

- 141 The Conservation Reserve Program is a land conservation program administered by the U.S. Farm Service Agency. In exchange for a yearly rental payment, farmers enrolled in the program agree to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. The long-term goal of the program is to re-establish valuable land cover to help improve water quality, prevent soil erosion, and reduce loss of wildlife habitat. For more information, see <http://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/index>.
- 142 See note 34.
- 143 Secretaría de Desarrollo Social. (2010). Huracán Alex en Nuevo León, la memoria. Riesgos, testimonios y acción social. Monterrey, Nuevo León. Available from [http://www.nl.gob.mx/sites/default/files/4-huracan\\_alex\\_en\\_nuevo\\_leon\\_la\\_memoria\\_riesgos\\_testimonios\\_y\\_accion\\_social\\_v2.pdf](http://www.nl.gob.mx/sites/default/files/4-huracan_alex_en_nuevo_leon_la_memoria_riesgos_testimonios_y_accion_social_v2.pdf) (accessed October 2016). (In Spanish).
- 144 Cázares Rodríguez, J.E. (2015). Evaluation of Flood Mitigation Strategies for the Santa Catarina Watershed using a Multi-Model Approach. Master's Thesis. Arizona State University. Available from [https://s3-us-west-2.amazonaws.com/gios-web-img-docs/dcde/website/documents/JorgeCazares\\_FinalThesis\\_2015.pdf](https://s3-us-west-2.amazonaws.com/gios-web-img-docs/dcde/website/documents/JorgeCazares_FinalThesis_2015.pdf)
- 145 Noticieros Televisa. (July 15, 2010). Incalculables, daños de 'Alex' a agricultura y ganadería. Obtenido de Noticieros Televisa: <http://www2.esmas.com/noticierostelevisa/desastre-inundacion-nuevo-leon-coahuila-tamaulipas-norte/186867/incalculables-danos-alex-agricultura-y-ganaderia>.
- 146 Estrada, J. (June 29, 2011). Intensa sequía en Nuevo León provoca pérdidas millonarias. Obtenido de Expansion: <http://expansion.mx/nacional/2011/06/29/intensa-sequia-en-nuevo-leon-provoca-perdidas-millonarias>.
- 147 CONAGUA. (2012). Programa Hídrico Regional Visión 2030 Región Hidrológico-Administrativa VI Río Bravo. [www.pronacose.gob.mx](http://www.pronacose.gob.mx). Available from <http://www.pronacose.gob.mx/pronacose14/contenido/documentos/VI%20PHOCRB.pdf>. (In Spanish).
- 148 Hesselbach M.H., Sánchez de Llanos J.A., Reyna-Sáenz, F., García Moral, F.J., León S.J., Torres-Origel F., and Gondor A. (2016). Plan de Conservación del Fondo de Agua Metropolitano de Monterrey, Primera Parte. México. The Nature Conservancy.
- 149 Bremer, L.L. and Farley, K.A. (2010). Does Plantation Forestry Restore Biodiversity or Create Green Deserts? A Synthesis of the Effects of Land-Use Transitions on Plant Species Richness. *Biodiversity and Conservation* **19**: 3893-3915.
- 150 Farley, K.A., Jobbág, E.G., and Jackson, R.B. (2005). Effects of Afforestation on Water Yield: A Global Synthesis with Implications for Policy. *Global Change Biology* **11**:1565–1576.
- 151 Muradian, R., Corbera, E., Pascual, U., Kosoy, N., and May, P.H. (2010). Reconciling Theory and Practice: An Alternative Conceptual Framework for Understanding Payments for Environmental Services. *Ecological Economics* **69**: 1202–1208.
- 152 All figures/statements are cited from Houghton, et al. (2012). Carbon Emissions from Land Use and Land-Cover Change. *Biogeosciences* **9**: 5125-5142.
- 153 Houghton, R.A., House, J.I., Pongratz, J., Van der Werf, G.R., DeFries, R.S., Hansen, M.C., Quéré, C.L., and Ramankutty, N. (2012). Carbon Emissions from Land Use and Land-Cover Change. *Biogeosciences* **9**: 5125-5142.
- 154 Van der Werf, G.R., Morton, D.C., DeFries, R.S., Olivier, J.G., Kasibhatla, P.S., Jackson, R.B., Collatz, G.J., and Randerson, J.T. (2009). CO<sub>2</sub> Emissions from Forest Loss. *Nature Geoscience* **2**: 737-738.
- 155 For our climate change mitigation analyses, we convert above-ground biomass to carbon using a conversion factor of 0.5 based on IPCC guidelines (IPCC 2003: *Good Practice Guidance for Land Use, Land-Use Change and Forestry*). When converting units of carbon to carbon dioxide, we use their atomic mass ratio (44/12 = 3.67). For additional reference, one gigatonne of carbon is equal to one billion tonnes of carbon.
- 156 Zarin, D.J., Harris, N.L., Baccini, A., et al., (2016). Can Carbon Emissions from Tropical Deforestation Drop by 50% in 5 Years?. *Global Change Biology* **22**: 1336-1347.
- 157 Houghton, R.A., Byers, B., and Nassikas, A.A. (2015). A Role for Tropical Forests in Stabilizing Atmospheric CO<sub>2</sub>. *Nature Climate Change* **5**: 1022-1023.
- 158 Joosten, H. (2009). The Global Peatland CO<sub>2</sub> Picture: Peatland Status and Emissions in all Countries of the World. Produced for the UN-FCCC meetings in Bangkok, September/October 2009. Available from [https://unfccc.int/files/kyoto\\_protocol/application/pdf/draftpeatlandco2report.pdf](https://unfccc.int/files/kyoto_protocol/application/pdf/draftpeatlandco2report.pdf) (accessed October 2016).

- 159 Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). (2014). Potentials for Greenhouse Gas Mitigation in Agriculture: Review of Research Findings, Options for Mitigation and Recommendations for Development Cooperation. Federal Ministry for Economic Cooperation and Development (BMZ) & GIZ, Germany. Available from <https://www.giz.de/fachexpertise/downloads/giz2014-en-potentials-greenhouse-gas-mitigation.pdf> (accessed October 2016).
- 160 Wiedinmyer, C. and Hurteau, M.D. (2010). Prescribed Fire as a Means of Reducing Forest Carbon Emissions in the Western United States. *Environmental Science & Technology* **44**: 1926-1932.
- 161 Intergovernmental Panel on Climate Change (IPCC). (2003). Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC National Greenhouse Gas Inventories Programme, Hayama, Kanagawa, Japan. Available from [http://www.ipcc-nccc.iges.or.jp/public/gpglucf/gpglucf\\_files/GPG\\_LULUCF\\_FULL.pdf](http://www.ipcc-nccc.iges.or.jp/public/gpglucf/gpglucf_files/GPG_LULUCF_FULL.pdf) (accessed October 2016).
- 162 Poeplau, C. and Don, A. (2015). Carbon Sequestration in Agricultural Soils via Cultivation of Cover Crops—A Meta-Analysis. *Agriculture, Ecosystems & Environment* **200**: 33-41.
- 163 United Nations Framework Convention on Climate Change (UNFCCC). Intended Nationally Determined Contributions (INDCs). Submitted INDCs. Available from <http://www4.unfccc.int/submissions/inde/Submission%20Pages/submissions.aspx> (accessed October 2016). Note that the European Union submitted one INDC representing its 28 member countries.
- 164 Food and Agriculture Organization of the United Nations (FAO). (2016). The Agriculture Sectors in The Intended Nationally Determined Contributions: Analysis. By Strohmaier, R., Rioux, J., Seggel, A., Meybeck, A., Bernoux, M., Salvatore, M., Miranda, J., and Agostini, A. Environment and Natural Resources Management Working Paper No. 62. FAO, Rome, Italy. Available from <http://www.fao.org/3/a-i5687e.pdf> (accessed November 2016).
- 165 See note 164.
- 166 See note 164.
- 167 Intergovernmental Panel on Climate Change (IPCC). Land Use, Land-Use Change and Forestry. Available from [http://www.ipcc.ch/ipccreports/sres/land\\_use/index.php?idp=3](http://www.ipcc.ch/ipccreports/sres/land_use/index.php?idp=3) (accessed October 2016).
- 168 Charman, D. (2002). Peatlands and Environmental Change. John Wiley & Sons Ltd., London, UK and New York, USA.
- 169 Parish, F., Sirin, A., Charman, D., Joosten, H., Minayeva, T., Silvius, M., and Stringer, L. (2008). Assessment on Peatlands, Biodiversity and Climate Change: Main Report. Global Environment Centre, Kuala Lumpur and Wetlands International, Wageningen, The Netherlands.
- 170 Page, S.E., Rieley, J.O., and Banks, C.J. (2011). Global and Regional Importance of the Tropical Peatland Carbon Pool. *Global Change Biology* **17**: 798–818.
- 171 See note 170.
- 172 Parish, F., Sirin, A., Charman, D., Joosten, H., Minayeva, T., Silvius, M., and Stringer, L. (2008). Assessment on Peatlands, Biodiversity and Climate Change: Main Report. Global Environment Centre, Kuala Lumpur and Wetlands International, Wageningen, The Netherlands.
- 173 Waddington, J.M. and Warner, K. (2001). Atmospheric CO<sub>2</sub> Sequestration in Restored Mined Peatlands. *Ecoscience* **8**: 359-368.
- 174 See note 167.
- 175 Pan, Y., Birdsey, R.A., Fang, J., et al., (2011). A Large and Persistent Carbon Sink in the World's Forests. *Science* **333**: 988-993.
- 176 Of this carbon, 44% is in soil (to 1-m depth), 42% is in live biomass (above and below ground), 8% is in deadwood, and 5% is in litter (Pan, et al., 2011: *A Large and Persistent Carbon Sink in the World's Forests*). For additional reference, one gigatonne of carbon is equal to one petagram of carbon.
- 177 Lal, R. (2010). Managing Soils and Ecosystems for Mitigating Anthropogenic Carbon Emissions and Advancing Global Food Security. *BioScience* **60**: 708-721.
- 178 See note 175.
- 179 See note 177.
- 180 Victoria, R., Banwart, S., Black, H., Ingram, J., Joosten, H., Milne, E., Noellemyer, E., and Baskin, Y. (2012). The Benefits of Soil Carbon. Pages 19-33 in UNEP Yearbook: *Emerging Issues in Our Global Environment 2012*. UNEP, Nairobi, Kenya.
- 181 Scharlemann, J.P.W., Tanner, E.V.J., Hiederer, R., and Kapos V. (2014) Global soil carbon: understanding and managing the largest terrestrial carbon pool. *Carbon Management* **5**:81-91.

- 182 See note 177.
- 183 Gullison, R.E., Frumhoff, P.C., Canadell, J.G., et al., (2007). Tropical Forests and Climate Policy. *Science* **316**: 985-986.
- 184 See note 157.
- 185 See note 156.
- 186 See note 156.
- 187 Jackson, R.B., Canadell, J.G., Le Quéré, C., Andrew, R.M., Korsbakken, J.I., Peters, G.P., and Nakicenovic, N. (2016). Reaching Peak Emissions. *Nature Climate Change* **6**: 7-10. Supplementary information.
- 188 Hansen, M.C., Potapov, P.V., Moore, R., et al., (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* **342**: 850-853. Data available online from: <http://earthenginepartners.appspot.com/science-2013-global-forest>.
- 189 World Resources Institute (WRI). (2014). Atlas of Forest Landscape Restoration Opportunities. World Resources Institute, Washington, D.C., USA. Available from [www.wri.org/forest-restoration-atlas](http://www.wri.org/forest-restoration-atlas).
- 190 Arino, O., Ramos Perez, J.J., Kalogirou, V., Bontemps, S., Defourny, P., Van Bogaert, E. (2012). Global Land Cover Map for 2009 (GlobCover 2009). European Space Agency (ESA) and Université catholique de Louvain (UCL). Available from [http://due.esrin.esa.int/page\\_globcover.php](http://due.esrin.esa.int/page_globcover.php) (accessed July 2016).
- 191 Stabilizing temperature increase to below 2 degrees relative to pre-industrial levels will require an urgent and fundamental departure from baseline scenarios. We use two Representative Concentration Pathways (RCPs) to estimate the potential contribution of three land-based mitigation activities (avoided tropical forest conversion; reforestation; and cover crops) to the reduction in carbon dioxide emissions that is needed in the year 2050 to drop from a baseline emission scenario to an emission scenario that aims to keep global warming likely below 2 degrees Celsius above pre-industrial temperatures. We estimate that the ceiling of climate change mitigation potential across urban source watersheds could help fill 16 percent of the total mitigation across all emission sectors in the year 2050 by dividing the contribution of climate change mitigation potential (10.17 gigatonnes of carbon dioxide (CO<sub>2</sub>)) by the difference in CO<sub>2</sub> emissions projected in the year 2050 between RCP 8.5 and RCP 2.6 (62.8 gigatonnes of CO<sub>2</sub>). The Representative Concentration Pathways make projections of 21st century pathways of greenhouse gas (GHG) emissions and atmospheric concentration based on scenarios of population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy.
- The RCP 8.5 is a so-called baseline scenario, meaning it corresponds with scenarios that don't include additional efforts to constrain emissions, while RCP 2.6 is representative of a scenario that aims to keep global warming *likely* below 2 degrees Celsius above pre-industrial levels. The IPCC uses "likely" to quantitatively characterize an outcome with 66 to 100 percent probability. We selected the year 2050 because Meinshausen and others (2009) report that the level of emissions in 2050 is a good indicator of the probability that temperature warming will not exceed 2 degrees Celsius relative to pre-industrial temperatures (Meinshausen, et al. (2009). Greenhouse-gas Emission Targets for Limiting Global Warming to 2 Degrees Celsius. *Nature* **458**: 1158-1162). While these results are put in the context of CO<sub>2</sub> emissions, reducing emissions of non-CO<sub>2</sub> agents is also an important element of mitigation strategies. These land-based activities can also be effective in mitigating non-CO<sub>2</sub> agents that also have a significant impact on climate change. It's also important to note that while RCP 2.6 was used to represent a scenario with a likely chance at limiting temperature rise above 2 degrees Celsius, there are many different pathways for such a transition to happen and the world is not limited to this specific pathway.
- 192 Le Quéré, C., Moriarty, R., Andrew, R. M., et al. (2015). Global Carbon Budget 2015. *Earth System Science Data* **7**: 349-396.
- 193 Intergovernmental Panel on Climate Change (IPCC). (2013). Annex II: Climate System Scenario Tables. In Stocker, T.F., et al. (eds). *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- 194 Minnemeyer, S., Laestadius, L., Sizer, N., Saint-Laurent, C., and Potapov, P. (2011). A World of Opportunity for Forest and Landscape Restoration. Brochure for *Atlas of Forest and Landscape Restoration Opportunities*. World Resources Institute, Washington, D.C., USA. Available from [http://www.wri.org/sites/default/files/world\\_of\\_opportunity\\_brochure\\_2011-09.pdf](http://www.wri.org/sites/default/files/world_of_opportunity_brochure_2011-09.pdf). Also see [www.wri.org/forest-restoration-atlas](http://www.wri.org/forest-restoration-atlas) (accessed September 2016).
- 195 United Nations, Department of Economic and Social Affairs, Population Division. (2014). World Urbanization Prospects: The 2014 Revision—Highlights. United Nations, New York, USA. Available from <https://esa.un.org/unpd/wup/Publications/Files/WUP2014-Highlights.pdf> (accessed October 2016).

- 196 The Nature Conservancy, Science for Nature and People Partnership (SNAP). (2015). An Opportunity for Water Security in 25 Cities in Latin America: Invest in Nature to Increase Water Security. The Nature Conservancy, Latin America Region. Available from [http://waterfunds.org/sites/default/files/booklet\\_tnc\\_letter\\_ingles\\_non\\_methodology\\_baja.pdf](http://waterfunds.org/sites/default/files/booklet_tnc_letter_ingles_non_methodology_baja.pdf) (accessed October 2016).
- 197 The Nature Conservancy-Brazil. Movimento Água para São Paulo. Available from [http://www.nature.org/cs/groups/webcontent/@web/@lakesrivers/documents/document/prd\\_287803.pdf](http://www.nature.org/cs/groups/webcontent/@web/@lakesrivers/documents/document/prd_287803.pdf) (accessed October 2016). (In Portuguese).
- 198 Borgo, M. and Tiepolo, G. (2012). Restoring the Cantareira Water Supply System: Carbon, Community and Biodiversity Initiative. The Nature Conservancy, Brazil. Available from [https://s3.amazonaws.com/CCBA/Projects/Watershed\\_Restoration\\_in\\_the\\_Cantareira\\_Water\\_System%3ACarbon%2C\\_Community\\_and\\_Biodiversity\\_Initiative/PDD+CPA+Cantareira+Cachoeira\\_08May11.pdf](https://s3.amazonaws.com/CCBA/Projects/Watershed_Restoration_in_the_Cantareira_Water_System%3ACarbon%2C_Community_and_Biodiversity_Initiative/PDD+CPA+Cantareira+Cachoeira_08May11.pdf)
- 199 See note 198.
- 200 UN Water. Climate change adaptation is mainly about water...Available from [http://www.unwater.org/downloads/UNWclimatechange\\_EN.pdf](http://www.unwater.org/downloads/UNWclimatechange_EN.pdf) (accessed July 2016).
- 201 Intergovernmental Panel on Climate Change (IPCC). (2014). Summary for Policymakers. Pages 1-32 in Field, C.B., et al., (eds). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- 202 Blunden, J. and Arndt, D.S. (eds). (2016). State of the Climate in 2015. *Bulletin of the American Meteorological Society* **97**: S1-S275.
- 203 See note 201.
- 204 Joyce, L.A., Running, S.W., Breshears, D.D., Dale, V.H., Malmsheimer, R.W., Sampson, R.N., Sohngen, B., and Wood-all, C.W. (2014): Chapter 7: Forests. Pages 175-194 in Melillo, J.M., Richmond, T.C., and Yohe, G.W. (eds). *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program.
- 205 National Flood Insurance Program. FloodSmart.gov. Flood after Fire Risks. Available from [https://www.floodsmart.gov/toolkits/flood/downloads/FS\\_FloodRisksFloodAfterFire.pdf](https://www.floodsmart.gov/toolkits/flood/downloads/FS_FloodRisksFloodAfterFire.pdf) (accessed October 2016).
- 206 See note 201.
- 207 Segan, D.B., Murray, K.A., and Watson, J.E. (2016). A Global Assessment of Current and Future Biodiversity Vulnerability to Habitat Loss–Climate Change Interactions. *Global Ecology and Conservation* **5**:12-21.
- 208 Verberk, W.C., Durance, I., Vaughan, I.P., and Ormerod, S.J. (2016). Field and Laboratory Studies Reveal Interacting Effects of Stream Oxygenation and Warming on Aquatic Ectotherms. *Global Change Biology* **22** 1769–1778.
- 209 Jump, A.S. and Penuelas, J. (2005). Running to Stand Still: Adaptation and the Response of Plants to Rapid Climate Change. *Ecology Letters* **8**:1010-1020.
- 210 ClimateWizard. Available from <http://climatewizard.org/> (accessed September 2016). Also see Girvetz, E.H., Zganjar, C., Raber, G.T., Maurer, E.P., Kareiva, P., and Lawler, J.J. (2009). Applied Climate-Change Analysis: The Climate Wizard Tool. *PLOS ONE* **4**: e8320.
- 211 Meixner, T. and Wohlgemuth, P. (2004). Wildfire Impacts on Water Quality. *Journal of Wildland Fire* **13**: 27-35.
- 212 Paige, G. and Zygmunt, J. (2013). The Science Behind Wildfire Effects on Water Quality, Erosion. Pages 31-34 in Thompson, J. and Miller, S.L. (eds). *Living with Wildfire in Wyoming*. University of Wyoming Extension. Available from [http://www.uwyo.edu/barnbackyard/\\_files/documents/resources/wildfire2013/waterqualityerosion2013wywildfire.pdf](http://www.uwyo.edu/barnbackyard/_files/documents/resources/wildfire2013/waterqualityerosion2013wywildfire.pdf) (accessed October 2016).
- 213 Moritz, M.A., Parisien, M.A., Batllori, E., Krawchuk, M.A., Van Dorn, J., Ganz, D.J., and Hayhoe, K. (2012). Climate Change and Disruptions to Global Fire Activity. *Ecosphere* **3**: 1-22.
- 214 See note 200.
- 215 See note 201.
- 216 See note 164.
- 217 See note 164.
- 218 See note 164.
- 219 Seavy, N.E., Gardali, T., Golet, G.H., Griggs, F.T., Howell, C.A., Kelsey, R., Small, S.L., Viers, J.H., and Weigand, J.F. (2009). Why Climate Change Makes Riparian Restoration More Important Than Ever: Recommendations for Practice and Research. *Ecological Restoration* **27**: 330-338.
- 220 See note 219.

- 221 Campbell, A., Kapos, V., Scharlemann, J.P.W., et al., (2009). Review of the Literature on the Links between Biodiversity and Climate Change: Impacts, Adaptation and Mitigation. CBD Technical Series No. 42. Secretariat of the Convention on Biological Diversity, Montreal, Canada. Available from <https://www.cbd.int/doc/publications/cbd-ts-42-en.pdf> (accessed October 2016).
- 222 United Nations International Strategy for Disaster Reduction (UNISDR). (2009). 2009 UNISDR Terminology on Disaster Risk Reduction. Available from [http://www.unisdr.org/files/7817\\_UNISDRTerminologyEnglish.pdf](http://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf) (accessed July 2016).
- 223 European Climate Adaptation Platform. Adaptation of Integrated Land Use Planning (2015). Available from <http://climate-adapt.eea.europa.eu/metadata/adaptation-options/adaptation-of-integrated-land-use-planning> (accessed September 2016).
- 224 U.S. Environmental Protection Agency (EPA). (2006). Economic Benefits of Wetlands. Available from <https://www.epa.gov/sites/production/files/2016-02/documents/economicbenefits.pdf> (accessed October 2016).
- 225 Gilbert, N. (2012). One-Third of Our Greenhouse Gas Emissions Come from Agriculture. *Nature News*.
- 226 Gliessman, S.R. (2006). Agroecology: The Ecology of Sustainable Food Systems. 2nd Edition. CRC Press. p.9.
- 227 See note 210.
- 228 U.S. Agency for International Development (USAID). (2013). Dominican Republic Climate Change Vulnerability Assessment Report. USAID and Tetra Tech ARD, Washington D.C., USA. Available from <https://www.usaid.gov/sites/default/files/documents/1862/Dominican%20Republic%20Climate%20Change%20Vulnerability%20Assessment%20Report.pdf> (accessed October 2016).
- 229 Latin American Water Funds Partnership. Yaque del Norte Water Fund. Available from <http://www.fondosdeagua.org/en/yaque-del-norte-water-fund> (accessed September 2016).
- 230 See note 228.
- 231 Riverside Technology. (2014). SWAT Hydrological Modeling and the Impact of Climate and Land Use Change on the Yaque del Norte, Ozama, Haina, and Nizao Watersheds. Riverside Technology, inc, Fort Collins, CO, USA. Available from [http://pdf.usaid.gov/pdf\\_docs/PA00JQ1N.pdf](http://pdf.usaid.gov/pdf_docs/PA00JQ1N.pdf) (accessed October 2016).
- 232 See note 231.
- 233 See note 231.
- 234 Calvache, A., Benítez, S., and Ramos, A. (2012). Fondos de Agua: Conservando la Infraestructura Verde. Guía de Diseño, Creación y Operación. Alianza Latinoamericana de Fondos de Agua. The Nature Conservancy, Fundación FEMSA y Banco Interamericano de Desarrollo. Bogotá, Colombia. Available from <http://www.fondosdeagua.org/sites/default/files/WATER%20FUNDS%20MANUAL-SPANISH%20VERSION.pdf> (accessed September 2016). (In Spanish).
- 235 See note 229.
- 236 World Health Organization (WHO). Health Impact Assessment (HIA). The Determinants of Health. Available from <http://who.int/hia/evidence/doh/en/> (accessed October 2016).
- 237 United Nations World Water Assessment Programme (WWAP). (2016). The United Nations World Water Development Report 2016: Water and Jobs. UNESCO, Paris, France.
- 238 Committee on Indicators for Waterborne Pathogens, National Research Council. (2004). Indicator for Waterborne Pathogens. National Research Council of the National Academics. The National Academics Press, Washington, D.C., USA.
- 239 Meade, M.S., Florin, J.W. and Gesler, W.M. (1988). Medical Geography. The Guilford Press, New York, USA.
- 240 Myers, S.S., Gaffikin, L., Golden, C.D., Ostfeld, R.S., Redford, K.H., Ricketts, T.H., Turner, W.R., and Osofsky, S.A. (2013). Human Health Impacts of Ecosystem Alteration. *Proceedings of the National Academy of Sciences* **110**: 18753-18760.
- 241 Whitmee, S., Haines, A., Beyrer, C., et al., (2015). Safeguarding Human Health in the Anthropocene Epoch: Report of The Rockefeller Foundation–Lancet Commission on Planetary Health. *The Lancet* **386**: 1973-2028.
- 242 Bayles, B.R., Brauman, K.A., Adkins, J.N., et al., (2016). Ecosystem Services Connect Environmental Change to Human Health Outcomes. *EcoHealth*.
- 243 Myers, S.S. and Patz, J.A. (2009). Emerging Threats to Human Health from Global Environmental Change. *Annual Review of Environment and Resources* **34**: 223-252.
- 244 See note 240.
- 245 Bratman, G.N., Daily, G.C., Levy, B.J., and Gross, J.J. (2015). The Benefits of Nature Experience: Improved Affect and Cognition. *Landscape and Urban Planning* **138**: 41-50.
- 246 See note 240.
- 247 See note 242.

- 248 Gaffikin, L. (2013). The Environment as a Strategic Healthcare Partner. *Current Opinion in Obstetrics and Gynecology* **25**: 494-499.
- 249 See note 240.
- 250 See note 242.
- 251 Prüss-Üstün, A. and Corvalán, C. (2007). How Much Disease Burden Can Be Prevented by Environmental Interventions? *Epidemiology* **18**: 167-178.
- 252 Prüss-Üstün, A., Bartram, J., Clasen, T., et al., (2014). Burden of Disease from Inadequate Water, Sanitation and Hygiene in Low-and Middle-Income Settings: A Retrospective Analysis of Data from 145 Countries. *Tropical Medicine & International Health* **19**: 894-905.
- 253 See note 240.
- 254 Wolf, J., Prüss-Ustün, A., Cumming, O., et al., (2014). Systematic Review: Assessing the Impact of Drinking Water and Sanitation on Diarrhoeal Disease in Low- and Middle-Income Settings: Systematic Review and Meta-Regression. *Tropical Medicine & International Health* **19**: 928-942.
- 255 Waddington, H., Snistveit, B., White, H., and Fewtrell, L. (2009). Water, Sanitation and Hygiene Interventions to Combat Childhood Diarrhoea in Developing Countries. The International Initiative for Impact Evaluation (3ie). 3ie Synthetic Reviews.
- 256 Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., and de Haan, C. (2006). Livestock's Long Shadow: Environmental Issues and Options. FAO, Rome, Italy. Available from <ftp://ftp.fao.org/docrep/fao/010/a0701e/a0701e.pdf> (accessed October 2016).
- 257 Graczyk, T.K., Evans, B.M., Shiff, C.J., Karreman, H.J., and Patz, J.A. (2000). Environmental and Geographical Factors Contributing to Watershed Contamination with *Cryptosporidium parvum* Oocysts. *Environmental Research* **82**: 263-271.
- 258 Kotloff, K.L., Nataro, J.P., Blackwelder, W.C., et al. (2013). Burden and Aetiology of Diarrhoeal Disease in Infants and Young Children in Developing Countries (the Global Enteric Multicenter Study, GEMS): A Prospective, Case-Control Study. *The Lancet* **382**: 209-222.
- 259 See note 240.
- 260 See note 240.
- 261 Whitmee, S., Haines, A., Beyrer, C., et al., (2015). Safeguarding Human Health in the Anthropocene Epoch: Report of The Rockefeller Foundation-Lancet Commission on Planetary Health. *The Lancet* **386**: 1973-2028.
- 262 Brauman, K.A., Daily, G.C., Duarte, T.K.E., and Mooney, H.A. (2007). The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. *Annual Review of Environment and Resources* **32**: 67-98.
- 263 Pattanayak, S.K. and Wendland, K.J. (2007). Nature's Care: Diarrhea, Watershed Protection, and Biodiversity Conservation in Flores, Indonesia. *Biodiversity and Conservation* **16**: 2801-2819.
- 264 Hurley, T. and Mazumder, A. (2013). Spatial Scale of Land-Use Impacts on Riverine Drinking Source Water Quality. *Water Resources Research* **49**: 1591-1601.
- 265 At least 20L a day per person are needed for basic cooking and drinking for short-term survival, and 20-70L is recommended for maintaining healthy lifestyles (WHO: What is the minimum quantity of water needed? [http://www.who.int/water\\_sanitation\\_health/emergencies/qa/emergencies\\_qa5/en/](http://www.who.int/water_sanitation_health/emergencies/qa/emergencies_qa5/en/))
- 266 See note 263.
- 267 See note 263.
- 268 See note 252.
- 269 See note 243.
- 270 Millennium Ecosystem Assessment. (2005). Ecosystems and Human Well-Being. Island Press, Washington, D.C., USA.
- 271 Jones, B.A., Grace, D., Kock, R., et al. (2013). Zoonosis Emergence Linked to Agricultural Intensification and Environmental Change. *Proceedings of the National Academy of Sciences* **110**: 8399-8404.
- 272 Patz, J. A., Daszak, P., Tabor, G. M., et al., (2004). Unhealthy Landscapes: Policy Recommendations on Land Use Change and Infectious Disease Emergence. *Environmental Health Perspectives* **112**: 1092-1098.
- 273 Medical geography focuses on the distribution of disease related to the environmental context, while disease ecology tries to understand the host-pathogen interactions within the context of their changing environment and evolution. Both are important to understanding the impacts of watershed alteration and land-use change on the spread of disease in human populations.
- 274 See note 272.

- 275 In most regions multiple mosquito species co-exist and can have different abundances, virulence and habitat preferences. Habitat change (e.g., deforestation and reforestation) may increase or decrease local human population exposure to malaria depending on which habitats are favored by the resident malaria-carrying mosquitos. Similarly, the ways that human populations interact with protected areas can influence whether these areas pose an increasing or decreasing malaria risk. For example, in a recent study, strict protected areas in Brazil were associated with decreased malaria incidence, while sustainable use protected areas that increased human interaction with forests were associated with increased incidence (Bauch, et al. (2015). Public Health Impacts of Ecosystem Change in the Brazilian Amazon. *PNAS* **112**: 7414-7419). Understanding how these local dynamics will play out is critical for planning land-use interventions that can minimize (or at least not increase) local disease prevalence.
- 276 Guerra, C.A., Snow, R.W., and Hay, S.I. (2006). A Global Assessment of Closed Forests, Deforestation and Malaria Risk. *Annals of Tropical Medicine and Parasitology* **100**: 189-204.
- 277 For example, after the Iquitos-Nauta highway was constructed in Amazonian Peru, the human bite rate was found to be 278 times higher per person in deforested areas along road with shifting cultivation, which creates ideal conditions for mosquitoes and attracted new farmers to the region. Similar patterns have been reported in Belem, Brazil and Trinidad (Vittor, et al. (2006). The Effect of Deforestation on the Human-Biting Rate of *Anopheles darlingi*, the Primary Vector of Falciparum Malaria in the Peruvian Amazon. *Am J Trop Med Hyg* **7**: 3-11).
- 278 Lower malaria rates in some forested areas have also been attributed to intact ecosystems having more complex food webs with many more mosquito predators as well as malaria hosts diluting the bite rate of infected mosquitos on humans (Myers, et al. (2013). Human Health Impacts of Ecosystem Alteration. *PNAS* **110**: 18753-18760; Pattanayak, et al. (2006). Deforestation, Malaria and Poverty: A Call for Transdisciplinary Research to Support the Design of Cross-sectoral Policies. *SSPP* **2**: 45-56). In these cases, shrinking of forest habitat aggregates both malaria-carrying mosquito and wild hosts (e.g., mammals) into forest fragments that are increasingly near to human settlements and land uses. In some cases, some species of mosquitos can switch their preference from feeding on native hosts to feeding on humans who are increasingly present at the forest frontier. In Malaysia, widespread deforestation for palm oil plantations has reduced the forest habitat, concentrating macaque populations and disease loads into remaining forest fragments. Nearby human communities at the forest edge who previously were rarely in contact with the primates were infected by mosquitos thriving there, transmitting the disease from macaques to humans (Fornace, et al. (2016). Association Between Landscape Factors and Spatial Patterns of *Plasmodium knowlesi* Infections in Sabah, Malaysia. *Emerg Infect Dis* **22**: 201-209).
- 279 See note 276.
- 280 Walsh, J.F., Molyneux, D.H., and Birley, M.H. (1993). Deforestation: Effects on Vector-Borne Disease. *Parasitology* **106**: S55-S75.
- 281 See note 270.
- 282 Lindsay, S.W. and Martens, W.J. (1998). Malaria in the African Highlands: Past, Present and Future. *Bulletin of the World Health Organization* **76**: 33-45.
- 283 Kibret, S., Wilson, G.G., Tekie, H., and Petros, B. (2014). Increased Malaria Transmission around Irrigation Schemes in Ethiopia and the Potential of Canal Water Management for Malaria Vector Control. *Malaria Journal* **13**: 360.
- 284 Eisele, T.P., Larsen, D., and Steketee, R.W. (2010). Protective Efficacy of Interventions for Preventing Malaria Mortality in Children in *Plasmodium falciparum* Endemic Areas. *International Journal of Epidemiology* **39**: i88-i101.
- 285 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). (2016). The Assessment Report on Pollinators, Pollination and Food Production—Summary for Policymakers. Secretariat of the IPBES, Bonn, Germany. Available from <http://www.ipbes.net/work-programme/pollination> (accessed October 2016).
- 286 Eilers, E.J., Kremen, C., Greenleaf, S.S., Garber, A.K., and Klein, A.M. (2011). Contribution of Pollinator-Mediated Crops to Nutrients in the Human Food Supply. *PLOS ONE* **6**: e21363.
- 287 A recent global study found that, in some regions, up to 50% of the plant-derived production of vitamin A, and up to 15 percent of the plant-derived production of iron requires pollination (Chaplin-Kramer, et al., 2014: *Global Malnutrition Overlaps with Pollinator-Dependent Micronutrient Production*).
- 288 International Food Policy Research Institute (IFPRI). (2015). Global Nutrition Report 2015: Actions and Accountability to Advance Nutrition and Sustainable Development. International Food Policy Research Institute, Washington, D.C., USA. Available from [http://www.fao.org/fileadmin/user\\_upload/raf/uploads/files/129654.pdf](http://www.fao.org/fileadmin/user_upload/raf/uploads/files/129654.pdf) (accessed October 2016).
- 289 See note 288.

- 290 von Grebmer, K., Saltzman, A., Birol, E., Wiesmann, D., Prasai, N., Yin, S., Yohannes, Y., Menon, P., Thompson, J., and Sonntag, A. (2014). 2014 Global Hunger Index: The Challenge of Hidden Hunger. Welthungerhilfe, International Food Policy Research Institute, and Concern Worldwide.
- 291 Vitamin A is critical for eyesight and healthy immune functioning, but an estimated 250 million children are vitamin A-deficient around the world, and 250,000 to 500,000 children go blind every year as a result (WHO, Micronutrient Deficiencies. See <http://www.who.int/nutrition/topics/vad/en/>). Similarly, iron is an essential mineral critical for motor and cognitive development, yet it is the most common and widespread nutritional deficiency globally. Children and pregnant women are especially vulnerable to anemia, which can sometimes cause death (United Call to Action 2009. *Investing in the Future: A United Call to Action on Vitamin and Mineral Deficiencies*. Available from [http://www.unitedcalltoaction.org/documents/Investing\\_in\\_the\\_future.pdf](http://www.unitedcalltoaction.org/documents/Investing_in_the_future.pdf) (accessed December 2016)).
- 292 Many countries suffer acute micronutrient deficiencies for vitamin A and iron. Most of Saharan and Sub-Saharan Africa, as well as Central Asia and India, suffer from severe vitamin A deficiencies, with more than 20 percent of school age children not obtaining minimum amounts in their diet. A similar set of countries in Africa and Asia also experience severe shortages of iron (>40 percent), leading to anemia. Together these present major public health challenges (WHO 2009: *Global Prevalence of Vitamin A Deficiency in Populations at Risk 1995–2005*. See note 307).
- 293 Remans, R., Wood, S.A., Saha, N., Anderman, T.L., and DeFries, R.S. (2014). Measuring Nutritional Diversity of National Food Supplies. *Global Food Security* **3**: 174-182.
- 294 See note 293.
- 295 Ricketts, T.H., Regetz, J., Steffan-Dewenter, I., et al., (2008). Landscape Effects on Crop Pollination Services: Are There General Patterns?. *Ecology letters* **11**: 499-515.
- 296 Kremen, C., Williams, N.M., Bugg, R.L., Fay, J.P., and Thorp, R.W. (2004). The Area Requirements of an Ecosystem Service: Crop Pollination by Native Bee Communities in California. *Ecology Letters* **7**: 1109-1119.
- 297 Kennedy, C.M., Lonsdorf, E., Neel, M.C., et al., (2013). A Global Quantitative Synthesis of Local and Landscape Effects on Wild Bee Pollinators in Agroecosystems. *Ecology Letters* **16**: 584-599.
- 298 See note 285.
- 299 Watanabe, M.E. (2014). Pollinators at Risk: Human Activities Threaten Key Species. *BioScience* **64**: 5-10.
- 300 See note 285.
- 301 See note 296.
- 302 See note 295.
- 303 See note 297.
- 304 Loss of pollination services can have serious implications for natural and agricultural ecosystems and people dependent on them. While many factors (e.g., food imports, consumption patterns, vitamin supplements) influence the degree to which local or regional pollination services and crop production determine actual micronutrient consumption, a recent study of micronutrient deficiency in Bangladesh, Uganda, Mozambique, and Zambia found that up to 56 percent of the populations would become newly at risk of micronutrient deficiency if all pollinators were removed (Ellis, et al. (2015). Do Pollinators Contribute to Nutritional Health?. *PLOS ONE* **10**: e114805).
- 305 Chaplin-Kramer R., Dombeck E., Gerber J., Knuth K.A., Mueller N.D., Mueller M., Ziv G., Klein A.-M. (2014). Global Malnutrition Overlaps with Pollinator-Dependent Micronutrient Production. *Proceedings of the Royal Society B Biological Sciences* **281**: p.20141799.
- 306 Klein, A.M., Vaissiere, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., and Tscharntke, T. (2007). Importance of Pollinators in Changing Landscapes for World Crops. *Proceedings of the Royal Society B Biological Sciences* **274**:303-313.
- 307 World Health Organization (WHO). (2009). *Global Prevalence of Vitamin A Deficiency in Populations at Risk 1995–2005*. WHO Global Database on Vitamin A Deficiency. WHO, Geneva, Switzerland.
- 308 See note 307.
- 309 World Health Organization (WHO). (2008). *Global Prevalence of Anaemia 1993–2005*. WHO Global Database on Anaemia. WHO, Geneva, Switzerland.
- 310 See note 309.
- 311 Monfreda, C., Ramankutty, N., and Foley, J.A. (2008). Farming the Planet: 2. Geographic Distribution of Crop Areas, Yields, Physiological Types, and Net Primary Production in the Year 2000. *Global Biogeochemical Cycles* **22**.
- 312 Food and Agriculture Organization of the United Nations (FAO). FAOSTAT. Available from <http://faostat3.fao.org/home/E>

- 313 Bratman, G.N., Daily, G.C., Levy, B.J., and Gross, J.J. (2015). The Benefits of Nature Experience: Improved Affect and Cognition. *Landscape and Urban Planning* **138**: 41-50.
- 314 Bratman, G.N., Hamilton, J.P., and Daily, G.C. (2012). The Impacts of Nature Experience on Human Cognitive Function and Mental Health. *Annals of the New York Academy of Sciences* **1249**: 118-136.
- 315 Hough, R.L. (2014). Biodiversity and Human Health: Evidence for Causality?. *Biodiversity and Conservation* **23**: 267-288.
- 316 Bratman, G.N., Hamilton, J.P., Hahn, K.S., Daily, G.C., and Gross, J.J. (2015). Nature Experience Reduces Rumination and Subgenual Prefrontal Cortex Activation. *Proceedings of the National Academy of Sciences* **112**: 8567-8572.
- 317 See note 314.
- 318 Lee, J., Park, B.J., Tsunetsugu, Y., Ohira, T., Kagawa, T., and Miyazaki, Y. (2011). Effect of Forest Bathing on Physiological and Psychological Responses in Young Japanese Male Subjects. *Public Health* **125**: 93-100.
- 319 Li, Q., Morimoto, K., Kobayashi, M., et al. (2008). A Forest Bathing Trip Increases Human Natural Killer Activity and Expression of Anti-Cancer Proteins in Female Subjects. *Journal of Biological Regulators and Homeostatic Agents* **22**: 45-55.
- 320 Morita, E., Fukuda, S., Nagano, J., Hamajima, N., Yamamoto, H., Iwai, Y., Nakashima, T., Ohira, H., and Shirakawa, T. (2007). Psychological Effects of Forest Environments on Healthy Adults: Shinrin-yoku (Forest-Air Bathing, Walking) as a Possible Method of Stress Reduction. *Public Health* **121**: 54-63.
- 321 Ohtsuka, Y., Yabunaka, N., and Takayama, S. (1998). Shinrin-yoku (Forest-Air Bathing and Walking) Effectively Decreases Blood Glucose Levels in Diabetic Patients. *International Journal of Biometeorology* **41**: 125-127.
- 322 Chan, K.M., Balvanera, P., Benessaiah, K., et al. (2016). Opinion: Why Protect Nature? Rethinking Values and the Environment. *Proceedings of the National Academy of Sciences* **113**: 1462-1465.
- 323 See note 270.
- 324 United Nations Development Programme (UNDP). Human Development Reports. Available from <http://hdr.undp.org/en/composite/HDI> (accessed October 2016).
- 325 Fritz, S., See, L., McCallum, I., et al., (2015). Mapping Global Cropland and Field Size. *Global Change Biology* **21**: 1980-1992.
- 326 Food and Agriculture Organization of the United Nations (FAO). (2005). Realizing the Economic Benefits of Agroforestry: Experiences, Lessons and Challenges. Pages 88-97 in FAO. *State of the World's Forests 2005*. Available from <http://www.fao.org/3/a-y5574e.pdf> (accessed December 2016).
- 327 World Agroforestry Centre. (2008). Annual Report 2007-2008: Agroforestry for Food Security and Healthy Ecosystems. World Agroforestry Centre (ICRAF), Nairobi, Kenya. Available from <http://www.worldagroforestry.org/downloads/Publications/PDFS/RP15815.pdf> (accessed October 2016).
- 328 Ewel, J.J. (1999). Natural Systems as Models for the Design of Sustainable Systems of Land Use. *Agroforestry Systems* **45**: 1-21.
- 329 Junsongduang, A., Balslev, H., Inta, A., Jampeetong, A., and Wangpakapattanawong, P. (2013). Medicinal Plants from Swidden Fallows and Sacred Forest of the Karen and the Lawa in Thailand. *Journal of Ethnobiology and Ethnomedicine* **9**: 44.
- 330 Thaman, R.R. (2014). Agrodeforestation and the Loss of Agrobiodiversity in the Pacific Islands: A Call for Conservation. *Pacific Conservation Biology* **20**: 180-192.
- 331 See note 330.
- 332 Asfaw, B. and Lemenih, M. (2010). Traditional Agroforestry Systems as a Safe Haven for Woody Plant Species: A Case Study from a Topo-Climatic Gradient in South Central Ethiopia. *Forests, Trees and Livelihoods* **19**: 359-377.
- 333 Jose, S. (2009). Agroforestry for Ecosystem Services and Environmental Benefits: An Overview. *Agroforestry Systems* **76**: 1-10.
- 334 Bruun, T.B., De Neergaard, A., Lawrence, D., and Ziegler, A.D. (2009). Environmental Consequences of the Demise in Swidden Cultivation in Southeast Asia: Carbon Storage and Soil Quality. *Human Ecology* **37**: 375-388.
- 335 Montagnini, F. and Nair, P.K.R. (2004). Carbon Sequestration: An Underexploited Environmental Benefit of Agroforestry Systems. *Agroforestry Systems* **61**: 281-295.
- 336 DeClerck, F.A., Fanzo, J., Palm, C., and Remans, R. (2011). Ecological Approaches to Human Nutrition. *Food and Nutrition Bulletin* **32**: S41-S50.
- 337 See note 305.
- 338 Johns, T. (2003). Plant Biodiversity and Malnutrition: Simple Solutions to Complex Problems. *African Journal of Food, Agriculture, Nutrition and Development* **3**: 45-52.

- 339 Steyn, N.P., Nel, J.H., Nantel, G., Kennedy, G., and Labadarios, D. (2006). Food Variety and Dietary Diversity Scores in Children: Are They Good Indicators of Dietary Adequacy? *Public Health Nutrition* **9**: 644-650.
- 340 Ellis, A.M., Myers, S.S. and Ricketts, T.H. (2015). Do Pollinators Contribute to Nutritional Health? *PLOS ONE* **10**: e114805.
- 341 Friedrich, T., Derpsch, R., and Kassam, A. (2012). Overview of the Global Spread of Conservation Agriculture. *Field Actions Science Reports Special Issue 6 | 2012*. Available from <http://factsreports.revues.org/1941> (accessed October 2016).
- 342 Brouder, S.M. and Gomez-Macpherson, H. (2014). The Impact of Conservation Agriculture on Smallholder Agricultural Yields: A Scoping Review of the Evidence. *Agriculture, Ecosystems & Environment* **187**: 11-32.
- 343 Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L., and Grace, P. (2014). Conservation Agriculture and Ecosystem Services: An overview. *Agriculture, Ecosystems & Environment* **187**: 87-105.
- 344 See note 342.
- 345 See note 343.
- 346 See note 341.
- 347 Gruber, J.S., Ercumen, A., and Colford, J.M. (2014). Coliform Bacteria as Indicators of Diarrheal Risk in Household Drinking Water: Systematic Review and Meta-Analysis. *PLOS ONE* **9**: e107429.
- 348 In the community of Alto Citano, the principal community source is a protected spring in a Watershared conservation area; monitoring in 2016 found no presence of *E. coli* there. By contrast, Santa Ana and Estancia Huaico are two communities with no forest conservation and both cattle and agriculture in the catchment upstream of their respective sources. Water supplies in these communities were found to have high levels of *E. coli*. Social survey data show that waterborne disease levels in these communities are correspondingly high, with over 30% of children in Santa Ana suffering from multiple episodes of diarrhea in 2015. In another example, the community of Moro Moro is supplied by three water sources, all of which are from nearby streams with heavy cattle grazing and agriculture in the upstream catchments. The Moro Moro community clinic recorded 298 cases of diarrhea (per 1000 inhabitants) in 2015 and monitoring by the Watershared Fund in 2015 and 2016 found the local water supply was highly contaminated with *E. coli*. Postrerville, an otherwise similar community, had under a quarter of the per-capita number of cases of diarrhea. The Postrerville water supply (a spring) is fenced in, protecting it from cattle intrusion, and no evidence of *E. coli* was found there in 2015 or 2016.
- 349 Bolivian Watershared Funds employ a three-pronged approach for improving water quality: 1) Selection of an appropriate source—i.e., springs are generally preferable to streams if they provide water in adequate quantity throughout the year. 2) Conservation of upstream catchment areas—i.e., reduction or removal of cattle grazing and agriculture from streamside land; elimination of deforestation. 3) Installation of simple, resilient and high quality downstream infrastructure—i.e., protection of water sources from external contamination, and construction of sedimentation chambers, filtration apparatus, and storage tanks.
- 350 Pimm, S.L., Jenkins, C.N., Abell, R., Brooks, T.M., Gittleman, J.L., Joppa, L.N., Raven, P.H., Roberts, C.M., and Sexton, J.O. (2014). The Biodiversity of Species and Their Rates of Extinction, Distribution, and Protection. *Science* **344**:1246752.
- 351 Monastersky, R. (2014). Biodiversity: Life—A Status Report. *Nature* **516**: 158-161.
- 352 WWF. (2016). Living Planet Report 2016: Risk and Resilience in a New Era. WWF International, Gland, Switzerland.
- 353 Mooney, H.A., Lubchenco, J., Dirzo, R., and Sala, O.E. (1995). Biodiversity and Ecosystem Functioning: Basic Principles. In Heywood V.H. (ed). *Global Biodiversity Assessment*. Cambridge University Press, Cambridge, UK.
- 354 Sala, O.E., Chapin, F.S., Armesto, J.J., et al. (2000). Global Biodiversity Scenarios for the Year 2100. *Science* **287**: 1770–1774.
- 355 Biological integrity is the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region. (Karr, J. (1991). Biological Integrity: A Long-Neglected Aspect of Water Resource Management. *Ecol Appl* **1**: 66-84.)
- 356 All statements regarding the impacts of high human disturbances are cited from Oakleaf, J.R., Kennedy, C.M., Boucher, T., and Kiesecker, J. (2013). Tailoring Global Data to Guide Corporate Investments in Biodiversity, Environmental Assessments and Sustainability. *Sustainability* **5**: 4444-4460.
- 357 Robbins, P., Chhatre, A., and Karanth, K. (2015). Political Ecology of Commodity Agroforests and Tropical Biodiversity. *Conservation Letters* **8**: 77–85.
- 358 See note 330.
- 359 See note 87.
- 360 Shvidenko, A., Barber, C.V., Persson, R., et al., (2005). Chapter 21 Forest and Woodland Systems. Pages 585-621 in Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being*. Island Press, Washington, D.C., USA.

- 361 Hoekstra, J. M., Boucher, T. M., Ricketts, T. H., and Roberts, C. (2005). Confronting a Biome Crisis: Global Disparities of Habitat Loss and Protection. *Ecology Letters* **8**: 23–29.
- 362 Grasslands typically receive less attention than forests, yet they cover an equivalent area of the Earth’s surface and support important biodiversity elements, including iconic species like zebra, bison, and lions. In addition, they support significant components of plant and bird diversity. Grasslands currently cover 41 to 56 million square kilometers or 31 percent to 43 percent of the Earth’s surface (White, et al. (2000). Pilot Analysis of Global Ecosystems: Grassland Ecosystems. World Resources Institute), and by some estimates almost 46% of global grassland habitat has been converted (Hoekstra, et al. (2005). Confronting a Biome Crisis: Global Disparities of Habitat Loss and Protection. *Ecol Lett* **8**: 23-29).
- 363 Wetlands occupy 6 to 7 percent of the Earth’s land surface and contain a considerable portion of global biodiversity (Lehner and Doll. (2004). Development and Validation of a Global Database of Lakes, Reservoirs and Wetlands. *J Hydrol* **296**: 1–22). Wetlands occur as floodplains, deltas, and coastal habitat components of river, lake, and ocean ecosystems, and well as discrete habitats within terrestrial landscapes, resulting in small and isolated populations of species vulnerable to local extirpation (Gibbs, J.P. (2000). Wetland Loss and Biodiversity Conservation. *Conserv Biol* **14**: 314–317). Wetlands have a higher economic valuation for ecosystem services, especially but not only per unit area, than any other component of terrestrial biomes (Costanza, et al. (2014). Changes in the Global Value of Ecosystem Services. *Global Environ Chang* **26**: 152–158).
- 364 See note 360.
- 365 See note 360.
- 366 See note 360.
- 367 See note 188.
- 368 See note 188.
- 369 Keenan, R.J., Reams, G.A., Achard, F., de Freitas, J.V., Grainger, A., and Lindquist, E. (2015). Dynamics of Global Forest Area: Results from the FAO Global Forest Resources Assessment 2015. *Forest Ecology and Management* **352**: 9–20.
- 370 Food and Agriculture Organization of the United Nations (FAO). (2016). Global Forest Resources Assessment 2015: How Are the World’s Forests Changing?, 2nd Edition. FAO, Rome, Italy. Available from <http://www.fao.org/3/a-i4793e.pdf> (accessed October 2016).
- 371 Lindenmayer, D.B., Hobbs, R.J., and Salt, D. (2003). Plantation Forests and Biodiversity Conservation. *Australian Forestry* **66**: 62–66.
- 372 Hua, F., Wang, X., Zheng, X., Fisher, B., Wang, L., Zhu, J., Tang, Y., Douglas, W.Y., and Wilcove, D.S. (2016). Opportunities for Biodiversity Gains Under the World’s Largest Reforestation Programme. *Nature Communications* **7**: 12717.
- 373 Olson, D. M. and Dinerstein, E. (2002). The Global 200: Priority Ecoregions for Global Conservation. *Annals of the Missouri Botanical Garden* **89**: 199–224.
- 374 Abell, R., Thieme, M., Ricketts, T. H., Olwero, N., Ng, R., Petry, P., Dinerstein, E., Revenga, C., and Hoekstra, J. (2011). Concordance of Freshwater and Terrestrial Biodiversity. *Conservation Letters* **4**: 127–136.
- 375 International Union for Conservation of Nature (IUCN). (2016). Map Shows Indigenous Peoples as Guardians of Central American ecosystems. Available from <https://www.iucn.org/content/map-shows-indigenous-peoples-guardians-central-american-ecosystems> (accessed October 2016).
- 376 See note 188.
- 377 See note 188.
- 378 Dudgeon, D., Arthington, A.H., Gessner, M.O., et al., (2006). Freshwater Biodiversity: Importance, Threats, Status and Conservation Challenges. *Biological Reviews* **81**: 163–182.
- 379 Food and Agriculture Organization of the United Nations (FAO). (2016). The State of World Fisheries and Aquaculture 2016: Contributing to Food Security and Nutrition for all. FAO, Rome, Italy. Available from <http://www.fao.org/3/a-i5555e.pdf> (accessed October 2016).
- 380 McIntyre, P.B., Reidy Liermann, C.A., and Revenga, C. (2016). Linking Freshwater Fishery Management to Global Food Security and Biodiversity Conservation. *Proceedings of the National Academy of Sciences* **113**: 12880–12885.
- 381 See note 352.
- 382 The primary sources of freshwater species declines include flow alteration, reduction in water quality, habitat degradation and destruction, overexploitation, and exotic species, all of which can all be exacerbated directly and indirectly by climate change (Dudgeon, et al. (2006). Freshwater Biodiversity: Importance, Threats, Status and Conservation Challenges. *Biol Rev* **81**: 163–182).
- 383 International Union for Conservation of Nature (IUCN) 2016. The IUCN Red List of Threatened Species. Version 2016-2. Available from <http://www.iucnredlist.org> (downloaded on 30 September 2016).

- 384 This analysis is largely based on assessments of freshwater fishes, molluscs, crabs, crayfishes, shrimps, amphibians, birds, mammals and odonates along with assessments of a few selected families of freshwater plants. Only the amphibians, birds, mammals, crabs, crayfish and shrimps have been comprehensively assessed (e.g., all known described species have been assessed). Other groups have only been partially assessed. IUCN aims to have all 100% assessed by 2020. There is therefore potential for some bias for those regions of the world where IUCN has not yet run an assessment of all described species (Darwall, W. *pers. comm.*).
- 385 Ricciardi, A. and Rasmussen, J.B. (1999). Extinction Rates of North American Freshwater Fauna. *Conservation Biology* **13**: 1220–1222.
- 386 See note 49.
- 387 The same study also developed a Human Water Security Index. The authors note that ‘Stressors within the catchment disturbance and pollution themes generally act in unison across human water security and biodiversity, highlighting shared sources of impact, with cropland the predominant catchment stressor and nutrient, pesticide and organic loads dominating pollution sources.’ (Vörösmarty, et al., 2010: *Global Threats to Human Water Security and River Biodiversity*. See note 49.)
- 388 See note 49.
- 389 What we know about the diversity of species on the planet, and where species occur, is improving every day through efforts like the Encyclopedia of Life (<http://www.eol.org/>). See also Blaustein, R. (2009). The Encyclopedia of Life: Describing Species, Unifying Biology. *Bioscience* **59**: 551–556) and the work of IUCN’s biodiversity assessment program (<http://www.iucnredlist.org/>). However, globally comprehensive maps of entire species groups are still largely limited to the best-known and studied groups, like mammals and birds, and even those suffer from geographic bias. For freshwater fish species—which comprise 25% of all known vertebrate species—the only comprehensive dataset at present maps them to freshwater ecoregions. For ease of comparison, we use rarity-weighted richness numbers at the ecoregion scale for both terrestrial and freshwater systems.
- 390 See note 374.
- 391 See note 374.
- 392 Young, B.E., Lips, K.R., Reaser, J.K., et al., (2001). Population Declines and Priorities for Amphibian Conservation in Latin America. *Conservation Biology* **15**: 1213–1223.
- 393 Lips, K.R., Burrowes, P.A., Mendelson, J.R., and Parra-Olea, G. (2005). Amphibian Population Declines in Latin America: A Synthesis. *Biotropica* **37**: 222–226.
- 394 Data on bird species acquired from BirdLife International and NatureServe. (2015). Bird Species Distribution Maps of the World. Version 5.0. BirdLife International, Cambridge, UK and NatureServe, Arlington, USA.
- Data on amphibian and mammal species acquired from International Union for Conservation of Nature (IUCN) 2016. The IUCN Red List of Threatened Species. Version 2016-2. Available from <http://www.iucnredlist.org> (downloaded on 01 July 2016).
- 395 International Union for Conservation of Nature (IUCN) 2016. The IUCN Red List of Threatened Species. Version 2016-2. Available from <http://www.iucnredlist.org> (downloaded on 01 July 2016).
- 396 Endangered and critically endangered status is determined, in the case of AZE sites, based on IUCN-World Conservation Union criteria. An AZE trigger species must also be restricted to a single site, have > 95 percent of its known resident population occurring at that site, or have >95 percent of the significant known population for one life history stage within a single remaining site.
- 397 Butchart, S.H., Scharlemann, J.P., Evans, M.I., et al. (2012). Protecting Important Sites for Biodiversity Contributes to Meeting Global Conservation Targets. *PLOS ONE* **7**: e32529.
- 398 Alliance for Zero Extinction (2010). 2010 AZE Update. Available from [www.zeroextinction.org](http://www.zeroextinction.org).
- 399 BirdLife International. Important Bird and Biodiversity Areas (IBAs). Available from <http://www.birdlife.org/worldwide/programmes/sites-habitats-ibas> (accessed September 2016).
- 400 BirdLife International. Sites—Important Bird and Biodiversity Areas (IBAs). IBAs in Danger. Available from <http://datazone.birdlife.org/site/ibasindanger> (accessed September 2016).
- 401 BirdLife International. (2015). Important Bird and Biodiversity Area (IBA) digital boundaries. January 2016 version. BirdLife International, Cambridge, UK. Available through request on <http://datazone.birdlife.org/site/requestgis> (downloaded January 2016).
- 402 See note 189 for WRI’s Atlas of Forest and Landscape Restoration Opportunities online tool; see note 194 for the dataset.

- 403 Reforestation opportunity” is defined as the wide-scale and remote restoration opportunities (excluding mosaic restoration opportunity) by WRI (2011). According to the dataset, up to about 500 million hectares would be suitable for wide-scale forest restoration of closed forests, and 200 million hectares of unpopulated lands, mainly in the far northern boreal forests, also have the potential to be reforested, despite difficulty due to remoteness. The total amount is 700 million hectares of “reforestation opportunity.” Also see note 194 and Appendix V-1.21.
- 404 Benayas, J.M.R., Newton, A.C., Diaz, A., and Bullock, J.M. (2009). Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis. *Science* **325**:1121-1124.
- 405 Chaudhary, A., Verones, F., de Baan, L., and Hellweg, S. (2015). Quantifying Land Use Impacts on Biodiversity: Combining Species–Area Models and Vulnerability Indicators. *Environmental Science & Technology* **49**: 9987-9995.
- 406 For definition of WRI’s reforestation opportunities, see note 403.
- 407 See note 189.
- 408 Hoskins, A.J., Bush, A., Gilmore, J., Harwood, T., Hudson, L.N., Ware, C., Williams, K.J., and Ferrier, S. (2016). Downscaling Land-Use Data to Provide Global 30” Estimates of Five Land-Use Classes. *Ecology and Evolution* **6**: 3040-3055.
- 409 See note 405.
- 410 See note 394.
- 411 Daily, G.C., Ehrlich, P.R., and Sánchez-Azofeifa, G.A. (2001). Countryside Biogeography: Use of Human-Dominated Habitats by the Avifauna of Southern Costa Rica. *Ecological Applications* **11**: 1-13.
- 412 Convention on Biological Diversity (CBD). Quick guide to the Aichi Biodiversity Targets—Target 11 Protected Areas Increased and Improved. Available from <https://www.cbd.int/doc стратегic-plan/targets/T11-quick-guide-en.pdf> (accessed September 2016).
- 413 Naiman, R., Decamps, H., and Pollock, M. (1993). The Role of Riparian Corridors in Maintaining Regional Biodiversity. *Ecological Applications* **3**: 209-212.
- 414 Osborne, L.L. and Kovacic, D.A. (1993). Riparian Vegetated Buffer Strips in Water-Quality Restoration and Stream Management. *Freshwater Biology* **29**: 243–258.
- 415 Lowrance, R., Altier, L.S., Newbold, J.D. et al. (1997). Water Quality Functions of Riparian Forest Buffers in Chesapeake Bay Watersheds. *Environmental Management* **21**: 687-712.
- 416 Moore, K. and Bull, G.Q. (2004). Guidelines, Codes and Legislation. Pages 707-728 in Northcote, T., Hartman, G. (eds). *Fishes and Forestry – World Watershed Interactions and Management*. Blackwell Science, Oxford, UK.
- 417 Thieme, M.L., Sindorf, N., Higgins, J., Abell, R., Takats, J.A., Naidoo, R., and Barnett, A. (2016). Freshwater Conservation Potential of Protected Areas in the Tennessee and Cumberland River Basins, USA. *Aquatic Conservation: Marine and Freshwater Ecosystems* **26**: 60-77.
- 418 Abell, R.A., Lehner, B.L., Thieme, M., and Linke, S. (2016). Looking Beyond the Fenceline: Assessing Protection Gaps for the World’s Rivers. *Conservation Letters*. Published online November 9, 2016.
- 419 Juffe-Bignoli, D., Harrison, I., Butchart, S.H., et al. (2016). Achieving Aichi Biodiversity Target 11 to Improve the Performance of Protected Areas and Conserve Freshwater Biodiversity. *Aquatic Conservation: Marine and Freshwater Ecosystems* **26**: 133-151.
- 420 Bertzky, B., Corrigan, C., Kemsey, J., Kenney, S., Ravilious, C., Besançon, C., and Burgess, N. (2012). Protected Planet Report 2012: Tracking Progress Towards Global Targets for Protected Areas. IUCN, Gland, Switzerland and UNEP-WCMC, Cambridge, UK.
- 421 Biodiversity Indicators Partnership. Coverage of Protected Areas. Available from <http://www.bipindicators.net/pacoverage> (accessed October 2016).
- 422 IUCN and UNEP-WCMC. (2016). World Database on Protected Areas (WDPA) [Online]. UNEP-WCMC, Cambridge, UK. Available from <https://www.protectedplanet.net/> (accessed July 2016).
- 423 Harrison, I.J., Green, P.A., Farrell, T.A., Juffe-Bignoli, D., Sáenz, L., and Vörösmarty, C.J. (2016). Protected Areas and Freshwater Provisioning: A Global Assessment of Freshwater Provision, Threats and Management Strategies to Support Human Water Security. *Aquatic Conservation: Marine and Freshwater Ecosystems* **26**: 103-120.
- 424 United Nations Development Programme (UNDP). (2011). COMPACT: Engaging Local Communities in Stewardship of Globally Significant Protected Areas. UNDP & The Global Environmental Facility (GEF) Small Grants Programme. Available from [http://www.undp.org/content/dam/undp/library/Environment%20and%20Energy/Local%20Development/Compact\\_Engaging\\_local\\_communities\\_in\\_stewardship\\_of\\_protected\\_areas.pdf](http://www.undp.org/content/dam/undp/library/Environment%20and%20Energy/Local%20Development/Compact_Engaging_local_communities_in_stewardship_of_protected_areas.pdf) (accessed October 2016).

- 425 Saporiti, N. (2006). Managing National Parks: How Public-Private Partnership Can Aid Conservation. The World Bank, Washington, D.C., USA. Available from [https://www.ifc.org/wps/wcm/connect/2f7eca80498391708494d6336b93d75f/VP\\_National%2BParks.pdf?MOD=AJPERES&CACHEID=2f7eca80498391708494d6336b93d75f](https://www.ifc.org/wps/wcm/connect/2f7eca80498391708494d6336b93d75f/VP_National%2BParks.pdf?MOD=AJPERES&CACHEID=2f7eca80498391708494d6336b93d75f) (accessed October 2016).
- 426 Nyce, C.M. (2004). The Decentralization of Protected Area Management in Ecuador: The Condor Bioreserve and Cajas National Park Initiatives. *Journal of Sustainable Forestry* **18**: 65-90.
- 427 Potapov, P., A. Yaroshenko, S. Turubanova, M., et al., (2008). Mapping the World's Intact Forest Landscapes by Remote Sensing. *Ecology and Society* **13**: 51.
- 428 Economist Intelligence Unit. (2011) Latin American Green City Index: Assessing the Environmental Performance of Latin America's Major Cities. Siemens AG, Munich, Germany. Available from <http://www.siemens.com/press/pool/de/events/corporate/2010-11-lam/Study-Latin-American-Green-City-Index.pdf> (accessed September 2016).
- 429 The Nature Conservancy. The Atlantic Forest harbors a range of biological diversity similar to that of the Amazon. Available from <http://www.nature.org/ourinitiatives/regions/southamerica/brazil/placesweprotect/atlantic-forest.xml>. (assessed September 2016).
- 430 de Rezende, C.L., Uezu, A., Scarano, F.R., and Araujo, D.S.D. (2015). Atlantic Forest Spontaneous Regeneration at Landscape Scale. *Biodiversity and Conservation* **24**: 2255-2272.
- 431 Iracambi. About the Atlantic Forest. Available from Iracambi: <http://en.iracambi.com/about-us/where-we-are/the-atlantic-rainforest> (accessed September 2016).
- 432 See note 429.
- 433 Latin American Water Funds Partnership. Guandu Watershed, Guandu – Brasil, 2008. Available from <http://www.fondosdeagua.org/en/guandu-watershed-guandu-brasil-2008> (accessed September 2016).
- 434 Bremer, L., Vogl, A.L., de Bievre, B., and Petry, P. (2015). Bridging Theory and Practice for Hydrological Monitoring in Water Funds. The Natural Capital Project and The Nature Conservancy. Available from [http://www.naturalcapitalproject.org/wp-content/uploads/2015/11/Monitoring\\_Theory\\_to\\_Practice\\_full\\_30Nov2015.pdf](http://www.naturalcapitalproject.org/wp-content/uploads/2015/11/Monitoring_Theory_to_Practice_full_30Nov2015.pdf) (accessed September 2016).
- 435 Rennó, B., Alves, F., and Pongiluppi, T. (2013). Monitoramento da Avifauna da Bacia do Rio das Pedras, Rio Claro, RJ. BirdLife International / Save Brazil. The Nature Conservancy, São Paulo, Brazil. Available from <http://www.terrabrasilis.org.br/ecotecadigital/images/Monit.%20Avifauna.pdf> (assessed September 2016). (In Portuguese).
- 436 Boyd, J.W. (2013). Measuring the Return on Program-Level Conservation Investments: Three Case Studies of Capabilities and Opportunity. Resources for the Future, Washington, D.C., USA. Available from <http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-14-12.pdf> (accessed September 2016).
- 437 Smil, V. (2002). Nitrogen and Food Production: Proteins for Human Diets. *AMBIO: A Journal of the Human Environment* **31**: 126-131.
- 438 Food and Agriculture Organization of the United Nations (FAO), International Fund for Agricultural Development (IFAD), and World Food Programme (WFP). (2015). The State of Food Insecurity in the World 2015 Meeting the 2015 International Hunger Targets: Taking Stock of Uneven Progress. FAO, Rome, Italy. Available from <http://www.fao.org/3/a-i4646e.pdf> (accessed October 2016).
- 439 Howarth, R., Ramakrishna, K., Choi, E., et al. (2005). Chapter 9 Nutrient Management. Pages 295-311 in The Millennium Ecosystem Assessment. *Ecosystems and Human Well-being Volume 3, Policy Responses*. Island Press, Washington, D.C., USA.
- 440 Fertilizer use (amount being spread) in North America is stagnant, at a 0.5 percent growth rate, the lowest in the world other than western Europe (FAO 2015: *World Fertilizer Trends and Outlook to 2018*. Available from <http://www.fao.org/3/a-i4324e.pdf> (accessed December 2016)). But what is changing is the rainfall amounts and intensity, so the timing and placement of fertilizer application needs to change along with that to reduce runoff of excess nitrogen into aquatic systems.
- 441 Michalak, A.M., Anderson, E.J., Beletsky, D., et al., (2013). Record-Setting Algal Bloom in Lake Erie Caused by Agricultural and Meteorological Trends Consistent with Expected Future Conditions. *Proceedings of the National Academy of Sciences* **110**: 6448-6452.
- 442 West, P.C., Gerber, J.S., Engstrom, P.M., et al. (2014). Leverage Points for Improving Global Food Security and the Environment. *Science* **345**: 325-328.

- 443 Howarth, R.W. (2008). Coastal Nitrogen Pollution: A Review of Sources and Trends Globally and Regionally. *Harmful Algae* **8**: 14-20.
- 444 Cleveland, C.C., Townsend, A.R., Schimel, D.S., et al. (1999). Global Patterns of Terrestrial Biological Nitrogen (N<sub>2</sub>) Fixation in Natural Ecosystems. *Global Biogeochemical Cycles* **13**: 623-645.
- 445 See note 443.
- 446 Nitrogen fixation is the process by which atmospheric nitrogen is assimilated into organic compounds, especially by certain microorganisms as part of the nitrogen cycle.
- 447 See note 443.
- 448 See note 442.
- 449 Food and Agriculture Organization of the United Nations (FAO). Fertilizer Consumption (Kilograms per Hectare of Arable Land). World Bank Database. Available from <http://data.worldbank.org/indicator/AG.CON.FERT.ZS> (accessed October 2016).
- 450 World Resources Institute (WRI). (2013). Eutrophication & Hypoxia Map Data Set. Available from <http://www.wri.org/resources/data-sets/eutrophication-hypoxia-map-data-set> (accessed October 2016).
- 451 Townsend, A.R., Howarth, R.W., Bazzaz, F.A., et al. (2003). Human Health Effects of a Changing Global Nitrogen Cycle. *Frontiers in Ecology and the Environment* **1**: 240-246.
- 452 Manassaram, D.M., Backer, L.C., and Moll, D.M. (2006). A Review of Nitrates in Drinking Water: Maternal Exposure and Adverse Reproductive and Developmental Outcomes. *Environmental Health Perspectives* **114**: 320-327.
- 453 Powlson, D.S., Addiscott, T.M., Benjamin, N., Cassman, K.G., de Kok, T.M., van Grinsven, H., L'hirondel, J.L., Avery, A.A., and Van Kessel, C. (2008). When Does Nitrate Become a Risk for Humans?. *Journal of Environmental Quality* **37**: 291-295.
- 454 U.S. Environmental Protection Agency (EPA). Table of Regulated Drinking Water Contaminants. Available from <https://www.epa.gov/ground-water-and-drinking-water/table-regulated-drinking-water-contaminants> (accessed October 2016).
- 455 World Health Organization (WHO). (2008). Guidelines for Drinking-Water Quality. 3rd Edition. Vol. I Recommendations. WHO, Geneva, Switzerland.
- 456 The U.S. city of Des Moines, Iowa has struggled to keep nitrates in their municipal water supply within safe levels for drinking. Two rivers feeding the city of 500,000 residents have repeatedly passed the 10 mg/l threshold, forcing local water agencies to use an expensive nitrate removal facility that has cost consumers about \$900,000 in treatment costs and lost revenues. Similar problems have plagued cities in agricultural zones including Waterloo, Canada (see <http://www.kwwl.com/story/30475175/2015/11/Monday/waterloo-water-safe-to-drink-following-spike-in-nitrate-levels>), Christchurch, New Zealand (see <http://www.stuff.co.nz/environment/82241785/Authorities-not-told-of-high-nitrate-levels-at-Christchurch-water-bore>) and parts of the UK (see <http://www.bgs.ac.uk/research/groundwater/quality/nitrate/home.html>).
- 457 Selman, M. and Greenhalgh, S. (2009). Eutrophication: Policies, Actions, and Strategies to Address Nutrient Pollution. World Resources Institute Policy Note. WRI, Washington, D.C., USA.
- 458 Howarth, R.W. and Marino, R. (2006). Nitrogen as the Limiting Nutrient for Eutrophication in Coastal Marine Ecosystems: Evolving Views over Three Decades. *Limnology and Oceanography* **51**: 364-376.
- 459 Elser, J.J., Bracken, M.E., Cleland, E.E., Gruner, D.S., Harpole, W.S., Hillebrand, H., Ngai, J.T., Seabloom, E.W., Shurin, J.B., and Smith, J.E. (2007). Global Analysis of Nitrogen and Phosphorus Limitation of Primary Producers in Freshwater, Marine and Terrestrial Ecosystems. *Ecology Letters* **10**: 1135-1142.
- 460 Carpenter, S.R. (2008). Phosphorus Control is Critical to Mitigating Eutrophication. *Proceedings of the National Academy of Sciences* **105**: 11039-11040.
- 461 See note 450.
- 462 Sun, S., Wang, F., Li, C., et al., (2008). Emerging Challenges: Massive Green Algae Blooms in the Yellow Sea. *Nature Precedings* **2266**.
- 463 Jacobs, A. (2013). With Surf Like Turf, Huge Algae Bloom Befouls China Coast. The New York Times, Asia Pacific, July 5, 2013. Available from <http://www.nytimes.com/2013/07/06/world/asia/huge-algae-bloom-afflicts-qingdao-china.html> (accessed October 2016).
- 464 McClurg, L. (2016). Poisonous Algae Blooms Threaten People, Ecosystems Across U.S. NPR, August 26, 2016. Available from <http://www.npr.org/2016/08/29/491831451/poisonous-algae-blooms-threaten-people-ecosystems-across-u-s> (accessed October 2016).

- 465 Neuhaus, L. (2016). Miles of Algae and a Multitude of Hazards. *New York Times*, July 18, 2016. Available from [http://www.nytimes.com/2016/07/19/science/algae-blooms-beaches.html?\\_r=0](http://www.nytimes.com/2016/07/19/science/algae-blooms-beaches.html?_r=0) (accessed October 2016).
- 466 Reis Costa, P. (2016). Impact and Effects of Paralytic Shellfish Poisoning Toxins Derived from Harmful Algal Blooms to Marine Fish. *Fish and Fisheries* **17**: 226-248.
- 467 U.S. Environmental Protection Agency (EPA). (2013). Impacts of Climate Change on the Occurrence of Harmful Algal Blooms. Available from <https://www.epa.gov/sites/production/files/documents/climatehabs.pdf> (accessed October 2016).
- 468 Recreational and drinking water exposure to toxic cyanobacterial blooms, and seafood consumption from those waters, are known to cause illness and even death (Camargo and Alonso. (2006). Ecological and Toxicological Effects of Inorganic Nitrogen Pollution in Aquatic Ecosystems: A Global Assessment. *Environ Int* **32**: 831-849; Mulvanna, et al. (2012). Health Risk Assessment for Cyanobacterial Toxins in Seafood. *Int J Environ Res Public Health* **9**: 807-820).
- 469 Flewelling, L.J., Naar, J.P., Abbott, J.P., et al. (2005). Brevetoxicosis: Red Tides and Marine Mammal Mortalities. *Nature* **435**: 755-756.
- 470 Diaz, R.J. and Rosenberg, R. (2008). Spreading Dead Zones and Consequences for Marine Ecosystems. *Science* **321**: 926-929.
- 471 Rabotyagov, S.S., Kling, C.L., Gassman, P.W., Rabalais, N.N., and Turner, R.E. (2014). The Economics of Dead Zones: Causes, Impacts, Policy Challenges, and a Model of the Gulf of Mexico Hypoxic Zone. *Review of Environmental Economics and Policy* **8**: 58-79.
- 472 Moffitt, S.E., Hill, T.M., Roopnarine, P.D., and Kennett, J.P. (2015). Response of Seafloor Ecosystems to Abrupt Global Climate Change. *Proceedings of the National Academy of Sciences* **112**: 4684-4689.
- 473 See note 467.
- 474 National Oceanic and Atmospheric Administration (NOAA). (2015). 2015 Gulf of Mexico Dead Zone 'Above Average'. Available from <http://www.noaanews.noaa.gov/stories2015/080415-gulf-of-mexico-dead-zone-above-average.html> (accessed October 2016).
- 475 See note 450.
- 476 See note 450.
- 477 See note 379.
- 478 Food and Agriculture Organization of the United Nations (FAO). (2010). The State of World Fisheries and Aquaculture 2010. FAO, Rome, Italy. Available from <http://www.fao.org/3/a-i1820e.pdf> (accessed October 2016).
- 479 See note 379.
- 480 Halpern, B.S., Longo, C., Hardy, D., et al., (2012). An Index to Assess the Health and Benefits of the Global Ocean. *Nature* **488**: 615-620.
- 481 See note 480.
- 482 See note 450.
- 483 See note 480.
- 484 Rogers, P. and Hall, A. W. (2003). Effective Water Governance. Global Water Partnership Technical Committee. Global Water Partnership, Stockholm, Sweden.
- 485 De Stefano, L., Svendsen, M., Giordano, M., Steel, B.S., Brown, B., and Wolf, A.T. (2014). Water Governance Benchmarking: Concepts and Approach Framework as Applied to Middle East and North Africa Countries. *Water Policy* **16**: 1121-1139.
- 486 Organisation for Economic Co-operation and Development (OECD). (2011). Water Governance in OECD Countries: A Multi-Level Approach – Executive Summary. OECD Publishing, Paris, France. doi: <http://dx.doi.org/10.1787/9789264119284-en>
- 487 Akhmouch, A. (2012). Water Governance in Latin America and the Caribbean: A Multi-Level Approach. OECD Regional Development Working Papers, OECD Publishing. <http://dx.doi.org/10.1787/5k9crzqk3ttj-en>
- 488 Scarlett, L. and McKinney, M. (2016). Connecting People and Places: The Emerging Role of Network Governance in Large Landscape Conservation. *Frontiers in Ecology and the Environment* **14**: 116-125.
- 489 Scarlett, L. (2012). Managing Water: Governance Innovations to Enhance Coordination. Resources for the Future, Washington, D.C., USA. Available from <http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-IB-12-04.pdf> (accessed October 2016).
- 490 Krievins, K., Baird, J., Plummer, R., Brandes, O., Curry, A., Imhof, J., Mitchell, S., Moore, M-L., and Gerger Swartling, Å. (2015). Resilience in a Watershed Governance Context: A Primer. Environmental Sustainability Research Centre, St. Catharines, ON. Available from <https://www.sei-international.org/mediamanager/documents/Publications/SEI-2015-Primer-EnvironmentalSustainabilityResearchCentre-ResilienceInAWatershedGovernanceContextAPrimer-Krievins-et-al.pdf> (accessed October 2016).
- 491 Simonović, S.P. (2009). Managing Water Resources: Methods and Tools for a Systems Approach. UNESCO Publishing, Paris, France and Earthscan, London, UK.

- 492 See note 3.
- 493 Organisation for Economic Co-operation and Development (OECD). (2015). OECD Principles on Water Governance. Available from <http://www.oecd.org/governance/oecd-principles-on-water-governance.htm>.
- 494 See note 493.
- 495 See note 493.
- 496 Bennett, G. and Carroll, N. (2014). Gaining Depth: State of Watershed Investment 2014. Forest Trends, Washington, D.C., USA. Available from [www.ecosystemmarketplace.com/reports/sowi2014](http://www.ecosystemmarketplace.com/reports/sowi2014).
- 497 Goldman-Benner, R.L., Benitez, S., Boucher, T., Calvache, A., Daily, G., Kareiva, P., Kroeger, T., and Ramos, A. (2012). Water Funds and Payments for Ecosystem Services: Practice Learns from Theory and Theory Can Learn from Practice. *Oryx* **46**: 55-63.
- 498 See note 234.
- 499 Climate & Development Knowledge Network (CDKN). (2016). *Watershared: Adaptation, Mitigation, Watershed Protection and Economic Development in Latin America*. Available from <http://cdkn.org/wp-content/uploads/2016/06/CDKN-Bolivia-watershared.pdf> (accessed October 2016).
- 500 Bremer, L., Auerbach, D.A., Goldstein, J.H., et al., (2016). One Size Does Not Fit All: Diverse Approaches to Natural Infrastructure Investments within the Latin American Water Funds Partnership. *Ecosystem Services* **17**: 217–236.
- 501 The Toolbox is available online at [www.nature.org/waterfundstoolbox](http://www.nature.org/waterfundstoolbox).
- 502 See note 496.
- 503 Bennett, G. and Ruef, F. (2016). Alliances for Green Infrastructure: State of Watershed Investments 2016. Forest Trends, Washington, D.C., USA. In press
- 504 See note 500.
- 505 Kauffman, C.M. (2014). Financing Watershed Conservation: Lessons from Ecuador's Evolving Water Trust Funds. *Agricultural Water Management* **145**: 39–49.
- 506 See note 22.
- 507 See note 500.
- 508 See note 496.
- 509 Paladines, R., Rodas, F., Romero, J., Swift, B., López, L., and Clark, M. (2015b). The Regional Water Fund (FORAGUA): A Regional Program for the Sustainable Conservation of Watersheds and Biodiversity in Southern Ecuador. Available from [http://www.watershedconnect.com/documents/files/theRegionalWaterFund\\_foragua\\_aRegionalProgramForTheSustainableConservationOfWatershedsAndBiodiversityInSouthernEcuador.pdf](http://www.watershedconnect.com/documents/files/theRegionalWaterFund_foragua_aRegionalProgramForTheSustainableConservationOfWatershedsAndBiodiversityInSouthernEcuador.pdf)
- 510 See note 499.
- 511 Grey, D., Garrick, D., Blackmore, D., Kelman, J., Muller, M., and Sadoff, C. (2013). Water Security in One Blue Planet: Twenty-First Century Policy Challenges for Science. *Philosophical Transactions of the Royal Society A Mathematical, Physical and Engineering Sciences* **371**: 20120406.
- 512 Akhmouch, A. and Clavreul, D. (2016). Stakeholder Engagement for Inclusive Water Governance: "Practicing What We Preach" with the OECD Water Governance Initiative. *Water* **8**: 204.
- 513 See note 484.
- 514 See note 500.
- 515 See note 500.
- 516 Sharp, R., Tallis, H.T., Ricketts, T., et al. (2016) InVEST +VERSION+ User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund. Available from <http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/>
- 517 Vogl, A.L., Tallis, H.T., Douglass, J., et al., (2015). Resource Investment Optimization System: Introduction & Theoretical Documentation, Natural Capital Project. Stanford University, Stanford, CA. Available from <http://www.naturalcapitalproject.org/RIOS.html>
- 518 The Soil and Water Assessment Tool (SWAT) is a public domain model jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research, part of The Texas A&M University System. SWAT is a small watershed to river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. For more information, see <http://swat.tamu.edu/>
- 519 See note 500.
- 520 See note 497.
- 521 See note 500.

- 522 Paladines, R., Rodas, F., Romero, J., Swift, B., López, L., and Clark, M. (2015a). First Person: How 11 Ecuadorian Cities Pooled their Resources to Support their Watershed. Available from <http://www.ecosystemmarketplace.com/articles/first-person-how-11-ecuadorian-cities-pooled-their-resources-to-support-their-watershed/>
- 523 The Latin America Water Funds Partnership has set goals for 2020 (Source: LAWFP communication material):
- Creation and strengthening of 40 water funds in Latin America and Caribbean
  - Positively impact 4 million hectares of natural ecosystems
  - 80 million people positively impacted with protection of their water sources
  - Leverage 500 million dollars to be invested in natural infrastructure
- 524 See note 500.
- 525 See note 499.
- 526 See note 505.
- 527 Asquith, N. (2013). Investing in Latin America's Water Factories: Incentives and Institutions for Climate Compatible Development. ReVista (Winter 2013), *Harvard Review of Latin America* **XII**: 21-24.
- 528 As in the case of the LAWFP in the Andes and Watershared funds in the Andes: e.g. Grillos, (2017), see note 557; Bremer, et al. (2016), see note 500.
- 529 Asquith, N.M., Vargas, M.T., and Wunder, S. (2008). Selling Two Environmental Services: In-Kind Payments for Bird Habitat and Watershed Protection in Los Negros, Bolivia. *Ecological Economics* **65**: 675-684.
- 530 See note 527.
- 531 Rodriguez, L.M. (2014). Monitoreo de impacto socioeconómico en la sub cuenca Aguacalera, cuenca Río Bolo. Valle del Cauca. Colombia. Unpublished report.
- 532 See note 500.
- 533 See note 505.
- 534 One program that has been rigorously evaluated is a Reciprocal Watershared Agreements program in Bolivia. Although it is the better-off members of society who tended to sign-up for the compensation scheme (Grillos, (2017), see note 557), evidence suggests that in addition to the value of the contract (farmers receive US\$100 of in-kind incentives at signing plus US\$10 per hectare annually) the conservation activities themselves add economic value to landholders through improved water quality (Botazzi, et al. (forthcoming), see note 553).
- 535 Arriagada, R.A., Sills, E.O., Ferraro, P.J., and Pattanayak, S.K. (2015). Do Payments Pay Off? Evidence from Participation in Costa Rica's PES Program. *PLOS ONE* **10**: e0131544.
- 536 Li, J., Feldman, M.W., Li, S., and Daily, G.C. (2011). Rural Household Income and Inequality under the Sloping Land Conversion Program in Western China. *Proceedings of the National Academy of Sciences* **108**: 7721-7726.
- 537 Porras, I., Barton, D.N., Miranda, M., and Chacón-Cascante, A. (2013). Learning from 20 years of Payments for Ecosystem Services in Costa Rica. International Institute for Environment and Development, London, UK. Available from <http://pubs.iied.org/pdfs/16514IIED.pdf> (accessed October 2016).
- 538 Groom, B. and Palmer, C. (2012). REDD+ and Rural Livelihoods. *Biological Conservation* **154**: 42-52.
- 539 See note 536.
- 540 Lin, Y., Yao, S., 2014. Impact of the Sloping Land Conversion Program on rural household income: An integrated estimation. *Land Use Policy* **40**: 56–63.
- 541 Yin, R., Liu, C., Zhao, M., Yao, S., and Liu, H. (2014). The Implementation and Impacts of China's Largest Payment for Ecosystem Services Program as Revealed by Longitudinal Household Data. *Land Use Policy* **40**: 45–55.
- 542 See note 536.
- 543 See note 538.
- 544 Hegde, R. and Bull, G.Q. (2011). Performance of An Agro-Forestry Based Payments-for-Environmental-Services Project in Mozambique: A Household Level Analysis. *Ecological Economics* **71**: 122-130.
- 545 See note 535.
- 546 Kosoy, N., Corbera, E., and Brown, K. (2008). Participation in Payments for Ecosystem Services: Case Studies from the Lacandon Rainforest, Mexico. *Geoforum* **39**: 2073-2083.
- 547 See note 535.
- 548 Van Hecken, G., Bastiaensen, J., and Vásquez, W.F. (2012). The Viability of Local Payments for Watershed Services: Empirical Evidence from Matiguás, Nicaragua. *Ecological Economics* **74**: 169-176.
- 549 See note 531.

- 550 Richards, R.C., Rerolle, J., Aronson, J., Pereira, P.H., Gonçalves, H., and Brancalion, P.H. (2015). Governing a Pioneer Program on Payment for Watershed Services: Stakeholder Involvement, Legal Frameworks and Early Lessons from the Atlantic Forest of Brazil. *Ecosystem Services* **16**: 23-32.
- 551 See note 531.
- 552 Markos, A. (Forthcoming). Can Payments for Watershed Services in a context of rural poverty build resilience for both ecosystems and households? Case study from Bolivia.
- 553 Bottazzi, P., Jones, P.G.J., and Crespo, D. (Forthcoming). Payment for Environmental "Self-Service": Exploring Farmers' Motivation to Participate in a Conservation Incentive Scheme in the Bolivian Andes.
- 554 For example: RIOS, see Vogl, A.L., Tallis, H.T., Douglass, J., et al., (2015). Resource Investment Optimization System: Introduction & Theoretical Documentation, Natural Capital Project. Stanford University, Stanford, CA. Available from <http://www.naturalcapitalproject.org/RIOS.html>
- 555 Vogl, A.L., Bryant, B.P., Hunink, J.E., Wolny, S., Apse, C., and Droogers, P. (*Accepted*) Valuing Investments in Sustainable Land Management in the Upper Tana River Basin, Kenya. *Journal of Environmental Management*.
- 556 Higgins, J.V. and Zimmerling, A. (eds.). (2013). A Primer for Monitoring Water Funds. The Nature Conservancy, Arlington, VA, USA. Available from [http://www.fondosdeagua.org/sites/default/files/Water%20Funds\\_Monitoring%20Primer\\_TNC\\_2013.pdf](http://www.fondosdeagua.org/sites/default/files/Water%20Funds_Monitoring%20Primer_TNC_2013.pdf) (accessed October 2016).
- 557 Grillos, T. (2017). Economic vs Non-Material Incentives for Participation in an In-Kind Payments for Ecosystem Services Program in Bolivia. *Ecological Economics* **131**: 178–190.
- 558 Bremer, L.L., Vogl, A.L., De Bièvre, B., and Petry, P. (eds.). (2016). Bridging Theory and Practice for Hydrological Monitoring in Water Funds. Available from [http://fondosdeagua.org/sites/default/files/study-cases-monitoreo-hidrico-water-funds\\_1.pdf](http://fondosdeagua.org/sites/default/files/study-cases-monitoreo-hidrico-water-funds_1.pdf) (accessed October 2016).
- 559 See note 557.
- 560 Bremer, L.L., Gammie, G., and Maldonado, O. (2016). Participatory Social Impact Assessment of Water Funds: A Case Study from Lima, Peru. Forest Trends and Natural Capital Project. Available from [http://www.forest-trends.org/documents/files/doc\\_5279.pdf](http://www.forest-trends.org/documents/files/doc_5279.pdf) (accessed October 2016).
- 561 See note 531.
- 562 See note 557.
- 563 Hess, S. and Leisher, C. (2014). Sagana and Gura Baseline Survey for the Upper Tana Water Fund. Baseline Report prepared by The Nature Conservancy and Partners, Kenya, Nairobi.
- 564 See note 496.
- 565 See note 503.
- 566 Bennett, G., Carroll, N., and Hamilton, K. (2013). Charting New Waters: State of Watershed Payments 2012. Forest Trends, Washington, D.C., USA. Available from <http://www.ecosystemmarketplace.com/reports/sowp2012>.
- 567 Latin American Water Funds Partnership, see: <http://fundosdeagua.org/en>
- 568 See <http://www.fonag.org.ec/inicio/que-hacemos/programas.html>
- 569 See note 527.
- 570 See note 499.
- 571 Bétrisey, F., Mager, C., and Rist, S. (2016). Local Views and Structural Determinants of Poverty Alleviation Through Payments for Environmental Services: Bolivian Insights. *World Development Perspectives* **1**:6-11.
- 572 Quote from Ariely, D. (2008). Predictably Irrational: The Hidden Forces That Shape Our Decisions. HarperCollins Publishers, NY.
- 573 See note 522.
- 574 See note 509.
- 575 Unidad Municipal de agua potable y alcantarillado de Loja (UMAPAL). Available from <http://www.loja.gob.ec/category/departamentos/umapal>
- 576 See note 509.
- 577 Maddocks, A., Shiao, T., and Mann, S.A. (2014). 3 Maps Help Explain São Paulo, Brazil's Water Crisis. WRI, November 4, 2014. Available from <http://www.wri.org/blog/2014/11/3-maps-help-explain-s%C3%A3o-paulo-brazil%E2%80%99s-water-crisis> (accessed October 2016).
- 578 See note 550.
- 579 Apse, C. and Bryant, B., The Nature Conservancy. (2015). Upper Tana-Nairobi Water Fund Business Case. Version 2. The Nature Conservancy, Nairobi, Kenya. Available from <http://www.nature.org/ourinitiatives/regions/africa/upper-tana-nairobi-water-fund-business-case.pdf> (accessed September 2016).

- 580 See Mogaka, H., Gichere, S., Davis, R., and Hirji, R. (2006). Climate Variability and Water Resources Degradation in Kenya: Improving Water Resources Development and Management. World Bank Publications, Washington, D.C., USA.
- 581 See <http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/texas/explore/edwards-aquifer-protection.xml>
- 582 See <http://www.nature.org/ourinitiatives/habitats/riverslakes/rio-grande-water-fund.xml>
- 583 See [http://www.nature.org/cs/groups/webcontent/@web/@lakesrivers/documents/document/prd\\_293976.pdf](http://www.nature.org/cs/groups/webcontent/@web/@lakesrivers/documents/document/prd_293976.pdf)
- 584 U.S. Forest Service. Partnerships. Available from <http://www.fs.fed.us/working-with-us/partnerships> (accessed September 2016).
- 585 See note 66.
- 586 Carpe Diem West. Healthy Headwater's Success Story: Santa Fe, New Mexico – Sustaining the Watershed. Available from [http://www.carpediemwest.org/wp-content/uploads/Santa-Fe-Success-Story\\_0.pdf](http://www.carpediemwest.org/wp-content/uploads/Santa-Fe-Success-Story_0.pdf) (accessed October 2016).
- 587 Paskus, L. (2016). Fired Up: Climate Change Spurs “New Normal” in Forest Management. New Mexico In Depth, March 9, 2016. Available from <http://nminddepth.com/2016/03/09/fired-up-climate-change-spurs-new-normal-in-forest-management/> (accessed October 2016).
- 588 Reed Jr., O. (2015). Forest Thinning Projects Gets Off to Good Start. Albuquerque Journal, December 20, 2015. Available from <http://www.abqjournal.com/693941/forest-thinning-project-off-to-good-start.html> (accessed October 2016).
- 589 Kent, L.Y. (2015). Climate Change and Fire in the Southwest. ERI Working Paper No. 34. Ecological Restoration Institute and Southwest Fire Science Consortium, Northern Arizona University, Flagstaff, AZ, USA.
- 590 Rio Grande Water Fund. (2014). Comprehensive Plan for Wildfire and Water Source Protection. The Nature Conservancy, New Mexico. Available from <http://nmconservation.org/rgwf/plan.html> (accessed October 2016).
- 591 Impact Datasource. (2013). The Full Cost of New Mexico Wildfires. Impact Datasource, Austin, TX, USA. Available from [http://pearce.house.gov/sites/pearce.house.gov/files/6%20Full\\_Cost\\_of\\_New\\_Mexico\\_Wild\\_Fires\\_1-24-13.pdf](http://pearce.house.gov/sites/pearce.house.gov/files/6%20Full_Cost_of_New_Mexico_Wild_Fires_1-24-13.pdf) (accessed October 2016).
- 592 The state of New Mexico ranks 37th in annual GDP so the implications of this forest fires in state level economy is far reaching.
- 593 See note 590.
- 594 See note 588.
- 595 See note 590.
- 596 See note 34.
- 597 See note 34.
- 598 Institutos de Investigación SINA. (2015). Informe del estado del Medio Ambiente y de los Recursos Naturales Renovables 2012, 2013 y 2014. Tomo II: Estado de los Ecosistemas y de los servicios Ecosistémicos (Versión preliminar). Available from <http://documentacion.ideam.gov.co/openbiblio/bvirtual/022971/IEARN2.pdf> (accessed October 2016). (In Spanish).
- 599 Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM). La Cifra de Deforestación en Colombia 2015 Reporta 124.035 Hectáreas Afectadas. Available from [http://www.ideam.gov.co/web/sala-de-prensa/noticias/-/asset\\_publisher/96oXgZAhHrhJ/content/la-cifra-de-deforestacion-en-colombia-2015-reporta-124-035-hectareas-afectada](http://www.ideam.gov.co/web/sala-de-prensa/noticias/-/asset_publisher/96oXgZAhHrhJ/content/la-cifra-de-deforestacion-en-colombia-2015-reporta-124-035-hectareas-afectada) (accessed October 2016). (In Spanish).
- 600 Comisión Económica para América Latina y el Caribe (Cepal). (2012). Valoración de Daños y Pérdidas: Ola Invernal en Colombia 2010-2011. Misión BID – Cepal, Bogotá, Colombia. Available from <http://www.cepal.org/publicaciones/xml/0/47330/olainvernalcolombia2010-2011.pdf> (accessed October 2016). (In Spanish).
- 601 Hoyos, N., Escobar, J., Restrepo, J.C., Arango, A.M., and Ortiz, J.C. (2013). Impact of the 2010–2011 La Niña Phenomenon in Colombia, South America: The Human Toll of an Extreme Weather Event. *Applied Geography* **39**: 16-25.
- 602 Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM). (2010). Segunda Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre Cambio Climático – República de Colombia. IDEAM, Bogotá, Colombia. Available from <http://documentacion.ideam.gov.co/openbiblio/bvirtual/021658/2Comunicacion/IDEAMTOMOIIIPreliminares.pdf> (accessed October 2016).
- 603 World Bank. Poverty & Equity Data – Colombia. Available from <http://povertydata.worldbank.org/poverty/country/COL> (accessed October 2016).

- 604 See note 195.
- 605 United Nations (UN) Sustainable Development Solutions Network. (2016). A Case Study of Colombia: Data Driving Action on the SDGs. Available from <http://unsdsn.org/news/2016/05/06/a-case-study-of-colombia-data-driving-action-on-the-sdgs/> (accessed October 2016).
- 606 Departamento Nacional de Planeación. Plan Nacional de Desarrollo 2014-2018: Todos por un nuevo país. Tomo 2. Available from <https://colaboracion.dnp.gov.co/CDT/PND/PND%202014-2018%20Tomo%20202%20internet.pdf> (accessed October 2016).
- 607 See note 606.
- 608 See note 598.
- 609 Gobierno de Colombia. Republic of Colombia's Intended Nationally Determined Contribution (INDC). Available from <http://www4.unfccc.int/submissions/INDC/Published%20Documents/Colombia/1/Colombia%20iNDC%20Unofficial%20translation%20Eng.pdf> (accessed October 2016).
- 610 SDGs in Colombia: Approaches and Challenges for their Implementation. Available from <https://sustainabledevelopment.un.org/content/documents/13299presentationcolombia.pdf> (accessed October 2016).
- 611 See note 20.
- 612 Center for International Earth Science Information Network (CIESIN) at Columbia University. (2016). Gridded Population of the World, Version 4 (GPWv4): Population Density. NASA Socioeconomic Data and Applications Center (SEDAC), Palisades, New York, USA. Available from <http://dx.doi.org/10.7927/H4NP22DQ> (accessed October 2016).
- 613 For SDG 13 and 15, see <http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-13-climate-action.html> and <http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-15-life-on-land.html>.
- 614 See note 579.
- 615 In 1999, it was estimated that 3.1 million people were living in the Upper Tana with a population density of about 250 persons per square kilometers (WRI et al. 2007: *Nature's Benefits in Kenya, An Atlas of Ecosystems and Human Well-Being*). The population has since increased to 5.29 million with estimated average population density of 300 persons per square kilometers (ETC East Africa Ltd. 2012: *Upper Tana-Nairobi Water Fund Technical Report*. See note 617).
- 616 Sources of off-farm activities include quarrying, sand harvesting, fishing, small-scale business and cottage industries, and public sector employment (ETC East Africa Ltd. 2012: *Upper Tana-Nairobi Water Fund Technical Report*. See note 617).
- 617 ETC East Africa. (2012). Upper Tana-Nairobi Water Fund Technical Report. Available from [http://www.nature.org/cs/groups/webcontent/@web/@lakesrivers/documents/document/prd\\_284437.pdf](http://www.nature.org/cs/groups/webcontent/@web/@lakesrivers/documents/document/prd_284437.pdf) (accessed September 2016).
- 618 The Upper Tana tributaries provide water to five hydropower dams that are located at various points along the mainstem of the Tana River that together provide nearly 70 percent of the total electric energy to the national grid (Agwata 2006: *Resource Potential of the Tana Basin with Particular Focus on the Bwathonaro Watershed, Kenya*. Available from <http://www.uni-siegen.de/zew/publikationen/volume0506/agwata.pdf> (accessed December 2016)).
- 619 Hunink, J.E. and Droogers, P. (2011). Physiographical Baseline Survey for the Upper Tana Catchment: Erosion and Sediment Yield Assessment. FutureWater Report for Water Resources Management Authority, Kenya. FutureWater, Wageningen, The Netherlands. Available from [http://www.futurewater.nl/wp-content/uploads/2013/01/2011\\_TanaSed\\_FW-1121.pdf](http://www.futurewater.nl/wp-content/uploads/2013/01/2011_TanaSed_FW-1121.pdf) (accessed September 2016).
- 620 See note 579.
- 621 See note 579.
- 622 See note 579.
- 623 See note 579.
- 624 See note 555.
- 625 Population data are from 2005 for the approximately 500 cities whose source watersheds were mapped through an earlier effort (McDonald and Shemie 2014: *Urban Water Blueprint*), and are from 2000 for the remaining approximately 3500 cities. In 2005 the global urban population was roughly 3.2 billion people (UN 2015: *World Urbanization Prospects: The 2014 Revision*).
- 626 See note 34.
- 627 World Bank. World Bank Database—World Development Indicators. Available from <http://data.worldbank.org/data-catalog/world-development-indicators> (accessed October 2016)
- 628 See note 627.

- 629 See note 503.
- 630 Clearly there are vast numbers of important and necessary policies and/or public or private expenditures that add value to the health of watersheds, but we focus here on a specific set of programs that are set up as investment models accessible to water sector and other sector investment.
- 631 Organisation for Economic Co-operation and Development (OECD). (2009). Managing Water for All: An OECD Perspective on Pricing and Financing. OECD Publishing, Paris, France. <http://www.oecd.org/tad/sustainable-agriculture/44476961.pdf> (accessed September 2016).
- 632 RobecoSAM. (2015). Water: The Market of the Future. RobecoSAM, Zurich, Switzerland. Available from [https://www.robeco.com/images/RobecoSAM\\_Water\\_Study.pdf](https://www.robeco.com/images/RobecoSAM_Water_Study.pdf) (accessed September 2016).
- 633 See note 503.
- 634 See note 496.
- 635 Different project types are explained as follows: 1) Bilateral agreements: A funding mechanism that involves a single water user, typically downstream, compensating one or more parties for activities that deliver hydrological benefits to the payer; includes direct investment for watershed protection. 2) Groundwater mitigation/offsets, also called voluntary compensation: Activities funded by companies and other organizations seeking to mitigate their own impacts on watershed services voluntarily. 3) Instream acquisition/leasing: Activities that involve governments or NGOs that act in the public interest by buying or leasing water use rights in existing water markets, which are not used but instead set aside to ensure a minimum level of flows and protect wildlife and habitats. 4) Public subsidies for watershed protection: A funding mechanism that leverages public finance for large-scale programs that reward land managers for enhancing or protecting ecosystem services. 5) Collective action fund: i.e. water funds. 6) Water quality trading/offsets: A mechanism that allow water users facing regulatory obligations to manage their impacts on watersheds by compensating others for offsite activities that improve water quality, availability, or other water-related values. 7) Not defined: Programs that are unclear in determining whether they are public subsidies or user-driven due to limited information. Also see Bennett and Carroll 2014: *Gaining Depth: State of Watershed Investment 2014* and Bennett and Ruef 2016: *Alliances for Green Infrastructure: State of Watershed Investments 2016*.
- 636 See note 503.
- 637 See note 503.
- 638 CDP. (2015). CDP Global Water Report 2015: Accelerating Action. CDP Worldwide. Available from <https://www.cdp.net/en/research/global-reports/global-water-report-2015> (accessed September 2016).
- 639 See <http://www.allianceforwaterstewardship.org/>
- 640 See <http://ceowatermandate.org/>
- 641 See note 34.
- 642 See note 503.
- 643 The Nature Conservancy. New Mexico, Rio Grande Water Fund. Available from <http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/newmexico/new-mexico-rio-grande-water-fund.xml>
- 644 See note 631.
- 645 See note 9.
- 646 See note 496.
- 647 Sáenz, L. and Mulligan, M. (2013). The Role of Cloud Affected Forests (CAFs) on Water Inputs to Dams. *Ecosystem Services* **5**: 69-77.
- 648 Sáenz, L., Mulligan, M., and Patiño, E. (2013). The Role of Cloud Forests in Maintaining Hydropower Performance. *International Journal on Hydropower and Dams* **20**: 72-77.
- 649 Sáenz, L., et al. (2016). Cloud Forests and Firm Capacity in Latin America: Economic Argument for Conservation and Restoration. *In Preparation*.
- 650 Sáenz, L., Mulligan, M., Arjona, F., and Gutierrez, T. (2014). The Role of Cloud Forest Restoration on Energy Security. *Ecosystem Services* **9**:180-190.
- 651 See note 650.
- 652 Kruse, S., Hartwell, R., and Buckley, M. (2016). Taos Return on Investment Study for the Rio Grande Water Fund. White paper for The Nature Conservancy. Ecosystem Economics LLC and ECONorthwest.
- 653 Kroeger, T., De Bièvre, B., Acosta, L., et al. (2015). Local and Downstream Returns to Watershed Investments in Andean Highlands. White paper for The Nature Conservancy.
- 654 See note 653.

- 655 Securitization is the process of taking an illiquid asset, or group of assets, and through financial engineering, transforming them into a security. A typical example of securitization is a mortgage-backed security (MBS), which is a type of asset-backed security that is secured by a collection of mortgages. See <http://www.investopedia.com/ask/answers/07/securitization.asp>
- Cash flow is the net amount of cash and cash-equivalents moving into and out of a business. Positive cash flow indicates that a company's liquid assets are increasing. See <http://www.investopedia.com/terms/c/cashflow.asp>
- 656 Credit Suisse AG and McKinsey Center for Business and Environment. (2016). Conservation Finance From Niche to Mainstream: The Building of an Institutional Asset Class. Available from <https://assets.rockefellerfoundation.org/app/uploads/20160121144045/conservation-finance-en.pdf> (accessed September 2016).
- 657 Groleau, G. and McCann, L.M. (2012). Designing Watershed Programs to Pay Farmers for Water Quality Services: Case Studies of Munich and New York City. *Ecological Economics* **76**: 87-94.
- 658 See note 656.
- 659 Eko Asset Management Partners. (2013). Water Fund Investment Evaluation. Unpublished report.
- 660 Impact investing is investing that aims to generate specific beneficial social or environmental effects in addition to financial gain. See <http://www.investopedia.com/terms/i/impact-investing.asp?ad=dirN&qo=investopediaSiteSearch&qsre=0&o=40186>
- 661 See <http://www.sanantonio.gov/EdwardsAquifer/About>
- 662 See <http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/illinois/explore/clean-water-in-bloomington-illinois.xml>
- 663 Kroeger, T. (2014). Estimating the 'Return on Investment' in Natural Infrastructure: Rio Camboriú watershed, Santa Catarina State, Brazil. Presentation on A Community on Ecosystem Service (ACES) Conference 2014: *Linking Science, Practice and Decision Making*. Washington, D.C., USA, December 8-12, 2014. Available from <http://conference.ifas.ufl.edu/aces14/presentations/Dec%202011%20Thursday/5%20Session%208H/Kroeger%20Timm.pdf>
- 664 Redstone Strategy Group. (2011). Project Finance for Performance: Lessons from Landscape-Scale Conservation Deals. Prepared by Redstone Strategy Group in collaboration with the Gordon and Betty Moore Foundation and the Linden Trust for Conservation. Available from <http://lindentrust.org/pdfs/2011-07-13-Project-Finance-for-Permanence-Report.pdf> (accessed October 2016).
- 665 The Economics of Ecosystems & Biodiversity (TEEB) Case. (2012). Converting Water-Intensive Paddy to Dryland Crops, China. Compiled by Sanjib Kumar Jha, mainly based on Bennett, M.T. (2009). Available from <http://doc.teebweb.org/wp-content/uploads/2013/02/TEEBcase-Converting-water-intensive-paddy-to-dryland-crops-China.pdf> (accessed October 2016).
- 666 See note 665.
- 667 WaterWorld. (2015). Peru Water Users to Invest Over \$110M in Green Infrastructure, Climate Change Efforts. WaterWorld, April 13, 2015. Available from <http://www.waterworld.com/articles/2015/04/lima-water-users-to-invest-more-than-110-million-in-green-infrastructure-and-climate-change-adaptation.html> (accessed October 2016).
- 668 California Legislative Information. AB-2480 Source Watersheds: Financing. Available from [http://leginfo.legislature.ca.gov/faces/billCompareClient.xhtml?bill\\_id=201520160AB2480](http://leginfo.legislature.ca.gov/faces/billCompareClient.xhtml?bill_id=201520160AB2480) (accessed October 2016).
- 669 Interview (Colin Herron)
- 670 See note 590.
- 671 United Nations (UN). Habitat III The New Urban Agenda. Draft outcome document of the United Nations Conference on Housing and Sustainable Urban Development (Habitat III). Available from <https://www2.habitat3.org/bitcache/99d99fb0824de50214e99f864459d8081a9be00?vid=591155&disposition=inline&op=view> (accessed October 2016).
- 672 See note 195.
- 673 See note 423.
- 674 McDonald, R.I., Weber, K., Padowski, J., et al., (2014). Water on an Urban Planet: Urbanization and the Reach of Urban Water Infrastructure. *Global Environmental Change* **27**: 96-105.

- 675 See note 34.
- 676 See note 674.
- 677 See note 674.
- 678 For more information, see <http://worldwaterforum7.org/main/>
- 679 See note 493.
- 680 Merriam-Webster Dictionary. Available from <http://www.merriam-webster.com/dictionary/system>
- 681 Holling, C.S. (2001). Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems* **4**: 390-405.
- 682 Fiksel, J., Bruins, R., Gatchett, A., Gilliland, A., and ten Brink, M. (2014). The Triple Value Model: A Systems Approach to Sustainable Solutions. *Clean Technologies and Environmental Policy* **16**: 691-702.
- 683 Arnold, R.D. and Wade, J.P. (2015). A Definition of Systems Thinking: A Systems Approach. *Procedia Computer Science* **44**: 669-678.
- 684 Virapongse, A., Brooks, S., Metcalf, E.C., Zedalis, M., Gosz, J., Kliskey, A., and Alessa, L. (2016). A Social-Ecological Systems Approach for Environmental Management. *Journal of Environmental Management* **178**: 83-91.
- 685 Nandalal, K.D.W. and Simonović, S.P. (2003). State-of-the-Art Report on Systems Analysis Methods for Resolution of Conflicts in Water Resources Management. A Report Prepared for Division of Water Sciences UNESCO. UNESCO, Paris, France. Available from <http://unesdoc.unesco.org/images/0013/001332/133284e.pdf>
- 686 Grey, D. and Sadoff, C.W. (2007). Sink or Swim? Water Security for Growth and Development. *Water Policy* **9**: 545-571.
- 687 Walker, B. (2002). Human Natures and the Resilience of Social-Ecological Systems: A Comment on the Ehrlich's paper. *Environment and Development Economics* **7**: 183-186.
- 688 See note 490.
- 689 Sadoff, C., Harshdeep, N.R., Blackmore, D., Wu, X., O'Donnell, A., Jeuland, M., Lee, S., and Whittington, D. (2013). Ten Fundamental Questions for Water Resources Development in the Ganges: Myths and Realities. *Water Policy* **15**: 147-164.
- 690 Chapin, M. (2004). A Challenge to Conservationists. *World Watch Magazine* (November/December 2004): 17-31. Worldwatch Institute. Available from <http://www.worldwatch.org/system/files/EP176A.pdf> (accessed October 2016).
- 691 Agrawal, A. and Redford, K.H. (2007). Conservation and Displacement. Pages 4–15 in Redford, K.H. and Fearn, E. (eds.). *Protected Areas and Human Displacement: A Conservation Perspective*. Working Paper 29. Wildlife Conservation Society, New York, USA.
- 692 Jack, B.K., Kousky, C., and Sims, K.R. (2008). Designing Payments for Ecosystem Services: Lessons from Previous Experience with Incentive-Based Mechanisms. *Proceedings of the National Academy of Sciences* **105**: 9465-9470.
- 693 Campese, J., Sunderland, T., Greiber, T., and Oviedo, G. (eds.). (2009). Rights-Based Approaches: Exploring Issues and Opportunities for Conservation. CIFOR and IUCN, Bogor, Indonesia. Available from [http://www.cifor.org/publications/pdf\\_files/Books/BSunderland0901.pdf](http://www.cifor.org/publications/pdf_files/Books/BSunderland0901.pdf) (accessed October 2016).
- 694 See note 693.
- 695 See note 693.
- 696 Morrison, J. (2016). Back to Basics: Saving Water the Old-Fashioned Way. Smithsonian.com. Available from <http://www.smithsonianmag.com/science-nature/saving-water-old-fashioned-way-180959917/?no-ist> (accessed September 2016).
- 697 See note 560.



Our path to clean water isn't lined exclusively  
in concrete. Nature can help.

**The Nature Conservancy**

4245 North Fairfax Drive, Suite 100  
Arlington, VA 22203-1606

Phone: 703-841-5300  
Website: [www.nature.org](http://www.nature.org)

**For more information, visit:**

[www.nature.org/beyondthesource](http://www.nature.org/beyondthesource)

Mapping portal: [www.protectingwater.org](http://www.protectingwater.org)

This report was developed in partnership with the Natural Capital Project, Forest Trends, the Inter-American Development Bank and the Latin American Water Funds Partnership.



# The Nature Conservancy

## The Benefits of Source Water Protection

