

# Great River Landscapes of South and Central America (A Conversation with Kenneth R. Olson)

## Editorial board<sup>1</sup>

Pollution and Diseases

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## Abstract

This interview discusses Book 5 of the Kenneth R. Olson Book Series, Great River Landscapes of South and Central America, co-authored by Kenneth R. Olson and Donna Tornoe. The book examines the environmental history, ecological dynamics, and management challenges of three major water systems: the Amazon River, the Rio de la Plata Basin, and the Panama Canal watershed. Through a series of case studies, the authors explore how climate variability, river migration, land-use change, deforestation, agricultural development, invasive species, and large-scale engineering projects have shaped river landscapes over time. Particular attention is given to long-term environmental impacts associated with pesticide and herbicide use in the Panama Canal Zone, including concerns regarding arsenic contamination, TCDD-associated herbicides, and potential implications for freshwater quality and public health. The interview highlights the interconnected relationships among environmental processes, political decisions, military activities, economic development, and water-resource management. The discussion emphasizes the importance of resilience-based river management, interdisciplinary environmental research, and long-term monitoring in addressing contemporary challenges related to freshwater sustainability, pollution, ecosystem health, and climate change.

*Keywords:* Amazon River; Rio de la Plata Basin; Panama Canal; Freshwater Resources; River Landscapes; Water Quality; Environmental Pollution; Arsenic Contamination; TCDD; Agent Orange; Climate Change; Soil Erosion; Sedimentation; Invasive Species; Watershed Management; Environmental History; Public Health; Freshwater Crisis; Environmental Resilience; South America.

## Key Points

1. The Amazon River, Rio de la Plata Basin, and Panama Canal watershed demonstrate how climate variability, geomorphic processes, and human activities have continuously reshaped river landscapes throughout history.

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These systems illustrate the dynamic relationship between environmental change and societal development across South and Central America.

2. Human-induced pressures, including deforestation, intensive agriculture, industrial development, invasive species introductions, and urban expansion, have contributed to declining water quality and ecosystem degradation in several major river basins. The case studies highlight the cumulative nature of environmental impacts and the need for integrated watershed management.
3. The construction and operation of the Panama Canal represent one of the most significant examples of large-scale environmental modification in modern history. While the canal transformed global trade and transportation, it also altered hydrological systems, submerged natural landscapes, and introduced long-term environmental management challenges.
4. Historical applications of pesticides, herbicides, and arsenic-containing compounds in the Panama Canal Zone raise important questions regarding the persistence of contaminants in soils, sediments, groundwater, and freshwater ecosystems. The interview emphasizes the need for continued environmental monitoring and scientific assessment of legacy pollution.
5. Environmental systems cannot be separated from political, military, economic, and social processes. Decisions regarding navigation, national security, land use, and infrastructure development often generate environmental consequences that may persist for decades and influence both ecosystem health and human well-being.
6. Climate change and increasing climatic variability are expected to intensify challenges associated with flooding, drought, sediment transport, soil erosion, agricultural productivity, and freshwater availability. The experiences of the Amazon, Rio de la Plata, and Panama Canal watersheds provide valuable insights into the management of future environmental risks.
7. The central conclusion of the book is that river systems are inherently dynamic and that resilience-based management offers the most effective approach for addressing uncertainty. Sustainable stewardship of major river basins requires the integration of hydrology, ecology, environmental science, public health, and adaptive governance.

## **Introduction**

*Interview conducted on June 17, 2026.*

*Prepared for the journal "Pollution and Diseases."*

Professor Kenneth R. Olson is an American soil scientist, environmental researcher, and author whose work focuses on great river landscapes, environmental degradation, flooding, war-related ecological damage, and freshwater systems around the world. In this interview, he reflects on decades of interdisciplinary research, the environmental consequences of war, and the future of the world's great rivers and deltas.

<b>Book title</b>	Great River Landscapes of South and Central America
<b>Authors</b>	Kenneth R. Olson and Donna Tornoe
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<b>Pages</b>	228 p.

### Why This Book Matters Now

This book is significant because it examines major river systems as dynamic socio-ecological environments in which hydrological processes, land-use change, pollution, infrastructure development, climate variability, and public health risks are closely interconnected. By focusing on the Amazon River, the Rio de la Plata Basin, and the Panama Canal watershed, the work demonstrates that large river landscapes cannot be understood solely through physical geography or engineering analysis. They must also be studied as historically evolving systems shaped by political decisions, economic development, military activities, agricultural expansion, and environmental management practices.

The book is particularly important in the present context of accelerating freshwater degradation and increasing climatic uncertainty. Rivers that once appeared to be stable natural resources are now increasingly vulnerable to deforestation, sedimentation, invasive species, industrial discharge, agricultural runoff, drought, flooding, and legacy contamination. The discussion of pesticide, herbicide, TCDD, and arsenic-related pollution in the Panama Canal Zone highlights the long-term consequences of past management decisions and the need for continued environmental monitoring.

The scientific value of this work lies in its interdisciplinary approach. It integrates environmental history, soil science, hydrology, ecology, public health, and watershed governance to show how cumulative pressures affect water quality, ecosystem resilience, and human well-being. The book therefore contributes to a broader understanding of freshwater sustainability and provides a relevant framework for evaluating river management challenges in other regions of the world.

At a time when global societies face growing pressure on water resources, food systems, transportation corridors, and ecological stability, this book offers an important reminder that river management must be based on long-term resilience rather than short-term optimization. Its central contribution is the demonstration that sustainable stewardship of great river systems requires scientific evidence, adaptive governance, historical awareness, and continuous monitoring of environmental change.

### INTERVIEW

#### Q: What is this book about?

A: This book examines two of the most influential river systems in South America—the Amazon River (1) and the Rio de la Plata Basin (2)—which together drain approximately 45% of the continent. Over thousands of years, shifting river channels, climatic fluctuations, and extreme weather events have continuously reshaped South American

landscapes, carving new pathways through floodplains, exposing upland formations, and creating fertile valleys. These dynamic river systems have altered their courses repeatedly, transforming both natural environments and human settlements.

The lands adjacent to these rivers consist largely of low-lying floodplains that continue to experience seasonal inundation and remain only partially constrained by human infrastructure. Through a series of case studies supported by maps and photographs, the authors examine the complex and evolving landscapes of the Rio de la Plata (Figure 1), the Amazon River (Figure 2), and their tributary systems. The book reviews the historical impacts of climate variability, economic development, and population growth, and evaluates management strategies aimed at protecting soil and water resources while maintaining social, economic, and ecological balance.

During the twentieth century, another major waterway—the Panama Canal (3)—was constructed in Central America and became a critical driver of global commerce. Its creation required extensive engineering modifications, including levees, locks, dams, flood-control structures, reservoirs, and the excavation of a navigation channel through the continental divide. This research also documents the long-term environmental consequences of pesticide and herbicide use within the Panama Canal Zone (Figure 3).



Figure 1. Rio de la Plata Delta wetlands. Photo Credit: Encyclopedia of Britannica. Reprinted with copyright permission of the Managing Editor of the Open Journal of Soil Science.



Figure 2. Rio de Janeiro with statue and view of the Sea. Photo Credit: Matador Network. Reprinted with copyright permission of the Managing Editor of the Open Journal of Soil Science.

**Q: Why did you decide to write this book specifically?**

A: After traveling extensively throughout South and Central America and conducting research on many of its major rivers and waterways, I became increasingly interested in the environmental and historical significance of the Rio de la Plata and Amazon River systems. Later field investigations in Central America further expanded this interest to include the Panama Canal and its surrounding landscapes. Together, these river systems illustrate how natural processes and human interventions interact to shape environmental change over time.

**Q: What makes this topic scientifically important?**

A: The opening of the Panama Canal in 1914 transformed global maritime transportation by dramatically reducing travel time between the Atlantic and Pacific Oceans. The canal increased the flow of internationally traded goods, enabled larger volumes of maritime commerce, and stimulated the growth of major port facilities on both coasts of Panama (3).

This research documents the long-term environmental consequences of pesticide and herbicide use within the Panama Canal Zone (Figure 3). Many of these chemicals, including 2,4-D, 2,4,5-T, and DDT, persist in aquatic environments for extended periods, while others, such as arsenic, do not undergo degradation and therefore remain in the environment indefinitely. During the rainy season, pesticides and associated

contaminants were transported into Lake Gatun through surface runoff, either dissolved in water or attached to sediment particles.

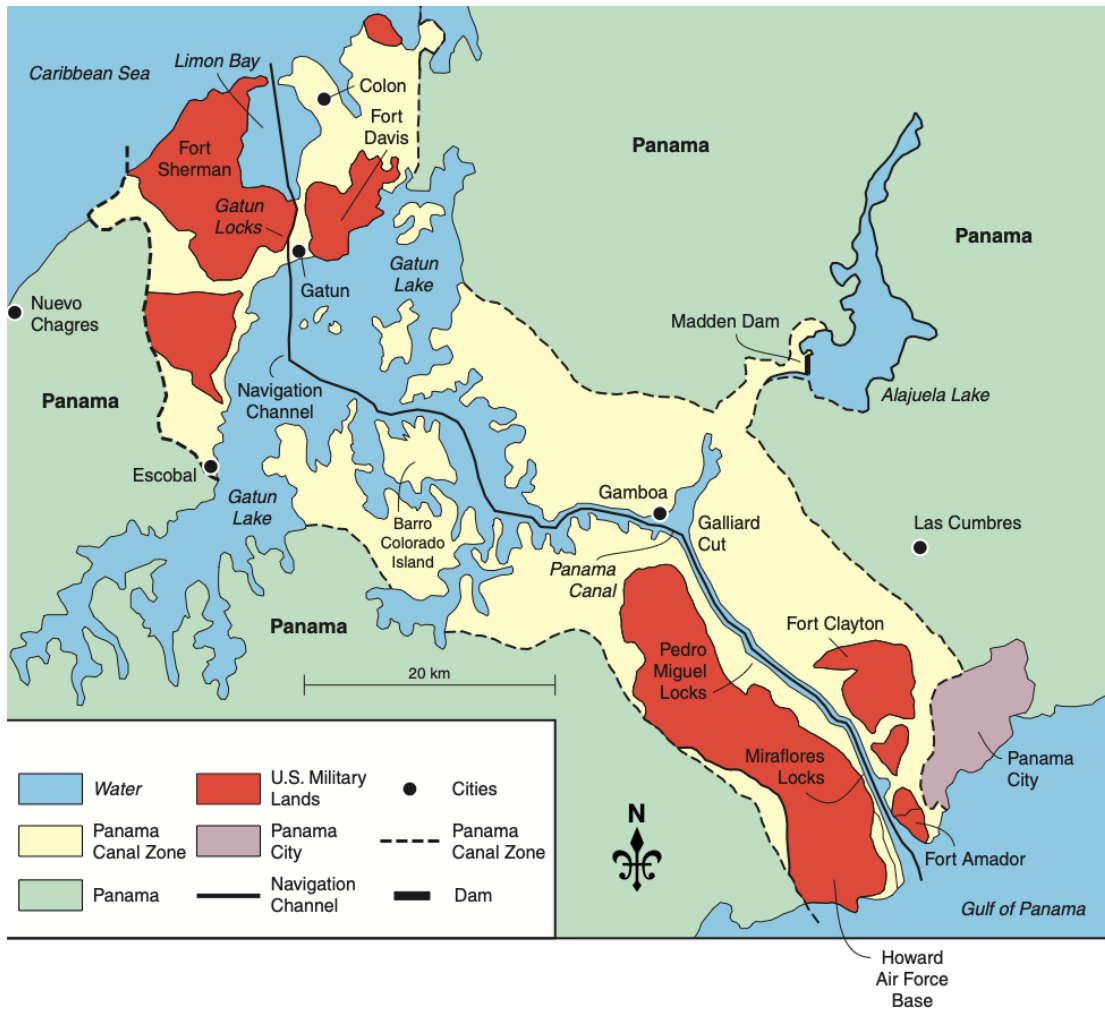


Figure 3. Panama Canal Zone map showing the location of the Panama Canal, Lake Gatun, military bases and Panama City. Map was created by Mic Greenberg. Reprinted with copyright permission of the Managing Editor of the Open Journal of Soil Science.

Particular attention is given to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), an unintended by-product formed during the manufacture of 2,4,5-T. TCDD can bioaccumulate in aquatic organisms and enter food webs, potentially affecting wildlife and human populations. The extent of current contamination on former U.S. military installations and within the sediments of Lake Gatun and the Panama Canal remains uncertain. Comprehensive soil and sediment investigations are needed to determine whether environmental remediation or mitigation measures are still required.

**Q: Which regions or case studies are central to the book?**

A: The Rio de la Plata Basin serves as the principal case study of this book (2). A primary objective of the analysis is to identify ways to reduce the environmental impacts of invasive species, soil erosion, deforestation, intensive cultivation, and sedimentation on declining water quality throughout the basin.

Estuaries are among the most productive ecosystems on Earth, providing a wide range of ecological functions and services. However, rapid population growth, urban expansion, and industrial development within coastal regions have created significant environmental challenges, particularly in developing countries. These pressures complicate efforts to achieve sustainable development and effective environmental management.

Human activities strongly influence ecosystem health within the Rio de la Plata Basin. Millions of people depend on the waters of the Rio de la Plata and its tributaries for domestic, agricultural, and industrial use. However, industrial discharges, untreated sewage, and agricultural runoff containing fertilizers and pesticides have contributed to declining water quality in many parts of the basin.

In addition, mechanized agricultural practices and large-scale deforestation along the Uruguay and Paraná River corridors have accelerated soil erosion and sediment transport throughout the region. These processes not only degrade agricultural lands but also contribute to sediment accumulation within aquatic ecosystems.

The introduction of non-native species has further complicated environmental management. Species originating from Asia and Africa, including the golden mussel, have been transported through international shipping activities and subsequently established populations within the Rio de la Plata system. Such invasive species threaten native aquatic communities, alter ecological interactions, and disrupt food-web dynamics that have evolved over centuries.

**Q: What were the most difficult aspects of the research?**

A: One of the most challenging aspects of this research was documenting the historical use of Agent Orange and related herbicides containing 2,4,5-T contaminated with TCDD within U.S. military facilities located in the Panama Canal Zone (4,5).

Particular attention was given to Fort Sherman, commonly known as the Jungle School, where approximately 300,000 U.S. military personnel received jungle warfare training before deployment to Southeast Asia during the Vietnam War. Over the years, Panama-era veterans who believe they were exposed to commercial herbicides containing 2,4,5-T and potentially TCDD have repeatedly sought recognition and benefits through the U.S. Department of Veterans Affairs. However, many claims have been denied because tactical herbicides were reportedly never officially offloaded or applied within the Panama Canal Zone (Figure 4).

Tornoe (6) reported that during a recent visit to Fort Sherman, a Panama-era veteran discovered nine heavily rusted barrels labeled as Agent Orange. According to the report, these barrels had been secured together with a steel cable and were being used as part of a makeshift barrier near abandoned buildings (Figure 5).

The discovery raises several unresolved questions. If Agent Orange was never officially transported to or used within the Panama Canal Zone, how did barrels identified as Agent Orange appear at a remote military installation? Were the barrels stored, buried, or otherwise concealed for decades? Why did they reportedly disappear shortly

after photographs were made publicly available? Who removed them, and where were they taken?



Figure 4. Ships going through a lock near the southern entrance of the Panama Canal. Reprinted with copyright permission of the Managing Editor of the Open Journal of Soil Science.



Figure 5. Rusted Agent Orange barrels which contained 2,4,5-T more than 50 years ago. Was part of a 2020 barrier protecting the Fort Sherman parking lot [1]. Photo credit: Eric Dziekan.

These questions remain unanswered. Because the region currently faces significant security challenges associated with criminal activity along portions of the Caribbean coast, any organized removal effort would likely have required substantial logistical

support and coordination. Consequently, the ultimate fate of these barrels remains unknown.

If the labels accurately reflected their contents, the containers would originally have held formulations containing 2,4-D, 2,4,5-T, and potentially varying concentrations of TCDD. Such materials would likely have been transported to Panama Canal Zone ports between the mid-1960s and early 1970s, prior to the discontinuation of Agent Orange production.

**Q: Did anything during the research surprise you?**

A: One of the most surprising findings was the continuing controversy surrounding the historical presence and use of Agent Orange and related herbicides within the Panama Canal Zone. More than five decades after the Vietnam War, disagreements persist regarding whether Agent Orange, commercial formulations containing 2,4,5-T, and associated TCDD contamination were transported to, stored within, or applied around military installations and perimeter fence lines in the region.

The persistence of these unresolved questions highlights the challenges of reconstructing historical environmental exposure pathways and evaluating their potential long-term consequences for both ecosystems and human health.

**Q: Which environmental processes described in the book are the most underestimated?**

A: One of the most underestimated environmental transformations was the ecological impact of constructing the Panama Canal. By cutting through the Isthmus of Panama and linking the Atlantic and Pacific Oceans, the project fundamentally altered regional hydrology, ecology, and land use patterns (3).

The creation of Lake Gatun through the damming of the Chagres River inundated extensive areas of fertile agricultural land, wetlands, and natural habitats. During canal construction, thousands of workers were exposed to tropical diseases, including malaria and yellow fever, which significantly affected project operations and public health.

Efforts to control disease vectors and aquatic vegetation also introduced substantial quantities of chemical agents into the environment. Beginning in the twentieth century, various pesticides and herbicides were used to manage mosquito populations and maintain navigable waterways. Following the creation of Lake Gatun, floating vegetation, particularly water hyacinth, increasingly obstructed water flow. To control these infestations, mixtures containing arsenic compounds were applied directly to aquatic vegetation over extended periods.

Because arsenic does not degrade naturally, residues introduced into the environment may persist for long periods. Arsenic compounds can dissolve in water, accumulate in sediments, and potentially affect aquatic ecosystems and water quality. Since Lake Gatun remains an important source of drinking water, understanding the long-term environmental legacy of these historical management practices remains a significant research priority.

**Q: How are environmental systems connected with political or military processes in this topic?**

A: Environmental systems within the Panama Canal Zone have been closely linked to political and military activities for more than a century. Because the canal was considered a strategic transportation corridor and a vital component of international commerce and national security, the United States established numerous military installations throughout the Panama Canal Zone (3).

Operating military facilities within tropical environments required continuous management of vegetation, insects, and other environmental conditions. Dense tropical vegetation, high rainfall, and favorable conditions for mosquitoes and other disease vectors created persistent challenges for military personnel and infrastructure.

Historical military manuals, including U.S. Army grounds maintenance guidance and medical training materials, provided detailed instructions regarding vegetation management and pest control. Herbicides were commonly recommended for controlling invasive and rapidly growing vegetation. For example, kudzu and other aggressive plant species were often treated with commercially available herbicides containing 2,4,5-T.

During the post-Vietnam War period, continued herbicide use may have contributed to environmental accumulation of TCDD and other contaminants associated with these formulations (4). Surface runoff transported pesticides, herbicides, and related chemicals into surrounding waterways, including Lake Gatun. Once introduced into aquatic environments, certain contaminants could accumulate within sediments and biological food webs.

The current extent of contamination on former military installations and within the sediments of Lake Gatun and the Panama Canal remains insufficiently documented. Additional soil, groundwater, and sediment investigations would improve understanding of historical environmental impacts and help determine whether remediation measures are warranted.

**Q: What should readers understand after reading this work?**

A: Through a series of case studies supported by maps, photographs, and historical analyses, readers gain insight into the complex and continuously evolving landscapes of the Amazon River, the Rio de la Plata Basin, and the Panama Canal system. These examples demonstrate how climate variability, economic development, population growth, technological change, and environmental management practices interact to shape river systems over time.

Much can be learned by observing the interactions between natural processes and human activities within river landscapes. These case studies demonstrate that change is the defining characteristic of river systems. Rivers are dynamic environments influenced by hydrological, ecological, geological, economic, and political forces that continuously reshape both landscapes and societies.

The strong connectivity between soil and water creates both vulnerabilities and opportunities. Decisions regarding land use, resource extraction, agriculture, transportation, and urban development often generate consequences that extend far beyond their immediate locations. As a result, effective river management requires an integrated understanding of environmental, social, and economic processes.

This book synthesizes a series of studies on the Great Rivers of South and Central America and examines them through the interconnected perspectives of pollution, environmental change, disease risk, and the growing global freshwater crisis. Rather than viewing rivers solely as hydrological or economic systems, the book presents major river corridors as integrated socio-ecological systems that influence environmental exposure, ecosystem health, and human well-being.

Particular attention is given to the cumulative effects of anthropogenic pollution, historical land-use practices, and institutional management decisions on freshwater quality and ecological resilience. The discussion also considers emerging scientific questions regarding interactions among chemical contamination, ecological disturbance, and microbial processes within aquatic environments.

The Great Rivers of South and Central America serve as examples of broader global challenges involving freshwater degradation, environmental vulnerability, and public health protection. Ultimately, the book emphasizes the importance of integrating hydrology, ecology, environmental science, public health, and governance when addressing increasingly complex freshwater challenges in the twenty-first century.

**Q: Who is this book intended for?**

A: This book is intended for a broad audience interested in river systems, environmental management, and sustainable development. Public and private landowners, resource managers, policymakers, and environmental practitioners working within major river basins will find the case studies particularly relevant.

The book may also be useful to soil scientists, hydrologists, ecologists, geographers, geomorphologists, geologists, agronomists, foresters, wetland specialists, urban planners, economists, conservation professionals, sociologists, and public health researchers. In addition, students and general readers interested in rivers, environmental history, and human-environment interactions may benefit from the interdisciplinary perspectives presented throughout the volume.

**Q: Which chapter is personally most important to you?**

A: Chapter 5 is particularly important to me because it examines the long-term environmental legacy of pesticide, herbicide, and arsenic use within the Panama Canal Zone.

Since the construction of the Panama Canal in the early twentieth century, chemical agents have been used extensively to control wetland vegetation, maintain navigation channels, and reduce mosquito populations (5). Aquatic plants such as water hyacinth frequently obstructed rivers, lakes, and canal operations, prompting repeated management interventions.

Many of these chemicals entered Lake Gatun through runoff processes, either attached to sediment particles or dissolved in water. Because Lake Gatun served as the primary drinking water source for much of the Panama Canal Zone, understanding the fate and transport of these contaminants became an important environmental and public health concern.

Military installations within the Panama Canal Zone also had access to arsenic-based herbicides through federal supply systems. Materials such as cacodylic acid were transported through Panama Canal ports, including Balboa and Cristóbal, and distributed to military facilities throughout the region (5).

The principal objective of this chapter was to examine the environmental fate of arsenic originating from two major sources:

(1) arsenic compounds applied between 1914 and 1935 for control of water hyacinth and other aquatic vegetation within canal navigation corridors; and

(2) arsenic-based herbicides, including cacodylic acid, applied on U.S. military installations between 1948 and 1999.

Understanding the persistence, mobility, and environmental distribution of arsenic remains essential for evaluating potential long-term impacts on soil, groundwater, surface water, ecosystems, and human health.

**Q: How does this book relate to current global environmental challenges?**

A: This book is closely connected to contemporary environmental, water resource, and food security challenges. The construction and operation of the Panama Canal fundamentally transformed global trade by reducing transportation times between the Atlantic and Pacific Oceans and increasing the movement of internationally traded goods.

At the same time, the book demonstrates that major engineering projects often produce long-term environmental consequences that may not become fully apparent for decades. Historical applications of pesticides, herbicides, and other chemicals within the Panama Canal Zone illustrate how environmental management decisions can create persistent contamination challenges affecting water resources, ecosystems, and potentially human health.

The case studies presented throughout the book also highlight broader global concerns regarding freshwater quality, agricultural sustainability, ecosystem degradation, and the increasing competition for limited water resources. As populations continue to grow and climate variability intensifies, maintaining healthy river systems will become increasingly important for food production, economic development, biodiversity conservation, and public health protection.

The experiences of the Amazon Basin, Rio de la Plata Basin, and Panama Canal watershed demonstrate the importance of balancing economic development with long-term environmental stewardship.

**Q: Are the problems discussed in the book improving or worsening today?**

A: The answer varies depending on the specific issue being considered. In some areas, environmental awareness, regulatory oversight, and scientific monitoring have improved substantially. However, several contamination concerns discussed in the book remain insufficiently understood and, in some cases, inadequately addressed.

One example involves arsenic contamination within portions of the Panama Canal Zone (5). Arsenic originates from both natural geological sources and historical human activities. Past applications of arsenic-containing compounds for aquatic vegetation control, industrial activities, military herbicide use, wastewater discharges, and other anthropogenic sources have contributed to elevated concentrations in certain locations.

Because arsenic can persist in soils, sediments, groundwater, and surface waters for extended periods, historical contamination may continue to influence environmental quality long after the original source has disappeared. Areas containing elevated arsenic concentrations require continued monitoring to ensure compliance with international drinking water standards and to reduce potential risks to human health.

The issue extends beyond drinking water. Agricultural irrigation using contaminated water may contribute to arsenic accumulation in crops, while aquatic ecosystems can facilitate arsenic transfer through food webs. Consequently, both environmental quality and food security considerations remain relevant.

Although substantial progress has been made in understanding arsenic behavior and toxicity, significant knowledge gaps remain regarding the extent of contamination within portions of Lake Gatun, the Panama Canal, and former military installations. Additional environmental investigations are needed to determine where restoration, remediation, or long-term monitoring programs may be appropriate.

**Q: Climate change and increasing climate variability are making river systems less predictable in many parts of the world. How might these changes affect the Amazon and Rio de la Plata basins and the Panama Canal Zone, especially flood frequency, drought risk, sediment movement, soil erosion, agricultural productivity, and the long-term reliability of waterways?**

A: Climate change and increasing climate variability are likely to affect all three regions significantly. River systems are highly sensitive to changes in precipitation patterns, temperature, evapotranspiration rates, and the frequency of extreme weather events.

In the Amazon Basin, altered rainfall patterns could influence river discharge, floodplain dynamics, forest ecosystems, and sediment transport processes. Extended drought periods may reduce river navigability, affect aquatic ecosystems, increase wildfire risk, and disrupt agricultural production. Conversely, more intense rainfall

events could increase flooding, erosion, and sediment redistribution throughout the watershed.

Within the Rio de la Plata Basin, climate variability may affect water availability, agricultural productivity, hydropower generation, and urban water supplies. Increased flood frequency in some areas and prolonged drought conditions in others could create substantial economic and environmental challenges. Changes in land use combined with more extreme precipitation events may further accelerate soil erosion and sediment delivery to rivers and estuaries.

The Panama Canal watershed faces a particularly unique challenge because canal operations depend directly on freshwater availability. Recent drought conditions within the Chagres River watershed have demonstrated the vulnerability of the system. Reduced rainfall lowered Lake Gatun water levels and limited the number of ships able to transit the canal each day.

As larger vessels require increasing volumes of freshwater during lock operations, prolonged drought conditions could reduce the reliability and efficiency of canal transportation. Such disruptions have implications not only for Panama but also for global supply chains and international commerce.

Overall, climate change is expected to increase uncertainty in water resource management and reinforce the need for adaptive strategies that enhance resilience across river basins, floodplains, and critical transportation corridors.

**Q: How did the decision to build the Panama Canal affect farmers and local communities in the Chagres River basin, and were their voices adequately considered in the decision-making process?**

A: Historical records provide limited evidence that local communities, farmers, and landowners within the Chagres River watershed were meaningfully consulted during the planning and construction of the Panama Canal.

At the time major decisions regarding canal construction were being made, the region was undergoing profound political transformation. The territory that later became the Panama Canal Zone was then part of Colombia, and negotiations were conducted primarily among national governments and international political actors.

Large-scale infrastructure projects during the late nineteenth and early twentieth centuries were typically designed and implemented with relatively limited public participation compared with contemporary standards. As a result, local social, cultural, and economic concerns often received less attention than strategic, political, engineering, or commercial objectives.

The construction of the canal and the creation of Lake Gatun transformed landscapes throughout the watershed. Agricultural lands, settlements, forests, and wetlands were altered or inundated, producing long-term consequences for local communities and regional land-use patterns.

From a modern perspective, the Panama Canal demonstrates the importance of incorporating stakeholder participation, social impact assessment, and community engagement into major environmental and infrastructure decisions.

**Q: Your book shows that river management is not only a scientific or engineering problem, but also a political, legal, economic, and social one. Even in a country with advanced science and strong public institutions, decisions about navigation can have unintended consequences. What does this reveal about the limits of expertise in managing large river systems?**

A: One of the most important lessons emerging from this book is that scientific knowledge alone cannot eliminate uncertainty in complex river systems.

Large rivers operate as coupled natural and human systems in which hydrology, ecology, economics, politics, engineering, and social values continuously interact. Even when decision-makers possess extensive scientific information, unforeseen consequences may emerge because environmental systems are inherently dynamic and interconnected.

The history of the Panama Canal illustrates this challenge. Over more than a century, decisions made for transportation, commerce, military security, public health, and environmental management have produced both intended benefits and unintended environmental consequences. Some impacts became apparent only decades after the original decisions were implemented.

The former military installations within the Panama Canal Zone provide a useful example. While many sites have been successfully redeveloped, questions remain regarding historical contamination, long-term environmental monitoring, and ecological restoration. These issues demonstrate that environmental legacies often persist long after political priorities, economic conditions, or institutional arrangements have changed.

Ultimately, expertise is essential, but it is not sufficient by itself. Effective river management requires scientific knowledge, adaptive governance, public participation, long-term monitoring, and the willingness to revise policies as new information becomes available.

**Q: Which future research directions emerge from this work?**

A: This work highlights several important directions for future research. First, there is a continuing need for long-term studies examining the cumulative effects of pollution, land-use change, climate variability, and watershed management on large river systems.

Additional investigations are needed to better understand the environmental fate and transport of historical contaminants, including pesticides, herbicides, arsenic compounds, and related by-products within riverine and floodplain environments. In particular, more comprehensive monitoring of soils, sediments, groundwater, and surface waters within former military installations and industrial areas would improve our understanding of long-term environmental exposure pathways.

Future research should also focus on the interactions among climate change, water availability, ecosystem resilience, agricultural productivity, and human health. As extreme weather events become more frequent in many regions, understanding how river systems respond to these pressures will become increasingly important.

Another promising direction involves integrating environmental science, hydrology, ecology, public health, and social sciences into unified analytical frameworks capable of addressing complex watershed-scale challenges. Such interdisciplinary approaches are essential for understanding the multiple dimensions of freshwater sustainability.

Building on the studies presented in this book, I have expanded my research interests to include the Great Rivers of Africa and the Middle East, where many of the same environmental, social, and water-resource challenges can be observed under different geographic and historical conditions.

**Q: If you could recommend one major change in river and floodplain management policy based on this book, what would it be?**

A: If I could recommend one overarching principle, it would be to manage river systems for resilience rather than for short-term optimization.

The future behavior of river systems cannot be predicted with complete certainty. Climate variability, extreme weather events, economic development, population growth, technological change, and unforeseen environmental disturbances all have the potential to alter river landscapes in ways that are difficult to anticipate.

Management strategies should therefore prioritize adaptability, ecological integrity, risk reduction, and long-term sustainability. Resilient river systems are better able to absorb disturbances, recover from environmental shocks, and continue providing essential ecosystem services to both human and natural communities.

Planning for resilience also requires protecting floodplains, maintaining water quality, preserving biodiversity, improving monitoring programs, and incorporating scientific knowledge into decision-making processes while remaining flexible enough to respond to new information.

**Q: If readers remember only one idea from the book, what should it be?**

A: If readers remember only one message from this book, it should be that change is the only constant in river systems.

Throughout history, rivers have continuously responded to climatic fluctuations, geological processes, ecological interactions, and human activities. River landscapes are never truly static. They evolve over time, often in ways that challenge human expectations and management plans.

Understanding this dynamic nature of rivers is essential for developing sustainable approaches to environmental management, water-resource protection, economic development, and public health. Those who recognize and plan for change will be better prepared to address the uncertainties and challenges of the future.

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*The Editorial Board of the journal "Pollution and Diseases" wishes you continued scientific success, new discoveries, and inspiration in your work.*

### **Conflict of Interest**

The authors declare no conflict of interest.

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No new data were created or analyzed in this study.

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