

Technologies for Climate Change Adaptation

– The Water Sector –



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Disclaimer:

This Guidebook is intended to be a starting point for developing country governments, planners, and stakeholders who are carrying out technology needs assessment and technology action plans for adaptation to climate change in the water sector. The findings, suggestions, and conclusions presented in this publication are entirely those of the authors and should not be attributed in any manner to the Global Environment Facility (GEF) which funded the production of this publication.

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Abbreviations

BSF	Biosand Water Filter
CAWST	Centre for Affordable Water and Sanitation Technology
CCP	Critical Control Point
CDC	US Centers for Disease Control and Prevention
COP	Conference of the Parties
DFID	UK Department for International Development
ED	Electrodialysis
EIA	Environmental Impact Assessment
EKC	Environmental Kuznets Curve
ENACAL	Empresa Nicaraguense de Acueductos y Alcantarillados
EU	European Union
GDP	Gross Domestic Product
GDWQ	Guidelines for Drinking Water Quality
GPR	Ground Penetrating Radar
HWTS	Household Water Treatment and Safe Storage
IPCC	Intergovernmental Panel on Climate Change
IWA	International Water Association
IWRM	Integrated Water Resource Management
LCC	Life Cycle Cost
MEE	Multiple-effect Evaporation
MIT	Massachusetts Institute of Technology
MSF	Multi-stage Flash distillation
NF	Nanofiltration
NGO	Non-Governmental Organization
NRW	Non-revenue Water
O&M	Operation and Maintenance
OECD	Organisation for Economic Co-operation and Development
PAHO	Pan American Health Organization
PATH	Program for Appropriate Technology in Health
PCS	Post-construction Support
POU	Point of Use
RO	Reverse Osmosis
RWH	Rainwater Harvesting
SODIS	Solar Disinfection
TDS	Total dissolved solids
UFW	Unaccounted for Water
UN	United Nations

UNC	University of North Carolina at Chapel Hill
UNEP	United Nations Environment Programme
UNFAO	United Nations Food and Agriculture Organization
USAID	US Agency for International Development
USEPA	United States Environmental Protection Agency
USGS	US Geological Survey
VCD	Vapour Compression Distillation
WEDC	Water, Engineering and Development Centre
WERF	Water Environment Research Foundation
WHO	World Health Organization
WSPs	Water Safety Plans

Preface

The statistics are eloquent: water resources and supplies will become increasingly pressing issues in the face of climate change. What's more, poor and vulnerable populations in developing countries are poised to take the brunt of the impact. With growing populations and increasing demands on water resources, these countries urgently need access to climate change adaptation options.

But the options in themselves are not enough. Developing nations also need assistance in identifying which options are appropriate for which situation, and how to incorporate these measures into their climate change adaptation strategies. This book is a guide to the most relevant adaptation technologies and practices for the water sector in developing countries. In addition to descriptions and explanations, the guidebook outlines practical steps for implementing these technologies, illustrated with case studies. It not only lays out institutional and capacity building requirements, but also explores costs and other potential barriers to getting projects off the ground. Finally, the text is supplemented by a rich list of references to external sources and case studies.

We hope that this comprehensive approach will make this book an effective tool that will prove useful to water sector policy makers and planners. But we also hope that it will serve as a valuable resource at the community level for village and district authorities, NGOs, and anyone else interested in the topic.

This guidebook is co-authored by Mark Elliott, Andrew Armstrong, Joseph Lobuglio and Jamie Bartram at the Water Institute of the University of North Carolina, in Chapel Hill, USA, an institution dedicated to critical global issues in water and health. Its director, Prof. Jamie Bartram, is an internationally acknowledged expert in this area, and served as the chair of UN Water from 2004 to 2006.

Thanakvaro De Lopez of the UNEP Risø Centre on Energy, Climate and Sustainable Development (URC) coordinated the guidebook's production. Sergios Santos, Director of Terrasystemics and an expert on adaptation planning with focus on Africa LDCs and small island states, and Sau Sisovanna, senior lecturer in climate change planning at the National University of Cambodia, provided many important comments and suggestions. Their inputs were invaluable and deeply appreciated.

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Executive Summary

This guidebook aims to provide expert information on the technologies most relevant for climate change adaptation in the water sector in developing countries. It is meant to be a practical tool for use by a broad range of stakeholders, including those in governmental agencies, water utilities, community water boards, non-governmental organizations, and private sector companies.

Adaptation is an essential element of human response to climate change. The adverse impacts of climate change on the water sector will be experienced worldwide and are often projected to be most severe in resource-poor countries. Therefore, it is necessary to have access to a diverse array of adaptation technologies and practices that are appropriate and affordable in various contexts. The scale of these adaptation technologies/practices should range from the individual household level (e.g. household water treatment), to the community scale (e.g. rainwater collection in small reservoirs), to large facilities that can benefit a city or region (e.g. a desalination plant).

The guidebook first reviews the projected impacts of climate change on the water sector. It then addresses the role of adaptation in the water sector and six typologies under which available strategies are categorized. Eleven technologies and practices are given detailed treatment in this guidebook and four others are covered briefly. While these do not constitute all of the adaptation technologies available in the water sector, they do represent many of the most important adaptation technologies for developing countries.

For each of the 11 adaptation technologies and practices, the following are addressed: basic description, contribution to climate change and development, institutional and capacity building requirements, costs, barriers and opportunities for implementation, and extensive reference to external resources and case studies. The practical steps and appropriate contexts for implementation are covered in the following chapter.

Adaptation should not be understood as simply implementing the correct technology or practice. It should be part of a coherent, inter-sectoral strategy to ensure sustainable water resources and safe water supply. Therefore, tools for planning and decision-making for climate change adaptation in the water sector are also considered. Integrated Water Resource Management (IWRM) is proposed here as an overall decision-making framework for climate change adaptation in water resources. Likewise, Water Safety Plans (WSPs) are suggested to provide an approach for climate change adaptation in water quality and water supply.

This guidebook has been developed as part of a larger program on technology needs assessment and technology transfer.¹ Other guidebooks, including those focusing on adaptation in coastal zones and the agriculture sector, were developed in parallel.² Therefore, methods for improving the efficiency of agricultural irrigation are not addressed here. Likewise, the implications of sea level rise and coastal storms are only addressed to the extent that they impact freshwater resources and water supply.

The technologies and practices described here are very diverse. However, recurring themes were identified that can greatly improve the efficiency and effectiveness of adaptation. Among these themes are the importance of preliminary steps, including data collection and knowledge of existing water resources

and water supply. Again, IWRM and WSPs provide approaches to address these preliminary steps. Additionally, local policies and legal frameworks can have a substantial impact on the effectiveness of many adaptation efforts.

	Diversification of Water Supply	Ground- water Recharge	Preparation for Extreme Weather Events	Resilience to Water Quality Degradation	Stormwater Control and Capture	Water Conservation
Boreholes/Tubewells as a Drought Intervention for Domestic Water Supply			●			
Desalination	●			●		
Household Water Treatment and Safe Storage (HWTS)				●		
Improving Resilience of Protected Wells to Flooding			●	●		
Increasing the Use of Water-efficient Fixtures and Appliances						●
Leakage Management, Detection and Repair in Piped Systems				●		●
Post-construction Support (PCS) for Community-managed Water Systems	●		●	●		
Rainwater Collection from Ground Surfaces— Small Reservoirs and Micro-catchments	●	●		●	●	
Rainwater harvesting from Roofs	●	●			●	
Water Reclamation and Reuse	●	●		●		
Water Safety Plans (WSPs)			●	●		

1. Introduction and Outline of the Guidebook

This guidebook is intended to provide expert information and practical guidance on climate change adaptation to stakeholders in the water sector. It is meant to be an accessible resource that can help readers progress from a basic to a more sophisticated understanding of the technologies and practices most useful for climate change adaptation in the water sectors of developing countries.

Climate change is projected to adversely impact water resources and water supply. Additional water stressors, including population growth and increasing per capita demand, will exacerbate these impacts.³ Therefore, substantial adverse impacts to the water sector are unavoidable.⁴

Adaptation was identified in the first and second Intergovernmental Panel on Climate Change (IPCC) assessment reports as an important element in responses to climate change. However, early global climate change negotiations and responses focused almost exclusively on mitigation.⁵ The Conference of the Parties meetings in 2001 and 2002 (COP7 and COP8, respectively) led to increased emphasis on, and funding for, adaptation. The “Delhi Declaration” at COP8 included the statement that adaptation was of “high priority” for developing countries and a demand for “urgent attention and action on the part of the international community.”⁶

The magnitude and location of climate change impacts in the water sector are uncertain. Therefore, “no regrets” adaptation strategies are especially appealing. No regrets strategies are those that “would generate net social and/or economic benefits irrespective of whether or not climate change occurs.”⁷ The World Health Organization (WHO) and UK Department for International Development (DFID) argue that climate change adaptation can be seen as an opportunity for focus on, and gains in, health, development and water resource sustainability.⁸

This guidebook includes detailed discussion of eleven adaptation technologies and practices in the water sector. Climate change adaptation is defined by IPCC as “the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.”⁹

The outline of the guidebook is as follows:

Chapter 2 includes a summary of the impacts of climate change on the water sector. The major resources used were the IPCC Fourth Assessment Report chapter on water resources 3 and key recent literature.

Chapter 3 begins with a brief introduction to human responses to climate change, with emphasis on adaptation in the water sector. This is followed by a description of six typologies of adaptation and their roles in decreasing the vulnerability of water resources and water supply to climate change. Each of the 11 technologies and practices described at length in Chapter 4 is categorized within one of more of these typologies. Four additional adaptation strategies that do not receive extended treatment in Chapter 4 are

briefly described. The chapter concludes with a call to consider the impact that adaptation technologies can have on mitigation efforts.

In **Chapter 4**, eleven technologies and practices for climate change adaptation in the water sector are described at length. The discussion of each includes a basic description, contribution to climate change and development, institutional and capacity building requirements, costs, barriers and opportunities for implementation, and reference to external resources and case studies.

Chapter 5 provides guidance on the implementation of the technologies and practices described in Chapter 4. For each of the 11 technologies/practices, the practical steps of implementation are outlined, in addition to discussion of the appropriate context and parties to carry out implementation.

Chapter 6 includes an assessment of overall conclusions and recommendations for adaptation technologies and practices in the water sector.

Back-matter includes a list of references and two appendices. A glossary of technical terms is included as Appendix I. Appendix II contains a list of additional sources that can contribute to identification, prioritization and implementation of water sector technologies; this includes a brief description of Integrated Water Resource Management (IWRM) and Water Safety Plans (WSPs) as holistic frameworks for approaching climate change adaptation related to issues of water quantity and water quality, respectively.

2. Summary of Key Findings on Projected Impacts of Climate Change on the Water Sector

Water is the primary medium through which climate change will influence the Earth's ecosystem and, thus, human livelihoods and well-being.¹⁰ According to the Intergovernmental Panel on Climate Change (IPCC), many experts have concluded that "water and its availability and quality, will be the main pressures on, and issues for, societies and the environment under climate change."¹¹ Climate research provides compelling evidence that increases in global temperatures are influencing the global hydrological cycle. Average temperature is projected to increase by varying amounts over all major landmasses and during all seasons. Higher temperature increase evaporation, glacial melt and thermal expansion of oceans. It also increases the holding capacity of water vapor in the atmosphere, leading to increased climate variability and a more intense hydrological cycle.¹²

Although temperature is projected to continue to increase globally, the effects of this increase on precipitation will vary from one area to another. The effect on precipitation may also vary seasonally; in some areas, precipitation is expected to increase in one season and decrease in another. Although the field of climate modeling has progressed rapidly in recent years, quantitative projections of changes in precipitation, river flows and water levels remain highly uncertain.¹²

Despite the inherent uncertainty associated with climate projections, the IPCC states with high confidence that the negative impacts of climate change on water resources and freshwater ecosystems will outweigh the positive impacts in all regions of the world. Those places in which precipitation and runoff are projected to decline are likely to derive less overall benefit from freshwater resources. In those places that receive more annual runoff, the benefits of increased water flows are expected to be offset by the adverse effects of that greater precipitation variability and changes in seasonal runoff have on water supply, water quality, and risk of flooding.¹²

Discussion of the effects of climate change on water resources are here separated into four categories: increased precipitation intensity, decreased water flows, greater precipitation variability, and sea level rise. The major effects of these four categories on the water sector are discussed below. Although these impacts on the water sector are anticipated in some areas, it is important to understand that the presence of a category does not imply a global, climate-related trend.

Increased precipitation intensity: The IPCC projects with high confidence that the intensity of precipitation will increase due to climate change.¹² Anticipated impacts on the water sector include:

- Increased risk of flooding, leading to infrastructure damage and contamination of water supplies and the environment. Piped sewer systems that combine storm and sanitary sewers are especially likely to overflow and spread fecal contamination. Extreme precipitation has been linked to 20-40% of waterborne disease outbreaks in the USA.¹² Although less data exist for developing countries, there is some evidence that excess rainfall leads to an increase of roughly 10% in diarrheal disease rates.¹³
- Increased runoff, decreasing infiltration and recharge of groundwater aquifers.

- Increased flushing of fertilizers, animal wastes and particulates into water supplies. Greater nutrient concentration in surface waters leads to increased growth of microbes and depletion of dissolved oxygen.

Greater precipitation variability: The IPCC predicts greater variability in precipitation, including changes in seasonal rainfall.¹² Societies and economies worldwide have developed based on historical patterns of water availability. While this is particularly true for rain-fed agriculture, it will also affect the water sector.

- Water supplies designed based on predictable rainfall and snow-melt patterns may have to increase reservoir storage requirements and/or explore supplementary water resources.¹⁴
- Longer droughts are likely, even in areas where net annual precipitation does not change.
- For many regions, a proportional increase in winter flows and decreased glacial/snow storage is anticipated to cause a further reduction in freshwater availability during low-flow periods.¹²
- The risks associated with greater rainfall are primarily related to changes in distribution (i.e. intensity) and are discussed above under “Increased Precipitation Intensity.”

Decreased water flows: A trend of decreasing precipitation over land for latitudes 10°S-to-30°N has been observed and is expected to continue. Many arid and semi-arid regions (e.g., southern Africa, north-eastern Brazil, the Mediterranean basin) are projected to face declining water resources.¹² By 2050, annual river runoff and water availability are projected to decrease 10-30% over some dry regions at mid-latitudes and in the dry tropics, including in some areas that are already water stressed.¹⁵

- Declining annual precipitation, especially when coupled with population growth and increasing affluence, can lead to rapid declines in per capita water availability. It is estimated that up to two-thirds of the world population could be living under water stress or water scarcity by 2025.¹⁶
- Groundwater recharge is expected to decrease considerably in some water-stressed regions. Additionally, groundwater depletion can be exacerbated as declining surface water availability leads to increasing groundwater abstraction.¹²
- Water quality of surface water sources can be adversely affected due to low flows, increased nutrient concentrations and longer residence times.

Sea level rise: The broader impacts of sea level rise on coastal zones are covered in the accompanying UNEP handbook entitled “Technologies for Climate Change Adaptation—Coastal Erosion and Flooding.”¹⁷ However, sea level rise will also affect the water sector. Coastal zones are generally water scarce and are experiencing rapid population growth.¹²

- Sea level rise will increase areas of salinization of groundwater, further decreasing freshwater availability in coastal areas.¹²
- Sea level rise also leads to the salinization of coastal surface waters. This is especially true during the “dry season” in regions with highly seasonal rainfall. In the Mekong Delta of Vietnam, saltwater is reported to intrude 30 km inland during the dry season.¹⁸
- Higher sea level will increase the vulnerability of freshwater resources, drinking water wells and water treatment works to inundation during coastal storms.

The impacts of climate change occur in parallel to and interact with anthropogenic water stressors. These anthropogenic factors may affect water resources more rapidly and acutely than climate change. Such stressors include: population growth, increasing per capita water demand, urbanization, deforestation and land-use change.¹² Population growth, economic development and the expansion of irrigated agriculture

have increased water demand, leading to unsustainable rates of groundwater abstraction and declining groundwater tables in many areas worldwide.¹⁹

Ensuring adequate water supply under climate change scenarios is projected to require significant investment. Many of the countries in which the water sector is expected to be most adversely affected by climate change are also the most resource-poor. Recent analysis indicates that the cost estimates for adaptation of water resources in developing countries exceed those in wealthy countries, both in absolute terms and as a percentage of GDP. Especially sobering is the finding that the largest adaptation costs are projected for Sub-Saharan Africa.²⁰ However, these estimates are based on the costs of expensive “hard-path” solution (e.g., expanding reservoirs, desalination) and do not account for conservation and other “soft-path” strategies.

Adaptation in the water sector must incorporate diverse approaches to ensure resilience of water supplies to climate change. Although some countries will require aid to support their adaptation efforts, affordable and appropriate adaptation technologies and practices are available in nearly any settings. Approaches to climate change adaptation in the water sector are discussed in Chapter 3.

3. Definition and Typology of Adaptation Options and Practices in the Water Sector

Climate Change Adaptation

Early strategies for addressing climate change focused almost exclusively on mitigation (i.e. reduction of greenhouse gas concentrations in the atmosphere). In recent years, more resources have been dedicated to adaptation of human and natural systems to the anticipated impacts of climate change. At the Conference of the Parties in Marrakesh (COP7) in 2001, three specific funds were created to support implementation of vulnerability assessment and adaptation. Since then, adaptation has become an increasingly important part of international strategies for responding to climate change.²¹

Definitions of climate change adaptation are diverse and vary between organizations. A report published by the Organisation for Economic Co-operation and Development (OECD) includes discussion of the definitions of adaptation and their implications for policy and implementation.²¹ Here we use the definition provided in the Introduction to the IPCC Fourth Assessment Report (Section G: Definition of key terms), which reads:

“Adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.”²²

Adaptation in the Water Sector

Examples of adaptation strategies in the water sector are provided in the IPCC Summary for Policy Makers: expanded rainwater harvesting; water storage and conservation techniques; water re-use; desalination; efficiency in water-use; and efficiency in irrigation.²³ Irrigation of agricultural crops makes up an estimated 69% of freshwater withdrawals worldwide and, thus, efficiency in irrigation is essential to water conservation efforts.²⁴ However, interventions in the agriculture sector are not addressed here but rather, in an accompanying handbook.²⁵

Adaptation in the water sector provides many opportunities for what are known as “no regrets” actions. A no regrets adaptation is one that “would generate net social and/or economic benefits irrespective of whether or not anthropogenic climate change occurs.”²⁶ Adaptation interventions that address issues like resilience to extreme weather events, contamination of drinking water supplies, and water resource diversification and conservation will yield social, economic and health benefits in almost any imaginable climate scenario. The no regrets framing can be especially important in the context of funding. Examples of settings where this is true include those in which: (1) climate change is a politically divisive issue or where climate change scepticism exists; and (2) funds available for the water sector can be supplemented by funds specifically allocated for climate change.

Typologies of Adaptation Technologies/Practices in this Handbook

Six typologies are used here to define the adaptive function to which that these technologies and practices contribute. In addition to the six typologies for the water sector, any notable contribution (positive or negative) of a technology/practice to mitigation efforts is also included.

Eleven technologies are described at length in Chapter 4. These 11 are categorized within the six typologies. Most technologies/practices fit into more than one typology because they can contribute to more than one aspect of climate change adaptation. The six typologies are:

- Diversification of Water Supply
- Groundwater Recharge
- Preparation for Extreme Weather Events
- Resilience to Water Quality Degradation
- Stormwater Control and Capture
- Water Conservation

In addition to the 11 technologies and practices described in detail in Chapter 4, other climate change adaptation strategies are relevant in many settings. These are discussed briefly at the end of this chapter, with reference to external sources for further information.

Table 1: Typologies of the eleven adaptation technologies and practices described in detail in Chapter 4.

	Diversification of Water Supply	Ground- water Recharge	Preparation for Extreme Weather Events	Resilience to Water Quality Degradation	Stormwater Control and Capture	Water Conservation
Boreholes/Tubewells as a Drought Intervention for Domestic Water Supply			•			
Desalination	•			•		
Household Water Treatment and Safe Storage (HWTS)				•		
Improving Resilience of Protected Wells to Flooding			•	•		
Increasing the Use of Water-efficient Fixtures and Appliances						•
Leakage Management, Detection and Repair in Piped Systems				•		•
Post-construction Support (PCS) for Community-managed Water Systems	•		•	•		
Rainwater Collection from Ground Surfaces—Small Reservoirs and Micro-catchments	•	•			•	
Rainwater Harvesting from Roofs	•	•		•	•	
Water Reclamation and Reuse	•	•		•		
Water Safety Plans (WSPs)			•	•		

Diversification of Water Supply: Precipitation patterns are projected to become more variable under most climate change scenarios. The response of water resources to precipitation events varies widely. For example, groundwater systems typically show a much slower and more muted response to drought and heavy precipitation than surface water.²⁷ Therefore, diversification of the resources used for water supply can reduce vulnerability to climate change. In addition, exploring alternatives to freshwater resources (e.g. water reuse or desalination) can further bolster resilience.

Diversification of water supply can occur at different scales, from massive dam projects that may serve an entire country to interventions at the household level. Additionally, it should not be assumed that every water source must be of sufficient quality for all uses (e.g. drinking and cooking). For example, non-potable treated wastewater can often be safely used for irrigation. The technologies and practices included under diversification of water supply are:

- Desalination
- Post-construction Support for Community-managed Water Systems
- Rainwater Collection from Ground Surfaces—Small Reservoirs and Micro-catchments
- Rainwater harvesting from Roofs (RWH)
- Water Reclamation and Reuse

Groundwater Recharge: Groundwater tables are declining in many areas around the world due to unsustainable rates of abstraction.²⁸ Intentional recharge of groundwater is becoming increasingly popular. Innovative schemes for groundwater recharge using harvested rainwater, reclaimed wastewater and other methods have demonstrated success in elevating or preventing the depletion of groundwater tables.^{29, 30} Such technologies and practices that are described in this handbook include:

- Rainwater Collection from Ground Surfaces—Small Reservoirs and Micro-catchments
- Rainwater Harvesting from Roofs (RWH)
- Water Reclamation and Reuse

Preparation for Extreme Events: The intensification of the global hydrological cycle is projected to increase risk of extreme wet and dry events in many areas.³¹ These adaptation technologies and practices can decrease vulnerability to extreme events:

- Boreholes/Tubewells as a Drought Intervention for Domestic Water Supply
- Improving Resilience of Protected Wells to Flooding
- Post-construction Support for Community-managed Water Systems
- Water Safety Plans (WSPs)

Resilience to Water Quality Degradation: Climate change is projected to have adverse impacts on water quality. Higher water temperatures, extreme precipitation events, and periods of low flow exacerbate many forms of water pollution.³¹ The following adaptation technologies can improve resilience to water quality degradation:

- Desalination
- Household Water Treatment and Safe Storage (HWTS)
- Post-construction Support (PCS) for Community-managed Water Systems
- Water Reclamation and Reuse
- Water Safety Plans (WSPs)

Stormwater Control and Capture: Most urban areas are designed so that stormwater and other runoff are channelled from drainage systems into waterways and away from the city to prevent flooding. Capture of stormwater with detention basins, porous asphalt, green roofs, infiltration galleries and cisterns can be used to turn stormwater from a possible hazard into resource. Technologies described here that contribute to stormwater capture and control include:

- Rainwater Collection from Ground Surfaces—Small Reservoirs and Micro-catchments
- Rainwater harvesting from Roofs (RWH)

Water Conservation: Water consumption per capita generally increases as a country experiences economic development. However, conservation measures in some of the most developed countries have led to a levelling off and eventual decline in per capita water use.^{32, 33} Conservation increases resilience to drought, prevents groundwater depletion, and can postpone significantly the need for expansion of water reservoirs and treatment facilities. Technologies and practices that contribute to conservation include:

- Increasing the Use of Water-efficient Fixtures and Appliances
- Leakage Management, Detection and Repair in Piped Systems

Other Adaptation Practices in the Water Sector: Selected adaptation options that are not discussed in detail in Chapter 4 are described briefly here. These adaptation options can be controversial, require legal frameworks or infrastructure unavailable in many settings, or their implementation is very context specific. Integrated Water Resource Management (IWRM) (see below) can provide a framework for decision-making under each of these approaches:

- **Artificial reservoirs:** Typically created by construction of a dam in a valley, artificial reservoirs have the potential to yield massive increases in available water supply. However, there are numerous adverse environmental and social impacts associated with dam construction, flooding and displacement of populations. Among the environmental impacts is the counter-intuitive finding that construction of some dams can potentially increase greenhouse gas emissions due to the decay of vegetation as the valley is flooded.³⁴ Framework for decision making around dam construction have been developed by the World Commission on Dams³⁵ and UNEP.³⁶ Additionally, a collection of papers, case studies and websites on dams and development has been compiled by Asian Development Bank and is available as an online resource.³⁷
- **Cross-sectoral collaboration:** Approaches to water resources management in many countries are dominated by sectoral divisions. Agriculture, municipal water supply, industry, energy and other sectors utilize and are dependent on access to water resources. When these competing interests are pursuing their goals independently the result can be incoherent and fragmented development and management. Integrated water resource management (IWRM) (see below) provides a framework for approaching cross-sectoral collaboration in any setting.
- **Improved knowledge of water resources and water demand:** Understanding available water resources and anticipating demand are essential to any water management strategy. IPCC states: “Information, including basic geophysical, hydrometeorological, and environmental data as well as information about social, cultural and economic values and ecosystem needs, is also critically important for effective adaptation.”³¹ Examples include understanding: groundwater systems, surface hydrology, the dynamics of salinization in coastal systems, and detailed domestic, industrial and agricultural water use. Further examples of the importance of preliminary data collection are provided in Chapters 4 and 5.
- **Water markets:** The Dublin Statement Principle No. 4 reads “Water has an economic value in all its competing uses and should be recognised as an economic good.”³⁸ The question of who has the

right to use a given water source is handled very differently depending on the local legal framework. The use of markets on which the right to extract water can be traded as an economic good has been explored and implemented in the USA, Chile, Australia and elsewhere.^{39, 40, 41, 42} The specific application of water markets as a tool for climate change adaptation has also been explored.^{43, 44}

Integrated water resource management (IWRM) is perhaps the most flexible and comprehensive tool for assessing water resources and meeting diverse water demands. IPCC acknowledged in the Fourth Assessment Report of 2007 that IWRM had the potential to be “an instrument to explore adaptation measures to climate change” while lamenting that it was still “in its infancy.”³¹ Since 2007, many publications on IWRM and its application in various settings have been released (see the references for representative examples).^{45, 46} Additionally, an ideal introduction to both IWRM and its relevance to climate change adaptation are the training manual⁴⁷ and supporting presentations⁴⁸ developed by Cap-Net, a network of UN and other international agencies.

Impact on Mitigation

Climate change adaptation programs are rightly differentiated from those focused on mitigation. However, the potential impacts of adaptation strategies on greenhouse gas emissions and their effects on mitigation goals should not be neglected.

Adaptation technologies and practices in the water sector that decrease the volume of water to be transported, treated and distributed will save energy and reduce greenhouse gas emissions. These include technologies that conserve water, that reduce demand, or that enable locally available water to be reused. Some of these are discussed in Chapter 4, including:

- Increasing the Use of Water-efficient Fixtures and Appliances
- Leakage Management, Detection and Repair in Piped Systems
- Rainwater Collection from Ground Surfaces—Small Reservoirs and Micro-catchments
- Rainwater harvesting from Roofs
- Water Reclamation and Reuse

Other adaptation technologies are energy-intensive, increasing greenhouse gas emissions relative to competing technologies. Desalination is the most notable of these technologies that is discussed in Chapter 4. The energy requirements for desalination can be one or more orders of magnitude higher than those of conventional water treatment.⁴⁹ However, there are cases in which desalination could conceivably lead to energy savings; desalination of locally available saline water may be preferable to transporting freshwater long distances, particularly when it requires construction or expansions of conveyance infrastructure

4. Description of Eleven Concrete Adaptation Technologies and Practices in the Sector

Human responses to climate change fall under two broad categories: mitigation and adaptation. Mitigation is defined by IPCC as “implementing policies to reduce greenhouse gas emissions and enhance sinks.”⁵⁰ Adaptation is defined by IPCC as “the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.”⁵¹

Adaptation was identified in the first and second IPCC assessment reports as an important element in responses to climate change. However, early global climate change negotiations and responses focused almost exclusively on mitigation.⁵² The Conference of the Parties meetings in 2001 and 2002 (COP7 and COP8, respectively) led to increased emphasis on, and funding for, adaptation. The “Delhi Declaration” at COP8 included the statement that adaptation was of “high priority” for developing countries and a demand for “urgent attention and action on the part of the international community.”⁵³

The magnitude and location of climate change impacts in the water sector are uncertain and resources are limited. “No regrets” adaptation strategies are those that “would generate net social and/or economic benefits irrespective of whether or not anthropogenic climate change occurs.”⁵⁴ Many water and sanitation interventions have been shown to produce positive impacts on health and development and strong benefit-to-cost ratio.⁵⁵ Now many of these interventions can claim additional benefits through contributions to climate change adaptation. Due to these synergies, the World Health Organization (WHO) and UK Department for International Development (DFID) argue that climate change adaptation can be seen as an opportunity for focus on, and gains in, health, development and water resource sustainability.⁵⁶

Eleven technologies and practices are described in detail here. Their ordering is alphabetical and does not imply priority or importance.

Boreholes/Tubewells for Domestic Water Supply During Drought

Topic areas: Preparation for extreme weather events

Terms for the Glossary: Borehole; Tubewell; Drought; Water Stress/Scarcity

A. What does the technology/practice consist of?

Increasing access to groundwater is a key strategy for household water supply (both potable and non-potable) during drought. Therefore, drought relief programs in rural areas typically incorporate drilling or deepening of tubewells and/or boreholes. However, these activities are often inefficient and may be unnecessary, as described below.⁵⁷ This chapter will describe options for increasing access to groundwater during drought and will provide references for pre-drought mitigation measures that reduce the need for emergency interventions. Brief definitions of drought and the types of drought are included below in Section B).

Tubewells consist of a narrow, screened tube or casing driven into a water-bearing zone of the subsurface. The term tubewell is sometimes used synonymously with borehole. However, boreholes are more specifically defined as tubewells penetrating bedrock, with casing not extending below the interface between unconsolidated soil and bedrock. Tubewells can often be installed by hand-auguring; boreholes require a drilling method with an external power source. The choice of technology and drilling method depends on the cost, resources, groundwater table, desired yield and other factors.⁵⁸ The distinctions between the tubewells and boreholes are not critical to this discussion and the terms are used interchangeably throughout.

A hand-powered or automated pump is used to draw water to the surface or, if the casing has penetrated a confined aquifer, pressure may bring water to the surface. The salient features of tubewells include: (1) plastic or metal casing (usually 100-150 mm diameter); (2) in unconsolidated soils, a “screened” portion of casing below the water table that is perforated; (3) a “sanitary seal” consisting of grout and clay to prevent water seeping around the casing; and (4) a pump to extract the water. Detailed information on tubewell construction options can be found in references including, for example, online resources from WaterAid^{58, 59} and UN FAO.⁶⁰

Three major strategies are employed for increasing borehole water supply during drought:

- **Drilling new boreholes/deepening existing boreholes:** These strategies form the basis of conventional approaches to improving groundwater access in rural areas during drought.^{61, 62} They are frequently appropriate for mitigating extreme symptoms of drought. However, they are often not the most efficient use of limited resources.⁵⁷ Additionally, groundwater surveys and proper siting of boreholes are necessary for achieving maximum impact. These issues are discussed further in Sections d) and g).
- **Repairing damaged boreholes:** In many droughts, regional groundwater depletion is not the main factor affecting domestic access to water. When individual boreholes fail during drought, the cause is often local drawdown or mechanical failure. During a recent drought in southern Africa, a survey of water points by Oxfam revealed that most non-functional boreholes had failed because of problems with hardware (e.g. pump failure) or demand management (e.g. localized drawdown). The failure of a water point (including traditional sources) increases pressure on boreholes, increasing demand, local drawdown and hardware failure. Repairing damaged boreholes is a quick and inexpensive way to prevent this cascade of water point failure.^{57, 66}
- **Relief boreholes with use restricted to drought periods:** Many authors have proposed developing deep “relief boreholes” that remain capped when water supplies are adequate and are uncapped for use during drought.^{62, 63} There are reports that these have been implemented successfully in Botswana.⁶⁴ However, discontinuing access following the drought can be problematic; this is discussed below in Section G).

B. How does the technology/practice contribute to climate change adaptation?

A warmer climate is highly likely to result in more frequent drought.⁶⁵ Deep tubewells, usually defined by engineers as those that penetrate at least one impermeable layer,⁵⁹ generally have much greater resilience to drought than traditional water supplies including springs, hand dug wells and surface water sources. In many regions, groundwater is the only perennial source of water supply.⁶⁶ However, a more nuanced understanding of drought is needed to formulate a proper response.

Drought is defined as “a temporary aberration” in a climate pattern and is driven by variability in precipitation and evapotranspiration. This is in contrast to aridity, which is the “ordinary” climatic condition for a given area, and water stress/scarcity, which reflects renewable water resources per capita.^{67,68} Drought is further divided into three categories: meteorological drought, agricultural drought, and hydrological drought. The former two are experienced earliest, but hydrological drought is the drought-type associated with shortfalls in surface water and groundwater supply.⁶⁷ Groundwater drought is sometimes used to further distinguish cases in which the water table declines and some wells dry up.⁶⁶ Many situations commonly described as drought can strongly impact rain-fed agriculture and other activities without having a direct impact on the availability of safe drinking water.⁵⁷

C. What are the contributions of the practice/technology to development?

Discontinuity of water supply during drought can halt economic development and hinder human health and well-being.⁶⁹ Access to groundwater prevents reliance on poor quality alternative supplies and reduces expenditures for bottled and vended water.

D. What are the knowledge/capacity building requirements?

Determining the best strategy for improving groundwater access during drought requires knowledge of population distribution, groundwater resources, and water point locations/status. A broad review of the factors (including capacity building) that impact the success of groundwater programs in Ethiopia and India has been published by World Bank Water and Sanitation Program. These include recommendations of personnel training needs in the public and private well-drilling sectors.⁷⁰

In some settings, boreholes can be sited based on available maps and observation. Sometimes expensive geophysical techniques are necessary, but the success of a method will vary widely depending on the geological environment. Guidance on various methods, from simple and observational to technologically complex, is available.^{71, 72}

E. What are the institutional/organizational requirements?

A central groundwater database is essential to making informed decisions for groundwater access during drought.⁶⁶ These data can be gathered through a central governmental initiative at great expense. Alternatively, governments can help to ensure that data from all major well-drilling entities (e.g. contractors, donors, NGOs, state enterprises) contribute to the database. Borehole logs, completion reports, test pumping data, and other useful information should be collected in a central repository for mutual benefit.⁷⁰ In addition to data on groundwater resources, having a map of existing water points and population can greatly increase drought-alleviation program efficiency. WaterAid has reported on a methodology for water point mapping and lessons learned in Malawi and Tanzania.⁷³

Borehole drilling, deepening and repair are very dependent on access to international markets for drilling equipment, spare parts and consumables. Decreasing the difficulties and costs associated with international business (e.g tariffs, import restrictions) can help to mobilize the private sector to improve groundwater access. These and other institutional aspects are covered in detail in the references.⁷⁰

F. What are the costs and financial requirements?

The costs of drilling new boreholes vary widely depending many factors, so quoting ‘typical’ costs can be misleading. However, the average cost in much of Africa is \$10,000-15,000; in contrast, the average cost in India is less than one-tenth as much.^{70, 74} A detailed methodology for costing borehole drilling operations in Ethiopia is available, incorporating (i) mobilisation/demobilisation, (ii) drilling, (iii) casing and completion, and (iv) development and test pumping.⁷⁵ Repairing damaged wells can cost far less (sometimes by three or more orders of magnitude) than drilling new boreholes.

G. What are the barriers to and opportunities for implementation?

Proper pre-drought management can greatly increase the efficiency of these interventions and prevent costly and inefficient emergency activities. Broadly, these have been suggested to include groundwater resource assessment, groundwater drought vulnerability analysis, and building drought resistance into water supply programs.⁶⁶ However, many of the critical functions that can improve their efficiency are not valued by key stakeholders. For example, attracting donor and government support for development of databases for mapping groundwater and water point access/status is generally difficult.^{57, 66}

The cause of a “dry” borehole is usually unclear to users and is often assumed to be due to regional groundwater depletion caused by lack of rainfall. In reality, the cause of deep borehole failure is more often localized drawdown or mechanical breakdown, both of which are made more likely by the overuse.^{57, 66}

Barriers for ‘relief boreholes’ include reported difficulties stopping access following the drought. UN FAO reports that informal settlements tend to spring up around relief boreholes⁷⁶ and there are reports of threats of violence when the time comes to cap the borehole.⁶²

Well-constructed deep tubewells generally yield water of good microbial quality. However, both deep and shallow aquifers can be contaminated with naturally occurring arsenic and fluoride. Although these waters can generally be used for non-potable domestic purposes, they should not be consumed without treatment. Arsenic is of particular concern in deltaic regions of South Asia and Southeast Asia.⁷⁷ Fluoride concentrations in groundwater are generally higher at the foot of mountains. However, concentrations of these chemical species can vary widely by well location and depth, even at small geographic scales. Therefore, water testing for arsenic and fluoride should be conducted for each new well following construction and periodically during continued operation. If either is detected during sampling, numerous technical resources are available to help guide operational response.^{78, 79, 80, 81}

H. Examples and case studies from different regions

Fact sheets on well types, drilling techniques and geophysical methods are also available.^{58, 71} WaterAid has published a report on mapping of water points and utilizing the data gathered.⁷³

The World Bank Water and Sanitation Program has disseminated a guide on cost-effective boreholes that covers technical, institutional and other aspects. It contrasts experiences in sub-Saharan Africa with those in India, using Ethiopia as a case study.⁷⁰ Many more case studies from droughts in Africa are also available.^{63, 66, 82}

Desalination

Topic areas: Diversification of water supply; Resilience to water quality degradation

Terms for the Glossary: Product water; Concentrate; Brackish; Salinity; Membrane treatment; Reverse osmosis; Conductivity; Total dissolved solids (TDS); Desalination; Low-level equilibrium

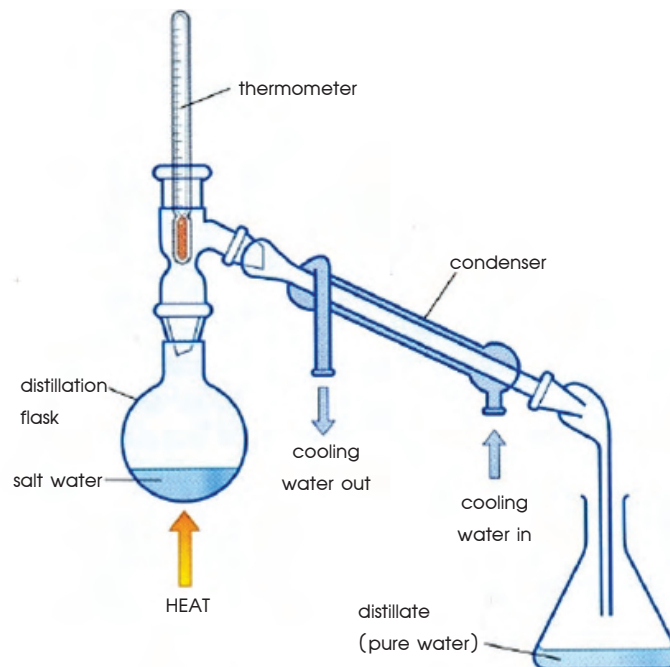
A. What does the technology/practice consist of?

Over 97% of the water on earth is unsuitable for human consumption due to its salinity. The vast majority (about 99%) of this is seawater, with most of the remainder consisting of saline groundwater.⁸³ Purification of this saline water holds the promise of nearly unlimited water resources for human civilizations in coastal regions. However, purification of seawater is expensive, energy intensive and often has large adverse impacts on ecosystems. Despite these drawbacks, desalination can be an appropriate technological choice in certain settings. Technological advancements continue to decrease the economic and environmental costs of desalination.⁸⁴

Desalination is the removal of sodium chloride and other dissolved constituents from seawater, brackish waters, wastewater, or contaminated freshwater. Approximately 75 million people worldwide rely on desalination and that number is expected to grow as freshwater resources are stressed by population growth and millions more move to coastal cities with inadequate freshwater resources.⁸⁵ Desalination is most widely used in arid regions; more than half of the world's desalination capacity (volume) is located in the Middle East and North Africa. Seawater accounts for over 50% of desalination source water worldwide. However, as of 2005 in the United States, only 7% of desalination plants used seawater. Brackish waters made up the majority of source waters for desalination, with most of the remainder consisting of river waters and wastewaters (application of desalination processes to wastewaters is covered in more detail in the section entitled Water Reclamation and Reuse).⁸⁶

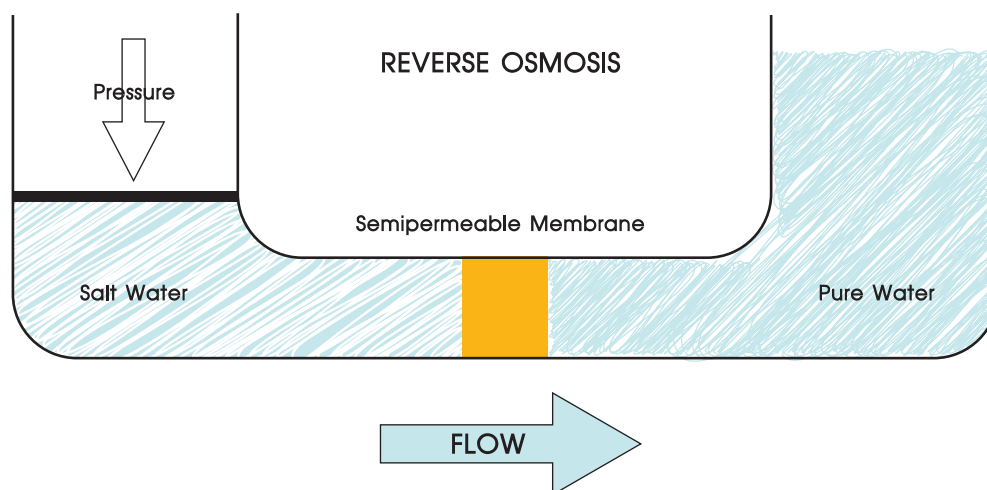
Two streams of water result from desalination: (1) a pure product water and (2) a high-concentration waste stream or brine. The principal desalination methods fall into two categories: thermal processes (Figure 1) and membrane processes (Figure 2).

Figure 1: A diagram of water distillation, the most simple thermal desalination process. Here, a flame is applied to a beaker containing salt water; the water evaporates leaving the salts behind. The water vapor then travels up and into the adjacent tube, where it condenses and drips into the flask as pure liquid water. Modern thermal processes (MSF, MEE, VCD, etc.) yield much greater energy efficiency than simple distillation.



Source: Filters Fast LLC.⁸⁷

Figure 2: A simple diagram of reverse osmosis, the most commonly used membrane process for desalination. In this diagram, high pressure is applied to salt water, forcing water molecules through a membrane with very small holes while leaving the salt behind.



Source: HydroLink⁸⁸

Thermal desalination processes generally use heat to evaporate water, leaving dissolved constituents behind. The water vapour is then condensed and collected as product water. Distillation is the simplest of these thermal processes and the energy efficiency of this simple process has been greatly improved.⁸⁹ The most common thermal desalination process today is multi-stage flash (MSF) distillation; in 2005, MSF was reported to account for 36% of desalination worldwide (Figure 4). MSF improves on the energy efficiency of simple distillation by utilizing a series of low-pressure chambers, recycling waste heat and, in some cases, can be operated at even greater efficiency by utilising the waste heat from an adjacent power plant. Multiple-effect Evaporation (MEE) (also known as multiple-effect distillation) is another thermal process that utilizes low-pressure chambers; it is possible to achieve much greater efficiency in MEE than in MSF. However, MEE is not as popular (see Figure 4) because early designs were plagued by mineral scaling. Newer designs have reduced mineral scaling and MEE is gaining in popularity.^{85, 90} For smaller operations with volume needs around 3000 m³/day, vapour compression distillation (VCD) can be an appropriate thermal distillation option. VCD is a technically simple, reliable and efficient process that is popular for resorts, industries and work sites where adequate freshwater is unavailable.⁹⁰

Membrane desalination processes utilize high pressure to force water molecules through very small pores (holes) while retaining salts and other larger molecules. Reverse osmosis (RO) is the most widely used membrane desalination technology, and represented 46% of global desalination capacity in 2005 (Figure 4). The name of the process stems from the fact that pressure is used to drive water molecules across the membrane in a direction opposite to that they would naturally move due to osmotic pressure. Because osmotic pressure must be overcome, the energy needed to drive water molecules across the membrane is directly related to the salt concentration. Therefore, RO has been most often used for brackish waters that are lower in salt concentration and, in 1999, only accounted for 10% of seawater desalination worldwide.⁸⁵ However, the energy efficiency and economics of RO have improved markedly with development of more durable polymer membranes, improvement of pretreatment steps, and implementation of energy recovery devices. In many cases, RO is now more economical than thermal methods for treating seawater.^{90, 91}

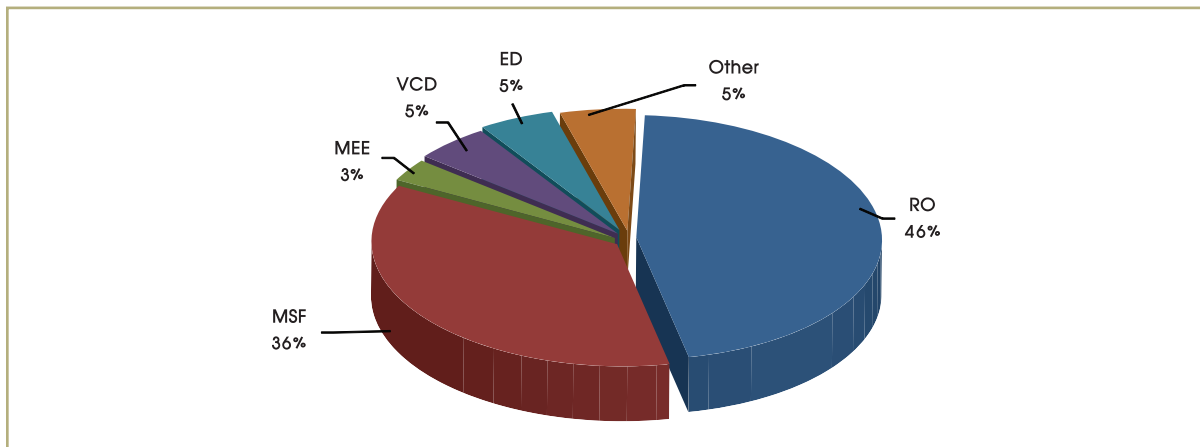
Figure 3: Aerial photo of the Perth Seawater Desalination Plant in Perth, Western Australia. This plant uses reverse osmosis to desalinate seawater.



Source : http://commons.wikimedia.org/wiki/File:Perth_Seawater_Desalination_Plant.jpg

About 90% of global volume capacity for desalination is represented by the four thermal and membrane processes discussed above. Other desalination processes include electrodialysis, freezing, solar distillation, hybrid (thermal/membrane/power), and other emerging technologies (Figure 4).

Figure 4: Global desalination capacity (volume) by process in 2005.



Source: Gleick et al., 2006.⁸⁶

RO: Reverse osmosis; MSF: Multi-stage flash distillation; MEE: Multiple-effect evaporation; VCD: Vapor compression distillation; ED: Electrodialysis; Other: includes freeze, hybrid, nanofiltration, thermal and all other processes.

Electrodialysis (ED) utilizes current to remove ions from water. Unlike the membrane and thermal processes described above, ED cannot be used to remove uncharged molecules from source water.⁹⁰ It is also

possible to desalinate water by freezing at temperatures slightly below 0° C, but it involves complicated steps to separate the solid and liquid phases and is not commonly practiced. However, in a cold climate, natural freeze-thaw cycles have been harnessed to purify water at costs competitive with RO.^{90, 92} Interest in harvesting solar energy has led to significant progress on solar distillation processes. Hybrid desalination combining thermal and membrane processes and usually operated in parallel with a power generation facility is a promising emerging technology that has been implemented successfully.^{93, 94} Nanofiltration (NF) membranes cannot reduce seawater salinity to potable levels but they have been used to treat brackish waters. NF membranes are a popular pretreatment step when coupled with RO.⁹¹

Progress in desalination technology has been incremental, resulting in consistent improvements in energy efficiency, durability and decreased operation and maintenance across many technologies. However, new technologies in research and development could potentially result in large improvements. These emerging technologies include nanotubes,^{95, 96} advanced electrodialysis membranes,⁹⁷ and biomimetic membranes.⁹⁸

The major drawbacks of current desalination processes include costs, energy requirements and environmental impacts. The environmental impacts include disposal of the concentrated waste stream and the effects of intakes and outfalls on local ecosystems. These are covered in more detail under barriers to implementation (Section G).

Despite these drawbacks, the use of desalination is widely expected to increase in the 21st Century, primarily for two reasons. Research and development will continue to make desalination less energy intensive, more financially competitive, and more environmentally benign. Increasing demand: population growth, economic development and urbanization are leading to rapidly increasing demand for water supply in coastal and other regions with access to saline waters.

B. How does the technology/practice contribute to climate change adaptation?

Desalination can greatly aid climate change adaptation, primarily through diversification of water supply and resilience to water quality degradation. Diversification of water supply can provide alternative or supplementary sources of water when current water resources are inadequate in quantity or quality. Desalination technologies also provide resilience to water quality degradation because they can usually produce very pure product water, even from highly contaminated source waters.

Increasing resilience to reduced per capita freshwater availability is one of the key challenges of climate change adaptation. Both short-term drought and longer-term climatic trends of decreased precipitation can lead to decreased water availability per capita. These climatic trends are occurring in parallel with population growth, land use change, and groundwater depletion; therefore, rapid decreases in per capita freshwater availability are likely.

However, the large energy demands of current desalination processes will contribute to greenhouse gas emissions and could set back climate-change mitigation efforts.

C. What are the contributions of the practice/technology to development?

Access to an adequate supply of freshwater for drinking, household, commercial and industrial use is essential for health, well being, and economic development.⁸⁴ In many settings, desalination processes can provide access to abundant saline waters that have been previously unusable.

D. What are the knowledge/capacity building requirements?

A World Bank report on desalination in the Middle East and Central Asia includes a chapter on capacity building.¹⁰⁰ The major needs identified include the inadequacy of:

- information and data resource assessment specifically on desalination
- technical capabilities
- financial resources dedicated to research
- national policies in long-term planning and establishment of institutional infrastructures for management and operation of desalination¹⁰⁰

Training and formal education requirements for desalination are also discussed in detail.¹⁰⁰

E. What are the institutional/organizational requirements?

Until recently, little information was available on institutional aspects of desalination. A World Bank project helped to define the key institutional issues related to desalination and provide recommendations for implementation. These issues include how and when desalination should be incorporated into a larger water policy, how to integrate desalination into energy policies and energy co-production, the role of private enterprise, and how to distribute and charge for desalinated water.^{84, 99, 100}

Many of the recommendations for development of desalination relate to remedying broader problems in the water sector. Desalination requires substantial economic investment; therefore inefficiencies, waste, and low-level equilibria in the water sector can be compounded when desalination is implemented.^{84, 100} Key recommendations for governments exploring development of desalination include:

- Develop a clear water policy using an integrated water resources management (IWRM) approach to determine accurately renewable freshwater resource potential, demand and consumption. Only when the adequacy of conventional water resources is understood should development of non-conventional (e.g. saline) water resources be pursued.¹⁰⁰
- Implement conservation and water demand management in all sectors. Key methods include reduction of non-revenue water in piped systems, use of only limited targeted subsidies, and prevention of groundwater pollution.^{99, 100}
- Consider desalination in combination with other non-conventional water sources including reuse of treated wastewater, importation of water across boundaries, rainwater harvesting and microcatchments.¹⁰⁰

The World Bank provides words of caution for those who believe that desalination is a panacea:

“It may be preferable not to engage in desalination on a large scale unless the underlying weaknesses of the water sector are addressed...desalination should remain the last resort, and should only be applied after having carefully considered cheaper alternatives in terms of supply and demand management.”⁹⁹

F. What are the costs and financial requirements?

A recently published review of desalination cost literature has shown that the costs are very much site-specific and the cost per volume treated can vary widely. Some of the factors reported to have the greatest

influence on the cost per m³ include: the cost of energy, the scale of the plant, and the salt/TDS content of the source water.¹⁰¹ Capital costs of construction are clearly a major consideration as well, but are almost entirely site specific.

The cost of membrane desalination decreases sharply as the salt concentration decreases. Seawater, on average, contains about 35,000 mg/L TDS; brackish waters, at 1000-10,000 mg/L, can be treated much less expensively.⁹¹ The costs per volume to desalinate brackish water using RO have generally been reported to range from \$0.26-0.54/m³ for large plants producing 5000-60,000 m³/day and are much higher (\$0.78-1.33/m³) for plants producing less than 1000 m³/day. Cost per volume for seawater RO are reported to be \$0.44-1.62/m³ for plants producing more than 12,000 m³/day.¹⁰¹

Thermal methods (generally used to desalinate seawater) are subject to the same economies of scale. Costs for thermal desalination plants were reported to be \$2-2.60/m³ for 1000-1200 m³/day and \$0.52-1.95/m³ for plants producing more than 12,000 m³/day.¹⁰¹

Climate change adaptation strategies must consider not only future climate forecasts but also future technological development. The costs associated with desalination continue to decline incrementally as technological efficiency improves. As mentioned above, it is also possible that a new technology will be developed that greatly decreases the costs of desalination.

G. What are the barriers to and opportunities for implementation?

Desalination enables utilities in many water poor areas to access a nearly unlimited water resource. However, as discussed briefly in Section E, implementing desalination can sometimes exacerbate the problems of a poorly functioning water sector.^{84, 99} Therefore, the best opportunities for implementation are in water sectors that are functioning well, with well-defined water policy, well-characterized water resource availability and demand, technical expertise, and relatively little waste and inefficiency.

Opportunities for desalination are greatest when:

- Freshwater resources are inadequate to meet demand (water stress or water scarcity)
- For membrane systems, an abundant source of brackish water with low salt/TDS concentration is available; or, for thermal systems, the population is located on a coastline with an adjacent facility (e.g., a power plant) that yields abundant waste heat
- Consumers are opposed to the reuse of treated wastewater (see the chapter entitled Wastewater Reuse)

Barriers to desalination include environmental impacts. These include: effects of the concentrated waste stream on ecosystems; the impact of seawater intakes on aquatic life; and greenhouse gas emissions. However, the environmental impacts of desalination must be weighed against those of expanding use of freshwater sources (e.g. groundwater depletion, diverting surface water flows).¹⁰² Although RO product water is almost totally pure, it is possible that some compounds of possible concern could get into product water; pre-treatment or post-treatment processes can be used to address the few compounds that are not removed well by RO (e.g., boron). A 20-page description of procedures for Environmental Impact Assessment (EIA) of desalination projects can be found in the World Health Organization guidance document.⁸⁴

H. Examples and case studies from different regions

The WHO guidance document provides a thorough overview of the health, environmental and technical aspects of desalination planning and implementation.⁸⁴ The World Bank main report on desalination in the Middle East and Central Asia includes overviews of additional topics, including institutional frameworks, capacity building, and the potential for private sector participation. It also includes lessons learned and overviews of desalination in six countries: Algeria, Tunisia, Jordan, Uzbekistan, Malta and Cyprus.¹⁰⁰

The U.S. state of Texas has compiled case studies from brackish water and seawater desalination projects encompassing many aspects of desalination implementation, including: development of saline water sources, technologies, economics and finance, siting, concentrate management, and others.¹⁰³

Many case studies of desalination projects can be found in the academic literature. The most common source for these is the journal *Desalination*, published by Elsevier.

Household Drinking Water Treatment and Safe Storage (HWTS)

Topic areas: Resilience to water quality degradation

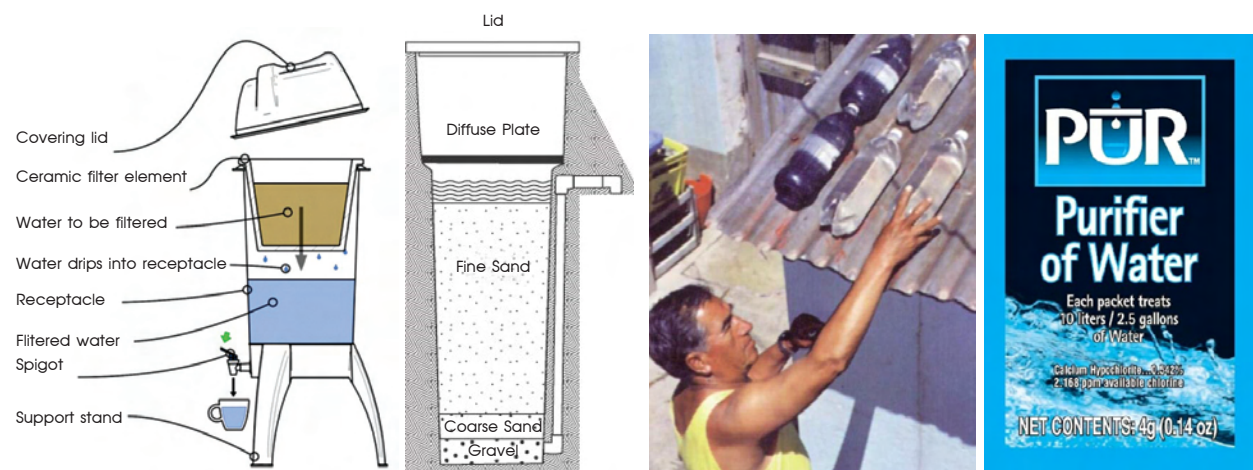
Terms for the Glossary: Point of use (POU); Coagulant; Household water treatment and safe storage (HWTS)

A. What does the technology/practice consist of?

Ideally, piped drinking water supplies incorporating source water protection and centralized treatment would be available to all. However, nearly one-billion people worldwide do not have access to an “improved” source of drinking water, and many improved sources are unsafe and some distance from the home.^{104, 105} Despite the eventual goal of providing a safe, sustainable supply of drinking water at home to all people, the World Health Organization (WHO) and other international bodies have recognized the benefit of targeted, interim approaches for those with unsafe drinking water.¹⁰⁶

Household or point of use (POU), drinking water treatment and safe storage provides a means to improve the quality of their water by treating it in the home. Popular treatment technologies include chemical disinfectants, coagulants, ceramic filters, biological sand filters, solar disinfection (SODIS) or ultraviolet disinfection processes, and combined products with both coagulant and disinfectant (e.g. Procter & Gamble PUR product).^{106, 107} These technologies have been shown to improve the microbiological and, in some cases, the chemical quality of drinking water and to reduce diarrheal disease.^{108, 109, 110} Four of the most widely promoted technologies are shown in Figure 5.

Figure 5: Cross-sections and photographs of four popular POU technologies. On the left are two popular POU filters with descriptions of the individual elements; the ceramic water purifier (on the far left) and a concrete biosand water filter (BSF) (second from left). Both of the devices pictured stand between 0.5-1 meter high. Second from the right is a photo of bottles used for solar disinfection (SODIS) being placed on a household roof. On the far right is an image of a Procter & Gamble PUR coagulation/chlorination packet; an individual packets contains 4 g of crystals and can be used to treat 10 liters of water.



An analysis of the potential for long-term sustained-use of the technologies that have been most widely promoted by the WHO Network to Promote Household Drinking Water Treatment and Safe Storage (HWTS Network) has been conducted. The results are summarized in Table 2.

Table 2: Scoring of popular point-of-use drinking water treatment technologies based on sustainability criteria. Higher numbers indicate better scores. Details of the methodology can be found in the source.

Technology	Quantity treated per day	Robustness to feed water quality	Ease of use	Cost per volume treated	Need for local supply chain	Overall score
Free chlorine (liquid)	3	1	3	3	1	11
Free chlorine (tablets)	3	1	3	2	1	10
Coagulation/chlorination	2	3	1	1	1	8
Solar disinfection	1	1	1	3	3	9
Ceramic filters	2	3	2	3	2	12
Biosand filters	3	3	2	2	3	13

Source: Modified from Sobsey et al. (2008).¹⁰⁸

In addition to these, HWTS products manufactured by large companies have become popular in both developed countries and emerging economies. These faucet and pitcher format products include the Procter & Gamble line of PUR filtration systems, Brita filters, and others. Recently introduced commercial products for emerging economies include the Hindustan Unilever Pureit and the Tata Swach filter lines; both filters are meant to sit on a table-top or counter-top, do not require electricity or running water, and have an incorporated safe storage vessel (Figure 6).

Figure 6: The Pureit (on the left) can be used to treat about 1500 liters of water (depending on the model) using a carbon block to absorb and filter impurities, followed by chlorine disinfection; replacement of the chlorine unit enables treatment of 1500 liters more. The Tata Swach (on the right) uses rice husk ash and silver to treat water; it enables treatment of up to 3000 liters before the so-called treatment “bulb” must be replaced.



New HWTS Technologies continue to emerge. The most current review of HWTS devices available worldwide was released by Program for Appropriate Technology in Health (PATH) in 2010. It includes qualitative assessments of treatment efficacy, health impact, safety, cost, acceptability, sustained use, supply chain and other factors for 19 popular technologies and eight promising devices still in research and development. The table from the PATH report is too large to reproduce in this report, but it is freely available online.¹¹¹

Household treatment of drinking water by heating, usually to the point of boiling, has been practiced in many societies for millennia and is far more widely practiced than all of the above HWTS methods combined.¹⁰⁶ It is highly effective at eliminating all classes of pathogens. However, boiling has numerous disadvantages and has not been generally promoted by HWTS practitioners. Among these disadvantages are the time to gather fuel, the sometimes prohibitive costs, and the degradation of indoor air quality that leads to increased health hazards including respiratory infections. Despite these, there have been recent calls to re-examine the costs and benefits of boiling and to optimize the process.¹¹²

HWTS has become an increasingly promoted technical options in the international health community since the introduction of the Safe Water System by the US Centers for Disease Control and Prevention (CDC) in 1992.¹¹³ The formation of the WHO HWTS Network in 2003 established the major community of practice for researchers, implementers, and advocates of HWTS.¹¹⁴

This handbook focuses on HWTS as an adaptation strategy for climate change. Therefore, the emphasis is on long-term adoption and scale-up. The principles of HWTS implementation in an emergency or natural disaster setting are fundamentally different. For guidance on HWTS in emergency situations, resources are included in the references.^{115, 116}

B. How does the technology/practice contribute to climate change adaptation?

Degradation of water quality is expected to be one of the key impacts of climate change on water resources and water supply. Projected increases in flooding, drought, decreasing water availability, algal blooms, coastal inundation, and sea level rise have both direct and indirect effects on drinking water quality.^{117, 118} Direct effects occur through transport of fecal and other wastes into water supplies, growth of harmful algal blooms, for example. Indirect effects on drinking water quality occur when users are forced to switch to lower quality drinking water supplies, for example when groundwater tables decline and users must switch to contaminated surface water. HWTS increases resilience to water quality degradation by enabling users to improve water quality at the point of use.

It is estimated that there were 18.8 million users of HWTS devices worldwide in 2007, with rapid growth of roughly 25% per year. The growth rate may have increased even further in recent years with the introduction and popularization of Hindustan Unilever, Tata and other HWTS products targeted to the Indian middle-class (see Figure 6). In addition to these HWTS users, 350 million people were estimated to boil water for household consumption from a survey of 58 low-income countries. Not included in this number were China, Indonesia and other large countries in which boiling is common.¹⁰⁶

C. What are the contributions of the practice/technology to development?

Diarrheal disease can be a key component of the “poverty trap” that hinders development by decreasing economic productivity.¹¹⁹ Preventing waterborne disease can lead to increased school attendance, more time spent in gainful activities and childcare, and less diversion of limited financial resources to pay for medical care. POU disinfection was the least expensive intervention reviewed in a World Health Organization (WHO) analysis of the costs and benefits of improved water and sanitation, resulting in a benefit-to-cost ratio of between \$5-and-\$60 per \$1 invested.¹²⁰

D. What are the knowledge/capacity building requirements?

Correct, sustained use of HWTS is necessary to achieve long-term impact on user health. Although HWTS devices are generally designed to be easy to operate and maintain, the complexity of design, and the

durability, operation and maintenance requirements vary. Additionally, some HWTS technologies (e.g. chemical disinfectants) are consumable and need to be replaced frequently. Although research on the factors affecting use rates of HWTS is evolving, most evidence indicates that durable technologies (e.g. filters) that do not include consumable components achieve higher rates of sustained use following implementation.^{108, 121}

Fact sheets and other concise implementation tools for HWTS devices and programs have been generated by HWTS Network members. These provide simple summaries of the research, best practices, training tools, and lessons learned from implementation for many popular HWTS devices. Many of these are linked from a page dedicated to “Fact sheets and tools” on the HWTS Network website.¹²² Further description of these resources can be found below in Section H.

E. What are the institutional/organizational requirements?

HWTS is a technology that is fundamentally operated and managed in the household; therefore, there are few if any institutional or organizational requirements for users. However, scaling up HWTS has proven a challenge. A WHO report examines the state of HWTS globally and presents ten key recommendations for scaling up (listed below) that are discussed in greater detail in the report.¹⁰⁶

1. Focus on the users.
2. Develop and use partners.
3. Improve and expand on boiling.
4. Continue to pursue non-commercial strategies.
5. Continue to pursue market-driven strategies.
6. Leverage existing local strengths.
7. Initiate and use relevant, practical research.
8. Overcome public policy barriers to advancing HWTS.
9. Engage national and regional governments.
10. Engage international leadership to support HWTS.

F. What are the costs and financial requirements?

Both capital and ongoing costs must be taken into account when considering the appropriateness of an HWTS implementation program for a given community. Some technologies (e.g. chemical disinfectants) have few if any capital costs but must be purchased periodically; others (e.g. biosand filters) have relatively large up-front costs with little or no on-going costs.

The costs associated with training and educating users will exceed all costs associated with the HWTS “hardware.” One example is solar disinfection (SODIS). In many settings, SODIS can be practiced with negligible costs, either capital or on-going. However, uptake and sustained use cannot be achieved without significant investment in training and education. Regardless of the technology, attempting to implement HWTS programs without a substantial education component is likely to decrease the long-term sustainability and impact.

Many HWTS implementation programs are donor-driven, offering partial or complete subsidization of product costs. Donor-driven HWTS programs have been successful in some settings, particularly in refugee

camps, following natural disasters and during waterborne disease outbreaks. Targeted subsidization can be used to establish products in a market. However, subsidized HWTS programs can distort the market and undermine long-term efforts to reach scale.^{123, 124} Arguments for and against subsidization are addressed in a 2006 report by the Massachusetts Institute of Technology (MIT).¹²⁵

Full cost recovery approaches provide the greatest potential for reaching scale. Recent studies focusing on full cost recovery and market mechanisms to scale-up HWTS are available.^{126, 127, 128, 129} In some settings, social marketing approaches can be effective.¹³⁰ Case studies of many HWTS programs covering various technologies and financial approaches are described and referenced in Section H.

G. What are the barriers to and opportunities for implementation?

Generally, opportunities for HWTS implementation are greatest when either (1) in the midst of a waterborne disease outbreak or (2) when non-health benefits of HWTS are perceived to be high. HWTS does not provide the key non-health benefit of improved drinking water supply at the home, namely time-savings from not having to fetch water. However, non-health benefits include aesthetic improvement of water quality, cost savings over other water sources (e.g. bottled or vended water), and the social status associated with being able to serve treated drinking water to guests. Marketing HWTS as an “aspirational” product associated with a better lifestyle can improve uptake.¹³⁰

Most marketing efforts of consumable HWTS products during non-crisis times have led to modest uptake and sustained use. However, recent evidence suggests that potential consumers that become aware of HWTS products through marketing campaigns will turn to those products when the perceived need is greater (e.g. during a waterborne disease outbreak).¹³¹

H. Examples and case studies from different regions

Since the establishment of the HWTS Network in 2003, the literature has grown exponentially. A bibliography of articles and reports published through the end of 2006, with brief summaries and links to online sources, is available through the USAID Environmental Health website.¹³² Periodic updates to the bibliography have been posted, along with links to reports, conference presentations and USAID sponsored activities.¹³³ For a qualitative overview of HWTS technologies available or in development in late-2010, see the “Global Landscape of HWTS Products” report by PATH.¹¹¹

Training materials, both general and for specific HWTS technologies, are widely available. Some of these resources are cited above or linked from the “Fact sheets and tools” page of the HWTS Network website.¹²² Additional training materials and resources include:

- Centre for Affordable Water and Sanitation Technology (CAWST)—training materials for biosand filters and other community health interventions.¹³⁴
- Resources Development International—Cambodia: materials on ceramic pot filter manufacture and implementation.¹³⁵
- SODIS safe drinking water for all—solar disinfection training materials.¹³⁶
- US Centers for Disease Control and Prevention (CDC)—chlorination and safe storage materials.¹³⁷

The WHO report on scaling up HWTS provides case studies across numerous technologies and settings (see Section 3 of the report).¹⁰⁶ Other reports cited above also include sections or appendices dedicated to case studies and lessons learned from diverse projects.^{123, 125, 126, 127, 128, 129, 130}

Improving the Resilience of Protected Wells to Flooding

Topic areas: Preparation for extreme weather events

Terms for the Glossary: Borehole; Tubewell; Flood; Apron (well); Casing (well)

A. What does the technology/practice consist of?

Protected wells can potentially provide a water supply that is highly resilient to flooding. However, improper design and construction can make them vulnerable during flooding. The key vulnerabilities of wells during flooding are: (1) ingress or infiltration of contaminated waters; (2) lack of wellhead access due to flood waters; and (3) collapse of unlined hand dug wells when soil becomes saturated.¹³⁸ This chapter will cover the design, construction and retro-fitting of dug wells, tubewells and boreholes to achieve high resilience to flooding.

Protected wells can include tubewells, boreholes and (hand) dug wells. Tubewells and boreholes are small diameter bores into a water-bearing zone of the subsurface. The bore is encased with a tube for some or all of the depth. They are described in more detail in the chapter entitled Boreholes/Tubewells as a Drought Intervention for Domestic Water Supply. Dug wells are generally more susceptible to contamination than tubewells/boreholes, but protected dug wells can also provide “improved” drinking water. The advantages of dug wells include inexpensive construction and, generally, greater volume yield per depth (due to their usually greater diameter).^{138,139, 140}

The salient features of all protected wells include the following: (1) a concrete apron to direct surface water away from the well; (2) a sanitary seal (normally clay, grout, and concrete) that extends at least 1-3 m below ground to prevent infiltration of contaminants; and (3) a method to access water that enables it to be sealed following use. Handpumps can be fitted to most wells (including hand dug wells) to improve convenience and decrease the likelihood of contamination.^{138, 142, 141}

Location is another key parameter in assessing the vulnerability of wells to flooding. Constructing drinking water wells in the vicinity of sanitation facilities can lead to contamination through subsurface transport of fecal pathogens, particularly during flooding. Wells should be constructed up the hydraulic gradient (usually uphill) from latrines and animal waste. The minimum recommended distance between a well and a single latrine is 30 m. However, in settlements where latrine density is high, greater distances are often needed.¹⁴²

Many of the key vulnerabilities related to flooding can be identified by undertaking a “sanitary survey” of all drinking water wells. Sanitary survey forms with illustration to guide inspection for many varieties of wells can be found in Annex 2 of the WHO Guidelines for Drinking Water Quality (GDWQ) 2nd Edition.¹⁴³ Additional well design issues that are relevant to flooding are covered in Chapter 6 of the GDWQ 2nd Edition. These include recommendations for the depth of the sanitary seal (3 m) and casing (to the water table) for tubewells. The minimum height of the casing above ground is recommended to be 30 cm. However, in flood-prone areas it should be higher.¹⁴⁰

In addition to protection of wells currently used for drinking water, sealing abandoned wells is also essential to protecting groundwater quality in flood zones.¹⁴¹ If an abandoned well is not properly sealed, floodwaters that inundate the abandoned well are likely to contaminate both shallow and deep groundwater.

Retro-fitting of drinking water wells by elevating handpumps has been undertaken systematically in flood-prone areas of Uttar Pradesh, India. An example of a flood-proofed handpump is shown in Figure 7. Further detail of the costs and success of the program can be found below.^{150, 151}

Figure 7: Flood-proofed handpump in Bahraich, Uttar Pradesh, India. The apron is 1-m high, 2.9-m in diameter. The slope of the base is 45-degrees, gradual enough to prevent damage to the base during flash flooding.



Source and photo credit: District Administration, District Bahraich, Uttar Pradesh, India.¹⁵⁰

This chapter addresses preemptive flood-proofing interventions that are generalizable to most types of flooding and in most settings. However, the magnitude, onset time, and setting can differ widely. Descriptions of the different classes of floods and guidance on preparation and response in urban¹⁴⁸ and rural¹⁴⁹ settings have been made published by the Global WASH Cluster.

B. How does the technology/practice contribute to climate change adaptation?

A warmer climate is highly likely to result in more frequent and intense rainfall and more flooding.¹⁴⁴ Flooding can lead to contamination of drinking water wells and can also prevent physical access when floodwaters are high enough.

C. What are the contributions of the practice/technology to development?

Community health and economic activity require continuity of safe water supply. Sealing and elevating wells can prevent both contamination of drinking water and loss of physical access to the wellhead. Ensuring continuous access to drinking water decreases the likelihood that populations will be displaced during moderate flooding.

D. What are the knowledge/capacity building requirements?

Some basic knowledge of water supply technology and public health principles is necessary to perform sanitary surveys.¹⁴⁵ Experience drilling a given type of well and basic concrete construction skills are also necessary.

Undertaking a survey of population distribution, and water point location, elevation and condition can greatly improve the efficiency of flood-proofing programs. This survey should then be compared against floodplain maps to determine priority areas for well flood-proofing. This procedure can be used to ensure that the WHO emergency guidelines are already met when flooding does occur: (1) at least one functioning water point per 250 people and (2) the maximum distance from any shelter to a water point is less than 500 meters.¹⁴⁶

E. What are the institutional/organizational requirements?

A training or certification program may be necessary for those carrying out sanitary surveys of wells in flood-prone areas. Some institutional capacity is necessary to determine if, where and how public funds should be allocated for constructing or retro-fitting wells (see Section D).

F. What are the costs and financial requirements?

Construction of new wells is very expensive and often requires drill rigs or other specialized equipment. Retro-fitting for flooding can generally be accomplished with basic construction supplies at or close to the ground surface. The costs of retro-fitting wells for drought by elevating the apron and handpump (Figure 7) were estimated to be \$315 per well in India.¹⁵⁰ By comparison, the costs of installing a new borehole are highly dependent on soil type, depth to the water table, and other factors; they have been reported to be between \$1000-1500 in India and \$10,000-15,000 in parts of Africa.¹⁴⁷

G. What are the barriers to and opportunities for implementation?

Frequent flooding causing temporary lack of access to handpumps has increased demand from local citizens for flood-proofing.¹⁵⁰ Communities with alternative (e.g. piped) water supplies may be less likely to demand/ less willing to invest in flood-proofing wells.

H. Examples and case studies from different regions

Descriptions of the distinct types of floods (predictable, regular; predictable, increased size; flash flooding, slow-onset, and coastal flooding) are available for both urban and rural contexts. The characteristics and lengths of these flooding events and key local factors strongly impact proper water and sanitation responses to flooding. For more detail, see the references for urban¹⁴⁸ and rural¹⁴⁹ settings.

Clear guidance on the planning, design and construction of sanitary protection works around drinking water wells can be found in Chapter 18 of the International Water Association book “Protecting Groundwater for Health.” It has been made freely available online.¹⁴¹

A case study of a program for flood-proofing handpumps in Uttar Pradesh, India is available online,¹⁵⁰ along with a news story on the program.¹⁵¹

Increasing the Use of Water-efficient Fixtures and Appliances

Topic areas: Water conservation

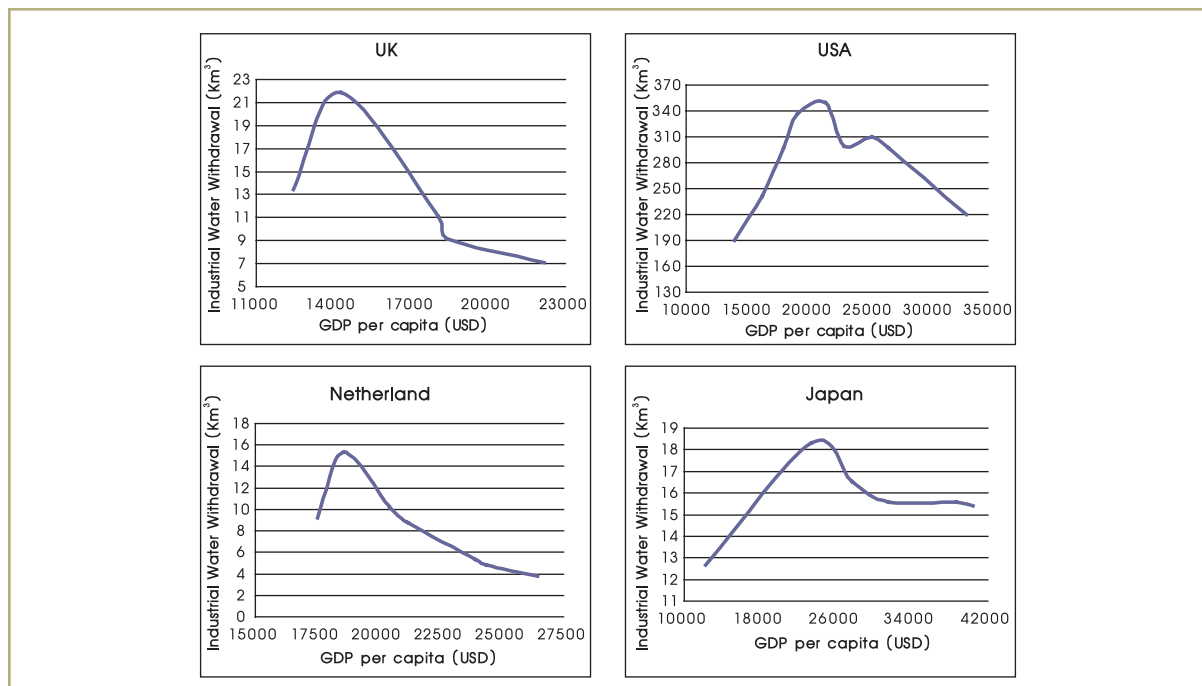
Terms for the Glossary: Environmental Kuznets Curve (EKC); Water fixture

A. What does the technology/practice consist of?

There is some evidence that per capita water use in a society follows the pattern of the Environmental Kuznets Curve (EKC).^{152,153} That is, per capita water use increases rapidly with economic development to a “turning point” where it begins to decline (Figure 8).

Examples of industrialized countries that have experienced declining per capita water use include the United States and Japan. In the US, per capita water use peaked in 1975 and then declined nearly 30% over the next 30 years.¹⁵⁴ Although most progress in the US has been attributable to improved industrial and agricultural efficiency, the use of water efficient appliances and fixtures in homes, institutions and businesses can contribute greatly to water conservation efforts. In Japan, residential per capita water use increased by about 25% in the 1980s, leveled off in the 1990s and began to decline in 2000. This progress has been attributed to the increasing use of water efficient appliances and fixtures.¹⁵⁵

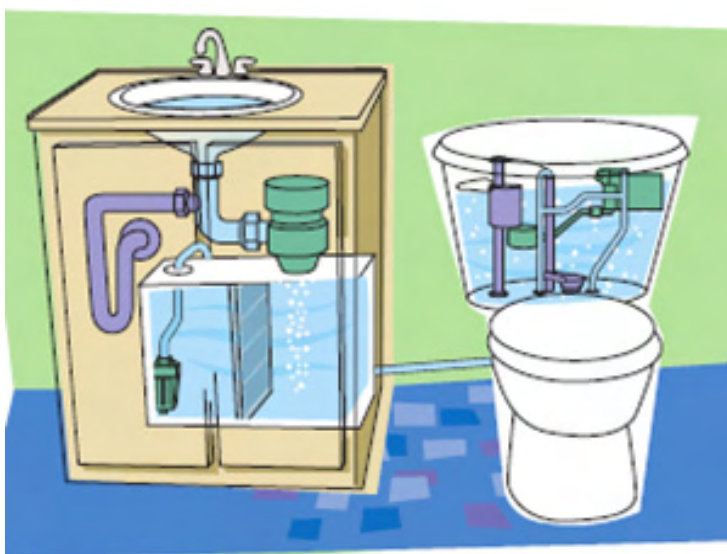
Figure 8: Industrial water use vs. GDP per capita in the USA, UK, Japan and the Netherlands.



Source: Adapted from Yang et al.

The most common water efficient appliances include dishwashers and clothes washing machines; popular fixtures include toilets, showerheads and faucets. They can simply use less water while yielding comparable performance (e.g. low-flow showerheads). Alternatively, these appliances can be more complex, as devices that use gray water from the sink for toilet flushing (see Figure 9). Other products give visual or audible feedback to the user about resource consumption and rely on behaviour change.¹⁵⁶

Figure 9: The Aqus™ toilet uses gray water from the sink for toilet flushing.



Source: Elizondo and Lofthouse (2010) ¹⁵⁶

The transfer of the water efficient technologies from wealthy countries to developing countries can potentially hasten progress toward the EKC “turning point” and conserve water resources.³³ Making efficient appliances available on the market is necessary but may not be sufficient. Three major strategies to increase the use of water efficient appliances and fixtures are discussed below:

- Mandates – mandating water efficiency standards for new construction and replacement of old fixtures and appliances; mandating use of water efficient products in government facilities.
- Labeling – certification systems for water efficient products; adding the estimated cost of use, also called the “second price tag,” to labels.
- Tax incentives – for purchasing and installing efficient products; for retro-fitting and replacing older fixtures.

Examples of how these three strategies have been used in the US are discussed briefly below. For further examples see Section H (Examples and case studies from different regions). In addition to these, some water utilities have experimented with giving away inexpensive low-flow showerheads for free in an effort to reduce pressure on water supplies.¹⁵⁸

Mandates: The US government legislated minimum water efficiency standards for new installations on a federal level in 1992 (Table 3). The decision to mandate the minimum standard of 6 liter/flush toilets is estimated to save nearly eight million cubic meters of water per day in the US.¹⁵⁹

Table 3: United States government mandated minimum water efficiency standards for new plumbing fixtures, in place since 1992.

Fixture	Volume
Water Closets (Toilets)	6 liters per flush
Showerheads	9.5 liters per minute
Faucets	8.3 liters per minute
Urinals	3.8 liters per flush

Source: Dickinson, 2000.¹⁵⁹

Labeling: The USEPA has implemented Energy Star and WaterSense certification and labeling programs. Water-using products that require electricity (e.g. clothes washers, dishwashers) must meet standards of energy and water efficiency to qualify for the Energy Star label.¹⁶⁰ WaterSense products must exceed federal minimum standards for water efficiency and generally use about 20% less water than average products in the same category.¹⁶¹

In addition to the general certification, labels can incorporate estimates of the annual or lifetime water-use or cost of operation and how it compares to that of competing products. Therefore, the consumer can be made aware of the “second price tag” (the cost to operate the appliance over its lifetime) and the long-term savings that can be realized.

Tax incentives: In addition to the savings attributable to lower operating costs, governments can provide further financial incentives by providing tax refunds for purchasing and installing water efficient appliances and fixtures. The US government provides tax incentives for the purchase and installation of some products that yield energy savings and also fund reimbursement programs carried out through local governments.

Although important and effective, these are only a few of the strategies used to reduce residential water use. Educating users, metering individual homes, implementing volumetric pricing, fixing leaks, and limiting outdoor water use are also important steps for conversion.^{156, 162}

B. How does the technology/practice contribute to climate change adaptation?

A warmer climate is highly likely to result in more frequent drought.¹⁶³ Additionally, growing population will push many countries into water stress and water scarcity by 2050. Water conservation is an essential part of comprehensive strategies to reduce pressure on existing water resources. The industrial and agricultural sectors account for a large majority of global freshwater use. However, total freshwater withdrawals reported for 163 countries by the Pacific Institute showed that in the median country residential water use accounted for 16% of total freshwater withdrawals.¹⁶⁴ Therefore, residential conservation efforts can make a strong positive contribution to reducing pressure on water resources.

Reducing water use in municipal systems also contributes to climate change mitigation by decreasing energy consumption and greenhouse gas emissions. Water conservation can lead to large savings in the energy used to transport, treat and distribute piped water.¹⁶⁵

C. What are the contributions of the practice/technology to development?

Increasing access to piped water at home leads to large gains in health and development. However, domestic water demand increases rapidly as households gain access to water intensive appliances and sanitary facilities.¹⁶⁶ As population expands and water resources are stressed, economic development can be hindered.¹⁶⁷ Implementing residential water efficiency measures can slow the onset of water stress and preserve water resources.

D. What are the knowledge/capacity building requirements?

A functioning infrastructure for standard-setting, testing and certification of water efficient products requires expertise across a range of areas. Professionals with experience from other sectors in standard-setting and certification may be able to transfer their knowledge to water efficiency. Alternatively, standards could be adopted in whole or part from a nearby country where the same products are generally available.

Regardless of the mechanism used to encourage water conservation, policy makers and residents must be educated. Initiatives to promote water conservation may be practical in schools, through media and by other means. Branding and marketing is necessary for any certification system so that residents know the label and associate it with quality and efficiency.

E. What are the institutional/organizational requirements?

Increasing the use of water efficient appliances is primarily an institutional challenge. Although some citizens may be motivated to save water by environmental concerns, economic or other incentives are likely to be necessary to either incentivize or mandate the installation, production and sale of such appliances.^{156, 168, 169} Transparent processes are necessary for standard-setting, testing and certification of individual products. Additionally, the use of tax incentives requires a tax structure that allows exemptions (e.g. from sales tax) or tax credits for certain purchases.

F. What are the costs and financial requirements?

Establishing a functioning certification process may be costly depending on existing capacity. However, the costs for individual households are generally small and may be fully recovered by water savings over the lifetime of the product.

G. What are the barriers to and opportunities for implementation?

Potential for misrepresentation or corruption in a certification and labelling process is a challenge. Even the US, with relatively well-functioning certification and legal systems, has struggled to ensure that Energy Star labels accurately reflect energy use.¹⁷⁰ Fixed (unmetered) water tariffs present a major barrier to implementation of residential water conservation programs as they remove any financial incentive to conserve.

Populations that perceive the importance of environmental and water resource conservation will generally be more open to changing behaviours around water. In areas where people feel tightly bonded to their communities, they are more willing to set aside self-interest to conserve a common resource.¹⁶⁹ Well-developed tax codes or the ability to exempt certain products from sales tax provide opportunities for additional incentives.

H. Examples and case studies from different regions

The most thorough overview of water efficiency standards worldwide is found in a 2009 European Union (EU) report.¹⁷¹ The EU does not currently have published mandatory efficiency standards for water using products, but is expected to have them soon through the Ecodesign Directive. The report provides an overview of voluntary and mandatory measures within the EU, in member states and around the world. It also provides detailed accounts of the impacts of existing policies, the anticipated efficiency gains if mandatory standards were implemented, product testing procedures, policy options, and other valuable content. The major findings of the report that may be useful to stakeholders from outside the EU include:

- In Europe, the devices that would yield the greatest water savings if they were replaced with more water efficient products include: dishwashers (55% less water), toilets (53%), and washing machines (32%). Replacing all standard residential devices with more efficient products would result in an overall decrease of 32% (over 40,000 liters per household).

- Mandatory water consumption standards for key water-using devices through the Eco-design Directive could lead to a 20% reduction in public water supply needs. Excluding fixtures that do not directly consume energy (e.g. showerheads and toilets) would reduce the effectiveness of such a program, decreasing public water supply savings from 20% to only 6%. By comparison to mandatory standards, voluntary labelling programs would generate much smaller benefits, leading to only a 0.7% reduction in public water supply needs.
- The indirect energy savings of water efficient fixtures (showerheads, taps and baths) are significant, reducing energy consumption for hot water heaters by 20%. This represents 0.5% of total EU primary energy supply.¹⁷¹

A report on water efficiency in the UK was developed by the British NGO Waterwise. It includes over 40 specific proposals for improving water efficiency, most of which are generally applicable and not specific to the UK.¹⁷²

Information on water-efficient appliances in Japan, the increasing usage rates, and references to Japanese-language descriptions of local initiatives are available.¹⁵⁵

US programs for water and energy conservation have an extensive online presence. Case studies of 17 communities in the US that implemented successful water conservation programs, many of which included programs to increase the use of water efficient fixtures and appliances, are available.¹⁵⁸ The US Geological Survey (USGS) maintains a detailed database of residential water use in the US. The database is updated every five years and many documents describing methods, data and are made available online.¹⁷³ Other online resources include a calculator for estimating the savings from use of WaterSense products¹⁷⁴ and clear descriptions of Energy Star standards for all categories of products.¹⁶⁰

Mandatory standards were found for Australia, New Zealand, Spain, Italy, UK, and Singapore. Voluntary standards were found for other Asian and European countries. No information on residential water efficiency standards was found for Latin America or Africa.

Leakage Management, Detection and Repair in Piped Systems

Topic areas: Water conservation

Terms for the Glossary: Non-revenue water (NRW); Unaccounted for water (UFW); Unauthorized consumption; Apparent losses; Real losses; Water audit; Leak management

A. What does the technology/practice consist of?

Non-revenue water is the difference between the volume input to a municipal distribution system (e.g. from a treatment plant) and the billed authorized consumption (e.g. water for which the utility receives payment). The term “non-revenue water” (NRW) has largely replaced “unaccounted for water” (UFW) among water professionals and is used here. NRW is commonly expressed as a percentage of the total water volume input into a system. NRW typically accounts for a large percentage of the water input. Surveys of Latin American and Indian cities found that 40% or more of their input water was lost as NRW.^{175, 176, 177}

NRW consists of three categories: unbilled authorized consumption; apparent losses; and real losses. Unbilled authorized consumption (e.g. water donated to a non-profit organization) usually makes up a small fraction. Apparent losses include unauthorized consumption (e.g. illegal connections) and meter inaccuracies; these often account for a considerable percentage of total NRW, especially in developing countries. Real losses consist of any water that is physically lost from the system before it reaches a consumer’s water meter. A small fraction of this may include overflow of storage tanks owned by the utility. However, the vast majority of real losses are due to leakage in distribution systems; this chapter focuses on detecting and addressing this leakage.

Leakage in distribution systems is a major problem for water utilities throughout the world, in both wealthy and developing countries. Water distribution pipes in many industrialized countries were installed decades ago and are approaching the end of their useful life. The US Environmental Protection Agency (USEPA) has declared that the replacement or rehabilitation of water distribution and transmission systems is one of the country’s biggest infrastructure needs. Leakage rates of 10-20% are considered normal and in some areas of the US, the aging infrastructure is losing up to 50% of water distributed.¹⁷⁸ In developing countries, common causes of leakage, in addition to aging pipes, include poor network design and construction, damage to exposed pipes, and leakage at poorly sealed connections.¹⁷⁷

Management, detection and repair of small leaks in a distribution system are critical functions of system operation and maintenance, yet they are often neglected. Large water main breaks can cause sensational damage and draw media attention, but those catastrophic failures only account for about 1% of water lost to leaks.¹⁷⁸ Some small leaks are noticeable at the ground surface and are easily identified, but many leaks continue below ground for months or years. A minor leak of four liters per minute would likely continue for years before it was noticed, resulting in the loss of over two million liters per year. Leak management methods can prevent or reduce leakage volume and leak detection technology can improve the ability of water utilities to respond quickly and repair leaks.^{178, 179}

Prior to implementing formal leak management, detection and repair programs, a water audit should be performed to quantify leakage and prioritize leak management activities. Water audits are typically conducted by monitoring water inputs, flow throughout the distribution system, and customer use during a low-flow period (at night); these are used to quantify losses and identify zones with high leakage. Further information and training materials for water audits can be found elsewhere.^{177, 180}

Leak management: In some countries, utilities address leaks reactively, responding to identified leaks and water audits. However, the UK has developed pro-active approaches to prioritizing leak detection and controlling system pressure. In summary, isolating small areas of metered homes yields total leakage for a local area and allows more intensive detection methods to be targeted to key zones. Pressure management, lowering system pressures during times of low demand, can lead to a decrease in the long-term volume lost to leakage and extend the life of pipes.¹⁷⁹ However, 24-hour continuous pressure

should be the first priority and pressure management should not be undertaken by utilities that struggle to maintain adequate 24-hr water pressure.¹⁸¹ Extensive guidance on leak management is available.¹⁸²

Leak detection: Many new technologies for leak detection have appeared in recent years. In the late-20th Century, the primary methods used for leak detection included acoustic, infrared thermography, chemical tracer, and mechanical methods. Among the acoustic methods were ground microphones, acoustic loggers on pipe fittings, and tethered in-line leak detectors. New and emerging technologies include ground penetrating radar (GPR), combined acoustic logger and leak noise correlators, digital correlators, and radio-frequency interferometers.¹⁸³ More advanced acoustic methods have also been developed recently, including un-tethered leak detection (e.g. the Sahara® and SmartBall® systems). Detailed discussion of some of these technologies can be found in the references.^{179, 184, 185}

Acoustic methods are able to recognize leaks based on the characteristic patterns of sound that leaks create; they have been and continue to be the most common leak detection methods. The choice of an appropriate leak detection technology must consider the pipe material and pipe diameter of a system. Acoustic methods have been used successfully for leak detection in metallic pipes for many years. However, their application in non-metallic piping is more challenging; the sounds created in plastic and concrete pipes tend to be lower-frequency and attenuate more quickly. Despite these challenges, recent technological innovations have enabled the successful application of acoustic methods to these types of piping.^{177, 178, 185, 186}

Leak repair: New technologies enable rapid and accurate detection of leaks, but investing in rapid detection is futile unless repairs can be performed quickly. Repairs to pipes with holes generally involve either covering the hole from outside the pipe or inserting a smaller pipe inside the one that is leaking. The complexity and time for repairs varies widely, from one employee tightening a loose nut to large crews and excavators spending days repairing a deeply buried main. Of course, an analysis of repair costs versus replacement costs should be conducted for older pipes.^{177, 192}

Water systems with intermittent supply cannot benefit from many of the methods for leak management and detection covered above. To compound this problem, leakage is even more serious in intermittent systems, where a residual chlorine concentration is not always maintained and infiltration is common.¹⁸⁵ High water pressure is required for leak detection equipment to be used effectively. Therefore, alternatives methods for leak detection in intermittent systems involve isolating a small zone of the network, closing the stop taps to customers, providing temporary water pressure to that zone, and then using conventional or modified leak detection methods. The basics of these methods can be found in the references.¹⁷⁷

Metered connections are essential for water conservation and they can also serve as a leak detection mechanism for pipe beyond customer meters. Customers will usually complain to the utility when they receive an unusually high water bill. Alternatively, an automated system to flag large increases in individual water bills or meter readings can alert utility personnel. A study conducted in the UK found that water consumption declined 10% following meter installation.¹⁷⁷

B. How does the technology/practice contribute to climate change adaptation?

A warmer climate is highly likely to result in more frequent drought.¹⁸⁸ Additionally, growing population will push many countries into water stress and water scarcity in the coming decades. Detection and repair of leaks in water systems is an important part of comprehensive strategies to reduce pressure on existing water resources.

Reducing water use in municipal systems also contributes to climate change mitigation by decreasing greenhouse gas emissions. Detecting and preventing leakage in piped water systems can lead to large savings in the energy used to transport, treat and distribute water.¹⁸⁹

C. What are the contributions of the practice/technology to development?

Increasing access to piped water at home leads to large gains in health and development. However, per capita demand for water increases rapidly during the development transition.¹⁹⁰ As population expands and water resources are stressed, economic development can be hindered.¹⁹¹ Leakage prevention can slow the onset of water stress and preserve limited water resources. Additionally, these programs often pay for themselves through water conservation, reduced costs for treatment and distribution, and reduced maintenance and pipe replacement costs (see Section F).

D. What are the knowledge/capacity building requirements?

The World Health Organization (WHO) training manual for leak management and detection is an excellent capacity building tool that can enable utilities to conduct their own high-level training at low cost.¹⁷⁷

Leak detection technology is developing rapidly. Large utilities should have internal expertise in the technologies best suited for monitoring their system and emerging technologies from which they may benefit.

E. What are the institutional/organizational requirements?

Institutional elements are largely governed by the perception of, and attitudes to, leakage and water waste within the water utility and political bodies.¹⁷⁷ Within water utilities, an organizational climate of water conservation and financial sustainability can motivate employees to help reduce leakage. If water conservation is seen as a priority by the population, particularly under water stress or during drought, politicians who are made aware of the potential water savings may be more receptive to funding leakage management and detection programs.

Leak detection and repair can be undertaken in any piped water system. However, the technologies utilized for leak detection must be appropriate to the resources of the system. For community-managed and rural systems with above-ground pipes, detection and repair of these should be prioritized. Most small utilities should generally contract leak detection to a firm with appropriate expertise.

F. What are the costs and financial requirements?

The costs of leak management, detection and repair include staff training, management, labor, and equipment. However, leak management, detection and repair programs generally pay for themselves by enabling early repair of leaks and reducing water waste.¹⁹² Leaks often damage pipes through erosion; therefore, additional benefits of early detection include reduced maintenance costs and lower probability of catastrophic failures. Monitoring systems remotely also enables confirmation that pipes are in good condition, preventing premature replacement.¹⁷⁹

An extensive treatment of the costs and benefits of leak management, detection and repair programs is included in the WHO training manual.¹⁷⁷

G. What are the barriers to and opportunities for implementation?

Opportunities for leakage management, detection and repair programs should abound when decision-makers are made aware that the economic benefits often outweigh the costs. The economic benefits of these programs are especially great when: (1) energy costs for transport, treatment and distribution are expensive; (2) infrastructure is aging and leakage is high; (3) high-profile water main breaks lead to media attention and political pressure; (4) under water stress or water scarcity conditions; and (5) water conservation is valued.

On the other hand, motivation to prevent leakage may be low when water is inexpensive and abundant, and when water utilities are short-staffed or under-funded.

H. Examples and case studies from different regions

The WHO published a thorough training manual on leakage management and control. The content is relevant for all water utility staff, from leak inspectors to senior managers. Annex 2 includes a workshop case study and additional case studies from the UK, Samoa and Cook Islands in Annex 3.¹⁷⁷

A report containing three case studies from Australia of leakage management through pressure control is available.¹⁹³ Another case study of leakage management, this one from South Korea, is available as a conference proceedings paper.¹⁹⁴

Many leakage detection case studies are published by corporations as a way of promoting their products. However, one conference proceedings paper of a case study comparing multiple methods for locating leaks in buried pipes is available.¹⁹⁵

Post-construction Support (PCS) for Community-managed Water Supplies

Topic areas: Diversification of water supply; Preparation for extreme weather events; Resilience to water quality degradation

Terms for the Glossary: Post-construction support (PCS); Cost recovery; Tariffs; Demand-driven, community-managed model

A. What does the technology/practice consist of?

There is a large and growing body of evidence demonstrating that post-construction support (PCS) increases the success and sustainability of community-managed water systems. This is even true for those systems that are implemented according to all the currently recognized the best practices of the “demand-driven, community-managed model.”^{197, 198, 199, 200, 201}

Rural water supply interventions have historically suffered from high rates of failure. By the 1990s a consensus developed that projects should: (1) be demand-driven; (2) be managed by a community water committee; (3) require partial recovery of capital costs; (4) require full recovery of operations and maintenance (O&M) costs; (5) ensure the availability of spare parts for purchase through local markets; and (6) include a larger role for women in decision-making. Applying this “demand-driven, community-managed” model to rural water projects has yielded substantial improvement in the success and sustainability of rural water supplies.^{196, 201, 202, 203} This success led many to the incorrect assumption that, if best practices were followed during implementation, PCS would be unnecessary.^{197, 198, 199, 200, 201}

PCS is typically carried out through government programs, municipalities, multilateral donors, and various NGOs. Types of PCS include, but are not limited to:

- Technical training for water system operators
- Technical and engineering support, including provision of technical manuals
- Financial and accounting assistance (e.g. setting tariffs)
- Help settling disputes (e.g. bill payment or water sources)
- Help with maintenance, repairs and finding spare parts
- Help finding external funding for O&M, expansion or repairs
- Help assessing the sufficiency of supply for expansion or in the case of drought
- Household visits to residents to discuss water system use, etc.¹⁹⁷

PCS can be broadly categorized as either demand-driven (solicited) or supply driven (non-solicited). Although data are limited and newly emerging, there is some evidence that the success of these programs may depend on whether the decision to pursue PCS is initiated by the community.¹⁹⁷

Preliminary findings indicate that large, non-solicited PCS or programs providing free repairs and free technical assistance do not lead to improved system sustainability or user-satisfaction.¹⁹⁷ This is consistent with the thinking behind the “demand-driven, community-managed” model, that requiring communities to take full responsibility for their systems will lead to improved performance. However, some non-solicited activities that help communities to renew or further develop their own capacities do show promise in improving system operation and user satisfaction. The activities that have shown greatest success in non-solicited settings include:

- non-technical financial and managerial training for committees or system operators and
- non-technical support visits to help water committees with administrative functions and resolution of disputes.¹⁹⁷

Water committees that received non-technical PCS were also reported to have more of a “small business” approach, prioritizing economic sustainability and collecting tariffs more frequently.²⁰² Reports on the efficacy of technical training programs for operators have reported success in some cases but not in

others.^{197, 198, 204, 205} Systematic study of solicited PCS programs has not been reported due to experimental difficulties, including self-selection bias.

Although systematic academic studies are few, extensive practical evidence indicates that PCS can improve system performance and sustainability. Case studies and lessons learned from PCS programs in many countries are referenced below.

B. How does the technology/practice contribute to climate change adaptation?

Piped water was the primary drinking water supply for fewer than 12% of rural residents in developing countries in 1990. By 2006, that percentage was over 21%, and it is projected to increase to greater than 28% by 2020.^{206, 207} Increasing the resilience of the growing number of rural, community-managed piped water supplies is one of the major challenges of climate change adaptation.

Community-managed water supplies are typically more vulnerable to extreme weather events and less able to assess water resource sustainability than utility-managed systems. PCS can empower community water committees and operators to access the financial, management and technical resources that enable utility-managed supplies to prepare for and adapt to adverse precipitation conditions.

C. What are the contributions of the practice/technology to development?

Access to safe and sustainable water supply, particularly water in the home, is crucial to development. However, community managed systems frequently struggle to achieve safe and sustained supply. PCS can contribute to improving performance and sustainability.

D. What are the knowledge/capacity building requirements?

It is important that PCS programme personnel have a broad and holistic understanding of the issues impacting the success and sustainability of rural water supplies. Historically, many practitioners have fixated on solutions within their specific area of expertise (e.g. engineers identified poor technology or construction, economists identified poor tariff structures, etc.) and were often blind to the actual problem.¹⁹⁷ The scope of capacity building will vary widely, but training programs, manuals and, possibly, certifications may be necessary if PCS is to be implemented on a large scale.

E. What are the institutional/organizational requirements?

Four basic PCS institutional models were identified during a multi-year USAID-funded study in Latin America. The definitions of all four are quoted directly from the source²⁰¹, which includes extensive discussion, case studies, and lessons learned from these models and hybrids combining aspects of more than one:

- Centralized Model: where support services are provided by a government agency or ministry operating from a centralized point, directly engaging with community management structures in rural areas
- Deconcentrated Model: under which support services are provided by a central government agency operating, with a degree of autonomy, through regional or departmental level offices
- Devolution Model: where the authority and responsibility for provision of support services is transferred from a central government agency to a decentralized tier of government, usually at the municipal level

- Delegated Model: where the responsibility for provision of support services is delegated from a central or local government agency to a third party, which could be an NGO, a private sector company or a relevant user association²⁰¹

Regardless of the model, it is important that the roles and responsibilities among PCS staff are defined. More crucially, perhaps, it is imperative that community water committees understand clearly which operation, maintenance and administration tasks are the responsibility of the community. The respective roles of all stakeholders should be recorded and disseminated.²⁰¹

F. What are the costs and financial requirements?

It is crucial that PCS programs have a reliable source of funding. These costs include salaries, office overhead, training costs, and a substantial transportation budget for field staff to travel to rural communities. Various financing models and case studies have been reported through a USAID-funded project.²⁰¹

G. What are the barriers to and opportunities for implementation?

The effectiveness of PCS is well-documented, but not all stakeholders are aware of its importance. Incorporation of PCS into the best practices of the rural water sector, as was accomplished with the demand-driven, community-managed model, requires education of key stakeholders.

PCS is sometimes viewed as a waste of resources by organizations (e.g. NGOs, donors) that prefer projects with clearer metrics of success (e.g. provided 3000 people with clean water) that are easily quantified and show rapid return on investment. Likewise, politicians prefer unveiling new projects with ribbon-cutting ceremonies. The benefits of PCS are primarily medium-term to long-term and are often difficult to quantify.

H. Examples and case studies from different regions

Thorough and insightful accounts of many PCS programs in Latin America were produced during a multi-year USAID-funded study. These are freely available online and touch on many facets of PCS, with particular emphasis on institutional aspects.²⁰¹ Extended case studies of a subset of these programs are also available.²⁰⁸

An example of these is the model used in Nicaragua since 1997 to provide backup support to community-managed rural water supplies. It adds to the existing structure of water committees that are supported by regional representatives of the national water and sanitation company (ENACAL) by adding an O&M promoter who works at a local level. The municipal promoter is an employee of the local government but works under the technical supervision of the regional ENACAL representative. The program was generally successful. After two years, 95% of the 300 systems were operating at acceptable or above-average levels.²⁰⁸

Case studies of WaterAid projects in four countries (Ethiopia, India, Ghana and Tanzania) include analysis of the impact of post-construction support.²⁰⁰

Lessons learned from study of PCS support to systems in Ghana, Peru and Bolivia are available as academic papers.^{197, 199} The findings of these same projects are also freely available online as presentation slides²⁰² and an extended account published by the World Bank.¹⁹⁸

A study of PCS training in rural Canadian First Nations communities is available as a book chapter.²⁰⁴

Rainwater Collection from Ground Surfaces—Small Reservoirs and Micro-catchments

Topic areas: Diversification of water supply; Groundwater recharge; Stormwater control and capture

Terms for the Glossary: Micro-catchment; Small reservoir; Runoff; Evapotranspiration; Transpiration; Bund; Tank/village tank; Watershed; Catchment area

A. What does the technology/practice consist of?

Most precipitation that falls on human settlements is lost to the atmosphere through evapotranspiration (evaporation plus transpiration of water taken up by plants), or runs into rivers away from settlements before it can be used. In some water-rich regions, particularly wealthy regions with centralized water infrastructure, these losses may not be a major concern. However, in many water-poor areas, small-scale collection infrastructure can contribute greatly to the volume of freshwater available for human use. This is especially true in arid and semi-arid regions, where the little rainfall received is usually very intense and often seasonal. Because of this, runoff and river flows can be abundant for brief periods and non-existent throughout the rest of the year.^{209, 210}

This chapter covers collection, storage and use of rainfall that lands on the ground. Direct collection from rooftops is covered in the chapter entitled Rainwater Harvesting from Rooftops. The two broad categories covered in this chapter are:

- Collecting rainfall from ground surfaces utilizing “micro-catchments” to divert or slow runoff so that it can be stored before it can evaporate or enter watercourses; and
- Collecting flows from a river, stream or other natural watercourse (sometimes called floodwater harvesting). This technique often includes an earthen or other structure to dam the watercourse and form “small reservoirs.”

Micro-catchments are often used to “store” water as soil moisture for agriculture. Small reservoirs are typically used in areas with seasonal rainfall to ensure that adequate water is available during the dry season.

This broad categorization can provide a basic framework for defining which strategies may be appropriate in a given setting. Detailed discussion of the technical definitions of these two categories can be found elsewhere;^{209, 211} the technical distinctions are not essential to understanding and are beyond the scope of this handbook.

Collection and storage infrastructure can be natural or constructed and can take many forms. These include:

- Below ground tanks (i.e. cisterns) and excavations (either lined for waterproofing or unlined) into which rainwater is directed from the ground surface. Volumes of these are typically small (a few m³ or less) and they are usually used by one household or institution (e.g. a school or health clinic).
- Small reservoirs with earthen bunds or embankments to contain runoff or river flow (“dugouts” in northern Ghana, “village tanks” in South Asia). The earthen bunds or embankments are typically built from soil excavated from within the reservoir to increase storage capacity. A spillway or weir allows controlled overflow when storage capacity is exceeded. Surveys of small reservoirs in Ghana and Sri Lanka revealed a wide range of surface areas and volumes; median surface areas for Ghana and Sri Lanka were 5 ha and 12 ha, respectively. The mean storage volume in Ghana was roughly 50,000 m³.^{210, 211}
- Groundwater aquifers can be recharged by directing water down an unlined well. Groundwater recharge is also an added benefit of unlined reservoirs; stored water will infiltrate permeable soils during storage and eventually reach the groundwater table. Successful examples of groundwater recharge through rainwater collection are included in the references.^{214, 215}
- As soil moisture for agriculture. Many runoff control methods for irrigation incorporate inundation or extended contact time with soils to increase topsoil moisture. Traditional methods were often

developed in response to local conditions and have been practiced for centuries. Examples of these practices include variations of contour farming, which is broadly defined as ploughing or digging trenches perpendicular to the direction of runoff flow; this slows rainfall, decreasing erosion and increasing infiltration. Numerous other examples are described in detail in the references.^{209, 211}

Subsurface dams are another form of collection/storage infrastructure that can be used to address these same problems. However, they do not fit strictly within the scope of this chapter, and are included only for comparison and to make the reader aware of another technical option. These dams do not technically collect rain from the ground, but they serve the same purpose as the above technologies and are discussed briefly here. Subsurface dams are typically used in arid and semi-arid areas where riverbeds are often dry for a portion of the year; they consist of a low-permeability barrier (e.g. concrete) inserted into the ground across a riverbed, blocking the direction of flow. Though a seasonal riverbed may be dry at the surface, subsurface flow often continues throughout the year. Drilling a well on the upstream side of the subsurface dam enables access to water year-round. Subsurface dams cannot be applied everywhere and will only work when the stream is underlain by a shallow impermeable layer such as bedrock or clay. However, they have the following advantages over conventional dams: less evaporative loss, superior water quality, and less vector/parasite breeding.^{216, 217}

Groundwater is generally of superior microbial and aesthetic quality when compared to surface water. Therefore, groundwater recharge is often used to replenish aquifers that provide high quality drinking water. Rainwater collected from the ground surface is typically used for non-potable purposes, including irrigation, general domestic use, and livestock. However, in some regions with seasonal rainfall small reservoirs are commonly used for drinking water supply during the dry season, despite the high turbidity and poor bacteriological quality of the water.²¹⁸

B. How does the technology/practice contribute to climate change adaptation?

Climate change is projected to increase the variability and intensity of rainfall. Variability is of particular concern close to the equator, where most developing countries are located.^{219, 220} Groundwater depletion due to excessive abstraction, land use change and population growth is likely to be exacerbated by these changing precipitation patterns.

Collection and storage of rainwater can provide a convenient and reliable water supply during seasonal dry periods and droughts. Additionally, widespread rainwater storage capacity can greatly reduce land erosion and flood inflow to major rivers.^{212, 213} Rainwater collection can also contribute greatly to the stabilization of declining groundwater tables.^{214, 215}

C. What are the contributions of the practice/technology to development?

Lack of adequate water supply during drought and seasonal dry periods can halt economic development and hinder human health and well-being.²²¹ Access to a convenient supply of stored rainwater can decrease travel time to remote water sources, increase agricultural productivity and reduce depletion of groundwater resources. Increasing the availability of irrigation water during the dry season and even during short dry spells has been shown to yield large increases in agricultural production.^{217, 222, 223}

D. What are the knowledge/capacity building requirements?

Rainwater collection projects can have adverse hydrological impacts on communities downstream if too much water is stored or diverted. Local governments must have the technical ability to assess

these impacts if they are to prevent major externalities and resolve conflicts. Knowledge of geographic information systems (GIS) and remote sensing/satellite imagery software and other tools are necessary to determine small reservoir storage capacity.²²⁴ See Section E for discussion of the institutional requirements associated with conflict resolution and externalities.

E. What are the institutional/organizational requirements?

Policies, legislation and institutional capacity are needed to address conflicts and externalities that can result from rainwater collection. Conflicts between small-scale farmers competing for limited runoff have been reported in Kenya. Additionally, as storage infrastructure grows larger it has the potential to reduce flows and negatively impact communities downstream. One state government irrigation department in India destroyed a communal reservoir for fear of negative hydrological consequences for communities downstream.²²³

Small reservoir projects are likely to fail if communities do not identify the need for rainwater storage and have a choice in the technology.^{223, 225, 226} Management strategies of communally owned storage and irrigation infrastructure are likely to be subject to the same determinants that govern the success of small drinking water systems. The “demand-driven, community-managed” model that has worked for small drinking water supplies is likely to work for these systems as well.²²⁷

F. What are the costs and financial requirements?

Implementation of large-scale rainwater collection programs should include a survey of current reservoir capacity and location. Satellite-based methods for tracking surface water, including radar and other methods that are not hindered by cloud cover, can reduce the costs of the survey.^{212, 228, 229}

It is difficult to find specific data on the construction and implementation costs of rainwater collection projects. Many factors, including the scale of the project, location, etc. will strongly affect costs. The program costs of foreign-funded rehabilitation and development of small reservoirs (locally known as “village tanks”) in Tamil Nadu, India have been reported. The village tanks in that program were relatively large (40 ha or greater) and the average cost for each project was about \$50,000.²²⁶

G. What are the barriers to and opportunities for implementation?

Increased agricultural productivity, the potential for year-round water supply, and decreased time spent collecting water provide strong incentives to landowners or communities considering rainwater collection. Increased opportunities for ground-level rainwater collection should arise when rainfall is highly variable or seasonal, agricultural productivity is clearly hindered by dry periods, and alternative water supplies are distant.

Barriers include the potential for adverse hydrological impacts downstream and the need for adequate capacity to assess these impacts (see Section D). However, the environmental and hydrological impacts of small reservoirs have been reported to be minor.²³⁰ Opportunities for small reservoir capacity development may arise where water availability is inadequate but environmental, social or legal concerns preclude the development of large reservoirs.

Additionally, surface storage can lead to parasite/vector breeding, algal blooms and poor water quality, particularly in small reservoirs fed by agricultural runoff. Despite the poor aesthetic and microbial quality of such waters, they are often used for drinking when other water points are distant or expensive.²¹⁸

Implementation of household water treatment technologies may be able to address this problem (see the chapter entitled “Household Drinking Water Treatment and Safe Storage” in this handbook).

H. Examples and case studies from different regions

The Small Reservoirs Project website (<http://smallreservoirs.org/>) has many resources on surface storage of rainwater in rural, semi-arid areas (particularly in Brazil, Zimbabwe and West Africa). The “Publications” page includes links to dozens of articles, reports, theses, presentations and posters, most of which are freely available online.

Extensive guidance on rainwater and floodwater harvesting schemes for agriculture has been published by the UN Food and Agriculture Organization (FAO). Also included in this publication is an annotated bibliography of key resources published prior to 1990.²¹¹

Groundwater recharge using collected rainwater has recently become more widely practiced in India and elsewhere. Case studies from India are available in the references.^{214, 215}

Case studies of subsurface dams in Kenya and Brazil have been published by the World Bank. These cover diverse aspects of construction, costs, problems encountered and economic benefits.²¹⁷

Rainwater Harvesting from Rooftops

Topic areas: Diversification of water supply; Groundwater recharge; Resilience to water quality degradation; Stormwater control and capture

Terms for the Glossary: Potable; Non-potable; Catchment; Conveyance; First flush; Dual systems

A. What does the technology/practice consist of?

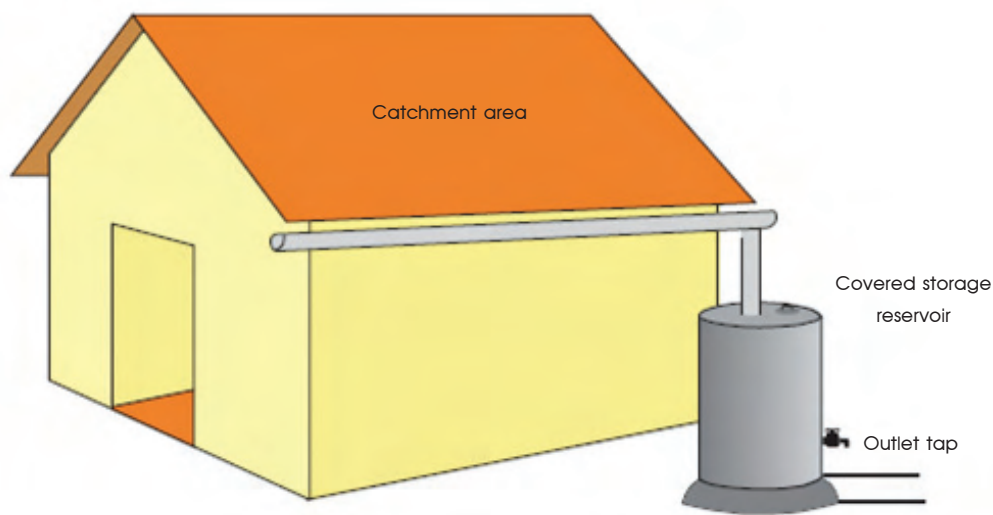
Collection of rainwater from rooftop catchments, although practiced since antiquity, is an increasingly promoted technical option for supplementing household and institutional water supply.²³² The increased proportion of hard (e.g. metal or tile) roofs and the availability of metal and plastic for conveyance have decreased the cost of implementing household rainwater harvesting (RWH).

In most developing country settings, RWH is used to collect water for potable and other household uses. In wealthier regions with safe and reliable piped supply, it is typically collected for non-potable uses, including irrigation of landscapes (lawns and gardens), toilet flushing, and washing clothes. The range of RWH options that are relevant in a given setting depends on the quality, cost, and sustainability of other residential water supplies, precipitation patterns, household income, and other factors.

This section of the handbook focuses primarily on RWH from residential rooftops for potable and other household uses. RWH for schools and other institutions follows the same general principles and generally benefits from economies of scale when serving large populations. Excess institutional roofwater can also be used to meet residential supply in some settings.²³³ RWH for solely non-potable use is also covered briefly. This includes a brief introduction to household dual piped systems that utilize harvested rainwater.

A basic household RWH system is illustrated in Figure 10. The salient features of rooftop RWH systems include: (1) a catchment surface where precipitation lands; (2) a conveyance system of gutters and pipes to transport and direct the water; and (3) containers to store the water for later use. Incorporating water quality protection adds one or more additional elements to system. Water quality can be protected by adding one or more of the following: filtration/screening, chemical disinfection, or a “first flush” system. First flush systems discard the initial volume of a precipitation event in order to protect water quality. It has been suggested that, as a rule of thumb, contamination is halved for each mm of rainfall discarded.²³⁴ Incorporating collected rainwater into the piped system of a residence or other building greatly increases both the expense and the expertise required.

Figure 10: Basic features of a household RWH system.



Source: Modified from UN-HABITAT

Before implementing a basic household RWH program for potable use, three questions must be answered in the affirmative. These have been modified slightly from Thomas and Martinson (2007).²³⁵

- Is current water provision thought by some householders to be seriously inadequate in quantity, cleanliness, reliability or convenience?
- Is there an existing capacity to specify and install RWH systems in the area, or could one be created in a suitable time?
- Is there adequate hard roofing area per inhabitant? This decision should be based on the planned use of rainwater (e.g. sole source of water all year, potable water only during the wet season), tank size, and average precipitation. Specific parameters are available from Thomas and Martinson (2007).²³⁵

If these three questions cannot be answered “Yes,” RWH may not be suitable.

B. How does the technology/practice contribute to climate change adaptation?

RWH contributes to climate change adaptation at the household level primarily through two mechanisms: (1) diversification of household water supply; and (2) increased resilience to water quality degradation. It can also reduce the pressure on surface and groundwater resources (e.g. the reservoir or aquifer used for piped water supply) by decreasing household demand and has been used as a means to recharge groundwater aquifers.²³⁶ Another possible benefit of rooftop RWH is mitigation of flooding by capturing rooftop runoff during rainstorms.

Climate change is projected to increase intensity and variability in precipitation. These are of particular concern close to the equator, where developing countries are concentrated. Storage of rainwater can provide short-term security against periods of low rainfall and the failure or degradation of other water supplies.^v

RWH is widely practiced in many countries worldwide. Over 60 million people were using RWH as their main source of drinking water in 2006 and that number is projected to increase to more than 75 million by 2020.²³⁷ It is likely that hundreds of millions more collect rainwater as a supplementary source of water for potable and non-potable uses. RWH can aid climate change adaptation even in the most developed countries. Economic growth in low-income countries leads to increases in piped water coverage and per capita water use.²³⁸ If safe, reliable piped supplies are available, RWH for non-potable uses can partially offset the increase in household use. In some parts of the United States, half of all residential and institutional water use goes to landscape irrigation²³⁹; simple rain barrels are commonly used to water landscapes without taxing the piped water supply. One-third of residential water in Europe is used for toilet flushing and 15% in washing machines and dishwashers.²⁴⁰ In Germany and elsewhere, the use of rainwater for these non-potable uses is becoming increasingly common.

C. What are the contributions of the practice/technology to development?

Incorporation of RWH into household water practices in developing countries can contribute significantly to development by saving money and time. Stored rainwater is a convenient, inexpensive water supply close to the home. This can greatly decrease the time spent fetching water or queuing at water points.²³⁵ It can also provide significant savings for households that are sometimes forced to purchase vended or bottled water. In many settings, RWH can reduce exposure to waterborne pathogens by providing improved potable water quality and high quality water for other household purposes including hygiene, bathing and washing.

Water scarcity can hinder economic development, human health and well-being.²⁴¹ Therefore, in arid and semi-arid countries, even in places with a safe and reliable piped drinking water supply, RWH can contribute to development. By reducing demand for high quality water supplies and capturing water that would otherwise evaporate, RWH effectively increases per capita water availability. This can increase the sustainability of water resources and reduce public and private expenditures associated with water infrastructure.

D. What are the knowledge/capacity building requirements?

RWH from rooftops into storage containers has been continuously practiced in parts of Africa and Asia for thousands of years.²⁴² In societies where RWH is a common part of water practices, simple household RWH can be practiced effectively with little training or capacity building; local supply chains for storage containers and other system components should be in place. Operation and maintenance consists primarily of simple cleaning and basic repairs. However, some training for households, especially related to protecting water quality (e.g. first flush methods, filtration) and budgeting rainwater are likely to lead to improved outcomes.

When establishing RWH in an area where it is not commonly practiced, significant capacity building is likely to be necessary. The most challenging aspects are likely to be generating sufficient demand for a self-sustaining industry and establishing supply-chains. However, most RWH hardware is not very specialized. Acceptable materials for storage and conveyance systems can be found in practically any city worldwide. Some guidance on implementing new RWH programs is available in the references.²³⁵

In contrast to simple systems, RWH for household dual piped systems requires professional plumbers who are trained to install such systems. Capacity building to establish regulatory frameworks for dual systems is addressed in Section E.

E. What are the institutional/organizational requirements?

Basic RWH involves collection, management and use by individual households and there are few if any institutional requirements. However, storage containers usually show strong economies of scale.²³⁵ Therefore, groups of households can often benefit by directing rainfall to one or more large, shared storage containers.

In developed regions, RWH for landscape irrigation is likewise driven by individual households. Guidance for establishing and designing these systems is available online.²⁴³

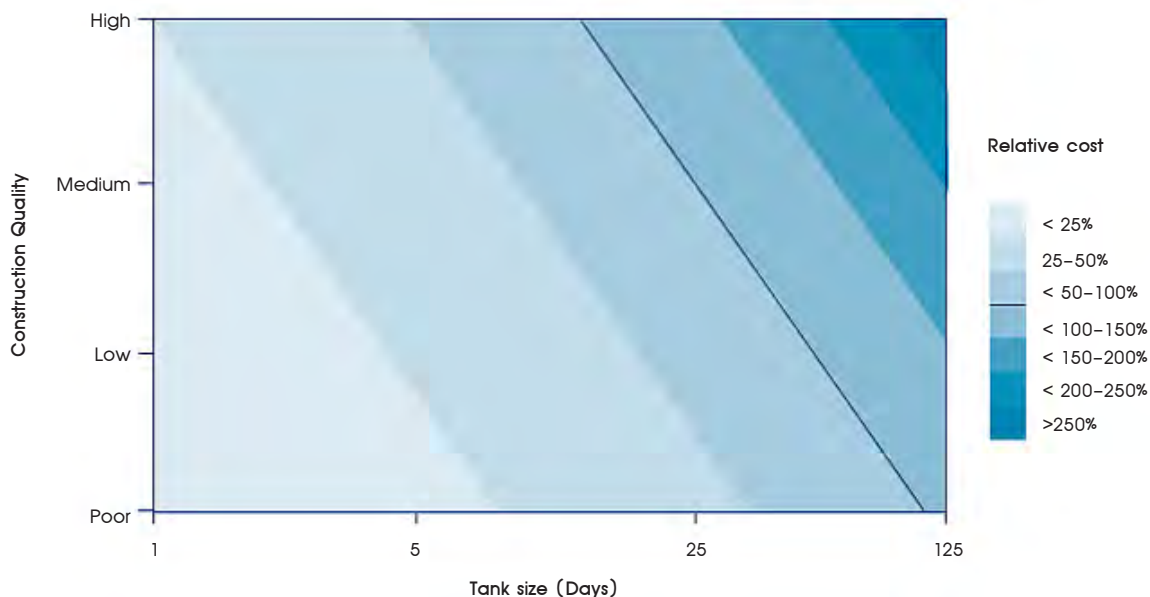
If RWH for piped dual systems is to be promoted, plumbing standards and building codes must often be modified. Many national and provincial governments have established codes and standards. Some of these are publically available.^{244, 245}

F. What are the costs and financial requirements?

In low-density rural areas, RWH can often provide household water at lower expense than other available options. If a household already has a suitable hard roof for use as a catchment surface, storage containers are the major expense. The cost of storage containers typically depends on construction quality, tank size, and other factors. A large, high quality storage container can be a major investment for poor households. In the context of climate change, increased precipitation extremes could necessitate greater storage volume, thus enabling the capture of maximum volume during intense periods and providing for household water needs during extended dry periods.

The relationship between cost, construction quality, and tank storage capacity is illustrated in Figure 11. Extensive discussion of tank design, construction, and cost can be found in Thomas and Martinson (2007).²³⁵

Figure 11: Schematic graph of relative storage container cost versus size (in days of storage) and construction quality.



Source: Thomas and Martinson (2007).^v

In developed countries, RWH for landscape irrigation is generally a minor investment. In contrast, dual piped systems incorporating rainwater can add significantly to the expense of a new home and retro-fitting an old home can be even more expensive.

G. What are the barriers to and opportunities for implementation?

Opportunities for investment in RWH are greatest when it can lead to time and cost savings, in addition to improved water quality and health gains. Conditions are most favorable for household RWH when other water sources are: far from the home, of degraded quality, unreliable, or expensive. When “hard” (e.g. metal or tile, in contrast to vegetative) roofing is already in use, capital costs are lower, and efficiency and water quality are superior. Barriers to implementation include inadequate or unsuitable (e.g. vegetative) roofing, lack of space for appropriate storage containers, and extreme air pollution.²³⁵

In developed countries, social awareness of water conservation is probably the most important factor creating opportunities for RWH. Cost savings and local ordinances against landscape irrigation with piped water can also increase rainwater collection. On the other hand, subsidization of piped water supply removes some of the economic incentives for RWH.

H. Examples and case studies from different regions

The University of Warwick (UK) Development Technology Unit has an extensive online RWH resource featuring technical releases, papers, and case studies from projects worldwide.²⁴⁶

Among these documents is a 150-page handbook that provides detailed guidance for practitioners of RWH. v It is freely available online and should be considered the primary resource for those attempting to implement household RWH in developing countries.

Seventeen case studies can be accessed from the University of Warwick RWH case study portal.²⁴⁷ They give detailed accounts of the design, manufacture, and construction of diverse RWH systems in Asia and Africa. Additionally, a broader case study of RWH implementation in the barrios of Tegucigalpa, Honduras is included (case study 9).

A UN-HABITAT report that is freely available online includes 23 pages of case studies on RWH projects worldwide.ⁱ

A case study of RWH in urban Bangalore, India is available, although it encompasses ground-level in addition to rooftop catchments.²⁴⁸

Water Reclamation and Reuse

Topic areas: Diversification of water supply; Groundwater recharge; Resilience to water quality degradation

Terms for the Glossary: Integrated water resource management (IWRM); Environmentally sound technology; Water reclamation; Water reuse; Recycled water; Augmentation; Unintentional reuse; Direct potable reuse; Indirect potable reuse; Nonpotable reuse

A. What does the technology/practice consist of?

In many communities around the world, the growth of populations and economies are causing demand for freshwater to increase at an alarming rate. Without a sound and sustainable strategy for integrated water resource management (IWRM), demand in these areas can quickly expand to exceed available supply. One integrated approach that is gaining acceptance is to consider municipal wastewater as a vital resource for appropriate applications, including agricultural and other irrigation, industrial and domestic uses. This practice is called *water reclamation* and *reuse* and is an example of an Environmentally Sound Technology because it protects the environment, results in less pollution, utilizes resources in a more sustainable manner, allows its waste and products to be recycled, and handles residual wastes in a more acceptable manner than the technologies for which it substitutes.²⁵⁰

The terms reclamation and reuse are often used in various contexts to mean different things. This chapter will adopt conceptual definitions from the textbook *Water Reuse: Issues, Technologies, and Applications*. Water reclamation is the treatment or processing of wastewater to make it reusable with definable treatment reliability and meeting appropriate water quality criteria; water reuse is the use of treated wastewater (or reclaimed water) for a beneficial purpose. It is also important to mention that, in common parlance, the term *reclaimed water* is used interchangeably with the often more culturally-acceptable term recycled water.²⁵¹

Though this chapter will focus on applications of water reuse that directly affect drinking water supplies, it is important to note that agricultural use accounts for the majority of freshwater consumption worldwide. Therefore, augmentation of agricultural irrigation with reclaimed water could potentially yield the greatest benefits to global water resources. In fact, reclaimed water is used to supplement agricultural irrigation in almost all arid areas of the world.²⁵² The WHO published an updated set of guidelines in 2006²⁵³ that were intended to serve as a framework for the development of national and international standards and regulations for managing the health risks associated with the use of reclaimed water in agriculture. These guidelines should be consulted when developing approaches for agricultural reuse.

A number of sustainable and safe approaches to meeting increasing water demand with municipal wastewater have been identified.²⁵¹ These general approaches include:

- Substituting reclaimed water for applications that do not require potable water
- Augmenting existing water sources and providing an additional source of water supply to assist in meeting both present and future water needs
- Protecting aquatic ecosystems by decreasing the diversion of freshwater, as well as reducing the quantity of nutrients and other toxic contaminants entering waterways
- Postponing and reducing the need for water control structures
- Complying with environmental regulations by better managing water consumption and wastewater discharges

Typical wastewater treatment schemes incorporate multiple levels of physical, biological, and chemical treatment in order to ensure that water discharged to the environment does not pose a significant risk of adverse environmental or health impacts. Treated wastewater is usually discharged to surface water and that surface water is often used by a water source for a water utility downstream. Thus, many water systems reuse wastewater inadvertently. Though such unintentional reuse (also called “unplanned”, “incidental” or “natural” reuse) occurs often, it is rarely acknowledged.²⁵² Drawing attention to unintentional reuse could possibly reduce public resistance to wastewater reuse (see section G).

Water reclamation and reuse approaches utilize the same treatment technologies as conventional wastewater treatment, including secondary clarifiers, filtration basins of various designs, membranes, and disinfection basins. Further reading regarding the applicability of such technologies to water reclamation and reuse is available.²⁵¹ Though it is likely that each and every water reclamation treatment scheme will require some degree of customization, a great deal of work has been done to define appropriate applications for water that has been treated by primary (such as sedimentation), secondary (such as biological oxidation and disinfection), and tertiary (such as chemical coagulation, filtration and disinfection) conventional wastewater treatment processes. The most comprehensive set of guidelines that recommend treatment processes for specific uses, reclaimed water quality limits, monitoring frequencies, and other controls for various water reuse applications have been developed by the United States Environmental Protection Agency (US EPA).²⁵² These guidelines are a valuable resource for water resource managers who are planning water reclamation and reuse programs. In general, uses that correspond to increasing levels of human exposure require water that has received higher levels of treatment. Though not comprehensive, Table 4 depicts a number of such uses that have been suggested by the US EPA. The UNEP report on water and wastewater reuse²⁵⁰ and the *Water Reuse: Issues, Technologies, and Applications* textbook²⁵¹ also contain a great deal of information regarding treatment considerations for appropriate uses of reclaimed water.

Direct potable reuse is very rarely recommended, regardless of the level of treatment reclaimed water has received. There are two technical reasons for this: (1) even when it is technically feasible to remove all known contaminants from wastewater, unknown contaminants may be present; and (2) in the case of an undetected failure in the treatment process, major risks to health are likely. These two issues still pose enough of a potential threat to health to render direct potable reuse impractical in most contexts. However, in most settings the main reason for not pursuing direct reuse is public opposition (see section G). In fact, the Windhoek plant in Namibia is the only case where drinking water supplies have been directly augmented by reclaimed water on a long-term basis.²⁵¹

Traditionally, it has even been uncommon for drinking water reservoirs to be augmented with reclaimed water. However this practice, known as indirect potable reuse, has increased in popularity over the last decade and has been successfully implemented in a number of cases around the world. For potable reuse, treatment requirements generally go beyond conventional tertiary treatment steps listed in Table 1. For example, the direct potable reuse plant in Namibia and the indirect potable reuse plants in Singapore (NEWater) and in Orange County, California (Water Factory 21) all incorporate advanced drinking water treatment technologies into water reclamation schemes, such as dissolved air flotation, membrane filtration, reverse osmosis, and UV irradiation.²⁵¹ It is still generally believed that nonpotable reuse can conserve water resources to the same extent as potable reuse while avoiding most of the public health risks.²⁵⁵

Since most urban wastewater treatment schemes and piped sewerage networks around the world are centralized, integration of reclamation and reuse approaches will likely require retrofitting of existing and construction of new infrastructure. This aspect of water reclamation and reuse is discussed in greater detail in section G) of this chapter.

A vast amount of information on water reclamation and reuse is available in peer-reviewed literature. A number of notable textbooks^{251, 254}, guideline documents^{250, 252}, and comprehensive reviews^{255, 256} have been developed in an attempt to gather and analyze this information. Water resource managers should consult these resources for guidance on water reuse regulations and guidelines, public health risks, appropriate water reuse technologies and treatment systems, applications for reclaimed water, and appropriate steps for planning and implementing water reuse approaches.

Table 4: Suggested Water Reclamation Treatment and Uses.

Level of Municipal Wastewater Treatment ^a			
	Primary (Sedimentation)	Secondary (Biological Oxidation, Disinfection)	Teritary (Advanced) (Chemical Coagulation, Filtration, Disinfection)
Suggested Uses ^b	No uses recommended at this level	Surface irrigation of orchards and vineyards	Landscape and golf course irrigation
		Non-food crop irrigation	Toilet flushing
		Restricted landscape impoundments	Vehicle washing
		Groundwater recharge of nonpotable aquifer ^c	Food crop irrigation
		Wetlands, wildlife habitat, stream augmentation ^c	Unrestricted recreational impoundment
		Industrial cooling processes ^c	Indirect potable reuse ^{c,d}

^a Level of human exposure increases with increasig level of treatment.

^b Suggested uses are based on US EPA's Guidelines for Water Reuse.

^c Recommended level of treatment is site-specific.

^d Indirect potable reuse includes groundwater recharge of potable aquifers and surface water reservoir augmentation.

Source: Adapted from US EPA Water Reuse Guidelines²⁵²

B. How does the technology/practice contribute to climate change adaptation?

Among a number of other predictions made by the Intergovernmental Panel on Climate Change, it is anticipated that climate change will lead to increased periods of drought, reduced freshwater stores, and sea level rise.²⁵⁷ Such changes can have drastic impacts on both the quantity and quality of the world's water resources. However, water reclamation and reuse approaches can and have been shown to be effective for adapting water resource management in the face of such stressors. Most importantly, water reclamation and reuse contributes to climate change adaptation by allowing water resources to be diversified and conserved. Using reclaimed water for applications that do not require potable water can result in greatly decreased depletion of protected water sources and prolong their useful lifespan. In addition, reclaimed water can be applied to permeable land surfaces or directly injected into the ground for the purpose of recharging groundwater aquifers and preventing saline intrusion in coastal areas. A successful example of this is the Montebello Forebay Ground Water Recharge Project, where for over 40 years recycled water has been applied to the Rio Hondo spreading grounds to recharge a potable ground water aquifer in south-central Los Angeles County in California.²⁵⁸

C. What are the contributions of the practice/technology to development?

The water and nutrients that can be recovered from wastewater are simply too valuable to waste in areas where resources are limited. For this reason, it is very common for farmers in developing countries to supplement their crop irrigation supplies with wastewater. In fact, except for a handful of cases where applications such as natural filtration systems for water reclamation²⁵⁹, sewage reclamation for industrial uses²⁶⁰, or direct potable reuseⁱ have been implemented, almost all water reclamation and reuse in developing countries is dedicated to agricultural irrigation. Not only does this practice increase the volume of water available for crops and utilize the nutrients in wastewater in a beneficial way, it also contributes to greater quality of human life by increasing household water availability.

It is important to mention that most of the wastewater used in developing countries for agricultural irrigation is done so without adequate treatment.²⁵¹ This often results in high burdens of enteric disease when these crops are consumed raw or undercooked. Such diseases diminish economic productivity and confine people to poverty. However, when implemented appropriately, water reclamation and reuse can contribute to social and economic development by reducing environmental pollution and enteric disease burden and increasing household water availability and crop production. The WHO *Guidelines for the Safe Use of Wastewater, Excreta and Grey Water, Volume 2: Wastewater Use in Agriculture* were developed in order to provide guidance on the safe use of reclaimed water. According to these guidelines, treatment options that can enable safe use of wastewater in resource-poor settings without modern centralized wastewater treatment include: waste stabilization ponds, wastewater storage reservoirs, and constructed wetlands. WHO provides basic guidance on design factors, retention time and climatic conditions to achieve adequate pathogen reduction.²⁵²

D. What are the knowledge/capacity building requirements?

A number of key capacity building elements that are required to ensure the quality of decision-making and managerial performance in the planning and implementation of water reclamation and reuse programs have been previously identified by UNEP.²⁶¹ Mentioned briefly here, these requirements are described in detail along with examples in the UNEP Water and Wastewater Reuse report.²⁵⁰

- Human resources: Implementation of water reclamation and reuse approaches requires the strengthening of local water and wastewater personnel's technical and managerial ability to evaluate limitations of current practice, potential benefits and requirements of wastewater reuse as well as the fostering of their capability to implement new programs.
- Policy and regulatory framework: It will be necessary for policies and legal frameworks that facilitate safe and appropriate reclamation and reuse programs to either be created or aligned in order to ensure the protection of human health and the environment.
- Institutions: National, regional, and local institutions will likely need to be supported in their efforts to identify ways in which they can improve effectiveness in regulating and managing water reclamation and reuse programs.
- Financing: Financing opportunities and services for water reclamation and reuse initiatives will need to be expanded in order to facilitate such initiatives. It is also likely that the capability of utilities and potential users to understand and access these services will need to be improved.
- Participation: Since public perception often determines the success or failure of water reclamation and reuse initiatives,²⁶² civil society will need to be educated about the benefits of water reclamation and reuse as well as encouraged to participate in the decision-making process and implementation of such programs.

E. What are the institutional/organizational requirements?

The institutions that are most likely to be involved in water reclamation and reuse projects are those responsible for water supply, wastewater management, water resources management, environmental protection, public health and agriculture.²⁵² Because of the complexity inherent in an initiative that attempts to coordinate so many institutions at the local, regional and national levels, it may be necessary to reorganize administrative duties into a general group that coordinates reclamation and reuse projects. In addition, it would be a clear conflict of interest for either the water supplier or the wastewater manager to function as a regulatory agency that has oversight and enforcement responsibility over all the partners involved in water

reuse. Therefore, it may also be necessary to task an independent agency, such as the entity charged with protection of public health or the environment, with such a role. A number of developing countries such as Tunisia, Morocco, and Egypt have successfully made such institutional changes in order to facilitate water reclamation and reuse programs.²⁵²

F. What are the costs and financial requirements?

In general, the most economically viable applications for water reuse are those that replace potable water with reclaimed water for use in irrigation, environmental restoration, cleaning, toilet flushing, and industrial uses.²⁵² These applications of reclaimed water contribute directly to conservation of water resources and pollution reduction.

The financial requirements for implementing water reclamation and reuse programs will vary significantly based on the type of application that is planned for the reclaimed water. Therefore, water resource managers must fully understand the costs associated with developing and managing the particular water supply, wastewater management system, and proposed water reuse system in order to compare the costs and benefits of implementing water reclamation and reuse programs with that of maintaining traditional water and wastewater management approaches. An economic analysis should be conducted in order to weigh the cost of maintaining traditional approaches and of possibly needing to develop additional water sources versus the cost of retrofitting existing and constructing new infrastructure for reuse applications. Such analyses should also consider the number of financial benefits associated with water reclamation and reuse approaches, such as reduced treatment costs and the recovery of valuable nutrients from wastewater.^{iv}

A particular type of economic analysis known as life cycle cost (LCC) analysis has been used to evaluate conditions under which water reclamation and reuse programs would be cost effective.²⁵⁰ This approach, which has been described extensively in a report by UNEP's Division of Technology, Industry and Economics, considers the cost of the reclamation and reuse program over its entire lifespan, including design, production, installation, operations, maintenance, repair, and disposal.²⁶³ An example of a case when the LCC approach has been used for such an application is in Tokyo, Japan, where options for wastewater reuse were compared with a conventional freshwater and sewage treatment option in a number of office buildings.²⁶⁴ The analysis found that if the reclaimed water volume was more than 100 m³ per day, the wastewater reuse option was more cost effective when compared to the conventional freshwater and sewage treatment option. Such analyses can be very helpful in determining the economic feasibility of water reclamation and reuse programs.

G. What are the barriers to and opportunities for implementation?

There are a number of socio-political barriers that often limit successful implementation of water reclamation and reuse programs. In many cases, public opposition to the use of reclaimed water for any application to which humans might be exposed (especially for potable reuse) can hinder progress. The NWater initiative in Singapore provides a strong example of how expansive public education campaigns and appropriate marketing can be used to positively influence public opinion towards water reclamation and reuse.²⁶⁵ Lack of communication and collaboration between stakeholders is also another significant socio-political barrier to water reclamation and reuse programs. The first step in the design and implementation of water reclamation and reuse initiatives should be to identify these institutional gaps and to forge the necessary links among agencies.²⁵²

Technical barriers can hinder successful implementation of water reclamation and reuse programs as well. Physical issues with transporting reclaimed water in distribution systems, such as corrosion of pipes, blockage of pipes and strainers, and biofilm formation in reservoir tanks due to reduction of residual chlorine in reclaimed water, are often cited as major concerns. In addition, implementation of reclamation and reuse programs often requires the retrofitting and construction of new and dual distribution systems as well as the development of new technologies for decentralized and satellite wastewater treatment. This can lead to prohibitively high costs that effectively limit the implementation of such programs. In depth discussions of dual distribution system and decentralized wastewater treatment can be found elsewhere^{251, 252, 255} The issue of unknown contaminants continues to be a barrier to the implementation of potable reuse. A series of publications issued by the Water Science and Technology Board of the National Research Council^{266, 267, 268} reported a general consensus that technology exists for rendering almost any wastewater safe for drinking by current standards, but that the uncertainties regarding trace organics and emerging contaminants impose risks, suggesting that potable reuse should be an option of last resort.²⁵²

The planning and management approaches of 65 international nonpotable water reuse projects were documented in a 2001 survey conducted by the Water Environment Research Foundation (WERF).²⁶⁹ The survey, which covered agricultural, urban, and industrial water reuse projects in both industrialized and developing countries in arid and semi-arid areas around the globe, showed that operational performance, sound institutional arrangements, conservative cost and sales estimates, and good project communication are the basis for success in reclamation and reuse projects. Likewise, the survey also showed that institutional obstacles, inadequate valuation of economic benefits, and lack of public information can delay water reclamation and reuse projects or cause them to fail.²⁵²

H. Examples and case studies from different regions

Water reclamation and reuse is growing steadily in arid, water-deficient areas as well as in highly populated countries in temperate regions around the world.²⁵² Many of the projects that have been successfully and unsuccessfully implemented have been documented in case studies.

Table E-2 of the *Water Reuse: Issues, Technologies, and Applications* textbook²⁵¹ includes brief descriptions of case studies from the following developed countries: Australia, Canada, Israel, Japan, Kuwait, Singapore, and Spain. Extended case studies from the United States are provided throughout the text. Case studies from Namibia, South Africa and Tunisia on the following topics are described briefly, with references to more detailed information:

- Namibia: the Goreangab Water Reclamation plant in Windhoek for direct potable reuse.
- South Africa: (1) groundwater recharge with treated municipal wastewater for withdrawal and reuse (2) use of treated industrial wastewater for groundwater recharge in coastal zones as a barrier for saltwater intrusion; and (3) water reuse in the paper industry.
- Tunisia: (1) reclaimed municipal wastewater for agricultural irrigation; and (2) golf course irrigation using reclaimed water and conducted at night.

Chapter eight of the US EPA's *Water Reuse Guidelines*²⁵² is entitled "Water Reuse outside the US" and section five of that chapter includes 30 pages of examples. The following are some of the countries with developing and emerging economies that are included in section 8.5 of the Guidelines, which encompass a description of reuse activities and references to more detailed accounts:

- Argentina: reclamation using stabilization ponds to produce water for irrigation of crops and an "oasis."

- Brazil: (1) reclamation of municipal wastewater and flood control reservoirs for industrial use and for select urban uses (including toilet flushing, street washing, irrigation of green space, etc.; and (2) for aquifer recharge and other uses in and around an international airport.
- Chile: installing wastewater treatment plants around a major city to improve the quality of wastewater that has long been used for irrigation.
- China: (1) treatment and reuse of internally generated wastewater in industrial facilities and power plants; and (2) recharge of groundwater aquifers with municipal wastewater that has received secondary treatment.
- Iran: penalizing municipalities that do not treat wastewater to ensure safe reuse in agriculture.
- Jordan: (1) agricultural irrigation with treated wastewater; and (2) planning for expanded water reuse as part of integrated water management to relieve pressure on limited freshwater resources.
- Mexico: (1) reuse in agriculture, recreational water bodies, urban irrigation, car washing, etc.; and (2) reuse of municipal wastewater in industry.
- Morocco: (1) reuse for agricultural and golf course irrigation; (2) public participation and institutional partnership programs; and (3) production of commercial goods for partial cost recovery with reclaimed water sold to farmers, reeds from wetlands harvested and sold, incorporation of dried sludge in compost, and burning of methane gas to power pumps.
- Oman: (1) groundwater recharge to prevent saltwater intrusion; and (2) plans to expand reuse for irrigation to 100% of all treated wastewater.
- Yemen: (1) providing reclaimed water to farmers to reduce groundwater depletion through agricultural over abstraction; and (2) use of some treated wastewater for industrial cooling.
- Zimbabwe: indirect potable water reuse, with discharge of treated wastewater to rivers and lakes used downstream for potable supply.

The book *Water Reuse: An International Survey of Current Practice, Issues and Needs*²⁵⁴ is a textbook containing an expansive collection international experience and case studies. Countries whose reclamation and reuse programmes are described in detail in Section 4: Study Cases include: Pakistan, Mexico, Namibia, Cameroon, Nepal, Vietnam, and numerous countries in North Africa and the Middle East.

These resources should be consulted for both general knowledge and experience gained from water reclamation and reuse projects that have been implemented around the world.

Water Safety Plans (WSPs)

Topic areas: Preparation for extreme weather events; Resilience to water quality degradation

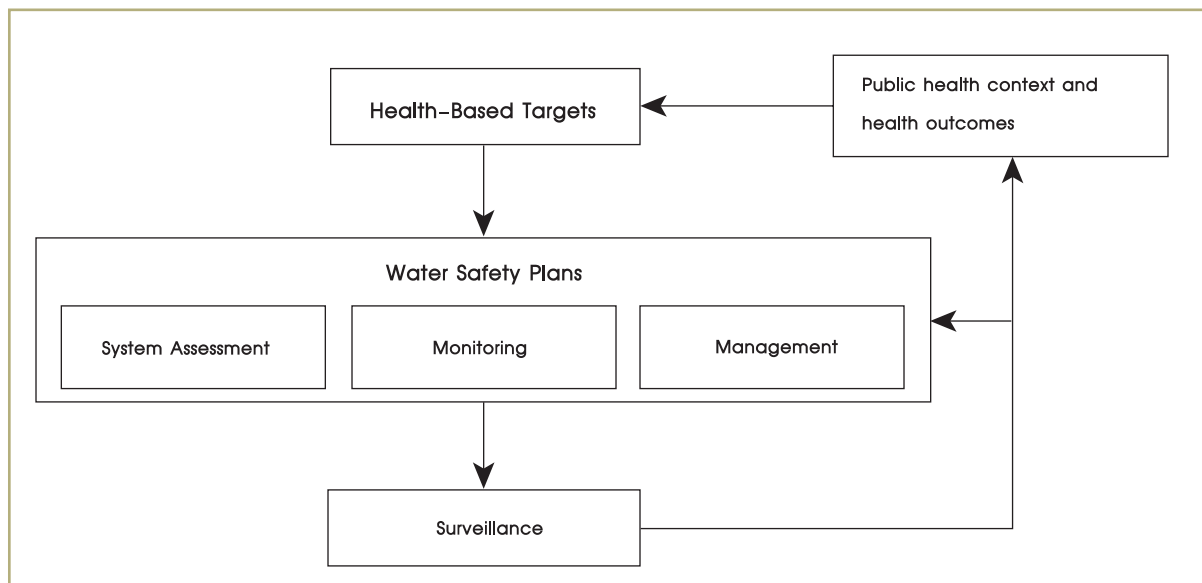
Terms for the Glossary: End-product testing; Water supply chain; Stakeholders; Health-based targets

A. What does the technology/practice consist of?

The World Health Organization Guidelines for Drinking Water Quality - 3rd Edition (GDWQ)²⁷⁰ is the basis for current water quality standards in many countries around the world. In the GDWQ, Water Safety Plans (WSPs) are described collectively as a systematic and integrated approach to water supply management based on assessment and control of various factors that pose a threat to the safety of drinking water. WSPs enable identification of threats to water safety during any and all steps in the catchment, transport, treatment and distribution of drinking water. This approach is fundamentally different from those traditionally adopted by water suppliers, which rely on treatment and end-product testing to ensure water safety. When implemented successfully, the WSP approach can ensure that water quality is maintained in almost any context. This section of the handbook will outline the key components of a WSP and will discuss the general steps that stakeholders must take when developing and implementing a WSP.

Chapter 4 of the GDWQ describes a framework for preventative management and delivery of safe drinking-water. This framework is illustrated in Figure 12. Though the specific inputs and outputs of WSPs may vary from case to case, the basic components remain the same regardless of the context. As shown in the figure, a WSP consists of three separate activities: system assessment, monitoring and management.

Figure 12: Framework for safe drinking water



Source: WHO (2008).ⁱ

System assessment: During this phase of a WSP, potential hazards to water quality and health are identified at key steps or locations, normally referred to as Critical Control Points (CCPs), within specified boundaries of a water supply chain. Typical health hazards might be source catchment contamination, poorly maintained service reservoirs, leaking valve boxes or unhygienic standpipe collection systems.²⁷¹ Associated risks of negative health outcomes due to these hazards are also quantified at this time.

Monitoring: Once health risks have been defined, they are used to develop a prioritized and system-specific plan for monitoring and controlling hazards at each CCP during the monitoring phase of a WSP. Such a plan will define operational parameters and associated sampling and reporting methods. Critical limits or targets for these parameters should be defined at this time. It is likely that a combination of observational

and traditional water quality monitoring methods will be implemented by members of the community as well as by trained personnel.

Management: The actions necessary to correct any issue identified during monitoring are established in the management phase of a WSP. Such measures may include alleviation of source water contamination through controlling activities in the watershed, optimization of physical or chemical treatment processes, and prevention of recontamination during distribution, storage and handling.²⁷² By controlling hazards at the water supply system's CCPs, any issue that occurs in the catchment or distribution network can be detected and corrected before water of poor quality is delivered to the consumer. This proactive method of monitoring reduces the amount of sampling that needs to be conducted in the distribution system. In addition, processes are established for documentation and record keeping, and validation and verification during the management phase.

The WHO has published a foundational document that describes the process water suppliers must follow in order to ensure that a WSP is planned and implemented properly.²⁷³ These steps are illustrated in Figure 13 and have been summarized as follows.²⁷¹ In order to develop a WSP, a water supplier must:

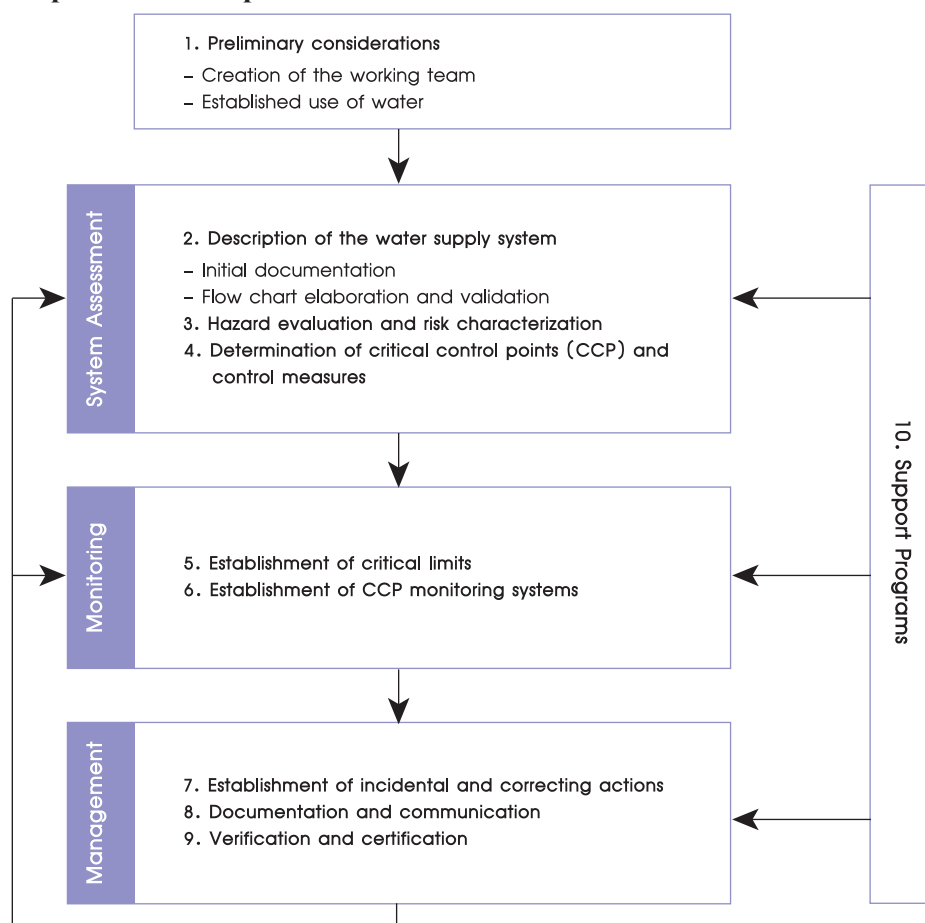
- Assemble a team that understands the water supply system and its capability to meet the water quality targets
- Identify where contamination could arise within the water supply, and how it could be controlled
- Validate the methods employed to control hazards
- Establish both a monitoring system to check that safe water is consistently supplied and agree to corrective actions in the case of deviation outside acceptable limits
- Periodically verify that the WSP is being implemented correctly and is achieving the performance required to meet the water safety targets

This WHO publication on WSPs²⁷³ is supported by a number of articles that address source protection, treatment processes (at supply and household level), distribution of drinking-water and selection of parameters and analytical methods.^{274,275,276,277,278,279,280} Further information about hazard analysis at CCPs is available in the references.^{281, 282} In addition, a manual that provides detailed guidance for implementing WSPs is freely available online.²⁸³ These publications should be consulted for further information when planning and developing a WSP.

Although the WSP approach is widely generalizable, there are a number of factors that make the design and implementation of WSPs in developing countries different than in developed countries. A WEDC report on WSP approaches for urban piped supplies developing countries is a valuable resource that is freely available online.²⁷¹

B. How does the technology/practice contribute to climate change adaptation?

The Intergovernmental Panel on Climate Change predicts that climate change will lead to, among other things, increased global temperatures, flooding events and periods of drought as well reduced freshwater resources and sea level rise.²⁸⁴ These changes are projected to have many adverse impacts worldwide drinking water resources: cyanobacterial activity will increase within water bodies; the frequency of physical and chemical contamination of water bodies will increase; harmful nutrients and other pollutants will become concentrated in water sources; unprotected sources will be used at increasing rates; and saline intrusion will occur in coastal rivers and groundwater sources. Any hazard that occurs as a result of climate change will lead to increased health risks in the water supply chain and will have implications on water safety.

Figure 13: Steps in the development of a WSP.

Source: Adapted from Davison, et al. (2005).²⁷³

WSPs contribute to climate change adaptation at the catchment level primarily through increased resilience to water quality degradation. The WSP approach allows for water suppliers to be flexible and responsive to changing input parameters. This means that the monitoring, management and feedback components of a successful WSP naturally absorb the acute impacts of climate change. The WSP approach can also be modified to adapt to long-term climate change and slow-onset hazards by recognizing how the water supply system may be affected by specific climate change effects, by factoring these effects into the risk assessment, and by identifying appropriate control measures.

C. What are the contributions of the practice/technology to development?

The burden of disease attributable to poor water, sanitation and hygiene has been estimated to be over 200 times higher in developing than in developed regions.²⁸⁵ Waterborne illnesses diminish economic productivity and confine people to poverty. Since WSPs are developed to meet health-based targets that are specific to the disease burden of a particular region, the approach can significantly reduce the risk of exposure to health hazards that contribute the most to disease in developing countries.²⁷³ Therefore, WSPs can make a significant contribution to economic development by reducing the burden of waterborne illness in resource-limited settings.

D. What are the knowledge/capacity building requirements?

The WSP design team must have a sound understanding of the catchment area, treatment facilities, and distribution networks that make up a water supply system. These components must be mapped and characterized in order for the system's capability to meet water quality targets to be fully understood and for control measures to be developed. This may require in-depth assessment of the water supply chain, as some information may be unknown prior to development of the WSP.

It is also important that WSP designers and stakeholders understand how water quality affects health in order for appropriate limits on specific water quality parameters to be set. This requires basic knowledge of sampling and monitoring techniques as described in the GDWQ. Furthermore, the members of the design team must have a working knowledge of the corrective actions that should be taken when water quality deviates outside acceptable limits.

A number of stakeholders are usually involved in various aspects of the water supply chain. Therefore, the WSP design team must understand how the implementation of a WSP will affect pre-existing water sector arrangements. Understanding such arrangements will allow WSP designers to facilitate cooperation among all stakeholders. This may require a review of the current organizational and institutional structure in order to establish which entities have a vested interest in or responsibility for water safety. The process for conducting an in-depth review of sector arrangements is available in the references.²⁷¹

E. What are the institutional/organizational requirements?

The institutional and organizational requirements of a WSP are related primarily to personnel needs. The first step in planning a WSP is to set-up a steering group that is composed of members from varied professional backgrounds. This interdisciplinary team will be responsible for gathering the background information required to plan a WSP and for developing its components. The steering group should include engineers, water quality managers, academics, planners, surveyors, sociologists and health scientists.²⁷¹ In addition to the steering group, it should be made clear which entities or individuals are responsible for carrying-out operational monitoring, for documenting and reporting monitoring results, for taking corrective action when necessary, for performing operational audits, and for certifying and validating the risk assessment plan.

In order for the implementation of a WSP to be successful, it is also important that all stakeholders buy into the process. While representation of all stakeholder entities on the steering group will help to encourage cooperation, some cases may require additional effort from WSP designers to foster an environment of acceptance and trust. Strategies for ensuring commitment from all levels of water sector involvement have been published in the literature.^{271, 273}

F. What are the costs and financial requirements?

The implementation of a WSP will potentially require water suppliers to increase sampling frequency and number of locations where process indicators (such as turbidity, chlorine, residuals, pH, etc.) are monitored. However, the amount of required microbiological tests will also decrease significantly. In fact, it is likely that the cost of providing and distributing safe water from a risk-based approach will actually be less than from a traditional end-product monitoring approach.²⁷³ This is especially true in developing countries, where consumables required for coliform and other microbiological testing are expensive and where a high percentage of monitoring funds are spent on field test kits or maintaining expensive certified

laboratories. Even in cases where the equipment required for on-line monitoring must be purchased, the recurrent cost savings of using process indicators for monitoring instead of microbiological indicators is almost certain to outweigh the initial capital investment.

The WSP approach can also result in long-term decreased institutional costs. In general, the planning process identifies opportunities for low-cost improvements on operations and management practices. However, WSPs also improve the efficiency of communication and collaboration between water providers, consumers, regulatory authorities and the commercial, environmental and health sectors. This creates an enabling environment where financial support can be leveraged and where capital improvement needs can be prioritized and sustained.²⁸⁶

G. What are the barriers to and opportunities for implementation?

Opportunities for WSP implementation arise whenever the supplier is motivated to pursue a risk-based approach and when the personnel capacity exists to make the necessary changes. The primary barrier to implementation of WSPs is that certain stakeholders may be hesitant to adopt such a fundamentally different paradigm for water supply management. Additionally, a number of barriers to the implementation of WSPs that are specific to developing countries have been reported.²⁷¹ These include, among others:

- Limited data availability
- Unplanned development
- Lack of sanitation infrastructure
- Limited system knowledge
- Limited equipment/human resource availability

Theoretically, a WSP can be put into practice at any time for a water supply of any size. In reality, small, community-managed water supply systems face a number of unique barriers to planning and implementing WSPs. In such systems, technologies may range in sophistication from a single borehole or tubewell fitted with a handpump to complex treatment schemes, and operation and maintenance is performed by members of the community with limited specialist skills. In most cases, the management personnel can commit only a limited amount of time to running the system and overseeing its operation, and they receive little or no formal training or financial compensation. They are often forced to rely significantly on local or national government for general support and guidance. Furthermore, it is likely that managers of such water supply systems will have limited access to proper water quality testing and construction equipment. Ways that managers of small, community-managed water supply systems can overcome these limitations in planning and implementing WSPs are addressed in chapter 13 of “Water Safety Plans: Managing drinking-water quality from catchment to consumer”.²⁷³

It is often very difficult to characterize water supply systems in developing countries. Limited development regulations have resulted in unplanned expansion of water and sewer networks. The fact that current and accurate network maps are rarely available makes it difficult to locate supply mains, and system analysis may then rely heavily on local knowledge. The matter is exacerbated by the fact that cross contamination of water pipes is common due to poor access to urban sanitation, and the lack of available resources limits the extent to which water suppliers are able to maintain adequate operation and maintenance. Although there are many challenges for implementing WSPs in developing countries, the approach enables a much more holistic and robust assessment of threats to drinking water safety than conventional approaches focusing on end-product testing.

H. Examples and case studies from different regions

There have been a number of interesting applications of WSPs in communities in almost every region of the world including Africa, the Americas and the Caribbean, Southeast Asia, Europe, and Western Pacific.²⁷² The two foundational cases of successful WSP implementation, one in a large utility-run system in Melbourne, Australia²⁸⁷ and one in a small community-based water supply in Kampala, Uganda²⁸⁸ are widely cited as examples to be followed.²⁷³

The WHO and International Water Association (IWA) have compiled an extensive online resource, called the WSPortal, that features case studies, references and tools which provide practical guidance and evidence-based material of relevance that can be applied appropriately for a range of circumstances.²⁸⁹ The United States Center for Disease Control and Prevention (CDC), in partnership with the Pan American Health Organization (PAHO) and the United States Environmental Protection Agency (USEPA) have developed a similar resource focused primarily on the implementation of WSPs in Latin American countries and in the Caribbean. Both of these web resources are extremely valuable and provide significant guidance for the effective implementation of WSPs.

5. Implementation of Technologies and Practices for Climate Change Adaptation

This chapter provides guidance on the implementation of the technologies and practices described in Chapter 4. For each adaptation technology/practice, the following questions are answered:

- How can the technologies be implemented, by whom, in which context?
- What are the practical steps to implement the technology?

The technologies/practices and their implementation vary widely; therefore, the organization of each section of this chapter differs. Many of the technologies/practices require substantial preparatory work prior to implementation and those preliminary steps are described here. Key external resources focusing on general aspects of implementation that were cited in Chapter 4 are also referenced here. However, case studies of specific projects that include information on the implementation process are usually not cited here and can be found in Chapter 4.

Boreholes/Tubewells as a Drought Intervention for Domestic Water Supply

Groundwater resources, particularly deep aquifers, are generally more resilient to drought than surface water resources. Therefore, increasing access to productive boreholes is one of the keys to drought alleviation. Settings in which these initiatives are especially important include rural areas of arid and semi-arid regions that are not served by a centralized supply.

There are three major strategies by which boreholes can be used to alleviate drought: drilling new boreholes/deepening existing boreholes; repairing damaged boreholes; and uncapping “relief boreholes” with use restricted to drought periods. Uncapping of relief boreholes is almost exclusively the domain of governments and government contractors. The former two strategies, when applied specifically for drought alleviation, are typically implemented by NGOs, international organizations, governments or private sector firms under contract to one of these.

Drought alleviation can be made much more effective through proper pre-drought management. Key elements of pre-drought management include: groundwater resource assessment, groundwater drought vulnerability analysis, and building drought resistance into water supply programs.²⁹⁰ For domestic water supply, it is also essential to understand population distribution and the location and status of water points.²⁹¹ A report on mapping water point access and utilizing the data is available from WaterAid.²⁹² If these data are not available prior to a drought, it may be necessary to proceed with emergency programming. However, even a cursory survey of population distribution and water point status has the potential to improve program efficiency.

Prior to initiating borehole drilling and deepening for drought relief, decision-makers should explore borehole repair. Repairing damaged borehole hardware (typically by fixing handpumps) is far more cost effective and quicker. The failure of a borehole increases pressure on other water points, potentially leading

to local groundwater drawdown and hardware failure. Borehole repair can prevent this cascade of water point failure. Local mechanics can be an important resource for handpump repair.^{66, 57}

Desalination

Desalination is most commonly implemented in water-poor areas of wealthy countries. It is generally expensive and is subject to large economies of scale.²⁹³ Weaknesses in a water sector can be exacerbated by the high costs of desalination. Therefore, desalination is most economically viable for well-functioning piped systems serving large populations in areas with inadequate freshwater resources.²⁹⁴

In preparation to implement desalination, the following steps should be taken:

- Develop a clear water policy using an integrated water resources management (IWRM) approach to accurately determine renewable freshwater resource potential, demand and consumption. Only when the adequacy of conventional water resources is understood should development of non-conventional (e.g. saline) water resources be pursued.²⁹⁵ Water reuse is generally less expensive than desalination and, thus, should receive strong consideration in the IWRM analysis as an alternative to desalination.
- Implement conservation and water demand management in all sectors. Key methods include reduction of NRW, use of only limited targeted subsidies, and prevention of groundwater pollution.^{294, 295}
- Consider desalination in combination with other non-conventional water sources including reuse of treated wastewater, importation of water across boundaries, rainwater harvesting, small reservoirs and microcatchments.²⁹⁵
- A feasibility study must be undertaken prior to construction of a desalination facility. Examples are available in the references.^{296, 297} This should include a formal Environmental Impact Assessment (EIA) that should include, but not be limited to, evaluation of the effects of the concentrated waste stream on ecosystems; the impact of seawater intakes on aquatic life; energy consumption; and greenhouse gas emissions.^{298, 299}

Following the feasibility study and EIA, a governmental panel should determine whether the project will move forward. For municipal supply, desalination is generally implemented by governments, with design and construction contracted to large consulting firms with specific expertise in the type of desalination planned. Once desalination has been approved, the approach should be similar to that used for other large infrastructure projects.

Household Water Treatment and Safe Storage (HWTS)

HWTS is an adaptation strategy that is fundamentally managed and operated at the household level. Therefore, diverse implementation programs are undertaken at different scales, with all of them sharing the goals of increasing the correct and sustained use of HWTS in the home. Examples of HWTS program strategies include: distribution of HWTS devices to a small group of households with education/training; building an indigenous industry for HWTS products; marketing and raising awareness of HWTS; increasing usage rates of a product already available on the local market; emergency response; and national roll-out of one or more technologies.

Small-scale implementation and training programs are typically carried out by NGOs. These programs sometimes incorporate training of local entrepreneurs to build businesses based on HWTS production and distribution. Private sector companies have led efforts to market and distribute their own HWTS products

at national and regional scales (e.g., Procter & Gamble's PUR, Hindustan Lever's Pureit). Partnerships between governments and large NGOs have also been formed for social marketing and distribution of HWTS products at large scale (e.g., IDE in Cambodia, USAID and PSI in numerous countries). Emergency response programs are typically facilitated by international organizations and national governments.

The practical steps to implementing HWTS will vary greatly based on the scale of the operation and the specific approach taken. Implementation may also vary based on which technology is chosen, particularly between those that are consumable (e.g., chlorine) and those that are durable goods (e.g., filters). However, there are factors that are important to all HWTS programs:

- Supply chain: ensuring that there is a reliable supply chain for any consumables or replacement parts is essential for long-term impact.
- Training: some amount of education and training in correct use and cleaning/maintenance is often necessary. Small programs usually utilize face-to-face training. Printed materials may suffice in some cases. All methods should be pilot-tested and evaluated both immediately and during a later follow-up phase.
- Public policy considerations: HWTS leads to improvements in water quality and health, but it should not be used as an excuse to delay provision of a safe, piped water supply. It is especially important for large HWTS initiatives that the appropriate government ministries and water utilities be engaged on this topic prior to implementation.

HWTS programs can be implemented wherever people do not have access to a safe, 24-hr supply of piped drinking water. However, some settings provide greater opportunity for success. This includes settings in which non-health benefits of HWTS are perceived to be high. Examples include: when water sources are very turbid; when purchasing higher-quality water is very expensive; and when social norms encourage provision of clean drinking water to guests. Additionally, during crises that are associated with water contamination, including natural disasters and waterborne disease outbreaks, demand for HWTS typically increases.

One of the key resources for exploring HWTS implementation options is the WHO report "Scaling-up Household Water Treatment among Low-Income Populations."³⁰⁰ It includes a section that addresses the major implementation strategies used for the most common HWTS technologies, with the lessons learned during implementation of each technology.

Improving Resilience of Protected Wells to Flooding

In many flood-prone regions, a large percentage of the population relies on protected wells for drinking water. Protected wells can potentially provide a water supply that is highly resilient to flooding. However, improper design and construction can increase vulnerability (see "Improving the Resilience of Protected Wells to Flooding" in this handbook).³⁰¹

Two preliminary steps can greatly increase the efficiency and cost effectiveness of implementation. The first step is to investigate the population distribution and water point location with respect to local floodplains. The focus should be on maintaining water point access during flooding, based on the WHO emergency guidelines for distance to a water point and persons per water point.³⁰² The second step is to assess the repair status and vulnerability of existing water points. For areas identified as high priority, a sanitary survey of protected wells should be conducted, as described in Annex 2 of the WHO Guidelines for Drinking Water Quality (GDWQ) 2nd Edition; additional considerations that are particularly relevant to flooding are

described in chapter six of the same.³⁰³ Within floodplains, it is also important to completely seal any abandoned wells to decrease the likelihood of direct contamination of groundwater through inundation.³⁰⁴

These preliminary steps are generally initiated by local or provincial governments. After the status of water points, population and floodplains has been determined, an appropriate implementation strategy can be devised. Key strategies include: repair of existing wells, raising/modification of existing wellheads and construction of new wells. The local engineering, mechanic and construction sectors can be contracted for piloting and carrying out the implementation.³⁰⁵

Increasing Use of Water-efficient Fixtures and Appliances

Industrialized countries have seen declines in residential water consumption through the widespread use of water-efficient fixtures and appliances.³⁰⁶ Although the introduction of these products to the marketplace will lead to moderate uptake, their use can be increased through three primary strategies: legal mandates, tax incentives and labeling. Additionally, some water utilities have experimented with free distribution of water-efficient, inexpensive fixtures (e.g., low-flow showerheads) in an effort to reduce domestic water use.³⁰⁷

Legal mandates and tax incentives are mechanisms that must be implemented by governments. However, lobbying for such legislation can be conducted by various environmental, professional and industry organizations. Labeling and certification systems could hypothetically be spearheaded by industry or professional groups but government sanctioning or oversight may be necessary to ensure that the system has credibility with consumers.

In general, these strategies work best in settings where:

- households have a metered connection (i.e. they are charged by volume)
- the monthly water bill accounts for a non-negligible portion of average income
- citizens are environmentally conscious
- communities desire to conserve their common resources

For setting in which a proportion of households have fixed (unmetered) water bills, legal mandates and tax incentives can be used to motivate use of water efficient appliances and fixtures. On the other hand, labeling may not be as effective because decreased water use will not lead to monetary savings.

Recommendations for the steps to establishing an EU approach are addressed in chapter seven of the 2009 European Commission report “Study on Water Efficiency Standards.”³⁰⁸ Key recommendations include:

- Fixtures and appliances should be scheduled for study and plans should be addressed with key stakeholders (e.g., the housing, building and manufacturing industries).
- Approaches (i.e., legislating, labeling or incentivizing) should be established for each class of products (e.g., legislated low-volume standards for toilets; labeling for dishwashers). This includes whether each parameter will be a mandatory standard or an optional guideline or certification.
- Ambiguities should be avoided in standards, testing, compliance procedures and sanctions.
- A large-scale promotional program should be established for publicizing any labeling/certification system.
- Provision must be made for revision and updating of standards. For an example of such a program, see the factors determining revision of US EPA Energy Star standards.³⁰⁹

Many countries have achieved significant reduction in domestic water consumption through such programs. The burden of establishing a new approach can be lessened by adopting standards and guidelines that have proven successful elsewhere. The most thorough review of water efficiency programs worldwide can be found in the European Commission report cited above.³⁰⁸

Leakage Management, Detection and Repair in Piped Systems

Reducing leakage losses in piped water distribution systems is a key strategy for water conservation in both wealthy and developing countries. Leakage rates of 10–20% are considered normal and in some areas of the United States aging infrastructure leaks up to 50%.^{310, 311} Management, detection and repair of small, underground leaks are essential functions of operation and maintenance for all water utilities and may also be important for water boards of community-managed systems. However, most leakage management and detection methods are only appropriate for systems operating at high pressure. Therefore, despite its importance, leakage is very difficult to detect and manage in poorly functioning systems with less than 24-hr service.

A water audit is a key preliminary step that should be undertaken prior to implementing a leak management, detection and repair program. Water audits are used to quantify leakage volume and location in a distribution system, thus enabling prioritization of program activities. Further information and training materials for water audits can be found elsewhere.^{310, 312}

Leak management constitutes both accurate identification of the location of leaks and pressure management. High pressure increases losses to leakage and damage to the system; therefore, it can be beneficial to decrease pressure during periods of low demand. Specialized valves can be installed to regulate pressure (e.g., products from CLA-VAL); consultants should be hired to assess the pressure management options appropriate for a system.³¹³ While pressure management can be an important tool, maintaining 24-hr pressure should be the first priority. Therefore, pressure management should not be used in systems that suffer from intermittent flow or that cannot meet demand 24-hr per day.³¹⁴

Leak detection and leak repair can be implemented in any piped water system. The technologies utilized, especially for leak detection, should be appropriate to the resources of the system. Most utilities, particularly small ones, should generally contract leak detection to a consulting firm with appropriate expertise.

Post-construction Support (PCS) for Community-managed Water Supplies

The evidence base for PCS is small but growing. It presents a compelling case that ongoing technical, financial and management support for community-managed water systems can greatly improve their functioning and sustainability. The key steps for planning and implementing PCS programmes are addressed in an excellent and thorough USAID report on institutional support for community-managed systems in Latin America that is available online.³¹⁵

PCS programmes are used in developing and developed countries worldwide; they are relevant in any context in which rural populations manage their own drinking water supplies. Some PCS programmes are the result of a formal process, usually initiated by government, to aid small water systems; others evolve over time in response to demand for support. In some settings, NGOs may already be heavily involved in PCS, often offering their services free of charge. In these cases, it is important to assess whether the expectation of NGO support might undermine the willingness of communities to invest in a newly established PCS programme.

Schematics included in chapter six of the USAID report provide guidance on the four major phases of planning and implementation. The first three phases are preliminary to implementation. To paraphrase the report, they are described as:

- **Assessment:** Review and analysis of the rural water sector and strategies used for rural water supply in the area.
- **Design:** Detailed design of the PCS model based on findings of the assessment phase, including the definition of institutional roles and responsibilities, the development of a detailed budget, and a monitoring system.
- **Preparation:** Acquiring equipment, establishing offices, recruiting and training staff, and developing a marketing program.³¹⁵

The USAID report also includes detailed instruction on implementation of PCS; these are briefly summarized here. All implementation programmes should begin at a piloting or field testing scale, during which linkages should be established with local organizations and institutions. Piloting and field testing programmes should incorporate evaluation and monitoring, with clear mechanisms for feedback and, if necessary, modification. After 18-36 months, a review of the progress and impact of the programmes should be undertaken; successful programmes should be evaluated for their potential for replication and expansion in other areas.³¹⁵

PCS programmes are diverse. Further detail and case studies on the implementation of specific PCS programmes can be found in the chapter of this handbook entitled “Post-construction Support (PCS) for Community-managed Water Supplies” and in the references cited there.

Rainwater Collection from Ground Surfaces—Small Reservoirs and Micro-catchments

In dry areas, small-scale water collection infrastructure can contribute greatly to the amount of freshwater available for human use. This is especially true in arid and semi-arid regions, where the little precipitation is usually very intense and often seasonal. Because of this, runoff and river flows can be abundant for brief periods and non-existent throughout the rest of the year.^{316, 317} Collection and storage infrastructure can be very important for agricultural communities, particularly those dependent on rain-fed agriculture or on groundwater that is being depleted. The opportunities for and benefits of small reservoir capacity development are generally greater where water availability is inadequate but environmental, social or legal concerns preclude the development of large reservoirs.

Prior to implementation of small communal-reservoir implementation, a feasibility study must be undertaken, including assessment of available storage capacity and potential hydrological impacts at potential sites. Feasibility studies are typically initiated by local governments; however, involving communities and other stakeholders is essential, as described below. A procedure for government evaluation of environmental and other impacts that is appropriate to the local setting should be required for approval.

Although the environmental and hydrological impacts of these projects have been reported to be minor, small reservoir construction can often lead to conflict.^{210, 318} Therefore, stakeholder participation must be encouraged during the planning and implementation stages. A framework used for incorporating stakeholders in small reservoir decision making in Zimbabwe is included in the references.³¹⁹ Like small drinking water supplies, small reservoir projects are more likely to fail if the technology and location are not driven by community demand.³²⁰

Following site selection, feasibility assessment and community buy-in, implementation should be carried out much like an infrastructure construction project. Surveyors, engineers and contractors can be contracted for various stages of the work. A flow chart of the process for small reservoir development in Zimbabwe is included in the references.³¹⁹

Rainwater Harvesting (RWH) from Rooftops

RWH, like HWTS, is an adaptation strategy that is managed and operated at the household level. Therefore, RWH implementation programmes are similar to those for HWTS in that both can utilize a broad array of strategies at different scales with a common goal. For RWH implementation, the goal (of the user and/or the implementer) is to increase the volume of relatively clean water captured and made available for household use.

The most extensive treatment of RWH implementation can be found in the IRC publication “Roofwater Harvesting: A Handbook for Practitioners.” Models for RWH delivery listed there include the following, with the party financing the system indicated in parentheses:

- self-built (household-funded)
- self-supplied from market (household-funded)
- government rural water programme (fully or partially government-subsidized with household contributing)
- NGO-aided (fully or partially NGO-subsidized with household contributing)
- installed with new construction (builder-funded, paid later for parts/labor by household).³²¹

Household-funded and builder-funded RWH models are generally market-driven, without subsidization or the involvement of external implementers. However, implementers can sometimes enhance local RWH markets by training artisans and micro-entrepreneurs or importing technologies from other countries, thus increasing the availability, quality and/or diversity of RWH products in the markets. Additionally, governments and NGOs may have some role in encouraging the use of RWH and ensuring product quality through education, quality control, product certification, or tax incentives.³²¹

Government-subsidized or NGO-subsidized RWH models have become increasingly popular, particularly since RWH was included as a category of “improved water supply” as part of the Millennium Development Goals. These programmes present special challenges. According to the IRC publication cited above, any programme of subsidized domestic RWH must include the following six activities:

- A preliminary study to confirm that DRWH is economically viable in the target area (i.e. that it will supply water more cheaply than by increasing the number of point sources)
- An education/popularization process by which householders are taught the benefits and also the limitations of the technology they are being encouraged to invest in
- A well-defined subsidy policy (e.g. that government or NGO funding will pay only for some minimum RWH system per household and that any excess must be covered by the benefiting household)
- A household selection process that identifies which are physically suitable for RWH, financially capable of paying a share of its cost and are ‘deserving of subsidy’ (due to, for example: poverty, distance from existing water points, etc.)
- A supply chain for replacement parts
- An installation process that utilizes local labor, with some form of quality control.³²¹

The technical options to be offered to households must also be determined. Ideally, this determination will be made through a process that is based on local user preference and demand, and that also involves technical review by RWH experts to determine their appropriateness in the local context. Extensive guidance on the technical aspects of design for RWH systems is available in the IRC publication cited above.³²¹

Water Reclamation and Reuse

Water reclamation and reuse, utilizing treated municipal wastewater as a resource, can be an important component of holistic strategies to conserve freshwater resources. It is almost universally practiced for agricultural irrigation in arid and semi-arid countries.³²² As freshwater resources are further stressed due to population growth and increased water use per capita, it has become necessary for many countries to utilize municipal wastewater as a resource. Water reclamation and reuse programmes are generally initiated and implemented by governments and government contractors.

Like desalination, possible implementation of water reclamation and reuse should be evaluated as part of an IWRM approach. A brief description of how water reuse can be evaluated and compared to other water supply options under an IWRM framework is provided in chapter 25 of “Water Reuse: Issues, Technologies and Applications.” Each of the major steps, below, includes “public perception and outreach” and an iterative feedback process:³²³

- Clarify the problem
- Formulate objectives and evaluation criteria
- Gather background information and make forecasts
- Identify project alternatives, including water reclamation and reuse
- Evaluate and rank alternatives
- Select an alternative, refine the proposal and develop a plan for implementation.³²³

The success of water reuse projects hinges on public acceptance to perhaps a greater degree than any other water supply intervention. Past approaches that have neglected public input, using a “decide, announce and defend” policy, are widely acknowledged to be ineffective. Additionally, using public education and outreach programs after a project’s conception has also been shown to be inadequate. The latest strategies for water reuse projects include the participation of the community prior to the conception of the project, in the planning stages and throughout implementation. A literature review of the factors influencing public perceptions of water reuse, case studies of successful and unsuccessful approaches and potential strategies to address public resistance is available online.³²⁴

In addition to public perception, factors that must be evaluated and addressed prior to implementation of water reclamation and reuse include:

- Human resources and technical capacity
- Policy and regulatory framework
- Institutional regulation and management
- Public financing

These items are addressed briefly in this handbook in the “Water Reclamation and Reuse” section of Chapter 5. Further detail is available in the UNEP report entitled “Water and Wastewater Reuse: An Environmentally Sound Approach for Sustainable Urban Water Management.”³²⁵

Water Safety Plans (WSPs)

The WSP approach is fundamentally different from the traditional approaches used by water suppliers to ensure water safety. WSPs do not rely as heavily on end-product testing but, rather, are designed to identify and address threats to water safety during all steps in the catchment, transport, treatment and distribution of drinking water.³²⁶

Opportunities for WSP implementation arise whenever the supplier is motivated to pursue a risk-based approach and when the personnel capacity exists to make the necessary changes. The primary barrier to implementation of WSPs is that certain stakeholders may be hesitant to adopt such a fundamentally different paradigm for water supply management.

The development of the WSP approach occurred relatively recently and the literature is largely composed of case studies and implementation guides. World Health Organization (WHO) and International Water Association (IWA) have published a concise implementation manual that is freely available online and is a valuable resource for any utility considering WSPs.³²⁷ The 11 modules are organized to provide a step-by-step approach for implementing WSPs:

- Assemble a WSP team
- Describe the water supply system
- Identify hazards and hazardous events and assess the risks
- Determine and validate control measures, reassess and prioritize the risks
- Develop, implement and maintain an improvement/upgrade plan
- Define monitoring of the control measures
- Verify the effectiveness of the WSP
- Prepare management procedures
- Develop supporting programmes
- Plan and carry out periodic review of the WSP
- Revise the WSP following an incident³²⁷

Additionally, an online WSP Quality Assurance Tool was recently developed by WHO and IWA.³²⁸ It provides a valuable resource for designing and implementing WSPs, as well as constantly evaluating and improving WSPs.

The WHO has also published a comprehensive report entitled “Water safety plans: Managing drinking-water quality from catchment to consumer”; it includes further detail on the processes water suppliers must follow to ensure that a WSP is planned and implemented properly. In addition to providing extended treatment of the key steps in implementation, the report includes a chapter on special considerations for implementing WSPs for small community-managed systems. Because small systems are unlikely to have the resources to develop system-specific WSPs, two approaches are presented for small systems: the use of generic WSPs; or the use of guides to aid local development. Implementation of both these strategies is described in chapter 13 of the WHO report.³²⁹

There may be additional barriers to implementation of WSPs in developing countries. These include: limited data on pipe networks, unplanned development, lack of sanitation infrastructure, and other factors. A WEDC report addressing these for urban piped supplies in developing countries is available online.³³⁰

6. Conclusions

This guidebook was designed to be an accessible resource for stakeholders in the water sectors of developing countries. It provides background on climate change in the water sector, expert information on adaptation technologies and practices, and practical guidance on their implementation.

Climate change is projected to adversely impact water resources and water supply. These effects are often exacerbated by other water stressors occurring in parallel, including population growth, land-use change and increasing per capita water demand. Mitigation alone will be insufficient to prevent substantial impacts on the water sector, particularly in developing countries.^{331, 332} The “Delhi Declaration” states that adaptation is of “high priority” for developing countries and includes a demand for “urgent attention and action on the part of the international community.”³³³

Eleven technologies and practices for climate change adaptation in the water sector are described in detail here. Four additional adaptation strategies are also presented briefly. This is by no means an exhaustive list of possible adaptations; however, it is meant to cover key adaptation options that range in scale from the individual household to a city or region.

Recurring themes emerged when describing the implementation of these diverse adaptation strategies. These included the importance of preliminary steps to ensure that interventions are efficient and effective. Many of these preliminary steps involve data gathering and understanding supply of and demand for water. For example, accounting for the current distribution and repair status of water points in rural areas is essential to maximize the impact of rural water programmes. Integrated water resource management (IWRM) and water safety plans (WSPs) provide approaches to data gathering in water resources and water supply. Another key theme that emerged was the importance of local policies and legal frameworks for many of the strategies. For example, water rights laws vary widely and can enable or rule out community efforts to collect rainwater and runoff.

Finally, adaptation should not be understood as simply implementing the correct technology or practice. It should be part of a coherent, inter-sectoral strategy to ensure sustainable water resources and safe water supply. Two broad frameworks were introduced to help guide decision-making for climate change adaptation in the water sector: IWRM and WSPs. Further detail and resources for applying these two strategies to climate change adaptation are provided in Appendix II.

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Appendix I: Glossary

Apparent losses – The percentage of non-revenue water in a piped water system that does not include leakage and is usually attributed to unauthorized consumption and/or meter inaccuracies (see also: Non-revenue water, Real losses)

Apron – A concrete pad that directs water away from a wellhead, preventing infiltration of water from the surface

Augmentation – The practice of supplementing an existing primary water supply with water from a secondary source

Borehole – A narrow hole penetrating bedrock and entering a water-bearing zone of the subsurface. Boreholes are similar to tubewells, but with casing not extending below the interface between unconsolidated soil and bedrock. Boreholes require a drilling method with an external power source. (see also: Tubewell)

Brackish – Referring to water that has less salinity than ocean water but more than fresh water, usually as a result of fresh and ocean waters becoming mixed in estuaries

Bund – A fabricated embankment or wall used to direct or contain the flow of water

Casing – A rigid housing, usually made out of PVC, metal or similar material, that prevents the collapse of a tubewell or borehole. These are often “screened” to allow water to flow into the casing.

Catchment – A surface, natural or constructed, where precipitation lands

Catchment area – A geographic basin over which surface water from precipitation is conveyed to a single outlet point, where it usually joins a river, lake, reservoir, estuary, wetland, sea, or ocean (alternative terms: drainage basin, catchment basin, drainage area, river basin, water basin, watershed; see also: Watershed)

Coagulant – A chemical that is added to water in order to condition suspended, colloidal, and dissolved matter for aggregation, precipitation and removal by gravity sedimentation and/or filtration (alternative term: flocculent)

Concentrate – A high-concentration solution of water, ions and other components that were retained in a membrane treatment process after the “pure” treated fraction has passed through the membrane (alternative terms: retentate, reject water, brine)

Conductivity – The ability of water to conduct an electric charge, which increases as more ionic species are dissolved in the water (see also: Total dissolved solids, Salinity)

Conveyance – Referring to a system of apparatuses and pipes used to direct water flow from a catchment or storage location to another destination (e.g., gutters and pipes used to direct rainwater from a roof into a storage container)

Cost recovery – In water supply, those utilities or community-managed systems that collect sufficient tariffs to pay operations, maintenance and capital costs (e.g., not subsidized by external sources)

Demand-driven, community-managed model – An approach to rural water supply that has become widely accepted. The basic characteristics of water systems developed under this framework are: (1) driven by consumer demand; (2) managed by a community water committee; (3) require partial recovery of capital

costs; (4) require full recovery of operations and maintenance (O&M) costs; (5) ensure the availability of spare parts for purchase through local markets; and (6) include a larger role for women in decision-making.

Desalination – The practice of removing dissolved solids from seawater or brackish water using membrane, thermal or other treatment processes (alternative terms: desalinisation, desalinization, desalting)

Direct potable reuse – The intentional introduction of reclaimed water into distribution systems or other supplies meant for human consumption

Drought – A temporary condition in a climate pattern that occurs due to low precipitation and/or high evapotranspiration. This is in contrast to aridity, which is the “ordinary” climatic condition for some areas.

Dual systems – A piped network that allows water from different sources to be distributed separately for different uses (e.g., a distribution system that includes one set of pipes for “high-quality” drinking water and another for lower-quality water to be used for irrigation or fire fighting)

Dugout – An alternative term for small reservoir (see also: Small reservoir)

End-product testing – The testing of water for biological or chemical contaminants immediately after it has passed through a water treatment chain

Environmental Kuznets Curve (EKC) – A curve that illustrates the theoretical relationship between per capita income and the use of natural resources and/or the emission of wastes as an inverted U-shape: the use of natural resources and/or the emission of wastes increases with income at relatively low incomes and then begins to decline with income as more resources are directed to conservation and environmental quality

Environmentally sound technology (EST) – A technology that has the potential for significantly improved environmental performance relative to other technologies for which it is a substitute; such technologies limit pollution, recycle or reuse their wastes and products, and use resources in a sustainable manner

Evapotranspiration – The process by which water vapor is released into the air by evaporation, from water bodies and surfaces, and by transpiration, through uptake by plants and subsequent release of water through leaves

First flush – The initial runoff from a rooftop after a rainstorm, generally representing the first few mm of rainfall following a dry period. The first flush usually contains higher relative concentrations of various particulate, organic and microbiological contaminants than later runoff. This portion of the rainfall is commonly diverted away from storage using some form of diversion device.

Flood – A temporary inundation of water onto land not normally covered by water

Health-based target – A desired level of health protection for a given exposure which can be based on a measure of overall disease or on the absence of a specific disease

Indirect potable reuse – The use of reclaimed water for recharging ground water aquifers or augmenting surface water reservoirs that are used as sources for potable water supply (contrast with: direct potable reuse)

Integrated water resource management (IWRM) – A systematic, inter-sectoral policy approach to the sustainable development, allocation and monitoring of water resources in the context of social, economic and environmental objectives

Leak management – A collection of pro-active approaches to prioritizing leak detection and controlling system pressure to reduce leakage losses in piped water systems.

Low-level equilibrium – A water supply scenario in which low quality, coverage, and net revenues are perpetuated by severe organizational inefficiencies and in which there are few incentives for new users to connect to the system

Membrane treatment – A modern physicochemical separation technique in which water is pumped against the surface of a semipermeable synthetic material so that product water passes while other, generally larger, constituents remain in the waste stream. Types of membrane treatment processes currently used in municipal water treatment include, in order of decreasing permeability: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse-osmosis (RO)

Micro-catchment – An area with contoured slopes and barriers designed to divert or slow runoff so that it can be stored before it can evaporate or enter watercourses. Micro-catchments are often used to “store” water as soil moisture for agriculture.

Nonpotable – Referring to water that is unfit or unsafe for consumption because it contains physical, chemical or microbiological contaminants

Nonpotable reuse – The use of reclaimed water for purposes other than consumption, such as agricultural irrigation and groundwater recharge

Non-revenue water (NRW) – The difference between the volume input to a municipal distribution system and the volume billed under authorized consumption, which consists of unbilled authorized consumption, apparent losses, and real losses; has come to replace the term “unaccounted-for water” (see also: Unaccounted-for water)

Point-of-use (POU) – The location where water is consumed or used for daily tasks. This term is usually used to refer to treatment of drinking water in the home.

Post-construction support (PCS) – A broad variety of programmes meant to provide ongoing financial, technical, administrative, legal and O&M support to community-managed water systems.

Potable – Referring to water of sufficient physical, chemical and microbiological quality to be suitable for human consumption

Product water – In membrane treatment, the fraction of water that has passed through a membrane (alternative term: permeate)

Real losses – The volume of water that is physically lost from a network before it reaches a consumer’s water meter, due to overflow of storage tanks or to leakage. Real losses account for a percentage of total non-revenue water. (see also: Apparent losses, Non-revenue water)

Recycled water – An alternative term for wastewater that has been treated and can be used for potable and/or nonpotable purposes, which is generally thought to be more culturally acceptable than “reclaimed water” (see also: Water reclamation, Water reuse)

Reverse osmosis (RO) – A type of membrane treatment process that utilizes high pressure to overcome natural osmotic pressure and separate dissolved constituents from water. RO is used for such purposes as desalination of seawater or brackish water and removal of specific contaminants such as NOM from surface waters and color from groundwaters. (see also: Membrane treatment)

Runoff – The portion of precipitation or snow melt that does not infiltrate into the subsurface but rather flows overland

Salinity – The total amount of all salts dissolved in water, generally expressed in parts per thousand

Small reservoir – A basin, usually surrounded by earthen banks, that is used to collect flows from rivers, streams or other natural watercourses. They are typically used by small communities as a source of domestic and agricultural water.

Tank/village tank – An alternative term for small reservoir, commonly used in south Asia (see also: Small reservoir)

Tariffs – The prices assigned to water supplies provided by a public utility through a piped network to its customers. Volumetric tariffs (cost/m³) often vary depending on monthly consumption. (alternative term: water rates)

Total dissolved solids (TDS) – A measure of the total mass of solids dissolved in a volume of solution and excluding suspended solids (typically expressed in mg/l) (see also: Salinity, Conductivity)

Transpiration – The process by which water is taken up by plants (mostly through the roots) and lost as water vapor through the leaves and other parts of plants (see also: Evapotranspiration)

Tubewell – A narrow, screened tube or casing driven into a water-bearing zone of the subsurface. Some tubewells are installed by hand-auguring while others require an external power source. (see also: Borehole)

Unaccounted for water (UFW) – The difference between the volume input to a municipal distribution system and the volume billed under authorized consumption, which consists of unbilled authorized consumption, apparent losses, and real losses; has been replaced in common practice with “non-revenue water” (see also: Non-revenue water)

Unauthorized consumption – The intentional withdrawal of water from a municipal distribution system in a manner that is unapproved by the water authority such as tapping illegal connections or using water from fire hydrants for domestic purposes

Unintentional reuse – The natural or unplanned use of treated wastewater that occurs as a result of treated wastewater discharge to water sources that are used for water supply by the same or other communities (alternative terms: incidental reuse, unplanned reuse)

Water audit – In piped water distribution, the process of systematically monitoring water inputs, flow throughout the distribution system, and customer use during a low-flow period (at night) to quantify losses and identify zones with high leakage

Water fixture – A valve or accessory that controls the release of water from a domestic plumbing or municipal distribution system without requiring electrical power (e.g., a faucet or a showerhead)

Water reclamation – The treatment or processing of wastewater to make it reusable with definable treatment reliability and meeting appropriate water quality criteria

Water reuse – The use of treated wastewater (or reclaimed water) for a beneficial purpose

Water stress – A state of low water availability per capita, typically defined as less than 1700 m³/capita/year (see also: Water scarcity)

Water scarcity – A state of low water availability per capita, typically defined as less than 1000 m³/capita/year (see also: Water stress)

Water supply chain – The means by which water makes its way to the consumer, including catchment, transport, treatment, and distribution. An assessment of potential hazards in each element of a water supply chain is a key component of water safety plans (WSPs).

Watershed – The entire geographical area over which precipitation drains to a given body of water (see also: Catchment area)

Appendix II: Recommended Sources for Additional Information

These resources were selected from among those cited within the chapters and appendices of this guidebook. This is meant to be a selection of the resources that will be most helpful to a broad range of stakeholders in the water sector. They are written in a way that is accessible to non-experts and nearly all are freely available online.

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Appendix III: Decision-making Frameworks—IWRM and WSPs

The list of adaptation technologies and practices presented in this guidebook is by no means exhaustive. Additionally, climate change adaptation in the water sector should not be undertaken as a series of technologies and practices implemented in isolation. Adaptation should be one facet of an integrated and intersectoral approach to water resources and water supply.

Two frameworks for approaching climate change adaptation in the water sector are presented here: integrated water resources management (IWRM) and water safety plans (WSPs). These two approaches and their potential contributions to climate change adaptation are described here briefly, with citation of key resources for those readers who desire to explore them further.

Integrated Water Resource Management

Historically, management of water resources in many countries has tended toward supply-oriented and engineering-dominated approaches. As pressure builds on water resources worldwide, there has been a transition toward demand-oriented, intersectoral approaches. The Dublin Statement on Water and Sustainable Developmentⁱ in 1992 laid the foundation on which Integrated Water Resources Management (IWRM) was built.ⁱⁱ Growing evidence that the IWRM approach can improve outcomes in water resources has led to its adoption in many settings.ⁱⁱⁱ

The IPCC Fourth Assessment Report of 2007 identified IWRM as “an instrument to explore adaptation measures to climate change” while lamenting that it was still “in its infancy.”^{iv} Since then, a substantial amount of research has been conducted on application of IWRM in various settings and its relevance to climate change adaptation.

An ideal introduction to both IWRM and its use in climate change adaptation are the training manual^v and supporting presentations^{vi} developed by Cap-Net, a network of UN and other international agencies. Cap-Net prepared these resources to fit the format of a short instructional course for water managers and climate change adaptation policy developers. However, they contain conceptual and practical knowledge presented at a level appropriate for a broad range of stakeholders.

The impacts of climate change on the water sector are uncertain and are projected to vary between settings.ⁱ Therefore, widely applicable climate change adaptation frameworks in the water sector should increase the resilience of populations under any plausible climate scenario. According to Cap-Net, IWRM provides a framework that is:

- Robust: not event-driven, includes cross-sectoral integration of development policy goals for meeting both current and future needs
- Flexible: not based on one scenario only, ideal combination of measures
- Adaptive: able to function under uncertainty and adjust the management approach based on the outcomes of implemented strategies and taking into account new realities

Although there is widespread agreement on the importance of the main principles of IWRM, its implementation in the real world can be challenging. Common barriers to implementation include entrenched sectoral interests, professional insecurities, transboundary conflicts, and sociocultural aspects of water.^{ii,iv} However, overcoming the barriers can substantially improve resilience to climate change across all sectors with substantial demand for water demand.

Among the key resources not cited above are an annotated list of references for “all those interested in getting familiar with IWRM issues” published by UN-Water. It contains brief descriptions and internet links for over 20 UN publications on IWRM. Included among these are guidance documents and case studies for implementing IWRM in Africa, Asia and Latin America.^{vii} Among the documents cited in this list of references is the 2008 “Status Report on Integrated Water Resources Management and Water Efficiency Plans.” It provides an overview of the status of IWRM implementation in over 100 countries, including 77 developing countries.

Water Safety Plans

IWRM addresses primarily water resources management and quantity. The IPCC predicts that climate change will lead to degraded water quality. Projections include an increase in cyanobacterial activity, physical and chemical contamination of water bodies, and saline intrusion.^{viii}

WSPs can supplement IWRM by providing a specific framework for ensuring the safety and quality of water supply. When implemented successfully, the WSP approach can ensure that water quality is maintained in almost any context. WSPs are described at length in Section 4 of this guidebook. The monitoring, management and feedback components of a successful WSP enable flexibility, adaptability and robustness necessary to protect water supplies in an uncertain climate.

Endnotes

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This guidebook focuses on adaptation technologies and practices in the water sector. The scope of the water sector is defined by the IPCC as freshwater resources and their management. Eleven technologies and practices are described in detail here. These technologies and practices are categorized according to their contribution to climate change adaptation: diversification of water supply, groundwater recharge, preparation for extreme weather events, resilience to water quality degradation, stormwater control and capture, and water conservation.

This publication is authored by Mark Elliott, Andrew Armstrong, Joseph LoBuglio and Jamie Bartram of the Water Institute at the University of North Carolina at Chapel Hill. Professor Bartram is Director of the Institute. He was formerly the Coordinator of the World Health Organization's Water, Sanitation, Hygiene and Health programme and was the first Chair of UN-Water. The authors describe adaptation technologies from source to consumer and discuss the interfaces between water, health, development and climate change.

The guidebook will be used by the national TNA teams, which consist of stakeholders from government, non-government organizations and the private sector.

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