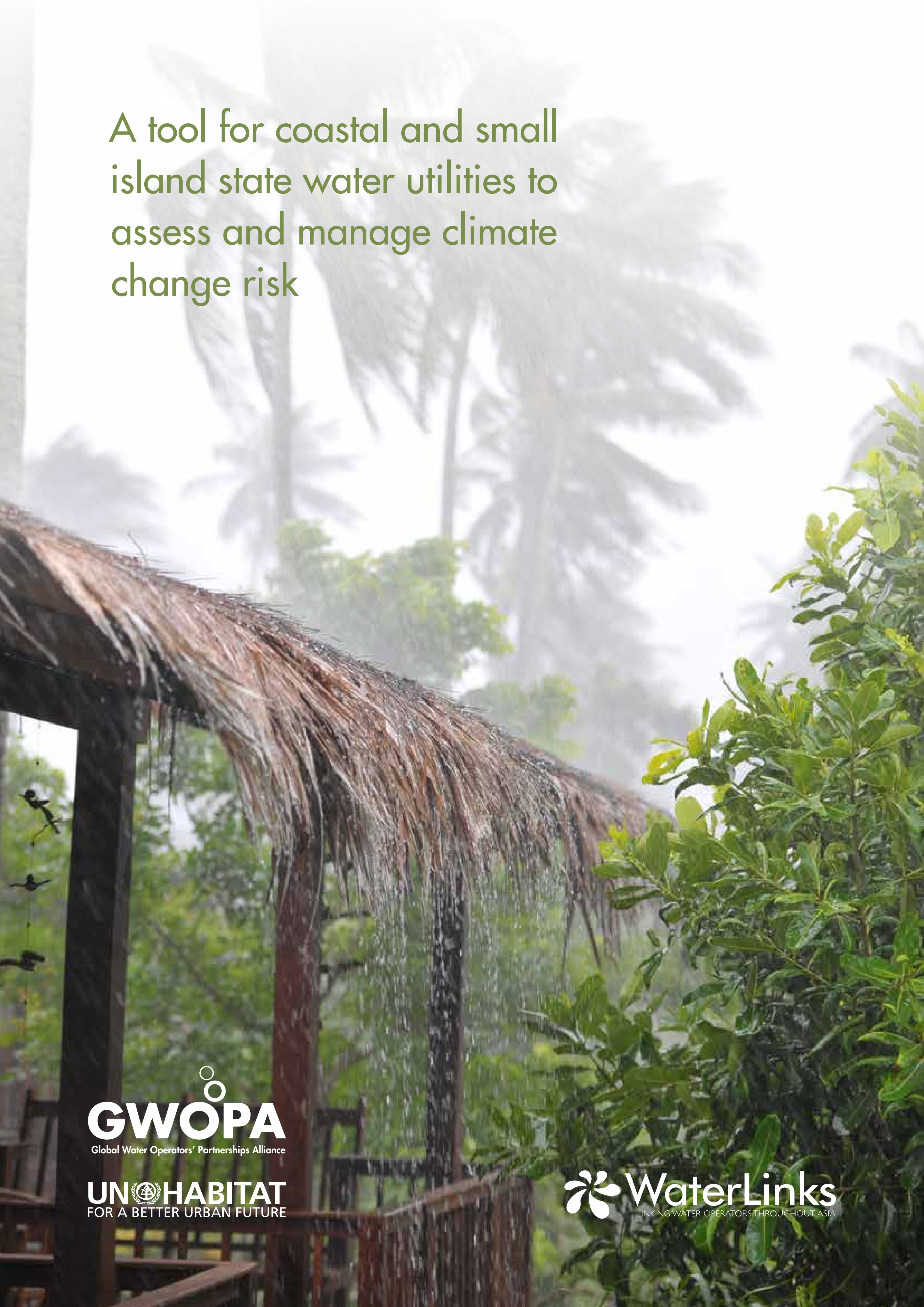
A tool for coastal and small island state water utilities to assess and manage climate change risk



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CONTENTS

PREFACE

Climate Change[1] iis big news all over the world. Ironically, water usually finds mention in the footnotes even though it is arguably the principal adverse fall-out of changing climate patterns and extreme weather events.

Since 2008, more than half of the world's population already lived in cities. This figure continues to grow, particularly in Africa and Asia, and coastal urban centres receive a disproporionate share of this growth. Urbanization can be a positive force, however safe, adequate, and predictable water supplies are a necessary feature of sustainable urban development.

Coastal water utilities and those of small island states, especially in the developing world, already bear the brunt of climate change, often to much higher degrees than their inland counterparts. Sharper, more concentrated rainfall or drier and longer periods without it; salt water intrusion; floods; and droughts, all take a heavy toll on the utilities' ability to fulfil their objectives.

This guidebook is designed to help utilities identify and assess climate change manifestations that impact adversely on their operations and formulate a credible response. It draws principles from the Water Operators' Partnership (WOP) between Yarra Valley Water, Melbourne, and the National Water Supply and Drainage Board, Sri Lanka and is targeted towards coastal and small island states. However the tool has universal application, especially in a developing economy environment such as those obtaining in Asia, Pacific, Latin America or Africa, which have limited capacities to conduct local vulnerability assessments, and where data availability and quality are often poor.

In light of the fact that many utilities have deficits in data and technical capacities, the guide offers two approaches. The first, a 'top-down' approach is recommended where the needed data is readily available. The second, a 'bottom-up approach' can serve utiliites that cannot easily aquire such data for decision making. Before undertaking the assessment process described in the guide, the utility should take time to review its contents and requirements, and based on an internal review of financial resources and technical capacities, the technical operations management can determine which approach is best for them.

Cognizant of the technical demands of the exercises that follow, the guide also endeavors to help utilities build their own understanding and capacities in dealing with climate change. Those utilities that mainstream long-term climate change monitoring and impact resolution into their operations will clearly benefit the most.

Utilities may want to pursue the excercises herein with the help of an external expert or partner utility that has extensive experience in conducting their vulnerability assessments. WOPs can also be helpful in implementing broader changes and improvements that may be identified through the exercises in the tool. It would be useful to identify utilities that are more prone than others to climate change impacts and assist them to prepare adaptation plans on the basis of this tool using a Water Operators' Partnerships (WOP) approach. This would ensure early testing of the tool and provide immediate benefit to affected utilities.

The authors received valuable technical insights from Yarra Valley Water, Melbourne; Palm Beach County Water Utility, Florida; National Water Supply and Drainage Board (NWSDB), Sri Lanka; and Seattle Public Utilities, Seattle. They peer-reviewed the tool; nonetheless, we remain responsible for all errors or omissions. We also consulted with Manila Water and Maynilad, the two concessionaires in Metro Manila, as also the National Water Resources Board of the Philippines, as well as the Metropolitan Water and Sewerage System. Their suggestions are gratefully acknowledged. Finally, we wish to thank the the authors Arjun Thapan, Chairman of WaterLinks, and Claudius Gabinete, United States Agency for International Development through the WaterLinks Alliance Project, without whose sustained support, insights, and technical contributions, this tool would not have seen the light of day.

This tool was prepared with support from the Cities and Climate Change Initiative and Global Water Operators' Partnerships Alliance of UN-Habitat. We hope that this tool will stimulate interest in utilities building greater resilience to climate change and adapting intelligently to a new environment. Comments, questions, and suggestions will always be welcome.

UN-Habitat

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[1] Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2013).

EXPLANATORY NOTE

What to expect from the Tool

Climate change manifests itself through variable precipitation, saline ingress, and extreme weather events such as floods and droughts. This tool will enable coastal water and wastewater utilities to assess their water resources for climate-related risks. It will help utilities to (i) understand the issues, (ii) assess the range and scale of climate change impacts to their water availability, (iii) identify a set of options, and (iv) identify an implementable program of response to ready themselves.

The current edition of the tool, by its intent and design, focuses on climate vulnerability and risk assessment of the utility's water resources. Although it offers guidance on the initial steps in identifying the potential range of adaptation options that utilities can take, it does not delve extensively into how these options can be implemented. There is an abundance of literature available to address water resource availability and quality problems, flooding and other water and sanitation problems that are anticipated to arise more frequently under climate change. The tool will be updated to address any novel impacts that may be identified later on.

The tool offers two approaches to assessing climate vulnerability and risk. The Top-down[2] approach incorporates a scientific outlook to identifying and assessing climate change impacts that will enable the design of a credible adaptation program. This approach is highly technical in nature and requires significant financial and time inputs, lasting for more than a year. The Bottom-up approach offers a more intuitive but evidence-based path to understanding climate change scenarios, impacts on operations, and options for mitigation. It is less technical, requires fewer resources and needs less time to resolve.

The two approaches are not mutually exclusive. In fact, these two can be complementary. The tool offers the two as separate approaches to highlight their distinct techniques and perspectives. There are cases where both approaches were combined – top down analyses utilizing downscaled projections and impact scenarios, and bottom-up practices involving multi-stakeholder forums to identify and build a range of adaptation responses based on the climatic (identified in top-down) and non-climatic (driven by economic, social, political vulnerabilities and capacities) scenarios (identified during stakeholder consultations). The blend of what elements from each approach or assessment model that can be included in a combined approach depends on the capacities and institutional willingness of the utility or participating utilities, in case of water operator partnerships or WOPs.

Choosing the best approach to take is not straightforward, and can be uncertain at times. This is a decision that rests on an internal review of the utility's financial and technical resources, and the political support and willingness of the regulator (s) and local government(s) in the area(s) the utility operates. Moreover, if the utility opts for a WOP, the selection would also be contingent on the mentor's capacities and limitations.

The 12 exercises under Top-down approach in the tool will allow you to produce the following outputs:

- Range and scale of exposure and sensitivity of your assets including water and wastewater facilities, machines and equipment, to extreme weather events such as storms, floods and droughts;
- Indicative trends and likely amounts of water lost (or gained) due to variability in precipitation, both current and projected, from surface and ground water resources;
- Indicative trends in concentration of salinity in your existing ground water resources, both current and projected;
- Range of adaptation options and technologies that you can deploy;
- A communications strategy that will enable you to pursue a continuous dialogue with your principal stakeholders; and
- A final implementation plan that you will need to action.

The Bottom-up approach endeavors to elicit similar outcomes through the outputs below:

- Critical climate variables and the water utility's sensitivity to these;
- Water system responses to a range of potential climate changes;
- Vulnerability of the water utility to climate change impacts;
- System performance according to the uncertainty associated with climate change factors driving the water utility's vulnerability; and
- Overall system risk analysis and areas in need of further analysis.

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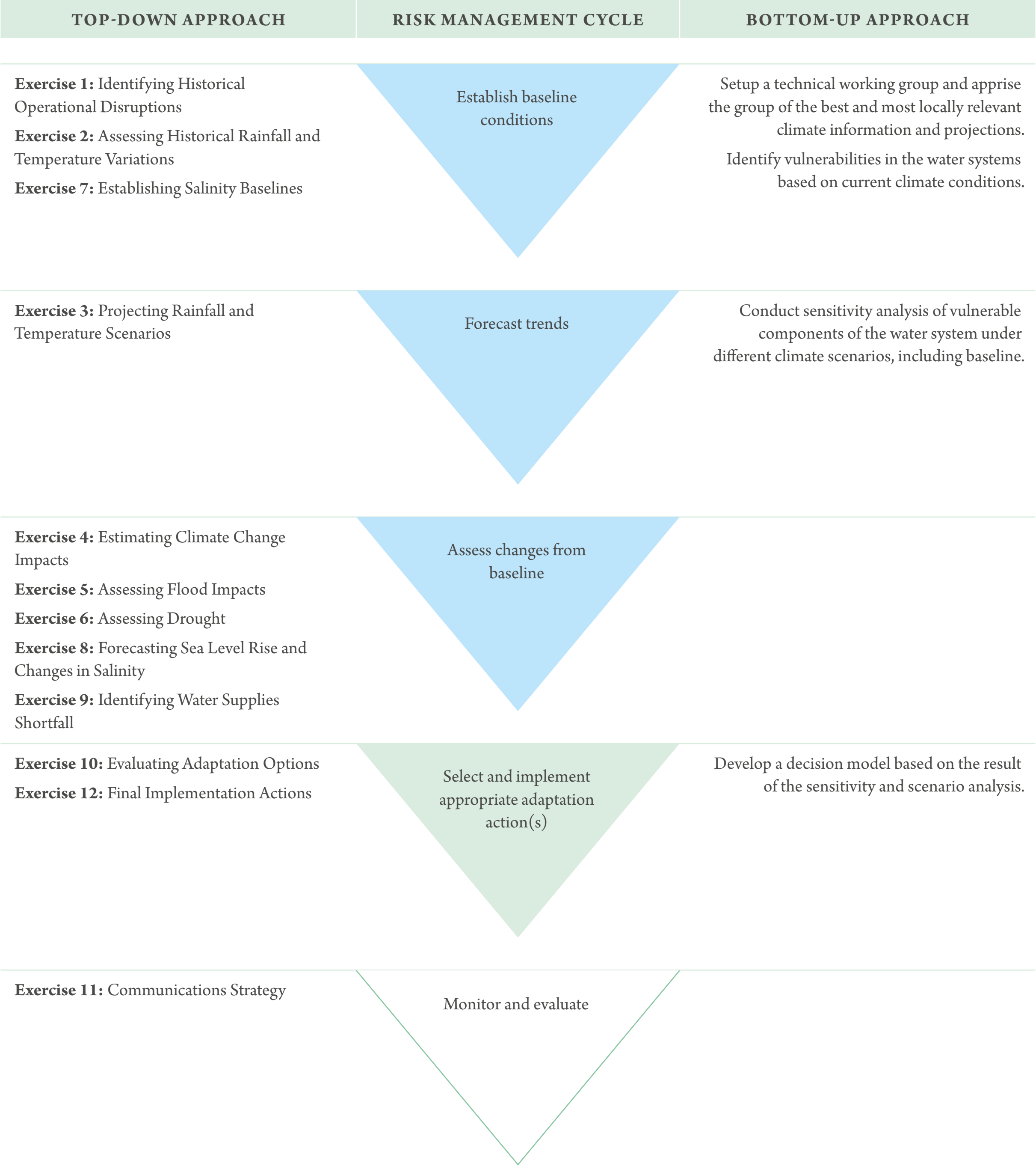
[2] The Top-down approach is so called because of the use of the downscaled general circulation climate models to commence the study of impacts and design adaptation solutions. For a more detailed definition of the top-down and bottom-up methodologies see 'Climate Change and Urban Water Utilities – Challenges and Opportunities' published by the World Bank in April 2010.

FIGURE 1: Climate change risk management cycle



TOP-DOWN APPROACH	RISK MANAGEMENT CYCLE	BOTTOM-UP APPROACH
Exercise 1: Identifying Historical Operational Disruptions **Exercise 2:** Assessing Historical Rainfall and Temperature Variations **Exercise 7:** Establishing Salinity Baselines	Establish baseline conditions	Setup a technical working group and apprise the group of the best and most locally relevant climate information and projections. Identify vulnerabilities in the water systems based on current climate conditions.
Exercise 3: Projecting Rainfall and Temperature Scenarios	Forecast trends	Conduct sensitivity analysis of vulnerable components of the water system under different climate scenarios, including baseline.
Exercise 4: Estimating Climate Change Impacts **Exercise 5:** Assessing Flood Impacts **Exercise 6:** Assessing Drought **Exercise 8:** Forecasting Sea Level Rise and Changes in Salinity **Exercise 9:** Identifying Water Supplies Shortfall	Assess changes from baseline	
Exercise 10: Evaluating Adaptation Options **Exercise 12:** Final Implementation Actions	Select and implement appropriate adaptation action(s)	Develop a decision model based on the result of the sensitivity and scenario analysis.
Exercise 11: Communications Strategy	Monitor and evaluate	

Note: The climate change risk management cycle is an iterative process. Blue colored groups of exercises denote the focus areas of the tool, while the green colored group receives less attention. Monitoring and evaluation are critical in a sound risk management process but outside the current scope of the tool.

How to use the Tool

The tool has 3 main parts: an introduction that discusses the background, the manifestations of climate change, and its principal impacts; the Top-down Approach that incorporates 12 exercises by identifying historical operational disruptions through to final implementation plans, and; the Bottom-up Approach that describes what the 5-week program of action should typically encompass. Impact assessments are made for each variable that affects supply and demand.

Following the principles of climate risk management cycle, this tool is structured to comprise the above five sequential main groups of exercises for each climate change impact area. These exercises are essential elements in getting your water utility ready for climate change. Specific data requirements and activities in each impact area are highlighted in each section.

Water Operators' Partnerships are a potential source of support for acquiring the knowledge, technical and technological required to assess climate change problems in a utility's water resources. They can also help utilities establish a credible adaptation response mechanism in countries with a deficit of data and technical skill or which have less experience in directly addressing water resource related climate change impacts. Utilities looking to engage in a WOP should involve the mentor even before the process starts. This provides the opportunity for both parties to settle on the assessment model(s) or approach(es) they are comfortable with and able to use. Establishing baseline conditions is not a technically intensive activity. However, forecasting future trends and impacts (changes from baseline) would often require external expert assistance apart from a mentor utility.

Chronology and Time Requirements

Note that the assessments described in the exercises under the Top-down Approach vary greatly in terms of preparation and implementation time required. In order to maximize resources, the tool recommends that utilities begin with the exercises related to stocktaking of historical and baseline information first, starting with Exercises 1 and 2. Analyses required for Exercises 3, 5 and 6, and elsewhere in tool should not take more than two months for a dedicated team of staff. Preparation for Exercises 4, 7, and 8 may take time depending on the availability of historical data and existing monitoring systems. The baseline data collection for groundwater resource estimation and salinity intrusion assessment parts in these exercises should be conducted at the same time, whether there is existing historical data or not, and could be accomplished within 12 months. The outputs from these two exercises are required for Exercises 8 and 9. Adaptation options can only be evaluated after the first 9 exercises have been completed. Ideally, a utility should be able assess the potential impacts of climate change to its operations and determine its adaptation action(s) within 20 months.

The communications strategy (Exercise 12) should be completed within the first two months of the program. It is crucial that the utility's initial effort towards climate-proofing water and wastewater systems be effectively communicated to all staff and management levels within the organization. Table 1 provides a sample work plan on the period of time within which all 12 exercises can be completed.

Progress and results of the assessment, as well as the potential adaptation options, should be disseminated to all identified stakeholders throughout the program period. A sample template outlining the salient results of tool exercises is given in Appendix A.

Scope and Limitations

The tool is essentially a climate change vulnerability and risk assessment guide for water utility operators. It addresses the following water and wastewater issues that may be exacerbated by climate change (i) water availability from surface and groundwater resources; (ii) extremes in the form of flood and drought; and (iii) saline intrusion. It also attempts to address differences in the capacities of utilities in terms of financial and technical capabilities by offering top-down and bottom-up approaches.

Due to limitations in current literature, the tool does not address the impact of potential increase in contamination of water supply due to anticipated higher temperatures. It is also, by design, limited in addressing the impacts of storm, floods, and droughts for which a wide range of literature and guidelines from well-established sources already exists. The tool also does not venture into areas such as protection of infrastructure or preparing of emergency response plans.

Managing Uncertainty

While the tool provides steps for discrete calculations, we recommend that the results be considered as indicative and not definitive. The results of climate models and equations incorporate a degree of statistical uncertainty and should not be taken as absolute. However, do note that while specifics on how much climate change will really affect us are not laid out as neatly as we hope, there is clear evidence that human activities have caused the earth to warm over the past five decades (and will continue to do so if our current carbon-intensive development pathway is unabated). The same is true with the figures that will result when estimating water availability. The rule of thumb is that if there is a positive trend in a factor (e.g., decreasing water availability) that will undoubtedly impact your utility's operation (i.e., potential risk), the tool recommends hedging in favor of managing and abating the risk (i.e., taking a no-regrets stance), rather than fumbling due to inaction over statistical nit-picking. This crucial element in managing risks, or uncertainty, needs to be communicated effectively – the problem needs to be framed, often with negative undertones, in a way that triggers caution – to elicit support and understanding up and down the management chain.

Use of Software Packages

The authors reviewed several software packages that generate downscaled climate change projections; these are essential in forecasting potential changes in local water resources unless utilities have recourse to other resources such as universities, meteorological departments, or weather observatories. For those utilities that choose to use such software, we suggest that the following be kept in mind:

- ease of use;
- low equipment requirements;
- low technical expertise requirements;
- inter-operability, portability and extendibility of data inputs and outputs;
- continuous upgrade and support; and
- existing wide user base and application.

TABLE 1: Sample Assessment Work Plan

	MONTH													
	1	2	3	4	5 ...	12	13	14	15	16	17	18	19	20
Exercise 1	🟩	🟩												
Exercise 2	🟩	🟩												
Exercise 3			🟩	🟩										
Exercise 4			🟩	🟩	🟩	🟩	🟩	🟩	🟩					
Exercise 5				🟩	🟩									
Exercise 6				🟩	🟩									
Exercise 7			🟩	🟩	🟩	🟩	🟩	🟩	🟩					
Exercise 8									🟩	🟩				
Exercise 9										🟩	🟩			
Exercise 10											🟩	🟩	🟩	
Exercise 11	🟩	🟩	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Exercise 12														🟩

LIST OF ACRONYMS

AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
CMIP5	Coupled Model Intercomparison Project Phase 5
GCM	Global Circulation Model
IPCC	Intergovernmental Panel on Climate Change
NRW	Non-revenue water
RCP	Representative Concentration Pathway
SLR	Sea level rise
SWI	Salt water intrusion
TDS	Total dissolved solids
UHI	Urban heat island
UNFCCC	United Nations Framework Convention on Climate Change
WOP	Water Operators Partnership

INTRODUCTION

Coastal city and small island states' water utilities suffer uniquely from climate change impacts. Changes in sea levels because of ocean warming and melting of land ice stores, heightened intensity of rainfall, or its absence, and a greater propensity to be hit by storms, cyclones, and tidal surges, impact them particularly and distinguish them from utilities based further inland. The table below highlights the largest cities in the world that are already experiencing water-stress.

TABLE 2: Largest cities under water-stress

URBAN AGGLOMERATION	COUNTRY	POPULATION (2010)	SOURCES
Tokyo	Japan	36,993,000	Surface (WG)
Delhi	India	21,935,000	Surface (WBM, WG), Ground
Mexico City	Mexico	20,142,000	Ground (stress), Surface
Shanghai	China	19,554,000	Surface (WBM, WG), Ground
Beijing	China	15,000,000	Ground (stress), Surface
Kolkata	India	14,283,000	Surface (WBM, WG), Ground
Karachi	Pakistan	13,500,000	Surface (WBM, WG), Ground
Los Angeles	United States	13,223,000	Surface (WBM, WG), Ground
Rio de Janeiro	Brazil	11,867,000	Surface (WG)
Moscow	Russia	11,472,000	Surface (WBM, WG), Ground
Istanbul	Turkey	10,953,000	Surface (WG), Ground
Shenzhen	China	10,222,000	Surface (WG)
Chongqing	China	9,732,000	Surface (WBM), Ground
Lima	Peru	8,950,000	Surface (WG), Ground (stress)
London	United Kingdom	8,923,000	Surface (WBM, WG), Ground
Wuhan	China	8,904,000	Surface (WBM, WG), Ground
Tianjin	China	8,535,000	Surface (WBM, WG), Ground
Chennai	India	8,523,000	Surface (WG), Ground
Bangalore	India	8,275,000	Surface (WG), Ground
Hyderabad	India	7,578,000	Surface (WBM, WG), Ground

Note: WBM = Water Balance Model shows stress, WG = WaterGAP model shows stress
Source: (McDonald, et al., 2014)

Assessing the nature and scale of climate change and making forecasts of climate behavior is fraught with considerable uncertainty. Climate Change General Circulation Models (GCMs) are global instruments that can be downscaled to regional levels with some loss of resolution and reliability. Downscaling to city level is technologically resource intensive, and downscaled models may have dubious reliability due to insufficient or lack of systematically collected local climate-related data.

What can utilities do to acquire a greater degree of certainty in modeling climate change in their operating environments so as to better understand their current and anticipated problems? Obviously, downscaled GCMs to city levels are worth using where the data is of sufficient detail and quality to be useful in making reasonable extrapolations. A more practical approach[3], however, and certainly in those cases where downscaled GCMs are not possible, would be to identify and assess climate change impacts on water availability in current or prospective surface and ground source areas, water quality, rainfall or flooding.

Once the impacts on availability have been identified, and their nature and magnitude on utility operations assessed, choices need to be made. One option is to forge a no-regrets approach. Essentially, this will be a full-scope program of remediation and adaptation that incorporates all of the utility's needs to provide high quality service to consumers in a long-term framework. This may include capital works programs that the utility has already included in its budget as well as additional programs (such as operational adjustments or non-structural strategies) that may be needed as a consequence of the impact analysis. The other option is to adhere strictly to a program that responds most effectively to climate change impacts. Utilities can apply adaptive solutions that can be modified in the future based on potential climate impacts which can be better quantified as the science and analysis improves. There will most likely be areas of overlap in elements of both approaches, e.g. creating new water as a consequence of growing demand will also be a requirement as insurance in the event of changes in precipitation levels and patterns, and frequent and longer dry seasons. But there will also be separating and distinguishing features of the two approaches. Utilities must choose that which affords them the best returns on the investments to be made

The Faces of Climate Change

The principal manifestations of climate change in coastal cities are:

1. Variable precipitation (increased variability of volume, timing, and area of rainfall)
2. Sea level rise (saline intrusion into surface water sources and groundwater aquifers)
3. Vertical land movement (either positive, i.e. uplift, thus reducing the extent of sea level rise, or negative, i.e. subsidence, that exacerbates the rate and extent of sea level rise)
4. Storms (typhoons, hurricanes, tidal surges) and Flooding
5. Droughts affecting rainfall, streamflow and groundwater recharge.
6. Increase in temperature that impacts on consumption water requirements of the energy, commercial, and industrial sectors

The Impacts on Water Utilities

Utilities require reliable sources of raw water – predictable in amount, in composition or quality, in timing, and in the areas from which raw water is traditionally drawn. Climate change increases natural uncertainty. Rainfall, run off, and stream flows are no longer assured – the worst case scenarios often become the norm. This imposes costs in terms of (i) reduced quantities of water sold, i.e. lower revenues, and lower service levels; (ii) variation in quality (e.g., salinity), necessitating other treatment options; (ii) sub-optimal utilization of treatment and distribution assets, (iii) reduced water recovery from wastewater (in cases of current or potential recycling), (iv) inability to plan expansions in the service area, or meet increased demands from customers, and (v) a decline in customer satisfaction. The economic costs are invariably significant.

Saline intrusion, in some cases up to 100 kilometres inland (e.g. Mekong delta), leaches into surface water sources (rivers, lakes, wetlands, ponds) and also into groundwater aquifers. Since both sources may be accessed by coastal utilities for raw water, primary treatment, followed by full scale desalination is required to remove salt. This requires additional capital and operating costs to set up and run the facilities.

Storms cause heavy damage to utility infrastructure. Raw water intakes are vulnerable, as are treatment facilities, and distribution networks. Power supply sources are impacted, and electric supplies are dislocated. Protecting this infrastructure and building and maintaining redundancies (alternative raw water sources, alternative (albeit) reduced levels of treatment, alternative emergency pumping systems, alternative power supplies, etc.) entails additional capital and operating costs.

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[3] The tool refers to this approach as the Bottom-up Approach, which is discussed in Part C.

Floods, the principal residual components of storms, render utility assets inoperative in variable measure depending on the severity and extent of flooding. Pumps, drives, controllers, electrical switchgear, transmission mains, reticulation systems, etc. are vulnerable to disruption when overwhelmed by floodwaters or impacted by local land and mudslides. Raw water sources (surface and ground) develop high turbidity values, and breaks in the network allow higher levels of pollutants to ingress thereby impacting water quality. Redundancies required to maintain a minimum level of emergency services, and establishment of alternative public distribution systems, involve significant additional costs on capital and operating account.

Droughts impact on raw water availability for indeterminate periods. The tendency for consumers to develop their own groundwater sources leads to unsustainable aquifer decline and exacerbates water shortages while quality can also be compromised. Developing desalination infrastructure as insurance to meet demand is increasingly a necessary option for coastal utilities. The costs of building such infrastructure and maintaining it, together with the costs of mothballing it when not required (as in the case of Sydney, Australia), impact significantly on a utility's bottom line.

Extreme heat events impact on bacterial action and beyond well known thresholds can lead to rapid die-off of bacteria beneficial to the sewage treatment process depending on the nature of the system in place. Recovery times for such events can be from days to weeks and the impact on outfall/debouching points from treatment facilities can cause severe health-related risks to downstream communities. The relationship between treatment plant outfalls and other 'downstream' intakes for freshwater supply need to be carefully considered when risk of contamination from such events exists.

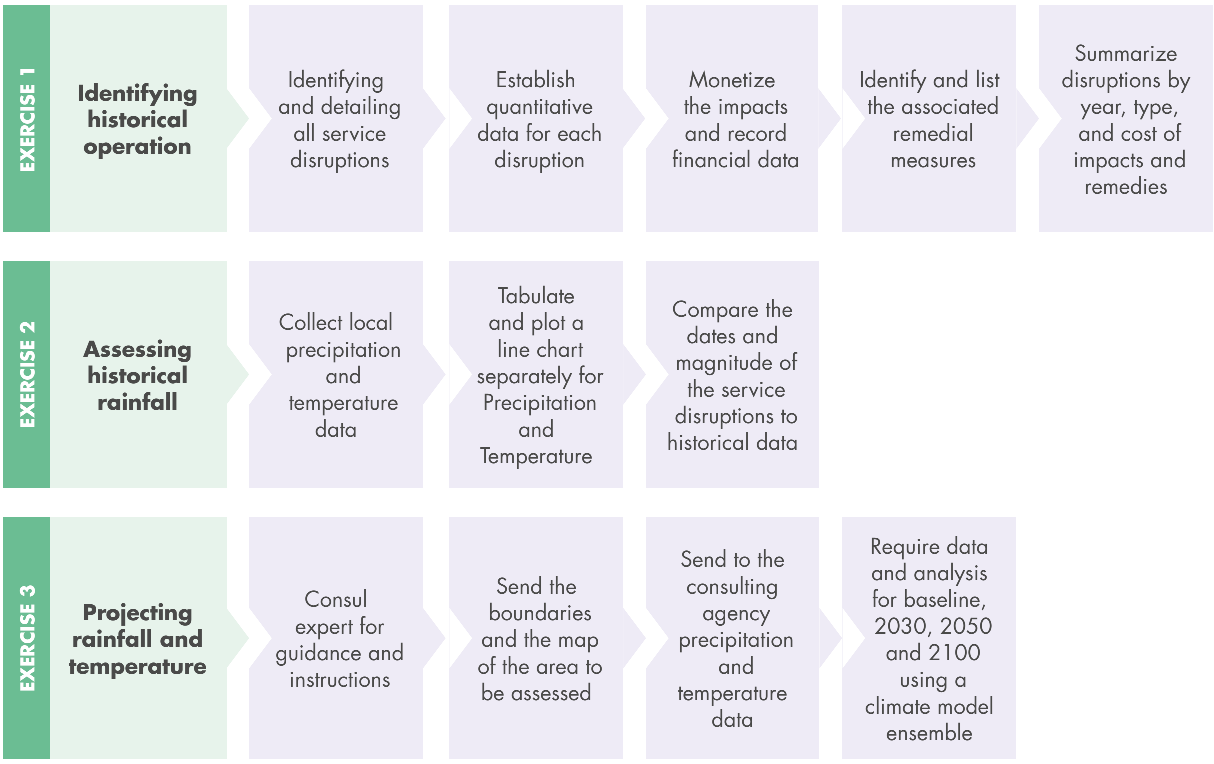
Finally, increased internal flooding is caused by the inability of the existing drainage infrastructure to drain to the outfalls that are affected by higher sea levels. Even otherwise, most coastal city drainage infrastructure is inadequate to cater to flash floods or storm surges.

THE TOP-DOWN APPROACH

UNDERSTANDING THE IMPACTS AND ESTABLISHING CLIMATE BASELINES

Two separate exercises need to be undertaken. The first will identify historical operational disruptions, and the second will analyse historical rainfall and temperature variability.

FIGURE 2: Overview of Tool Processes from Exercise 1 to Exercise 3



EXERCISE 1	**Identifying historical operation**	Identifying and detailing all service disruptions	Establish quantitative data for each disruption	Monetize the impacts and record financial data	Identify and list the associated remedial measures	Summarize disruptions by year, type, and cost of impacts and remedies
EXERCISE 2	**Assessing historical rainfall**	Collect local precipitation and temperature data	Tabulate and plot a line chart separately for Precipitation and Temperature	Compare the dates and magnitude of the service disruptions to historical data		
EXERCISE 3	**Projecting rainfall and temperature**	Consul expert for guidance and instructions	Send the boundaries and the map of the area to be assessed	Send to the consulting agency precipitation and temperature data	Require data and analysis for baseline, 2030, 2050 and 2100 using a climate model ensemble	

EXERCISE 1

Identifying Historical Operational Disruptions

WHY SHOULD WE UNDERTAKE THIS EXERCISE? Climate change has not only materially altered the scale and pattern of the physical and natural environment but will also exacerbate the impact of extreme weather events. It will be helpful for utility managers to collect, assemble, and analyze historical data relating to extreme weather events and disruptions caused to the utility's functioning.

WHAT WILL WE GAIN FROM THIS EXERCISE? The analysis will help managers understand the adequacy of business continuity plans, and whether their implementation was efficient or not. Questions relating to repetitive events, and whether lessons were learnt (including their quality and the efficacy of response to improve matters) will be answered, and managers enabled to think concretely of what might be expected in the future and how it should be dealt with.

WHAT PROCESS DO WE FOLLOW? The data can be collected from a variety of utility sources. The asset register will typically have a chronological record all equipment purchases, breakdowns, causes of breakdown, associated costs, etc. Relating this information to information of disruptions to internal operations and external services will enable an assessment of (i) the nature and extent of the breakdown, (ii) the type, extent and duration of the extreme weather event it is related to, (iii) the costs of the disruption, and (iv) remedial measures taken (including their cost).

STEP 1

Establish the exposure and sensitivity of your assets by identifying and detailing all service disruptions over a 30-year period (or whatever maximum period for which data is available) that were presumed caused by extreme weather-related events. List, for instance, time periods (hours/days/weeks) for which services (intake, treatment, bulk supply, distribution, sewage disposal) were disrupted on account of (a) excessive precipitation (or extreme dry weather), (b) high temperatures, (c) power failures on account of typhoons and storms, (d) and internal flooding as a result of sea level rise and storm surges.

STEP 2

Establish quantitative data for each disruption. There may be significant variations in the time-scale of various datasets but it will help to collect the highest resolution data possible. Establish corresponding disruption of operation or service, e.g. shortfalls in supply of distributed water (water planned for bulk distribution less water actually distributed).

STEP 3

Monetize the impacts and record financial data at prevailing tariffs alongside the volumetric data, if available.

STEP 4

Identify and list the associated remedial measures (whether short – or long-term), and indicate the costs in nominal prices.

STEP 5

Prepare summaries of disruptions by year, type, and cost of impacts and remedies

Below is an example of a table that utilities may prepare to consolidate the results of Steps 1-5.

TABLE 3: Sample Matrix of Extreme Weather Events Record in Metro Manila

DATE	ASSOCIATED WEATHER EVENT	EVENT	DESCRIPTION OF EVENT	IMPACT OF DISRUPTION	ACTIONS TAKEN	TOTAL COSTS (INC. SUPPLY SHORTFALLS, DAMAGE, REPLACEMENT, REVENUE LOSS, AND OTHER COSTS)
September 11, 2009	Typhoon Storm Ketsana	Flooding	2 meter flash flood breached flood walls and inundated WT facility for 2 days	Treatment plant inoperable for 3 days. Supply shortfall of 600 million liters	Water pumping	$2.8 million
September 11, 2009	Typhoon Storm Ketsana	Power outage	48-hour service disruption in many parts of Metro Manila	Bulk supply and pressure pumps down intermittently. Supply shortfall of 200 million liters.	Purchase and installation of 10 additional generator sets; purchase of 720 L of fuel	$1.9 million
July 15, 2014	Typhoon Storm Rammasun	Power outage	24-hour service disruption in many parts of Metro Manila	Breakdown of distribution pumps. Supply shortfall of 120 million liters	Purchase and installation of 7 additional generator sets; purchase of additional 300 L of fuel	$1.3 million
April 2, 2011 to June 14, 2011	Extremely dry and hot period	Water outage	Extremely low precipitation for a three month period	Only 10 mm of rainfall in Angat Dam forced guaranteed water supply to decrease to 200 mld from 250 mld	Water rationing in low pressure areas	$1 million

EXERCISE 2

Assessing Historical Rainfall and Temperature Variations

WHY SHOULD WE UNDERTAKE THIS EXERCISE? It is necessary to collect historical data relating to climate and weather patterns in the immediate vicinity of a coastal utility including, particularly, the catchment areas to establish a baseline climate scenario. Such a scenario could, typically, describe a calendar year with defined wet and dry seasons (with averages and spikes therein), high and low temperature periods (with extremes), high and low humidity, and variations in tidal patterns. These trends will be helpful in testing the climate projections, or for running software packages to develop climate change scenarios (details follow).

WHAT WILL WE GAIN FROM THIS EXERCISE? The utility will be able to correlate its experiences with extreme weather events and specific hydro-meteorological conditions. It can, for instance, retrospectively determine the number of dry days before a certain level of water shortages was observed, or the volume of precipitation in a day/weeks/month when flooding may occur.

WHAT PROCESS SHOULD BE FOLLOWED? In order to establish the most accurate baseline climate scenario, and to generate climate projections with higher levels of confidence, the utility should collect, collate, and assemble data in respect of (i) precipitation, and (ii) temperature, over 30 years. A shorter period, say 20 years, is also acceptable but the likelihood of inaccuracy remains. Also, shorter data records from sites in the area may capture extreme events that are useful to determining intensity, depth, and frequency. These can often be integral to system design and operational parameters.

STEP 1

Collect local precipitation and temperature data from the hydro-meteorological station(s) nearest to your source(s) of fresh water or treatment plant sites. Precipitation (measured in millimeters) and Temperature (Celsius or Kelvin) data is usually available as hourly, daily, or monthly averages. Each data set needs to have uniform sampling frequency. Collect at least 20 years of historical data and ensure that it is qualitatively accurate.

STEP 2

Tabulate and plot a line chart separately for Precipitation and Temperature showing annual averages for all data. Separately, tabulate and plot a line and/or bar chart depicting monthly averages within the time period of historical data that you collected. Such data may be available from your local weather bureau. In that case, you may rely on it.

STEP 3

Compare the dates and magnitude of the disruptions in service and related operational functions (see Exercise 1) to the plotted historical data and identify any obvious correlations. Evaluate the results and attempt to establish patterns and probable causalities (e.g. if increasing dry periods are resulting in longer service interruptions). Include in the analysis any probable reasons for extreme deviation in patterns.

Note that this activity does not aim to establish direct correlations. Rather, it aims to identify that part of the utility's system that is exposed and its probable sensitivities given a particular intensity. Similarities in intensity of extreme events does not guarantee the same magnitude of damage to the utility. Take specific note, for instance, of the equipment and machineries damaged or lost for each type of event and intensity, and the cost to replace or repair them.

Results

At the end of this exercise, you will have the following data and analyses:

TABLE 4: Information and analyses required for setting baseline climate information

INFORMATION	ANALYSIS
Daily or monthly precipitation/ temperature	Average monthly precipitation and temperature for a 20 to 30-year period.
Annual precipitation/ temperature	Linear trends of climate parameters. High rainfall and low rainfall months. Dates with extreme rainfall amounts reviewed vis-a-vis recorded operational disruptions.
Vertical land movement	Land subsidence rate. Historical sea level rise.

Data Sources

Data required for this exercise may be obtained from the following agencies. In some cases, the above analyses may be readily available or may be produced for you by the agencies.

1. Local hydro-meteorological stations that collect site-specific historical data for variables such as precipitation, temperature, solar radiation, and wind velocity, among others should be your utility's preferred choice for data source. A complete list of such stations is available at the World Meteorological Organization (http://www.wmo.int)
2. National statistical bureaus may also hold data for annual averages, but these are usually abstracted on city, provincial, national-level spatial averages and are, therefore, less useful.
3. National/regional/local water resources board(s)
4. Ministries of Agriculture or Water Resources
5. Research and academic institutions
6. National weather or hydro-meteorological bureaus
7. National, or local irrigation agencies

A list of agencies country specific agencies where this data can be obtained is found in http://www.wmo.int/pages/members/.

EXERCISE 3

Projecting Rainfall and Temperature Scenarios

WHY SHOULD WE DO THIS EXERCISE? It is necessary for you to understand how future variations in rainfall and temperature scenarios will affect (i) your water availability, (ii) your infrastructure assets and their operation, and (iii) your ability to meet demand. Note that forecasting climate parameters is a technically intensive task. It requires a substantive understanding of climate and hydrology sciences, and a working knowledge of statistics.

WHAT WILL WE GAIN FROM THIS EXERCISE? The projected scenarios will provide utilities with the necessary climate information that they can use to estimate the impact of precipitation and temperature in their operation in the future.

WHAT PROCESS SHOULD BE FOLLOWED? We recommend 3 options for you to consider. Option 1 is stand-alone and allows you to fully outsource the exercise at minimal cost. Options 2 and 3 are for those utilities who wish to develop expertise in-house so as to maintain a sustained, long-term handle on climate change and its impacts.

Option 1: If your utility does not wish to make investments in developing in-house capacities in climate change impact analysis, it may use the services of a climate change consultancy agency, to develop the projections and undertake the analysis. This is the least technically demanding option; it gives you immediate access to data and analysis; and data quality is backed by reputable climate scientists. The costs are affordable; however, it does require your utility to invest in a small unit staffed by persons who are familiar with climate science and are able to interpret results.

Option 2: Here, your utility may wish to to develop the projections in-house through applying numerous downscaling methods but will secure their detailed analysis through use of software (see Appendix B). The benefits include partial development of in-house capacity but requires competent staff to accurately process the data and interpret results.

Option 3: In this case, your utility may wish to acquire data from hydro-meteorological research and monitoring agencies and undertake the analysis in-house. The benefits include full ownership of the process and its results; increased institutional capacity; and the potential to incorporate into your utility's regular work.

TOOL RECOMMENDATION. We recommend that, for the short term, utilities consider Option 1. It will require you to engage at least one or two staff with a basic knowledge of climate change science and a working knowledge of basic statistical analysis.

Options 2 and 3 assume the acquisition of general circulation model data from a third party. Accessing this data and processing it for application in modeling tools is a highly specialised activity and is not advised except for the most technically proficient utilities with considerable staff capacity and appropriate data handling and computing facilities. For utilities with little or no experience of this subject, it is advisable to gradually develop the capacity to undertake either of the two options.

Why do we recommend software packages for Option 1?[4] A variety of software packages are designed to facilitate climate risk and adaptation assessments. Many use the latest climate change data (CMIP5). Maps, graphs, and charts of various aspects of climate change can be generated for sites, and spatially for cities, counties, provinces, and countries. In some cases, outputs can be reformatted by the software agency to seamlessly integrate with other modeling packages useful in conducting climate risk assessment for water resources, including hydrologic models, water system models, and flood models.

Some of the better software packages provide projections beyond precipitation and temperature, including sea level rise (SLR). They allow users to have, and apply, downscaled data derived using multiple methods (statistical and dynamical) and make that data accessible on one platform for analysis. They also have built-in analytical tools for assessing risks, SLR (including vertical land movement), and extreme events, where the projected data can be used as inputs.

Next Steps. If you wish to exercise either Option 2 or Option 3, please review Appendix B for suggested detailed steps. Option 1 is discussed below.

Implementing Option 1. The following steps are suggested.

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[4] See also Explanatory Note.

STEP 1

Contact the consulting agency for guidance and instructions on procedures to procure their services and other information they might require.

STEP 2

Send the boundaries (described in longitude and latitude) and/or the map of the area to be assessed, to the consulting agency. The area should cover that from where your utility gets its raw water. The area must also cover the location of the hydro-meteorological station from where the historical climate data will be taken and the coastal area that will be evaluated for inundation due to sea level rise.

STEP 3

Send to the consulting agency (a) precipitation and temperature maps (if available[5]), and (b) historical data that you have collected for precipitation, temperature, river discharge rate and vertical land movement.

STEP 4

Ask the consulting agency for the following data and analysis based on baseline and RCP[6] 8.5, and using a climate model ensemble[7] of all available climate models:

1. Precipitation, and maximum and mean temperature from baseline to 2100
2. Average monthly precipitation for 2025 to 2050 and 2075 to 2100, and precipitation change (in %) compared to baseline or historical data (if available)
3. Spatial data for precipitation and temperature projections for 2025, 2050, 2075 and 2100
4. Precipitation and temperature vector maps showing averages
5. Extreme events analysis for precipitation and streamflow
6. Sea level rise in 2025, 2050, 2075 and 2100.

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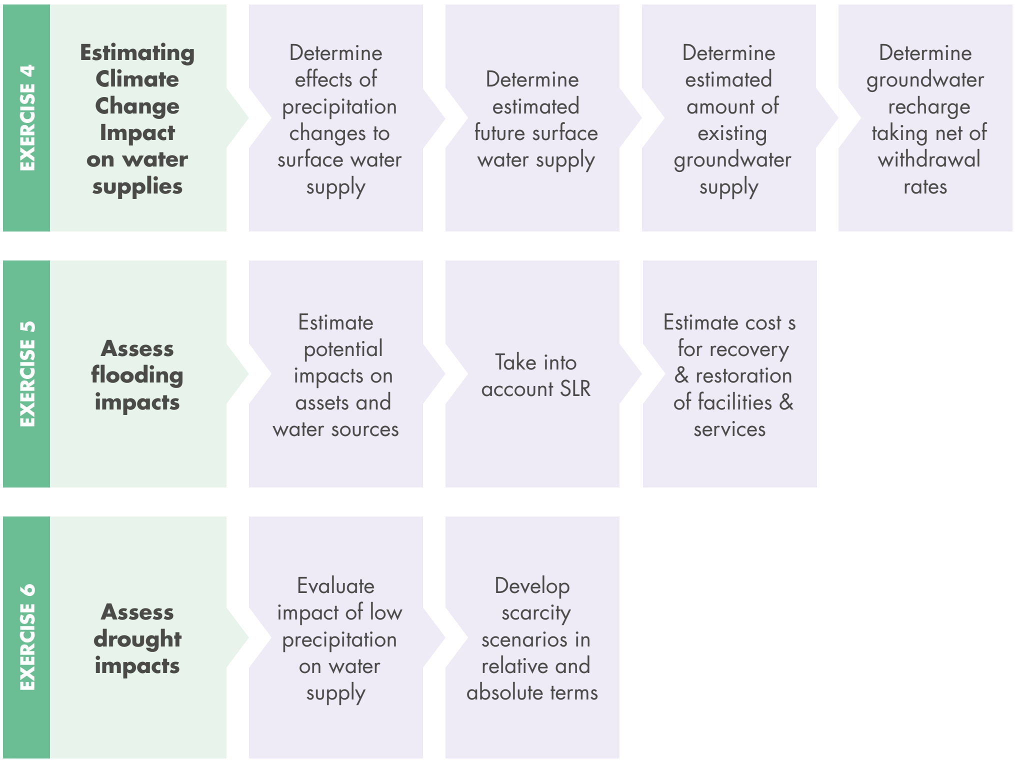
[5] Not all hydro-meteorological stations may have this data.

[6] Representative concentration pathways (see Appendix F for explanatory note).

[7] Using all available climate models.

FIGURE 3: Overview of Tool Processes from Exercise 4 to Exercise 5



ASSESSING CLIMATE CHANGE IMPACTS

Exercises 4 through 6 deal with assessing climate change impacts.

WHY SHOULD WE DO THESE EXERCISES? Determing the probable impact or range impacts to the utility's assets and operations provides the information needed to determine the types and level of response the utility has to contend with in the future.

WHAT WILL WE GAIN FROM THESE EXERCISES? The analyses for Exercises 4 to 6 will provide the impact on the water resources based on the changes in precipitation and temperature, including extremes, compared to baseline or historical data. It will also help forecast future surface and ground water supplies, as well as risks arising from floods and droughts.

WHAT PROCESS SHOULD BE FOLLOWED? Ideally the utility should start assessing the future climate change induced impacts of the hazards they are already epxposed to. Exercises 4 to 7 provides the necessary steps to analyze the impacts of floding, drought and saline intrusion to the utility.

EXERCISE 4

Estimating Climate Change Impacts

SURFACE WATER SUPPLIES

STEP 1

Verify the extent to which the raw water supplied to you, or within your own control and management, is affected by changes in precipitation.

If no formula is available, run a correlation analysis between water supply level data with historical precipitation data. If a significant correlation exists between the two, use this correlation to explain the effect of changes in precipitation in your utility's supply. If there is no correlation, you can conclude that you have not had a problem with water availability to meet demand regardless of changes in precipitation or temperature.

Consult with the authority responsible for supplying your raw water and determine if there are significant leaks or boundary inflows/outflows, and other factors that can affect the volume of water supplied to you. These can diminish any direct correlation between the water supplied and precipitation. You may then wish to run a multiple linear regression exercise and attempt to establish relationships among the different variables.

STEP 2

Use the correlation established to determine estimated future supply for a particular month, or set of months.

For purposes of illustration, we may assume that for every 5 percent decline in monthly precipitation, supply levels drop by 10%. If we further assume that annual precipitation will decrease by 20% in 2050, then the level of water supply will decline by 40% for that period.

This analysis may be conducted for shorter periods of, say, 3 months.

GROUNDWATER SUPPLIES

STEP 1

This step helps identify the extent of available groundwater in unconfined and confined aquifers. A spreadsheet file (http://goo.gl/E0453z) is provided to automate the calculation of outputs required in this exercise. For manual calculations, equations and sample calculations are provided in Appendix B.

1. Identify the study area; this may be the established basin area, a part of it, or the area where you currently draw (or plan to draw) water from (or where the local population and industry draws its water directly). Establish cell grids of 500m x 500m in your study area, and assign a unique number or identification code for each grid.
2. Determine the total area of the gridded study area. For example, if the area consists of 10 similarly sized grid cells, the total area is equal to 2,500,000 m2 or 2.5 km2.
3. For each grid or cell, drill a borehole and determine:
    a. Hydraulic head/groundwater level for both unconfined and confined aquifers
    b. Type of subsurface material
    c. Top soil type
    d. Land-use cover
    e. Total dissolved solids, or conductivity

Existing boreholes may also suffice. If this is the case, use existing data instead and record data for another 12 months using the same sampling interval as the existing data. If you wish to extend your sample base, you will need to drill additional boreholes. The boreholes (both existing and new ones) should ideally be able to represent different depths of your local aquifer.

Soil type and land use cover will be factors used to determine recharge rates in the computations.

Total dissolved solids, or conductivity, will be used to determine salinity intrusion for groundwater resources in Appendix D. These indicators need to be collected monthly for at least 12 months. A longer period is better to determine long-term aquifer behavior.

It is advantageous to also monitor other water quality and environmental quality indicators, such as coliform, pH, and total organic carbon.

STEP 2

Using the Excel worksheet provided, input the following parameters for each of the cell.

- Area (m2)
- Groundwater level of unconfined and confined aquifers (m)
- Hydraulic conductivity (m/day)
- Hydraulic gradient
- Sub-surface material type
- Soil type
- Land use cover type
- Rate of withdrawal (groundwater pumping) for both unconfined and confined aquifers (m3/day)
- Annual precipitation

For land use cover, soil and sub-surface material types, please consult the reference tables in Appendix D. These are also found on the spreadsheet. The equations used for the calculations can also be found in the same appendix. Also indicate whether you want to assume a zero net boundary recharge.

With these steps having been taken, you will have obtained a better definition of your groundwater resources. In particular, you will have estimated quantities for your system's groundwater reserve potential, rainfall and net recharge rate, and boundary recharge.

STEP 3

You may compare these figures with your current withdrawal rates to estimate when your utility will reach critical withdrawal rates and when your groundwater resources may reach critical levels. For unconfined aquifers, this can be estimated by multiplying the area of the aquifer with its depth then taking 25% (specific yield of sand, for example) of it as your potential groundwater storage, the other 75% of which are sand particles. Please consult the reference tables in Appendix D for specific yields for each sub-surface material. For confined aquifers refer to storativity8 values instead.

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8. The volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer.

EXERCISE 5

Assessing Flood Impacts

Note that Exercises 5 and 6 are only to evaluate the range and scale of potential impacts, and estimate their costs. The full range of options to mitigate impacts is described in Exercise 10.

STEP 1

Using the extreme events analysis provided to you by the consulting agency, and using the historical operational disruptions evaluation as a guide, estimate probability-of-damage-and-disruption impacts on (i) raw water intake areas, (ii) treatment facilities, and (iii) distribution systems, including water quality monitoring facilities, based on frequency and intensity of storm-type and floodwater retention.

STEP 2

Take in to account the SLR projections determined from Exercise 8 in your flood impact assessment.

STEP 3

Estimate costs including (i) asset repair, rehabilitation, or replacement, (ii) disruption of services (loss of sales), (iii) renewal of services, and (iv) alternative service provision during period of disruption.

EXERCISE 6

Assessing Drought Impacts

STEP 1

Again, based on the extreme events analysis given to you by the consulting agency, and your own analysis of historical operational disruptions, evaluate the impact of low to below-average precipitation, on traditional raw water sources (surface and ground).

STEP 2

Develop scarcity scenarios in relative and absolute terms, e.g. relative to growth or decline in demand, or relative to efficiency improvements within the utility, and identify the range and extent of scarcity, e.g minimum and maximum levels.

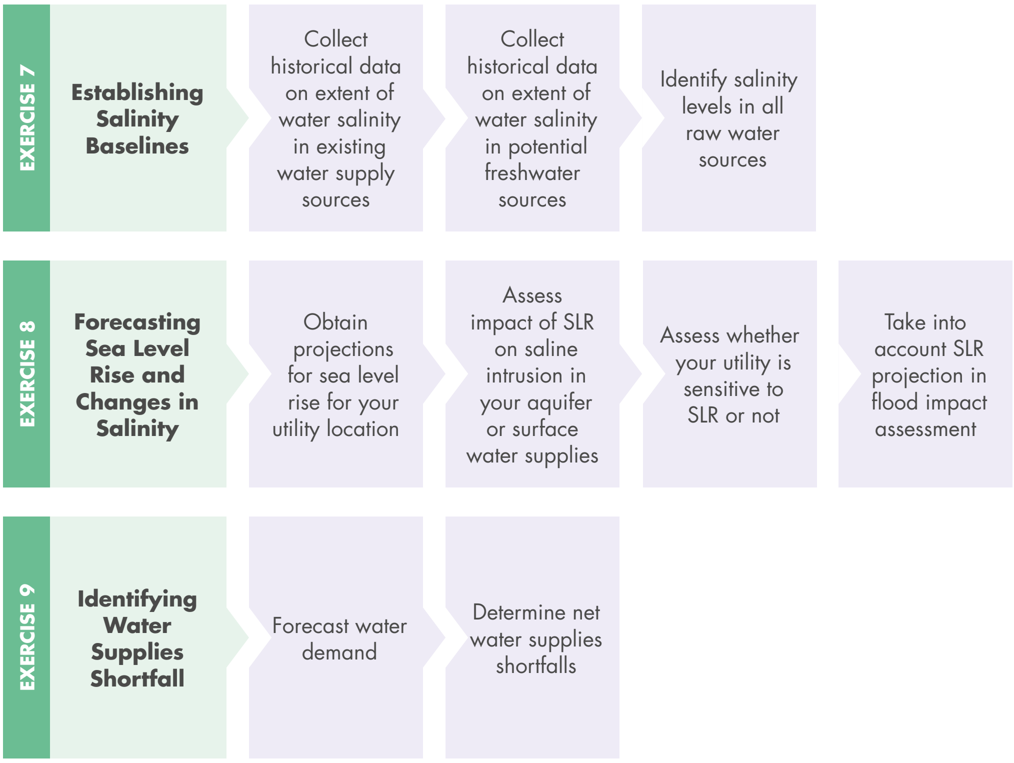
SALT WATER INTRUSION

Exercises 7 and 8 deal with Salt Water Intrusion. The first is to establish baselines. The other is to forecast sea level rise and estimate its impact on salinity. Both steps are important.

Coastal water utilities are typically dependent on rivers and groundwater for their raw water requirements. Both sources are prone to salt water intrusion (SWI). Rivers, as in the Mekong Delta, are unable to maintain an adequate base flow rate, and sea water displaces fresh water. Groundwater aquifers are affected because of insufficient natural or artificial recharge relative to rates of drawdown. SWI may also occur more non-specifically when subsoil strata are heavily dominated by sea water and seepage occurs at various rates through infiltration into a leaky network comprised of mainly buried pipes. Any increase in sea level rise will impact on the concentration of salinity in river mouths, estuaries, and coastal aquifers. Forecasting the increases in salinity relative to your utility's dependence on groundwater, or river water sources, is the first step in determining its impact on the utility's operations.

Storm surges may also push saline water inland and impact wells, often rendering them inoperable. Also, upconing of coastal wells may occur; high pumping rates often bring dense salt water from the bottom of the well to the top.

FIGURE 4: Overview of Tool Processes from Exercise 7 to Exercise 9



EXERCISE 7	**Establishing Salinity Baselines**	Collect historical data on extent of water salinity in existing water supply sources	Collect historical data on extent of water salinity in potential freshwater sources	Identify salinity levels in all raw water sources	
EXERCISE 8	**Forecasting Sea Level Rise and Changes in Salinity**	Obtain projections for sea level rise for your utility location	Assess impact of SLR on saline intrusion in your aquifer or surface water supplies	Assess whether your utility is sensitive to SLR or not	Take into account SLR projection in flood impact assessment
EXERCISE 9	**Identifying Water Supplies Shortfall**	Forecast water demand	Determine net water supplies shortfalls		

EXERCISE 7

Establishing Salinity Baselines

WHY SHOULD WE UNDERTAKE THIS EXERCISE? Assessing the level of salinity in the utility's freshwater sources.

WHAT WILL WE GAIN FROM THIS EXERCISE? This exercise provides a standard methodology on determining the level of salinity in the utility's water sources.

WHAT PROCESS DO WE FOLLOW? Ideally, the utility should have regular monitoring program that measures the saline concentration in their water sources. While the following steps can provide some guidance, utilities are advised to consult experts or established literature in setting up their water quality monitoring program.

STEP 1

Collect historical data on extent of water salinity[9] in surface water and groundwater sources over a 10-year period. For groundwater sources, establish a representative sample of wells that provide the bulk of the utility's drawals based on factors such as rate of drawal, location of well (in densely populated, or densely industrialised areas, for example), and geological conditions. A guide on borehole sampling can be found on Exercise 4 under Groundwater Supplies. The samples should, ideally, be able to represent various depths of the aquifer to get an idea of the water quality as a function of depth. This will also allow you to see the interface between the freshwater and salt water. Over time, it will be important to track the movement of the salt water not only horizontally inland but also vertically within the aquifer.

For surface water areas, sources such as rivers, or estuaries, both upstream and downstream should be taken into account in the sampling. This is useful if you are planning to invest in a long-term and more rigorous assessment of your local hydrology. However, for this exercise, it is sufficient to monitor only the point(s) of intake from which you draw water.

Data should be at time intervals sufficient to establish trends especially when correlated to sea level rise, tidal surges resulting in internal flooding, and extreme wet and dry season events[10].

STEP 2

Collect historical data on extent of water salinity in non-groundwater (river bodies, estuaries, or remote source) and ground water sources of raw water over a 10-year period. Establish trends based on elements indicated in Step 1, above.

STEP 3

Collect historical data on extent of water salinity in potential freshwater sources for the utility. This will enable a useful comparison especially when extending the reticulated network.

STEP 4

If no historical data is available, identify salinity levels in all raw water sources of your utility (or representative samples in case the number of sources is extensive and unmanageable). Benchmark the figures, and collect data afresh every 3 months over the next 12 months (a total of 4 data sets will be obtained – these will be adequate to determine levels and trends).

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[9] The indicators used to monitor salinity are total dissolved solids or TDS (measured in parts per million, or ppm), if a laboratory assessment of water samples is available, and electrical conductivity (measured in micro Siemens per cm or µS/cm). If taking sample readings on-site, TDS (Mg/L) is approximately equal to electrical conductivity multiplied by 0.6 when sample readings are made at room temperature or 25 degrees Celsius.

[10] This data may be obtained from any of the sources indicated in Exercise 2 or from local hydro-meteorological stations or climate monitoring agencies.

EXERCISE 8

Forecasting Sea Level Rise (SLR) and Changes in Salinity

WHY SHOULD WE UNDERTAKE THIS EXERCISE? Sea level rise can exacerbate flooding and enhance salinity intrusion.

WHAT WILL WE GAIN FROM THIS EXERCISE? The analysis will help utilities to project future SLR and determine an indicative level of saline intrusion their system would face in the future.

WHAT PROCESS DO WE FOLLOW? The utility should establish the current baseline salinity conditions in their water resources. They can then obtain SLR projections available on public domain websites. The utilities can use the SLR data in their flood risk analyses. A simple decision matrix was provided to help manager assess the level of saline intrusion risk they may encounter in their water resources.

STEP 1

Obtain projections for sea level rise for your utility location from any one of the following sources. These are publicly available at no cost.

a. Software modeling package generated SLR projections (see Appendix B)
b. WB Climate Wizard Custom[11]
c. WeAdapt Portal[12]
d. CLIMSystem's Cities SLR Web Application[13]

STEP 2

Include SLR projection in the your utility's assessment of potential f lood impact in your facilities and service area.

STEP 3

The next step is to asssess impact of SLR on saline intrusion in your aquifer or surface water supplies. However, it is not advisable to undertake your own studies as this is a technically complex and expensive exercise especially in the context of a one-time result that is sought. There is no single, standard methodology to quantify the impact of sea level rise on saline intrusion.

Current methodologies for establishing the exact amount of salinity in groundwater are still works-in-progress. Methodologies vary from one study to another – mainly because the groundwater conditions also vary from one study area to another. Hence, we suggest partnering with a local university, research agency, or an external expert, to help you in this study. However, the following methodologies are usually considered:

a. MODFLOW/MT3D/SEAWAT (also available at no cost in the public domain) – key inputs are based on hydraulic head observations and are validated against geochemical and geophysical data from new investigation wells, including borehole logs, and from an airborne transient electromagnetic survey by Rasmussen, Sonnenborg, Goncear, & Hinsby (2013);
b. Tidal estuary measurements by Liu & Liu (2014) – also used in Vietnam by Nguyen et al. (2008); and
c. Coastal inundation modeling – direct surface water intrusion via potential coastal inundation due to sea level rise by Dasgupta et al. (2014) and Werner & Simmons (2009).
d. Use of computer-aided numerical models coupled with downscaled climate change projection and SLR projections to produce a decision support system for estimating salinity effects on Georgia and South Carolina Coasts by Roehl et al. (2012).

STEP 4

If you do not have the resources to conduct the above or similar studies, you can refer to the following pointers that you can use to qualitatively assess whether your utility is sensitive to SLR or not. The sensitivities provided below are based on the studies above and assume a conservative (risk averse) position, and that current sources of freshwater are not yet under threat of salinity. If you are already receiving reports of saline intrusion in your system, then the sensitivity of your freshwater resource might be even higher.

STEP 5

If you have done previous assessments that give rise to suspicion that your aquifer falls into any of these typologies, take the following appropriate course(s) of action: (i) commence expansion of your treatment facilities if still possible, (ii) dilute water from this source with other sources of freshwater to levels that your treatment system can handle, (iii) establish new sources or intake points, or (iv) build a desalination plant (see Exercise 10, Option 3). For the third and fourth options, it may be prudent to start conducting a detailed examination of the conveyance and reticulation systems and identify the extent of salt water contamination. Collect data on degree of contamination in terms of monthly throughputs. This should help you establish further necessary baseline to design an appropriate treatment facility.

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[11] http://climatewizard.ciat.cgiar.org/

[12] https://weadapt.org

[13] http://slr-cities.climsystems.com

TABLE 5: Sensitivity of freshwater sources to SLR influenced saline intrusion

SOURCE OF WATER	CONDITIONS	SENSITIVITY
Unconfined aquifer	Any	High
	High withdrawal rate Low recharge	Very high
	Proximity to shore	Very high
Confined aquifer	High withdrawal rate Low recharge (from rainfall)	High
	High withdrawal rate High recharge rate	Medium
	Withdrawal rate unchanged Low or unchanged recharge rate	Low
	Proximity to shore	Medium to high
River (assuming higher or constant streamflow conditions)	Lower projected precipitation rate upstream Medium (0.5 m) to high SLR (≥1 m)	High
	Higher projected precipitation rate upstream Medium (0.5 m) to high SLR (≥1 m)	Medium
	Proximity of intake source to estuary	High
	Intake source far (≥ 50 km) from estuary	High to medium (in highly urbanized deltas) Medium to low (depending on tide levels and rainfall recharge)

EXERCISE 9

Identifying Water Supplies Shortfall

WHY SHOULD WE UNDERTAKE THIS EXERCISE? This exercise guides utilities to determine potential water supply shortfalls in the future due to changes in water demand and supply.

WHAT WILL WE GAIN FROM THIS EXERCISE? Utilities will be able to determine whether they will have enough water supply to continue operating and distributing water efficiently to their service area.

WHAT PROCESS DO WE FOLLOW? The exercise will make use of the project water supply available to the utility in the future. Use the projected water supply and forecasted water demand based on increases in population in the service area and increases in temperature to estimate net water supply.

Now that you have identified overall water scarcity scenarios based on climate change factors, it will be necessary to establish net water supplies shortfalls. For doing so, the first step will be to assess demand.

FORECASTING WATER DEMAND

The continuing rise in temperatures are a major factor in aggravating urban heat islands[14] (UHI), and the typical increase in hotter and dryer periods, usually leads to increased domestic consumption of water and electricity, higher industrial water demand, and increased evapotranspiration rates leading to lower groundwater recharge rates.

Several studies have confirmed the positive correlation between temperature and household water consumption. But the relationship is local, and the specificity of the correlation is contingent on the months or seasons when the temperature changes occur. To determine the relationship between temperature and water consumption you need to conduct your own studies. The methodologies available are still being developed and may neeed to be adapted for your area. If your utility lacks the expertise, we recommend that you partner with a local university, or research agency, and build on the existing scientific literature.

The study can include multiple linear regression analysis to determine the relationship of not only temperature change and household consumption, but also the extent of rainfall/dry days, price, tourism, conservation strategies, sewer bill and other water related tariff, energy consumption, among others, depending on your local socioeconomic conditions. Please see Appendix G for a list of studies that you can use as a basis to start your own exercise.

It is important to keep in mind other factors that are sensitive to fluctuations in temperature (heating and cooling and tourism-based activities for instance). Should your utility decide to forego this type of study, we recommend that your utility take a no-regrets approach. You can utilize the established correlations found in previous studies listed in Appendix G and adopt these as indicative references for your strategic plans. For example, a study by Guhathakurta & Gober (2007) on the influence of UHI on water consumption in Arizona indicates that a 1ºF (5⁄9ºC) in increase in low temperature results in a 290-gallon (1.1 m3) increase in a typical single-family unit in a month. You may increase or decrease the effect of temperature rise depending on the nature of typical households in your area, and/or the presence of other major water consumers such as hotels. Your decision on how to adjust this variable should also take into account macro-scale factors outside your utility's service area and control. These can be increased allocation for power plant cooling, agriculture, or allocations made for other cities sharing the same water resources. By taking into account the projected temperature scenarios in Exercise 3, you can integrate this correlation into your future water demand projections.

As an alternative, you can use the above correlation to determine the sensitivity of your utility to water demand increases due to temperature change. Refer to the results for projected temperatures in Exercise 3. If the projected temperature in your area is significantly lower than 5⁄9ºC and if your city is not expecting any major modifications to land surface cover in the future, then there may be no need to do this analysis.

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[14] Urban heat island (UHI) is a phenomenon when an urbanized area is significantly warmer than its surrounding rural areas. This arises due to extensive modification of land surface to a less-permeable one, trapping the heat (short-wave radiation) in the city's surface. Note that ambient temperatures due to UHI is different from land surface temperatures. However, UHI is always higher than the latter.

EXERCISE 10

Evaluating Adaptation Options

WHY SHOULD WE UNDERTAKE THIS EXERCISE? This exercise provides the utility with ways to directly address climate change risks that may hamper or disrupt their operations and services.

WHAT WILL WE GAIN FROM THIS EXERCISE? At the end of this exercise, utilities will be able to identify a set of adaptation options that they can choose from.

WHAT PROCESS DO WE FOLLOW? Utilities, should first and foremost address any hazards that may cause temporary or permanent damages and failures in their facilities. These are floods and droughts. They can then proceed with actions that can mitigate or prevent water supply shortfalls.

Before we address the question of options in the event of a shortfall in supply, we would like to suggest ways in which impacts relating to floods and droughts could be addressed.

IN THE CASE OF FLOODS, evaluate options for addressing damage to infrastructure and service disruption in terms of (i) permanent infrastructure protection, (ii) provision of modular infrastructure that will allow different degrees of substitutability based on the critical nature of the asset or the service, e.g. discrete power packs that can keep the distribution network alive when storms knock out municipal power systems, (iii) provision of emergency water services to designated institutions or consumer localities to sustain key public (including industrial) functions and (iv) emergency interconnections with neighboring water providers. An exhaustive amount of literature is available on this subject matter. The utilities may refer to these resources for planning and support guidance. They are also advised to seek local expert assistance, and coordinate with local government agencies to address flooding in the areas where the utility's assets are located sustainably and cohesively.

IN THE CASE OF DROUGHTS, if the analysis suggests sustained long-term dry periods, then you may wish to identify options to develop a New Water Project, i.e. to create new water in response to growth in demand and shortfalls in supply [options will include (i) optimizing non-revenue water reduction, (ii) reduction in demand via an assortment of conservation and efficiency-of-use instruments, (iii) maximization of on-site water augmentation, e.g. through domestic rain water harvesting, (iv) improved watershed management to maximize catchment performance, (v) reuse of wastewater for industrial and/or municipal applications, and (vi) trading of wastewater with agricultural freshwater.

IN THE EVENT OF AN OVERALL SHORTFALL IN SUPPLY, you will need to identify options for creating 'new water', i.e. look for alternatives to remedy the shortfall. Four principal options may be considered. Detailed guidelines are not being suggested as these options may vary in scale and scope based on local circumstances. They will need to be considered as individual projects and will vary in cost and time.

Option 1: Reduce Non-revenue Water (NRW)

The process of identifying the range and scale of the NRW problem, and its repair, is variable but may take from 3 to 5 years depending on the rate of investments and the rate at which reduction in NRW is sought.

Typically, a utility should be able to recover 50% or more of NRW. In most cases, this would be sufficient to meet shortfalls in supply, although the lowest possible figure of resultant NRW should be aimed at. Extreme situations where rates of increase in demand are high, coupled with a steep decline in raw water availability on account of climate change-related factors, will require a higher rate of reduction in NRW over a shorter (or longer) time frame depending upon the need.

Note that there is a single, universal truism. It is more cost effective to create new water by reducing NRW than it is to identify new sources, develop them, and build the infrastructure to access, treat, and distribute the additional water. The numbers will obviously vary, but the fact will not alter.

STEP 1

Undertake a comprehensive audit of your water loss situation including (i) volume, rate, and points of loss, (ii) principal causes of loss, e.g. whether through network leakages, faulty meters, unbilled consumption, or plain theft, (iii) deficient operating systems and processes, and (iv) remedies. These will include pipe replacements, repairs, building district metering areas to manage water supply in discrete hydrologically operable areas, adopting technology-based solutions for leak detection, repair, and control, and creating an active leakage management system with trained staff and technology integrated seamlessly. Unless you have sufficient in-house expertise to address this issue, you may wish to seek expert assistance. A WOP on NRW management is a good option to consider. Many WOPs on this subject have previously been conducted with excellent results.

STEP 2

Identify (i) a range of options with volume of water saved at different levels of NRW reduction, e.g. 50 million liters per day (MLD) at 40% NRW; 100 MLD at 20% NRW; and 125 MLD at 10% NRW, (ii) estimate costs and time frames associated with each, (iii) correlate the savings to the estimated shortfalls in supply over points of time and judge optimal scenarios. Note that 80% of NRW in most utilities is physical loss; concentrating on reducing this loss creates new water. The remaining 20% are typically commercial losses; reducing them often enables you to secure sufficient revenues to finance the entire NRW reduction program.

STEP 3

If reducing NRW creates sufficient new water to meet your estimated shortfall, you may need to take no further steps. However, creating new water is not an infinitely elastic exercise and, at some point (typically sooner than later) demand will have to moderate and be based on (i) efficient consumption, and (ii) the economic price of water. It will be in your interest to signal efficient consumption of water given the long-term negative climate change impact scenarios.

Option 2: Reduce Demand

A reduction in demand is typically applied when there is obvious wasteful consumption, there is insufficient raw water to meet current needs, and where long-term supply:demand scenarios are adverse. For instance, several utilities have design parameters that include daily per capita consumption of between 180-400 liters. In most cases, this parameter is rarely met mainly because of an absolute shortage of water coupled with high rates of NRW. Driving down demand should be considered a primary utility function given the uncertainties of long-term raw water availability. Urban water demand has two principal elements: (i) domestic, and (ii) industrial. These will need to be addressed separately (with one common step; see below).

STEP 1

Calculate the extent to which you seek a demand reduction based on demand and supply projections over 5-year intervals. Inflate the net demand with an assumed worst case-scenario factor of, say, 15% for each 5-year segment (to cater to unforseen growth). Arrive at final figures of daily demand that you wish to reduce such that you have a 20% supply cushion. This cushion assumes a reduced NRW figure. See sample calculation below. These percentages are purely illustrative; you may adopt figures based on your needs.

A.	Projected Total Daily Demand:	100 MLD
	Projected Total Daily Supply:	100 MLD
B.	Inflate Demand by 15%:	115 MLD
C.	Provide 20% Supply Cushion:	80% of 100 MLD = 80 MLD
D.	Demand to be reduced:	115-80=35 MLD

STEP 2

Based on consumption data available to you, calculate the extent to which demand can be reduced in the domestic and industrial sectors separately. You may wish to seek a proportionate reduction, i.e. a reduction in proportion to the relative consumption by the two principal consumers. Alternatively, you may wish to consider a reduction in domestic demand by setting a new service ceiling of, say, 160 litres per capita per day (lpcd) against a current ceiling of, say 230 lpcd. For industrial consumers, you may seek a flat rate reduction of, say, 10% across the board. It is more difficult to shrink industrial demand because of the time lag to develop more water-efficient industrial processes. You may wish to use alternative sets of numbers that enable you to reach the final demand figure of 35 MLD (in the sample calculation above).

STEP 3

You may consider designing a demand reduction program that incorporates a blend of the following elements:

(i) **Price Mechanism.** This is a complex exercise. Essentially, you will need to develop a formula that goes beyond recovery of costs of supply and includes a 'climate change insurance premium'. Often, this is a proxy for the scarcity value of water (or its economic value), and helps in moderating demand. Penalties need to be imposed for extraordinary consumption. Seek expert advice to design a formula that is credible with consumers and does not compromise access by vulnerable groups, and that has the clear potential to reduce demand.

(ii) **Consumption Reduction Fittings.** Design a program to require domestic consumers to move to technologies such as efficient shower heads, low-flush toilets, front loading washing machines and efficient garden irrigation systems.

(iii) **Rainwater Harvesting.** Require all prospective commercial, residential, and government buildings to incorporate rainwater harvesting facilities. Require also retrofitting of such facilities wherever feasible. Design urban space for stormwater recharge to groundwater and shallow aquifers.

(iv) **Reducing Industrial Consumption.** Design a program to induce reduced water consumption by industrial, business, and energy consumers through measures such as (i) reduced water losses, (ii) efficient water use processes, and (iii) arrangements that require treatment and reuse of wastewater. If you lack in-house expertise to design such a program, seek expert assistance. Several WOPs on this subject have been conducted and utiltiies may wish to consider this as an option.

(v) Fit for Use Water. Different activities require waters of different qualities. Fit for purpose water reuse is an overall approach to reducing demand by encouraging and enabling the use of water of lower quality for various domestic, agricultural, municipal and industrial purposes that don't require water of drinking quality.

Option 3: Improving water supply quality

Based on the results of the baseline assessment under Exercise 7, compare the salinity levels that you were able to sample and monitor with the levels that your current treatment system is able to reduce to acceptable standards in Exercise 4, under Groundwater Supplies. The baseline trends you have established in Exercise 4 will already provide you an indicative reference as to whether your treatment system is nearing or has already crossed the said threshold.

If this is the case, then you will need to consider (i) expanding your treatment facilities, if this is feasible, (ii) dilute water from this source with other sources of freshwater to levels that your treatment system can handle, (iii) establish new sources or intake points, if feasible or (iv) evaluate the economics of investing in a desalination plant if the problem is acute and there are no alternatives (see next option).

Option 4: Desalination

As a coastal utility, or even a small island state utility, you have the option of investing in a desalination plant if all other options have been judged to be economically and financially (or technically) infeasible. Many coastal utilities operate such plants, some as a matter of insurance, e.g. Sydney Water, while others use the plant for mainstream supply, e.g. Chennai.

OTHER OPTIONS AND NEXT STEPS

STEP 1

If Options 1-3 are not able to help you match forecast demand with forecast supply (this will be very unlikely), identify alternative raw water sources for development and access separately for surface and groundwater, as also for associated transmission, treatment, and distribution. Determine estimated costs.

STEP 2

Estimate the relative costs of the above options and develop a least-cost, ranked set of projects to create 'new water' (it may be efficient to combine some options such as NRW reduction with demand reduction through the price mechanism). Also, assess the financial viability of the least-cost options. Identify sources and costs of funds for capital investments, operation and maintenance costs, and debt service. Determine the best method of financing the chosen option(s) typically through a blend of local government financing and commercial loans. Evaluate the impact of the costs of the chosen option(s) on tariffs and prepare a program to revise tariffs in consultation with your local government.

EXERCISE 11

Communications Strategy

The impacts of climate change on a community's water demand and supply arrangements are sufficiently serious for your utility to design and implement a communications strategy that both educates the community on the major impacts and the proposed means of addressing them, and includes them as active participants in the process.

The major stakeholder groups will be (i) domestic consumers and especially those segments of the urban population who either have no or limited access to piped water supplies, (ii) commercial and industrial consumers, (iii) local government officials, (iv) elected representatives of communities, (v) NGO groups involved in water and sanitation services, and (vi) the media.

A communications strategy should, typically, explain in simple and clear terms the:

(i) objectives of the overall impact assessment and remediation exercise with the stakeholder community,

(ii) approaches and methodology used,

(iii) sequence and timing of constituent elements,

(iv) results of option studies with costs and benefits transparently demonstrated, and

(v) the manner of engagement of key stakeholders with the progress of the program, and their participation in it.

IIt will be helpful to establish mechanisms to report progress to the wider water community and to seek feedback into the process. The involvement of stakeholder groups is key to the success of the remediation exercise. This part of the strategy will require careful design, perhaps with expert assistance.

EXERCISE 12

Final Implementation Actions

STEP 1

Assemble a comprehensive program of actions to deal with climate change impacts. Go to customers, local government officials, partner agencies (electric power supply, storm water management, town and country planning, etc.), interest groups and other stakeholders, and share the program components and details together with reasoning and costs. Build consensus and acceptance for the program in a with-program and without-program scenario.

STEP 2

Integrate the program with the utility's capital and operating budgets. Review monitoring and evaluation arrangements and strengthen as required to provide real-time reports on implementation and results.

STEP 3

Commence program implementation.

THE BOTTOM-UP APPROACH

A bottom-up approach to climate change planning for water utilities is essentially a qualitative analysis that comprises (US EPA, 2011):

(i) identifying the critical climate variables and exploring their sensitivity to the water utility;

(ii) determining water system responses to a range of potential climate changes;

(iii) assessing the vulnerability of the water utility to climate change impacts;

(iv) assessing system performance according to the uncertainty associated with climate change factors driving the water utility's vulnerability; and

(v) evaluating overall system risk and identifying areas in need of further analysis.

This approach is recommended in cities and municipalities that might have insufficient support from local governments, who lack financial resources, or who have difficulty in securing climate change-related data. Under these circumstances, water utility managers may opt to conduct a sensitivity analysis as a preliminary means of identifying potential vulnerabilities in their systems under perturbed future climate conditions.

The format is essentially workshop-based, but also involves considerable outside-of-workshop exercises. It is based on previous work of East Bay Municipal Utility District (2009), CH2M HILL (2008), Miller & Yates (2006), and the framework proposed by Brown, Ghile, Laverty, & Li (2012), a report of the U.S. Environmental Protection Agency (2011), and an analysis by Barsugli, Vogel, Kaatz, Smith, Waage, & Anderson (2012). Typically, this is a 5-week long exercise.

In essence, the bottom-up approach requires the following steps to be taken:

(i) Setup a technical working group and apprise the group of the best and most locally relevant climate information and projections.

(ii) Identify vulnerabilities in the water systems based on current climate conditions.

(iii) Conduct sensitivity analysis of vulnerable components of the water system under different climate scenarios.

(iv) Develop a decision model based on the result of the sensitivity and scenario analysis.

Establishing an effective communications strategy and implementing the final set of options follows. These steps are discussed in Exercise 11 and 12 under the bottom-up approach.

WEEK 1

Setting up the Technical Working Group

(i) Setup a technical working group (TWG) composed of decision-makers and managers in charge of the operations and commercial side of your utility. Keep the group small – no more than 10 persons.

(ii) It will be helpful to associate academia, e.g. professors from relevant fields such as hydrology, meteorology, civil engineering, geological engineering from local universities or research institutes that are actively engaged in research. The utilities may also consult with local urban planners, storm water managers, and electricity and other utility mangers. Their guidance to the TWG will be useful.

(iii) It wll also be helpful if the TWG can develop an effective communications strategy to sensitize the all of the utility's personnel on the impacts of climate change and ways and means to deal with them. The communications strategy should also keep the whole utility abreast with assessment the TWG is doing. More information about this communications strategy can be found in Exercise 11 under Top Down Approach.

(iv) Distribute resource materials to group members. These could include the report from Miller and Yates (2006), briefs on climate information for your utility's immediate area, climate maps of the region or sub-region where your basin(s) is located, and an adapted version of this Tool.

(v) Typically, Exercise 1 will come in handy (see Week 3 and Week 4, below). Other exercises that will be helpful relate to evaluation of impact mitigation options, developing a communications strategy, and final implementation plans. You will need to decide for yourselves, based on your utility's capacities, as to which exercises can be undertaken usefully in a manner that dovetails sensibly into the methodology suggested in the Bottom-up approach.

WEEK 2

Subject Familiarization

(i) It is important that TWG familiarise itself over 2 days of workshops on the basics of climate science in the context of water utility operations, hydrologic implications for water utilities, and the use of climate change information in water utility planning. This activity needs a facilitator and appropriate resource speakers. A suggested outline of the subjects is given below. It is mainly adapted from Miller and Yates (2006). The said report can also be used as the main reference material for the workshop.

The Science of Climate Change

- What is climate and what does "climate change" mean?
- Uncertainties regarding climate change
- Is climate change likely to occur in a time-scale relevant to water utilities?

Hydrologic Implications for Water Utilities

- Precipitation amount, frequency and intensity
- Evaporation and transpiration
- Changes in average annual runoff
- Natural variability
- Coastal zones
- Water quality
- Water storage
- Water demand

Use of Climate Change Information in Water Utility Planning

- Bottom-up and Top-down approaches
- Vulnerability and sensitivity assessments
- Scenario analysis

(ii) Finally, the workshop should cover the methods that the group will be using in the assessment, including definition and shared understanding of sensitivity analysis, scenario analysis, thresholds, and adaptation, among others.

WEEK 3

Workshop on Local Climate Information and Development of Climate Scenarios

(i) This activity will require a facilitator and appropriate resource speakers. The TWG needs to be informed of the climate change-related hazards that have already impacted utility operations, including past extremes, and past trends. Consult Exercise 1 for a guide on how to implement this activity. The workshop should be able to identify which of the climate variables are critical to utility operations. Both the operations and commercial wings of the utility should identify the specific impacts on their duties and quantify them.

(ii) Using the best available climate projections that cover the local area of the water utility, the TWG should develop multiple scenarios for each climate change parameter (precipitation, temperature, and sea level rise) available for 2025/2030, 2050 and 2100. You may also use national, sub-regional (multi-country) maps if available, but within certain parameters. Your utility needs to be located in the same contiguous coastal zone, shared basins and aquifers, the region should share similar geographic characteristics, and the spatial-based data should have a resolution high enough to quantify the impacts in your service area and supply source. This needs to be decided and prepared by an appropriate resource person/subject matter expert.

(iii) The scenarios could, for example, represent changes of precipitation compared to baseline (current temperature trend) that are:

a. Little or no change (0% for 2030, – 5% for 2050, – 10% for 2100)
b. Moderate (-5% for 2030, – 10% for 2050, – 20% for 2100)
c. Radical (-10% for 2030, – 20% for 2040, – 40% for 2100)

Each of the climate scenarios should have its accompanying projected impacts, including magnitude and frequency (i.e., max flood level of 1.2 m, 10-year return period) relevant to your utility's operations.

WEEK 4

Brainstorming on Vulnerable Water Utility Subsystems and Sensitivity Analysis

(i) Based on the information collected and analyses made during the third week, the TWG should be able to identify which system components are dependent on the conditions of climate variables (e.g., precipitation, temperature, sea level rise) and the overall system risk to climate change, resulting in a preliminary risk assessment based on the professional judgment of experts who know the system and the planning area (CH2M HILL, 2008, p. 32).

(ii) TWG should identify thresholds and boundaries (physical and operational) based on performance, operations history, service reliability, past decisions, based on cost benefit analysis, environmental thresholds. It should also be able to establish climate responses based on trends and extremes already observed/experienced (e.g., past supplies indicate that if annual precipitation is X millimetres, guaranteed supply/rights from reservoir is Y million liters per day). A detailed method for this part can be found in Exercise 1 of the Tool.

WEEK 5

Scenario Analysis and development of the Decision Model

(i) Using the scenarios developed, the TWG should brainstorm and determine the water utility's operational (management) and system (infrastructure) responses to a range of potential climate changes.

(ii) The TWG should design a simple decision support system, or model, based on their past experiences, the climate projections studies, established thresholds, and responses developed from previous step (e.g., if precipitation increases by X then no action is taken; however, if it increases by Y then Z action is taken). Outputs from this exercise can be integrated into your utility's Emergency Response Plan.

(iii) Based on the scenarios developed, and the decision support system designed, the TWG may estimate costs of various alternatives for consideration of the utility's Management in the development of an overall program to respond to climate change.

Based on the alternatives that the TWG is able to identify, it can internally deliberate which options they would take, and the order in which they should be implemented. As any chosen action will have impact beyond the utility, the participation of a broader gathering of stakeholders in decision making would be important for the sustainability of the adaptation efforts.

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APPENDICES

APPENDIX A

Sample Report Outline for Top-down Approach

1. Baseline conditions
    a. Physical and geographical characteristics (sources of fresh water and their physico-chemical properties)
    b. Hydro-meteorological characteristics (precipitation, temperature)
    c. Other baseline parameters as needed
2. Future climate conditions and projected impact
    a. Climate change projection
    b. Projected Impacts
        i. Surface water
        ii. Groundwater
        iii. Salinity intrusion
        iv. Flooding
        v. Drought
3. Recommended adaptation options
4. Implementation strategies and next steps

APPENDIX B

Running Software Packages for Generating Projections and Analysis

The World Bank offers short courses on the basics of climate science at no cost. Local hydro-meteorological or climate change research institutes may also offer a wide-range of courses in this discipline. These are recommended to those utilities wishing to invest in developing their capacities for applying climate model data. In regard to software packages, their operation requires staff who are familiar with basic climate change sciences, have a basic understanding of the latest IPCC Fifth Assessment Report (AR5) and the new AR5 emission pathways (CMIP5 RCPs), and may have a basic working knowledge of GIS software packages. Both the understanding of the underlying concepts and the operation of the software can be self-taught within three person months (see Appendix E for the technical capacities expeted for a potential staff).

The following basic steps will need to be taken:

1. Generate, or obtain downscaled climate data[1].
2. Determine changes in precipitation and temperature, including extremes, compared to baseline or historical data
3. Use the results to forecast future surface and ground water supplies and flooding risks etc.

Required Data and Analysis Specifications

Typical downscaled climate data will contain projections on temperature and precipitation. Sea level rise projections are available as separate data but should also be procured. The processed downscaled data will be for a specific site/area of interest, or may be obtained as a time-slice Geographic Information System (GIS) vector data set for each year or period. The latter is more useful when determining whether catchment areas will be affected by variations in precipitation. It also provides required data to assess groundwater recharge over the utility's source area. The data will also be used to generate projected return periods of extreme precipitation and temperature. The climate models may be used with a GEV (Generalized Extreme Event) tool to estimate current and climate changed return periods[2].

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[1] It is advisable to access such data from reputable groups involved in on-going downscaling activities such as CORDEX groups in your region or your national climate change or meteorlogical agency. Such data may need secondary processing for application in the tools required to conduct risk assessments.

[2] A 'return period' is defined as the period (usually in years) in which an extreme weather event is estimated to recur.

It is advisable to obtain raw data (instead of analyzed data) as it will be used extensively in the climate forecasting excercises. Further, the utility should have the capacity to construct and apply an ensemble of climate models. This is done by using all available global and regional climate models when downscaling climate change projections at the local level. A multi-model ensemble provides more robust and higher quality climate change projections compared to single model projections. An explanation is provided in Box 1 below.

In order to secure a high level of confidence in the projections, at least 30 years of daily (hourly or sub-hourly) data is required, although 20 years may suffice. A shorter period is not advisable. Fewer data points, as with any other statistics of means, will lead to less accurate results.

BOX 1: Multiple climate model ensembles

A climate ensemble is composed of several member climate models. It reduces uncertainties that may occur in a downscaled climate data set (that used only a single climate model) by taking into account the outputs of other climate models. The downscaled data from each member model is combined to form the projections. A climate projection software (such as the SimCLIM package) utilizes an ensemble of climate models by taking the median value of all the values of the climate models in the ensemble, for each grid cell in the projection (i.e., 5x5 km grid), where each grid cell may have used a different model. This is done by sorting the climate models according to their value, and then taking the value of the middle one (i.e., with 21 climate models that would be the 11th one). By taking the median (and not the average), the more extreme values at the lower and higher ends (i.e., the 1st and 21st model) do not impact the result of the ensemble.

The recommended steps require the following conditions when obtaining downscaled climate data from a hydro-meteorological research institute. This will ensure a higher level of confidence in the data, and also a higher and wider degree of analysis. The data should be based on:

- A Multi-model ensemble
- The individual climate models and scenarios being founded on the latest available climate models (CMIP5)[3] for interoperability with future impact assessments that utilities may wish to undertake
- Site-specific data that is collected continously, at least on a monthly inverval, for the past 30 years
- A resolution of at least 25 km x 25 km grid of spatial data
- Daily or, at least, monthly projections up to 2100

Please consult with your data provider if all of the conditions, above, are addressed adequately in their downscaled data.

The table below indicates the information and analyses that will result from the steps suggested hereafter.

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[3] Coupled Model Intercomparison Project (CMIP) Phase 5. This refers to the latest framework from which the latest climate models are derived.

TABLE 6: List of information and analyses required for generating climate change scenarios

INFORMATION	ANALYSIS
• Projections (to 2100) for Baseline, RCP[4] 4.5, 6.0 and RCP 8.5 (or if using AR4 scenarios: Baseline and A1F1) on the following parameters: • Precipitation • Temperature • Sea level rise • Solar radiation	• Changes from historical or baseline climate data
• Projected average monthly precipitation and temperature for the periods of 2025 to 2050 and 2075 to 2100	• Percentage changes from historical average monthly precipitation (covering the period of 30 years or the entire coverage of historical data, whichever is longer)
• Return periods and corresponding amounts for extreme precipitation, and temperature.	• Percentage changes from related past extreme precipitation and temperature recorded
• Spatial data showing average monthly precipitation and annual precipitation for periods 2025 to 2050 and 2075 to 2100.	• Percentage change from baseline

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[4] Representative Concentration Pathways (RCPs) are the new greenhouse gas concentration trajectories adopted by the IPCC in its Fifth Assessment Report. Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover (Moss, et al., 2008). A good introductory resource on RCPs can be found on Skeptical Science's website (http://www.skepticalscience.com/rcp.php). An explanatory note can also be found in Appendix F.

Generating climate change projections

The following steps require the use of a commercially available software package that can generate downscaled climate change projections using publicly available global climate models from CMIP5. UNFCCC maintains a comprehensive online database[5] of tools, software and guidebooks on climate change assessments, including generating projections and risk and impact assessment. Alternatively, you can refer to Appendix C for an indicative list of software packages that can do this for you. The maps, graphs and charts of various aspects of climate change can be generated for sites and spatially for cities, counties, provinces, and countries.

Ideally the software package should also be able to provide projections beyond precipitation and temperature, including sea level rise (SLR), and could be seamlessly integrated with other modeling packages useful in conducting climate risk assessment for water resources, including hydrologic models, water system models, and flood models. The software package should also be able to generate downscaled data derived using multiple methods (statisitical/dynamical) and make that data accessible different platforms for analysis. In addition, built-in tools for projecting sea level rise and extreme event analysis or options for exporting data to other software packages to conduct the said analyses should also be available.

Each software has its unique functions and user interfaces. This Tool recommends thoroughly consulting the detailed manual on how to use all the features of the software. The software package developer may also offer in-house training. The Tool also highly recommends participating at these trainings to make full use of all the features the software package can offer. Software package license fees may vary depending on the nature of the user. Generally, government, academic and non-profit organizations will get discounted rates. Additional fees may be charged for generating maps, spatial data, data processing and other value added services. The license period is usually one year, with annual paid renewals that allows for upgrades, updates and continued access. The spatial area includes the monthly average climate variables of precipitation (mm), minimum, mean and maximum temperature (°C). Additional variables of solar (W/m2), relative humidity (%) and wind (m/s) are available on request at an additional cost.

In general, the following information is needed by software packages to run impact models and conduct extreme event analysis. The software developer may recommend further parameters depending on where the utility is located.

- Twenty years or more historical data for the following climate parameters:
  - Temperature
  - Precipitation
  - Solar Radiation (optional)
  - Vertical Land Movement (VLM) currently mainstreamed in the software but can be augmented by local data sets when available and processed offline for the end user.
- Coordinates (longitude and latitude) of the hydro-meteorological station(s) where the above data was obtained
- Optional: Historical spatial map data for the following parameters
  - Temperature
  - Precipitation
  - Solar Radiation

Note that the steps provided below may be totally different depending on the software package that you will use. Please refer to the software manual or contact the software developer for detailed help on using the software.

STEP 1

The software package may require specific data format. As such, request the necessary data set(s) for your utility's area from the software developer by sending them (through email) boundaries (described in longitude and latitude) and the map of the area to be assessed. The area should include that from where you obtain your raw water, and also the location of the hydro-meteorological station(s) where the historical climate data was obtained, and the coastal area that will be evaluated for inundation due to SLR.

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[5] http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5457.php

STEP 2

Also send to the software developer a) precipitation and temperature maps (if available), and b) historical data that you have collected for precipitation, temperature, solar radiation, stream flow and vertical land movement.

STEP 3

The software developer will then send the utility a file that includes data that will be used to generate downscaled data for precipitation and temperature. The file should also contain a vectored map of the study area. Refer to the software manual for detailed instructions.

STEP 4

Create a climate ensemble using all available climate models in your utility's area for the following analyses: precipitation and temperature, sea level rise, and extreme events.

STEP 5

Use the actual coordinates of hydro-meteorological station(s) where you obtained your historical climate data to generate precipitation and temperature projections for your study area, following the specifications below:

- Generate for both baseline and RCP 8.5 scenarios (Note: example below shows A1F1)
- Use medium sensitivity
- Generate for (i) annual; (ii) monthly; and (iii) seasonal frequencies

STEP 6

Tabulate data for precipitation, and maximum and mean temperature projections for 2025 to 2050 years (or over the same period of your organization's long-term strategic plan), and, for future reference, for 2075-2100.

Using baseline and RCP 8.5 and using a climate ensemble of all available climate models, generate annual and seasonal precipitation and temperature maps for the years 2050 and 2100.

Generating SLR projections

(i) Obtain vertical land movement (VLM) data from any of the organizations below. Note that not all stations have an associated value. Please contact data provider for more details and further assistance.

  a. SONEL initiative (http://www.sonel.org/) where VLM is estimated from continuous Global Position System (GPS) measurements at fixed locations, often coinciding with tidal observation stations

  b. Permanent Service for Mean Sea Level (http://www.psmsl.org/) maintains an archive of observed tides. An analysis of the data for these stations to estimate their trends (which are reflecting the rise in sea level).

  c. Provincial or national mines and geosciences bureau, national mapping bureau, land development agencies, local civil engineering office and/or coastal and marine agencies may have monitoring data on tidal gauges and/or independent stationary GPS measurements.

(ii) Using a climate change modeling software package, generate SLR projections using ensemble GCMs and/or RCMs, for Baseline and for RCP 8.5. Make sure to input vertical land movement rate obtained in the SLR analysis.

APPENDIX C

Indicative List of Software Packages and Web Applications for Generating Climate Change Projections

APPLICATION	WEBSITE
ClimDex	A project that produces a suite of in situ and gridded land-based global datasets of indices representing the more extreme aspects of climate change. Indices are derived from daily temperature and precipitation data. **http://www.climdex.org/**
CLIMWAT 2.0	A climatic database to be used in combination with the computer program CROPWAT that allows the calculation of crop water requirements, irrigation supply and irrigation scheduling for various crops for a range of climatological stations worldwide. **http://www.fao.org/nr/water/infores_databases_climwat.html**
Climate Wizard Custom	Enables technical and non-technical audiences alike to access leading climate change information and visualize the impacts anywhere on Earth. The first generation of this web-based program allows the user to choose a state or country and both assess how climate has changed over time and to project what future changes are predicted to occur in a given area. **http://climatewizard.ciat.cgiar.org/**
DIVA Model	An integrated, state-of the-art research model of coastal systems that assesses biophysical and socio-economic consequences of sea-level rise and socio-economic development taking into account coastal erosion (both direct and indirect), coastal flooding (including rivers), wetland change and salinity intrusion into deltas and estuaries, as well as adaptation in terms of raising dikes and nourishing shores and beaches. **http://www.diva-model.net**
MAGICC/SCENGEN	A coupled, user-friendly interactive software suites that allow users to investigate future climate change and its uncertainties at both the global-mean and regional levels. **http://www.cgd.ucar.edu/cas/wigley/magicc/**
MarkCLIM	A stochastic weather-generating platform that aims to help fill this knowledge gap, by helping online users generate simulated daily weather data across the globe. It can deliver information about rainfall, maximum and minimum temperatures and solar radiation, and has been specifically designed for tropical countries. **http://ccafs.cgiar.org/marksimgcm**
SDSM	A decision support tool for assessing local climate change impacts using a robust statistical downscaling technique. **http://www.sdsm.org.uk**
SimCLIM 2013	A user-friendly "open-framework" software package that can simulate the impacts of climatic variations and change, including extreme climatic events, on sectors such as agriculture, health, coasts or water resources. **http://www.climsystems.com**

APPENDIX D

Equations used and sample computations for estimating Groundwater Storage and Recharge Rates

STEP 1

Estimate aquifer storage volume

The total unconfined[6] and confined[7] aquifer storage volume is derived from the aquifer geometry and aquifer storage properties, illustrated by the following equations:

Storage of shallow/unconfined aquifer =

$$S_1 = A_c \times h \times S_y \quad \text{(Equation A)}$$

Storage of deep/confined aquifer =

$$S_2 = A_c \times h \times S_c \quad \text{(Equation B)}$$

Where A_c is the area of the cell, h is the hydraulic head/groundwater level, S_y = specific yield, and S_c = storage coefficient.

Specific yield is the fraction of the aquifer occupied by water that is drainable. Refer to Table 8 for the specific yields for each type of subsurface material catalogued by Johnson (1969).

TABLE 8: Values of specific yield

MATERIAL	SPECIFIC YIELD (%)		
	MIN	AVG	MAX
Unconsolidated deposits			
Clay	0	2	5
Sandy clay (mud)	3	7	12
Silt	3	18	19
Fine sand	10	21	28
Medium sand	15	26	32
Coarse sand	20	27	35
Gravelly sand	20	25	35
Fine gravel	21	25	35
Medium gravel	13	23	26
Coarse gravel	12	22	26
Consolidated deposits			
Fine-grained sandstone		21	
Medium-grained sandstone		27	
Limestone		14	
Schist		26	
Siltstone		12	
Tuff		21	
Other deposits			
Dune sand		38	
Loess		18	
Peat		44	
Till, predominantly silt		6	
Till, predominantly sand		16	
Source: (Johnson, 1967)			

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[6] An aquifer, which has a water table forming its upper boundary.

[7] An aquifer confined between aquitards or aquicludes (a water-bearing layer of rock or sediment that transmits small quantities of water).

Storage coefficient is computed as follows:

$$S_c = S_s b \quad \text{(Equation C)}$$

Where S_s is the specific storage, and b is the aquifer thickness.

Specific storage is the volume of water released from storage from a unit volume of aquifer per unit decline in hydraulic head. This is calculated using the following equation:

$$S_s = \rho g(\alpha + n_e \beta) \quad \text{(Equation D)}$$

where **p** is mass density of water (=999.97 kg/m^3) [M/L^3], **g** is gravitational acceleration (= 9.8 m/sec^2) [L/T^2], α is aquifer (or aquitard) compressibility [T2L/M], $\mathbf{n}_e$ is effective porosity [dimensionless], and β is compressibility of water (= 4.4x10^{-10} m sec^2/kg or Pa^{-1}) [T^{2}L/M].

Compressibility values for various aquifer materials can be found on Table 9 (Freeze, 1979).

TABLE 9: Compressibility values of various aquifer materials

MATERIAL	COMPRESSIBILITY, A (M^2/N OR PA^{-1})
Clay	10^{-8} to 10^{-6}
Sand	10^{-9} to 10^{-7}
Gravel	10^{-10} to 10^{-8}
Jointed rock	10^{-10} to 10^{-8}
Sound rock	10^{-11} to 10^{-9}

TABLE 10: Representative porosity values for various unconsolidated sedimentary materials, sedimentary rocks and crystalline rocks

UNCONSOLIDATED SEDIMENTARY MATERIALS	
Material	Porosity (%)
Gravel, coarse	24 – 37
Gravel, medium	24 – 44
Gravel, fine	25 – 39
Sand, coarse	31 – 46
Sand, medium	29 – 49
Sand, fine	26 – 53
Silt	34 – 61
Clay	34 – 57
Sedimentary Rocks	
Rock Type	Porosity (%)
Sandstone	14 – 49
Siltstone	21 – 41
Claystone	41 – 45
Shale	1 – 10
Limestone	7 – 56
Dolomite	19 – 33
Crystalline Rocks	
Rock Type	Porosity (%)
Basalt	3 – 35
Weathered granite	34 – 57
Weathered gabbro	42 – 45

Source: (Morris & Johnson, 1967).

Note that these estimates do not account for consequences such as water levels dropping below the bottom of wells, capturing poor quality water, or changes in groundwater-surface water interactions.

STEP 2

Estimate change in groundwater storage

This activity uses water table fluctuation (WTF) method to estimate annual changes in groundwater storage volume. The method in this tool was adapted from the New South Wales General Purpose Water Accounting for Groundwater Methodology (Ali, 2011). Storage change using this method is estimated using the following general equation:

$$\Delta S = A\Delta hSy \quad \text{(Equation E)}$$

Where ΔS is change in groundwater storage in a defined time interval (e.g. t_0 to t) (m^3); A is the surface area of the aquifer (m^2); Δh is water level rise in observation wells at a defined time interval (e.g. t_0 to t) (m); and Sy is the specific yield of the aquifer.

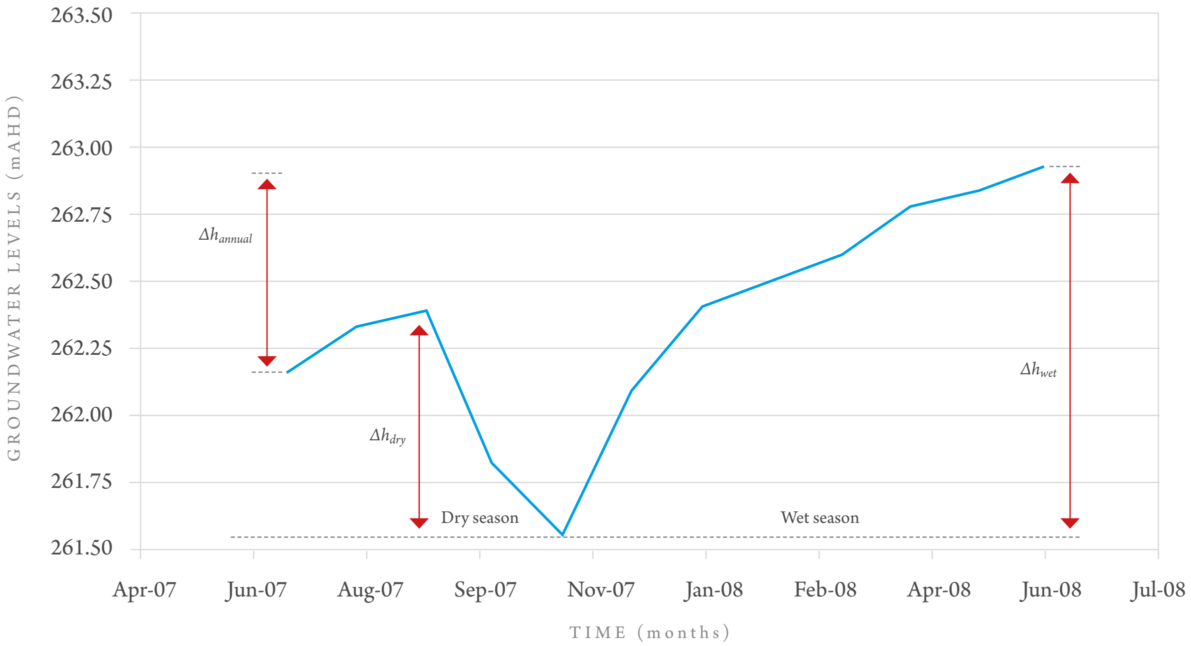
A summary of the required steps for estimating groundwater recharge using WTF can be found below:

1. Define a wet and dry period
2. Estimate the water level change (Δh)
3. Calculate the Specific Yield using the defined dry period
4. Calculated Recharge in the wet period using the specific yield calculated above and water level rise.

Observe and record monthly average groundwater level in your unconfined aquifer for a period of 12 months. Determine your locality's wet and dry period months and demarcate the water level changes for the whole year (annual), during wet season, and during dry season.

The water level rise during the wet season (Δh_{wet}) and is estimated as the difference between the peak of a water rise and the lowest level that the water had reached before it started to rise. This estimate generally relies on the assumption that there will be one distinct rise during the wet season from recharge, and only minor fluctuations as a result of other components of the budget. Similarly, the water level drop during the dry season (Δh_{dry}) is estimated as the difference between the peak of a water rise and lowest level that the water level had reached before it starts to rise again. Annual groundwater level change (Δh_{annual}), which is the change in water levels over a 12-month period (for example; water level change between July 2009 and July 2010). The line graph below is an example of a graphical presentation of the data that needs to be collected for this particular exercise.

FIGURE 5: Monthly average groundwater levels



Source: General Purpose Water Accounting Reports: Groundwater Methodologies (2011)

The change in storage in confined aquifer, ΔS_2, can be estimated using the following equation:

$$\Delta S_2 = Ac \times S_c \times \Delta h_{annual2} \qquad \text{(Equation F)}$$

where Ac is surface area of the confined aquifer; S_c is storage coefficient of the layer 2; $\Delta\ \Delta h_{annual2}$ is the average annual groundwater level change in the confined aquifer (i.e., water levels at Dec '14 – water levels at Dec '15). Storage coefficient is obtained using Equation C.

Similarly, the change in storage in the unconfined aquifer, ΔS_2, can be estimated using the following equation.

$$\Delta S_1 = A_c \times S_y \times \Delta h_{annual2} \qquad \text{(Equation G)}$$

Specific yield values can be obtained from Table 8.

STEP 3

Estimate boundary flux

1. Net boundary recharge, expressed as B, can be estimated using Darcy's flow rate[8] (V = KI) multiplied by the vertical cross area (A_c) of each of the corresponding cell, expressed as follows:

$$B = A_c \times V = A_c \times K \times I \qquad \text{(Equation H)}$$

where B_2 denotes the boundary recharge (L3/T) and K is the hydraulic conductivity (L/T) (see for range values), and I is the hydraulic gradient in the confined aquifer. Positive and negative values denote lateral boundary inflows and outflows, respectively.

A sample calculation of the recharge rate for each cell can be found below.

$B = 250{,}000\ m^2 \times 0.0002 \times 1 = 50$

STEP 4

Determine rainfall recharge

This step provides two options for computing groundwater recharge due to rainfall.

Option 1. The first option is for tool users located in India. You may choose from any of the formula below depending on your location and/or the rainfall conditions of your area.

TABLE 11: Representative values of hydraulic conductivity for various unconsolidated sedimentary materials, sedimentary rocks and crystalline rocks

UNCONSOLIDATED SEDIMENTARY MATERIALS	
Material	Hydraulic Conductivity (m/sec)
Gravel	3x10-^{4} to 3x10-^{2}
Coarse sand	9x10-^{7} to 6x10-^{3}
Medium sand	9x10-^{7} to 5x10-^{4}
Fine sand	2x10-^{7} to 2x10-^{4}
Silt, loess	1x10-^{9} to 2x10-^{5}
Till	1x10-^{12} to 2x10-^{6}
Clay	1x10-^{11} to 4.7x10-^{9}
Unweathered marine clay	8x10-^{13} to 2x10-^{9}
SEDIMENTARY ROCKS	
Rock Type	Hydraulic Conductivity (m/sec)
Karst and reef limestone	1x10-^{6} to 2x10-^{2}
Limestone, dolomite	1x10-^{9} to 6x10-^{6}
Sandstone	3x10-^{10} to 6x10-^{6}
Siltstone	1x10-^{11} to 1.4x10-^{8}
Salt	1x10-^{12} to 1x10-^{10}
Anhydrite	4x10-^{13} to 2x10-^{8}
Shale	1x10-^{13} to 2x10-^{9}
CRYSTALLINE ROCKS	
Material	Hydraulic Conductivity (m/sec)
Permeable basalt	4x10-^{7} to 2x10-^{2}
Fractured igneous and metamorphic rock	8x10-^{9} to 3x10-^{4}
Weathered granite	3.3x10-^{6} to 5.2x10-^{5}
Weathered gabbro	5.5x10-^{7} to 3.8x10-^{6}
Basalt	2x10-^{11} to 4.2x10-^{7}
Unfractured igneous and metamorphic rock	3x10-^{14} to 2x10-^{10}
Sourcec: (Domenico & Schwartz, 1990, p. 824)	

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[8] Describes the flow of a fluid through a porous medium.

TABLE 12: Rainfall recharge formulae developed for India

	FORMULA	EQUATION	CONDITIONS
1	Charturvedi	$R = 2.0 (P - 15)^{0.4}$	Areas with P = 14 ~ 18 inches
2	UP IRRI, Roorkee	$R = 1.35 (P-14)^{0.5}$	Areas with P = 14 ~ 18 inches
3	Krishna Rao	$R = 0.20 (P - 400)$	areas with P between 400 and 600mm
		$R = 0.25 (P - 400)$	areas with P between 600 and 1000mm
		$R = 0.35 (P - 600)$	areas with P above 2000mm

Note: For formula #1 an #2 R is recharge rate and P is precipitation. Both are expressed in inches. For formula #3, R & P are expressed in millimeters.

Source: Kumar & Seethapathi (2002).

Option 2. The following uses the methodology based on mass-balance model employed by Jang et al. (2012) in their study of Taiwan's groundwater budget estimation.

1. Obtain annual precipitation data from hydro-meteorological station for the current year.

For the purposes of demonstration and simplification, let us use the annual precipitation of 2,440 mm/year or an average 6.685 mm/day, and evapotranspiration rate of 6 mm/day.

Note that this can also be taken from existing baseline climate data already gathered from previous exercises. Evapotranspiration[9] rate should be calculated using the FAO recommended Penman–Monteith equation. This data should also be available from local and national hydro-meteorological organizations, and national irrigation agencies. Alternatively, it can also be estimated using the Coudrain-Ribstein et al. (1998) evaporation formula, described as follows:

$$E = \frac{71.9}{Z^{1.49}} \quad \text{(Equation I)}$$

where E is evaporation from the water table (mm/year); and Z is the depth to the water table (m)

2. Based on the soil type determined from Step 1, determine the soil infiltration rate of each cell using the estimates below provided by Tsao et al (1979) – sandy gravel of 150 mm/day; gravel sand of 43.7 mm/day; sand of 25 mm/day; loamy sand of 15.9 mm/day; sandy loam of 11.5 mm/day; and clay of 4.04 mm/day.
3. Based on the land use type of each cell determined from Step 1, determine the rainfall infiltration ratio of each cell using the estimates provided by Chow et al (1998) – cultivated land (64%), pasture (70%), forest (72%), and town (17%).
4. For each cell, calculate for the rainfall recharge rate based on the following conditions:

- If Daily total rainfall is within the range of daily evapotranspiration, then Infiltration = 0
- If Daily effective rainfall < daily evapotranspiration, then use Equation J
- If Daily effective rainfall > daily evapotranspiration, then use Equation K
- If No Daily rainfall, use Equation A but calculate infiltration using – 1mm/day

$$Q = 0.001 \times P \times A_c \times \propto \quad \text{(Equation J)}$$

Where ***Q*** is the amount of infiltration; ***P*** is the effective rainfall (mm/day); A_c is the area of each discretized cell (500 m x 500 m); and $\propto\propto$ is the infiltration ratio of different land uses

$$Q = 0.001 \times \varphi \times A_c \times \propto \quad \text{(Equation K)}$$

Where A_c is the area of the cell, φ = saturated soil infiltration rate (mm/day), and $\propto$ infiltration ratio of different land uses

Using the given annual precipitation and evapotranspiration, we can infer that daily precipitation is more than evapotranspiration. Hence, we calculate for infiltration Q using Equation K. For example, in Cell A, using 'sand' as soil type and 'pasture' as land use type, we compute for the rainfall infiltration rate as

$Q = 0.001 \text{ x } 25 \text{ mm/day x } 250{,}000 \text{ m}^2 \text{ x } 0.7 = 4{,}375 \text{ m}^3\text{/day}$.

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[9] The sum of evaporation and plant transpiration (evaporation through plants leaves, stems, flowers) from land and ocean surfaces to the atmosphere.

APPENDIX E

TOR for Climate Change Officer

Educational Background	Civil Engineering, Chemical Engineering, Water Engineering and Management, Meteorology, Statistics, Urban Planning and Management, Environmental Science, Environmental Management
Technical Skills	Cartography, GIS, Environmental Impact Assessments, Hazard Assessment, Environmental Monitoring, Water Quality Monitoring
Professional Experience	Five years of professional experience directly relevant to any of the following: environmental impact assessments, urban planning, water and wastewater management, hydrological modeling, water quality modeling, environmental engineering Master's or Ph.D. level research experience
Software Proficiencies	ArcGIS, ERDAS, Excel, working knowledge on modeling software packages (QUAL2K, Flood Modeller Pro, MODWAT, WASP, among others)

APPENDIX F

Notes on Representative Concentration Pathways

The Fifth Assessment (AR5) report of the IPCC introduced new set of scenario family called Representative Concentration Pathways (RCP). This new set of scenarios unlike the SRES scenarios of AR4 is not GHG emission scenarios. Each RCP denote a different possible future of greenhouse gas concentration conditions (as opposed to emissions). Socio-economic data does not form as any part of the RCP database. This will be developed later to compliment the RCPs and produce different combination-scenarios. Van Vuuren (2011) puts forward the following clarification:

> "The RCPs were selected from the existing literature on the basis of their emissions and associated concentration levels. This implies that the socio-economic assumptions of the different modeling teams were based on individual model assumptions made within the context of the original publication, and that there is no consistent design behind the position of the different RCPs relative to each other for these parameters."

The four RCPs, RCP2.6, RCP4.5, RCP6.0, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 (of 2.6, 4.5, 6.0, and 8.5 W/m^2, respectively).

TABLE 13: Different RCPs and their SRES emission scenario equivalents

	DESCRIPTION*	CO2 EQUIVALENT	SRES EQUIVALENT	PUBLICATION – IA MODEL
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100.	1370	A1FI	Raiahi et al. 2007 – MESSAGE
RCP6.0	Stabilization without overshoot pathway to 6 W/m^2 at 2100	850	B2	Fujino et al.; Hijioka et al. 2008 – AIM
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 2100	650	B1	Clark et al. 2006; Smith and Wigley 2006; Wise et al. 2009 – GCAM
RCP2.6	Peak in radiative forcing at ~ 3 W/m^2 before 2100 and decline	490	None	van Vuuren et al., 2007; van Vuuren et al. 2006 – IMAGE

* Approximate radiative forcing levels were defined as ±5% of the stated level in W/m^2 relative to pre-industrial levels. Radiative forcing values include the net effect of all anthropogenic GHGs and other forcing agents.

For more information please visit Skeptical Science's beginner's guide for the new RCP scenarios at: http://www.skepticalscience.com/rcp.php.

APPENDIX G

List of Temperature and Demand Studies

STUDY/REGION	DEPENDENT VARIABLE	INDEPENDENT VARIABLES	MODEL(S)	RESULTS
Maidment and Miaou (1986)	Daily seasonal use	Tmax, prcp, price, Income	A physics-type Transfer function	Model explains up to 99% of variance; Response to rainfall depended on frequency and magnitude. A non-linear response of water use to temperature changes
Billings and Agthe (1998) Arizona (arid)	Monthly total household water demand	Tmean, prcp, water price, block rate subsidy, per capita income	State-space, multiple regression	Model error ranged from 7.4-14.8% for multiple regression and 3.6-13.1% for state-space
Martínez- Espiñeira (2002) Spain (semiarid)	Average monthly water consumption	Temperature, population density, household size, water &sewer bill, income, marginal price, population, prcp, percentage of housing as main residence dweling tourism index, Nordin-difference	Instrumental variable models	Significant difference In summer-only elasticities and major impact of climatic variables on monthly consumption.
Gutzler and Nims (2005) New Mexico (arid)	Daily summer residential demand	Tmax, prcp	Multiple regression	Over 60% of variance in water demand is explained by climate variables
Ruth et al. (2007) New Zealand (humid)	Daily total per capita water demand	Day of the week, Tmax, rcp, # dry days, wind speed, conservation	Multiple Regression	Projected climate change and population growth scenarios result in 30-40% probability of water shortages
Praskievicz and Chang (2009) Seoul, Korea (humid)	Residential seasonal water use	Tmax Wind speed	Multiple regression ARIMA	Tmax and wind speed explain between 39 and 61% of the variations in seasonal water use

Tmax = maximum temperature; Tmin = minimum temperature; Prcp = precipitation

Adapted from (Chang, Praskievicz, & Parandvash, 2014).

Note: Further list of other similar studies can be found in pages 2 to 4 of the article.

APPENDIX H

Additional References

- Water Utility Climate Alliance[10] (WUCA) provides advice and mutual support to utilities on climate change adaptation.
- EU PREPARED Project[11]
- There are also government sponsored support arrangements for utilities to assess their response to climate change impacts. In the United States, the EPA offers advice, toolkits, training courses and various other resources to help US water utilities on these issues. See link in footnote below[12].
- The UK Government required all UK water utilities to produce comprehensive reports on how their functions would be impacted by climate change, their approach to dealing with the problems, and a risk assessment. These substantial and technically detailed documents are publicly available. See, for example, the Wessex Water (owned by YTL International of Malaysia) 2011 Report to the UK Government titled "Climate Change Adaptation Reporting Duty"[13].
- In less developed countries, and those challenged by the MDGs, such resources are thinner on the ground but some resources do exist such as the UN-Habitat "Climate Change Vulnerability and Assessment Guidebook[14]" produced for water utilities in the Lake Victoria region and designed for replication throughout Africa.

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10. http://www.wucaonline.org/

11. http://ec.europa.eu/programmes/horizon2020/en/news/helping-water-utilities-adapt-climate-change

12. http://water.epa.gov/infrastructure/watersecurity/climate/index.cfm

13. http://www.wessexwater.co.uk/sustainability/environment/default.aspx?id=7988

14. http://unfccc.int/secretariat/momentum_for_change/items/7380.php

Global Water Operators' Partnerships Alliance
UN-Habitat Office
Nostra Senyora de la Mercè Pavilion
Sant Pau Art Nouveau Site
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