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# Total Water Management

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### *Desktop Analysis Case Study Disclaimer*

The total water management options and levels of implementation presented in this case study are for illustrative example only, and meant to demonstrate the potential benefits using realistic water resources information for a large urban watershed. The options presented here do not necessarily reflect actual or planned implementation by the City of Los Angeles, nor do they reflect official policies of the City. Although the majority of data assumptions regarding costs and benefits for these options are based on the work completed during the City's Integrated Resources Plan, other studies and reports were utilized.

# Abstract

There is a growing need for urban water managers to take a more holistic view of their water resource systems as population growth, urbanization, and current operations put different stresses on the environment and urban infrastructure. Total Water Management (TWM) is an approach that examines urban water systems in a more interconnected manner, focusing on reducing water demands, increasing water recycling and reuse, creating water supply assets from stormwater management, matching water quality to end-use needs, and achieving environmental goals through multi-purpose, multi-benefit infrastructure.

This study documents the benefits of TWM to water management decision-makers and can be used to support the development of management techniques that could be adopted in order to improve urban systems. This study includes a comprehensive literature review that summarizes TWM principles and real world applications in the United States and abroad. The literature review was organized into different regions of the country in order to reflect geographic water management drivers and challenges.

An evaluation protocol for analyzing TWM is presented, along with a detailed discussion of modeling techniques. A desk top analysis was conducted to demonstrate how TWM alternatives would perform against traditional approaches to water management using a systems model. The model simulates supply reliability, total lifecycle costs, water wastewater capacity, quality of receiving waters, and a number of environmental indicators. The Water Evaluation and Planning (WEAP) software, developed by the Stockholm Environment Institute, was used as the modeling platform.

The City of Los Angeles was used as the case study for desktop analysis, using real data within a real planning context. The City was divided into four demand areas, each with its own connections to surface water, groundwater, and imported water supply sources, i.e., water from outside City limits, as well as connections to wastewater treatment plants and receiving waters. TWM strategies that were evaluated included increased water conservation, expanded water recycling and reuse, graywater, stormwater recharge, and rainwater harvesting. The WEAP model simulated how integrated water supply, stormwater and water quality management can provide increased opportunities for achieving urban system goals that would not exist in single-purpose, traditional planning.

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## Acronyms and Abbreviations

| | |
|---|---|
| AFY | = Acre-feet per year |
| AF | = Acre-feet |
| AWWA | = American Water Works Association |
| AwwaRF | = American Water Works Association Research Foundation |
| BMP | = Best management practice |
| BOD | = Biochemical oxygen demand |
| Central | = Central City (demand zone) |
| CSS | = Combined sewer systems |
| CSO | = Combined sewer overflows |
| CWA | = Clean Water Act |
| DO | = Dissolved oxygen |
| DWR | = California Department of Water Resources |
| DWF | = Dry weather flow |
| DWUR | = Dry weather urban runoff |
| EPA | = U.S. Environmental Protection Agency |
| ET | = Evapotranspiration |
| GCM | = Global climate model |
| GHG | = Greenhouse gas |
| GPD | = Gallons per day |
| GPY | = Gallons per year |
| HTP | = Hyperion Treatment Plant (Los Angeles) |
| IRP | = Integrated Resources Plan (Los Angeles) |
| IRWMP | = Integrated Regional Water Management Plans |
| IRWD | = Irvine Ranch Water District |
| JPA | = Joint project authority |
| LAA | = Los Angeles Aqueduct(s) |
| LADWP | = Los Angeles Department of Water & Power |
| LAGWRP | = Los Angeles/Glendale Water Reclamation Plant |
| LID | = Low impact development |
| MF/RO | = Microfiltration/reverse osmosis |
| MGD | = Million gallons per day |
| MOU | = Memorandum of understanding |
| MWD | = Metropolitan Water District of Southern California |
| MWDOC | = Municipal Water District of Orange County |
| NPDES | = National Pollutant Discharge Elimination System |
| NPS | = Nonpoint source |
| NPV | = Net present value |
| ORD | = Office of Research and Development |
| O&M | = Operations and maintenance |
| PPCPs | = Pharmaceuticals and personal care products |
| RO | = Reverse osmosis |

| | |
|---|---|
| SFV | = San Fernando Valley (demand zone) |
| SP | = San Pedro (demand zone) |
| SSO | = Sanitary sewer overflows |
| SWP | = State Water Project |
| TITP | = Terminal Island Treatment Plant (Los Angeles) |
| TDS | = Total Dissolved Solids |
| TMDL | = Total Maximum Daily Load |
| TWM | = Total water management |
| TWRP | = Tillman Water Reclamation Plant (Los Angeles) |
| WEAP | = Water Evaluation and Planning, a systems model developed by Stockholm Environment Institute |
| West | = Westside (demand zone) |
| WRP | = Water reclamation plant |
| WWF | = Wet weather flows |
| WWTP | = Wastewater treatment plant |
| UPC | = Uniform Plumbing Code |
| U.S. | = United States |
| USDA | = U.S. Department of Agriculture |
| UV | = Ultra-violet |

## Acknowledgements

An undertaking of this type requires the dedication and cooperation of a team. The technical direction and coordination for this project was provided by the technical project team of the EPA, under the direction of Mr. Thomas P. O'Connor, the Project Officer. Dr. James Goodrich of the EPA, Dr. Charles Rowney of ACR, LLC and Dr. Youn Sim, Watershed Management Division, Department of Public Works, the County of Los Angeles performed reviews of this report. Mrs. Carolyn Esposito of EPA reviewed the quality assurance project plan and the report as well.

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# Executive Summary

As population growth, urbanization and current water management operations put different stresses on the environment and urban infrastructure, there is a need for urban water managers to take a more holistic view of their water resource systems. In this urbanizing world, water managers need to develop new planning and management frameworks in order for municipalities to meet challenges, such as limited fresh water supplies, degradation of receiving water quality, increasing regulatory requirements, flood management, aging infrastructure, rising energy and therefore utility costs, population dynamics, and climate change. The traditional paradigm for water resources and infrastructure management - characterized as once-pass-through use of resources, supply-side solutions to growth, end-of-pipe solutions to waste and pollution, and single-purpose projects - is no longer adequate to meet these rapidly evolving challenges or the long term impacts of human activity on the environment.

Traditional water resources management will need to be transformed into a more sustainable form of urban water management. This transformation requires new ways of thinking about urban water management and new frameworks for planning, decision-making, design, engineering and operations. Total Water Management (TWM) is an interconnected approach that can reduce water demands for freshwater, increase water recycling and reuse, change stormwater management into water supply assets development, match water quality to end user needs and achieve environmental goals through multi-purpose, multi-benefit infrastructure. TWM represents a new paradigm for urban water systems. Traditional urban water management separates a municipality's water resources into distinct classes of potable water, wastewater, and urban runoff, while TWM views all water as a resource that undergoes a continual cycle which can be managed in a fully integrated manner.

This study was funded by the United States Environmental Protection Agency (EPA) to communicate the benefits of TWM to water management decision-makers, municipalities, and policy decision-makers and aid in the development and adoption of management techniques to improve urban water systems. A comprehensive literature review summarizes TWM principles and applications in the U.S. and abroad. The U.S. portion of the literature review was organized into different regions of the country in order to reflect geographic water management drivers and challenges.

A systems model was developed and tested based on Water Evaluation and Planning (WEAP) software, an object oriented platform in which a water schematic is created by using a drag and drop approach. WEAP allows users to build a customized model of the water system, which can include water supply, distribution, treatment, recycling/reuse, and disposal infrastructure. The software performs a mass balance throughout the system and allocates water based on user-defined demand priorities and supply preferences. Water storage (both reservoir and groundwater) can all be tracked over time and indoor and outdoor water demands can be split to account for conservation and irrigation with recycled water, respectively. The software can simulate supply reliability, total lifecycle costs, water quality of receiving waters, and a number of other environmental indicators.

The case study presented in this report for the TWM model is based on the City of Los Angeles, California. Los Angeles is one of the few cities that adopted the principles of TWM for future water resources management citywide. In 1999, the City of Los Angeles embarked on an entirely new approach, called the Integrated Resources Plan (IRP), for managing its water resources. The IRP took a holistic, watershed approach, and was a partnership between the different departments within Los Angeles that managed water supply, wastewater and stormwater. The goal was to develop multi-purpose, multi-benefit strategies to address chronic droughts, achieve compliance with water quality laws, provide additional wastewater system capacity, increase open space, reduce energy consumption, manage costs and improve quality of life for its citizens. This IRP was completed in 2006 and projects identified in the IRP are planned to be implemented over the next 20 years.

Currently, 85 percent (%) of the water Los Angeles consumes is from outside the city limits. Almost 50% of the supply is imported from the Sierra Nevada via the Los Angeles Aqueducts. The Metropolitan Water District provides 35% of the supply, imported via the State Water Project and Colorado River. The imported water has to be pumped hundreds of miles to reach its destination, resulting in high energy use and carbon gas emissions. The imported water is also highly susceptible to droughts and environmental restrictions.

The current Los Angeles wastewater system consists of a large secondary treatment plant and three water reclamation plants. By 2020, new wastewater and collection system capacity will be required. As of the completion of the IRP, recycled water only comprised 1% of the supply.

The stormwater runoff system is separate from the wastewater system. Additionally, dry-weather runoff from excessive irrigation water is collected and channeled untreated into receiving waters (e.g., Los Angeles River, Santa Monica Bay and ocean). Total maximum daily loads (TMDL) for bacteria, metals and other constituents require Los Angeles to treat or manage this urban runoff.

For this case study, Los Angeles was divided into four demand zones – each with its own connections to surface water, local groundwater basins, and imported water sources, as well as connections to downstream wastewater treatment plants and receiving waters. TWM strategies that were evaluated to meet projected indoor and outdoor demands included increased water conservation, expanded recycling and reuse, graywater, groundwater recharge and rainwater harvesting.

The model was designed to run on a monthly time step from 2008 to 2033, with a specified historical hydrologic sequence representing 1978 to 2003. The TWM options used in the desktop analysis case study were programmed in the WEAP model with capital, fixed operations and management (O&M) and variable O&M estimates. Greenhouse gas emissions were based on energy requirements of different elements (e.g., water supply, treatment) and assumptions regarding the mix of available energy sources in California. Hydrographs were used to determine stormwater (wet weather) flows and variability, and stormwater gage data was used to determine the average dry weather urban runoff. For the purpose of demonstrating the model, zinc was used a proxy for water quality and TMDL compliance. Wastewater treatment and water recycling capacities were based on the IRP. Water supply yields and cost data for TWM strategies were derived from a variety of sources including the IRP and the literature search.

Three alternatives (or scenarios) were evaluated in the WEAP systems model: (1) baseline scenario, representing traditional water management; (2) total water management scenario 1, focusing on increasing local water supplies; and (3) total water management scenario 2, focusing on improving water quality. The output from the WEAP systems model was analyzed in order to assess the relative benefits of TWM versus traditional water management (baseline scenario).

The systems modeling of the urban water system for Los Angeles clearly shows that TWM is superior to traditional water management. Both of the TWM scenarios had greater benefits at lower costs when compared to the baseline scenario approach. This is mainly a result of the high cost for imported water, which is also very vulnerable to droughts. Additional analysis of effects of climate change and damage to water systems due to earthquake reinforced the benefits of the TWM scenarios versus the traditional baseline approach.

The WEAP model demonstrated how TWM approaches would perform against traditional water management approaches. The results presented in this case study are an example that can be used by other municipalities. TWM does not necessarily need to be limited to water supply analysis alone as in other areas of the country it may produce benefits for water quality and flood management. By examining water resources in a more interconnected and integrated manner, TWM allows water managers to explore multi-purpose projects and determine whether or not it makes economic sense to move forward with TWM. Each application of TWM needs to be evaluated based on local water resources challenges and unique baseline conditions. Decision support tools such as WEAP and other system simulation models can be useful in analyzing whether TWM produces net benefits.

# Chapter 1 - Introduction

In order for municipalities to meet challenges such as limited fresh water supplies, degradation of receiving water quality, increasing regulatory requirements, flood management, aging infrastructure, and rising utility costs, new planning and management frameworks must be developed for urban areas. The traditional approach for managing water resources and infrastructure is no longer adequate to meet these rapidly evolving challenges or the long term impacts of human activity on the environment.

Traditional water resources management — characterized as "once-pass-through" use of resources; supply-side solutions to growth; "end-of-pipe" solutions to waste and pollution; and single-purpose projects — will need to be transformed into a more sustainable, holistic approach. This transformation will require a new paradigm for water resources management and new frameworks for planning, decision-making, design, engineering, and operations.

Total Water Management (TWM) is an approach based on a holistic view of the water resources system and principles of sustainability. TWM can be utilized to increase water resources efficiency and enhance overall benefits. It examines urban water systems in a more interconnected manner, focusing on reducing water demands for fresh water, increasing water recycling and reuse, creating water supply assets from stormwater, matching water quality to end-use needs, and achieving environmental and societal goals through multi-purpose, multi-benefit solutions. While traditional urban water management separates a city's water resources into the three distinct classes of water, i.e., potable, wastewater, and stormwater, the TWM approach views all water as a resource that undergoes a cycle that can be managed in a fully integrated manner.

## *Objective*

This study introduces TWM as an approach to plan and manage water systems in an urban watershed, and to illustrate and communicate the potential benefits of TWM to utility managers, municipalities, policy decision-makers and practitioners. The first element of the study was a comprehensive literature review that summarized TWM strategies being implemented in the United States and internationally. The second element was development of a standardized analytic approach that can be used to guide those wishing to implement TWM. The third element was the development of a desktop analysis to demonstrate how two TWM alternatives would perform against the traditional approach to water management, using the City of Los Angeles as a case study.

## *Report Organization*

The main report is divided into five chapters: (1) Introduction; (2) Total Water Management Defined; (3) Total Water Management Evaluation Protocol; (4) Modeling Total Water Management; (5) Desktop Analysis Case Study; and (6) Conclusions. Technical assumptions for the Case Study are presented in Appendices A through C. The literature review of Total Water Management strategies is presented in Appendix D

# Chapter 2 - Total Water Management Defined

## 2.1 What is Total Water Management?

TWM presents a new paradigm for urban water systems. It is an approach that seeks better management and efficiency of water resources, and breaks down institutional barriers that separate water into the silos of drinking, wastewater, and stormwater. TWM analyzes the entire water cycle to develop sustainable water supplies, improve water quality, and reduce impacts of stormwater in a cost-effective manner. Through the process of TWM, wastewater and stormwater become water supply assets to meet water demands based on end user needs, and land uses are analyzed to reduce impermeable surfaces to allow water to be retained onsite.

The American Water Works Association Research Foundation (AwwaRF) (1996) defines TWM as: "*The exercise of stewardship of water resources for the greatest good of society and the environment."* This definition of TWM is very broad and related to concepts such as Integrated Resources Planning (AwwaRF, 1998) and Integrated Water Resources Management (Grigg, 1996). Common to all of these concepts is the integration across water sectors and geopolitical boundaries. Most practically, the term TWM has been applied to planning and projects with an emphasis on multi-purpose, multi-beneficial solutions to solving water resources problems. A variety of TWM projects with a central objective on water supply are described in Hill et al. (2007), Baldwin et al. (2007), and Muniz et al. (1993).

## 2.2 Benefits of Whole-System Management of Water Resources

In TWM we seek solutions that meet both community and environmental needs. Grigg (2008) mentions that TWM "is about the balance between our responsibilities to provide safe and reliable water services and to protect the environment." Young (2006) proposes that TWM is driven by four principles: (1) recognizing freshwater as a finite but renewable resource; (2) managing water resources on the basis of watersheds and involving relevant stakeholders; (3) preserving water resources, and (4) allocating water equitably. The concepts of renewable resource, watersheds, stakeholders and equitable allocation can all be implemented in a TWM approach that uses the watershed as a unit of analysis, and that evaluates water in its entire cycle.

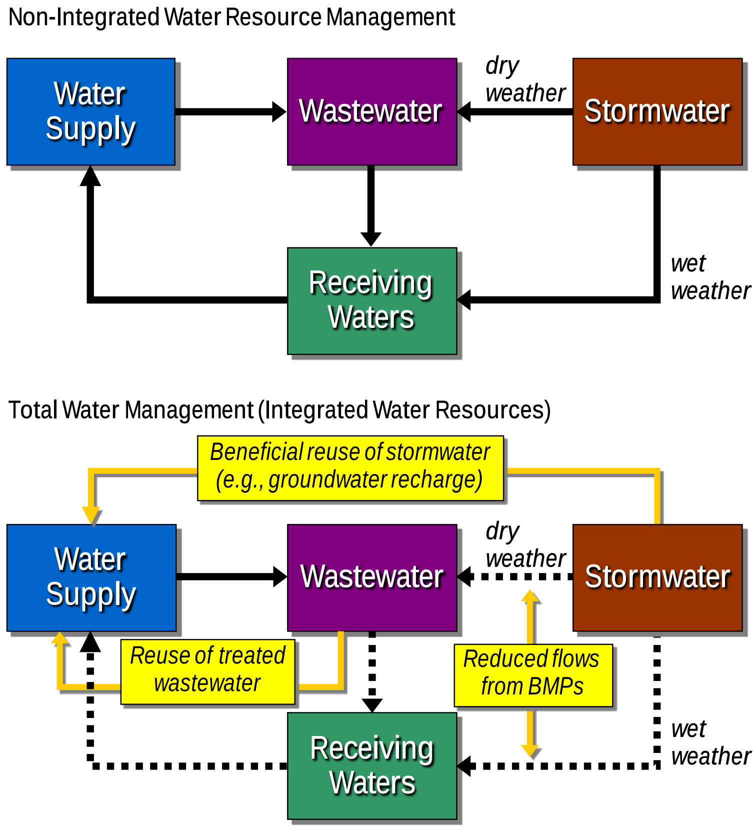



**Figure 1. Non-integrated water resources management vs. total water management**

Figure 1 illustrates the difference between non-integrated water resources management and TWM. In this figure, receiving waters represents surface and groundwater sources while dry-weather stormwater represents non-peak storm events or low flows that occur from over irrigation in urbanized watersheds. In some locations of the U.S., these dry-weather stormwater flows are conveyed to the wastewater system for treatment and discharge. In the non-integrated approach, urban watersheds use more receiving waters for their water supply, and heavily discharge wastewater and stormwater into receiving waters. This approach can result in detrimental environmental impacts, as well as lead to inefficiencies in the use of water. TWM significantly improves the opportunities to obtain benefits from water, regardless of its stage in the water cycle. Water conservation reduces the demand for fresh water. Rather than stormwater being viewed as a nuisance—something to get rid of as soon as it starts flowing in order to avoid flooding—it should be an asset, where it can be allowed to recharge groundwater through best management practices (BMPs) such as swales and use of porous pavement, or directly captured using cisterns. Furthermore, wastewater can be recycled, providing both environmental and dependable water supply benefits. The end result of TWM is reduced discharges to receiving waters and reduced reliance on natural surface and groundwater supplies to meet water demands.

Typically, TWM strategies include:

- Water conservation
- Reuse of wastewater
- Reuse of graywater
- Stormwater best management practices (BMPs)
- Rainwater harvesting
- Dry weather urban runoff treatment plants
- Dual plumbing for potable & non-potable uses
- Separate distribution systems for fire protection
- Multi-purpose infrastructure
- Using the right water quality for intended use
- Green roofs
- Low impact development (LID)

# Chapter 3 - Total Water Management Analysis Protocol

The purpose of this chapter is to give water resource practitioners guidance on how to analyze TWM, and outline the major steps and elements of the planning process. Evaluating TWM follows many of the same principles of traditional planning.

Generally, the TWM planning process includes the following general steps:

- Define study area and problem
- Define planning objectives and develop performance criteria
- Characterize existing conditions and project future scenarios
- Identify and characterize individual TWM options
- Combine TWM options into complete alternatives or portfolios
- Develop systems model approach and select appropriate analysis tools
- Evaluate TWM alternatives
- Select preferred TWM alternative
- Develop implementation strategy, addressing risk and uncertainty through adaptive management

Not all of these steps are chronological or applied in series. The different planning steps can be performed as three parallel paths at the beginning of a project converging on the analysis and decision making as illustrated in Figure 2.

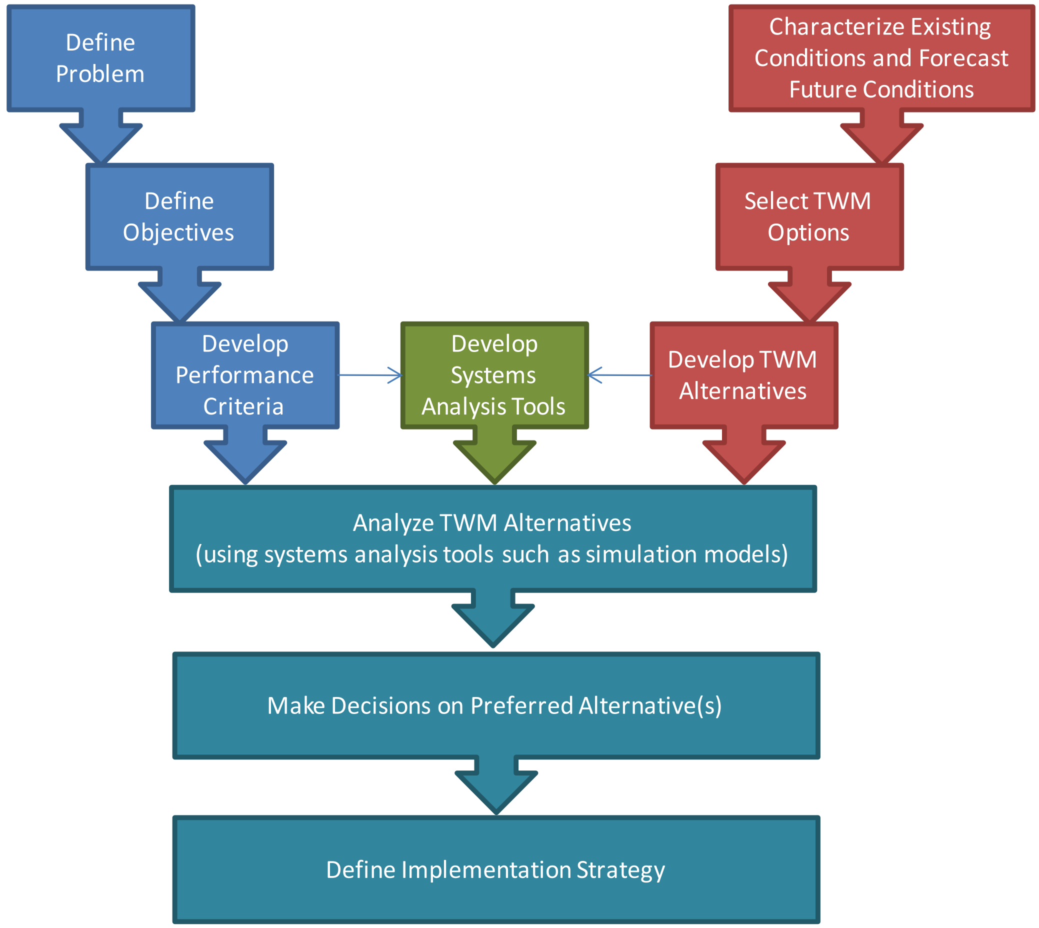



**Figure 2. Total water management planning process**

## 3.1 Problem Definition

The first step in the process is to define the problem and the drivers for the project. Is the project driven by demand growth? Is there a supply reliability problem? Is it driven by regulatory compliance on water quality? Is it a strategic first step to define capital investments? The problem definition helps to guide the entire planning process. This step is can be done with utility officials or with stakeholders in a facilitated workshop. Often, a mission statement for the project is developed during this step.

This step is also where major issues and stakeholders are identified. Is there an established group of stakeholders that collaborates with the utility or city? Are there contentious issues or antagonistic relationships with some members of the public? Do we have sufficient technical knowledge about the engineering issues? Is there significant lack of relevant data? These type of situational analysis questions help define the TWM process in its technical and stakeholder dimensions.

## 3.2 Development of Objectives and Performance Criteria

Before identifying and analyzing any solution, project or strategy, planning objectives need to be clearly defined. Objectives set out to answer the questions: "what are we trying to achieve?" or "why are we preparing this plan?" Objectives define the broad goals of the program, in easy to understand statements. And while it is not essential, it is recommended that objectives should be defined in a collaborative setting with public stakeholders and utility officials. A TWM overall goal is achieved when achieving individual objectives simultaneously by implementing TWM strategies.

Examples of TWM individual objectives may include:

- Ensuring water supply reliability under all hydrologic events
- Improving drinking water quality
- Managing utility costs
- Providing adequate wastewater system capacity
- Reducing impacts of stormwater on the environment
- Increasing water use efficiency

When a TWM strategy is successful, these sample objectives listed above can be achieved simultaneously, to different degrees. This contrasts significantly with traditional water planning where a single objective may be pursued, such as improving water reliability at the minimum cost. For each objective, performance metrics need to be developed in order to quantify how well alternatives achieve the desired goals. Examples of performance metrics include:

- Frequency and magnitude of water shortages
- Amount of arsenic in drinking water
- Total lifecycle costs
- Bacteria count in receiving waters

These performance metrics need to be specifically mapped to all of the objectives. A good description of criteria development is presented by Michaud (2009) explaining not only the process to develop criteria but the attributes that criteria need to have to be effective in discriminating among alternatives.

## 3.3 Characterizing Existing Conditions and Forecasting Future Conditions

Characterizing the existing conditions and forecasting future conditions establishes the baseline for the project. This characterization will need to answer the following questions: What are the existing water supplies? Will these existing water supplies decrease over time? What are the current or expected water quality and environmental regulations? What is the current infrastructure for water, wastewater and stormwater? What are the current and projected water demands?

In many cases, this baseline condition can be established with information from recently completed utility master plans for water and wastewater. This is also sometimes referred to as a "no project" or "no action" alternative.

## 3.4 Selecting Options and Developing Alternatives within TWM Approach

The term "option" refers to individual projects or programs for each of the historically individual sectors of water: drinking water; wastewater; and stormwater. Identifying and characterizing these options is a very important step in the TWM process. For each option, it is important to identify the benefits provided and full costs.

Because no one option will likely solve all of the water resources goals identified, options must be combined to form complete alternatives or portfolios. This is especially true in TWM, where goals are to be met for multiple water sectors. The creation of alternatives is an important step because evaluation criteria are applied at the alternatives level and not individual project level. The reason for this is simple; any one specific project may not perform well by itself, but when combined with another option or several options, the entire alternative may perform well due to the synergistic nature of TWM.

Given the number of potential options spread across three utility sectors, i.e., drinking water, wastewater and stormwater, the number different permutations or combinations will result in dozens of alternatives to evaluate. To keep the number of alternatives manageable, the planning objectives can be used to develop alternatives centered around "themes." Example alternatives based on themes could include:

- Balanced impacts
- Balanced benefits
- Low cost alternative
- Low risk alternative
- High reliability alternative
- High sustainability alternative
- Alternative with high adaptability to regulatory, technology and market changes

Using themes are an effective way to keep the number of initial alternatives manageable. Once these initial alternatives are evaluated, hybrid alternatives can be constructed by taking the best elements from the initial alternatives in order to create "super performing" alternatives. Figure 3 depicts how alternatives are developed from individual options.

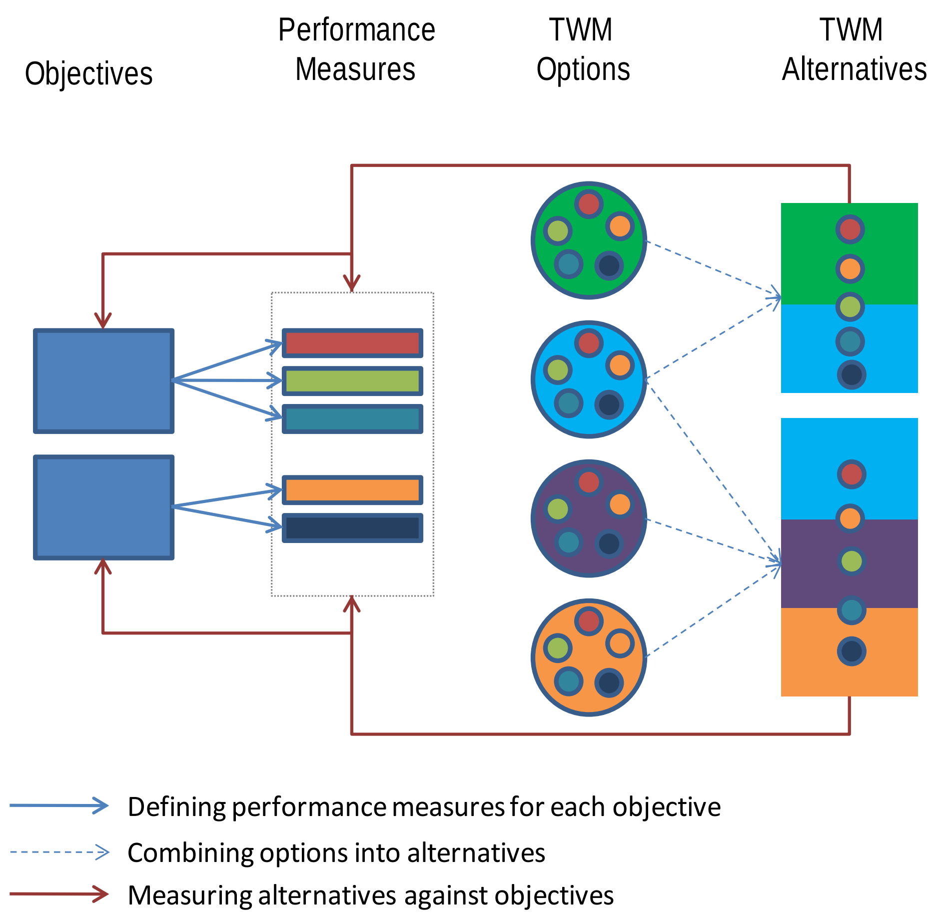



**Figure 3. Building total water management alternatives**

The alternative definition step may be one of the most valuable in a TWM process. Creativity and expertise, as well as knowledge of the system and the issues, are necessary to define innovative solutions. This step in a TWM process, where options are combined into alternatives, traditionally requires an internal workshop with experts and members of the team with significant knowledge of the system.

## 3.5 Development of Systems Model

A systems model adds significant value in evaluating the alternatives against the objectives and performance criteria. Chapter 4 explains the significant advantages in developing a systems model as a central analytical tool in TWM planning. The first important step of developing a systems model is defining the 'modeling' objectives which will define how the model can help inform the problem statement and meet the planning goals.

A second step in developing the systems model is the definition of its scope, which as the following dimensions:

- Geographic space (city, county, urban watershed)
- Sectors (water, wastewater, stormwater)
- Analysis layers (cost, water quality, environmental impacts, etc.)
- Time scale (annual, monthly, daily)

In every modeling effort, it is critical to write a modeling plan describing the modeling objectives and the scope, as well as important characteristics of the system. When the modeling plan is complete, the selection of the tool can take place. Chapter 4 includes a more detailed discussion on modeling TWM and the tools that are available.

Before programming the model begins, a conceptualized model of the system needs to be constructed, i.e., drawn in one or several schematics. The conceptual model needs to include all relevant model (system) elements and relationships. After the conceptual model is developed, the programming task can take place. It is important to recognize that the development of the conceptual model will be an ongoing task until the programming is finished due to the fact that the programming task results on a better and deeper understanding of the system.

After the programming takes place and the model is complete, it needs to be tested and validated. Several checks need to take place during and after model programming, and the model needs to be validated with the simulation of existing conditions. Validation includes tests to see if mass is conserved, meaning all sources of water are tracked from when it enters to when it leaves the system. Validation is also important to make sure all units are converted properly and that all cost calculations are tested. In more complex models, validation can be used to test how the model simulates water storage operations for a past hydrologic condition.

## 3.6 Evaluation of TWM Alternatives

After the systems model is programmed and validated, the evaluation of the alternatives can take place. This step involves the quantitative analysis of how each alternative performs against the performance measures. It is important in this step to clearly define how the performance measures will be reported. Will the performance be measured cumulatively over the planning horizon (e.g., build-out conditions), or for a specific design year? It is also important to determine whether results will be presented as a probability distribution or as a point estimate. Many of the system model softwares allow for runs of Monte Carlo simulations. In Monte Carlo simulations, random draws are made for key decision variables (e.g., hydrologic years, variability in operations and maintenance (O&M) costs, etc.) and the model output can then be presented as a histogram or exceedance probability plot. A score card of alternatives and their performance is another way in which output from this step can be displayed.

## 3.7 Selecting the Preferred Alternative (Decision-Making)

After the analytical phase of the project, the technical team needs to synthesize the great amount of information that is generated as part of the analysis. Because there will likely be many performance measures that are reported from the systems model and these measures will all be reported in different units, i.e., flows in million gallons per day (MGD), or costs in dollars per year, the use of a multi-criteria decision tool is often used to standardize the output and rank alternatives. The use of such a tool will clearly show tradeoffs between the alternatives and help decision-makers in selecting a preferred alternative.

## 3.8 Defining an Implementation Strategy

The decision-making step usually results in the selection of one alternative or a short-list of alternatives. TWM plans can formally address uncertainties and risk associated with the forecasting step using adaptive management to develop an implementation strategy. For example, if there are several variables that are highly uncertain, such as demand forecast or regulatory requirements, the systems model can be used to develop separate implementation paths associated with different scenarios of the future. Trigger points can be established in the future, and when a specific path is becoming more apparent, then the implementation strategy can be adjusted accordingly.

Because TWM by its very nature explores all water sectors, implementation of TWM projects will require greater coordination between those who manage water, wastewater and stormwater. In some cases, two or even all three of these water sectors are managed by a single city agency, such as public works, and this will make the implementation of TWM more straight forward. But more commonly (and especially in larger cities), there are three separate utilities or city agencies that manage water resources. In this case, implementation of TWM projects will require some institutional barriers to be eliminated and greater cooperation between utilities.

Implementation of TWM projects will likely involve different ways to finance and fund capital infrastructure between multiple partners, as well as agreements on how facilities will be operated once constructed. These agreements can be in the form of a memorandum of understanding (MOU), through an oversight entity such as the mayor's office, or through a joint project authority (JPA).

# Chapter 4 - Modeling Total Water Management

## 4.1 Modeling in a Planning Process

Any planning process involves the systematic evaluation of alternatives in order to make a rational decision, given baseline and projected data. McAllister (1995) describes environmental planning as a process encompassing five steps: "(1) identify the problem to be addressed; (2) design alternative solutions to the problem; (3) evaluate the alternatives; (4) decide on the action to be taken through the appropriate political process and implement it; and (5) monitor the results." The third step, the evaluation step, is an analytical step and usually is highly quantitative in nature. The quantitative analysis of alternatives can be performed with a range of analytical tools. Selecting which tool to use should be based on the complexity of the problem and what is at stake in the decision making process.

Computer models are common analytical tools used to understand and simulate water resources and environmental systems in which the alternatives are applied. The evaluation and quantification of the response of those systems to a set of management and planning decisions (alternatives) is adequately performed with models. Models can optimize or simulate a system, and quantify the water resource and environmental system variables over time. Models can give decision makers the information needed for Step 4 of the planning process in McAllister's description of the planning process.

In traditional planning, usually one flow model is used for each stage of the water cycle. For example, hydraulic model for drinking water; collection system model for wastewater; and hydrology model for stormwater. In addition, treatment and/or water quality models may also be necessary. But in TWM when all water resources are modeled as an interconnected system, more closely mimicking the real watershed, then a different type of model is required. A "systems" model, as it is commonly called, is a higher-level model that simultaneously simulates the entire water cycle. This systems model does not replace more detailed models for water supply, wastewater, or stormwater, but in fact is used in conjunction with these detailed models.

## 4.2 Systems Modeling in TWM

The concept of TWM requires a systemic view of an urban watershed. In TWM, water at different stages of the water cycle is not seen as independent "types" of water such as raw water, potable water, wastewater and runoff but rather as a resource that undergoes a cycle which can be managed holistically. Pollutants are not seen as specific attributes i.e., sometimes assumed to be inherent, of a "type" of water. Instead, pollutants are seen as elements that the water will transport once introduced into the water cycle at specific locations and as a result of specific human activities and practices and natural processes. In TWM, managers track where pollutants are introduced in the water cycle and how they are transformed and removed from it. Pollutants are not just tracked within a sector of the system, i.e., potable water, wastewater, and stormwater, but also as they move between sectors. TWM describes the pollutant's ultimate fate and how managing decisions can impact that fate and transport.

Systems models are well suited as analytical tools for TWM. The term "systems model" is used to define a model that includes the representation of different components of an overall system. A systems model of an urban watershed could include a representation of the water demands, water sources, water transmission and treatment, wastewater collection and treatment, wastewater and stormwater discharges, and receiving waters. It could also include economic variables and environmental impacts. A systems model differs from the "model of a system" (e.g., a groundwater model, a wastewater treatment plant (WWTP) process model, or a water distribution network model) in that, in modeling the urban watershed, the systems model places emphasis on the *interrelationships* between the components of the overall system. The systems model of an urban watershed would place an emphasis on the interrelationships between: indoor water demands and household wastewater generation; wastewater recycling and irrigation water demands; surface runoff and groundwater recharge; and stormwater and water quality in receiving waters.

Systems models are dynamic models. These models simulate variables over time to allow decision-makers to test how alternatives change the system, and also to test "what-if" scenarios of different possible future conditions. A systems model can estimate specific benefits from water management decisions that can impact more than one sector in the watershed (e.g., water supply and water quality in receiving waters). In the context of TWM, a systems model can also be used to measure the economic, environmental and social elements of sustainability. Figure 4 presents a schematic representation of a systems model of an urban watershed.

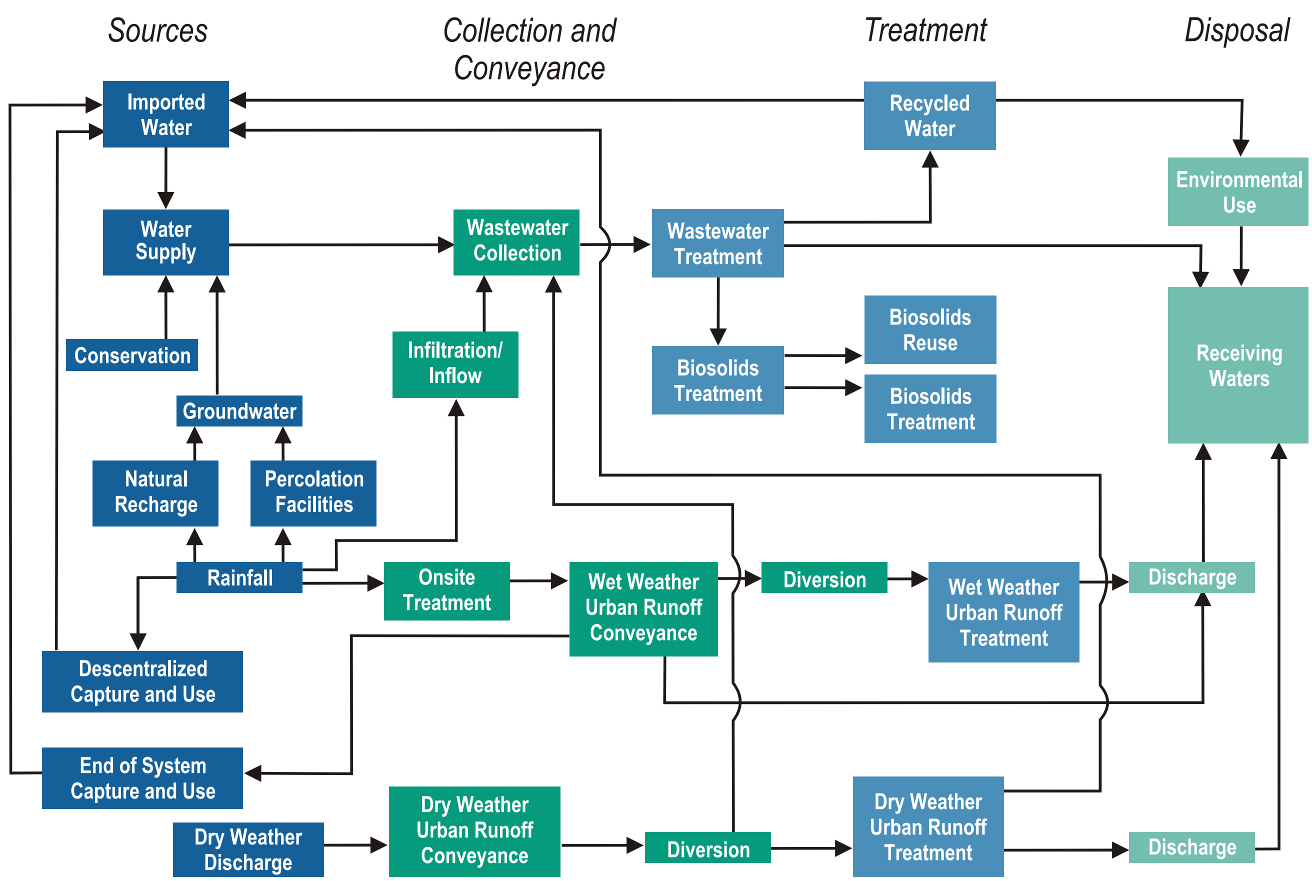



**Figure 4. Conceptual representation of a systems model in an urban watershed (Lopez et al., 2001)**

The use of a systems model can help formalize the relationships, i.e., establishing actual equations representing the relationships and quantifying the effects of management options on a specific area of the system. The main advantage of a systems model is that it can keep track of a number of simple relationships and generate one comprehensive list of outputs relevant for managers, enabling them to keep track of all of the system responses, costs and benefits. For example, the systems model would quantify the impact indoor water conservation will have on water demand and wastewater discharges. Additionally, conservation will come at a certain cost of implementation, but can represent savings on water and wastewater infrastructure. The overall energy requirements to operate the system will also vary with the conservation strategy. One management decision can trigger responses in several variables of interest and when the number of decisions and system components grows, a system model for TWM becomes crucial.

Systems models can be constructed to simulate the variability in hydrology, or any other variable that has volatility or a probabilistic nature, over time and are able to simulate the response of a system over different time scales. A systems model can simulate a system under normal hydrology conditions, droughts and wet periods as well.

## 4.3 System Modeling Software Tools

Many simulation tools are available that could be used for a TWM study. Common systems modeling software include:

- STELLA - http://www.iseesystems.com/softwares/Education/StellaSoftware.aspx
- PowerSim - http://www.powersim.com
- Vensim - http://www.vensim.com
- ExtendSim - http://www.extendsim.com
- GoldSim - http://www.goldsim.com

These "generic" simulation tools allow users to build a customized model of any kind of system (e.g., business system, ecosystem, natural or physical system, or water system). These models can be simple, one-sector systems, or highly complex, interconnected systems. What makes these tools so powerful is the ability to see dynamically how a system responds to external forces or actions, i.e., strategies. The models are built using object-oriented programming, show results visually through interactive graphics, and are very transparent. They also have the ability to run Monte Carlo simulations, enabling probabilistic analysis to be conducted. Because these models are generic in nature, they are well suited for water resources system evaluations.

In their application for TWM, the system models perform a mass balance throughout the system and allocate water based on user-defined demand priorities and supply preferences. In these models, important system performance measures can be defined and tracked – including supply reliability, cost, water quality, storage (surface and groundwater), return flows, stream flows and impacts to the environment. However, these models require the entire system to be constructed from scratch, and the user must be careful in explicitly defining the units of measurements and formulas for all conversions. Therefore, these models are to be used by experienced practitioners in the fields of systems modeling and engineering.

The software WEAP (http://www.weap21.org), developed by the Stockholm Environment Institute, is a systems model created specifically for water resources planning. Unlike the generic systems models described above, WEAP has built-in water resources elements and does all unit conversions automatically. WEAP can evaluate runoff, groundwater/surface interactions, water conservation, water quality and storage. It is more suited for planners, and models can be constructed more quickly than the generic system models described above. However, WEAP has limited output and certain important performance measures would need to be evaluated outside of the model, using a spreadsheet or some other means. WEAP is also not able to directly run Monte Carlo analysis. So if the nature of the problem is highly variable or uncertain, other systems models may be more appropriate.

For this study WEAP was selected to analyze TWM for the case study presented in Chapter 5. The decision was based on the ease of use and quickness in developing the model, and the fact that WEAP is commonly used all across the globe for similar integrated water resources planning.

## 4.4 Common Modeling Elements in TWM

TWM models incorporate elements in two dimensions: (1) the different water sectors, such as drinking water, wastewater, or stormwater; and (2) the analytical layers, such as supply reliability, cost, water quality, and environmental impacts.

Included in the water sectors is the demand for water, and how water moves through the urban watershed cycle, i.e., sources of water supply, drinking water distribution and treatment, wastewater collection and treatment, stormwater flows and system, and disposal of wastewater and stormwater to receiving waters. Figure 5 shows an example of water sectors in an urban watershed and how they are interconnected. Figure 5 is one conceptualization of a water system out of many that can take place in a TWM project, depending on the case-by-case emphasis of the different elements of the system (e.g., groundwater vs. wastewater). But all TWM conceptualizations need to include the interrelationship between the systems and treat water, regardless of its stage in the water cycle, as a traceable entity with conservation of mass.

In addition to the water sectors, a TWM model can contain additional analytical layers for all of the performance metrics that are important to decision makers, i.e., costs, supply reliability, greenhouse gas (GHG) emissions, water quality, and environmental impacts. Figure 6 provides a schematic of analytical layers in relation to water elements.

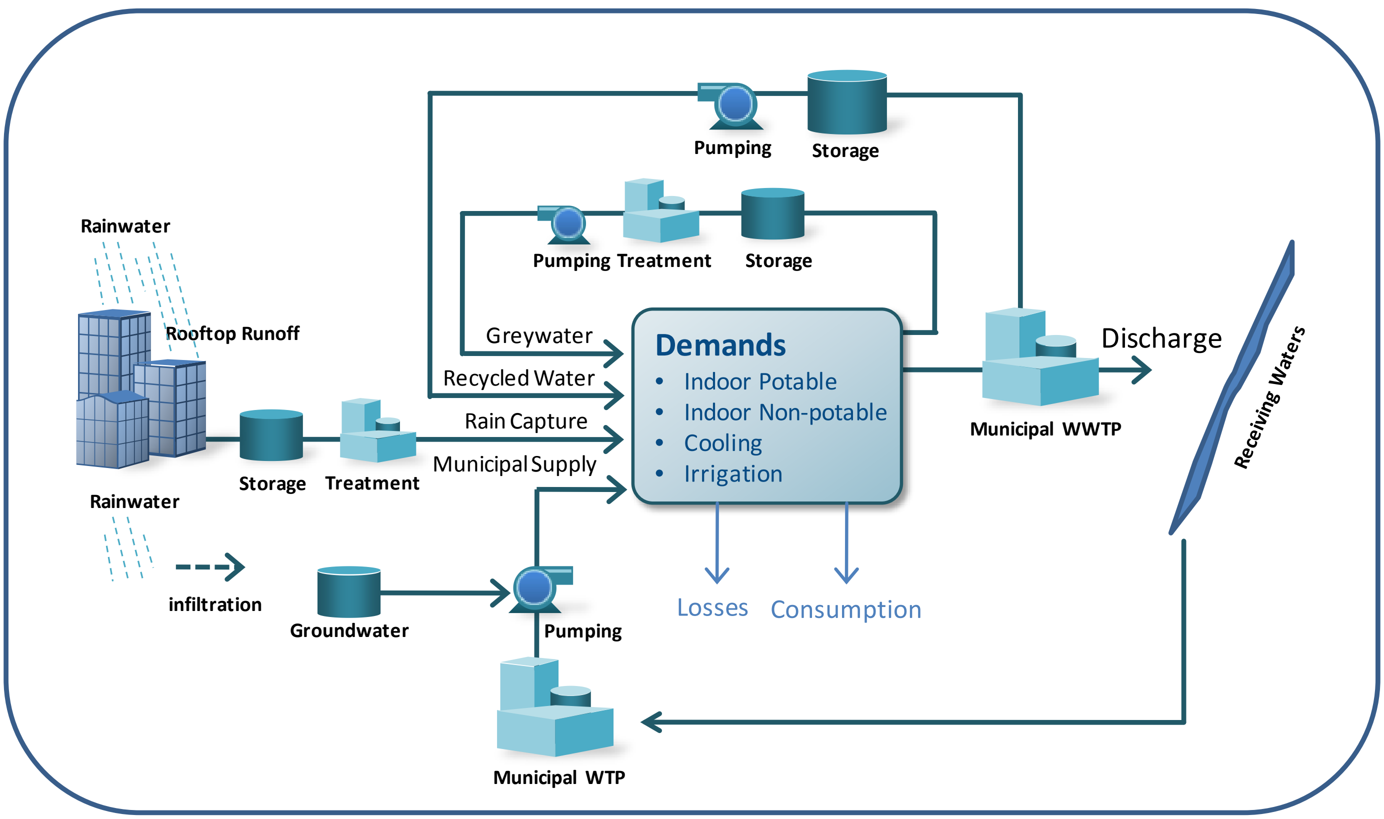



Figure 5. Water sectors and routing in a total water management model

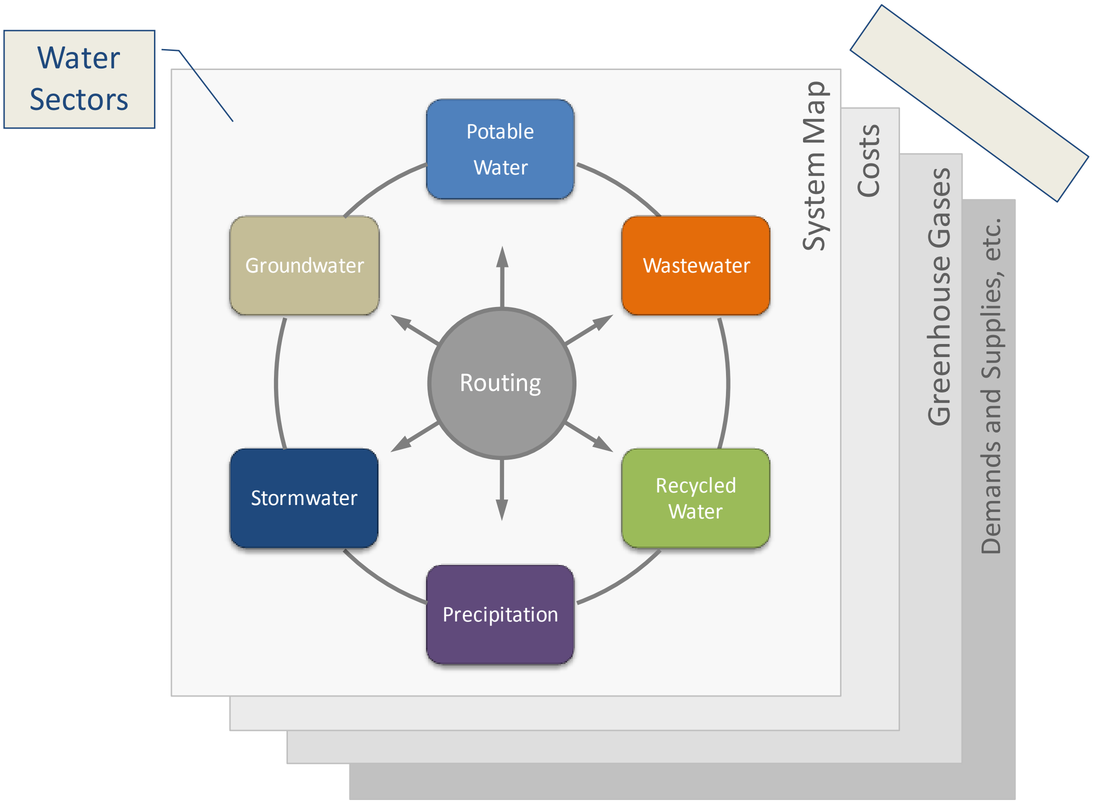



**Figure 6. Analytical layers in relation to water sectors of a typical total water management model**

## Balancing Water Demands and Supplies

An important aspect of a TWM model is the balance between water demands and supplies in the system. Demands need to be differentiated according to the quality of water required, as well as the timing and seasonality of demand. Geographic location of the demands may also be important, depending on the complexity of the watershed and limitations of water supply. In most cases, separation of indoor and outdoor water demands will be important in order to evaluate the potential for water conservation, recycled water, graywater and other alternatives that are targeted for non-potable demand.

The supply side in the TWM model needs to incorporate all the different sources of water, including safe yield, annual and monthly hydrologic variation, and long-term sustainability. Operational assumptions, especially as they relate to storage, are also very important to explicitly define. For example, a water supply source may be more than adequate to meet average annual water demands, but the capacity of conveyance and/or treatment facilities may not be sufficient to meet peak-day demands. Thus, the TWM must be able to measure operational constraints as well as supply availability.

## Routing and Mass Balance

In a TWM model, the flow paths of the volume of water in each water sector should be tracked rigorously. For example, potable water enters a building and it is used; some of it is consumed and some is discharged as wastewater. The consumption path and the discharge path are tracked in TWM models to conserve mass. Depending on the supply options evaluated in a TWM model, the paths can be simplified or can multiply elevating the complexity of the system. Figure 7 shows an example of tracking of flows within buildings with and without graywater systems.

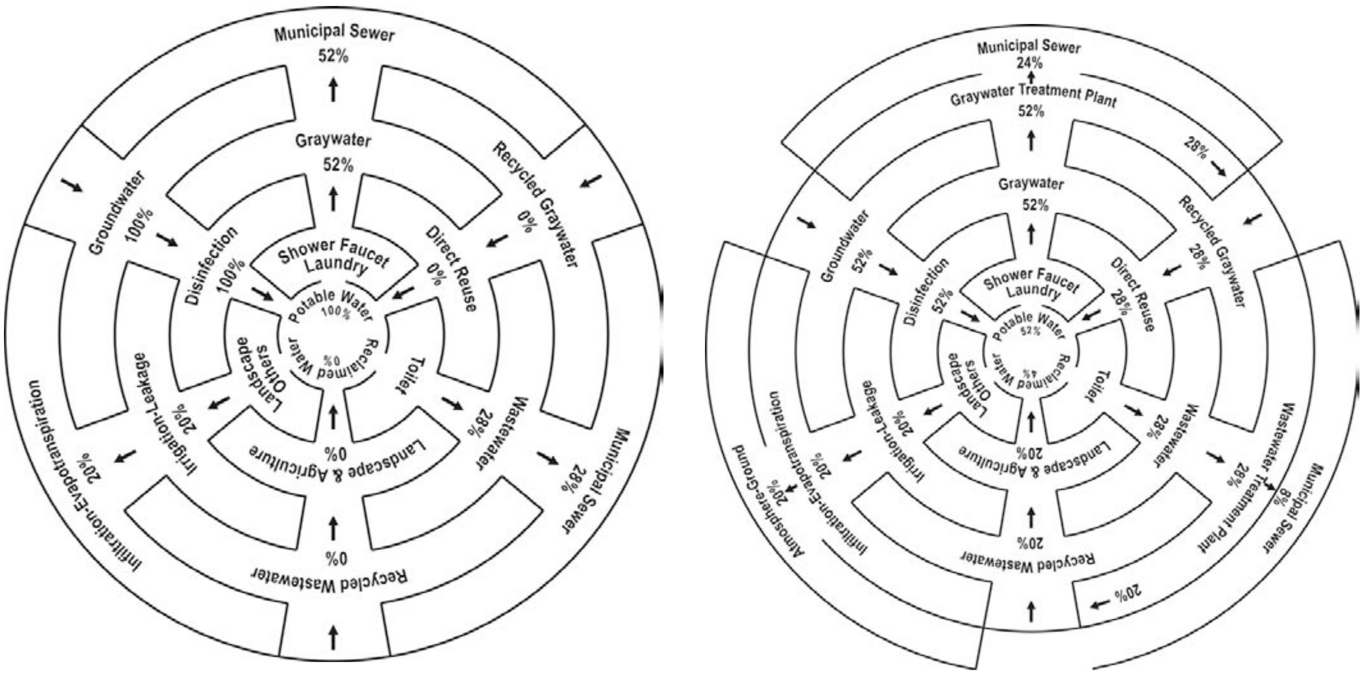



**Figure 7. Water mass balance at the household level (from Mendoza-Espinoza et al. 2006)**

Mass balance in a TWM model is fundamental. The software tools described earlier have different degrees of rigorousness regarding conservation of mass. In some cases, the tool requires the analyst to program mechanism to enforce mass balance and in some cases, as in the case of WEAP, mass balance is enforced by the program.

## Drinking and Receiving Water Quality

In a TWM study, water quality is an essential element that is of interest to decision makers. Water quality can be tracked for drinking water or receiving waters, or both. TWM models use the same mass balance routines to estimate water quality constituents. However, TWM system models generally don't include sophisticated kinetics. Temperature and residence times of appropriate scale are two variables commonly absent in TWM models and thus the quality elements are limited to simplified mass balance and fate and transport. TWM models can include some decay or uptake processes but they will be modeled with simplifying assumptions due to the time scale relevant to TWM, i.e., years, months and, rarely, days. All of the simulation tools mentioned as appropriate for TWM have the ability to accept data from other models (with varying degrees of user-friendliness), and all of the models can include transform functions that are derived from traditional water quality models.

## Costs

Cost is a layer of analysis always present in TWM models and studies. Given that most TWM models will have the ability to simulate the system and quantify the actual use of each water source per unit time (e.g., monthly), it is appropriate to separate variable costs from fixed costs in addition to having capital costs included in the model. Variable costs, when tracked and accounted appropriately, can make a difference to decision makers when deciding on planning alternatives.

Costs in TWM need to include the operation and maintenance costs of programs and not only capital projects. For example, water conservation usually does not involve infrastructure projects, but its cost to the utility or city implementing the program need to be accounted for nonetheless. Costs of compliance with regulations also need to be included. Some costs can be accounted for as benefits if they are considered avoided costs.

## Benefits

The step of the planning process when decision makers select a specific alternative is not the analysis step but rather a synthesis step where a method to interpret the information from the systems model is used to compare alternatives. Conceivably, any TWM process could include a "cost-benefit" comparison in the traditional sense where all benefits are monetized. In most cases, however, benefits in TWM are not aggregated into one monetized metric. Rather TWM studies compare alternatives from a multiple-objective perspective.

In that sense, benefits can be associated to the degree to which the alternatives meet different objectives. If a TWM study includes objectives on environmental protection, compliance with regulations, adaptability of the plan, or environmental justice, then benefits can be measured qualitatively or quantitatively in terms of how well each alternative meets the objectives. Output from the TWM model, usually in terms of unit flows from different sources of supply, can be used to measure these benefits. For example, based on unit flows of different supply sources, energy consumption can be derived, and from this energy consumption GHG emissions can be estimated.

# Chapter 5 - Desktop Analysis Case Study: City of Los Angeles

## 5.1 Background on Case Study

In 1999, the City of Los Angeles (City) embarked on an entirely new approach for managing its water resources, called the Integrated Resources Plan (IRP) (City of Los Angeles 2006a, 2006b and 2006c). The IRP took a holistic, watershed approach and was a partnership between the different departments within the City that managed water supply, wastewater, and stormwater. Prior to the IRP, the three departments that managed the City's water resources rarely coordinated or looked at their respective systems as part of a bigger whole. The goal of the IRP was to develop multi-purpose, multi-benefit strategies to address chronic droughts, achieve compliance with water quality regulations, provide additional wastewater system capacity, increase open space, reduce energy consumption, manage costs, and improve quality of life for its citizens. The IRP was completed in 2006, winning numerous state and national awards, and well supported by the City's diverse stakeholders. The projects identified in the IRP preferred strategies will be implemented over the course of the next 20 years, including increased use of recycled water, beneficial use of stormwater, increased water conservation, and multi-purpose/multi-benefit infrastructure.

### Description of Water Resources Systems

The City and surrounding urban watershed is geographically diverse and large. It stretches from the vast San Fernando Valley, a large downtown and central city area, the west side beach areas, and a port area in the southern part of the City. Running throughout the City is the Los Angeles River, now mostly a concrete channel designed for flood management. The urban watershed also has several groundwater basins located within the City or adjacent to the City. The City's water resources systems are composed of drinking water, wastewater, and stormwater. Each of these systems is briefly described to provide a basic understanding of the issues and challenges facing this urban watershed. The cited sources for these system descriptions come from the Los Angeles Department of Water & Power (LADWP) Urban Water Management Plan (LADWP, 2005) and the Los Angeles Integrated Resources Plan (City of Los Angeles 2006a, 2006b and 2006c).

#### *Water*

The City relies primarily on three water supply sources: (1) the Los Angeles Aqueducts (LAA); (2) local groundwater; and (3) supplemental water purchased from the Metropolitan Water District of Southern California (MWD). See Figure 8 for a map and historical reliance on these water supply sources. Historically, these water sources have delivered an adequate water supply to meet the City's needs. Currently, the City relies on imported water, water from outside City limits, for 85 percent (%) of its water demands. Almost 50% of the supply is imported from the Sierra Nevada via the LAA. The MWD provides 35% of the City's supply, imported via the State Water Project (SWP) and Colorado River. The imported water has to be pumped hundreds of miles to reach its destination, resulting in high energy use and carbon gas emissions. The imported water is also highly susceptible to droughts and environmental restrictions. Approximately 15% of the City's water supply is pumped from local groundwater.

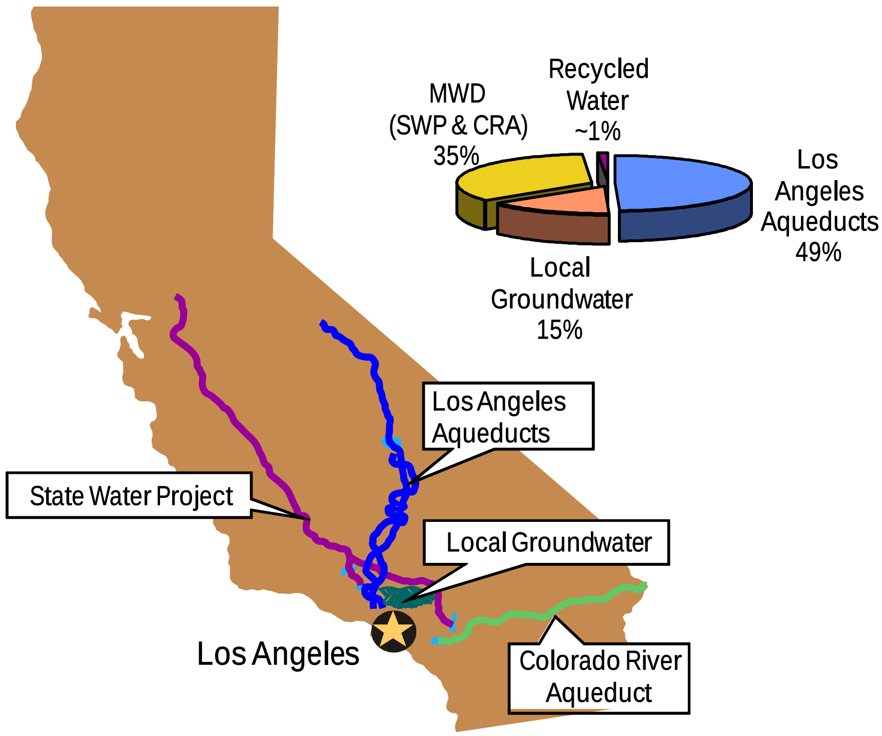



**Figure 8. City of Los Angeles water supply sources**

The City has been a national leader in implementing water conservation. Since 1991, LADWP has installed over one million ultra-low-flush toilets, hundreds of thousands of low-flow showerheads, and provided rebates for high efficiency clothes washer machines and smart irrigation devices. In fact, the City uses less water now than it did in 1990, despite adding over 700,000 new residents to its service area.

<u>Los Angeles Aqueducts</u>

Supplying almost 50% of the City's water supply, the LAA delivers water via gravity alone from the Mono Basin region in the eastern Sierra Nevada extending approximately 340 miles south. The First Los Angeles aqueduct was completed in 1913. To meet the growing needs of its population, the City completed construction of the Second LAA in 1970. Seven reservoirs on the system have a total combined reservoir capacity of the system is approximately 300,560 acre-feet (AF). Deliveries since 1989 from the LAA have averaged approximately 275,000 acre-feet/year (AFY) compared to a total annual demand around 650,000 AFY. Of the three supply sources for the City, the LAA supplies the highest quality water.

Surface runoff from snowmelt in the eastern Sierra Nevada feeds the LAA system. Runoff peaks in the late spring and summer providing flexibility in operating the LAA system and the water system as a whole. However, this supply source is subject to substantial variability due to hydrologic variability in the eastern Sierra Nevada with wet and dry years. Annual system deliveries are dependent upon annual snowfall in the eastern Sierra Nevada. Years with higher snowpack levels typically result in larger volumes of imported water delivered to the City.

Since the late 1980's environmental issues have required the City to use an increasingly significant volume of its LAA supplies for environmental mitigation in the Owens Valley and Mono Basin regions. As of 2005, the City has committed approximately 166,000 AFY or approximately 40% of its historic LAA water supply to environmental enhancements in these regions. To offset the supply reduction, the City has developed other resource management opportunities to maintain a reliable water supply system.

## Local Groundwater

Local groundwater provides approximately 15% of the total water supply, increasing up to 30% of the total water supply during droughts. The City has water rights in five groundwater basins. Approximately 86% of the City's groundwater supply, on average, is pumped from the Upper Los Angeles River Area groundwater basins, the San Fernando, Sylmar, and Eagle Rock groundwater basins. The Central Basin supplies the remaining 14% of the City's groundwater supply. Groundwater rights in the West Coast Basin are not utilized as a result of localized water quality issues. All of the basins are adjudicated, i.e., water rights for specific users have been established, and are administered by an administrative entity with jurisdiction over a specific basin called Watermaster.

The San Fernando Basin is the City's primary groundwater source supplying approximately 80 % of the total groundwater supply. In accordance with the adjudication the City has the right to the native safe yield of 43,660 AFY and the return of imported water of approximately 43,000 AFY providing an annual total entitlement of approximately 87,000 AFY. The adjudication allows the City to store water in the basin to supplement the annual SFB entitlement. In 2005 the stored water credit was approximately 320,000 AF. The practice of recharge and extraction known as conjunctive use in the basin is practiced by pumping the annual entitlement generally between April through October, the highest water demand months, and relying on more readily available imported water during the lower demand months, November through March. Captured stormwater and/or imported water are used to recharge the basin. Average annual recharge through spreading basins is approximately 25,390 AFY.

## Metropolitan Water District

Approximately 35% of the City's water supply is provided by MWD. Supplies are purchased by the City from MWD to use as a supplemental supply to make-up any deficits between the City's water supplies and customer demands. As the largest water wholesaler in California for domestic and municipal water use, MWD obtains its supplies from the SWP as a contractor, its ownership of the Colorado River Aqueduct, and from storage and water transfer programs. The City is one of MWD's 26 member agencies.

MWD is the largest contractor of the SWP, with a contract for 2.01 million AFY of the project's capacity of 4.23 million AFY. SWP water is pumped from the Sacramento-San Joaquin River Delta (Delta) in Northern California and delivered via aqueducts to Southern California. Environmental issues and variable hydrology dramatically reduce actual deliveries from the SWP. MWD's goal is to receive 650,000 AFY during drying years and 1.5 million AFY on average. But in recent years, due to a prolonged three-year drought and court-ordered pumping restrictions due to Endangered Species Act issues, MWD has received a small fraction of its contract supply (less than 200,000 AFY). In fact, in 2009 and 2010 MWD had to allocate its imported water for the first time since 1991 resulting in wide spread mandatory water restrictions throughout Southern California.

The State of California has a basic apportionment of 4.4 million AFY of water from the Colorado River, although California has historically taken an additional 1 million AFY of surplus water and unused apportionments from Nevada and Arizona. MWD's basic apportionment is 503,000 AFY, although until recently MWD has been able to utilize surplus and unused apportioned water of up to 1.2 million AFY. However, the U.S. Secretary of Interior has asserted California must develop a plan to live within its apportionment leading to development of the a Colorado River Water Use Plan has been developed, which has the key element of completing a Quantification Settlement Agreement establishing baseline water use for each California party with rights to Colorado River water. As such, MWD has developed storage and water transfer programs to boost its reliability of Colorado River Aqueduct deliveries.

## Recycled Water

The City uses recycled water to meet a small portion of its overall water demands. The City realized the potential of recycled water early on and constructed two water reclamation treatment plants, the Los Angeles-Glendale Water Reclamation Plant (LAGWRP) and Donald C. Tillman Water Reclamation Plant (TWRP), to produce tertiary treated recycled water upstream instead of enlarging its two terminus WWTPs, Hyperion Treatment Plant (HTP) and Terminal Island Treatment Plant (TITP). In 1979, the City first began delivering recycled water to irrigate parks areas in the Griffith Park area. Since that time recycled water deliveries have been expanded to include, but are not limited to, freeway landscaping, golf courses, environmental enhancement, and non-governmental industrial and commercial uses. In 2005 almost 65,000 AFY of the City's wastewater is recycled. This includes municipal and industrial use of 1,950 AFY, or less than 1% of the City's water supply, to offset potable demands. An additional 28,500 AFY of recycled water is used for environmental purposes and 34,000 AFY of secondary treated water is sold to West Basin Municipal Water District for recycling.

To further increase recycled water use, the City is in the process of developing a comprehensive Recycled Water Master Plan to greatly expand both non-potable use of recycled water and indirect potable use through advanced treatment of recycled water for groundwater recharge. The goal of this master plan is to develop over 30,000 AFY of new supply by 2018.

### *Wastewater*

The City's wastewater system provides wastewater collection, treatment, and disposal. This system is composed of a wastewater collection system that includes approximately 6,500 miles of major interceptors and mainline sewers, 46 pumping plants, and various other support facilities, such as corporation yards and diversion structures. The City's treatment facilities include a large secondary treatment plant, which is located at the coast and serves the majority of the City, two water reclamation plants (tertiary treatment) located in the northern part of the City (San Fernando Valley and Central City), and one water reclamation plant (tertiary and advanced treatment) located in the southern most part of the City (TITP). The existing cumulative average dry weather flow (DWF) treatment capacity is 543 MGD. By 2020 additional treatment and collection system capacity will be required. This additional capacity could be constructed at the secondary treatment plant or at the two northern water reclamation plants.

There are four WWTP within the City's service area, the TITP, HTP, TWRP and LAGWRP. Figure 9 shows the location of these plants.

The TWRP is a full tertiary treatment facility with capacity to treat 80 MGD; flows in excess of 80 MGD are by-passed for treatment downstream at the HTP. The TWRP currently supplies tertiary effluent for reuse and it also discharges to the Los Angeles River. No solids handling or processing are performed at the TWRP. Solids removed from the treatment processes are returned to the sewer system for treatment at the HTP.

The LAGWRP serves the Glendale/Burbank area and can treat excess flow that by-pass the TWRP. The LAGWRP is the City's oldest tertiary treatment facility and has the capacity to treat 20 MGD. Like the TWRP, the LAGWRP is an upstream plant that treats constant flows, since it has the ability to bypass flow to the HTP for treatment. The LAGWRP supplies effluent for reuse (primarily landscape irrigation and cooling water), with the remaining effluent discharged to the Los Angeles River. Like the TWRP, there are no provisions for solids handling or processing at the LAGWRP. Solids removed from the treatment processes are returned to the sewer system for treatment at the HTP.

The HTP is the City's oldest and largest wastewater treatment facility and is designed to provide full secondary treatment for a maximum monthly flow of 450 MGD and corresponding average DWF of 413 MGD. The HTP is an end-of-the-line plant, subject to normal diurnal and seasonal flow variation. The HTP currently exports 21 MGD of secondary effluent to the West Basin Water Reclamation Plant, managed by the West Basin Municipal Water District for further treatment and reuse. The remaining secondary effluent is discharged to the Santa Monica Bay via a 5-mile ocean outfall.

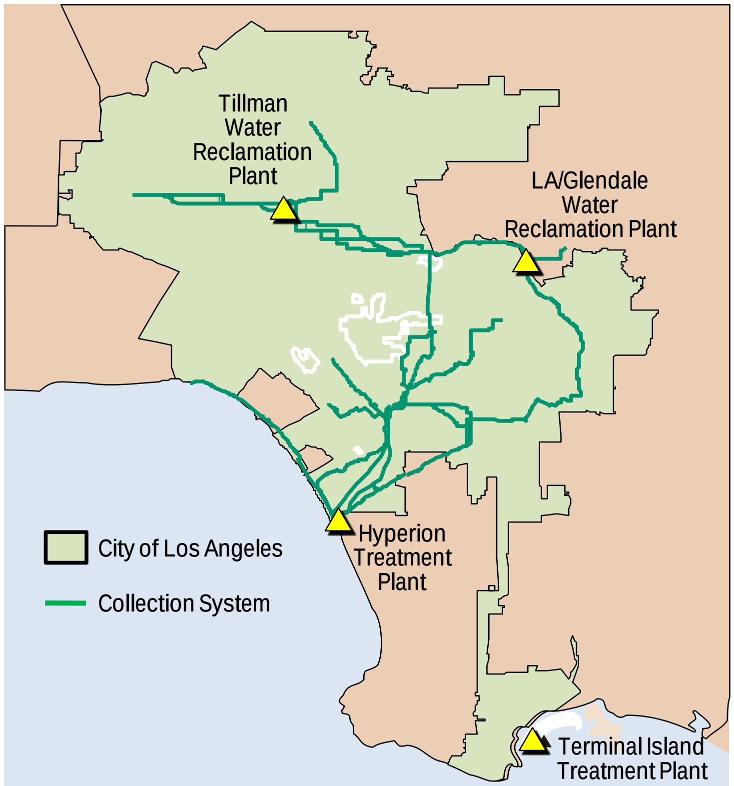



**Figure 9. City of Los Angeles Wastewater System**

The fourth treatment plant, TITP, is in the vicinity of the Los Angeles Harbor. Currently, TITP has the capacity to provide tertiary treatment and advanced treatment (microfiltration and reverse osmosis) for an average flow of 30 MGD. Like the HTP, the TITP is an end-of-the-line plant, subjected to normal diurnal and seasonal flow variation. At the TITP, biosolids are treated to Class B levels and hauled for land application and reuse as a soil amendment in the region.

### *Stormwater*

The City's runoff service area consists of approximately 295,000 acres spread throughout portions of four major watersheds and more than 2,000 sub-watersheds. Most of the land area is highly urbanized and impervious. A myriad of government agencies jointly cooperate to operate the extensive runoff management system, including the City, Los Angeles County, State of California, and Federal agencies, to protect the City's citizens and property from flood hazards. As a whole the system includes flood control basins, open channels, storm drains, catch basins, culverts, low-flow diversions to direct runoff to the sanitary sewer system, pumping plants, spreading grounds, and detention basins. The stormwater system is completely separate from the wastewater system. The portion of the runoff management system owned and operated by the City is composed of approximately 34,000 catch basins, 2,457 culverts, 157 flood control basins, and over 1,200 miles of storm drains. The runoff management system also has approximately 2,000 outlets to the largest river in the City, the Los Angeles River, and has 315 outlets to Ballona Creek.

Discharges occur throughout most of the system in both dry and wet weather. Working together the system components drain dry and wet weather from City streets into gutters and then catch basins. Catch basins route runoff into an underground network of pipes and drains discharging the runoff either directly to the Pacific Ocean or into inland streams and channels which may ultimately discharge into the Pacific Ocean or to wetlands, flood control basins, or lakes. DWFs are derived from a variety of sources including landscape irrigation runoff, street washing, car washing, groundwater seepage, illegal connections, hydrant flushings, construction runoff, and other commercial activities. DWFs attributed to the City are estimated at 58 MGD. Wet weather flows are intermittent in nature and potentially large volumes are discharge during wet weather events. The average annual volume of discharged attributed to wet weather is estimated at 56,200 million gallons or approximately 172,000 AFY which is equivalent to about 25% of the City's annual demand (City of Los Angeles, 2006b).

## Water Resource Challenges

Each water resource system in the City faces unique challenges. However, these individual systems also face common challenges. Common challenges include regulations, community concerns with siting of facilities, lack of funding for infrastructure, and interagency coordination.

### *Water*

Providing adequate and reliable water supplies in a semiarid climate presents multiple challenges. Constraints imposed on the City's water supply are primarily driven by cycles of drought. Drought conditions have the largest impact on the City's imported water supplies. Imported water supply availability can vary substantially due to hydrology. Cyclical hydrologic conditions in the eastern Sierra Nevada result in a pattern of wet and dry years influencing snowpack levels and ultimately deliveries to the City via the LAA. During wet years deliveries have exceeded over 400,000 AFY, while during critical droughts, only 75,000 AFY has been delivered. Droughts also impact imported water deliveries from MWD. Potential climate change will also likely cause greater variability in imported water. To mitigate against the effects of recurring droughts and future climate change, the City continues to make substantial investments in groundwater, water conservation, and recycled water.

Other water supply challenges include environmental restrictions and water quality issues. The Owens Valley and Mono Basin regions are the sources of the LAA water to the City and both regions are experiencing environmental impacts related to withdrawals of large volumes of lake water to the LAA. Thus, diversion of LAA supplies has been necessary for environmental mitigation in these regions reducing deliveries to the City. Also, environmental constraints in the Sacramento-San Joaquin Bay Delta, the source of the SWP that delivers water to Southern California, have greatly affected imported water deliveries to MWD. Finally, local groundwater contamination in the San Fernando Valley has curtailed groundwater production at multiple City wells requiring wells to be taken offline.

### *Wastewater*

System capacity is the primary driver of the City's wastewater system. Population projections prepared for the IRP indicate system capacity will be inadequate in 2020. Additional system capacity will be required for the both the treatment and collection system components. Additional wastewater system challenges include reducing infiltration into the collection systems during wet-weather events and biosolids disposal (City of Los Angeles, 2006a).

### *Stormwater*

Compliance with Total Maximum Daily Loads (TMDLs) is the major driver of the stormwater system. Major water bodies within the City, including the Los Angeles River, Ballona Creek, Dominguez Channel, Santa Monica Bay, and many of the tributary channels and creeks are on the Clean Water Act 303(d) list for impairments. Most constituents are conveyed into receiving water without treatment. Fourteen TMDLs including trash, bacteria and several heavy metals have been adopted and more than 60 are expected to be adopted by 2012.

Additional stormwater system challenges include: development of an approach to combine source control of urban pollutants, runoff volume reduction, and technologies to remove pollutants from runoff; administration, since stormwater affects departments throughout the City; legislative and policy changes at the local, county, and state levels to regulate urban runoff and provide guidelines for urban runoff reuse; and, scientific advancements since stormwater management inherently has many uncertainties (City of Los Angeles, 2009).

## 5.2 Relationship between City of Los Angeles IRP and TWM Desktop Analysis

The following sections in this chapter describe the desktop analysis for this TWM technical report. The development of the model, TWM options and their characterization, the combination of options into TWM alternatives, and the simulation and evaluation of the TWM alternatives are all original to this desktop analysis and not from the City's IRP. This chapter, however, draws significantly from the IRP in the geographical characterization, the TWM approach (similar to the City's approach for the IRP), and the much of the data required for the analysis. Thus, the results presented in this chapter illustrate the same general benefits that were estimated in the IRP.

The TWM options and levels of implementation presented in this case study are for illustrative example only, and meant to demonstrate the potential benefits using realistic water resources information for a large urban watershed. The options presented here do not necessarily reflect actual or planned implementation by the City, nor do they reflect official policies of the City. Although the majority of data assumptions regarding costs and benefits for these options are based on the work completed during the City's IRP, other studies and reports were utilized. This disclaimer is also under the Notice.

## 5.3 Model Conceptualization and TWM Options

Based on the facilities and watershed features of the City, the project's geographic scope was divided into 4 demand zones: San Fernando Valley (SFV), Central City (Central), Westside (West) and San Pedro (SP) (see Figure 10). The SFV zone includes TWRP, the Central zone includes LAGWRP, the West zone includes HTP, and the SP zone includes TITP. The Los Angeles River flows through the SFV zone, into and out of the Central zone and discharges into the ocean in SP zone.

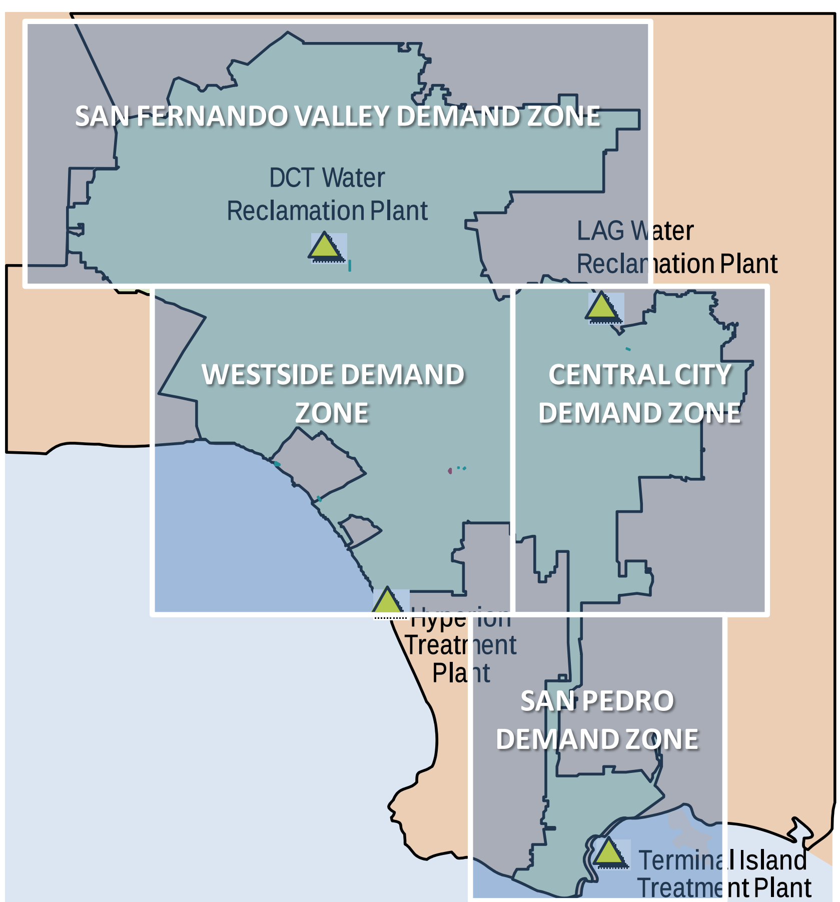



Figure 10. Demand zones for Los Angeles total water management systems model

## TWM Options

A number of TWM options were included in the case study model. Many of the options described in this case study are currently being implemented, in planning stages, or being considered by the City, and were included in order to demonstrate the types of benefits that can be achieved through TWM. While these TWM options are particularly relevant to the water resources context of Los Angeles, many of these options could benefit other regions of the U.S. with varying degrees.

Another key aspect of the case study is to demonstrate the value of using a systems model to evaluate an urban watershed. While the TWM options could be implemented separately for each water sector, it is the power of integration and ability to analyze the entire impact of such strategies that is unique to TWM.

The systems model built for this study includes the TWM options described below. The options are available in each of the four demand areas in the study area. Each can be "switched" on or off in the model and different scenarios can be run to compare the capital and operating costs as well as the water supply and water quality benefits of the different options (or combinations thereof). Appendices A through C include detailed assumptions and calculations regarding cost, hydrologic variability, and local watershed yield estimates for these options.

Water quality is an important attribute for each of the TWM options, and is modeled for every flow path in the system. The constituent selected as a proxy for water quality impacts, either positive or negative, from TWM alternatives was zinc. There are mainly three reasons for the selection of zinc as a proxy for water quality: (1) it is generally a conservative constituent, which is important for the monthly time scale of the model; (2) there is a specific monitoring program of concentrations from City which generates data to input to the model; and (3) the concentrations are high enough to be able to observe benefits of TWM options with impacts on water quality, i.e., some other constituents regularly monitored by the City have many data points as "non-detect," which doesn't allow to show impacts of TWM options in their concentrations.

### *Water Conservation*

The water conservation option specifies an overall reduction in water demand, and assumes a variety of water saving and water efficiency programs and technologies. The conservation option can be individually selected for indoor and outdoor water demands in each demand zone. The degree of conservation savings is specified as a percent reduction in demand. In the WEAP model, conservation is applied directly to the indoor and outdoor "demand nodes." The conservation percentages are applied uniformly in each month and year of the simulation as a scalar to the input demand projections.

Two levels of water conservation were considered in this study: "moderate conservation" and "aggressive conservation." For moderate conservation, the indoor and outdoor demand reduction percentages were 5% and 10%, respectively. For aggressive conservation, the indoor and outdoor reduction percentages were 10 % and 20 %, respectively. It should be noted these conservation savings represent additional conservation over and above what has already occurred within the City. As noted earlier, current conservation has reduced City demands by almost 15% from 1990 levels of water use.

Modeling water conservation assumes annual operating program costs. The assumptions are based on actual conservation measures that would be implemented to achieve the levels specified in the options (see Appendix A for more details on cost assumptions). Water quality is only impacted by the conservation options in so far as required flow rates are reduced.

### *Non-potable Wastewater Recycling*

Non-potable wastewater recycling is defined in this study as the collection and tertiary treatment of municipal wastewater flows to meet outdoor irrigation and industrial process water demands. The City currently recycles and reuses some of its wastewater through existing facilities, but this study looks at the costs and benefits of expanded wastewater recycling projects.

In the WEAP model, wastewater volumes are determined at each of the four demand zones as a percentage of the indoor potable water usage minus losses and consumption of water. Additionally, wastewater volumes include any outdoor flows that enter the local sewer system with specific diversions. Wastewater recycling is represented as a "transmission link" flow pathway from the demand zone's reclamation plant to an outdoor demand node. Each water reclamation plant has a specified wastewater recycling capacity and a portion of the plant effluent (according to demand, and up to capacity) is treated to tertiary standards and then conveyed through a recycled water distribution system to meet outdoor demands.

Modeling the wastewater recycling option assumes additional and/or expanded treatment and conveyance facilities for the use of the recycled water. It is assumed that wastewater recycling operations include treatment, pumping and conveyance, as well as annual maintenance. These all have associated capital, fixed, and variable costs – which are accounted for in the model.

For water quality modeling, each water reclamation plant has a specified effluent concentration for the constituent of interest, i.e., zinc. Flows upstream of the plant have a zinc concentration but it is assumed that the plant will be able to meet the effluent concentration in all simulated months, and the concentration of zinc is reset when the wastewater effluent leaves the plant to a concentration equal to the standard.

For each demand zone, the water reuse pathway can be switched on or off, and a capacity for water reuse facilities is specified. The model doesn't include an option to decouple the fire flows from the potable water system at this time. The reason for excluding the option from the desktop analysis is that the City's potable system is practically built out. This means that facilities have been sized to meet fire flows. Decoupling the fire flows would, in the case of Los Angeles, represent a significant additional cost – to establish a system with recycled water used for fire flows. However, the separation between potable and non-potable systems for fire flows does have merit in new development or in suburban areas, and potentially in the City if significant infrastructure replacement programs are implemented in the future.

### *Dry Weather Urban Runoff Capture and Reuse*

Dry weather urban runoff (DWUR) in Los Angeles is defined as the flows that enter the stormwater collection infrastructure from over irrigation and other outdoor water uses (e.g., car washing). These flows are termed "dry weather" because they are present in the stormwater system even during periods when there is no precipitation. For this study, three options are considered for DWUR management. The first option is for DWUR to be collected and conveyed to a dedicated DWUR treatment facility – where the treated effluent is reused to meet outdoor demands. With the second option, DWUR is collected and conveyed to the existing WWTP through the local sewer system. And with the third option, the DWUR persists as runoff and is collected in the existing stormwater system and then is managed and treated as stormwater to comply with TMDL requirements before discharged to the receiving waters.

Los Angeles currently has a number of facilities for diverting DWUR, mostly in the West zone. This study looks at the costs and benefits of existing and expanded DWUR management practices. Each demand zone is assumed to have its own DWUR facilities and infrastructure (according to the selected option), and managed DWUR flows are either used to offset outdoor demands or discharged to the receiving bodies of the given demand zone. Depending on the option, the facilities required can include collection, treatment, and conveyance. Operations include treatment and/or conveyance, as well as annual maintenance. These all have associated capital, fixed, and variable costs.

In the WEAP model, the DWUR management options are represented using "return flow" pathways and/or the internal "reuse" parameter of the outdoor demand sites (the reader is referred to the WEAP software documentation for more information). Depending on the option selected, return flows are used to divert a portion of the DWUR flows (up to the specified facility capacity) to the local sewer system and WRP, and to divert the remainder of DWUR flows to the stormwater system. The internal reuse parameter at the outdoor demand node is used to account for DWUR treated and reused at a dedicated treatment plant. The reuse parameter acts as a reduction in demand – as a portion of the required flow in each month is offset by "internal" management practices. The costs and benefits of the different DWUR options are associated appropriately with these flow pathways and node parameters.

For water quality modeling, the DWUR options are handled differently. Dry weather urban runoff flows that are treated (either at the local WRP or at a new, dedicated treatment facility) are assumed to have effluent pollutant concentrations suitable for reuse for outdoor demands. Dry weather urban runoff flows that enter the stormwater system are assumed to take on the stormwater pollutant concentrations.

In the model, for each demand zone, the DWUR management option can be specified, and a capacity for the DWUR management facilities is specified.

### Graywater

Graywater is defined as water captured from relatively "clean" indoor water usage (e.g., bathroom sink and shower flows, clothes washers, and dishwashers) and then minimally treated for outdoor water use. This water is distinct from "blackwater" which includes sewage water from toilets and kitchen sinks. In this study, some percentage of the indoor water use can be collected and reused to meet outdoor demands within the same demand zone, rather than being conveyed to the WWTP. This diverted graywater requires some treatment and pumping in order for it to be reused onsite.

In the WEAP model, the graywater option is represented in each demand zone as a "transmission link" flow pathway from the indoor demand node to the outdoor demand node. A constraint is applied to the transmission link to limit the maximum amount of indoor graywater that can be reused. The graywater constraint is the product of a "graywater potential" factor and a "coverage" factor. The graywater potential is assumed to be 65% of the total indoor water use at any household or business that could potentially be diverted for onsite graywater reuse. The coverage factor is variable for different scenarios, and represents the extent of application of graywater systems to households and businesses in the demand zone (e.g., 25% of all households will have graywater systems).

The graywater option is assumed to require additional household plumbing, storage, and treatment facilities. Operations require treatment and pumping, as well as annual maintenance. All of these have associated capital, fixed, and variable costs – which are accounted for in the model.

For water quality modeling, it is assumed that the graywater sources are relatively clean at that minimal treatment is required to produce water suitable for outdoor demands. These assumptions are implicit in the approach, but are not explicitly modeled in WEAP.

Within the model, and at each demand node, a graywater switch can be turned on or off, and a percent diversion of indoor water use is specified. This percent diversion includes the amount of water that can potentially be reused as graywater, as well as the extent of application of graywater systems to households and businesses within the demand zone. When graywater is implemented, water supplies increase and flows to the wastewater system are reduced.

It should be noted that use of graywater systems in California is still considered an emerging practice as there are significant regulatory issues that municipalities will need to address. However, graywater systems have been used in small-scale demonstration projects successfully in California and full-scale elsewhere around the world.

### Rainwater Harvesting

Rainwater harvesting is defined as the direct collection, storage, and use of rainwater from the rooftops of buildings. The captured rainwater can be used to meet outdoor demands with minimal or no treatment and minimal pumping.

In the WEAP model, rainwater harvesting is represented in each demand zone as a "transmission link" flow pathway from the (combined) "urban node" and "urban catchment" elements to the outdoor demand node. The urban catchment node includes all of the surface area of the demand zone, i.e., sub-watershed. Some portion of that surface area represents the total rooftop area of buildings in the demand zone, and a decision variable in the WEAP model indicates how much of the total building roof area is dedicated for rainwater harvesting. The upper limit on the monthly availability of harvested rainwater is the product of the rooftop area, the monthly rainfall depth, and a rainwater capture coefficient (which includes losses related to storage, weather, and use patterns in the rainwater harvesting systems). This limit is applied as a constraint on the rainwater harvesting transmission link. See Appendix B for detailed assumptions regarding rainfall/watershed analyses related to rainwater harvesting.

This rainwater harvesting option is assumed to require onsite rain collection plumbing and storage. Operations require some pumping of the captured water to its eventual use, as well as annual maintenance. All of these have their associated capital, fixed, and variable costs – which are accounted for in the model. For water quality modeling, the rainwater harvesting option is assumed to be a clean source of water without pollutants, in this case, without zinc, the pollutant of interest in the model.

For each demand zone in the model, the rainwater harvesting option can be switched on or off, and the total rooftop catchment area (in the zone) is specified. The underlying assumptions about captured rainwater storage, and rainwater capture efficiency are also specified within the model.

### *Indirect Potable Reuse for Groundwater Recharge*

Based on current regulatory constraints, recharging groundwater aquifers in the Los Angeles basin will involve advanced treatment beyond tertiary treatment of wastewater. The standard practice for advanced treatment is microfiltration and Reverse Osmosis (MF/RO). This option assumes a MF/RO treatment process adjacent to the WRP, and then this advanced-treated recycled water would be conveyed to existing spreading grounds in the San Fernando groundwater basin for recharge using natural percolation. The recycled water would then travel through the groundwater basin for a number of years to be extracted for potable use.

In the WEAP model, the recharge of groundwater with WRP effluent option is represented in the SFV and Central demand zones as a “return flow” pathway from the reclamation plant to the groundwater basin (the other two demand zones do not manage the groundwater for water supplies). A decision variable in the model allows specification of the percent of WRP effluent that is diverted to the basin for recharge.

For water quality modeling, the recharge water is effluent from the reclamation plants – with the associated effluent pollutant concentration. WEAP does not track water quality in groundwater basins due to the complexity and uncertainty of mixing in different basins. The initial conditions of groundwater storage and zinc concentrations in the basin are not known. Thus, an outflow concentration is specified for groundwater extractions.

In the model, groundwater recharge from the water reclamation plant can be switched on or off for each demand zone, and for each zone is specified the percent of the WRP effluent that is directed for groundwater recharge.

### *Centralized and Decentralized Stormwater Recharge*

Two options for groundwater recharge with stormwater are included in this study: centralized stormwater collection and recharge, and decentralized stormwater recharge.

Centralized stormwater recharge is defined as the diversion of some portion of collected stormwater flows into conveyance infrastructure that carries the stormwater to groundwater recharge facilities (either percolation basins, or injection wells). In the WEAP model, the centralized stormwater recharge option is represented in each demand zone as a flow from the combined “urban node” and “urban catchment.” Rainwater in the urban catchment that does not naturally infiltrate into the ground, and that is not diverted as direct rain harvesting, will become stormwater in each demand zone. A decision variable for the capacity of the centralized stormwater recharge facilities (in each demand zone) is included in the model, and is applied as a constraint to the transmission link. Groundwater recharge is “forced” in WEAP by using a “dummy” demand node of arbitrarily high value. When performing the supply and demand allocation, WEAP will send available stormwater to the groundwater basin, up to the capacity of the centralized recharge facilities, as it tries to meet the dummy demand.

For the centralized option, it is assumed that conveyance and recharge facilities are required. Operations include pumping, treatment, and recharge. Annual maintenance is also required. These elements all have associated capital, fixed, and variable costs – which are accounted for in the model. Water quality pollutant concentrations are specified and tracked in the model for the urban stormwater flows.

Decentralized stormwater recharge is defined as allowing additional infiltration of stormwater to take place at smaller sites scattered throughout the demand zone. Increased infiltration of localized stormwater flows takes place through "non-conventional" stormwater entities, such as swales and percolation ponds. In the WEAP model, the decentralized stormwater recharge option is represented in each demand zone as an adjusted runoff/infiltration ratio of the stormwater volumes at the urban catchment nodes. Rainwater is specified in WEAP at the urban catchments as a time series of rainfall depth per month. The monthly rainfall volume (product of rain depth and catchment surface area) is routed along two pathways – runoff and infiltration. The proportion of rain volumes becoming runoff or infiltrate are specified as simple percentages of the total flow. The decentralized stormwater recharge option increases the proportion of rain water infiltrating to the ground, while decreasing the proportion becoming runoff. This approach captures the essence of decentralized stormwater management made up of small stormwater recharge facilities scattered throughout the demand zone.

For the decentralized option, it is assumed that the stormwater management infrastructure (swales and ponds) need to be constructed. Operations are minimal, but the facilities require annual maintenance. These elements all have associated capital, fixed, and variable costs – which are accounted for in the model. Water quality pollutant concentrations are specified and tracked in the model for the urban stormwater flows.

Both the centralized and decentralized options can be switched on or off for each demand zone. For the centralized option, the capacity of the recharge facilities is specified, and for the decentralized option the total area of "non-conventional" stormwater facilities and their infiltration coefficient are specified. The conceptual model of these options is described in Appendix B.

## 5.4 Systems Model

As part of this study, a high-level decision support model was developed using the WEAP software to demonstrate how TWM alternatives would perform against traditional, segmented and non-integrated approaches to water management. The model was constructed to represent the main water resources features of the City. The model is intended to be used at the planning level of detail and so aggregates many of the features of the potable-water, wastewater, and stormwater systems into the four demand zones described above (along with the relevant connections between zones).

The WEAP model tracks the urban water supply and demand balance, supply reliability, total lifecycle costs, and water quality of receiving waters. The TWM options described above are programmed into the model for each zone and can be selected and specified (in terms of size and extent) in the setup of different scenarios to run and compare. The model simulates how integrated water supply and water quality management can provide increased opportunities for achieving urban system goals that would not exist in single-purpose, traditional planning.

### WEAP Software

WEAP is a software package developed by the Stockholm Environment Institute that allows integrated modeling for water resources planning, management, and decision- making. WEAP allows users to build a customized model of their water infrastructure as one interconnected system including water supply, distribution, treatment, recycling/reuse, and disposal infrastructure. The software performs a mass balance throughout the system and allocates water based on user-defined demand priorities and supply preferences. In the analysis, important system performance measures can be defined and tracked including reliability, cost, and water quality. Models are built in WEAP with a user-friendly interface consisting of a graphical schematic of the system and a set of data tables and graphs. The user can then run simulations for various scenarios and view results in terms of water reliability, water quality, and cost. Figure 11 shows a sample of the graphical interfaces of WEAP.

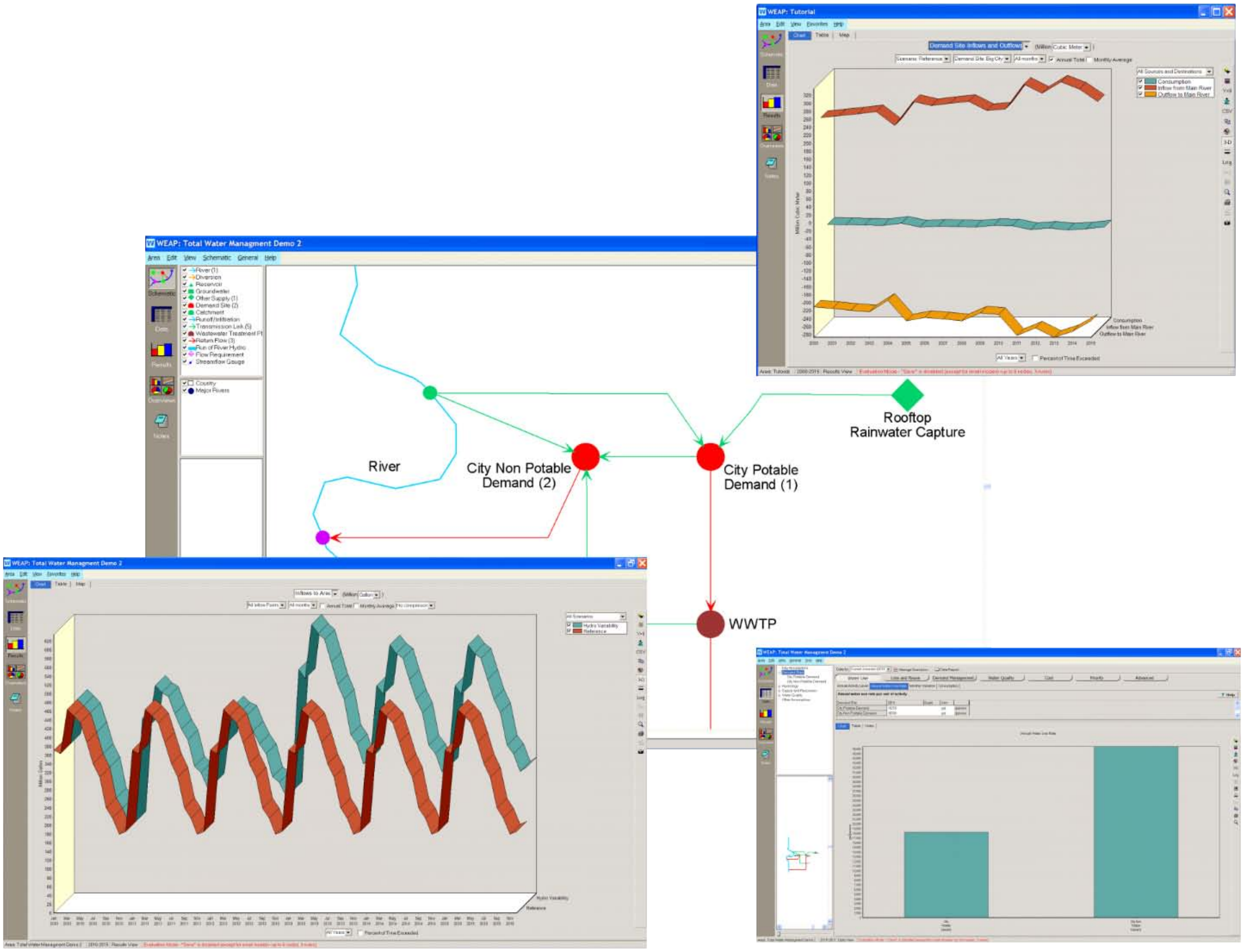



**Figure 11. Screen capture of WEAP interfaces**

Complete documentation of WEAP is included with the software in its comprehensive user manual, as well as through the SEI website and online tutorials. However, brief descriptions of the relevant components and features of WEAP are provided here.

## *WEAP Model Components*

Water resources systems are described and modeled in WEAP using the following basic components.

### Demand Nodes

Demand nodes are used to specify water demands. Demands can be further specified by type, such as single family homes, multi-family homes, commercial, industrial demands, and/or indoor vs. outdoor. Demands are entered as projections into the future. Demand nodes also have important parameters, including water loss and consumption rates, water reuse rates, and demand reduction (conservation) rates. For the Los Angeles case study, each "demand zone" was made up of two demand nodes – indoor demands and outdoor demands.

### Wastewater Treatment Plants

WWTPs receive water from demand nodes or catchments and represent the treatment of water to some specified effluent standard. The treatment plants also have a specified capacity, and any flows entering the plant in excess of the capacity pass downstream, untreated. For the Los Angeles case study, each demand zone uses a WWTP to represent the water reclamation facility.

### Catchments

Catchments represent watersheds or sub-watersheds. Catchments have a specified surface area and are associated with a specified time-series of rainfall (along with a number of other weather and agricultural parameters that were not used in this study). The area and rainfall parameters of the catchments are used to determine total monthly rainfall volumes. The rainfall volume is then routed as either runoff or groundwater infiltration. For the Los Angeles case study, each demand zone is represented as an urban catchment – with its respective surface area and runoff/infiltration coefficients.

### Groundwater Basins

Groundwater basins are nodes which track inflows, outflows, and storage volumes. The groundwater basins require a specified time series of "natural recharge" flows, as well as a specified storage capacity. A maximum monthly withdrawal rate can also be specified for the groundwater basins. Outflows from demand nodes, catchments, or water treatment plants can be used to represent various infiltrations or recharge processes. And the groundwater basins can have their own outflows to represent groundwater pumping. For the Los Angeles case study, each demand zone has a groundwater basin; but only two are modeled, as only the SFV and Central basins are actively managed by the city for water supply.

### Other Supplies

Other supplies represent generic sources of water and can be used to model entities such as desalination plants or imported water supplies. Other supplies are specified with a time series of inflows. WEAP allocates water from the other supplies up to the inflow value. Any inflow water not used in the time step will be lost from the system i.e., other supplies have no storage. In the Los Angeles case study, other supplies were used to represent the two imported water supplies, i.e., LAA and MWD.

### Transmission Links

Transmission links are flow pathways that actively convey water between two system elements. WEAP performs a prioritized demand-supply allocation analysis that routes water from supplies to demands through transmission links. Transmission links can be specified with monthly flow capacities. WEAP will allocate water supplies according to their availability and the ability for transmission links to carry the flows. Transmission links can also be specified with loss fractions.

### Return Flows

Return flows are flow pathways that passively convey water between two system elements. Return flows exiting a demand node or WWTP node are each given a percentage of the total node effluent (with the sum equaling 100%). WEAP calculates the total effluent, and routes water in proportion to the return flow routing percentages. Return flows can also be specified with loss fractions.

## *WEAP Model Calculations*

WEAP performs three general kinds of calculations during a simulation. These include a water supply/demand mass balance, a water quality mass balance, and a financial analysis (including costs and benefits).

WEAP includes a powerful, systems-view allocation algorithm for performing the supply and demand balance throughout the modeled area. The network of supply, demand, and treatment nodes and the flow pathways between them are represented as a system of equations that are solved simultaneously by WEAP using linear algebra algorithms. Demands are served by supply sources according to user-defined demand priorities and using user-defined supply preferences. In the case of water shortages, the priorities are used to determine the allocated volumes of water to each demand node. These calculations takes place 'behind the scenes' in WEAP, but provide a powerful tool for the integrated analysis of water systems with multiple supply sources, demand nodes, and flow options.

WEAP is able to track the mass balance and dynamic behavior of a number of built-in water quality parameters, such as total suspended solids (TSS), biochemical oxygen demand (BOD), dissolved oxygen (DO), and temperature. Additionally, the user may define other constituents or pollutants to track over time and space. WEAP includes a number of built-in methods for modeling the different water quality constituents – including methods for conservative pollutants, decaying pollutants, and specialized methods for BOD and DO. In this study only a single, representative, and conservative pollutant was modeled (zinc). Calculations for zinc concentrations in the model required only a simple mass balance at nodes in the model where flows mixed. The weighted average of pollutant concentrations of the mixing streams was taken as the combined concentration.

WEAP includes a cost layer which allows specification of capital, fixed annual, and variable operating costs at each node and flow pathway in the system. Costs can be specified for model elements to represent WWTP facilities and processes, demand management programs, conveyance through transmission links and return flows, facilities and pumping at groundwater basins, acquisition and conveyance of imported supplies, etc. Capital costs are amortized at an assumed discount rate, fixed costs are incurred each year in the simulation, and variable costs are applied per unit of flow. WEAP performs a financial analysis on all of the costs to produce a total Net Present Value for the simulated scenario. WEAP also reports the Net Cost of the scenario and the Average Cost of Water for the scenario.

### *Running Simulations and Viewing Output with WEAP*

WEAP allows the setup and simulation of various water resources planning scenarios. Any of the input variables (or combinations of variables) can be changed and run as a separate scenario. WEAP will simulate the performance of the scenario on a monthly time step for any future period defined by the user. During the simulation, WEAP determines the water quantity and quality mass balances and calculates the operational costs.

WEAP has built in tools to conveniently manage the scenarios (e.g., save scenarios, open saved scenarios, and define scenarios based on inherited values from a parent scenario). Within WEAP scenario results can be viewed individually or compared against one another. Additionally, WEAP output can be exported to Microsoft Excel spreadsheets for further analysis or presentation.

WEAP has a dynamic output screen that provides flexibility and diverse formatting options for viewing simulation results. Results can be viewed for any of the system metrics. Examples include:

- Demand projections
- Supply requirements at demand nodes (after conservation, etc)
- Supply reliability
- Supply mix from the different water sources
- Reliance on imported water supplies
- Stream flow and in-stream water quality
- Groundwater inflows/outflows and storage volume
- Capital, fixed, and variable costs
- Financial analysis (e.g., average water cost, net cost)

### *Data Requirements for Input to WEAP*

WEAP provides a lot of flexibility for the input of data. Input data can be entered directly into the WEAP interface, imported through a specially formatted excel spreadsheet, or read directly from an external file. The following data are required in order to fully define a water system/scenario in WEAP.

<u>Demand Data</u>

- Specify the "activity level" at demand nodes and the water use rate for that activity [e.g., demand at a node is calculated as the number of people in the node ("activity") multiplied by the gallons of water used per person per year ("use rate")].

- Demands can be disaggregated at the demand node level (e.g., household water use can be broken up by water used for showers, toilets, drinking, or washing).

- Demands are entered as annual volumes though monthly variations can be applied to give higher seasonal resolution.

<u>Supply Data</u>

- Water supplies to the system can be defined as rivers, groundwater basins, local surface bodies, rain catchments (runoff), or imported/transfer water connections to other agencies or basins.

- Each supply can be specified differently, either as user-defined inflow series, or calculated based on hydrology (using "water year types" or calculated based on rainfall and runoff).

- Constraints can be added to the supply sources and used to represent various capacities on the supply (e.g., well capacities, conveyance capacities, or contractual capacities).

<u>Treatment and Conveyance Capacities</u>

- Specify the capacities of water treatment plants.

- Specify the capacities of conveyance pipelines or well fields.

<u>Water Quality Data</u>

- The user enters the constituent concentrations at the various supply sources and the removal rates at the treatment plants.

- During each time step WEAP calculates a water quality mass balance for each constituent at all of the nodes and arcs in the system.

<u>Cost and Benefit Data</u>

- The user may specify the levels of costs and benefits for different supply elements, including: capital costs for new projects, fixed O&M costs, as well as variable O&M costs.

- Costs and benefits are entered for supply sources, flow pathways, treatment plants, and demand management programs.

- Financial parameters, such as discount and inflation rates, are entered to calculate net costs, net-present-value costs, and 'total cost of water' values.

### *Model Description*

A high-level, integrated systems representation of the City was programmed in the WEAP software using the previously defined four demand zones – SFV, Central, West, and SP. Each of these four demand zones is included as an identical "module" in WEAP. Figure 12 shows a representative schematic for the SFV demand zone "module." Figure 12 includes the basic model elements: an indoor and outdoor demand node, i.e., SFV Outdoor Demand and SFV Indoor Demand, a wastewater treatment and reclamation plant (TWRP), an urban catchment node (SFV Urban Catchment), a groundwater basin (SFV Groundwater Basin), and all of the flows between entities (called "transmission links" in WEAP) and return flows. Figure 12 shows inflows into the demand nodes, which represent the sources that can supply those demands. Included is, for example, a flow between SFV Indoor Demand and SFV Outdoor demand, which is representing graywater. The attributes of that graywater flow are established in a different layer in WEAP, where flows, capacities, costs, etc. can be included. The SFV "Dummy" variables for WWTP return flow and for groundwater are elements that allow WEAP to establish a specific flow, as opposed to just a flow that results from WEAP internal calculations. This module is repeated for all of the City areas, with corresponding interconnections such as the Los Angeles River and process flows between upstream and downstream WWTPs.

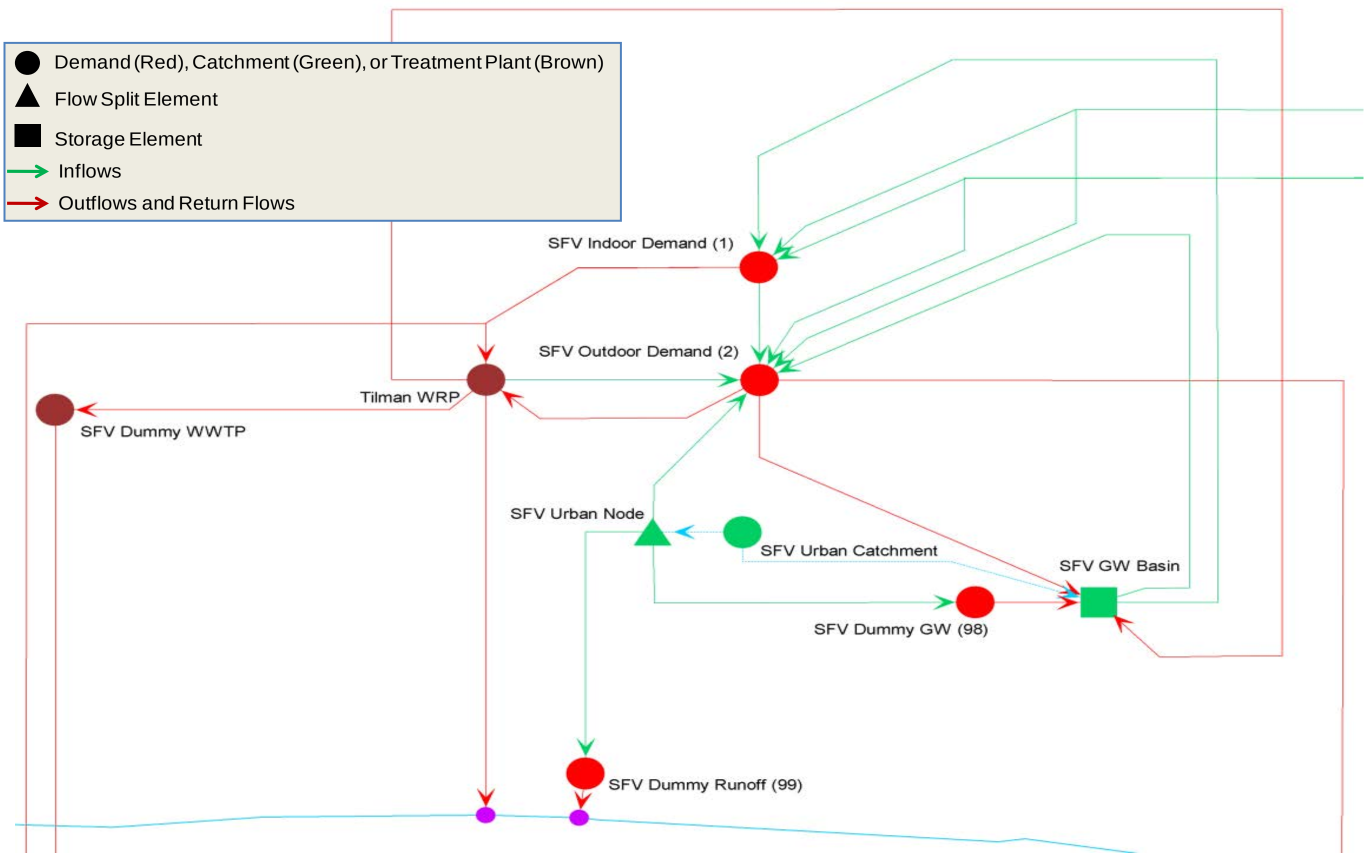



**Figure 12. Representative schematic of demand zone 'module' in WEAP**

The module for each demand zone characterizes the water, wastewater, and stormwater systems for the City, and the TWM options investigated in this study. The potable water system is described by the indoor and outdoor demand nodes with the transmission links coming from the imported supplies (not shown in Figure 12) and the groundwater basin. The transmission link between the indoor and outdoor demands represents the option for graywater reuse. The wastewater system is described by the WWTP, with associated inflows from the demand nodes, and associated outflows. Wastewater recycling and recharge are represented as the transmission link and return flow from the WWTP to the outdoor demand node and to the groundwater basin, respectively. Finally, the stormwater system is described by the urban catchment, the urban node, and the "dummy" demand nodes draining into the groundwater basin and the river. Rainwater harvesting is represented as the transmission link from the urban node to the outdoor demand node (SFV Urban Node and SFV Outdoor Demand in Figure 12). And the centralized and decentralized stormwater recharge options are represented as the various flow pathways out of the urban catchment and urban node.

Within WEAP, calculations take place for the water supply and demand mass balance, the water quality mass balance, and the financial analysis – all according to the schematic as shown in Figure 12.

Figure 12 presents a summary of one of the demand zones in the model. The demand zones, however, are interconnected in the model (as in real life) by the following flow paths: raw wastewater can bypass the TWRP and LAGWRP to be routed and treated at HTP; biosolids and process flows from TWRP and LAGWRP are discharged to the collection system and flow downstream to HTP; and the Los Angeles River flows in the SFV zone receiving return flows and flows into the Central zone and eventually into the TITP.

### *Total Water Management Options and Model Interface*

To facilitate the use of the WEAP model as a decision support tool, a customized user-interface was developed in MS Excel. Data can be easily imported to WEAP from Excel, and Excel provides a very convenient and flexible platform for creating a user-friendly "control panel" and for performing necessary pre-processing calculations outside of WEAP. The control panel contains switches and input cells for selecting TWM options and specifying facilities' capacities as decision variables. A screen-shot of the Excel control panel is shown in Figure 13.

### *Data Management and Programming*

WEAP provides a relatively simple, but comprehensive environment for programming and analyzing TWM and urban water resources management. WEAP contains a database for storing input and output data, and a powerful calculation engine. WEAP's internal database stores and processes complex input data and also allows flexible viewing of the modeled results from various scenario simulations. The calculation engine performs the supply and demand calculations, as well as derives the resulting cost and water quality values.

To solve the supply and demand calculations in WEAP, the network of supply, demand, and treatment nodes and the flow pathways between them are represented as a system of equations that are solved simultaneously by WEAP using linear programming algorithms. Demands are served by supply sources according to user-defined demand priorities and using user-defined supply preferences. In the case of water shortages, the priorities are used to determine the reduced allocations of water to each demand node. These calculations take place "behind the scenes" in WEAP, but provide a powerful tool for the integrated analysis of water systems with multiple supply sources, multiple demand nodes, and multiple flow options.

The setup and programming of a model in WEAP involves first drawing the system on the schematic layer (demand nodes, treatment plants, groundwater basins, and connecting pathways), and then entering data into the data base to describe the system demand and hydrology projections, facility capacities, routing rules, cost parameters, water quality parameters, and any other system constraints. Data can be entered into the model directly through WEAP's interface, through a specially formatted data import spreadsheet, or read from external data files.

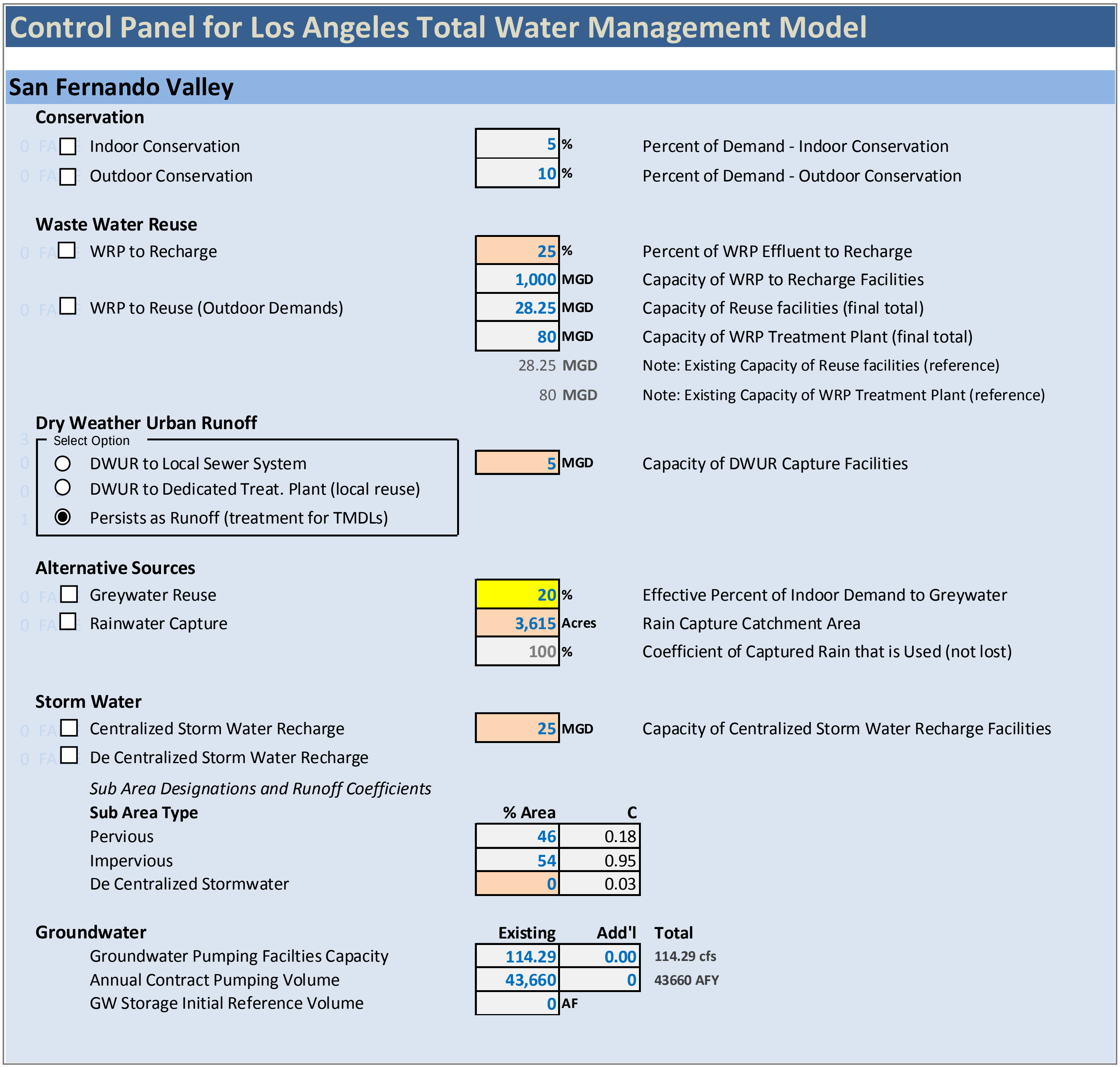



**Figure 13. Screen capture of the management panel for the model developed in Microsoft® Office Excel**

## TWM Alternatives

TWM options are specific projects or programs that can be implemented to manage runoff, increase supply, reduce demand, or recharge groundwater. As stated in Chapter 3, it is necessary to combine these TWM options into complete alternatives in order to be evaluated (WEAP software uses the term "Scenarios" for alternatives).

To demonstrate the benefits of TWM, three alternatives were developed:

1. Baseline – represents traditional planning, or status quo

2. TWM Alternative 1: Water Supply – represents a TWM approach with emphasis on improving supply reliability

3. TWM Alternative 2: Manage Runoff – represents a TWM approach with emphasis on improving water quality through stormwater management

As Figure 14 shows, there are some meaningful differences between the two TWM alternatives and Baseline Alternative. TWM Alternative 1 "pushes the envelope" with regards to reduction of the City's dependence on imported water supplies. Significant conservation levels, both for indoor and outdoor demands are included, along with aggressive levels of recycled water, groundwater recharge and graywater system implementation. Additionally, it includes facilities to beneficially use DWUR.

| Options and Settings | Units | Baseline | Alternative 1 | Alternative 2 |
|---|---|---|---|---|
| | | *Base Case* | *Water Supply* | *Manage Runoff* |
| **Conservation** | | | | |
| Indoor Conservation Switch | switch | No | Yes | Yes |
| Indoor Conservation - Percent of Demand (additional from current levels) | [%] | 0% | 10% | 5% |
| Outdoor Conservation Switch | switch | No | Yes | Yes |
| Outdoor Conservation - Percent of Demand (additional from current levels) | [%] | 0% | 20% | 10% |
| **Recycled Water Recharge** | | | | |
| Recycled Water Recharge Switch | switch | No | Yes | Yes |
| Capacity of Recharge Facilities | [MGD] | 0 | 80 | 80 |
| **Recycled Water Use (Excluding Existing Uses and Recharge)** | | | | |
| Additional Recycled Water Switch | switch | No | Yes | No |
| Recycled Water for Outdoor Demands (additional to existing) | [MGD] | 0 | 10 | 0 |
| **On-Site Sources** | | | | |
| Greywater Switch | switch | No | Yes | No |
| Percentage of Buildings with Systems for Use of Greywater | [%] | 0% | 20% | 0% |
| Rainwater On-Site Capture | switch | No | No | Yes |
| Total Rain Capture Area | [AC] | 0 | 0 | 1,150 |
| **Dry Weather Urban Runoff (DWUR)** | | | | |
| DWUR Managed but Not Beneficially Used | switch | Yes | No | Yes |
| DWUR Dedicated Treatment for Beneficial Use Switch | switch | No | Yes | No |
| Capacity of DWUR Dedicated Treatment Facilities for Beneficial Use | [MGD] | 0 | 9 | 0 |
| **Stormwater infiltration** | | | | |
| DeCentralized Stormwater Infiltration Switch | switch | No | No | No |
| Centralized (Large-Scale) Stormwater Infiltration Switch | switch | No | No | Yes |
| Capacity Centralized Stormwater Facilities for Recharge | [MGD] | 0 | 0 | 10 |

**Figure 14. Options and settings included in the baseline and total water management alternatives**

TWM Alternative 2 also includes indoor and outdoor conservation but at lower levels. TWM Alternative 2 also includes options for rainwater capture and for stormwater (wet-weather) recharge, while treating the DWUR for compliance with TMDLs. The Baseline Alternative includes no TWM option although it also assumes treating the DWUR for compliance with TMDLs. Baseline represents the status quo approach for Los Angeles in which the City is heavily reliant on imported water.

## Emergency and Climate Change Scenarios

Two scenarios were run in this study related to two elements of risk and uncertainty associated with water supply in the Los Angeles area: (1) earthquake emergency scenario and (2) climate change scenario.

### *Earthquake Emergency Scenario*
This emergency scenario was set up simply by assuming an earthquake that would significantly disrupt imported supply from MWD, to the Los Angeles area. The model did not assign specific probabilities for this scenario. The analysis consisted in selecting one month simulated by WEAP, in the year 2030 (2030 demands) and eliminating the MWD supply from the supply mix of resources. Results for the Baseline and the two TWM Alternatives are then compared.

### *Climate Change Scenario*
This scenario was set up by assuming reductions in imported supply by MWD and the LAA due to climate change conditions. The analysis consisted in establishing a time series of forecasted reductions of MWD and LAA supplies based on data for deliveries from northern California through the SWP (DWR, 2007). The 2007 reliability report by the DWR presents forecasted reductions with more restrictive flow targets due to required ecological flows in the Sacramento-San Joaquin Bay Delta and with climate change (specifically using the global climate model (GCM), and the emission scenario A2).

MWD delivery reductions were based on the flows from Northern California to contractors located in Southern California (known as SWP Table A Deliveries) and the reduction of these deliveries. For the case of MWD, estimates of reduction in Table A Deliveries were adjusted based on the fact that MWD can count on a mix of supplies other than SWP (such as Colorado River, storage and transfers) which reduce impacts of SWP supply reductions.

LAA water reductions were estimated based on the difference between the Table A deliveries with and without climate change reported in the DWR's 2007 reliability report. The same difference is assumed to apply to the LAA system due to the fact that the source is subject to a fairly similar hydrology and snowfall/precipitation pattern than the SWP.

The estimated reductions in imported supply are input into WEAP which simulates the TWM alternatives with and without climate change and compares to the baseline under the same conditions. Appendix C presents a more detailed discussion on the modeling of hydrology for imported supply in WEAP.

## 5.5 Case Study Results
The Baseline and two TWM Alternatives analyses in WEAP give us objective information about many of the variables of interest in making decisions. The results listed below include elements of water balance and reliability, effects of TWM alternatives on the environment, and financial results. Results of the climate change and earthquake emergency scenarios are also presented in terms of impacts on supply reliability.

### Water Balance and Reliability
For this TWM case study, a monthly time step was used for the WEAP model. This decision was made because of the seasonal nature of water demands and supplies for the City. Figure 15 shows the demand in the SFV demand zone (all areas show a similar demand pattern). As the figure shows, the majority of seasonal variability is due to outdoor demands, while indoor demand remains relatively constant (with the exception of growth and some small variation due to weather). Outdoor water use in the City is highly variable due to evapotranspiration (ET) that drives irrigation demands. In addition to seasonal variability, there is also variability in demand year-to-year. This yearly variability is also due to weather. Demand in hot and dry years is higher than demand in cooler/wet years, and this is reflected in the time series presented in Figure 15. The weather associated with each year in the projection from 2010 to 2033 is linked to the historical record 1980-2003. As explained in Appendices B and C, a historical record is imposed in the model for future years.

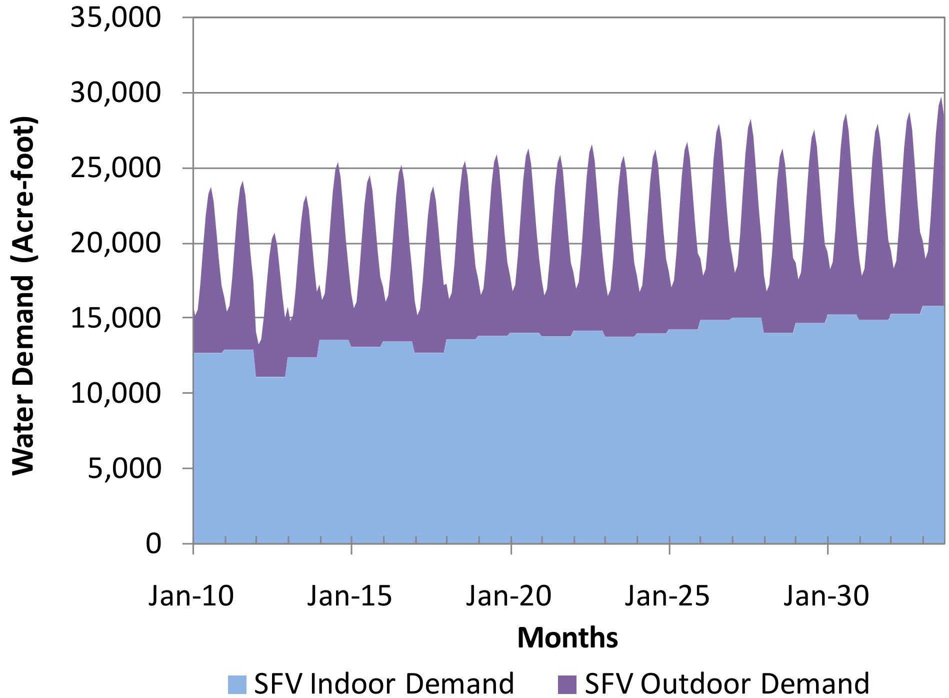



**Figure 15. Monthly water demands for San Fernando Valley zone (based on 1980-2003 Weather)**

By design, the TWM Alternative 1 (water supply emphasis) had very aggressive water conservation, reducing water demands by 16% from the Baseline. Alternative 2 (runoff management emphasis) had moderate levels of water conservation, reducing water demands by 7% from the Baseline. The impact of these conservation assumptions are illustrated clearly in the differences in total water demand presented in Figure 16. Under the Baseline, projected water demands in the year 2030 are 760,000 AFY, while projected water demands for TWM Alternative 1 and TWM Alternative 2 were 648,000 AFY and 718,000 AFY, respectively.

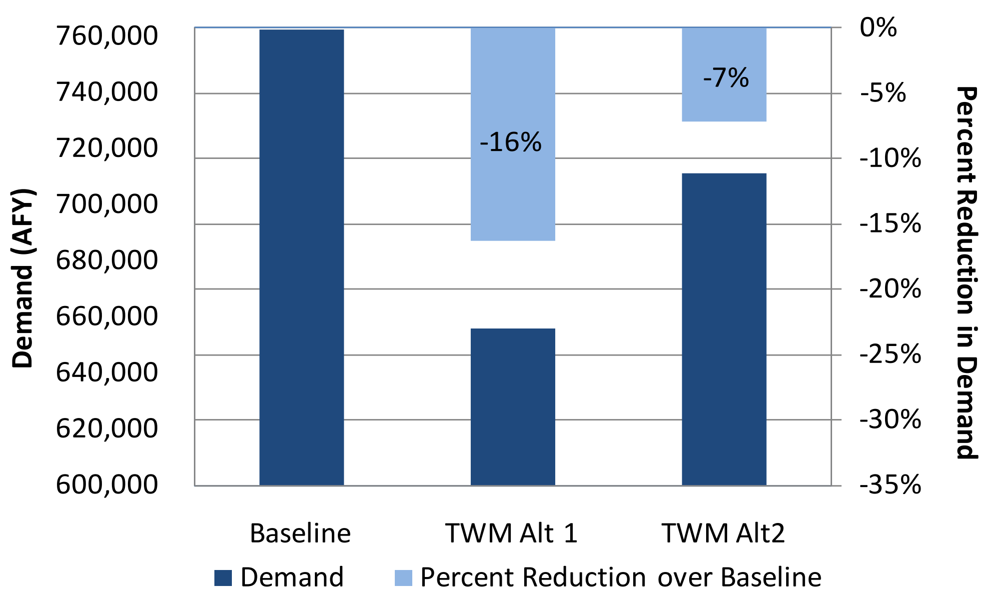



**Figure 16. Projected total water demand for baseline and total water management alternatives**

The seasonal demands are supplied by the different sources of supply available in each alternative and the Baseline. Figure 17 shows the supply mix time series for the Baseline, between 2010 and 2033 on an annual basis. The figure shows a significant reliance on imported supply, from LAA and MWD, which are by far the main sources in the period simulated.

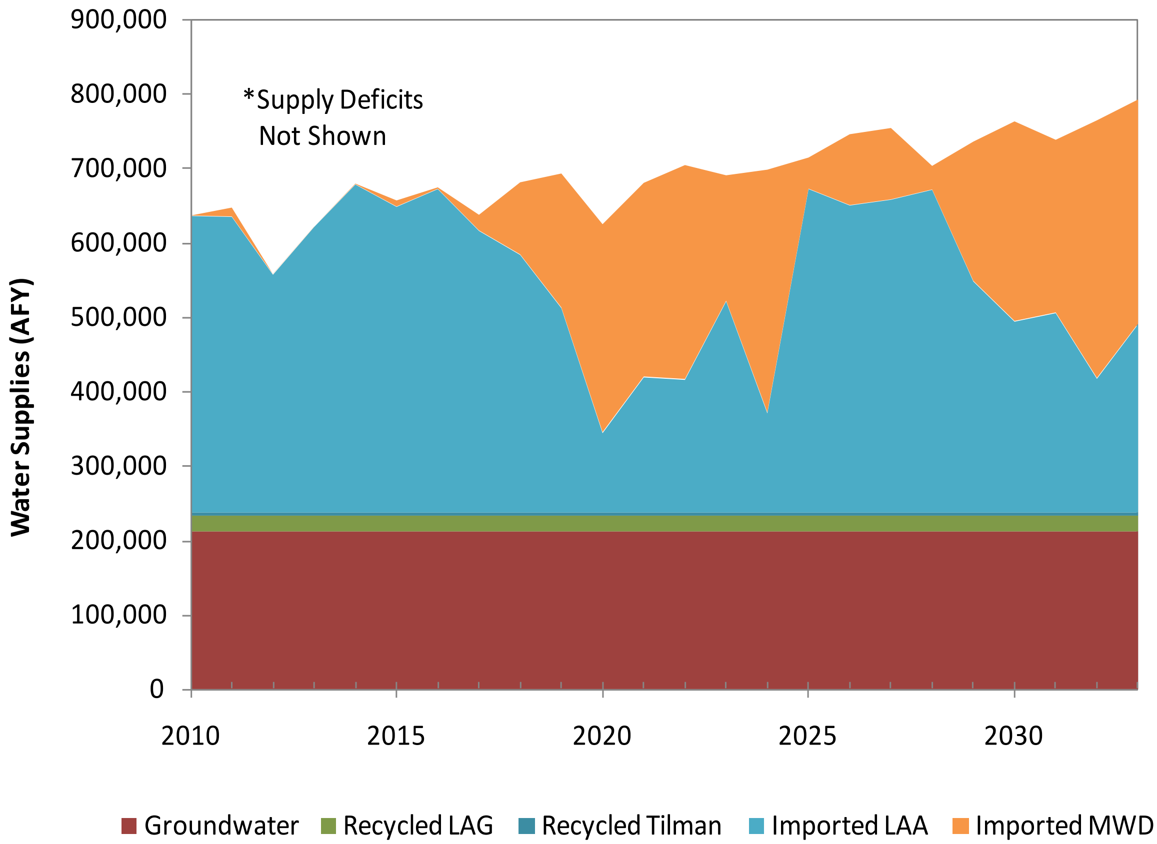



**Figure 17. Mix of water supplies for baseline**

The variability in the use of sources in Figure 17 is dues to the hydrologic variation of some of those sources. In this figure and subsequent figures, the hydrology imposed in the demand years from 2010 to 2033 corresponds to the historical period between 1982 and 2003. Figure 17 shows a significant decrease in LAA water from 2018 to 2024 and a gain from 2028 to 2033, corresponding to droughts in the historical record. During these drought periods impacting the LAA system, MWD supply is purchased. However, this figure does not show water supply shortages from MWD that are generally correlated with drought conditions for the LAA system (see Figure 20 for water shortages for the Baseline and TWM Alternatives).

For comparison, Figures 18 and 19 shows the supply mix for TWM Alternatives 1 and 2, which shows a significant increase in local supplies and a great reduction in imported supplies i.e., LAA and MWD, compared to the Baseline. Conservation, groundwater, recycled water and graywater significantly contribute to the overall water supply. For both TWM Alternatives, groundwater is significantly increased through recharge of stormwater and highly treated recycled water. In both alternatives (Figures 18 and 19) we can observe a decrease in groundwater production in 2032. This corresponds to a locally dry year, which reduces the amount of stormwater being recharged. As explained in the modeling section and Appendix A, groundwater modeling in the systems model was simplified to a mass balance because the initial groundwater basin levels were not available for the model. A groundwater numerical model of the basin may simulate a less significant reduction in supply due to the combination of the low storage and the dry year. The WEAP model, however, does keep track of groundwater use with a level of accuracy adequate for this analysis and shows the significance of that supply in the overall supply mix.

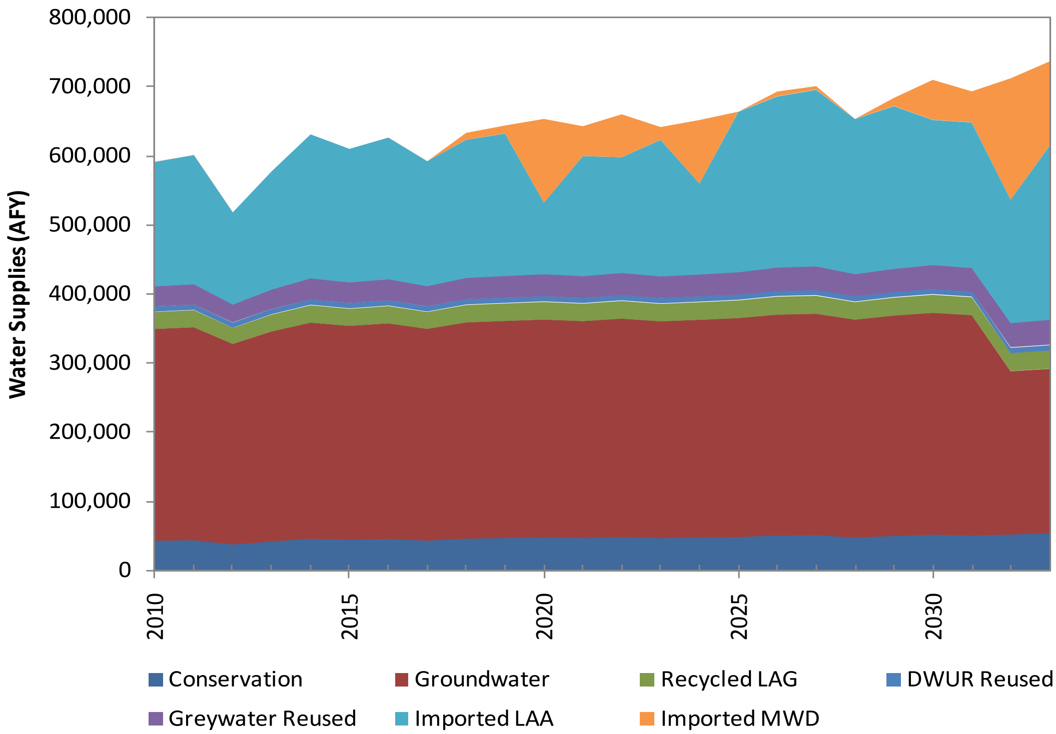



Figure 18. Mix of water supplies for total water management alternative 1

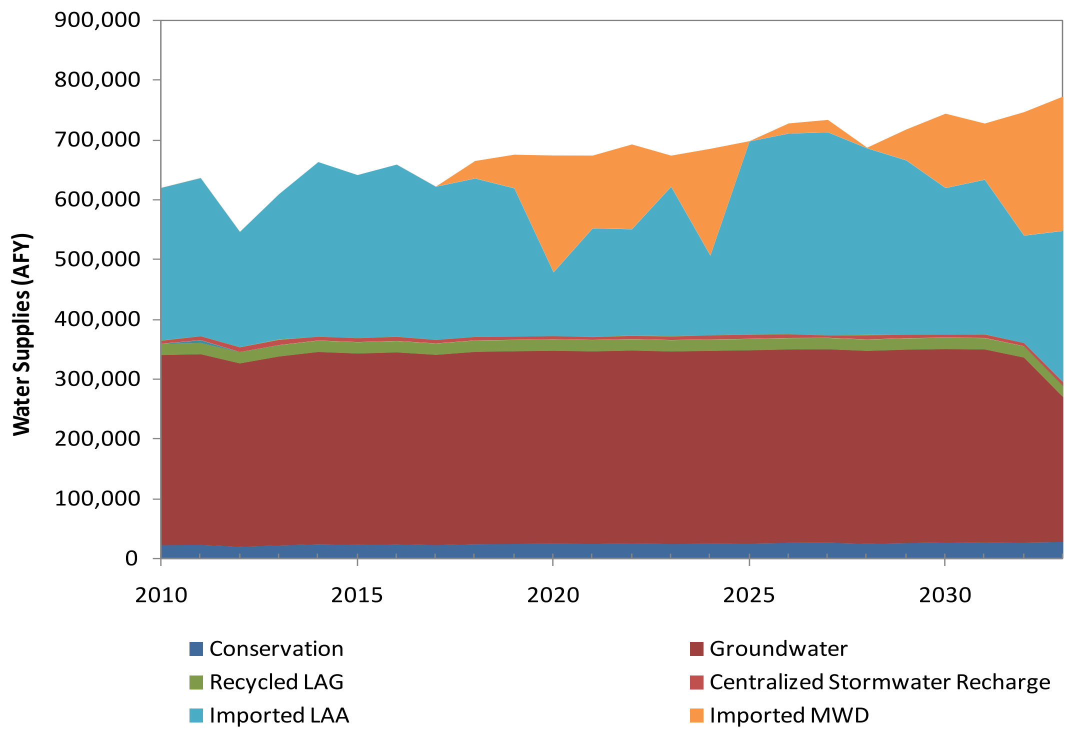



Figure 19. Mix of Water Supplies for total water management alternative 2

The main differences between Figures 18 and 19 is that there is more water conservation and graywater being implemented in Figure 18. Therefore, there is less imported water (LAA and MWD) in Figure 18 than in 19. However, Figure 19 does have considerably less imported water than in Figure 17 (the Baseline).

Figures 17, 18 and 19 only show the supply delivered to the demands in the demand zones, but do not show the supply deficits when they exist. Figure 20 shows the supply deficits observed for all three alternatives. Not surprisingly, the Baseline had the greatest supply deficits, both in number and in magnitude of shortage. These supply deficits are directly correlated to the dependency on imported supply (LAA and MWD), as these sources of water are highly vulnerable to droughts.

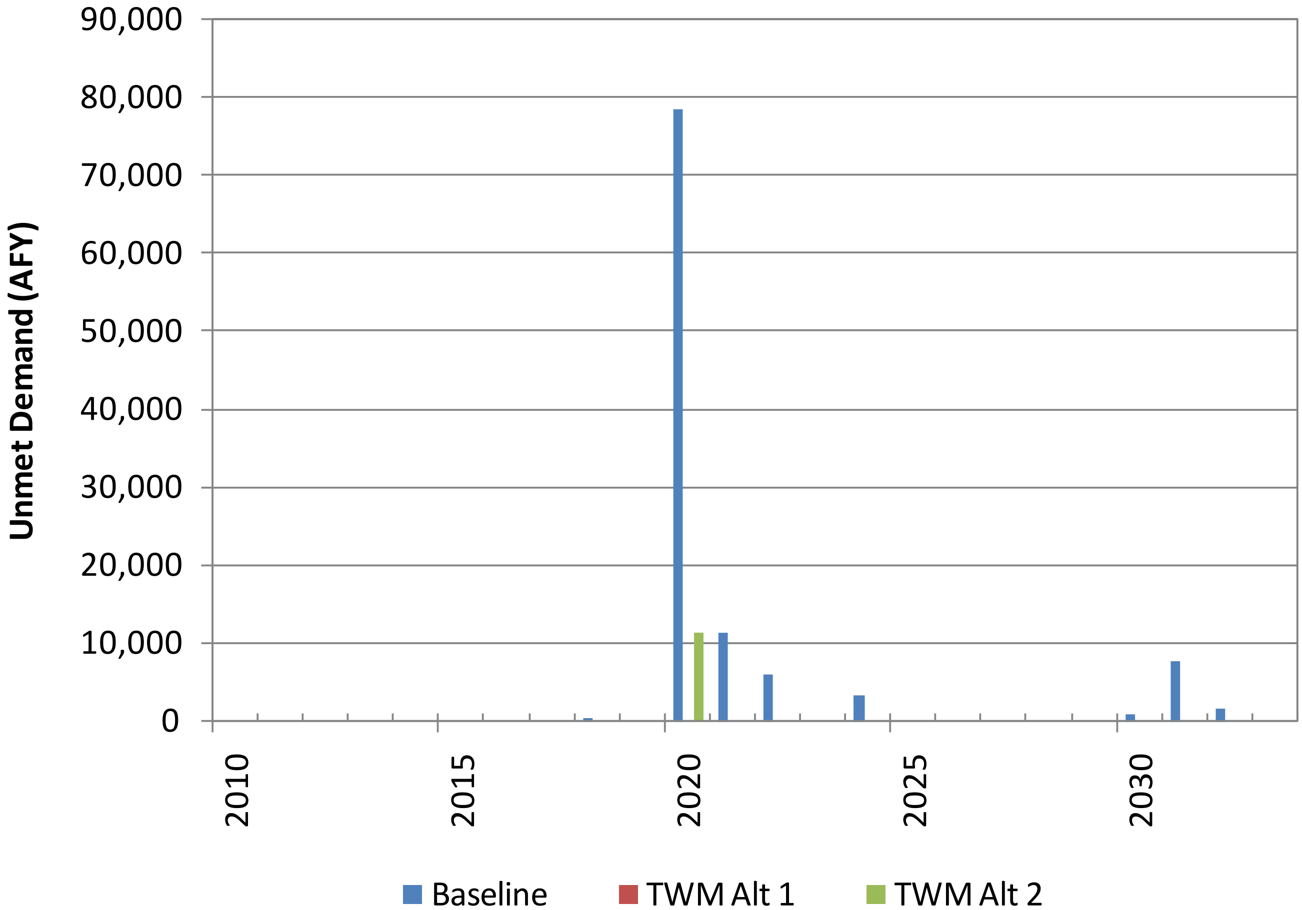



**Figure 20. Water supply deficits for baseline and total water management alternatives**

The largest water supply deficit occurred in year 2020 for the Baseline, which corresponded to a repeat of the 1990 drought conditions and results in an unmet demand of almost 80,000 AFY. TWM Alternative 2 only had one year of supply deficit, which corresponded to the 1991 drought year. Only TWM Alternative 1 had no water supply deficits, as this alternative had much greater levels of water conservation and implemented graywater systems.

### Effects of TWM on Environment

The TWM alternatives can impact the system in many different ways. In this study we established three metrics related to environment: (1) groundwater levels; (2) water quality in the Los Angeles River; and (3) GHG emissions. Energy consumption in every alternative and the Baseline can also be used to define air emissions for the Los Angeles area based on assumptions about the fuel mix used to generate energy in the region. With the assumed mix of fuels for energy generation (and hydropower), pollutant emissions (other than GHGs) can be approximated. However, in this study we have not added any other pollutant emissions except GHGs.

### *Groundwater levels*

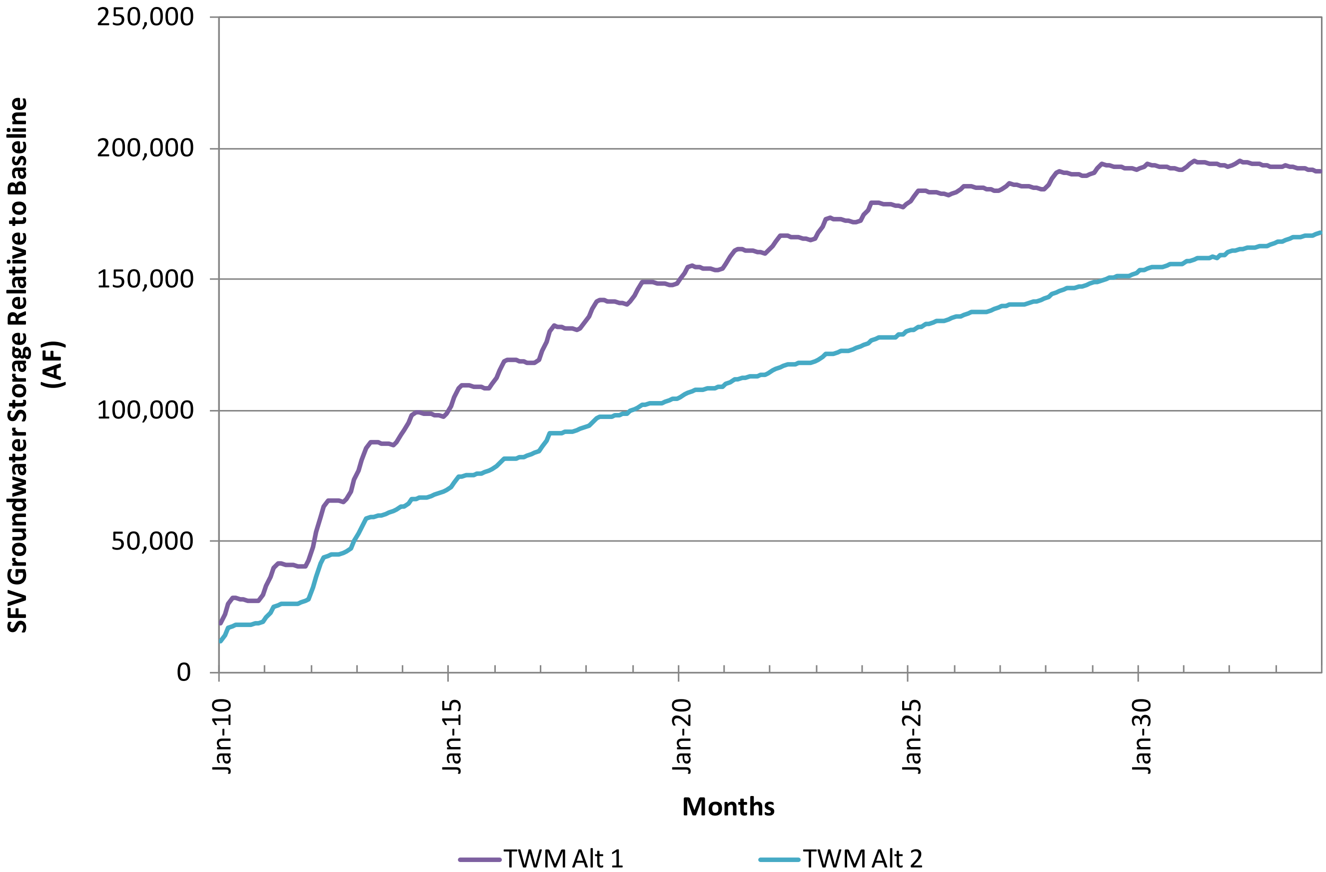
The TWM model developed in WEAP includes the groundwater basin in the SFV where recharge of advanced treated recycled water and wet weather flows can occur. Within the model, the storage element was programmed to track net storage as a result of three actions:

1) Pumping to satisfy demands - outflow
2) Recharge of advanced treated recycled water - inflow
3) Enhanced recharge of wet weather flows - inflow

Even though the model tracks groundwater storage, the actual storage values estimated by WEAP in this study are not representative of what could be observed in real conditions. The reason is that the initial storage value given to WEAP is an arbitrary reference value (given the difficulty in obtaining actual groundwater basin levels for the SFV zone). Additionally, the natural inflows and outflows are not strictly represented in the model and the groundwater pumping activity of other users (outside of Los Angeles) required more detailed analysis than this study could warrant.

The assumption in this model is that the natural inflows and outflows and the pumping by others take place along with the three storage elements (listed above) which can be controlled in the model. Actual storage values output by WEAP are not predictive of what the field conditions actually are, but the comparative trends in storage between the Baseline and the TWM Alternatives are valid and illustrative of positive or negative impacts to the basin as a result of the management decisions simulated in the model. Therefore, if everything else is equal for the three alternatives, the rationale is that the actions simulated in WEAP for a specific alternative will result in more or less storage compared to the other alternatives simulated. Figure 21 presents the comparison of groundwater storage between the TWM Alternatives on a monthly basis, as compared to the Baseline reference. In the figure, the Baseline reference is a flat line with a value of zero. The trends plotted in Figure 21 are the result of subtracting the simulated Baseline storage from the storage simulated for each TWM alternative.

Figure 21 shows that TWM Alternatives 1 and 2 are both significantly better than the baseline, even though the pumping rates significantly increase. The reason for the improvement in groundwater levels in relation to the baseline is the great amounts of recharge taking place as part of the TWM alternatives. In Figure 21, the reason TWM Alternative 1, which has less groundwater recharge than TWM Alternative 2, presents better storage results is that TWM Alternative 2 presents more pumping. Given that TWM Alternative 2 has sources that contribute less to the overall supply mix compared to TWM Alternative 1, we have allowed more pumping in the simulation under TWM Alternative 2, relative to TWM Alternative 1. Even with the additional pumping, storage is significantly better than in the baseline (not shown in the figure but corresponding to a value of zero along the x-axis).




Note: Baseline represented as a line along X-axis with value of zero.

**Figure 21. Groundwater storage or total water management alternatives relative to baseline**

### *Water Quality*

Water quality impacts were measured in the Los Angeles River using zinc as a proxy for other pollutants of interest as explained above. WEAP tracks zinc in every flow route and computes concentrations and loading at specific points of interest in the Los Angeles River. Specifically, return flow nodes where used as sampling locations in the simulation.

Figure 22 indicates that there is seasonality in the zinc loads along the river for the baseline, with higher loads during the wet season (which in Southern California corresponds to the period between November and March) and lower loads in the dry season. A second pattern observed in the chart is that loading increases as we move downstream in the river, as expected in a simulation with no pollution control assumed throughout the city. This pattern is observed by comparing the multiple bars in each month. The bars corresponding to lower reaches have greater concentrations of zinc.

When looking at the effects of TWM options in water quality, Figure 23 shows a clear positive impact in the reduction of loading from the Baseline. TWM Alternative 1, with emphasis on water supply, presents a clear reduction in loads while TWM Alternative 2, with emphasis in runoff management, performs even better in that regard. Figure 23 data corresponds to the year 2015, but the same trends were observed for generally all years simulated.

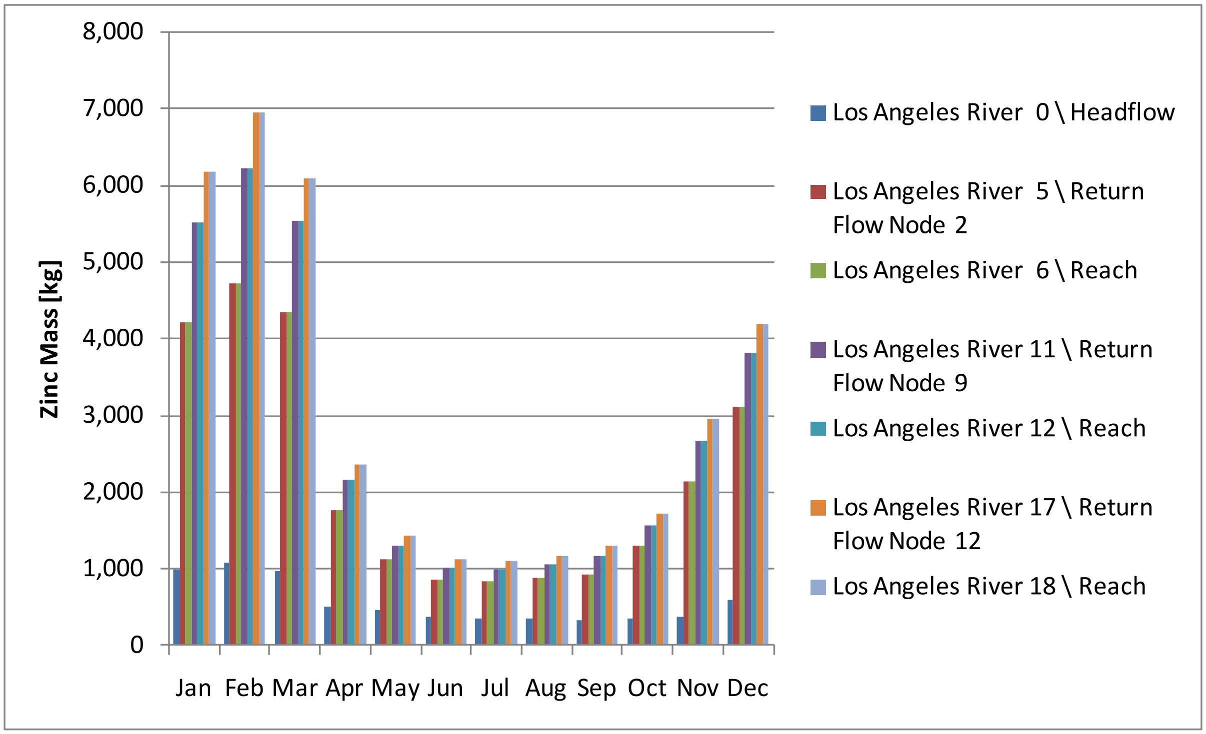



**Figure 22. Seasonality of zinc loading in the Los Angeles River for baseline**

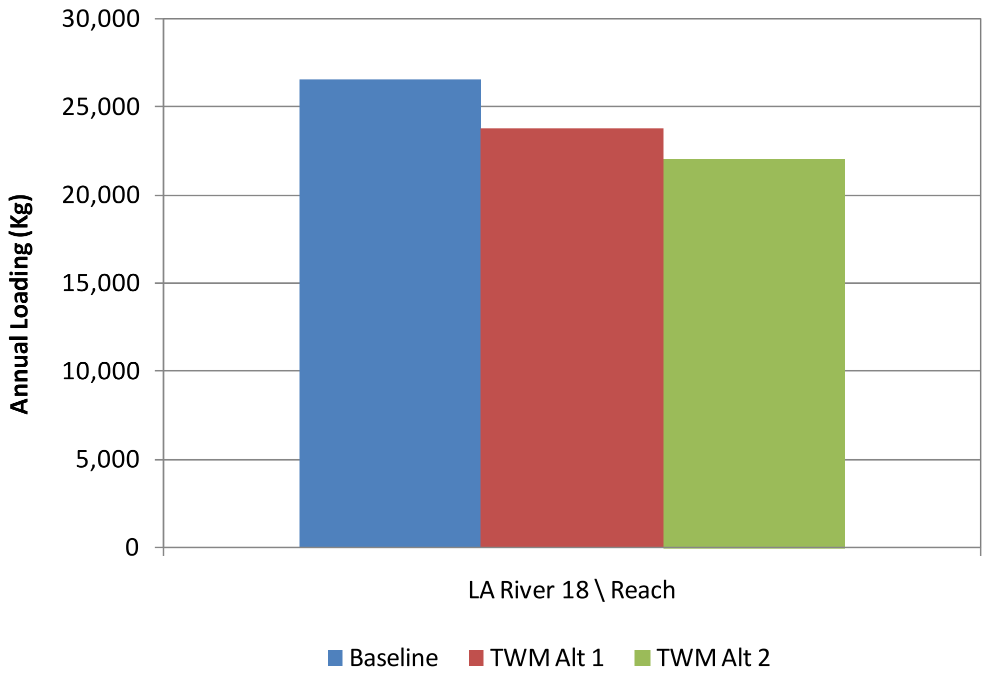



**Figure 23. Comparison of annual zinc loading in Los Angeles River in 2015 for baseline and total water management alternatives**

## *Greenhouse Gas Emissions*

The third environmental related metric in the analysis corresponds to GHG emissions. Specific GHG emission estimates exist for imported water in Southern California. These estimates were applied to the amounts of imported water in each simulation on a per acre-foot of basis. The method use in this study for the estimates of GHG emissions for all sources consists of the following steps:

- Define percentage of the O&M costs (excluding imported water) due to energy
- Estimate energy consumption based on costs of energy
- Apply region-specific factors of $CO_2$, $CH_4$ and $NO_x$
- Make $CH_4$ and $NO_x$ conversions to $CO_2$ equivalents
- Add $CO_2$ equivalent emissions from imported water (estimated separately)

This method can be applied in any TWM project in the U.S., as long as reasonable assumptions can be made about the source of the energy and, more specifically, about the fuel mix used in energy generation. Figure 24 presents the estimates of GHG emissions for the baseline and the TWM alternatives.

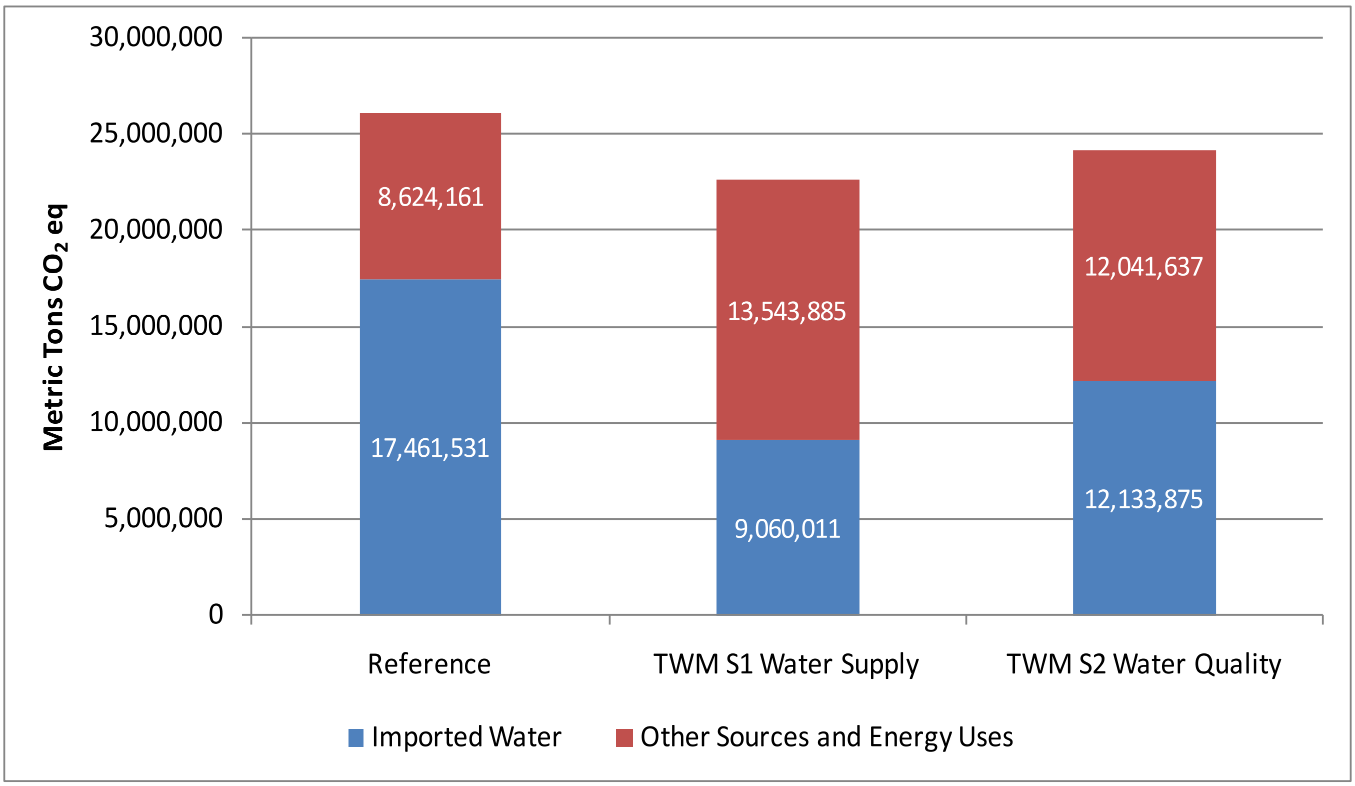



**Figure 24. Predicted greenhouse gas emissions over 25 years for the baseline and total water management alternatives**

The emissions presented in Figure 24 indicate that the Baseline is the worst performing alternative, even though the emissions due to operation of local sources are much higher in the TWM alternatives (maroon bars). The "savings" in the local supply options for the Baseline are not sufficient to offset the great difference between the alternatives in terms of the GHG emissions from transporting imported supplies over hundreds of miles.

## Financial Results

There are a number of ways and different metrics to compare alternatives in relation to their costs. Financial results in this TWM analysis included the Net Present Value (NPV) over the 25 years, average unit cost of the supply mix, and annual operating costs. Figure 25 presents the comparison of the NPV and Table 1 presents the average unit cost of the supply mix for the simulation period.

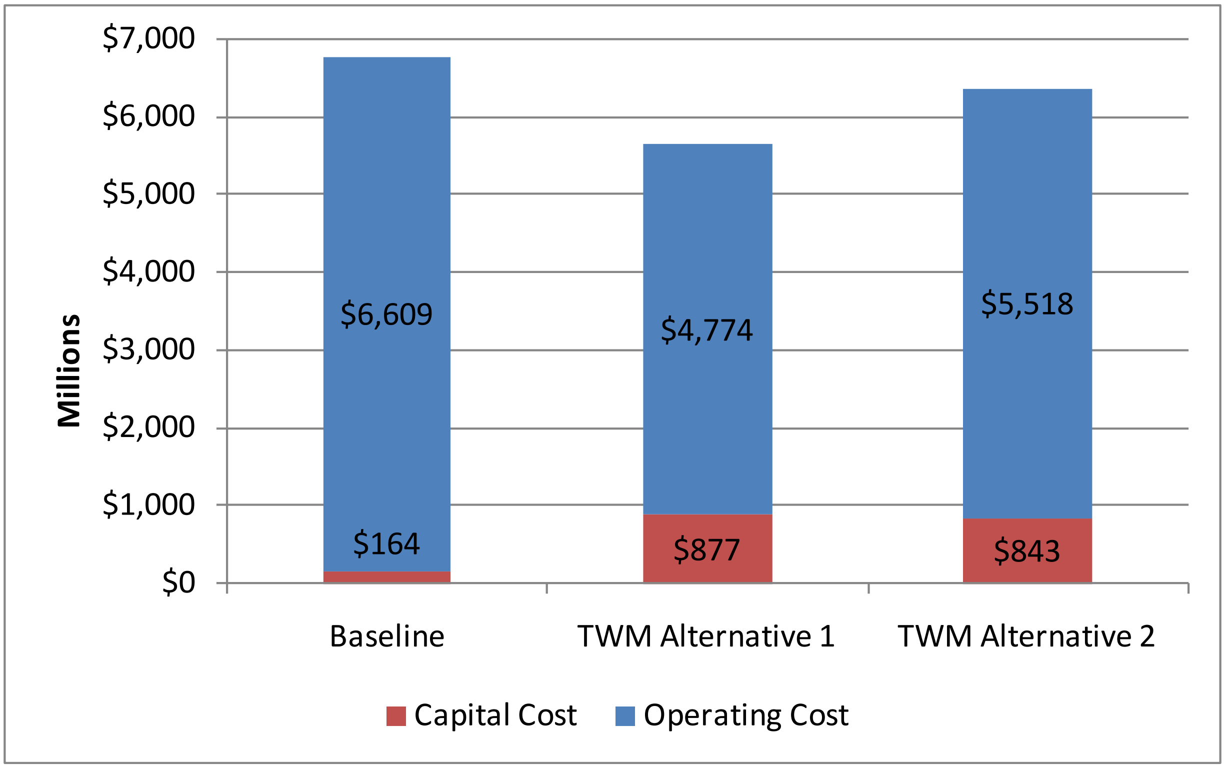



**Figure 25. Net present value cost of baseline and total water management alternatives for simulation period**

**Table 1. Financial Measures Comparing Alternatives**

| Alternative | Net Present Value of Capital ($ Millions) | Net Present Value of O&M ($ Millions) | Total Net Present Value ($ Millions) | Average Unit Cost of Water Supply |
|---|---|---|---|---|
| Baseline | 164 | 6,609 | 6,772 | $587/AF |
| TWM Alt 1 | 877 | 4,774 | 5,651 | $553/AF |
| TWM Alt 2 | 843 | 5,518 | 6,362 | $580/AF |

Figure 25 and Table 1 show that the capital costs of TWM Alternatives 1 and 2 are very similar with higher operating costs for TWM Alternative 2, resulting in an overall higher NPV for that alternative. Both TWM alternatives present lower NPV costs than the baseline. That is due to the fact that imported water cost is the main driving element in the NPV and total costs of the alternatives simulated. Figure 26 presents the breakup of the annual operating costs for the alternatives. The total operating costs of the Baseline are the highest of the three alternatives while TWM Alternative 1 is the lowest. Figure 26 shows TWM Alternative 1 has the lowest proportion of imported water (51%) while the Baseline has the highest (80%). On average in the 25 years simulated, TWM Alternative 1's proportion of 49% for non-imported water costs corresponds to about $163 million per year. It is the highest annual cost of the three alternatives with the Baseline at $92 million for non-imported water costs and TWM Alternative 2 at $146 million. Yet, on the total costs, TWM Alternative 1 has the lowest figure due to the high costs of imported supply.

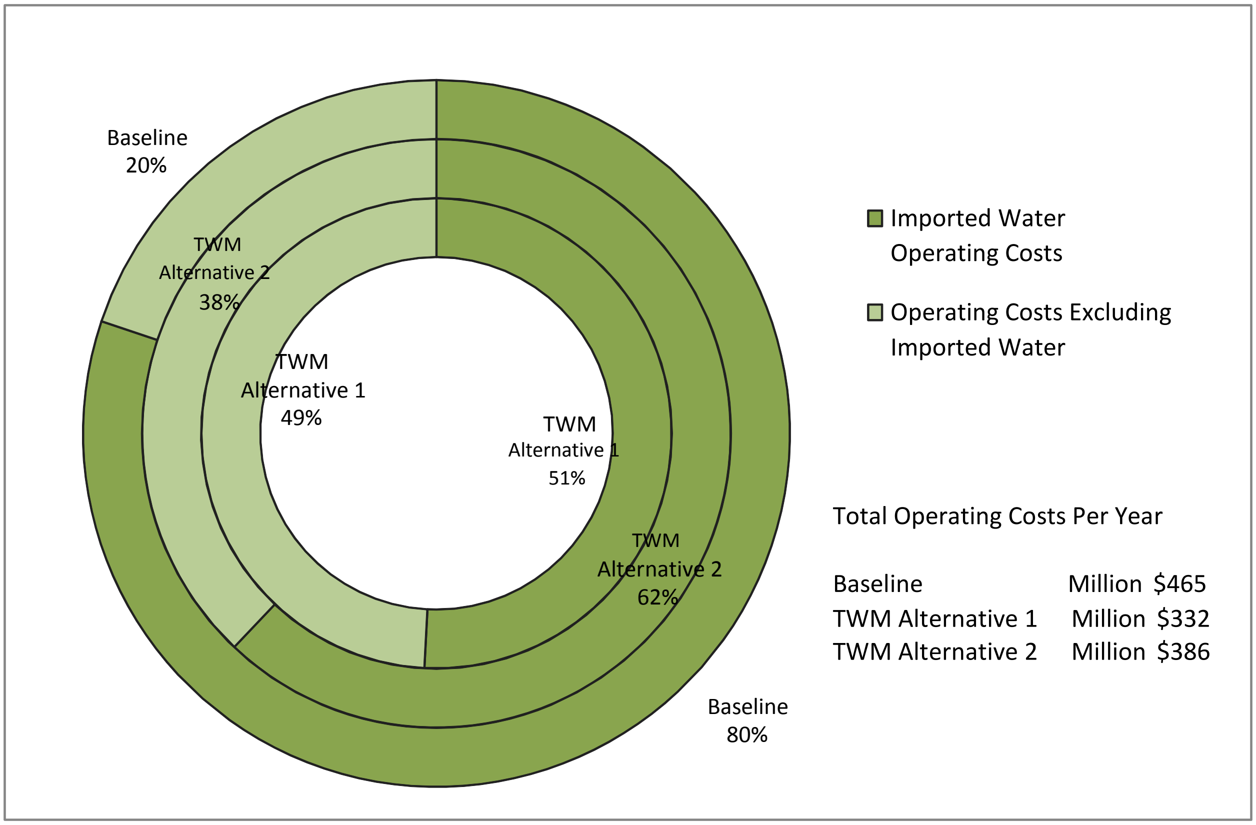



**Figure 26. Annual operating costs of baseline and total water management alternatives**

## Infrastructure Related Benefits

Another benefit of TWM is reducing or avoiding the need for additional infrastructure. The WEAP model tracks every flow path in the system so that it is possible to determine the amount of influent reaching HTP, which is the downstream WWTP for much of the City (see Figure 9). This WWTP is where full secondary treated water is discharged into the ocean. The following benefits could occur from reducing wastewater flows to HTP: (1) reducing annual operating costs of the treatment plant and discharges into the ocean; (2) delaying or eliminating any future need to expand the ocean outfall; (3) delaying or eliminating the need for future expansion of the treatment plant itself; (4) delaying or eliminating the need for expansion of major inceptor sewers; and (5) reducing the impact of wastewater discharges on the ocean environment.

For the purposes of this study, flows to HTP were used as a proxy for all the potential benefits of TWM. Figure 27 shows the average monthly inflow (year 2030) into the HTP, the City's largest WWTP. TWM Alternative 2 had a 13% reduction in wastewater flows to HTP from the Baseline, which was accomplished by increased recycled water for groundwater recharge in the SFV zone. TWM Alternative 1 had a 27% reduction in wastewater flows to HTP from the Baseline, due to increased recycled water for groundwater recharge and non-potable use, as well as implementation of graywater systems. Deferment of wastewater infrastructure may be one of the most significant benefits of TWM because these benefits can occur in urban areas where water supply is not a significant problem.

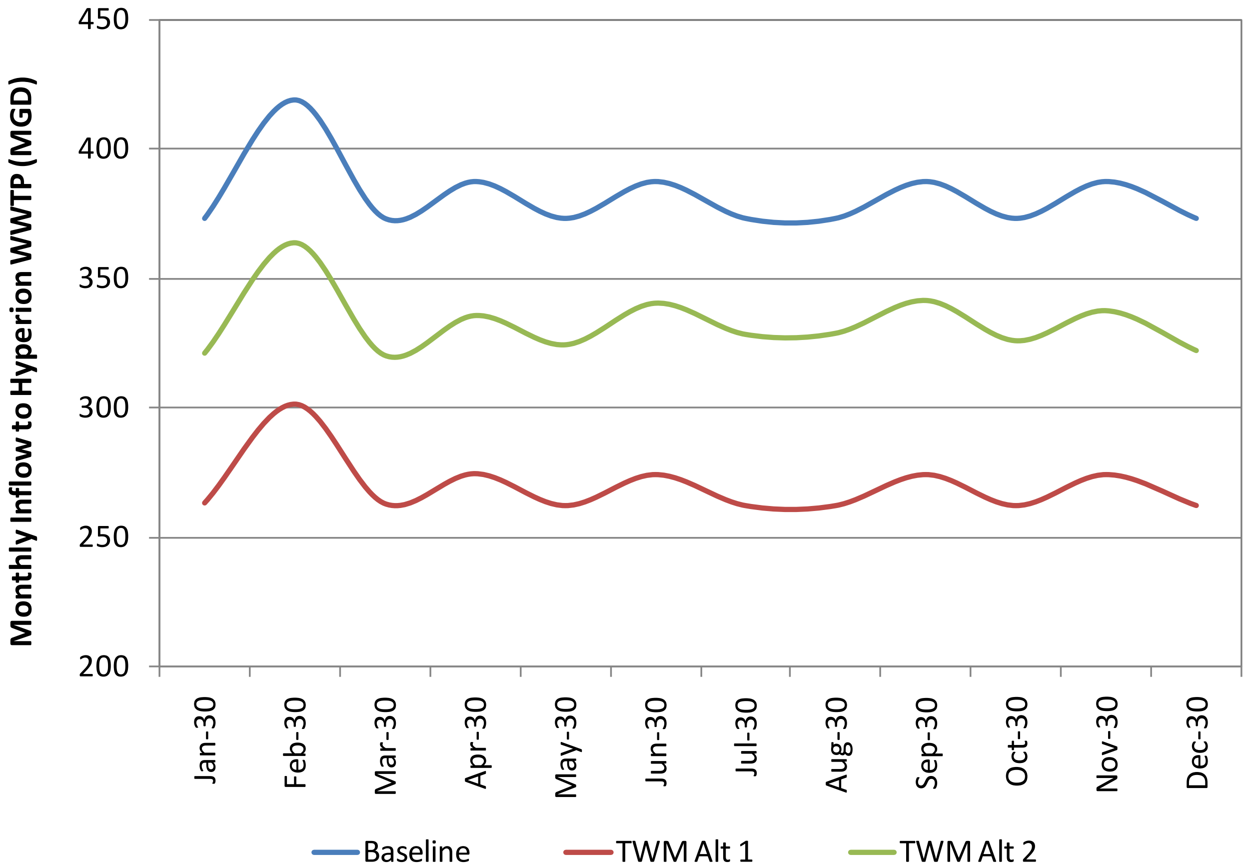



**Figure 27. Average potential monthly wastewater flows into Hyperion Treatment Plant for baseline and total water management alternatives**

Another potential infrastructure benefit of TWM is decoupling the water distribution system for fire flows. Fire flows impose significant peaking requirements for the design of water distribution systems and using recycled water to provide fire flow could eliminate the need for additional pumping, storage or pipe sizing. The City is considerably built out and decoupling the fire flows from the water system would be enormously expensive and likely not provide net benefits unless a thorough replacement of the potable system is required in the future, i.e., due to infrastructure replacement needs or catastrophic damage, e.g., earthquake. The infrastructure replacement need is beyond scope of this report; however, regions with new demand areas or significant replacement programs for water lines should consider the evaluation of that TWM option.

## Climate Change Scenario Results

To estimate the sensitivity to potential climate change, the Baseline and the TWM alternatives were simulated under a specific climate change scenario, evaluated by the DWR. DWR conducted several climate change simulations for their report on State Water Project Reliability Report (DWR, 2007). The report presents estimated reductions in water deliveries from northern California based on the downscaling of several GCMs and emission scenarios.

Appendix C describes the assumptions and logic behind the hydrology dependent variables. Because the LAA and MWD water supplies are highly dependent on snowpack, they are very vulnerable to the impacts of climate change. Although specific analysis for climate change on the LAA has not yet been completed, it was assumed that climate change would have the same impact (in terms of reduction in supply) as the SWP (as discussed in Appendix C).

Results of the climate change scenario are mostly observed in supply reliability. The result of the analysis was that, under the Baseline, average annual supply deficits increased by almost 1,500 AFY. Under TWM Alternative 1, there were still no supply deficits even with climate change. TWM Alternative 2 was also not impacted by climate change.

An interesting result in the climate change scenario is that the NPV of the each of the alternatives under climate change conditions is higher than the no climate change scenario. Under climate change, the NPV of the alternatives increases from the values presented in Figure 25 (no climate change) by $2,000,000 to $18,000,000. This is the result of the reduction in LAA water with the required increases purchases of MWD supplies, which are more expensive per volume. As demand increases, the reductions in LAA water become more important and the increases in MWD water are more significant. Over the 25 year simulation, there is sufficient added volume of MWD in the climate change scenario to have an impact on the NPV. Figure 28 shows the increased MWD annual flows (per year and cumulative) for all alternatives, when climate change is assumed. In the real system, the MWD supplies are indeed much more reliable given that MWD's system has much larger storage than the LAA.

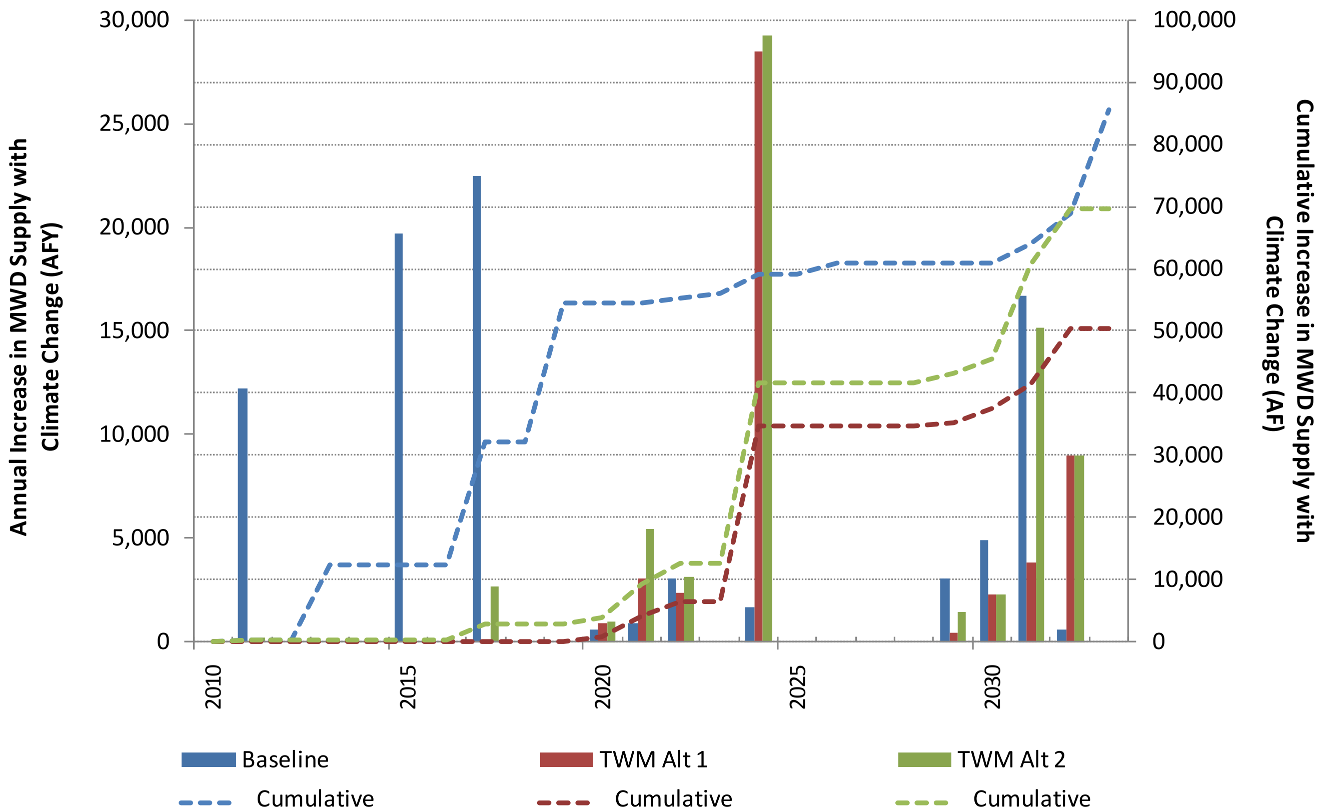



**Figure 28. Increased Metropolitan Water District of Southern California imported water supplies in the climate change scenario for baseline and total water management alternatives**

Figure 28 presents how much more MWD water, i.e., expensive water, is purchased under climate change conditions, but it does not show how much *total* MWD water is used each simulated year. That is why in the year 2024 there is a significant increase in MWD water for the TWM Alternatives whereas the baseline shows only a slight increase. Th is because the baseline is already close to maximum MWD deliveries under no climate change (requiring over 326,000 AFY). When climate change is simulated, only an additional 1,700 AFY is available for a total of 328,000 AFY as MWD deliveries "max out" that particular year. For the TWM alternatives, the increases in MWD purchases are almost 30,000 AFY; these values are nowhere close to the maximum MWD deliveries (92,000 AFY and 178,000 AFY for TWM Alternative 1 and TWM Alternative 2, respectively). When climate change is simulated, the TWM alternatives do become more dependent on MWD but these alternatives can actually get the additional supply before reaching the maximum. Figure 28 also shows the cumulative additional MWD over the study years, which causes the additional NPV.

In climate change simulations, a better picture of potential impacts can be obtained by running a probabilistic analysis. Figure 28 does not present a probabilistic analysis, since it was developed with a direct application of the hydrology sequence from 1980 to 2003, imposed in demand projections from 2010 to 2033. The WEAP Model could accommodate a probabilistic run in which the sequence of hydrology could be applied to a single year, and thus generate an envelope of outcomes for that given single year. That analysis was beyond the scope of this study, in which a simple analysis was developed to show one of the potential benefits of TWM regarding climate change.

### Earthquake Emergency Scenario Results

This emergency scenario was set up by assuming an earthquake that would significantly disrupt imported supply from MWD, to the Los Angeles area. The model did not assign specific probabilities for this scenario. The analysis consisted in selecting one month simulated by WEAP, in the year 2030 (2030 demands) and eliminating the MWD supply from the supply mix of resources.

The results presented in Figure 29 assume that the MWD supply is interrupted in October of 2030. The seasonality factor for the month of October (as explained in Appendix B) is equal to 1.22, which means demands are higher than the average month (for comparison, the highest seasonality factor corresponds to August with 1.59). The baseline presents a deficit for that month of 27,842 AF but that deficit is much smaller for TWM Alternative 1 and TWM Alternative 2. The maximum reliability benefits for TWM Alternative 1 come from increased conservation, recycled water and added graywater use as compared to the Baseline. For TWM Alternative 2, the greatest benefit is also from increased conservation and recycled water. The supply deficit in the Baseline Alternative is more than four times as large as the TWM Alternative 1, and more than doubles TWM Alternative 2.

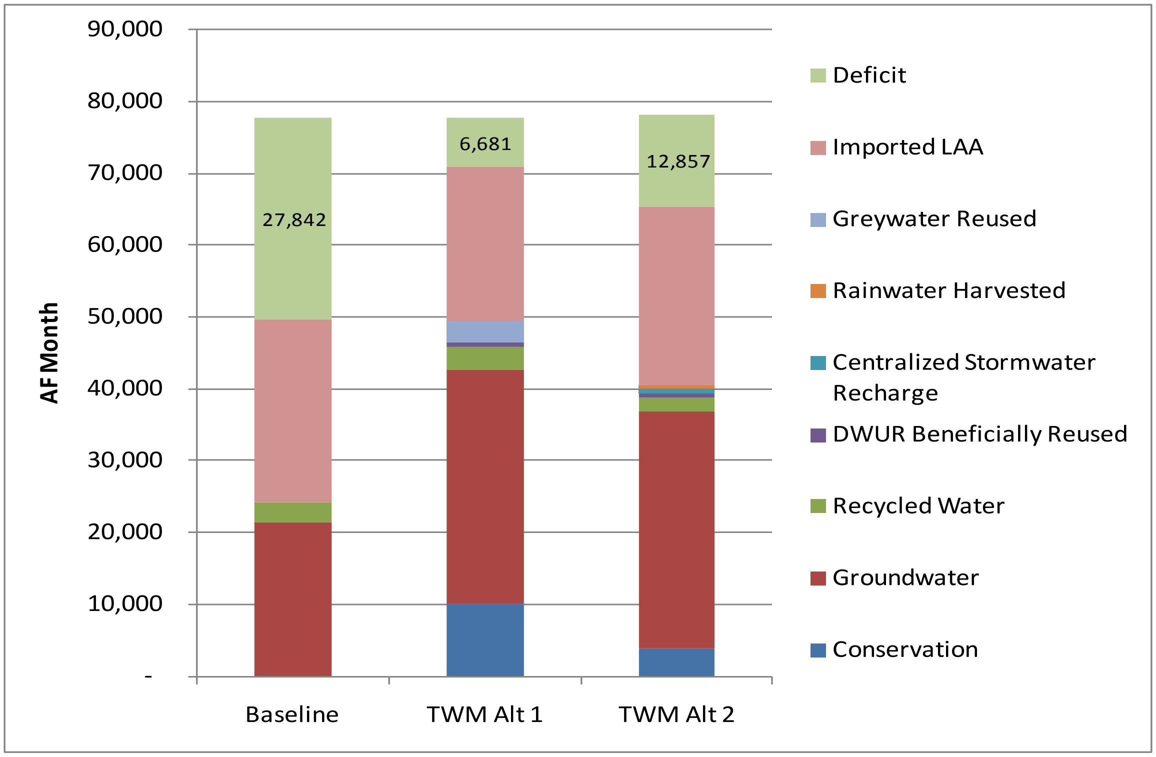



**Figure 29. Water supply mix and supply deficit for emergency scenario for baseline and total water management alternatives**

## Case Study Conclusions

The case study for Los Angeles clearly shows the benefits of TWM, as demonstrated in Table 2. All of the performance measures, including overall net present value costs, were significantly better for the TWM Alternatives, compared to the Baseline (which represents the traditional water management approach).

This conclusion will likely not be the case everywhere TWM is evaluated. But this case study can be used to help water managers establish a credible evaluation framework for analyzing each component of TWM and determine if the benefits outweigh the additional costs.

**Table 2. Comparison of Performance Measures for Baseline and Options**

| Performance Measure | Baseline | TWM 1 | TWM 2 |
|---|---|---|---|
| Water Demand in 2030 (AFY) | 762,700 | 655,800 | 711,400 |
| Maximum Annual Supply Deficit (AFY) | 78,400 | - | 11,400 |
| Average Annual MWD Imports (AFY) | 135,267 | 32,599 | 62,939 |
| Zinc Loading at Downstream End of Los Angeles River (kg/yr) | 26,569 | 23,788 | 22,089 |
| Cumulative CO2 Emissions (metric tons) | 26,085,692 | 22,603,896 | 24,175,512 |
| Average Monthly Wastewater Flows into HTP (MGD) | 375 | 270 | 335 |
| Supply Deficit in Emergency Scenario (AF/month) | 27,840 | 6,680 | 12,860 |
| Net Present Value ($ millions) | $6,672 | $5,651 | $6,362 |

This case study has used a large urban area (Los Angeles) to illustrate the potential benefits of a TWM approach. The results and conclusions, however, are applicable to smaller areas and to cities with less financial resources than the City. TWM options are not necessarily more or less cost effective than traditional engineering and planning options, but it is through the formal evaluation and quantitative analysis that decisions should be made about the merits of the approach.

Implementation of the TWM alternatives in the City presents the same challenges that would be faced in other cities and regions, where different agencies have jurisdiction and mandates that are exclusive of a system. In fact one of the main tenants of TWM is to break down the barriers that often exist between the multiple agencies and city departments that have some role in water management.

# Chapter 6 Conclusions

This report has illustrated the state of knowledge and practice of TWM. Through the analysis of a real a case study, the report has demonstrated some of the system-wide benefits that can be achieved by implementation of TWM.

The literature review and desktop analysis have shown that TWM is generally better suited to meet challenges such as limited fresh water supplies, degradation of receiving water quality, increasing regulatory requirements, flood management, aging infrastructure, and rising utility costs. However, the implementation of a TWM approach will require new frameworks for planning, decision-making, design, engineering, and operations that involve more than one administrative entity.

TWM can be implemented when different service functions of a region (e.g., utilities such as water, wastewater, and stormwater) integrate planning and project implementation functions. Implementation of the TWM alternatives can present challenges in most cities and regions, where multiple agencies or departments have different jurisdictions and mandates. Functional barriers need to be addressed and considered when implementing TWM. One key lesson learned from urban watersheds implementing TWM is that agencies do not have to give up control over the implementation and operation of projects and facilities. But by collaborating and cooperating on the planning process and decision-making, new opportunities for better water resources management will likely arise.

Additionally, it is fully recognized that there are currently many regulatory barriers that may impede taking a TWM approach, such as:

(1) uses of recycled water;

(2) full-scale implementation of graywater systems;

(3) water right issues associated with stormwater capture; and others.

The framework for TWM planning and evaluation presented in this report can be used to objectively determine if the benefits outweigh changing these regulations.

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# Appendix A - Cost Assumptions for Case Study

The TWM options used in the desktop analysis case study were programmed in the WEAP model with capital, fixed O&M and variable O&M estimates. This appendix describes the cost assumptions and sources for all options. The appendix also includes costs assumptions for sources not related to TWM but included in the model, such as imported water costs.

### Metropolitan Water District's Imported Water Costs

Imported water costs (dollars per AF) were entered in the model as a time series with forecasted projections between 2008 and 2033. These projections are in projected-year dollars, including inflation. Projections for the earlier years are from MWD (www.mwdh2o.com), while the outer years are based on past historical rates of change. Table A-1 presents the projected rates used in the model, which correspond to MWD's Tier 1 treated water rates.

**Table A-1. Projected MWD Unit Cost for Imported Water**

| Year | Cost per AF | | Year | Cost per AF |
|---|---|---|---|---|
| 2008 | $ 508 | | 2021 | $ 1,078 |
| 2009 | $ 579 | | 2022 | $ 1,112 |
| 2010 | $ 643 | | 2023 | $ 1,145 |
| 2011 | $ 694 | | 2024 | $ 1,178 |
| 2012 | $ 746 | | 2025 | $ 1,211 |
| 2013 | $ 798 | | 2026 | $ 1,237 |
| 2014 | $ 850 | | 2027 | $ 1,262 |
| 2015 | $ 901 | | 2028 | $ 1,287 |
| 2016 | $ 930 | | 2029 | $ 1,312 |
| 2017 | $ 959 | | 2030 | $ 1,337 |
| 2018 | $ 988 | | 2031 | $ 1,363 |
| 2019 | $ 1,016 | | 2032 | $ 1,388 |
| 2020 | $ 1,045 | | 2033 | $ 1,413 |

### Conservation

The TWM options included in the on conservation include both, indoor and outdoor conservation measures. The model used two separate estimates of for the two types of programs:

- Indoor conservation: $390/AF
- Outdoor conservation: $430/AF

These estimates are very general in nature but based on estimates of total water savings (indoor and outdoor) and annual costs associated with those savings from other cities including San Diego area (Santa Fe Irrigation District and Edmond Oklahoma).

Water conservation measures that would result in waster savings between 5% and 10% include: distribution of water conservation education and awareness material to customers and in schools; distribution of dye tablet kits with instructions for detection and correction of leaky toilets; providing instructions to customers on proper setting adjustments of irrigation controllers; distribution of moisture sensors for use with irrigation controllers; providing water audits of residential customer properties on request, and target high water using customers.

As part of a planning effort, the City of Edmond Oklahoma conducted a review and analysis of similar conservation programs throughout the U.S. concluding that these programs could be implemented and administered for $0.20 or less per gallon per day of water savings. For higher levels of efficiency in water use, the water conservation measures that would need to be implemented include: providing rebates for installation of dual-flush toilets which have separate settings for urine and fecal flush; providing rebates for water efficient clothes washers; with a cost to these programs (implemented and administration) for $0.50 or less per gallon per day of water savings. Applying the costs of these programs to their expected water efficiency levels resulted in the unit costs presented above.

## Wastewater Recycling

Los Angeles has existing reclamation facilities as described in Chapter 5. None of the TWM options evaluated included the expansion of those reclamation facilities. Some options however, included the expansion of the recycled water system. The costs for the expansion the system was based on estimates for pipelines and pump stations of sizes similar to the options included in the analysis (10 MGD or lower).

Estimates were derived using the following costs items for the system:

Pipeline Capital Costs: $15/ft-inch diameter. Assuming 4.5 miles of 20 inch pipeline, pipeline costs are: $7,128,000

Pump Station Capital Costs: $4,060/hp of installed capacity. Assuming a medium size pump station of 1,980 hp, the capital costs are $7,985,000

These dimensions of the system assumed a 6 MGD expansion. The unit cost per MGD of installed capacity expansion of the system is then:

$15,113,000/6 MGD = $2,518,700/MGD

This capital unit cost was applied in the model to expansions of recycled water (distribution only).

Fixed O&M costs for this system were assumed at 1% of capital cost, and variable O&M costs were obtained from the City of Los Angeles Recycled Water Master Plan – Draft Site Assessment Technical Memorandum (City of Los Angeles DPW, 2010). This report, specifically for Los Angeles, reports variable O&M costs equal to $179/AF, for the TWRP. This variable cost includes the costs of treatment in addition to the costs of pumping to demands.

## Dry-Weather Urban Runoff Capture and Reuse

This TWM option includes two main components: diversion from the stormwater system, and treatment for beneficial use. The diversion from the stormwater system can be to the wastewater collection system or to the dedicated treatment facility, but its costs are assumed to be the same (regardless of the fate of the DWUR).

### *Diversions*

The capital cost for the diversion structures was obtained from the City's IRP (City of Los Angeles, 2006a, 2006b, 2006c). A unit cost of $1,855,000/MGD was used for this project, based on the costs used in cited report.

Fixed O&M costs are assumed at 2% of capital, and variable costs were estimated at $64/AF for the pumping required.

### *Dedicated Treatment*

The facility assumed for the estimates of dedicated treatment for DWUR includes the processes of dissolved air flotation and microfiltration, and the associated pumping with those processes. This facility is similar an existing facility in the City of Santa Monica.

Capital costs were obtained from the City's IRP (City of Los Angeles, 2006a, 2006b, 2006c) for the Wastewater Program and updated. The unit cost is $2,810,000/MGD of capacity installed.

Variable O&M costs are assumed at 1% of capital costs and variable O&M are based on the treatment processes included and based on the City of Los Angeles Integrated Plan for the Wastewater Program, and correspond to $128/AF. This estimate assumes the system is shut down during rain events.

## Graywater

Graywater cost estimates are based on information from a vendor for a typical domestic system. The size of the system assumed would provide estimated savings of 1,200 to 1,300 gallons per month.

The capital cost of the system is $1,369 per unit. The fixed O&M costs are assumed to be 1% of the capital and variable costs are $0.15 per AF.

## Rain Water Harvesting

Rain Water harvest system cost estimates are based on information from the Texas Manual on Rain Waster Harvesting (Texas Water Development Board, 2005) for a typical domestic system. Estimates were updated from the 2005 data included in the manual. The size of the system assumed for cost estimates is for an average house of 1,300 sq. ft.

Capital costs for the system are $1,909 per system. The fixed O&M costs are assumed to be 1% of the capital and variable costs are $0.15 per AF.

## Water Recycling Through Groundwater Recharge

Significant work exists on this option with several reports available from the City. The data used for this study is based on the "City of Los Angeles Recycled Water Master Plan – Draft Site Assessment Technical Memorandum" (City of Los Angeles DPW, 2010).

The capital cost assumes advanced wastewater treatment including reverse osmosis. The unit cost for capital is equal to $6,758,000/MGD of capacity installed.

The fixed O&M costs are based on a 60 MGD facility of tertiary treatment with 32 MGD facility for advance water treatment with RO. The annual estimates correspond to $11,218,000.

Variable costs for treatment and pumping to the recharge facilities are $179 per AF.

## Centralized and Decentralized Stormwater Recharge

### *Centralized System*

Stormwater recharge facilities costs were obtained from estimates in the City of Los Angeles IRP for a system in the SFV zone. Capacity was estimated at 245 MGD for 26 days (dictated by 100 inch pipeline diameter). There are no dimensions given for the recharge facilities as it is assumed existing recharge facilities would be used.

The capital cost for a facility with a yield of 245 MGD is equal to $87 million. Fixed O&M costs are assumed at 1% of capital. Since variable costs are not provided in the document for this facility, variable costs were assumed to be the same as a decentralized system (see below).

### *Decentralized System*

Stormwater recharge facilities costs were obtained from various estimates of systems in the City from project proposals submitted as part of the City's "Proposition O"(proposition O is a ballot initiative that was voted by the citizens of Los Angeles that made city funds available for environmental projects proposed by government agencies and citizen groups). Various capacities and costs were compiled and an average cost per acre of project was derived. The types of projects ranged from neighborhood recharge in vacant lots, to neighborhood recharge in parks and open space, and recharge in abandoned alleys. The acreage of projects ranged from 15 acres to over 340 acres.

The unit capital cost of this option is $1,161,000/Acre. Fixed costs were also based on an acreage basis and were equal to $9,800/acre. Variable costs are estimated at $81/AF, which means that the cost will vary depending on the volumes managed.

## Expansion of Groundwater Pumping Facilities

In addition to the TWM options described above, costs estimates were included in the model for expansion of groundwater pumping and delivery capacity. This expansion is necessary to utilize groundwater recharged under some of the TWM options. Not expanding the groundwater wells would result in not being able to utilize the recharged water since the groundwater system in Los Angeles is practically operated at capacity today.

The cost estimates were based on estimates from other studies in California, in the Los Angeles area. Expansion of the groundwater wells assumes: land acquisition, production well (assumed 800 ft deep), connection to distribution system, water quality sampling, and pump station. The well estimate does not include treatment costs.

The unit capital cost of the expansion is $1,819,000/MGD. Fixed O&M costs are assumed at 1% of capital and variable costs are assumed at $200/AF.

# Appendix B - Rainfall and Stormwater Calculations

The WEAP model is programmed to compute the system-level rainwater volumes and routing along various user-defined pathways on a monthly basis. The model is structured and parameterized to be able to track the amount of rainfall that infiltrates into the ground and the amount that becomes urban runoff. The model also includes parameters and decision variables to allocate rainwater for direct capture (e.g., "harvesting" in cisterns and rain barrels) and for groundwater recharge – both "centralized" and "decentralized" cases. The approach and calculations for rainfall and stormwater in the model are described below.

**Demand Zones, Rainfall Data, and Rainfall Volumes**
In the model, the City has been divided into four "demand zones" (SFV, Central, West, and SP). Each demand zone is associated with a physical area in the city, and thus has a surface area attribute (in acres). Historic monthly rainfall data was obtained from a gauge for each of the demand zones. The model runs a 23 year simulation (2010-2033), and uses rainfall data from the period of record from 1980-2003. The rainfall data used in the model is presented in Table B-1 at the end of this appendix.

The total monthly volume of rainfall,*V*, to be accounted for and routed in each demand zone is calculated as the product of the rainfall depth and the zone surface area:

$$V = Rain(month) \text{ x } Area(zone)$$

The routing pathways for this rainfall volume are depicted in the schematic in Figure B-1. Monthly rainfall generally becomes either infiltration (to groundwater) or urban runoff. The urban runoff can be routed as "rain harvest", "centralized stormwater recharge", or "conventional stormwater." The calculation and routing of these flows are described below.

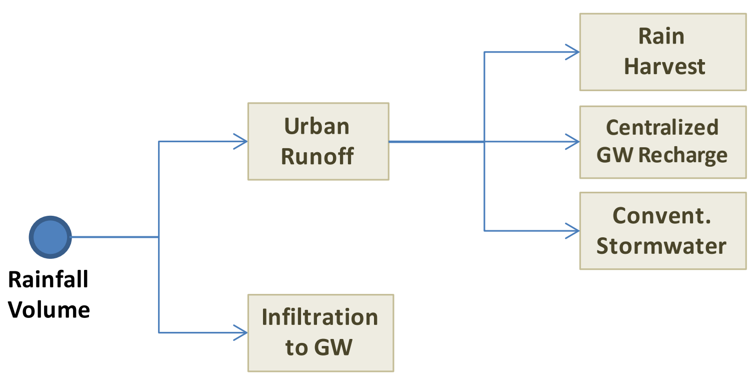


**Figure B-1: Schematic Diagram of Rainfall Routing**

**Rainfall Runoff and Infiltration**
The routing of monthly rainfall volumes as infiltration and runoff can generally be specified by the percentages flowing as infiltration and runoff:

$$Infiltration = V \text{ x } \%Inf$$
$$Runoff = V \text{ x } \%RO$$

Rainfall accounting has been adjusted according to the approach employed for simplistic groundwater basin tracking. In this study, data on the "natural groundwater recharge" was not available. As such, it was not possible to model based on actual inflows, outflows, and storage in the groundwater. Instead, the model demonstrates the benefits of storing water by recharging the groundwater basin – which in the model is termed "banked" storage.

For this reason, the model only tracks the city's efforts at active recharge of water into the basins (for the 'natural recharge' the model assumes that each year the amount of groundwater that Los Angeles is entitled to is naturally infiltrated and then pumped by the city, i.e., IN=OUT). Monthly inflows are assumed to match the seasonal pumping demands; but the model does not track the exact amount of natural inflow to the basin, only the amount to cover Los Angeles' "normal" groundwater demands.

For infiltration, there are two types: "normal" infiltration, i.e., from the pervious areas of the demand zones, according to the runoff coefficients, and the infiltration that takes place due to "decentralized stormwater recharge" (see Section 5.3.7 in the main body of the report). Since the model is only tracking "banked" water in the groundwater basin, it only needs to count the water that infiltrates from the "decentralized" stormwater recharge system. It is assumed that the "normal infiltration" is included in the natural groundwater recharge (and not explicitly tracked).

These assumptions about groundwater require making adjustments to the rainfall depths and the routing percentages for Infiltration and Runoff. The adjustments apply a correction that separates the decentralized amounts from the other infiltration amounts. The term "infiltration" really reflects an effective infiltration in that it is assumed to account for losses.

The primary assumptions are that:

- Volume(rain) = Area * Precipitation
- Volume(rain) = Infiltration + Runoff (and "infiltration" accounts for losses, as a percentage in WEAP)
- The total runoff volume is the same, before and after correction
- The modeled infiltration volume must include *only* the volume from the decentralized stormwater areas

From these assumptions and the definition and mass balance equations around the urban catchment, the correction factors are derived for the three components:

$$AdjVolume(rain) = Volume(rain) \times factorRain$$

$$factorRain = [(\%Area_p \times C_p) + (\%Area_i \times C_i) + (\%Area_d \times C_d)] + [\%Area_d \times (1 - C_d)]$$

$$\%Inf(Adj) = \frac{\%Area_d \times (1 - C_p)}{factorRain}$$

$$\%R0(Adj) = \frac{[(\%Area_p \times C_p) + (\%Area_i \times C_i) + (\%Area_d \times C_d)]}{factorRain}$$

Where:

| | | |
|---|---|---|
| AdjVolume(rain) | = | Adjusted rain volume (monthly) |
| Volume(rain) | = | Normal rain volume (monthly) |

| | | |
|---|---|---|
| factorRain | = | Correction factor for rain volume |
| $\%Area_p$ | = | Percent of demand zone area that is pervious surface |
| $\%Area_i$ | = | Percent of demand zone area that is impervious surface |
| $\%Area_d$ | = | Percent of demand zone area that is dedicated to "decentralized stormwater recharge" (user defined, decision variable) |
| $C_p$ | = | Runoff coefficient for pervious surface |
| $C_i$ | = | Runoff coefficient for impervious surface |
| $C_d$ | = | Runoff coefficient for decentralized stormwater recharge surfaces |

These adjusted factors get applied as system parameters in WEAP. The C values used in the WEAP model were obtained and simplified from current TMDL models in Los Angeles. The "factorRain" term is applied to the rainfall data series, and the two adjusted routing percentages are applied as the routing parameters for each demand zone's catchment node flow pathways.

The runoff and infiltration volumes determined from the above parameters are then routed in WEAP as described in the following sections.

Figure B-2 shows a simple schematic of an urban watershed with its area and runoff parameters and flow routes.

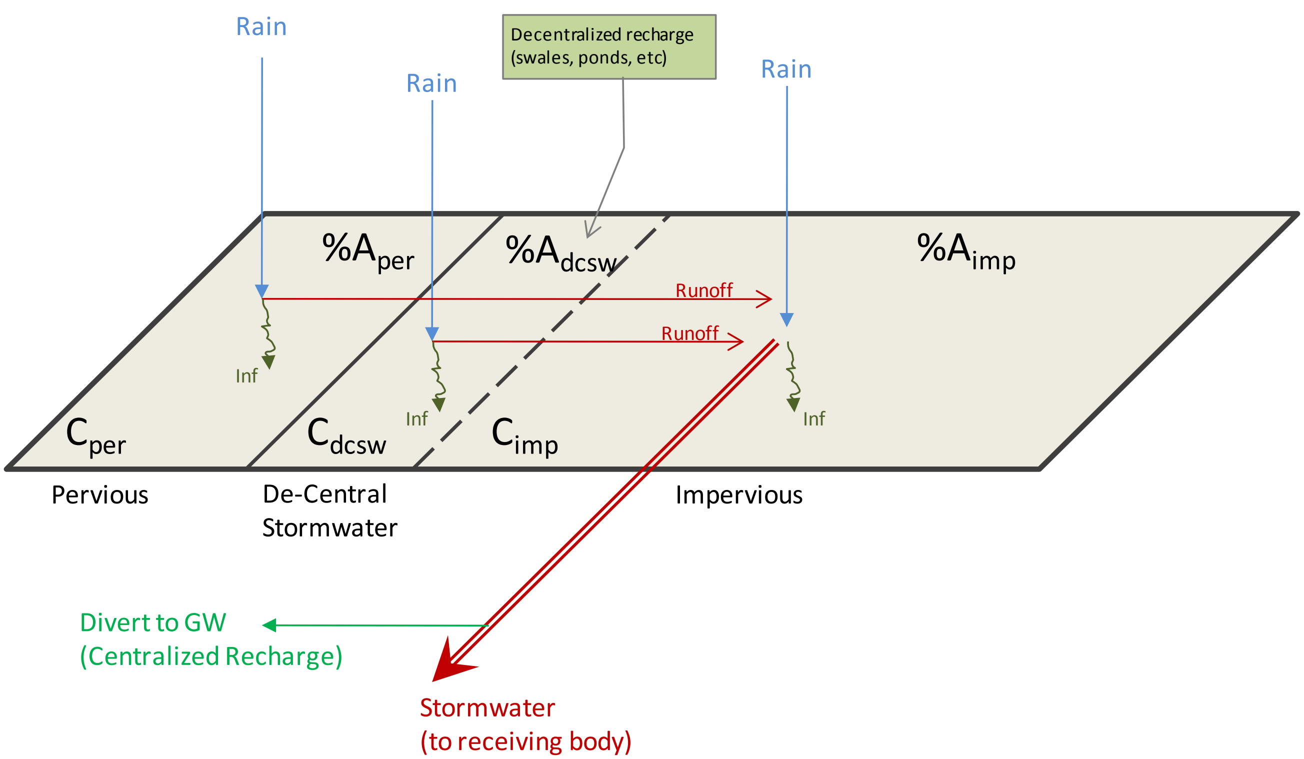


**Figure B-2: Simple Schematic of Urban Watershed**

## WEAP System Schematic for Rainfall and Stormwater Components

Figure B-3 presents the model components as used in the WEAP model for Los Angeles. These components include an urban catchment, an urban node, two dummy demand nodes, a groundwater basin node, an outdoor demand node, a receiving water body, and the various linking pathways. The components are referred to and defined in following sections.

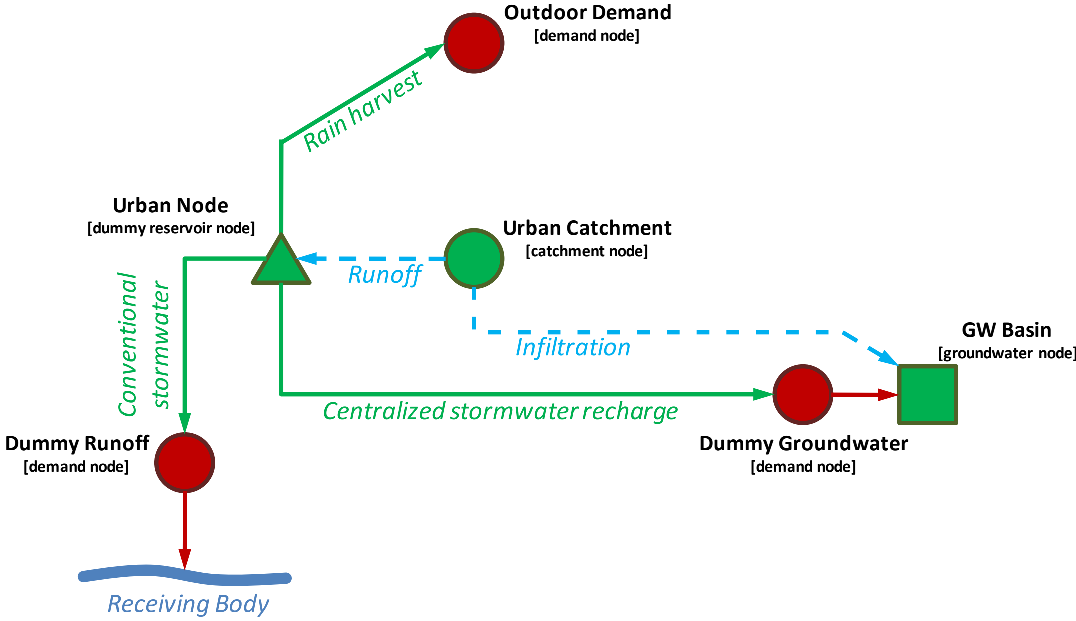


**Figure B-3: WEAP Schematic for Rainfall and Stormwater Components**

### *Urban Wet-Weather Runoff*

The urban wet weather runoff is the volume calculated using the "%RO(Adj)" term above multiplied by the total rainfall volume in the demand zone's catchment node. This volume is then routed to the demand zone's "Urban Node" – which is a *dummy* node in the model used only for calculation purposes (see Figure B-3). In WEAP, the Urban Node is a zero-storage reservoir where the sum of all inflows equals the sum of all out flows. This approach is used to route the urban runoff through three pathways: rain harvesting, centralized groundwater recharge, and conventional stormwater (each described in sections below). WEAP routes the water through the three pathways according to:

- Runoff availability, i.e., all inflow to Urban Node must be routed
- Water demand, according to the demand priorities
- Flow path constraints

### *Rain Harvesting*

Rain harvesting is modeled in WEAP as a transmission link from the (*dummy*) Urban Node to the Outdoor Demand node, in each demand zone (see Figure B-3). Outdoor demands are specified in the model as the second highest priority demand category (after Indoor Demands), and thus of the available urban runoff volumes in each month, WEAP will first route water along the rain harvest pathway.

A monthly flow constraint is applied to the rain harvest pathway in order to limit runoff routing according to assumptions about the size and operations of the rain harvesting system.

The monthly constraint on the rain harvesting transmission link is defined as:

$$MaxVolume(rainHarvest) = OnOff(rainHarvest) \times CaptureArea \times Depth(rain) \times \%EffCapture$$

Where:

| | | |
|---|---|---|
| MaxVolume (rainHarvest) | = | Monthly constraint on rain harvest pathway |
| OnOff(rainHarvest) | = | Decision variable "switch" for TWM option |
| CaptureArea | = | Decision variable of roof area dedicated to rain capture [Ac] |
| Depth(rain) | = | Monthly rainfall depth [in] |
| %EffCapture | = | Percentage of total rainfall volume that can be captured and used (based on rainfall patterns, storage volumes, demand and use rates, etc) |

The typical system assumed in the model was one cubic meter (1000 liters), which results in a supply of 10 to 15 days for irrigation. This means that completely full system would be depleted after 10 to 15 days if no rain re-fills the system. The sizing (assumed size) of the system was based on considerations of reliability vs. practical realities to fit a system in a typical residence. The 1,000 liters system was selected as a "middle of the range" size for reliabilities as reported by Guo and Baetz (2007).

***Centralized Stormwater Recharge of Groundwater***

The centralized stormwater recharge TWM option is modeled in WEAP as a transmission link between the (*dummy*) Urban Node and a "*Dummy* GW" node in each demand zone (see Figure B-3). The dummy groundwater node is used to drive water recharge into the groundwater basins (WEAP does not have a "demand" parameter for groundwater basins). The dummy groundwater node is given and arbitrarily high demand value, which will force WEAP to route water into the basin through this pathway. Monthly flows are limited however by a constraint on the transmission link, which represents the centralized stormwater recharge facilities capacity. The dummy groundwater demand node is given a low demand priority (so that WEAP satisfies other, "real" demands in the system first).

The monthly constraint on the centralized stormwater recharge transmission link is defined as:

$$MaxVolume(centralSW) = OnOff(centralSW) \times Capacity(centralSW)$$

Where:

| | | |
|---|---|---|
| MaxVolume (centralSW) | = | Monthly constraint on centralized stormwater recharge pathway |
| OnOff(centralSW) | = | Decision variable "switch" for TWM option |
| Capacity(centralSW) | = | Decision variable capacity for facilities [MGD] |

***Conventional Stormwater***

The default flow for urban runoff in the model is through the city's conventional stormwater system. Excess urban runoff that does not get captured and used as rainwater harvesting or centralized stormwater recharge flows through the conventional stormwater system. The conventional system is modeled in WEAP as a transmission link between the (*dummy)* Urban Node and a "*Dummy* Runoff" node in each demand zone (see Figure B-3). Similar to the dummy demand node in the centralized stormwater recharge pathway described above, the dummy runoff node has an arbitrarily high demand value – to drive WEAP to route urban runoff through the transmission link. The dummy runoff demand nodes have the lowest demand priority in the system, and represent the "default" routing path for urban runoff – WEAP will utilize all other pathways first in order to meet demands up to facilities capacities. For this study, there is no capacity constraint placed on the stormwater transmission link.

Table B-1 Historic Rainfall Data for Los Angeles Demand Zones [in/month]

| | | | Demand Zone | | | |
|---|---|---|---|---|---|---|
| Historic Year | Simulation Year | Month | San Fernando Valley | Central City | Westside | San Pedro |
| 1980 | 2010 | Jan | 7.5 | 7.5 | 7.0 | 7.2 |
| 1980 | 2010 | Feb | 14.4 | 12.8 | 9.1 | 9.4 |
| 1980 | 2010 | Mar | 3.8 | 4.8 | 3.7 | 2.9 |
| 1980 | 2010 | Apr | 0.4 | 0.3 | 0.2 | 0.3 |
| 1980 | 2010 | May | 0.1 | 0.1 | 0.1 | 0.1 |
| 1980 | 2010 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1980 | 2010 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 1980 | 2010 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1980 | 2010 | Sep | 0.0 | 0.0 | 0.0 | 0.0 |
| 1980 | 2010 | Oct | 0.0 | 0.0 | 0.0 | 0.0 |
| 1980 | 2010 | Nov | 0.0 | 0.0 | 0.0 | 0.0 |
| 1980 | 2010 | Dec | 1.1 | 0.9 | 1.6 | 1.5 |
| 1981 | 2011 | Jan | 2.3 | 2.0 | 1.5 | 1.9 |
| 1981 | 2011 | Feb | 2.1 | 1.5 | 1.6 | 1.6 |
| 1981 | 2011 | Mar | 5.0 | 4.1 | 3.2 | 3.4 |
| 1981 | 2011 | Apr | 0.5 | 0.5 | 0.5 | 0.3 |
| 1981 | 2011 | May | 0.0 | 0.0 | 0.0 | 0.0 |
| 1981 | 2011 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1981 | 2011 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 1981 | 2011 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1981 | 2011 | Sep | 0.0 | 0.0 | 0.1 | 0.1 |
| 1981 | 2011 | Oct | 0.5 | 0.5 | 0.4 | 0.6 |
| 1981 | 2011 | Nov | 2.6 | 1.8 | 2.6 | 2.4 |
| 1981 | 2011 | Dec | 0.6 | 0.5 | 1.5 | 1.0 |
| 1982 | 2012 | Jan | 3.1 | 2.2 | 2.8 | 1.9 |
| 1982 | 2012 | Feb | 0.6 | 0.7 | 0.7 | 0.2 |
| 1982 | 2012 | Mar | 5.7 | 3.5 | 3.4 | 3.1 |
| 1982 | 2012 | Apr | 2.2 | 1.4 | 1.6 | 0.8 |
| 1982 | 2012 | May | 0.1 | 0.1 | 0.1 | 0.2 |
| 1982 | 2012 | Jun | 0.1 | 0.0 | 0.0 | 0.0 |
| 1982 | 2012 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 1982 | 2012 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1982 | 2012 | Sep | 0.7 | 0.8 | 0.8 | 0.4 |
| 1982 | 2012 | Oct | 0.3 | 0.2 | 0.2 | 0.2 |

Table B-1 Historic Rainfall Data for Los Angeles Demand Zones [in/month]

| Historic Year | Simulation Year | Month | Demand Zone: San Fernando Valley | Central City | Westside | San Pedro |
|---|---|---|---|---|---|---|
| 1982 | 2012 | Nov | 6.6 | 4.4 | 3.5 | 3.1 |
| 1982 | 2012 | Dec | 1.2 | 1.1 | 0.7 | 0.9 |
| 1983 | 2013 | Jan | 7.3 | 6.5 | 5.3 | 3.0 |
| 1983 | 2013 | Feb | 4.8 | 4.4 | 5.6 | 4.2 |
| 1983 | 2013 | Mar | 12.4 | 8.4 | 6.4 | 8.8 |
| 1983 | 2013 | Apr | 3.3 | 5.2 | 3.2 | 2.3 |
| 1983 | 2013 | May | 0.0 | 0.4 | 0.0 | 0.2 |
| 1983 | 2013 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1983 | 2013 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 1983 | 2013 | Aug | 1.3 | 0.8 | 1.3 | 0.6 |
| 1983 | 2013 | Sep | 1.2 | 2.0 | 1.9 | 1.3 |
| 1983 | 2013 | Oct | 2.2 | 0.8 | 0.9 | 1.4 |
| 1983 | 2013 | Nov | 2.6 | 2.5 | 2.7 | 2.9 |
| 1983 | 2013 | Dec | 3.5 | 3.2 | 2.1 | 2.0 |
| 1984 | 2014 | Jan | 0.1 | 0.2 | 0.4 | 0.3 |
| 1984 | 2014 | Feb | 0.1 | 0.0 | 0.0 | 0.0 |
| 1984 | 2014 | Mar | 0.1 | 0.3 | 0.1 | 0.1 |
| 1984 | 2014 | Apr | 0.4 | 0.7 | 1.2 | 1.1 |
| 1984 | 2014 | May | 0.0 | 0.0 | 0.0 | 0.0 |
| 1984 | 2014 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1984 | 2014 | Jul | 0.0 | 0.0 | 0.0 | 0.1 |
| 1984 | 2014 | Aug | 0.1 | 0.4 | 0.3 | 0.1 |
| 1984 | 2014 | Sep | 0.2 | 0.2 | 0.1 | 0.2 |
| 1984 | 2014 | Oct | 0.2 | 0.2 | 0.3 | 0.4 |
| 1984 | 2014 | Nov | 2.3 | 1.4 | 1.2 | 1.2 |
| 1984 | 2014 | Dec | 6.1 | 5.5 | 4.2 | 5.2 |
| 1985 | 2015 | Jan | 0.8 | 0.7 | 0.7 | 0.9 |
| 1985 | 2015 | Feb | 1.0 | 2.8 | 1.9 | 1.6 |
| 1985 | 2015 | Mar | 1.0 | 1.3 | 0.7 | 0.6 |
| 1985 | 2015 | Apr | 0.0 | 0.0 | 0.0 | 0.0 |
| 1985 | 2015 | May | 0.0 | 0.2 | 0.2 | 0.2 |
| 1985 | 2015 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1985 | 2015 | Jul | 0.1 | 0.0 | 0.0 | 0.0 |
| 1985 | 2015 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1985 | 2015 | Sep | 0.1 | 0.2 | 0.3 | 0.2 |
| 1985 | 2015 | Oct | 0.3 | 0.4 | 0.4 | 0.1 |
| 1985 | 2015 | Nov | 4.9 | 2.9 | 4.8 | 4.2 |
| 1985 | 2015 | Dec | 1.0 | 0.3 | 0.4 | 0.3 |

| Table B-1 Historic Rainfall Data for Los Angeles Demand Zones [in/month] | | | | | | |
|---|---|---|---|---|---|---|
| | | | Demand Zone | | | |
| Historic Year | Simulation Year | Month | San Fernando Valley | Central City | Westside | San Pedro |
| 1986 | 2016 | Jan | 3.1 | 2.2 | 2.3 | 1.9 |
| 1986 | 2016 | Feb | 5.9 | 6.1 | 5.4 | 5.0 |
| 1986 | 2016 | Mar | 5.2 | 5.3 | 4.9 | 2.7 |
| 1986 | 2016 | Apr | 0.0 | 0.5 | 0.3 | 0.4 |
| 1986 | 2016 | May | 0.0 | 0.0 | 0.0 | 0.0 |
| 1986 | 2016 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1986 | 2016 | Jul | 0.0 | 0.2 | 0.1 | 0.2 |
| 1986 | 2016 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1986 | 2016 | Sep | 0.6 | 2.0 | 1.4 | 1.4 |
| 1986 | 2016 | Oct | 1.1 | 0.5 | 0.1 | 0.4 |
| 1986 | 2016 | Nov | 1.3 | 0.9 | 1.1 | 1.1 |
| 1986 | 2016 | Dec | 0.3 | 0.4 | 0.3 | 0.4 |
| 1987 | 2017 | Jan | 1.4 | 1.4 | 1.3 | 1.9 |
| 1987 | 2017 | Feb | 0.7 | 1.2 | 0.6 | 1.4 |
| 1987 | 2017 | Mar | 1.3 | 1.0 | 0.9 | 0.6 |
| 1987 | 2017 | Apr | 0.1 | 0.1 | 0.0 | 0.1 |
| 1987 | 2017 | May | 0.0 | 0.0 | 0.0 | 0.0 |
| 1987 | 2017 | Jun | 0.0 | 0.1 | 0.1 | 0.1 |
| 1987 | 2017 | Jul | 0.0 | 0.0 | 0.1 | 0.1 |
| 1987 | 2017 | Aug | 0.0 | 0.0 | 0.0 | 0.1 |
| 1987 | 2017 | Sep | 0.0 | 0.1 | 0.1 | 0.0 |
| 1987 | 2017 | Oct | 5.9 | 2.4 | 1.7 | 1.6 |
| 1987 | 2017 | Nov | 1.2 | 1.1 | 0.6 | 0.6 |
| 1987 | 2017 | Dec | 4.0 | 1.8 | 1.8 | 1.8 |
| 1988 | 2018 | Jan | 2.5 | 1.7 | 1.6 | 1.7 |
| 1988 | 2018 | Feb | 2.2 | 1.7 | 1.8 | 1.1 |
| 1988 | 2018 | Mar | 0.2 | 0.3 | 0.1 | 0.0 |
| 1988 | 2018 | Apr | 4.6 | 3.4 | 1.1 | 1.3 |
| 1988 | 2018 | May | 0.0 | 0.0 | 0.0 | 0.0 |
| 1988 | 2018 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1988 | 2018 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 1988 | 2018 | Aug | 0.0 | 0.1 | 0.0 | 0.0 |
| 1988 | 2018 | Sep | 0.2 | 0.0 | 0.1 | 0.0 |
| 1988 | 2018 | Oct | 0.0 | 0.0 | 0.0 | 0.0 |
| 1988 | 2018 | Nov | 0.8 | 0.7 | 0.7 | 0.8 |
| 1988 | 2018 | Dec | 4.4 | 3.8 | 2.5 | 3.2 |
| 1989 | 2019 | Jan | 0.3 | 0.7 | 0.6 | 0.4 |
| 1989 | 2019 | Feb | 2.2 | 1.9 | 1.7 | 0.9 |

| Table B-1 Historic Rainfall Data for Los Angeles Demand Zones [in/month] | | | | | | |
|---|---|---|---|---|---|---|
| | | | Demand Zone | | | |
| Historic Year | Simulation Year | Month | San Fernando Valley | Central City | Westside | San Pedro |
| 1989 | 2019 | Mar | 0.6 | 0.8 | 0.9 | 0.8 |
| 1989 | 2019 | Apr | 0.0 | 0.0 | 0.0 | 0.0 |
| 1989 | 2019 | May | 0.0 | 0.1 | 0.0 | 0.0 |
| 1989 | 2019 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1989 | 2019 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 1989 | 2019 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1989 | 2019 | Sep | 0.4 | 0.4 | 0.3 | 0.3 |
| 1989 | 2019 | Oct | 0.7 | 0.4 | 0.3 | 0.5 |
| 1989 | 2019 | Nov | 0.4 | 0.3 | 0.4 | 0.1 |
| 1989 | 2019 | Dec | 0.0 | 0.0 | 0.0 | 0.0 |
| 1990 | 2020 | Jan | 2.5 | 1.2 | 1.2 | 1.6 |
| 1990 | 2020 | Feb | 2.7 | 3.1 | 2.6 | 2.1 |
| 1990 | 2020 | Mar | 0.3 | 0.2 | 0.1 | 0.1 |
| 1990 | 2020 | Apr | 0.3 | 0.6 | 0.3 | 0.5 |
| 1990 | 2020 | May | 0.7 | 1.2 | 0.8 | 1.2 |
| 1990 | 2020 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1990 | 2020 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 1990 | 2020 | Aug | 0.1 | 0.0 | 0.0 | 0.0 |
| 1990 | 2020 | Sep | 0.0 | 0.0 | 0.0 | 0.0 |
| 1990 | 2020 | Oct | 0.0 | 0.0 | 0.0 | 0.0 |
| 1990 | 2020 | Nov | 0.4 | 0.2 | 0.1 | 0.2 |
| 1990 | 2020 | Dec | 0.1 | 0.0 | 0.0 | 0.0 |
| 1991 | 2021 | Jan | 1.7 | 1.2 | 1.4 | 1.4 |
| 1991 | 2021 | Feb | 3.6 | 0.0 | 2.5 | 3.4 |
| 1991 | 2021 | Mar | 8.0 | 5.9 | 4.0 | 4.9 |
| 1991 | 2021 | Apr | 0.0 | 0.0 | 0.0 | 0.1 |
| 1991 | 2021 | May | 0.0 | 0.0 | 0.0 | 0.0 |
| 1991 | 2021 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1991 | 2021 | Jul | 0.1 | 0.1 | 0.2 | 0.1 |
| 1991 | 2021 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1991 | 2021 | Sep | 0.0 | 0.1 | 0.1 | 0.0 |
| 1991 | 2021 | Oct | 0.4 | 0.4 | 0.1 | 0.1 |
| 1991 | 2021 | Nov | 0.0 | 0.0 | 0.0 | 0.1 |
| 1991 | 2021 | Dec | 5.8 | 3.2 | 2.9 | 2.1 |
| 1992 | 2022 | Jan | 2.6 | 1.7 | 1.6 | 1.5 |
| 1992 | 2022 | Feb | 16.0 | 8.0 | 4.7 | 4.5 |
| 1992 | 2022 | Mar | 8.5 | 7.1 | 5.1 | 5.3 |
| 1992 | 2022 | Apr | 0.2 | 0.3 | 0.2 | 0.0 |

| Table B-1 Historic Rainfall Data for Los Angeles Demand Zones [in/month] | | | | | | |
|---|---|---|---|---|---|---|
| | | | Demand Zone | | | |
| Historic Year | Simulation Year | Month | San Fernando Valley | Central City | Westside | San Pedro |
| 1992 | 2022 | May | 0.1 | 0.0 | 0.0 | 0.0 |
| 1992 | 2022 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1992 | 2022 | Jul | 0.1 | 0.1 | 0.3 | 0.1 |
| 1992 | 2022 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1992 | 2022 | Sep | 0.0 | 0.0 | 0.0 | 0.0 |
| 1992 | 2022 | Oct | 0.0 | 0.7 | 0.5 | 0.5 |
| 1992 | 2022 | Nov | 0.0 | 0.0 | 0.0 | 0.0 |
| 1992 | 2022 | Dec | 7.7 | 4.7 | 4.2 | 5.0 |
| 1993 | 2023 | Jan | 12.6 | 11.8 | 10.6 | 9.1 |
| 1993 | 2023 | Feb | 9.8 | 6.6 | 5.5 | 5.5 |
| 1993 | 2023 | Mar | 4.1 | 2.7 | 1.8 | 2.0 |
| 1993 | 2023 | Apr | 0.0 | 0.0 | 0.0 | 0.0 |
| 1993 | 2023 | May | 0.0 | 0.0 | 0.0 | 0.0 |
| 1993 | 2023 | Jun | 0.5 | 0.8 | 0.7 | 0.9 |
| 1993 | 2023 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 1993 | 2023 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1993 | 2023 | Sep | 0.0 | 0.0 | 0.0 | 0.0 |
| 1993 | 2023 | Oct | 0.5 | 0.2 | 0.1 | 0.0 |
| 1993 | 2023 | Nov | 0.7 | 0.7 | 0.9 | 0.9 |
| 1993 | 2023 | Dec | 1.2 | 0.8 | 1.0 | 0.8 |
| 1994 | 2024 | Jan | 0.5 | 0.3 | 0.3 | 0.3 |
| 1994 | 2024 | Feb | 4.6 | 3.2 | 4.4 | 5.2 |
| 1994 | 2024 | Mar | 1.8 | 1.9 | 1.0 | 1.3 |
| 1994 | 2024 | Apr | 1.3 | 0.8 | 0.4 | 0.4 |
| 1994 | 2024 | May | 0.4 | 0.3 | 0.1 | 0.2 |
| 1994 | 2024 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1994 | 2024 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 1994 | 2024 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1994 | 2024 | Sep | 0.0 | 0.0 | 0.0 | 0.0 |
| 1994 | 2024 | Oct | 0.6 | 0.2 | 0.1 | 0.1 |
| 1994 | 2024 | Nov | 0.8 | 0.6 | 0.7 | 0.4 |
| 1994 | 2024 | Dec | 1.1 | 1.4 | 1.1 | 0.5 |
| 1995 | 2025 | Jan | 16.8 | 12.6 | 12.7 | 12.8 |
| 1995 | 2025 | Feb | 1.6 | 1.3 | 0.6 | 0.5 |
| 1995 | 2025 | Mar | 7.4 | 7.0 | 5.7 | 5.2 |
| 1995 | 2025 | Apr | 0.9 | 0.6 | 0.7 | 0.5 |
| 1995 | 2025 | May | 0.3 | 0.2 | 0.6 | 0.0 |
| 1995 | 2025 | Jun | 0.5 | 0.6 | 0.6 | 0.5 |

| Table B-1 Historic Rainfall Data for Los Angeles Demand Zones [in/month] | | | | | | |
|---|---|---|---|---|---|---|
| | | | Demand Zone | | | |
| Historic Year | Simulation Year | Month | San Fernando Valley | Central City | Westside | San Pedro |
| 1995 | 2025 | Jul | 0.2 | 0.0 | 0.1 | 0.1 |
| 1995 | 2025 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1995 | 2025 | Sep | 0.0 | 0.0 | 0.0 | 0.0 |
| 1995 | 2025 | Oct | 0.0 | 0.0 | 0.0 | 0.0 |
| 1995 | 2025 | Nov | 0.1 | 0.1 | 0.1 | 0.0 |
| 1995 | 2025 | Dec | 1.5 | 1.3 | 2.2 | 2.0 |
| 1996 | 2026 | Jan | 1.8 | 3.2 | 1.9 | 1.8 |
| 1996 | 2026 | Feb | 4.1 | 4.9 | 4.2 | 4.4 |
| 1996 | 2026 | Mar | 2.6 | 2.2 | 1.4 | 1.3 |
| 1996 | 2026 | Apr | 0.3 | 0.7 | 0.4 | 0.4 |
| 1996 | 2026 | May | 0.0 | 0.0 | 0.1 | 0.0 |
| 1996 | 2026 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1996 | 2026 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 1996 | 2026 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1996 | 2026 | Sep | 0.0 | 0.0 | 0.0 | 0.0 |
| 1996 | 2026 | Oct | 1.3 | 1.1 | 1.5 | 1.5 |
| 1996 | 2026 | Nov | 1.6 | 1.6 | 1.9 | 1.8 |
| 1996 | 2026 | Dec | 5.6 | 4.1 | 4.7 | 4.1 |
| 1997 | 2027 | Jan | 4.6 | 5.6 | 5.1 | 6.2 |
| 1997 | 2027 | Feb | 0.3 | 0.1 | 0.1 | 0.1 |
| 1997 | 2027 | Mar | 0.0 | 0.0 | 0.0 | 0.0 |
| 1997 | 2027 | Apr | 0.0 | 0.0 | 0.0 | 0.0 |
| 1997 | 2027 | May | 0.0 | 0.0 | 0.0 | 0.0 |
| 1997 | 2027 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 1997 | 2027 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 1997 | 2027 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1997 | 2027 | Sep | 0.4 | 0.5 | 0.3 | 0.5 |
| 1997 | 2027 | Oct | 0.0 | 0.0 | 0.0 | 0.0 |
| 1997 | 2027 | Nov | 3.1 | 2.1 | 2.7 | 2.5 |
| 1997 | 2027 | Dec | 5.7 | 2.5 | 3.9 | 3.7 |
| 1998 | 2028 | Jan | 3.1 | 4.1 | 3.7 | 3.0 |
| 1998 | 2028 | Feb | 18.0 | 13.7 | 13.8 | 12.1 |
| 1998 | 2028 | Mar | 3.9 | 4.1 | 3.4 | 4.8 |
| 1998 | 2028 | Apr | 1.9 | 1.0 | 1.0 | 1.5 |
| 1998 | 2028 | May | 4.1 | 3.1 | 2.5 | 1.7 |
| 1998 | 2028 | Jun | 0.1 | 0.1 | 0.1 | 0.0 |
| 1998 | 2028 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 1998 | 2028 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |

| Table B-1 Historic Rainfall Data for Los Angeles Demand Zones [in/month] | | | | | | |
|---|---|---|---|---|---|---|
| | | | Demand Zone | | | |
| Historic Year | Simulation Year | Month | San Fernando Valley | Central City | Westside | San Pedro |
| 1998 | 2028 | Sep | 0.1 | 0.0 | 0.0 | 0.0 |
| 1998 | 2028 | Oct | 0.0 | 0.0 | 0.0 | 0.0 |
| 1998 | 2028 | Nov | 1.4 | 1.3 | 1.9 | 1.4 |
| 1998 | 2028 | Dec | 0.4 | 0.5 | 0.7 | 0.6 |
| 1999 | 2029 | Jan | 1.4 | 1.9 | 1.2 | 1.5 |
| 1999 | 2029 | Feb | 0.4 | 0.6 | 0.5 | 0.4 |
| 1999 | 2029 | Mar | 2.0 | 1.2 | 2.1 | 1.8 |
| 1999 | 2029 | Apr | 2.6 | 2.6 | 2.2 | 2.3 |
| 1999 | 2029 | May | 0.0 | 0.0 | 0.0 | 0.1 |
| 1999 | 2029 | Jun | 0.7 | 0.0 | 0.6 | 0.5 |
| 1999 | 2029 | Jul | 0.0 | 0.0 | 0.0 | 0.1 |
| 1999 | 2029 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 1999 | 2029 | Sep | 0.0 | 0.0 | 0.0 | 0.0 |
| 1999 | 2029 | Oct | 0.0 | 0.0 | 0.0 | 0.0 |
| 1999 | 2029 | Nov | 0.5 | 0.4 | 0.3 | 0.2 |
| 1999 | 2029 | Dec | 0.3 | 0.4 | 0.0 | 0.1 |
| 2000 | 2030 | Jan | 1.2 | 0.9 | 0.9 | 0.5 |
| 2000 | 2030 | Feb | 6.4 | 5.5 | 4.7 | 2.9 |
| 2000 | 2030 | Mar | 2.0 | 2.8 | 2.4 | 1.7 |
| 2000 | 2030 | Apr | 2.7 | 1.5 | 1.9 | 1.2 |
| 2000 | 2030 | May | 0.0 | 0.0 | 0.0 | 0.0 |
| 2000 | 2030 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 2000 | 2030 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 2000 | 2030 | Aug | 0.1 | 0.1 | 0.0 | 0.0 |
| 2000 | 2030 | Sep | 0.1 | 0.2 | 0.0 | 0.0 |
| 2000 | 2030 | Oct | 0.0 | 1.0 | 1.1 | 2.3 |
| 2000 | 2030 | Nov | 0.0 | 0.0 | 0.0 | 0.0 |
| 2000 | 2030 | Dec | 0.0 | 0.0 | 0.0 | 0.0 |
| 2001 | 2031 | Jan | 6.6 | 5.6 | 4.7 | 2.1 |
| 2001 | 2031 | Feb | 9.8 | 8.9 | 7.3 | 5.8 |
| 2001 | 2031 | Mar | 3.4 | 1.2 | 1.3 | 0.3 |
| 2001 | 2031 | Apr | 1.1 | 1.1 | 1.1 | 0.4 |
| 2001 | 2031 | May | 0.0 | 0.0 | 0.0 | 0.0 |
| 2001 | 2031 | Jun | 0.0 | 0.0 | 0.0 | 0.0 |
| 2001 | 2031 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 2001 | 2031 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 2001 | 2031 | Sep | 0.0 | 0.0 | 0.0 | 0.0 |
| 2001 | 2031 | Oct | 0.2 | 0.1 | 0.0 | 0.0 |

| Table B-1 Historic Rainfall Data for Los Angeles Demand Zones [in/month] | | | | | | |
|---|---|---|---|---|---|---|
| | | | Demand Zone | | | |
| Historic Year | Simulation Year | Month | San Fernando Valley | Central City | Westside | San Pedro |
| 2001 | 2031 | Nov | 1.7 | 1.4 | 1.3 | 1.0 |
| 2001 | 2031 | Dec | 2.1 | 1.4 | 1.3 | 0.6 |
| 2002 | 2032 | Jan | 0.7 | 0.8 | 0.7 | 0.3 |
| 2002 | 2032 | Feb | 0.1 | 0.3 | 0.4 | 0.1 |
| 2002 | 2032 | Mar | 0.1 | 0.3 | 0.3 | 0.1 |
| 2002 | 2032 | Apr | 0.0 | 0.1 | 0.0 | 0.1 |
| 2002 | 2032 | May | 0.1 | 0.1 | 0.1 | 0.1 |
| 2002 | 2032 | Jun | 0.0 | 0.0 | 0.1 | 0.0 |
| 2002 | 2032 | Jul | 0.0 | 0.0 | 0.0 | 0.0 |
| 2002 | 2032 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 2002 | 2032 | Sep | 0.1 | 0.0 | 0.1 | 0.0 |
| 2002 | 2032 | Oct | 0.0 | 0.1 | 0.1 | 0.0 |
| 2002 | 2032 | Nov | 2.2 | 2.4 | 1.6 | 0.5 |
| 2002 | 2032 | Dec | 3.2 | 3.3 | 1.8 | 1.5 |
| 2003 | 2033 | Jan | 0.0 | 0.0 | 0.0 | 0.0 |
| 2003 | 2033 | Feb | 7.8 | 4.6 | 3.8 | 3.8 |
| 2003 | 2033 | Mar | 2.7 | 4.3 | 1.7 | 1.7 |
| 2003 | 2033 | Apr | 1.7 | 0.7 | 0.5 | 0.4 |
| 2003 | 2033 | May | 2.0 | 1.0 | 1.0 | 1.7 |
| 2003 | 2033 | Jun | 0.0 | 0.0 | 0.0 | 0.1 |
| 2003 | 2033 | Jul | 0.0 | 0.0 | 0.0 | 0.3 |
| 2003 | 2033 | Aug | 0.0 | 0.0 | 0.0 | 0.0 |
| 2003 | 2033 | Sep | 0.0 | 0.0 | 0.0 | 0.0 |
| 2003 | 2033 | Oct | 0.0 | 0.5 | 0.7 | 0.1 |
| 2003 | 2033 | Nov | 0.3 | 0.8 | 0.8 | 0.3 |
| 2003 | 2033 | Dec | 1.5 | 1.4 | 1.1 | 1.3 |

# Appendix C - Hydrology and Imported Supply Assumptions

The WEAP model is programmed to introduce hydrology-related variability on some of its variables. In addition to computing the system-level rainwater volumes and stormwater routing described in Appendix B, some variables include fluctuations above and below a reference value depending on hydrology. The approach for hydrologic variability (for non-rainfall variables) in the model is described below. Variables described in this appendix include:

- Water Demands
- MWD Imported Water Supply (with and without climate change)
- LAA Water Supply (with and without climate change)

## Period of Record

Data was collected for all the variables that depend on hydrology. MWD delivery information was available from 1922 to 2004, LAA was available from 1978 to 2008, while precipitation data was available for about a century. Out of the three data sets, the limiting one was the LAA. This data set, however, was sufficiently long to be used in the WEAP model, given that the model only needed 25 years. The period of record was then established as the period between 1978 and 2003. Once the record was established, a check was made of the statistics and periods included in the period to make sure that a drought of significance was included in the model. This was confirmed since the data includes a drought period of the late 1980's and early 1990's.

## Demands

Demands, and specifically outdoor demands, are highly correlated to weather. ET dictates irrigation demands and ET is related to weather. Hot and dry years present higher ET and are therefore higher in water demand. Demands were varied by hydrology in two different scales: monthly and annual. For monthly demand factors real data was used and the factors developed are presented below, in Table C-1.

Table C-1. Monthly Demand Factors

| | |
|---|---|
| January | 0.59 |
| February | 0.44 |
| March | 0.47 |
| April | 0.69 |
| May | 1.00 |
| June | 1.32 |
| July | 1.53 |
| August | 1.59 |
| September | 1.47 |
| October | 1.22 |
| November | 0.95 |
| December | 0.72 |

Demands were also varied annually based on data on demand over time, corrected by the demand growth not related to weather. Figure 15 shows how demands vary not only seasonally, but also on a year-to-year basis *in addition to the demand increase due to population growth*. Figure 15 shows how demand increases over time, but on a year-to-year basis there are ups and downs due to hydrology. Those increases and decreases over and above the average forecasted demand are due to the hydrology factors applied to the model, presented in Table C-2.

### Metropolitan Water District of Southern California Supply

As explained in Chapter 5, MWD receives water from two main sources: the SWP (sources in the Sacramento San Joaquin Bay Delta) and the Colorado River. MWD system includes significant surface storage but their supplies are subject to variability due to demand and some shortages do occur during extended periods of drought (or pumping restrictions in the Bay Delta). MWD has modeled their system and projected shortages based on the different hydrology type years. The WEAP model used their predictions for hydrology types 1980 to 2003 (the period of record in the WEAP model).

MWD projections are projections of percent shortages. So a baseline flow is needed to apply the percent reductions. The baseline in the WEAP model was established after research on likely maximum delivery levels. In their UWMP, the city presents historical data of MWD water purchases. The maximum flow purchased by the city from MWD was approximately 450 MGD. Additionally, the UWMP presents projections of demand and supply, and for 2030, the maximum level of MWD purchases assumed (forecasted) is also 450 MGD. The WEAP model used this annual rate as the basis to apply the percent shortages in Table C-2, which presents the shortages with and without climate change.

### Los Angeles Aqueduct

The Los Angeles aqueduct brings high volumes of water to Los Angeles from the California sierras as explained in Chapter 5. Actual data on LAA water is available and was used in the WEAP model. These data are presented in Table C-2.

The hydrology that impacts the source of the LAA is similar to the hydrology of the SWP. Table C-2 presents "Table A" delivery reductions with and without climate change. "Table A contractors" are users of Bay Delta water in the California central valley and in southern California. "Table A" is the name of the delivery schedule established for the users of the SWP (contractors). Given that the hydrology of the SWP and the LAA water is similar, Table A deliveries (DWR, 2007) were used to calculate the reductions that could be observed during climate change. The values for LAA flows, and the percent of maximum estimated are presented in Table C-2.

Table C-2. Hydrology Dependent Variable Time Series used in WEAP model

| Year | State Water Project Table A Deliveries (% of contract) | | Metropolitan Water District of Southern California Supply Cutbacks (%) | | Los Angeles Aqueduct Annual Deliveries | Los Angeles Aqueduct Percent Available Of Non Climate Change Basis | Demand Annual Factors |
|---|---|---|---|---|---|---|---|
| | Without Climate Change | With Climate Change (PCM-A2) | Without Climate Change | With Climate Change (PCM-A2) | Without Climate Change | With Climate Change (PCM-A2) | With and Without Climate Change |
| 1978 | 94 | 94 | 0 | 0 | 472,161 | 100% | 1.017 |
| 1979 | 74 | 67 | 0 | 0 | 492,669 | 91% | 1.035 |
| 1980 | 94 | 94 | 0 | 0 | 514,546 | 100% | 1.010 |
| 1981 | 62 | 52 | 0 | 0 | 465,083 | 84% | 1.020 |
| 1982 | 100 | 100 | 0 | 0 | 482,970 | 100% | 0.871 |
| 1983 | 94 | 94 | 0 | 0 | 518,511 | 100% | 0.965 |
| 1984 | 100 | 100 | 0 | 0 | 516,337 | 100% | 1.046 |
| 1985 | 73 | 59 | 0 | 0 | 496,312 | 81% | 1.010 |
| 1986 | 69 | 79 | 0 | 0 | 515,095 | 100% | 1.029 |
| 1987 | 55 | 41 | 0 | 10 | 428,085 | 75% | 0.965 |
| 1988 | 10 | 15 | 25 | 25 | 360,230 | 100% | 1.025 |
| 1989 | 77 | 77 | 0 | 0 | 274,457 | 100% | 1.035 |
| 1990 | 5 | 4 | 30 | 30 | 106,746 | 80% | 1.043 |
| 1991 | 18 | 15 | 20 | 25 | 180,853 | 83% | 1.019 |
| 1992 | 27 | 25 | 20 | 20 | 176,919 | 93% | 1.040 |
| 1993 | 85 | 86 | 0 | 0 | 288,538 | 100% | 1.004 |
| 1994 | 55 | 33 | 0 | 20 | 132,530 | 60% | 1.014 |
| 1995 | 94 | 94 | 0 | 0 | 443,538 | 100% | 1.026 |
| 1996 | 87 | 89 | 0 | 0 | 421,800 | 100% | 1.065 |
| 1997 | 78 | 80 | 0 | 0 | 435,624 | 100% | 1.073 |
| 1998 | 95 | 95 | 0 | 0 | 466,836 | 100% | 0.995 |
| 1999 | 100 | 99 | 0 | 0 | 309,037 | 99% | 1.037 |
| 2000 | 80 | 78 | 0 | 0 | 255,183 | 98% | 1.068 |
| 2001 | 24 | 15 | 20 | 25 | 266,923 | 63% | 1.036 |
| 2002 | 50 | 45 | 0 | 10 | 179,338 | 90% | 1.058 |
| 2003 | 69 | 69 | 0 | 0 | 251,942 | 100% | 1.088 |

# Appendix D - Total Water Management Literature Review

## D.1 Literature Review Methodology

A literature review was conducted in order to better understand the potential for TWM. The review included planning approaches consistent with TWM, as well as innovative water resources strategies that have been implemented in the U.S. and internationally.

To make this review more useful, results from the literature search were summarized into four regions of the U.S.—West, South, Northeast, and Midwest (see Figure D-1). For each of these regions, climate and water resources drivers were identified in order to characterize the regions and better align the water resources strategies that are summarized here.

## D.2 Water Resources Drivers

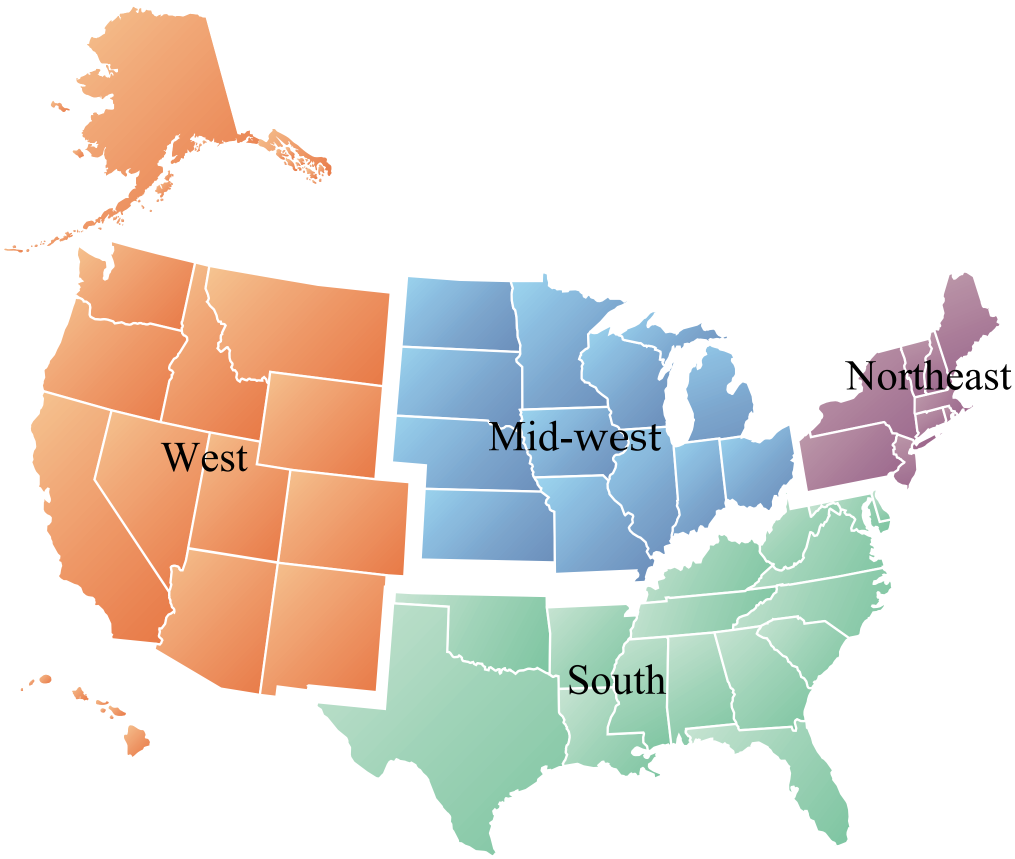


**Figure D-1 Regions of the United States**

Throughout the U.S., water resources issues are influenced by multiple regional drivers such as climate, population trends, water quality, water supply and environmental issues.

### D.2.1 West Region Drivers

#### Climate

Climate in the West is the most diverse of all the regions in the U.S. It ranges from arid to semi-arid in the southwestern portion, marine and Mediterranean along the coast, and highland in the mountain and northern portions (Weathereye, 2009). Winters are typically cool to mild with average temperatures ranging from 30-40°F in the mountain and Pacific Northwest areas, and 50-60°F in the southwest and along the coast (HowStuffWorks, 2009). Summers are dry with low humidity, with average temperatures ranging from 50-70°F in the mountain and Pacific Northwest areas, and 85-95°F in the southwest. The majority of precipitation falls along the coast or with increasing elevation. Precipitation tends to occur with greater extent during the winter months in the form of rain in coastal areas and snow in the mountain and northern areas. Average annual rainfall ranges from 8-15 inches in the southwest, 16-64 inches along the coast, and as high as 96 inches in the Cascade Mountains. Snowfall can range from 32-64 inches in the mountains.

### Population

Between 2000 and 2005, population growth in the West outpaced all other regions, with a growth rate of approximately 8.1% (US Census Bureau, 2005). Growth rates were the highest in the desert states of Arizona (15.8%) and Nevada (20.8%), while lowest in the Rocky Mountain States of Montana (3.7%) and Wyoming (3.1%).

### Water Quality Drivers

Within the West, water quality is driven by achieving compliance with TMDLs, compliance with discharge requirements, nonpoint source (NPS) pollution, total dissolved solids (TDS) management, and to a lesser extent CSO concentrated in the northwest portion of the region. TMDLs have and continue to be adopted in sub-regions of the West for both inland waters and oceans impacting both dry and wet weather discharges. Bacteria and metals are the main TMDLs in the region. NPS pollution impacts both groundwater and surface waters in the West and requires watershed-based management plans. Compliance with discharge requirements has required innovative solutions to reduce discharge volumes and refinement in treatment processes. High TDS or salinity levels are prevalent in western areas relying on water from the Colorado River and localized groundwater basins. High TDS levels adversely impact groundwater and agriculture, as well as potentially limit the application of recycled water for urban irrigation.

### Water Supply Drivers

Multiple factors drive availability of water supplies in the West including droughts, water rights issues, population growth, environmental protection, and potential climate change. Outside of the pacific northwest, the West has few large lakes or high-flowing rivers. Snowpack in the region's mountains accounts for the majority of water replenishment for the region's rivers, man-made reservoirs, and groundwater basins. This fact makes the West highly susceptible droughts and potential climate change. Further, most large river systems, such as the Colorado River, are fully allocated; and competition between agricultural, urban and environmental demands for water is the greatest in the West. Agriculture uses the vast majority of water in the West, upwards of 80%. Water right battles over Native American rights and allocations of the Colorado River have been at the forefront of conflicts in this region.

High population growth concentrated in the desert regions, with low annual precipitation rates, further exacerbate water supply shortfalls. And finally, demands for the environment (e.g., minimum flows for fish) are increasingly impacting water supply availability for urban and agricultural water use. In recent years, water deliveries from the Klamath River in Oregon and the SWP in the Bay-Delta region of California have been significantly curtailed to reduce environmental impacts to aquatic organisms (Oregon State University and University of California, 2001).

## D.2.2 Midwest Region Drivers

### Climate

Climate in the Midwest is characterized as humid continental in the eastern portion and semi-arid on the western edge of the region (Weathereye, 2009 and HowStuffWorks, 2009). Winters are cold, with temperatures averaging 0-30°F and snowfall ranging from 10-60 inches. Summers are warm, humid and wet, with average temperatures of 70-85°F. Rainfall is generally heaviest in spring and summer months, averaging between 16-35 inches .

## Population

Population growth in the Midwest is low. Between 2000 and 2005 a growth of 2.4%, far lower than the national growth rate of 5.3% (US Census Bureau, 2005). Within the region, growth was highest in Missouri (3.6%) and Minnesota (4.3%), while negative growth was experienced in North Dakota (-0.9%)

## Water Quality Drivers

Major water quality drivers in the Midwest include CSO, sanitary sewer overflows (SSO), and NPS pollution. Combined sewer systems (CSS) are prevalent throughout the Midwest and Northeast regions. Approximately 772 cities serving 40 million people in the U.S. are served by CSS (EPA, 2009a). At least 40,000 SSOs are estimated to occur throughout the U.S. (EPA, 2009b). SSOs are caused by excessive runoff entering the systems, excessive sewage flows, and/or mechanical failures in the system. NPS pollution attributed to urban and agricultural runoff is increasingly becoming major water quality drivers in the region with impacts downstream and outside of the region in the Gulf of Mexico. Contamination and water quality issues in the Great Lakes have been at the forefront of conflicts in this region.

## Water Supply Drivers

Water supply availability in the Midwest is generally a function of system delivery capacity, periodic droughts and contamination of fresh water sources. Major mid-western urban centers are, for the most part, concentrated near rivers or lakes which are relatively drought resistant. These water bodies include the Great Lakes, Mississippi River, and Ohio River. Droughts periodically occur throughout the Midwest and particularly impact agricultural areas and suburban areas located away from major water bodies. However, settlement agreements between other states and Canada have caused water shortages to occur in major urban areas, such as Chicago, Illinois.

Aging or lack of infrastructure to move water efficiently has caused the most water supply shortfalls in the regions, mainly impacting suburban areas or cities that are not in close proximity to large water bodies.

# D.2.3 Northeast Region Drivers

## Climate

Similar to the Midwest, the Northeast climate is humid continental (Weathereye, 2009 and HowStuffWorks, 2009). Winters are cold with temperatures averaging 0-25°F, and snowfall ranging from 32-100 inches. Summers are warm and humid, with temperatures averaging 65-80°F. Noreasters in the winter provide steady, rain along the coast while spring and summer thunder storms account for the remaining rainfall. Annual rainfall ranges from 32-64 inches.

## Population

Population growth is the lowest in the Northeast region. The northeast region experienced the lowest growth rate of all regions between 2000 and 2005 with a rate of approximately 2% (US Census Bureau, 2005), 3.3% below the national average. Growth rates were highest in the northern states of Maine (3.7%) and New Hampshire (6.0%) and lowest in Pennsylvania (1.2%) and Massachusetts (0.8%).

## Water Quality Drivers

Major water quality drivers in the Northeast include CSOs, TMDL requirements, pharmaceuticals and personal care products (PPCPs) in water supplies, beach closures after major storm events related to high fecal coliform counts, and presence of the parasite *cryptosporidium* in drinking water supplies. Similar to the Midwest, CSOs are prevalent throughout the Northeast with the majority of cities following Long Term Control Plans and many cities under consent decrees to reduce overflows. Control plan costs in major cities are in excess of a billion dollars. TMDL compliance is leading to the development of new approaches throughout the East, with sediment the most common TMDL. Flow based approaches, in areas where erosion is a major problem, are being developed. Contaminants from PPCPs are a concern for drinking water supplier in groundwater and surface water based systems. WWTPs are concerned about implications related to removal of the contaminants. After storm events beach closures along the coast and inland rivers related to high fecal coliform counts are major concerns. Presence of *cryptosporidium* in drinking water supplies is one of the most common causes of waterborne illnesses in the (U. S. Department of Health and Human Services, 2009).

### Water Supply Drivers

Water supply drivers in the Northeast are revolve around droughts and water allocation issues. Water supply issues during normal climatic conditions are relatively minor, but recent droughts have driven drought related water supply issues to the forefront. New Jersey suppliers and many smaller suppliers throughout the region have asked consumers to conserve water during recent droughts with multiple areas declaring drought emergencies. Allocation of water supplies impacts available water supplies for states and major metropolitan areas. Past battles over water supplies in the Delaware River Basin led to the formation of the Delaware River Basin Commission in the 1961. Members of the Delaware River Basin Commission, New York, New Jersey, Pennsylvania, and Delaware, work together to address water management issues in the basin.

## D.2.4 South Region Drivers

### Climate

Climate in the South is characterized as humid and sub-tropical(Weathereye, 2009). Winters are mild in the south, with little to no snowfall and average temperatures ranging 50-70°F (HowStuffWorks, 2009). Summers are hot and humid, with temperatures ranging 80-90°F. Annual rainfall averages between 32-64 inches with significant rainfall occurring both in the summer and winter.

### Population

The South region experienced a high growth rate of approximately 7.3 %, exceeding the national average by 2 % between 2000 and 2005 (US Census Bureau, 2005). Growth was highest in Georgia (10.8%) and Florida (11.3%) and lowest in West Virginia (0.5%) and the District of Columbia (-3.8%).

### Water Quality Drivers

Water quality is driven in the South by TMDLs, environmental resource permits, and tourism. Major TMDL impairments in the South include nutrients, bacteria indicators, and dissolved oxygen. Environmental resource permits are drivers of water quality in Florida. In Florida, environmental resource permits are required for projects involving construction or a significant alteration to storm water or surface water management systems. Water related tourism in the South is a major industry and providing clean surface and ocean water is essential to maintaining that industry. CSOs are not prevalent in the South. In a few sub-regional areas, including Atlanta and Columbus in Georgia, Alabama, and Nashville, Tennessee CSOs are water quality drivers.

### Water Supply Drivers

A multitude of factors drive water supply related issues in the South including droughts, an increasing population, saltwater intrusion in aquifers in coastal areas, maintaining minimum flows and levels to ecological goals, and state water negotiations, especially between Georgia, Alabama, and Florida. Droughts have been prevalent in the south and are reinforced by the recent multi-year severe drought in Georgia. Population growth continues to place demands on limited water resources in the South. Aquifer draw down in coastal areas is leading towards increasing levels of saltwater intrusion into sources of drinking water. In areas such as Florida the majority of potable water supplies are extracted from groundwater sources. Maintaining minimum flows and levels in surface waters at levels determined to meet ecological goals for hydrology and water quality further reduces available potable water supply sources in the South.

Water supplies in the tri-state area of Georgia, Alabama, and Florida continue to be contested in federal courts in a multi-decade battle over water supplies originating from Lake Lanier. Atlanta relies on Lake Lanier to supply its 3 million residents. Florida wants to maintain flows from the lake into Apalachicola Bay to maintain flows for its oyster industry and federally protected fish and mussels. Alabama wants a portion of the Lake Lanier supplies to operate its nuclear power plant near Dothan (Shelton, 2009).

## D.3 Water Resources Strategies

Each region of the U.S. has taken different approaches to solving water resources problems based on the characteristics and drivers described above. Further, cost-effective solutions in one region may not be cost-effective in another region due to these differences. Within this section TWM strategies are presented for each region of the U.S. However, it should be noted that this does not represent the exhaustive list of what is occurring; but rather, this is a representative sample of the types of TWM strategies that are being implemented across the country. The most commonly implemented components of TWM include water conservation programs, recycled water, stormwater management, rainwater harvesting, graywater systems and integrated water management plans.

Regulatory constraints are also described to illustrate the myriad of regulations and variations that must be taken into account when evaluating TWM. Finally, international TWM strategies are summarized to illustrate what types of solutions are being implemented globally.

Before TWM strategies are implemented, they should be evaluated from an integrated perspective. For example, implementing a graywater system not only provides a new water supply for summer irrigation, but will also reduce flows to wastewater system facilities. On the other hand, a substantial effort of rainfall harvesting to increase water supply by recharging groundwater may have localized undesirable impacts to groundwater table due to mounding, if the soils are not characteristically prone to infiltration. Therefore, it is important to take a "systems" approach that examines all impacts: water supply, wastewater, stormwater, and the environment when evaluating TWM. Chapter 3 of this report presented an approach for how TWM should be evaluated in order to make sure that all costs and benefits are incorporated into the decision making.

Knowledge sharing among leading experts and development of solutions applicable to water resources management issues occurs throughout the world at conferences and workshops. Many sources cited in this literature review are from abstracts presented at these conferences. In 2006, leading environmental specialists, scientists, and engineers from eight countries, including members of the National Academy of Engineering and endowed chair professors, gathered to participate in the Wingspread International Workshop *Cities of the Future – Bringing Blue Waters to Green Cities*. Much of what was presented at this first-of-the-kind workshop is directly applicable to TWM. Proceedings of the workshop were published in Cities of the Future, Towards Integrated Sustainable Water and Landscape Management (Novotny and Brown, 2007).

### D.3.1 West Region Strategies

In the West many agencies have prepared integrated water resource plans and have initiated efforts to identify non-traditional water supplies and conservation efforts. Water supply reliability is at the forefront of planning efforts in the West to address periodic prolonged drought periods and growing populations in an arid region. Efforts in the West are focused on developing non-traditional water supplies to supplement traditional supplies and complying with TMDLs in a cost-effective manner. In the West, wet-weather runoff reducation focuses on capturing runoff to conserve water and recharge groundwater. While most areas have not formally adopted TWM, they have made significant strides in utilizing integrated water resources planning to examine the whole water cycle as a part of long-range water supply planning.

#### Integrated Resources Planning

IRP is a technique that explores both supply-side and demand-side strategies to meet multiple objectives. IRP estimates the total lifecycle costs (capital and O&M costs over the entire planning horizon) and fully examines risk and uncertainty. And unlike traditional planning, IRP involves stakeholders in the decision-making process. The American Water Works Association (AWWA) has formally incorporated IRP in its updated M50 manual on water resources planning (AWWA, 2007).

Although IRP has mainly been applied solely to water supply planning, the technique can also be applied across all water resources (drinking water, wastewater, and stormwater). When IRP is applied in this manner, it comes very close to TWM. However, there are only limited case examples where IRP has been applied in this manner.

In 1999, Los Angeles embarked on the development of an IRP utilizing a unique approach of technical integration and community involvement to guide water resources and facility planning at the watershed level for 20 years. The City was faced with many challenges, including droughts, wastewater capacity issues, compliance with TMDLs, aging infrastructure, quality of life issues, environmental regulations, and community concerns with facility siting and expansions. The IRP took a bold new approach and represented the first time that various city departments worked together to solve comprehensive water resources issues. From our literature search, this IRP represents the closest application of TWM that exists today. For this reason, it was selected as the TWM Case Study for this study (see Chapter 4 of the main report).

Another similar concept to TWM is integrated watershed planning. In California, all watershed regions must develop comprehensive Integrated Regional Water Management Plans (IRWMPs) to be eligible for state funding of water resources projects. IRWMPs must address water supply, water quality, stormwater, flood management, environmental restoration and recreation. This process also involves multi-agency governance and regional cooperation not seen in any other part of the country. In many ways these IRWMPs represent a watershed version of TWM.

Other integrated resources plans that have been implemented in the West include:

- Butte County, CA
- Eastern Municipal Water District, CA
- Metropolitan Water District of Southern California, CA
- Rancho California Water District, CA
- San Diego, CA
- Santa Clara Valley Water District, CA
- Santa Ana Watershed Protection Authority, CA
- Colorado Springs, CO
- Denver, CO
- Santa Fe, NM
- Portland, OR

## Indirect Potable Water Reuse Projects

Planned indirect potable water reuse is the reuse of highly treated wastewater in an indirect manner, such as allowing percolation into an aquifer used for groundwater production. Planned indirect potable reuse of reclaimed water occurs in multiple locations throughout the West and country. A few of the major facilities in the West are highlighted here. The proposed State of California treatment and testing criteria for groundwater recharge were published in a World Health Organization Water (2003) report on the potential risk of using wastewater for groundwater recharge.

***Orange County Water District and Orange County Sanitation District***
***Fountain Valley, CA***
Groundwater Replenishment System:

- Seawater intrusion barrier, indirect potable water reuse treated with advanced treatment consisting of microfiltration, reverse osmosis, ultraviolet light, and hydrogen peroxide
- Production: 72,000 Acre Feet per Year (Phase 1)
- Spreading of treated wastewater for percolation into deep groundwater aquifers
- Replaced Waterworks Factory 21 completed in 1976 for recycled water barrier injection (Orange County Water District, 2009)

***Water Replenishment District of Southern California, Montebello, CA***
Montebello Forebay Natural Groundwater Recharge Project:

- Spreading of treated wastewater to augment existing groundwater supplies for use as drinking water (35% of total recharge to groundwater basin is treated wastewater)
- In operation since 1962

***West Basin Municipal Water District, Carson, CA***
Membrane Treatment Facility:

- Injection (pumping water into aquifer instead of withdrawing water) of treated wastewater into aquifers for groundwater barrier also produces “designer” recycled water treated for specific industrial and irrigation uses.
- Production: 33,600 AFY
- Online 1995

***Water Replenishment District of Southern California, Long Beach, CA***
Alamitos Barrier Reclaimed Water Project:

- Injection of a blend of treated wastewater and potable water to form a groundwater barrier
- Production: 30 AFY
- Phase 1 completed 2005

***Aurora Water, Aurora, CO***
Prairie Waters Project:

- Wells alongside the banks of the Lower South Platte River, below Denver Metro Reclamation Facility (WWTP); takes advantage of river bank filtration and incorporates aquifer storage/recovery before pumping to a water filtration plant and blending with reservoir water

- Production: 10,000 AFY (2010) (Aurora Water, 2009)

***Scottsdale Water Resources Department, Scottsdale, AZ***
City of Scottsdale Water Campus:

- Injection of treated wastewater into aquifer for withdrawal as drinking water supplies, also used for golf course irrigation

- Production: 24,640 AFY (13,440 AFY golf course, 11,200 AFY advanced treatment for groundwater replenishment) to be expanded to 26,880 AFY for irrigation, 24,640 AFY for advanced treatment

- In operation since 1998

***Cloudcroft , NM***
Cloudcroft Indirect Potable Water Reuse:

- Blending with other well and spring water, as part of drinking water supplies

- Production: 112 AFY

## Designer Recycled Water

The West Basin Municipal Water District a provider of potable and recycled water located in Carson, California produces designer recycled water. Recycled water is produced at their West Basin Water Recycling Facility to varying water quality levels to meet specific end user requirements. The recycling facility receives secondary effluent from Los Angeles' HTP and provides additional levels of treatment based on the ultimate use of the recycled water. Production to a prescribed water quality level allows recycled water to be produced at the greatest cost-effective level necessary. Five types of recycled water are produced by the recycling facility:

- Disinfected Tertiary Water – Secondary treated water from HTP treated to Title 22 standards used for industrial and irrigation purposes

- Nitrified Water – Tertiary treated water with ammonia removed by nitrification used in industrial cooling towers

- Softened Reverse Osmosis Water – Secondary treated water from HTP pretreated with microfiltration and lime softeners and then reverse osmosis, for use in the seawater barrier

- Pure Reverse Osmosis Water – Secondary treated water from HTP pretreated with microfiltration and additional treatment with reverse osmosis for use in low pressure boiler feeds, for use industrial sites and refineries

- Ultra Pure Reverse Osmosis Water – Secondary treated water from HTP pretreated with microfiltration and then treated twice with reverse osmosis to ensure minerals are removed, for use in high pressure boilers

Recycled water from WBMWD is used for groundwater replenishment, landscape irrigation, and industrial processes.

## Decentralized Recycled Water Systems

Decentralized recycled water systems or "satellite treatment facilities or scalping plants" have become popular as many areas experience severe water supply shortages. Satellite treatment facilities are wastewater reclamation facilities constructed at or near the point of use, and sized for a reclaimed water demand as opposed to a wastewater treatment need. These facilities are often constructed in close proximity to urban areas.

At a minimum satellite treatment facilities must address the following questions:

- Is there enough wastewater flow in the area to meet the reclaimed water demand?
- Is there land available for construction of a satellite plant?
- Will the public accept a water reclamation facility in their neighborhood?
- Expected cost of the facility vs. other reclaimed water options?

The benefits of using satellite treatment facilities in urban areas include:

- Compact footprint
- Minimal operator attention
- Easily enclosed and architecturally treated to meet surrounded architecture
- Sustainable water resource management (Rimer, et al, 2003).

In Washington State, the LOTT alliance, the regional wastewater treatment system servicing the cities of Lacey, Olympia, Tumwater, and northern Thurston County, has developed a long range wastewater management plan focused on constructing three satellite treatment facilities. Two of the facilities are constructed with reclaimed water used for recharge, irrigation, dust suppression, boat washing, constructed wetlands, and other uses. The facilities were designed to treat 1 MGD with incremental expansion to 5 MGD in a just-in-time construction process to meet future capacities when needed (LOTT, 2009 and McCauley and Dennis-Perez, 2008).

## Urban Runoff Reuse

Santa Monica's Urban Runoff Recycling Facility (SMURRF) captures dry weather runoff for treatment and reuse and treats up to 0.5 MGD from the City's two main storm drains. Treated water is used for landscape irrigation and toilet flushing at public facilities to offset potable water demands. The facility will potentially offset 4% of the City's daily water use. Additionally, the facility was designed for the public to walk through to access the beach to serve as an educational source. The facility and recycled water distribution system cost approximately $12 million (City of Santa Monica, 2009).

## Rainwater Harvesting

Rain barrels and cisterns are low cost options for collecting rainwater from impervious surfaces reducing peak stormwater flows and conserving water. Cities throughout the West (where it is legal to harvest rainwater) have encouraged rainwater harvesting to reduce runoff and conserve water. Some states, such as Hawaii have been practicing rainwater harvesting for years due to limited water resources.

In cities such as Seattle and Portland where downspouts are typically directly connected to CSS, rain barrels and cisterns have the added benefit of reducing combined sewer overflows during storm events. Rain barrels are typically installed aboveground at buildings to collect water from impervious roof surfaces for future outdoor water use. Cisterns can collect water from multiple types of impervious surfaces including roofs, play grounds, and artificial turf sports fields. Stored water serves as a source of chemically untreated soft water for outdoor irrigation needs. Water savings from rain barrels and cisterns are dependent upon the storage volume and the number installed in a jurisdiction.

Many jurisdictions are encouraging the installation of rain barrels and cisterns through customer education and handouts on installation techniques. Multiple cities, such as Seattle offer programs where residents can purchase rain barrels at a subsidized cost savings of $15 compared to other vendors. Water savings from rain barrels and cisterns are dependent upon the storage volume and the number installed in a jurisdiction. In Portland, rainwater can also be used for toilet flushing with a permit. Table D-1 provides estimated material and installation costs for rain barrels and pre-fabricated cisterns.

**Table D-1**

**Estimated Rain Barrel and Cistern Costs**

| Type | Size (gallons) | Materials | Installation | Total |
|---|---|---|---|---|
| Single Rain Barrel | 60 | $120 | $96 | $216 |
| Polyethylene Cistern | 165 | $160 | $400 | $560 |
| Polyethylene Cistern | 1,800 | $1,100 | $1,000 | $2,100 |
| Fiberglass Cistern | 5,000 | $5,000 | $1,500 | $6,500 |
| Fiberglass Cistern | 10,000 | $10,000 | $2000 | $12,000 |
| Source: CH:CDM, *City of Los Angeles Integrated Resources Plan, Facilities Plan, Volume 3: Runoff Management, 2004* | | | | |

## Green Roofs

Portland, Oregon has taken measures to incentivize the installation of green roofs or eco-roofs which are roofs that can help manage stormwater along with providing other environmental benefits. These programs include:

- Bonus floor to area ratios for new buildings in the central core based on eco-roof coverage in relationship to the buildings footprint – 10-30%, 30-60%, and 60% or greater results in bonus of one, two, and three additional square feet per square foot of green roof, respectively.
- Use of eco-roofs in Central to satisfy Design Guidelines requirement of integrating roofs and use of rooftops
- Requirement that all new projects have an eco-roof and/or Energy Star rated roof material
- Potential funding through City of Portland Green Investment Fund
- Requirement of eco-roofs is developer agreements in specified areas (City of Portland, 2009).

## Lawn Buy-Back Rebate Programs

Throughout the West, lawn buy-back programs or rebates are increasingly gaining popularity in various forms. Typical programs involve the removal of turf and replacement with a xeriscape or native plants in a manner that remains aesthetically appealing. Hybrid programs involve the replacement of turf with artificial turf.

### *Southern Nevada Water Authority*

Southern Nevada Water Authority has been offering rebates since 1999 and has conducted an extensive study funded by the Bureau of Reclamation on the conversion of turf to xeric landscaping or water efficient landscaping. Completed in 2005 the study indicates turf replacement is an effective means of reducing water consumption within its member agency jurisdictions. Since inception of the program in 1999 to the end of 2007 over 100 million sq ft of turf area has been converted to water efficient landscaping. This program coupled with other conservation programs has reduced water demands by 14% between 2002 and 2006 while the population increased by 400,000.

The Authority's study indicates conversion of one square foot of turf to a xeriscape saves on average 55.8 gallons of water per year or an equivalent to 89.6 inches of rain as illustrated in Table D-2. Total residential water consumption decreased by approximately 30% for turf conversion participants. Turf requires approximately 73 gallons of water per square foot annually or an equivalent of 117.2 inches of rain while a typical xeriscape requires 17.2 gallons of water or 27.6 inches of rain for an equivalent area in the study area. Water use tends to drop immediately upon conversion with no decay in savings overtime.

Examples of rebate programs offered by other agencies are shown in Table D-3.

**Table D-2**

**Lawn Buy-Back Water Savings and Costs[1]**

| | Average Savings per Square Foot per Year | | Average Installation Cost per square foot ($) | | |
|---|---|---|---|---|---|
| | Gallons | Rainfall Equivalent (Inches) | Self | Contractor | Average |
| Water Efficient Landscape Converted from Turf | 55.8 | 89.6 | 1.37 | 1.93 | 1.55 |

1. "Xeriscape Conversion Study Final Report" by K. A. Sovocool, Southern Nevada Water Authority, 2005.

## Smart Irrigation

Smart irrigation or ET controllers control the application of water from outdoor irrigation systems based on local weather conditions. These controllers reduce water use by adjusting watering times on a daily basis to reflect actual weather data, including ET, soil moisture, precipitation, and other factors. Water savings rate vary by user types and geographic locations. Smart irrigation controllers also have the added benefit of reducing dry weather runoff associated with overwatering. Municipal Water District of Orange County (MWDOC) and Irvine Ranch Water District (IRWD) in California completed pilot study regarding controller efficiency (MWDOC and IRWD, 2004). Results are summarized here.

Water savings attributed to smart irrigation systems vary based on the land use (residential or large landscape users), local landscaping, and geographic location. These studies have indicated that water savings experienced in the first year is maintained in subsequent years and a decay in the water savings is not experienced in the years after installation of the controllers.

Table D-4 presents savings associated with installation of smart irrigation controllers for single-family residential and large landscape users based on joint IRWD, MWDOC and US Bureau of Reclamation studies. Savings are provided in terms of gallons per day (gpd), gallons per year (gpy), and percent of total water saved. For large landscape users percent saved is a more applicable measure of savings as large landscaped areas can vary dramatically in size.

## Table D-3
## Example Lawn Buy-Back Rebates for Other Agencies

| Agency | Rebate | Summary |
|---|---|---|
| *Santa Clara Valley Water District, CA* | | |
| Residential | Santa Clara County: Up to $1,000; Morgan Hill and Palo Alto $150 per 100 sq. ft. with residential maximum of $2,000[1] | Replacement of high water use plants with plants on agency approved list or permeable hardscape; No artificial turf, Must remain for 5 years, No net increase in irrigated area, No pop-up sprinkler irrigation; Requires pre-inspection |
| Non-Residential | Santa Clara County: Up to $10,000; Morgan Hill and Palo Alto up to $20,000[1] | |
| *North Marin Water District, CA* | | |
| Residential | $50 per 100 sq. ft with maximum of $400 for single-family, $100 for townhouses, condos, and apartments; Additional rebate up to $100 for mulch for 25% of mulch cost | Replace with California native low water use plants; Mulch to at least 4 inches; Requires lawn irrigation to be replaced |
| *Metropolitan Water District of Southern California* | | |
| Non-Residential | $0.30 per sq ft/$13,000 per acre | Synthetic turf must replace irrigated areas; Available for new or retrofit landscapes; No minimum or maximum areas; Member agency must be a participant in rebate program |
| *Aurora, CO* | | |
| Residential | $1 per sq. ft converted | Minimum area of 500 sq. ft, maximum of 10,000 sq. ft.; 50% of new xeriscape must be covered with plants; Must submit design drawings to scale (City offers design classes); Any unhealthy or dead plants in 2009 must be replaced; Specific plants sizes are required; Seeding does not qualify for rebate; 2-3" of mulch required; Requires pre-approval and post-inspection |
| Non-Residential (includes multi-family and HOAs) | $1 per sq. ft converted | Minimum area of 500 sq. ft, maximum of 10,000 sq. ft.; Same requirements as above |
| *Glendale, AZ* | | |
| Residential Existing | Up to $750, varies by tiers of turf removal | Minimum of 500 sq. ft. of turf removed; Removal area must be landscaped; 75% of plants must be on State's low water list; |
| Residential New | $200 | More than 50% of total landscape must be non-grass not including driveways, pools, patios, and walkways; Landscape area must exceed 1,000 sq. ft.; Both front and back must be landscaped - no bare soil; More than 75% of plants must be on State recommended low water use list |
| Non-Residential (includes multi-family and HOAs) | $1,500 for completion of Water Budgeting Program and $150 per 1,000 sq. ft. of grass removed | Maximum of $3,000 per application per year; Must participate in Water Budget Program; Minimum of 1,000 sq. ft. of grass removed; No bare soil; Must submit 3 estimates of work |
| *Scottsdale, AZ* | | |
| Residential | Option 1: $0.25 for turf removal only; Option 2: $0.50 for turf removal and low water plant installation; Maximum of $1,500 | No impermeable weed barriers; Exposed soil must be covered, if granite used must be 2 inches thick; Pre and post inspections required; Option 2 requires 50% plant coverage of converted area with plants listed on State low water plant list; |
| Non-Residential (includes multi-family and HOAs) | 25% of total costs, excluding taxes; Maximum of $3,000 | Minimum of 1,000 sq. ft. of lawn area to be converted to low water use landscaping; Approved landscape plan required from Planning and Development Services; Pre and post inspections required; Contractor bid and itemized receipts to be submitted |
| | | |

**Table D-4**

**Smart Irrigation Controller Water Savings and Costs**

| | Average Savings per User[1,2] | | Percent of Total Water Saved (%) | Cost per Unit ($)[3] |
|---|---|---|---|---|
| | Day (GPD) | Year (GPY) | | |
| Single-family Residential | 41 | 14,965 | 8 | 315-2,399 |
| Large Landscape Users | 545 - 601 | 198,925 - 219,365 | 16 | N/A |

1. "The Residential Runoff Reduction Study" Municipal Water District of Orange County and Irvine Ranch Water District, July 2004.
2. "Commercial ET-Based Irrigation Controller Water Savings Study" Prepared for Irvine Ranch Water District District and US Bureau of Reclamation by A & N Technical Services, September 2006.
3. Not including installation.

Referenced studies indicate single-family residential water savings associated with installation of a smart irrigation controller are approximately 41 gpd per residence or approximately 14,965 gpy per residence. This results in a savings of approximately 8% of total water use for a typical household in the study area, which is approximately an 18% reduction in estimated landscape water use. The bulk of residential savings occurs in the fall and summer months.

Large landscape user savings varies between 545 to 601 gpd per user or approximately 198,925 to 219,365 gpy. Large landscape users include users with dedicated landscape meters including parks, medians, homeowners associations, multi-family residential landscape areas, and commercial/industrial businesses. As indicated by the studies, these users typically experience a 16% savings in water use with installation of smart irrigation controllers. Water reductions associated with large landscaper users are typically eight times greater than single-family residential users.

Controllers are designed as retrofits to replace existing automatic irrigation controllers or to be designed as new controllers for new landscaping. Costs vary dependent upon the designed use. As illustrated in Table 3-3, typical single-family residential controllers range in price from $315 to $2,399 dependent upon the selected systems and options. Costs for controllers for large landscapes vary dramatically based upon irrigation system requirements and are largely a function of the number of irrigation valves. The greater the number of valves the greater the number of controllers required to operate the system. Installation varies based on the selected installer and is not included in the controller price range. The IRWD studies (IRWD and US Bureau of Reclamation, 2006) indicate professional installation is recommended to correctly set-up the controller for local weather conditions, including precipitation. Controllers receive data from local ET stations via various methodologies, including the internet, satellites, and local stations installed at the point of application as a part of the controller. Monthly subscription fees are required for internet and satellite updates. Most manufacturers provide the service for free for the first year. Stations installed as part of the controller do not require subscription fees.

Many water agencies offer rebates to customers installing smart irrigation controllers. In the IRWD service area rebates for single-family residential customers are currently $60 per activated valve. For large landscape users rebates are $750 per irrigated acres. Rebates are a sum of IRWD and the local wholesaler, MWDOC. Dependent upon installation charges and the selected controller the rebates may potentially offset the entire cost of the controller and installation (MWDOC and IRWD, 2004 and IRWD and US Bureau of Reclamation, 2006).

## Residential Indoor Dual Plumbing Systems

Indoor dual plumbing is an additional set of plumbing waterlines to deliver reclaimed water for non-consumptive uses, such as toilet and urinal flushing and cooling towers in high rise buildings. In the United States dual plumbing for toilet and urinal flushing includes commercial buildings, public facilities, universities, jails, and more recently residential high rises.

### *Irvine Ranch Water District, California*

IRWD received the first unrestricted recycled water use permit in California in 1991 allowing for the installation of dual plumbing systems in its service area. IRWD determined that 70-90% of water use in commercial buildings was used for toilet and urinal flushing. A study was conducted indicating that the use of reclaimed water was feasible in buildings over six stories for flushing toilets and urinals and priming floor drain traps. IRWD initially subsidized the incremental cost of dual plumbing systems for two high rises. Dual plumbing raised the overall plumbing costs for the building by approximately 9%. After three years, water charges for one of the buildings were approximately $6,200. Without dual plumbing costs were projected at approximately $22,800 resulting in a savings of over $22,000. Since that time 15 buildings are using recycled water for toilet flushing. IRWD requires all non-residential buildings over 80,000 sq ft to be dual plumbed (Crook, 1998).

### Indoor Water Conservation

Many large water utilities in the West have incentive programs or provide rebates for replacing high water using fixtures with high efficiency models, such as toilets, urinals, clothes washing machines and dishwashers. Examples of large regional rebate programs for indoor water conservation include:

- Metropolitan Water District of Southern California
- San Diego County Water Authority
- Denver Metropolitan Area
- Seattle Metropolitan Area
- Phoenix Metropolitan Area

In Los Angeles, for example, over 1 million ultra low flush toilets were provided since 1991 as a result of these types of rebate programs.

## D.3.2 Midwest Region Strategies

In the Midwest, agencies are addressing portions of TWM that tend to impact the region. Efforts in the Midwest are focused on addressing water quality issues of CSOs, SSOs, NPS pollution and to a lesser extent water supply issues such as conservation, peak demand reductions, and water reuse. In the Midwest stormwater management solutions do not tend to focus on conserving water or increasing recharge as a means to increase water supplies, but rather focus on reducing peak runoff during storm events as a means to reduce CSOs, SSOs, and NPS pollution. A large portion of the population centers in the Midwest are centered on the Great Lakes region. With such a vast water supply in the past water was not conserved. Efforts in areas, such as Chicago, are beginning to address water conservation at the government level and at targeting outreach to residents. Methodologies summarized here are innovative at the regional or national level and can be applied elsewhere as a part of a TWM strategy.

### Milwaukee, Wisconsin

Milwaukee, Wisconsin has undertaken multiple initiatives to address water quality and water conservation issues. The City's Office of Environmental Sustainability has developed a green program for the City with facets including water quality improvement. Milwaukee Metropolitan Sewerage District has initiated a $1 billion overflow reduction plan to be completed by 2010 to reduce CSO and SSO to receiving waters. Additional benefits of the plan include a reduction in NPS pollutants. Applicable sections to TWM include stormwater reduction and flood management, each with applications to water conservation. Prior to initiating efforts to reduce CSO/SSO an average of 8 to 9 billion gallons of water in the sewer system was released to Lake Michigan per year. Programs with application to TWM are summarized here. All sewer overflows in this section refer to both CSO and SSO (Milwaukee Metropolitan Sewerage District, 2009 a,b).

### *Greenseams Program*

More than 1,600 acres of undeveloped private property exhibiting soil properties acceptable to infiltration to reduce flooding ha ve b een purchased through the The C onservation F und (Milwaukee Metropolitan S ewerage D istrict, 2009c), a national non-profit organization that handles program operations. This voluntary program targets properties in areas forecast to have major growth in the next 20 years and areas along streams, wetlands, and shoreline of Lake Michigan. L and a cquisitions w ill be r estored a nd maintained t o s tore r ain a nd s now. A ncillary be nefits include wildlife habitat preservation and recreation opportunities.

### *Rain Gardens*

To r educe pol luted r unoff and s ewer ov erflows, r ain g ardens a re e ncouraged t hrough a grant pr ogram. G rants a re awarded via approximately 50% reductions in the price of plants suitable for a rain garden. Grants do not include the planning, de sign, a nd construction of the rain garden. G rant recipients m ust pr ovide t ransport the p lants from t he pick-up location. Eligible applicants include government, residents, and groups. Schools receiving grants must post a sign paid for by M ilwaukee Me tropolitan Sewerage District next t o t he g arden ( Milwaukee Me tropolitan Sewerage District, 2009d).

### *Rain Barrels*

Rain barrels are provided to residents throughout Wisconsin at a cost of $30 per hook-up ready, 55 gallon barrel. The program is designed to reduce water use, save energy, reduce sewer overflows and polluted runoff, and protect Lake Michigan (Milwaukee Metropolitan Sewerage District, 2009e).

### *Conservation Best Management Practices*

The district provides customers with a list of BMPs designed to reduce water consumption, sewer overflows, polluted runoff, and energy costs. Water conservation BMPs include:

- Postpone laundry to periods when heavy rain is not forecast
- Reduce shower times
- Turn off water while shaving and brushing teeth
- Fix leaky plumbing
- Install high efficiency plumbing (Milwaukee Metropolitan Sewerage District, 2009f).

### *Stormwater Pilot Programs*

Multiple p ilot pr ograms w ere in itiated as part of the Stormwater R unoff Reduction Program. T hese p rograms are discussed and evaluated in detail in The Application of Stormwater Runoff Reduction Best Management Practices in Metropolitan Milwaukee in 2007. P ilot programs evaluated included low impact development projects including rain gardens, green roofs, pervious pavement, low, downspout disconnection, wetlands, and cisterns. A review of BMPs to determine negative impacts on sewer infiltration an inflow was also conducted. Innovative programs are discussed in more detail elsewhere in this section (Milwaukee Metropolitan Sewerage District, 2007).

### *Menomee Valley Stormwater Park*

Menomee Valley Stormwater Park was created to improve stormwater runoff water quality from a 100-acre business park. P ark water qua lity c omponents in clude t hree d etention cells mimicking a tr eatment train with a wet pr airie, wetland forest, and an emergent wetland. Additional benefits include play fields, natural areas, and river access (Milwaukee Metropolitan Sewerage District, 2007).

### *Menomee Valley Bioretention Facility*

The Menomee Valley Bioretention Facility, a two-acre shallow water area with vegetation was created to filter runoff stormwater runoff from approximately 70 acres. Highlights of the facility include the use of permeable soils with a clay liner and underdrain to discharge treated water to the Menomee River. Grasses and forbs (e.g., sunflower, clover and milkweed) were planted to maximize ET and reduce peak runoff flows and volumes entering the river. Additional benefits include habit and aesthetic improvements in an urban area (Milwaukee Metropolitan Sewerage District, 2007).

### *Menomee Central Valley Planning*

In a joint effort between Milwaukee Metropolitan Sewerage District, City of Milwaukee, Menomee Valley Partners, Milwaukee Transportation Partners, Sixteenth Street Community Health Center, and private landowners, an integrated approach to stormwater management in the Menomee Central Valley was developed. An outcome of the process was the development of coordinated projects to serve the area, such as redevelopment of the stockyards to include a regional treatment system and the previously discussed Menomee Valley Biorention Facility.

A Cooperative Agreement was signed between the stockyard redeveloper, Menomee Valley Partners, and the City to create a comprehensive stormwater plan for the parcel with a regional treatment system. The City will construct and fund the system up to $1 million along with providing technical and financial support. Phase 1 of the project will treat runoff from a five-acre right of way and 10 acres of development on the stockyards site using a two-acre treatment system. Phase 2 will expand the system to four-acres to treat an additional 20- acres of private property. A goal of the system is to assist property owners in complying with state and local stormwater regulations.

As part of the agreement the City is taking an innovative approach to ensure the system is regionally used by other property owners. One approach is to amend the City's stormwater ordinance to require future development to use the system. Another approach is to create a renewal plan, stormwater, or zoning overlay district requiring offsite property owners to provide cost sharing for construction, operation, and maintenance of the regional system (Milwaukee Metropolitan Sewerage District, 2007).

### *Pharmaceutical Collections*

Milwaukee Waterworks was one of the first cities in the country to test source waters for PPCPs. An outgrowth of testing for PPCPs was the establishment of medicine collection days to reduce the introduction of PPCPs in treated wastewater to its source waters of Lake Michigan (Milwaukee Waterworks, 2009).

## Minneapolis, Minnesota

Originally utilizing a CSS to handle wastewater and stormwater, the City of Minneapolis has separated more than 95% of the system to reduce CSOs and improve water quality. Separation of the outstanding portions of the system are difficult and expensive, thus the City embarked on a five-year plan to reduce future CSOs. Efforts to reduce runoff have included green roofs, rain gardens, pervious pavement installation, rain barrels, tree planting, and mandatory downspout disconnection from the sanitary sewer system (Minneapolis, 2009a and b).

### *University of Minnesota Subsurface Stormwater System*

When constructing the new TCF Bank Stadium at the University of Minnesota in Minneapolis, a subsurface stormwater system to reduce stormwater runoff and improve water quality prior to discharging to the Mississippi River, was included within the project. An Environmental Passive Integrated Chamber system was installed beneath an open space area that is also used for broadcast trucks, emergency vehicles, and other vehicles to maximize space and eliminate above ground detention areas. The grass landscaped area can support the weight of vehicles with the use of geomembranes while retaining 60,000 gallons of water below the surface. The system is expected to remove 70-85% of TSS and up 35% of pathogens (Geosynthetics, 2009).

## Illinois Statewide Planning

To address future water demands, Illinois initiated a statewide water planning program in 2006 based on anticipation of needing 20-50% more water in future decades to meets economic and residential needs. A goal of the program is to encourage regional planning beyond local and county boundaries and to examine entire water cycle. Two regions have started efforts to develop regional planning, Northeast Illinois and East-Central Illinois. At this stage the regions have not developed water management options, but are currently considering a plethora of water supply options (Illinois Water Supply Planning, 2009).

Within Illinois, the City of Chicago is at the forefront in addressing water related issues. Examples of the programs implemented to address water issues with applicability to TWM are presented below.

### *Chicago, Illinois*

In 2003, the Mayor of Chicago, Richard Daley, issued Chicago's Water Agenda 2003 focusing on three interrelated main points regarding water: water conservation, water quality protection, and stormwater management. The agenda recognizes problems associated with these three interrelated aspects of water and establishes actions the City can take to address issues. Actions include changes the City can make in its operations and potential changes to building codes. The document concludes with development of outreach and mobilization actions to develop long terms solutions and educate citizens. This high level document establishes actions to guide the City as it moves forward in proactively addressing the components of the water cycle (City of Chicago, 2003).

A few examples of actions taken to date on behalf of the City include:

- Installation of shut-off buttons on drinking fountains
- Street medians designed to capture storm runoff and remove pollutants
- Diversion of runoff in new construction away from sewers
- Installation of 1 million sq ft of green roofs on a combination of public and private buildings
- Repairing leaking water mains attributing to an estimated 19% reduction in water consumption.

**Stormwater Conservation.** The City of Chicago has implemented a stormwater conservation program to reduce CSOs and improve infiltration of stormwater. An additional benefit of the program is water conservation. This program includes encouragement of the following stormwater conservation measures in conjunction with public education:

- Green design in public and private buildings including green roofs
- Biofiltration with rain gardens to promote onsite infiltrations
- Naturalized detention basins to detain stormwater onsite
- Drainage swales to retain stormwater
- Filter strips to slow the speed of runoff from impervious surfaces

- Natural landscaping to reduce water consumption and stormwater runoff
- Permeable paving to promote infiltration of rain and snow melt
- Downspout disconnection
- Installation of rain barrels and cisterns (City of Chicago, 2009a).

**MeterSave.** MeterSave, a volunteer program implemented by the City of Chicago Department of Water Management, is designed to allow residences to switch from non-metered billing to metered billing. The program provides a seven year guarantee that the water bill with a meter will be no higher than the non-metered rate. As an additional incentive to switch to a meter the choice of a rain barrel, outdoor water conservation kit, indoor water conservation, or water meter monitor is provided to customers. The goal of the program is to reduce water consumption and protect Lake Michigan (City of Chicago, 200b).

**Residential Graywater System.** Chicago's first residential graywater system in a residential building opened in 2007 in the Near North Apartments, a privately operated facility designed for low-income and disabled residents. Gray water is collected from showers and bathroom sinks and treated onsite. Recycled water is then used for toilet flushing. The project is expected to conserve approximately 45,000 gallons of water a year (Sokol, 2007).

**Intake Restrictors on Catch Basins.** Almost 200,000 inlet restrictor valves were installed throughout Chicago in catch basins to reduce peak flows during storm events to the CSS. Restrictors slow peak flows into the system using the streets as temporary storage areas (Walesh, 1999). Reductions in peak flows reduce water quality issues associated with CSO discharges to waterways and reduce the possibility of backflows from the system into basements. The overall cost was approximately $75 million, a quarter of the cost of comparable sewer improvements with the same benefits (City of Chicago, 2009c).

## Indianapolis, Indiana

Indianapolis, Indiana's two major water issues revolve around water quality in waterways and occasional peak demands exceeding water system capacity. Indianapolis is a under a consent decree from the EPA and Indiana Department of Environmental Management to reduce raw sewage overflows into waterways. Efforts to comply with the decree and to reduce peak water demands are highlighted in this section.

### *Sewage Overflow Long Range Control Plan*

To improve water quality and comply with the consent decree the City if Indianapolis has implemented a long-term program aimed at reducing the occurrences of sewage overflows into waterways. Currently, the White River and its tributaries do not meet Indiana state standards for dissolved oxygen to protect fish and bacteria to protect recreation. The $1.73 billion (City of Indianapolis, Department of Public Works (2008) plan is expected to reduce overflows from 45-80 times per year to two to four times per year. Additionally, the City plans to implement watershed improvement projects costing an additional $64.3 million. To reduce the overflows the plan contains multiple components. Major components include construction of a deep tunnel to capture overflows for treatment after peak flows subside, new sewers to capture overflows and direct them to the tunnel, and construction of separate sewers (City of Indianapolis, Department of Public Works, 2009 and 2006)

### *Demand Management Outreach*

In 2005, Indianapolis's water system demands exceeded the system's capacity during a hot and dry period in the summer for fourteen days. To reduce strains on the water system capacity Veolia Environement, operator of Indianapolis's water supply system initiated an outreach program in 2006 to avoid a repeat of peak system demands in summer months. Outreach included water conservation measures such as watering on odd/even days based on addresses, install moisture sensors for irrigation systems, use low flow devices, and follow water use advisories

(Indianapolis Water, 2009). In 2006 with initiation of the outreach program, system capacity was only exceeded on three days (Veolia Environment, 2009 and Indianapolis Water, 2009).

## Midwest Agriculture

Farmers in the Midwest are beginning to look at watersheds as a whole and improve farming practices to reduce downstream impacts. As a an area characterized by heavy agricultural upstream farming practices results in a range of impacts from local water resource issues to negative impacts hundreds of miles below in the lower watershed and Gulf of Mexico.

### *Water Reuse in Poultry Industry*

Hudson Foods poultry facility located in Noel, Missouri was faced with a water purveyor that was having difficulty in meeting the needs of the facility with existing water supplies. Hudson Foods initiated a four phase project to conserve water and reuse their extraordinarily quality effluent. Phase 1 involved reducing unnecessary water use, such as educating employees and reducing excessive washdowns. Phase II involved modifications to the facility to reuse high quality effluent in those areas that do not require potable water. Phase III encompassed using high quality effluent in areas subject to U.S. Department of Agriculture (USDA) regulations. Recycled water use commenced in the screen wash bars. Screen wash bar water does not contact products. Phase IV incorporates further use of high quality effluent in areas subject to USDA regulation and development of database to illustrate the quality of the effluent as compared to EPA National Primary and Secondary Drinking Water Standards. A goal of Phase IV is to allow use of the high quality effluent in further processes subject to USDA regulation where potable water is not required and the high quality effluent would not come in contact with product. It is estimated after final implementation of Phase IV, 72 million gallons of water will annually not need to be pumped from the local aquifer by the water purveyor. Other benefits include improved water quality in the community from reduced pollutant discharge to the Elk River, preservation of ground water supplies, and reduced operating costs. Applications learned at the Noel facility have been applied to three other Hudson Food facilities, including the use of effluent from a WWTP for washdown and cooling water in a broiler plant, resulting in additional water savings of over 450,000 gpd (EPA, 2011).

### *Non-Point Source Pollution from Agriculture*

Conservation and agricultural groups within the Mississippi River Basin have started an initiative to address water quality and wildlife habitat throughout the basin and the Gulf of Mexico by targeting NPS pollution from agricultural operations. Funded by Monsanto Corporation the initiative is led by The Nature Conservancy, Iowa Soybean Association, and Delta Wildlife. The initiative will work with farmers to reduce nutrient and sediment loading in the Mississippi River Basin. The National Audubon Society will work with residents to reduce NPS pollution in the Basin and improve wildlife. Pilot studies will be conducted in various agricultural areas throughout the Basin to improve farming practices to likewise improve water quality and enhance wildlife in the Basin. Pilot programs include BMP installation and improvement practices designed to improve the health of the Mississippi River ecosystem. Data results will be gathered and disseminated annually to farmers so they can apply the practices to improve water quality and wildlife habitat. Results of the program are expected to be able to be integrated into other major river management plans throughout the world. Additionally, a Mississippi River Farm Nutrient Working Group will be formed to engage other organizations, industry-related groups, and other organizations in working with experts improve the watershed (Environmental News Service, 2008 and The Nature Conservancy, 2008).

## Rouge River National Wet Weather Demonstration Project

The Rouge River National Wet Weather Demonstration Project in Michigan utilized a systematic watershed management approach to address water quality impacts from all pollution sources and use impairments in the watershed. Applications learned in this watershed are being applied to other watersheds throughout the country and are applicable to addressing water quality as it relates to TWM. The Rouge River Watershed is located in southeast Michigan covering an area of approximately 438 square miles, including all or a portion of 48 municipalities. Initially, the project began in 1992 and was joint effort involving federal, state, and local agencies narrowly focused on CSO control. As the project evolved and early projects were implemented, monitoring indicated other pollution sources were impacting the watershed, preventing watershed restoration, and water quality standards were still not being met. A watershed-wide strategy was developed followed by development of seven subwatershed plans. Subwatershed plans were developed to identify steps to address outstanding water quality problems including stormwater, CSOs, SSOs, failing septic tanks, and non-point pollution sources. Throughout plan development an extensive public information and education program was developed emphasizing that downstream residents have the right to expect clean water from upstream residents. In 2000, water quality monitoring indicated improvements to date had resulted in the cleanest water in decades (The Rouge River National Wet Weather Demonstration Project, 2009a, b and c).

## D.3.3 Northeast Region Strategies

Similar to the Midwest, water planning solutions in the Northeast tend to mainly focus on reducing peak loading to sewers during storm events to reduce CSOs, SSOs, and achieve compliance with TMDLs with the notion of planning for a combination of natural controls and large infrastructure source controls. To a lesser extent, solutions address reducing *cryptosporidium* in drinking water sources, conservation, and water system reliability have been implemented. Multiple innovative principals, such as housing all aspects of water management in one department, integrated planning, and implementation of onsite wastewater recycling have been adopted in the Northeast and can be applied elsewhere in the development of a TWM strategy.

### New York, New York

The City of New York is dealing with multiple issues to alleviate problems associated with water quality and water supplies. While New York's water supplies are relatively abundant, its water infrastructure system is aging and requires repairs necessitating the need for improved reliability if portions of the system need to be taken off line. Poor water quality in waterways is driving efforts to manage runoff as a means to improve water quality, but not as a means to improve water supplies. New York has developed plans to address poor water quality in waterways, remove *cryptosporidium* from source waters, maintain pure water sources not requiring filtration, reduce impacts of suburbanization on watersheds, and ensure reliability of its water supplies by investigating innovative approaches.

#### *PlaNYC*

Beginning in 2006, New York City initiated a sustainable plan, PLaNYC, focusing on the five key aspects: land, water, transportation, energy, air, and climate change. The water plan is divided into two plans, one for water quality and one for the water network.

**Sustainable Stormwater Management Plan 2008.** The Sustainable Stormwater Management Plan 2008 component of PlaNYC addresses water quality issues associated with TMDLs, CSOs, and SSOs. The overall goal of the plan is to increase public access and use of waterways from the current level of 40-90% by 2030. A major target of the plan is to enact policies within the next two years that will use source controls to capture an additional billion gallons of stormwater annually. The interagency plan seeks to use source controls, green infrastructure, low impact development techniques, BMPs, green roofs, alternative roadways allowing infiltration, and rain barrels or cisterns to reduce runoff. As stated in the plan, the most cost-effective option for stormwater control is to incorporate controls into planned construction or reconstruction. New York City is leading the challenge by conducting demonstration projects as a showcase to landowners and developers regarding costs, benefits, and feasibility.

A three part strategy has been developed to meet the plan goal: implement the most cost effective and feasible controls, resolve the feasibility of promising technologies, and explore funding options for source controls. Ten initiatives have been developed:

- **Capture benefits of ongoing PlaNYC green initiatives** – zoning amendments to requiring street trees and green parking areas; planting a million trees; green roof tax abatement; engineered wetlands in Bluebelt system; convert asphalt fields to turf; convert school yard areas into playgrounds; and protect natural wetlands

- **Continue with implementation of source control efforts** – zoning amendments restricting pavement of front yards; requiring planting of green areas in private owned public plazas; incentives for water conservation; coordination among agencies for construction specifications; use of High Level Storm Sewers; and multiple measures to reduce flooding

- **Establishment of new guidelines for public projects** – release of the following manuals incorporating cutting-edge stormwater management practices: Street Design Manual, Park Design for the 21st Century; Sustainable Urban Site Design Manual, and the Water Conservation Manual

- **Adopt performance standards for new development in sewer regulation and codes**

- **Improvements in notification of CSOs**

- **Completion of ongoing demonstration projects and other studies** – testing of source controls to determine applicability to broader applications; develop answers to feasibility of source controls; mapping impermeable surfaces throughout the City, and updating the soil survey for the City

- **Continue planning efforts for implementing promising source control strategies** – development of designs and identification of funding mechanisms for source control strategies that can be included in sidewalk standards, road reconstruction standards, green roadway infrastructure, and building performance standards

- **Planning for maintenance of source controls** – consideration of maintenance costs in initiatives

- **Establishment of new funding options for cost-effective source control** – examine rate increases to water and sewer charges, enact stormwater charges, or a combination of charges; use of the general fund; investigate use of outside funding, federal funding for infrastructure, or funds that would be expended for conventional pollution control methods

- **Complete water and wastewater rate studies and assess rates for stormwater services** (City of New York, 2008a).

**PlaNYC Report on Water Network.** To maintain reliability and drinking water quality, New York City has developed a Water Network Report as part of PlaNYC. The report develops three strategies to ensure water supply reliability: ensure the quality of drinking water, create redundancy for aqueducts to the City, and modernize the distribution network in the City. Initiatives developed to meet these strategies include:

- **Continuation of the watershed protection program** – purchase additional land in watersheds; work with farmers and foresters to develop sustainable practices; and repair septic systems within water supply watersheds

- **Construction of a ultra-violet (UV) disinfection plant for Catskill and Delaware water systems** – opening of largest UV disinfection facility in the world in 2012 to control *cryptosporidium*

- **Construction of the Croton Filtration Plant** – suburbanization in the watershed has resulted in negative impacts to water supply

- **Launch a new water conservation effort** – launch new rebate programs for toilets, urinals, high efficiency washing machines in apartment buildings and Laundromats with the goal of reducing total water use for the City by 5% saving 60 MGD ; and evaluation of other programs including gray water reuse, leak detection, and water efficient industrial equipment

- **Maximize existing facilities** – maximize supply sources to reduce impacts of droughts and construct alternative connections to reservoirs

- **Evaluate new water supply sources** – ensure adequate water supplies are available if Delaware Aqueduct is required to be shut down for repairs by evaluating groundwater; water recycling for steam, toilets, or air conditioning; capture and collect groundwater currently disposed of from subway system and clean it for potable use; regional interconnections; and new infrastructure

- **Complete water tunnel No. 3** – to provide system redundancy to complete repairs in aging infrastructure

- **Complete back**-up water tunnel to Staten Island – Army Corps of Engineers dredging harbor and will remove existing back-up system

- **Increase pace of upgrades to water main infrastructure** – increase pace from 60 miles of upgrades per year to 80 miles per year (New York, 2008 b and c).

*Solaire Apartments Dual Plumbing*

The Soliare Apartments in New York are an example of a dual plumbed building using onsite recycled wastewater for toilet flushing and cooling towers. Collected stormwater is used for irrigation purposes. Potable water demand is 75% less than a comparable single plumbed 380 unit apartment building. Completed in 2003, the building contains the first onsite wastewater treatment system in a multi-family building in the U.S. Water savings are estimated 9,000 gpd for toilet flushing, 11,500 gpd for cooling towers, and 6,000 gpd for irrigation. The building is a LEED gold building (GE, 2006 and Cosentini Associates, 2009).

## Philadelphia, Pennsylvania

Philadelphia Water Department, which manages stormwater, drinking water, and wastewater within Philadelphia, has embarked on a watershed based methodology using a balanced "land-water-infrastructure" approach to control CSOs. The Department uses an integrated regional watershed planning approach emphasizing adaptive management to appropriate balance of each approach. Each component is balanced to achieve an overall solution to control CSOs. Land is focused on source control, water on ecosystem restoration, and infrastructure on capital improvement projects. The overall goal is to minimize the introduction of runoff into the sewer system.

The land or wet weather source control portion of the approach involves a variety of structural and non-structural measures and low impact development techniques. Philadelphia enacted new post-construction regulations for development and redevelopment in 2006 to achieve a natural balance between runoff and infiltration rates. Projects can achieve compliance with the regulations through land-based practices designed to use natural processes such as redirecting runoff to pervious green areas, onsite bioretention, subsurface storage of runoff, infiltration, green roofs, swales, and tree canopies. Planned low impacts development programs for the Department's service area include:

- Large scale street tree program for aesthetics and improvement of stormwater at the source

- Incentives for preservation of open space for use of stormwater management at the source

- Incentives and requirements to manage stormwater on private property and streets in a green manner thereby reducing sewer demands

- Implementation of stormwater management on public lands and streets reducing in a green manner thereby reducing sewer demands.

Ecosystem restoration or the water portion of the approach utilizes projects to restore aquatic ecosystems impacted by CSOs. Typical projects include bank stabilization, creation of aquatic habitat, fish passage improvements, removal of plunge pools, stream bed stabilization, riparian buffer creation, and enhancing wetlands.

The Capital Improvement Program approach is used to construct CSO infrastructure to reduce CSOs. Projects include storage, conveyance, and treatment facilities. In some cases it is more cost-effective to construct infrastructure projects in conjunction with the other approaches (Philadelphia Water Department, 2009).

## D.3.4 South Region Strategies

Unlike the Midwest and Northeast but similar to the West, water supplies are more constrained in the South as a result of climate, increasing populations, and drought. Water resources agencies in the South have had the need to expand their water supply portfolios to include innovative solutions such as extensive recycled water use, indirect potable recycled water reuse, and a strong emphasis on water conservation. For example, Florida has tapped recycled water as a major water source in cities and districts across the state (Florida Department of Environmental Protection, 2009). While the area does not have as widespread of an issue with CSOs and SSOs, compliance with water quality issues still remains a challenge. Typical BMPs and LID are used to retain and treat stormwater throughout the region. Integrated planning in some areas has embraced TWM at the watershed level to maximize water benefits in a cost–effective manner. This section highlights some of the more notable solution applicable to TWM and approaches used to incorporate TWM into the planning process.

### Total Water Management in the South

In the South where water is less plentiful than the Mid-west and Northeast, TWM has been incorporated into long-range integrated water resource planning in multiple areas. Two examples of efforts in Georgia and Florida are highlighted.

#### *Total Water Management: Clayton County Water Authority, Georgia*

Clayton County Water Authority (CCWA) has implemented at TWM strategy into its planning processes as it was faced with a multitude of constraints, requirements, and demands. Within its service area water and sewer demands are attributed to population growth, however, water supply sources are constrained due to water conflicts and wastewater discharges are impacted by TMDL requirements. The Authority first applied TWM during its 2000 planning process and further refined it in its 2005 planning cycle. A desired outcome using the TWM process was to maximize its water supply portfolio and achieve compliance with both federal and state regulations while simultaneously meeting customer service goals in a cost-efficient manner.

TWM has already provided the Authority with multiple benefits. During the recent drought in Georgia, a 200 day water supply was maintained at all times without compromises to water quality both in the watershed and in the water system. Drought proofing of water supplies has occurred with indirect reuse of treated wastewater by increasing reclaimed water recharge to its water supply reservoirs via a constructed wetland treatment system from 10 MGD to 26 MGD. Utilization of reclaimed water allowed reservoirs to remain at near full capacity during the recent drought. As a direct result of TWM, the Authority now includes stormwater and watershed management for the entire county as part of its management responsibilities allowing for control of water resources by one agency that can manage all aspects of water in a reliable, economical, and sustainable manner (Jeffcoat, et al, 2009).

#### *St. Johns River Water Management District, JEA, and Clay County Utility Authority*

TMDLs and water quality issues are driving efforts in the St. Johns River Water Management District to improve water quality and develop long-term reliable water supplies. The District is assisting water and wastewater utilities in meeting these goals. The district launched a multi-media Water Conservation Public Awareness Campaign along with more than 20 utility partners (Wilkening, 2007). By maximizing water reuse JEA (a local utility) and the Clay County Utility Authority are seeking to offset potable water demands and achieve nutrient discharge requirements for wastewater. Both agencies integrated TWM into their master planning processes. Elements of the approach used include:

- Stakeholder identification of project goals and objectives – 1) comply with TMDL requirements 2) Reduce potable water use 3) Identify opportunities for water reuse

- Collection and analysis of data – for each service area collect date for 1) potable water supplies 2)wastewater production 3) reuse demand

- Utilization of decision-support software (VOYAGE model) to identify project meeting project objectives

Output of the approach resulted in the identification of least-cost alternatives that met project objectives. Modeling additionally indicated excess wastewater within JEA's service area could satisfy reclaimed water demands in Clay County service area (Patwardhan et al., 2008).

## Dual Distribution Systems

Dual distribution systems can provide many advantages to municipalities; specifically in the case where small distribution lines are used for potable water service, and separate non-potable distribution lines are used for fire flow and irrigation. While potentially feasible in new developments, retrofits to existing developments tend to be less economical. By utilizing smaller potable water lines, smaller volumes of water are being transported, resulting in the following advantages:

- Reduced degradation of water quality in the distribution system prior to reaching the customer

- Reduced chlorine dosing at the water treatment plant resulting in a lower disinfection by-product formation.

- Increased velocity of water through smaller pipelines when compared to typical pipe sizes, resulting in less static water, and less biofilm growth (Okum, 2005).

Two examples of proposed dual distribution systems in the South are in St. Petersburg, Florida and in the service area of South Martin Regional Authority in Florida. In Chatham County, North Carolina a study was initiated to determine the feasibility of a dual system in comparison to a traditional system as discussed in the following section.

### *Chatham County, North Carolina*

Briar Chapel, a proposed master-planned community in Chatham County, North Carolina, was the subject of a case study analyzing the costs and benefits of three options for a dual water distribution system (reclaimed and potable) for phase one of the development. Phase one of Briar Chapel consists of 350 single-family homes. One option was a traditional water distribution system where fire flows are included in the potable distribution system. Option A was a dual system using reclaimed water for landscape purposes. Option B was a dual system using reclaimed water for landscape and toilet flushing. Options A and B both include fire flows as part of the non-potable distribution systems. Each of the options was modeled using EPANET2 using multiple assumptions.

Results of this case study indicate at this development multiple benefits could be achieved. Length-average pipe diameter for the traditional system was 8.6 inches. With Option A this was reduced to 4.4 inches and further reduced to 2.8 inches with Option B. Average water residence times were reduced from 16.5 hours to 4.4 hours for Option A and 3.8 hours for Option B. As indicated in the cost study capital costs require further refinement. In general, capital costs associated with the pipe network of the distribution systems are greater for Options A and B. Offsets are available for the use of smaller decentralized wastewater facilities associated with Options A and B and may reduce the cost differences (Digiano et al., 2009).

## Decentralized Water Recycling Systems in the South

Provided below is a listing of satellite treatment facilities within the South. This listing is not intended to be a comprehensive listing. If available, the distance from the satellite treatment facility to the point of use versus the distance from the closest WWTP to the point of use, is provided:

- Cauley Creek, Georgia (5 MGD)
- Oak Island, North Carolina (0.4 MGD)
- Midland, Texas (0.1 MGD) – 1 mile from point of use vs. 6 miles from closest WWTP.

## Indirect Potable Reuse Projects

Planned indirect potable reuse of reclaimed water occurs in multiple locations throughout the South. A few of the major facilities are highlighted here.

***El Paso Water Utilities, El Paso, TX***
Hueco Bolson Recharge Project

- Injection of treated wastewater into aquifer for withdrawal as part of drinking water supplies. Also used for industrial and irrigation purposes.
- Production: 8,400 AFY
- In operation since 1985

***IWVA, Lawrenceville, GA***
F. Wayne Hill Water Resources Center

- Treated wastewater used for irrigation with excess discharged to Chattahoochee River, pending further approval may potentially be discharged to Lake Lanier a water supply source for Atlanta
- In operation since 2000, expanded 2005
- Design Capacity 67,424 AFY (Australian Capital Territory, 2009)

***Upper Occoquan Sewage Authority, Fairfax County, VA***
Upper Occoquan Project

- Discharge of treated wastewater to Occuquan Reservoir, which is used for drinking water supplies; at times has accounted for 4/5 of flow into reservoir
- In operation since 1978
- Production: 32 MGD expanding to 54 MGD, tripling its original capacity (in progress)

## Regional Water Planning

Regional water planning is used in the south to make water decisions at the larger regional levels. Regional water planning efforts for Florida and Texas are provided as examples.

### *Florida*

Florida has formed five water management districts tasked with managing water resources in the state under the Department of Environmental Protection. Each district is highly involved in all water management issues within their individual boundaries. Districts perform the following functions:

- Develop water management plans for water shortages
- Acquire and manage lands related to water management purposes
- Manage consumption of water, aquifer recharge, surface water, and well construction
- Administer stormwater management programs
- Assist with development of water elements in local government comprehensive plans.

The structure of these districts and interaction with local governments and utilities allows for the districts to assist local governments and utilities with integrated planning in watersheds (Florida Department of Environmental Protection, 2009).

### *Texas*

The Texas Water Development Board has divided Texas into 16 planning regions to develop regional water solutions in a cost-effective manner. Regions are required to develop regional water plans. Each regional water plan seeks to determine the following:

- Water demands
- Water supplies for drought use
- Areas of surpluses and needs for additional supplies
- Social and economic impacts if water demands not met
- Identify ecologically unique waterways
- Identify sites for reservoir construction
- Coordinate with neighboring regions
- Propose recommendations to improve water resource management in Texas
- Identify strategies to meet future demands in the next 30 years and in the next 30 to 50 years
- Identify where no feasible solutions exist to meet demands (Texas Water Development Board, 2009).

**Southwest Florida Water Management District Stormwater Reuse**

As proposed Southwest Florida's Water Management District's recycled stormwater project consists of diverting stormwater through an alternative outfall from the Venice Golf and Country Club to a Sarasota County operated pond for irrigation needs. Use of stormwater for irrigation needs at the golf course will allow other users access to 349,000 gpd of reclaimed water currently used by the golf course. Capture of the stormwater runoff will reduce nutrients in surrounding waterbodies and will allow nutrients conveyed in stormwater to be reapplied to the golf course. Estimated construction costs are approximately $165,512 dollars in 2005 dollars (Southwest Florida Water Management District, 2005).

## D.4 Regulatory Constraints

Regulatory constraints impacting TWM vary from state to state. States have adopted regulations based on needs. Water quality regulations associated with surface waters, such as CSOs, SSOs, and TMDLs are mandated by the federal government with enforcement and administration of the regulations typically at state levels. Water use regulations are developed at the State and local levels. States in the South and West have been at the forefront of adopting regulations to safely expand water supply portfolios to include non-traditional options. In many states innovative solutions may require new or revised regulations.

### D.4.1 Reclaimed Water for Fire Protection

Currently, guidelines or regulation for the use of reclaimed water for fire protection exist in only nine states: Arizona, California, Florida, New Jersey, Hawaii, North Carolina, Texas, Utah and Washington. Each of these nine states also allow toilet flushing using reclaimed water, thus new developments could realize the benefits from having dual distribution systems that take advantage of using reclaimed water indoors for toilet flushing. Extensive implementation of reclaimed water for fire flows also must overcome the hurdle of receiving the support of firefighter unions (Digiano et al., 2009).

### D.4.2 Rain Collection and Water Rights

Regulations regarding the collection and use of rainwater onsite vary by state. LID and BMPs, such as rain barrels and cisterns, used to capture and retain water onsite for use are not legal in every state. Colorado and Utah are the only western states that do not allow the collection of rainwater. The following provides a summary of a few state regulations:

- Colorado - In Colorado rain falling on private land does not legally belong to the landholder, but belongs to those downstream holding pre-emptive water rights. However, Coloradans have passed a bill that allows certain homeowners to capture and use roof runoff (Colorado Division of Water Resources, 2010).

- Arizona – Individual income tax credits of 25 %, up to $1,000, are offered to offset the cost of a rain harvesting system

- New Mexico – In Santa Fe County cisterns are required on all commercial building and for houses exceeding 2,500 sq ft. Houses smaller than 2,500 sq ft must have swales, berms, or rain barrels to harvest the rainwater.

- Utah – All rainwater legally belongs to the state. Legislation is proposed to allow residents to harvest rainwater

- Washington – Laws regarding rainwater harvesting are not clear, thus the state does not enforce regulations that could potentially regulate rainwater harvesting (Riccardi, 2009 and McCausland, 2009).

## D.4.3 Gray Water Regulations

Similar to other water use regulations, gray water regulations are developed at state levels. Regulations vary differently by state with some states, such as Arizona and New Mexico, with regulations that are more amenable to gray water systems. Other states, such as California and Utah, increase the difficulty in installing gray water systems. Arizona's regulations are an example of a tiered approach with requirements based on system sizes. Arizona has taken a three tiered approach to regulating gray water systems based on system size:

- First Tier: Residential less than 400 gpd and meeting list of requirements – covered under general building permit
- Second Tier: Residential over 400 gpd or commercial, multi-family, and institutional systems, or systems not meeting list of requirements – requires a standard permit
- Third Tier: Any system over 3,000 gallons a day – considered on an individual basis.

New Mexico has based its regulations on Arizona's approach (Oasis Design, 2009).

## D.4.4 Recycled Water Use Regulations

Recycled water use is regulated at the state, regional, and local levels. Regulations differ across the country with California and Florida in the forefront of encouraging recycled water use. The greatest concern relates to the potential for cross-connections between the potable and reclaimed water plumbing systems, and water quality of recycled water that is used for groundwater recharge. As of January 1, 2008 California allows dual plumbing installation in condominiums. Previous uses of dual plumbing in California were limited to apartments and other non-residential uses where the potential for cross-connections are limited as building owners controls maintenance of plumbing systems. In California, regional water quality control boards have made it more challenging to use recycled water for groundwater recharge—effectively requiring advanced treatment using reserve osmosis and membranes.

EPA has developed a summary of water reuse regulations by state, and offers guidelines on implementation of water recycling (EPA, 2004).

## D.4.5 Impact of Plumbing Codes on Water Conservation

In multiple cases, current plumbing codes can interfere with adoption of new water conserving fixtures. Plumbing codes vary at the local, regional, and state levels dependent upon the location and the code adopted. Three major areas commonly impacted by plumbing codes include hot water distribution losses, shower efficiency, and waterless urinals.

Currently, codes allow water waste related to hot water demands as people allowing cool water to flow out of the fixtures until hot water reaches the fixture. Reducing this waste of water can be achieved by placing limits on the diameter and length of hot water pipes, insulating pipes, and requiring utilization of on-demand recirculation systems.

Showerhead efficiency is regulated by the Federal Energy Policy Act limiting the maximum flow rate of a showerhead to 2.5 gallon per minute. However, this requirement does not regulate the number of showerheads installed in a single shower, provide for a maximum flow rate for all heads in a single shower, or establish a minimum spacing between showerheads.

Regulations of waterless urinals vary dependent upon the adopted plumbing code used by a regulatory agency. Recent version of the International Plumbing Code allow the installation of waterless urinals, but other codes such as the Uniform Plumbing Code (UPC) do not mention the use of waterless urinals. Interpretation of the lack of specifically mentioning the device in the UPC is interpreted differently among agencies. Some agencies believe that since the device is not mentioned, it does not comply with the UPC (Pape, 2008).

A study by Dickinson et al. (2003) forecasted reductions in water production due to adoption of a national plumbing code, 5% in 2010, increasing to 8% water savings by 2020 (base year of study 1999). Estimated utility savings were $26 per person which equates to $7.5 billion nationwide in reduced infrastructure costs.

## D.5 Innovative TWM Strategies at the Global Level

Throughout the world innovative TWM strategies have been developed to address water quality and water supplies problems. In many cases countries have developed progressive solutions such as "sewer mining"(tapping into a sewer and withdrawing wastewater flows for treatment and recycled water use) in Australia, and direct potable use of recycled water in Namibia.

### D.5.1 Windhoek, Namibia

Windhoek, Namibia is the economic center of Namibia located in the Central Highlands with a population of approximately 213,000 people in 1998. Population growth was approximately 5.44% per year between 1991-1995. Water resources include three surface reservoirs located on ephemeral rivers, groundwater and reclaimed water. The nearest year around waterway is located 700 kilometers away. Since 1968, Windhoek has supplemented potable water directly with recycled water. Rainfall averages 360 millimeters (14.17 inches).

#### Integrated Water Demand Management Planning

As a result of water production increasing by 13.5% during 1990-1991 related to an influx of people from rural areas and high population growth, it was determined demands would eventually outstrip supplies. In 1994 an integrated water demand management policy was approved by the City Council for implementation over a five-year period using least cost planning. The planning process required investigation of unconventional water sources. A severe drought in 1996 resulted in immediate implementation of the entire plan. Policies adopted include:

- Tier tariff system – a block system reflecting the true cost of water and to reduce excess usage
- Maximum reuse of water – use of semi-purified effluent for irrigation; expansion of the direct potable water reuse facility; and graywater reuse on private property
- Reduce plot sizes and increase densities – residential plot sizes in new developments were decreased; increase densities in urban areas to allow two house per lot; and in older sections of the City allow implement rezoning to businesses and townhouses
- Guidelines for urbanization development
- Reduction of municipal water use – reduce consumption of water by 50% in municipal gardens
- Wet industries – provide wet industries with guidelines for efficient water use on a continuous basis and new wet industries required to reuse water

A public outreach campaign was coupled with the adopted measures, new water conservation measures, and technical requirement. Technical requirements included:

- Lowering unaccounted water use – conduct leakage detection on a continuous basis, implement repair programs, conduct water audits, manage meters, implement pipe replacement program
- Efficient ways of water gardens – irrigate municipal gardens with proper systems and advise gardeners on water efficient irrigation systems
- Artificial recharge of Windhoek aquifer – investigate and implement natural and artificial recharge of aquifer

- Rainwater harvesting – implement rainwater harvesting program.

Numerous successes have resulted from implementation of the plan. Overall, the plan has resulted in postponement of major water infrastructure projects for at least ten years and an annual savings $13.54 million (1998, Namibia). Water reliability during drought periods has increased with groundwater recharge. Daily per capita residential use has decreased from 201 liters in 1990/91 to 117 liters in 1996/97 (Merwe, 2009).

### Direct Reuse of Recycled Water

The New Goreangab Water Reclamation Facility, operated by Windhoek Goreangab Operating Company Pty Ltd. and located in Windhoek, Namibia, is an example of a facility where recycled wastewater treated with advanced treatment is directly delivered into the potable water distribution system where it blends with other water supply sources. As summarized in a compilation of recycled water facilities throughout the world, the facility located in Windhoek, Namibia typically delivers a blend of 35 % recycled to 65 % potable water for human consumption. During low water demand month in the winter season, a blend of 50% recycled to 50% potable water is distributed. Currently, 6, 160 AFY of recycled water are produced in the facility operating since 2002 (Australian Capital Territory, 2009).

The facility uses the following treatment technologies to treat secondary effluent: powdered activated carbon, acid, polymers, pre-ozonation, coagulation/flocculation, dissolved air flotation, rapid sand/anthracite filtration, ozonation, biological activated carbon filtration/adsorption, granular-activated carbon filtration, membrane ultra-filtration, and chlorination/stabilization. Product water is continuously monitored. If preset water quality parameters are not met, then the water is recycled through the facility again. To prevent the mixing of household wastewater and industrial wastewater, industrial wastewater is collected and treated separately with the end product used for irrigation only (Australian Capital Territory, 2009 and Lahnsteiner, 2005).

## D.5.2 Singapore Public Utilities Board, Singapore

Singapore's Public Utilities Board had developed an integrated approach to water management to promote sustainable development, boost economic development, and enhance the urban quality of life by ensuring adequate water supply, controlling flooding, and providing water-related recreational and cultural opportunities.

### Stormwater Runoff Reuse

Since 1985 the Bedok-Seletar project has captured stormwater runoff from a 5,000 hectare area for use as a raw water source. Runoff is captured both directly and indirectly. Runoff is either intercepted a series of diversion points, stored, and then pumped into a reservoir or runoff is captured and directly conveyed to a reservoir (CDM, 2009a).

In 2008, the Singapore Marina Barrage project was completed consisting of a 1,000 foot long barrage or dam acting as a tidal barrier to prevent high tides from flooding inland areas while creating a freshwater reservoir behind the dam through natural flushing. The project provides three main benefits:

- Water supply – isolating a river outlet to provide an additional source of raw water to bolster drinking water supplies by impounding 35 MGD of urban runoff per day

- Flood control – providing protection from high tides for low lying inland areas

- Quality of life improvements – linking the central business district with a recreational and visual attraction of the Marina Basin.

Normally, the dam gates will remain closed, however during extreme storm events when the tide is low the gates will be raised to release excess flows. Under high tide events and during extreme storm conditions a pump station with a capacity of 5,400 MGD will pump excess water to the ocean. A small boat hoist was constructed as part of the barrage to allow the occasional movement of boat traffic between the Marina Reservoir and ocean (CDM, 2009a).

### Indirect Potable Water Reuse

Four NEWater Plants operated by the Singapore Public Utilities Board produce reclaimed water for indirect potable reuse utilizing a three step process, microfiltration, reverse osmosis, and ultraviolet light. A contract for construction of a fifth plant was awarded in 2008. Approximately 20 MGD of water are produced from the four plants. Reclaimed water is used for irrigation, air cooling towers, bottling, and industrial uses, as well as blending with drinking water in raw water supply reservoirs. Raw water from the reservoirs undergoes conventional water treatment prior to entering the potable distribution system. Approximately, 1% of the total daily water consumption in Singapore (3 MGD) is derived from reclaimed water. In 2011, this percentage is planned to increase to 2.5% in 2011 (Singapore Public Utilities Board, 2009).

## D.5.3 Other Indirect Potable Water Reuse Projects

Planned indirect potable reuse of reclaimed water occurs in multiple locations throughout the world. One of the major facilities is the IWVA facility in Wulpen, Belgium. In operation since 2002, the Wulpen Aquifer Recharge Project located in Wulpen, Belgium utilizes reclaimed water for groundwater replenishment in groundwater basins designated for drinking water source (Australian Capital Territory, 2009).

## D.5.4 Seawater Desalination in Israel

To meet consumer demand for water in a dry climate, Israel constructed the world's largest desalination plant, the Ashkelon Desalination Plant. Commencing operation in 2005, the facility converts approximately 26 billion gallons of sea water to potable a year. The facility supplies 5-6% of Israel's potable water demand and meets 13% of consumer demand. To improve energy efficiency, the facility incorporates energy recovery devices designed to collect pressurized brine (Water-Technology.Net 2009).

## D.5.5 Dual Plumbing

### Seawater Toilet Flushing, Hong Kong

To conserve potable water after a severe drought in the 1960's Hong Kong embarked on using seawater for toilet flushing (Tang, 2007). Approximately 80% of the 6.8 million people in Hong Kong use seawater for toilet flushing which reduced potable water demands by approximately 20% and equated to 241 million m$^3$ in 2003. Hong Kong is continuing to look at applications for the use of seawater in lieu of potable water, such as use in air conditioning systems and seawater desalination.

The seawater system is relatively simplistic with limited treatment consisting of screening and disinfection. Seawater is withdrawn directly from the sea, treated in the pump stations, pumped to surface reservoirs, and then into the seawater distribution system. Corrosion is avoided with the use of polyethylene or polyvinyl chloride pipes.

Advantages of the system are summarized below:

- Unlimited resource
- Seawater quality and aesthetics are dictated by regulations
- Reductions in potable water demands
- Single water supply system would be approximately 39% more expensive than a dual system

Disadvantages of the system – and remedial actions - are:

- Cross connections – adoption of standard procedures to prevent cross-connections

- Corrosion of pipes and deterioration of concrete and window frames from leaking water - use of non-corrosive pipes and improving water quality of supply reservoirs

- Deposits and growth in pipes leading to aesthetic complaints – use of regular flushing to remove algal accumulation and electro-chlorination to control marine growth

- Ecology problems – in rural areas wastewater is treated by septic tanks and discharged to rivers thus the use of seawater in these areas can impact the salinity of the rivers

- Treatment process for mixed freshwater and saltwater sewage – typical treatment systems have been modified to deal with increased salinity of mixed waste sources

- Chlorination – use of electro-chlorination process to reduce biological growth

- Seawater quality can suddenly deteriorate leading to complaints and stains in toilet bowls – marine water quality meets toilet flushing requirements most of the time, but existing treatment process cannot guarantee turbidity of flushing water.

## Australia

In Australia, reclaimed water is provided to single-family residences for indoor toilet flushing and for outdoor use, including hose bibs, with thousands of additional new residences to be constructed in the near future. Dual plumbing in Australia can also include hookups for washing machines.

After experiencing a severe drought in the early part of the decade, Australia has encouraged the use of recycled water for residential purposes. In the Rouse Hill residential development over 16,000 single-family residences have dual plumbing for toilet flushing and outdoor irrigation resulting in a potable water savings of approximately 35% per since 2001 (Urban Ecology Australia, 2009). In summer months demand commonly outstrips the supply resulting in the need to add potable water to the system. On average 15% of the non-potable supply is potable drinking water.

Yarra Valley Water Ltd. (2011) in Victoria estimates dual plumbing for toilet flushing and outdoor irrigation at signal family residences reduced potable demands by 45-50% and estimates additional plumbing costs of $2,000 (Australian dollars) per unit. An additional $3,000 dollars is charged to developers per lot for recycled water use, $1,000 for dual delivery pipes (before the service connection) and $2,000 for the recycled water plant and associated appurtenances.

The Pimpama and Coomera suburbs located south of Brisbane are undergoing tremendous growth and in response will be required to have three water systems for residential use, drinking water, rain water, and recycled water. A current population of 15,000 people is expected to increase to 120,000 by 2056. As a result all new developments are proposed to be dual plumbed to reduce potable water demands by up to 84%. Homes will be dual plumbed to receive recycled water for toilet flushing. Additionally, rainwater tanks will serve bathrooms, laundries, and hot water systems. Drinking water will be plumbed only to kitchens. Gold Coast Water, the local water provider has launched an extensive educational campaign for plumbers in the region (Gold Coast City Council, 2009).

A relatively new process in recycled water use, “sewer mining” (Sydney Water, 2009), is also occurring in Australia to supply locally treated recycled water for dual plumbing systems. “Sewer mining” as defined by Sydney Water is “the process of tapping directly into a sewer and extracting wastewater for treatment and reuse as recycled water.” Sewer mining operations can be privately owned which should spur competition. In Sydney Water’s jurisdiction sewer mining operations are first-come first served to prevent upstream extraction of an existing facility if it would impact the volume of wastewater required. Multi-family residential projects, such as Discover Point in Sydney (Waste Management & Environment Media Pty Ltd., 2011), are treating wastewater onsite beneath the project for toilet flushing and irrigation. Excess water will be sold to irrigate an adjacent sports field. The recycled water portion of the project capital costs is approximately $3.5 million (Australian dollars) and is expected to reduce potable water use in the building by approximately 35%.

Table D-5 summarizes examples of dual plumbing in Australia.

**Table D-5**
**Dual Plumbing Installation Examples in Australia**

| Location | Recycled Water Use | Potable Water Savings | Cost Range |
|---|---|---|---|
| Rouse Hill, Australia[1] | 16,000 single-family residences, outdoor use and toilet flushing | 35% (demand exceeds supply in summer requiring 15% of supply to be potable) | N/A |
| Yarra Valley Water, Victoria[2] | Toilet flushing and outdoor irrigation | 45-50% | $2,000 per unit (Australian) incremental cost for dual plumbing; $1,000 per unit for delivery pipes, $2,000 for share of treatment plant |
| Pimpama and Coomera Suburbs, Australia[3] | Recycled water for toilet flushing, rainwater for bathroom, clothes washer, and hot water | 84% (Forecast) | N/A |
| Discover Point, Sydney, Australia[4] | Sewer mining operation to be used for toilet flushing and irrigation with excess water sold to adjacent sports fields | 35% | $3.5 million (Australian) for recycled water treatment |

1. http://www.urbanecology.org.au/topics/waterrecyclingrousehill.html and http://www.goldcoastwater.com.au/t_gcw.asp?PID=5894

2. http://www.yvw.com.au/yvw/groups/public/documents/content/yvw000781.pdf

3. http://www.goldcoastwater.com.au/t_gcw.asp?PID=5885

4. http://www.sydneywater.com.au/SavingWater/RecyclingandReuse/RecyclingAndReuseInAction/SewerMining.cfm and http://www.wme.com.au/categories/water/dec4_07.php

## D.5.6 Water Tanks in Australia

Australia has extensive experience with the use of water tanks to collect rainwater from roofs for outdoor water use, toilet flushing, water heating, car washing, spas and ponds, clothes washing swimming pools, and fire fighting (Australian Government, 2004). Indoor non-potable water use requires installation of dual plumbing. Water tanks are comparable to cisterns and are installed above or below ground. Water is captured via rain gutters and is screened before draining into water tanks. Water tanks connected to non-potable indoor water uses provide maximum use of collected water as water collected during storm events is used immediately providing additional capacity in the tank. Over 17% of Australian households have water tanks. Currently most new developments are required to install water tanks.

Sydney Water has given out over 30,000 rebates to its residential and business customers saving approximately 317 million gpy. Rebates for residences and businesses vary depending upon tank size and ultimate use of stored water ranging from $150 to $1,500. Public and private schools can receive up to $2,500. Table D-6 provides current rebate amounts in Australian dollars.

**Table D-6 Water Tank Rebates for Sydney Water[1]**

| Qualifying Items | Rebate Amount[2] |
|---|---|
| 2,000 -3,999 Liter Water Tank | $150 |
| 4,000 - 6,999 Liter Water Tank | $400 |
| 7,000 + Liter Water Tank | $500 |
| Water Tank Connected by Plumber to Toilet | $500 |
| Water Tank Connected by Plumber to Washing Machine | $500 |
| Schools | $2,500 |
| 1.http://www.sydneywater.com.au/savingwater/InYourGarden/RainwaterTanks/ 2. All dollars are Australian dollars | |

Program requirements stipulate that all installations are required to meet building codes and local requirements. All plumbing must be installed by a licensed plumber. Tank sizes can vary, but Sydney Water recommends a 5,000 liter tank if the tank will supply all non-drinking water uses and a 2,000 liter tank if the tank will supply water for toilet flushing and a small garden. Rebate amounts cannot exceed the cost of the water tank and installation. Eligible costs include delivery, installation, gutter and roof pipe installation, foundation for above ground installation, excavation for below ground installation, backflow prevention, flow regulator, first flush device, screens and guards, extra plumbing, pump, and piping to top off tank. Rebates are not issued for buildings required to install water tanks.

Program requirements for schools have additional requirements. All schools applying must complete a water education program, participate in a water conservation program, install a minimum of a 10,000 liter tank, and the tank must be connected to fixed irrigation and/or toilet supply water.

A benefit of installing a water tank is that mandatory water restrictions do not apply to locations with a water tank as long as long as the source of the water is the tank and the tank is not topped off with potable water (Sydney Water, 2009).

A study completed in 2007 by Marsden Jacob Associates, *The Economics of Rainwater Tanks and Alternative Supply Option,* presented numerous extensive findings regarding water tank costs and associated economic impacts in comparison to alternative water supply sources. The study concludes water tanks could defer acquisition of future water supply resources among other environmental benefits. Throughout Australia a 5,000 liter tank installed usually costs between $2,500 and $3,500 including connections to plumbing.

Costs were developed in the study for a typical installation and on a yield basis. On average in Australia a 5,000 liter tank installed usually costs between $2,500 and $3,500 including connections to plumbing. Costs per $m^3$ of water captured were developed in the study for areas across Australia. Costs were determined by dividing the annualized capital and O&M costs by expected annual yield. Costs ranged between $2.15 and $12.30 per $m^3$ of water. The wide range in costs per yields is dependent on local climate conditions, tank size, and roof size. Lower range costs were associated with buildings having greater roof sizes. Lower range costs are less than or comparable to yield costs associated with other water source options under investigation in Australia. Higher end costs are as high as or higher than most alternative water supply options under consideration. However these yield cost ranges do not take into consideration the savings associated with reductions in stormwater infrastructure systems, potential reductions in water main sizes, carbon impacts, and reduction in pollutants conveyed in stormwater (Marsden Jacobs Associates, 2007).

### D.5.7 Graywater Use in Canada

The Canada Mortgage and Housing Corporation has completed extensive studies in the use of graywater for reuse in toilet flushing in residential and non-residential settings. In Vancouver, a 20-unit apartment building, Quayside Village, is being constructed as a demonstration project featuring graywater for toilet flushing. Each unit will collect light and dark grey wall from all plumbing fixtures, except toilets, for reuse as toilet flushing water. Dual plumbing is provided in the units to toilets and showers. Showers were dual plumbed in case future use is feasible. An onsite wastewater treatment system uses a settling tank, biofilter, pre-ozonation, multi-stage sand filtration, and ozonation to treat the graywater. Toilet wastewater and excess graywater is discharge to the sewer system. Capital costs were approximately $115,000 (Canadian) with an estimated monthly maintenance cost of $100 (Canadian). Water demands and wastewater flows are expected to be reduced by approximately 40% with this project (Canada Mortgage and Housing Corporation, 2009).

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