

THESIS

DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR INTEGRATED URBAN  
WATER RESOURCES MANAGEMENT

Submitted by

Bradley I. Reichel

Department of Civil and Environmental Engineering

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 2011

Master's Committee:

Advisor: Sybil Sharvelle

Co-Advisor: Larry Roesner

Scott Glick

## ABSTRACT

### DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR INTEGRATED URBAN WATER RESOURCES MANAGEMENT

The challenges of addressing the needs of aging water and wastewater infrastructure require new management approaches. Traditional municipal water management practices may not be the most cost effective solutions. Savings may be realized through the adoption of new integrated water management concepts such as treated wastewater effluent and/or graywater reuse, rainfall harvesting, etc. Determining which water management practices are best suited to a particular urban area can be a difficult task as costs, climate, and population characteristics vary across regions.

The Integrated Urban Water Model (IUWM) has been developed by the Urban Water Center at Colorado State University to aid urban planners and utility managers in the assessment of which water management practices may prove most beneficial to their communities. These practices include: indoor conservation, irrigation conservation, wastewater treatment plant (WWTP) reuse for irrigation, graywater reuse for toilet flushing and irrigation, and stormwater capture reuse for irrigation. The model is native to the Windows operating environment and includes a graphical user interface through which the user can easily add information about the region and assess the potential benefits of the included water management practices. A case study application of the model to five cities in

different climatological regions of the United States is included in the report. The case study serves as both an example of how the application may be used and demonstrates its capabilities. The results of the case study reveal that hydrologic conditions impact the effectiveness of selected water management practices.

## ACKNOWLEDGEMENTS

Great appreciation is extended to Dr. Sybil Sharvelle and Dr. Larry Roesner for committing their knowledge and time to the completion of this project. Thanks are also owed to Adam Jokerst and Matt Becker for their previous efforts with the model. Thanks to the USEPA, WERF, and Colorado State University for providing the funding that provided the opportunity to complete the work on this project.

## TABLES OF CONTENTS

Abstract.....	ii
Acknowledgements.....	iii
Table of Contents.....	v
List of Tables.....	xiii
List of Figures.....	ix
1. INTRODUCTION .....	1
1.1 Overview.....	1
1.2 Review of Previous Work.....	3
1.2 IUWM Capabilities.....	6
1.2.1 Water Management Practices .....	11
1.2.1.1 Indoor Conservation .....	11
1.2.1.2 Irrigation Conservation .....	12
1.2.1.3 Graywater Reuse for Toilet Flushing and Irrigation .....	12
1.2.1.4 Wastewater Treatment Plant (WWTP) Reuse for Irrigation .....	12
1.2.1.5 Stormwater Capture Reuse for Irrigation .....	13
1.2.2 Selection of Input Data Format .....	13
1.2.3 Basic Procedure for Using the Model .....	14
1.3 Organization of this Manual and Other Available Documentation .....	14
2. IUWM COMPUTATIONAL METHODOLOGY .....	16
2.1 Model Organization.....	16
2.2 Data.....	16
2.2.1 Residential Indoor Demands .....	17
2.2.1.1 Review of Available Residential Indoor Demand Data .....	17
2.2.1.2 Residential Indoor Demand Data Included in the Model.....	19
2.2.1.3 Residential Indoor Demand Data Supplied by User .....	19
2.2.2 Commercial/Institutional and Industrial Indoor (CII) Demands .....	20
2.2.2.1 Review of Available Commercial Indoor Demand Data .....	20
2.2.2.2 Commercial Indoor Demand Data Included in the Model.....	24
2.2.2.3 Commercial Indoor Demand Data Supplied by the User.....	24
2.2.3 Irrigation Demands .....	25
2.2.3.1 Review of Available Irrigation Demand Data.....	25
2.2.3.2 Irrigation Demand Data Included in the Model .....	26

2.2.3.3 Irrigation Demand Data Supplied by the User .....	26
2.3.4 Hydrologic Data .....	27
2.3.4.1 Review of Available Hydrologic Data .....	27
2.3.4.2 Hydrologic Data Included in the Model.....	27
2.3.4.3 Hydrologic Data Supplied by the User .....	27
2.3 Calculations .....	28
2.3.1 Base Calculations .....	29
2.3.2 Water Management Practices Calculations .....	31
2.3.2.1 Indoor Conservation Calculations .....	31
2.3.2.2 Irrigation Conservation Calculations.....	33
2.3.2.3 Graywater Reuse for Toilet Flushing and Irrigation Calculations ..	33
2.3.2.4 Wastewater Treatment Plant (WWTP) Reuse Calculations.....	35
2.3.2.5 Stormwater Capture for Irrigation Calculations.....	36
2.4 Outputs.....	38
<b>3. GETTING STARTED WITH IUWM .....</b>	<b>39</b>
3.1 Installing IUWM.....	39
3.2 Quickstart Utility .....	41
3.3 Step 1: Create a New Project .....	42
3.4 Step 2: Add Service Areas and Water User Categories.....	46
3.5 Step 3: Apply Water Management Practices .....	49
3.6 Step 4: Save Model Setup as a Scenario.....	52
3.7 Step 5: Run a Simulation .....	53
3.8 Step 6: Review Simulation Results.....	55
3.9 Step 7: Create Additional Scenarios .....	56
<b>4. DETAILED MODEL FUNCTIONS .....</b>	<b>57</b>
4.1 Creating, Saving, and Opening IUWM Projects .....	57
4.2 Adding, Editing, and Deleting Water Users .....	59
4.3 Applying and Editing Water Management Practices.....	61
4.3.1 Indoor Conservation .....	61
4.3.2 Irrigation Conservation.....	62
4.3.3 Graywater Reuse for Flushing and Irrigation .....	63
4.3.4 WWTP Reuse for Irrigation .....	64
4.3.5 Stormwater Capture for Irrigation .....	65
4.4 Editing Defaults and Adding Custom Data .....	66
4.4.1 Editing Default Values .....	66
4.4.2 Custom Water User Categories .....	67
4.4.3 Editing and Adding Custom Hydrologic Regions.....	68
4.4.4 Editing and Adding Custom Irrigation Demand Regions .....	72
4.5 Saving, Loading, and Deleting Scenarios.....	74

4.6 Viewing and Results .....	75
4.7 Exporting Inputs and Results.....	78
5. CASE STUDY APPLICATION.....	80
5.1 Introduction.....	80
5.2 Inputs .....	80
5.2.1 Selected Cities and Hydrologic Conditions.....	80
5.2.2 Service Area and Water User Categories Input.....	82
5.2.3 Water Management Practice Parameters.....	84
5.2.3.1 Indoor Conservation.....	84
5.2.3.2 Irrigation Conservation .....	84
5.2.3.3 Graywater Reuse for Flushing and Irrigation.....	85
5.2.3.4 Wastewater Treatment Plant (WWTP) Reuse for Irrigation.....	85
5.2.3.5 Stormwater Capture for Irrigation.....	86
5.3 Case Study Scenarios.....	86
5.4 Results.....	87
5.4.1 Fort Collins.....	87
5.4.2 Orlando .....	90
5.4.3 Philadelphia .....	93
5.4.4 San Diego .....	96
5.4.5 Seattle .....	99
5.5 Discussion.....	102
5.5.1 Indoor Conservation Simulation.....	103
5.5.2 Irrigation Conservation Simulation .....	104
5.5.3 Graywater Reuse for Flushing and Irrigation Simulation .....	105
5.5.4 WWTP Reuse for Irrigation Simulation.....	107
5.5.5 Stormwater Capture for Irrigation Simulation .....	109
5.6 Conclusions.....	113

## LIST OF TABLES

Table 2-1 Default Residential Demands Included in IUWM .....	18
Table 2-2 Ranges of CI Total Water Demand .....	21
Table 2-3 Selection of Typical CII Demand Distributions.....	24
Table 5-1 ET Values for Selected Cities .....	81
Table 5-2 Percent ET Values for Selected Cities .....	81
Table 5-3 Average Precipitation Totals from NCDC Data .....	82
Table 5-4 Single-Family Residential Service Area Input.....	83
Table 5-5 Multi-Family Residential Service Area Input .....	83
Table 5-6 Percent Reduction of Indoor Demands .....	84
Table 5-7 Reduced Demands with Indoor Conservation.....	84
Table 5-8 Potential Savings from Indoor Conservation .....	103
Table 5-9 Potential Savings from Irrigation Conservation.....	105
Table 5-10 Potential Savings from Graywater Reuse for Flushing and Irrigation .....	107
Table 5-11 Potential Savings from WWTP Reuse for Irrigation .....	109
Table 5-12 Potential Savings from Stormwater Capture for Irrigation .....	111
Table 5-13 Results of Increased Stormwater Capture Storage Volume .....	112

## LIST OF FIGURES

Figure 1-1 IUWM Process Flowchart.....	6
Figure 1-2 Depiction of the IUWM Integrated Water System .....	7
Figure 1-3 IUWM Main Interface .....	8
Figure 1-4 Depiction of the IUWM Integrated Water System .....	10
Figure 2-1 Sample of Morales Method for CII Demand Estimates.....	23
Figure 3-1 IUWM Installer Window .....	40
Figure 3-2 IUWM Shortcuts.....	40
Figure 3-3 IUWM Main Interface Window.....	41
Figure 3-4 Quickstart Walkthrough Window .....	42
Figure 3-5 Create New Project Window .....	42
Figure 3-6 Browse for Folder Window .....	43
Figure 3-7 Define Project Defaults Window .....	44
Figure 3-8 Quickstart Walkthrough Window .....	45
Figure 3-9 Create New Service Area Window .....	45
Figure 3-10 Add Water User Category Window .....	46
Figure 3-11 Quickstart Walkthrough Window .....	48
Figure 3-12 Quickstart Walkthrough Window .....	49
Figure 3-13 IUWM Main Interface .....	50
Figure 3-14 Edit Indoor Conservation Parameters Window .....	51
Figure 3-15 Save Scenario Window .....	52
Figure 3-16 Quickstart Walkthrough Window .....	53
Figure 3-17 Run Simulation Window.....	53
Figure 3-18 Simulation Results Summary Window .....	55
Figure 3-19 IUWM Overwrite Prompt.....	56
Figure 4-1 IUWM Main Interface .....	58
Figure 4-2 Browse for Folder Window .....	59
Figure 4-3 Water User Browser Window.....	60
Figure 4-4 Water User Browser Window .....	61
Figure 4-5 Edit Indoor Conservation Parameters Window .....	62
Figure 4-6 Edit Irrigation Conservation Parameters.....	63
Figure 4-7 Edit Graywater Reuse Parameters Window.....	63
Figure 4-8 Edit WWTP Reuse for Irrigation Parameters Window.....	65
Figure 4-9 Edit Stormwater Capture Parameters Window .....	65

Figure 4-10 Edit Default Values Window .....	67
Figure 4-11 Create Custom Water User Category Window .....	68
Figure 4-12 Edit Default Hydrology Window .....	68
Figure 4-13 Edit/Add Hydrology Window .....	69
Figure 4-14 Select Hydrology Dates Window .....	70
Figure 4-15 Add Custom Hydrology Window .....	71
Figure 4-16 Edit Irrigation Region Window .....	72
Figure 4-17 Create Custom Irrigation Region Window .....	73
Figure 4-18 Save Scenario Window .....	74
Figure 4-19 Load Scenario Window .....	75
Figure 4-20 Delete Scenario Window .....	75
Figure 4-21 View Results Window .....	76
Figure 4-22 Compare Simulation Results Window .....	76
Figure 4-23 Graph Simulation Results Window .....	77
Figure 4-24 IUWM Results Chart .....	78
Figure 4-25 Export Results Window .....	78
Figure 4-26 Simulation Inputs Summary .....	79
Figure 4-27 Export Results Window .....	79
Figure 5-1 Fort Collins Treated Water Savings .....	88
Figure 5-2 Fort Collins Wastewater Reduction .....	89
Figure 5-3 Fort Collins Total Cost Savings .....	90
Figure 5-4 Orlando Treated Water Savings .....	91
Figure 5-5 Orlando Wastewater Reduction .....	92
Figure 5-6 Orlando Total Cost Savings .....	93
Figure 5-7 Philadelphia Treated Water Savings .....	94
Figure 5-8 Philadelphia Wastewater Reduction .....	95
Figure 5-9 Philadelphia Total Cost Savings .....	96
Figure 5-10 San Diego Treated Water Savings .....	97
Figure 5-11 San Diego Wastewater Reduction .....	98
Figure 5-12 San Diego Total Cost Savings .....	99
Figure 5-13 Seattle Treated Water Savings .....	100
Figure 5-14 Seattle Wastewater Reduction .....	101
Figure 5-15 Seattle Total Cost Savings .....	102
Figure 5-16 Irrigation Conservation Treated Water Savings Comparison .....	104
Figure 5-17 Irrigation Conservation Total Cost Savings Comparison .....	105
Figure 5-18 Graywater Reuse Treated Water Savings Comparison .....	106
Figure 5-19 Graywater Reuse Total Cost Savings Comparison .....	107
Figure 5-20 WWTP Reuse for Irrigation Treated Water Savings Comparison .....	108
Figure 5-21 WWTP Reuse for Irrigation Total Cost Savings Comparison .....	109
Figure 5-22 Stormwater Capture for Irrigation Treated Water Savings Comparison .....	110

Figure 5-23 Stormwater Capture for Irrigation Total Cost Savings Comparison ..... 111

# CHAPTER 1

## INTRODUCTION

### 1.1 Overview

Today, cities throughout the United States are facing the reality that there may not be enough water to satisfy demands, nor enough money to continue business as usual by simply replacing or rehabilitating deteriorated water and wastewater infrastructure. Water management for the 21<sup>st</sup> century requires a fundamental shift in the policies and methods of the past. A finite water supply combined with limited resources for water management and treatment pose management challenges. The United States Environmental Protection Agency (USEPA) has recognized these issues and has committed itself to the support of research for solutions through creation of new concepts for water and wastewater management (USEPA, 2007).

The current policy of plumbing a city for potential growth may not be the most cost effective solution. With the need for replacement of existing infrastructure looming, and new economic realities becoming certain, cities and utilities are seeking lower cost solutions to the continually increasing demands on urban water infrastructure. Development of water systems and support of infrastructure for growth that may not occur for decades does not fall into the low cost category. Management practices such as conservation campaigns, wastewater treatment plant (WWTP) reuse, graywater reuse, and stormwater capture are potential lower cost solutions that are well developed and increasing in popularity.

While utilities generally think that these management practices sound good, most managers and decision makers are unsure to what extent these practices may result in the water and cost savings for their service area. The Colorado State University Integrated Urban Water Management (IUWM) application has been developed to evaluate water and cost savings of emerging sustainable water management practices, thus providing guidance to decision makers on implementation of water management practices. The model is intended to assist decision making for implementation of new concepts in water management. IUWM began as a spreadsheet application in Microsoft Excel and has evolved into a standalone Windows application. The model is available to the public through the Water Environment Research Foundation (WERF) and development is ongoing.

IUWM is a mass balance simulation model for review and forecasting of the efficacy of sustainable urban water management practices. The model simulates daily demands for various water user categories and uses empirical data to determine irrigation demand and simulate the effectiveness of water management practices such as rainfall harvesting. The details of an urban watershed are entered into the model for one or more service areas; each including unique water user categories. The included management practices are then applied to the water user categories within each service area according to selected parameters. Multiple management scenarios can be applied to each watershed and simulations of the scenarios can be run, saved, and compared. The goal of the model is to provide urban water managers and planners with a tool that can be used to determine if a proposed water management practice is suitable for their community.

## 1.2 Review of Previous Work

Increased interest in water conservation and water reuse management practices has brought with it the need to evaluate the effectiveness of the proposed measures. Existing models, while well thought out and developed, are often too complicated or require proprietary software. IUWM was developed with the goal of providing an easily deployable, user-friendly tool that would allow water managers to quickly assess the potential savings of implementing water management practices.

One of the best known water management models is IWR-MAIN. The program is widely used by state agencies and provides a robust demand forecasting model that includes traditional determines the savings from active, passive, and emergency conservation programs (USDOE 2011). While IWR-MAIN considers many water user sectors and is capable of advanced economic analysis, it is not well developed for emerging water management practices. There is also a considerable cost for a license for the software which many water managers may be unwilling to pay when exploring the possible savings from conservation and reuse programs.

Another tool for modeling integrated water concepts is the Aquacycle model distributed by the Australia based eWater cooperative (Lekkas 2008). The model is freely available and very similar in scope and capabilities to IUWM. While Aquacycle is well developed and addresses graywater and stormwater capture practices, its interface is non-intuitive. Furthermore, the level of detail may be excessive for a water manager seeking to obtain an estimate of the potential benefit from applying for and It was determined that while Aquacycle held great promise, it is no longer under development with the latest release dating to 2005.

A number of water management simulation models have been developed at the academic level. Often, these models are created with powerful software such as Matlab and include detailed assessments of proposed water management systems. The Urban Water Optioneering Tool (UWOT) from the Centre for Water Systems at the University of Exeter in the United Kingdom is an example of this type of model (Makropoulos 2008). UWOT simulates the application of water management practices and uses genetic algorithm optimization to assist with selection of the best management alternatives. While UWOT provides these advanced features and considers the very similar water management practice capabilities as IUWM, it also requires installations of both Excel and Matlab with the Simulink package for full functionality. The combination is intended to provide users unfamiliar with Matlab a familiar interface from which to operate the model. However, Matlab is rarely available outside of academic settings and license costs make tools such as this infeasible for the majority of water managers. Additionally, this level of analysis may be overreaching for the purposes of estimation of benefit from proposed implementation of water management practices.

The combination of Excel spreadsheet tools with proprietary water management packages is not uncommon. The Total Water Management (TWM) approach to modeling an integrated urban water system combines a custom Excel spreadsheet with the Water Evaluation and Planning (WEAP) software package (O'Connor 2010). The focus of the case study application of the method is the Los Angeles, California metropolitan area. The approach requires detailed input to an Excel spreadsheet for preparation for import into WEAP. The obvious drawback to this approach is the considerable cost of the WEAP package in professional or government agency settings. The level of detail required for the

input to the Excel spreadsheet would also likely be a hindrance for a user seeking a general assessment of potential savings. The method is intended to assist in the creation of active management plans rather than preliminary review and analysis of potential savings from implementation of water management practices.

Among the most advanced water management models is the newest version of the Water Community Resource Evaluation and Simulation System (WaterCress). The model focuses on analyzing time step hydrologic data and applying alternative systems designs including water management practices such as graywater reuse, stormwater capture, and WWTP reuse (WaterSelect 2011). The beta version of the model is currently made available free of charge with stipulation that it may become proprietary in the future after a final version is released. The strengths of the model could also be considered drawbacks as consultation of the user manual is almost certainly required prior to use due to the complex interactions between objects in the model. It is also noted that some aspects of the model are not fully functional in the beta version.

The current version of IUWM is based upon previous work at Colorado State University which resulted in the development of an Excel spreadsheet tool of the same name (Jokerst 2010). Many features and characteristics of this predecessor to IUWM have been incorporated into the latest release. Deficiencies in the spreadsheet tool such as lack of the ability to consider multiple water user groups and apply conservation and reuse scenarios to each of have been addressed. Default data values have also been added to IUWM. Perhaps most importantly, the development of IUWM as a standalone application eliminates the dependence on Excel while also adding stability to the model.

## 1.2 IUWM Capabilities

IUWM is a new desktop application analysis tool that provides the user with the ability to simulate water demands and potential cost savings under various urban water management scenarios. The model was designed with water managers in mind as the primary user group, providing the capability to evaluate the efficacy of proposed integrated urban water management practices and scenarios. The flowchart below (Figure 1-1) is a graphical representation of the inputs and outputs in the model.

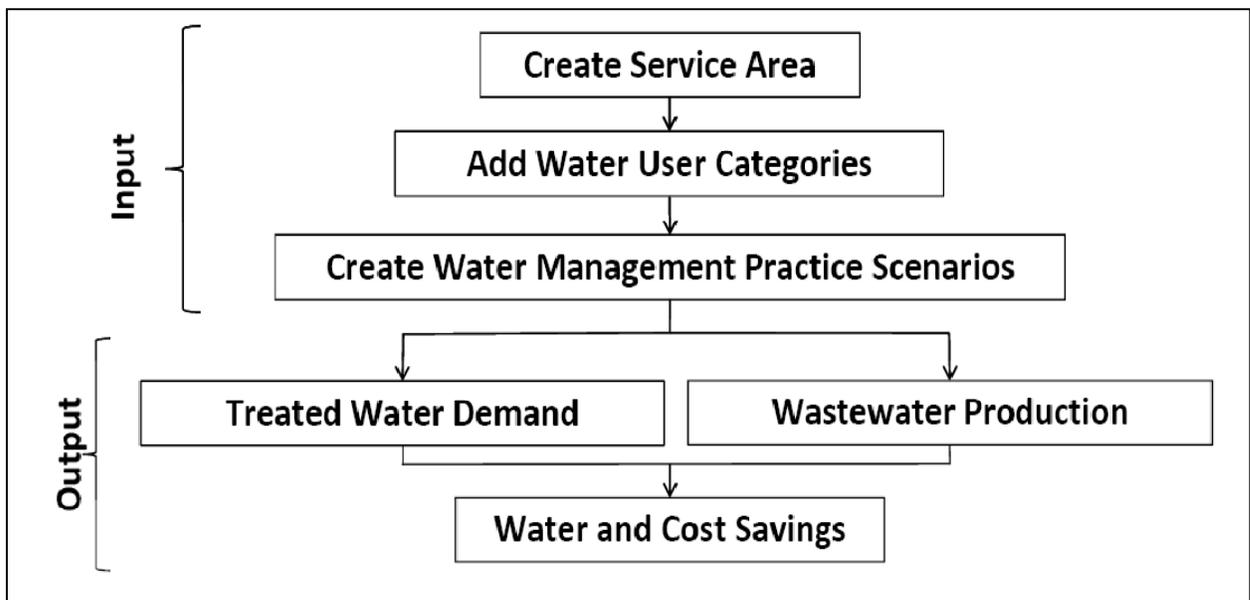


Figure 1-1 IUWM Process Flowchart

IUWM simulates the application of water management practice scenarios over time. Each simulation calculates water demand, wastewater production, and cost estimates for both status quo and proposed water management practice scenarios. The results are then compared to forecast potential savings resulting from application of the selected water management practices. The outputs of the model include treated indoor water demand, wastewater production, and treated irrigation demand. Potential water savings are annualized and the results are presented in millions of gallons or dollars per year. Other outputs include simple

estimates of the costs of treated water and wastewater treatment in expressed in terms of millions of gallons per year. These estimates are based on a flat rate, per volume cost input by the user.

IUWM delineates a project area into multiple service areas within a city or region. Each service area contains multiple water user groups which are described by their sector or water user category (Figure 1-2).

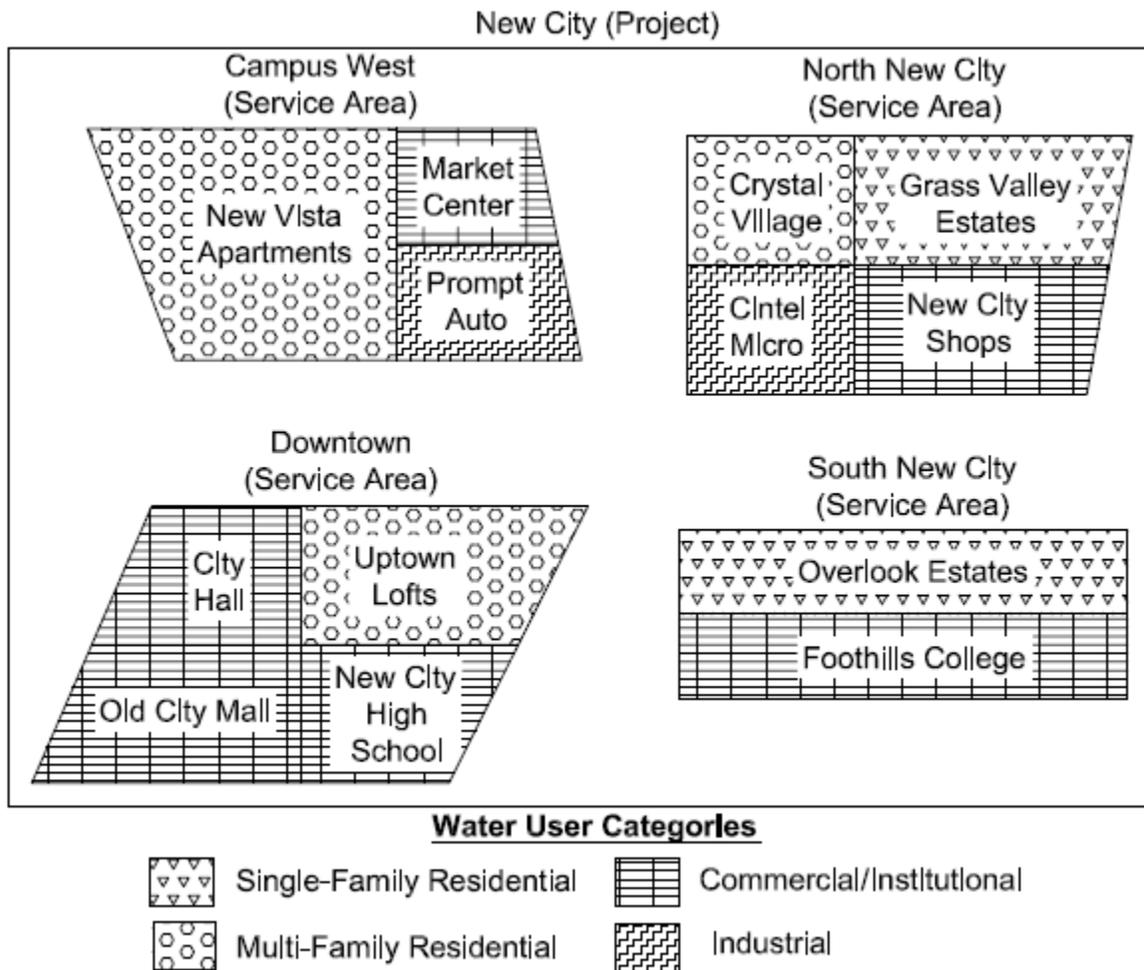


Figure 1-2 Depiction of the IUWM Integrated Water System

Water service areas may be neighborhoods or portions of a city or region. Water user categories are groups of water users such as residential, commercial, and industrial areas.

Once the properties of the water service area(s) and its water user categories have been input, water management practice scenarios can be applied.

The water management practices include: indoor water conservation, irrigation conservation, graywater reuse for flushing and irrigation, WWTP reuse for irrigation, and stormwater capture for irrigation. These practices include adjustable parameters that determine the degree of implementation and specific measures such as reduced demands and available storage volumes. After the parameters are specified, combinations of the water management practices are saved as water conservation and reuse scenarios. This allows practices to be applied separately or in combination to each water user category from the *IUWM Main Interface* (Figure 1-3).

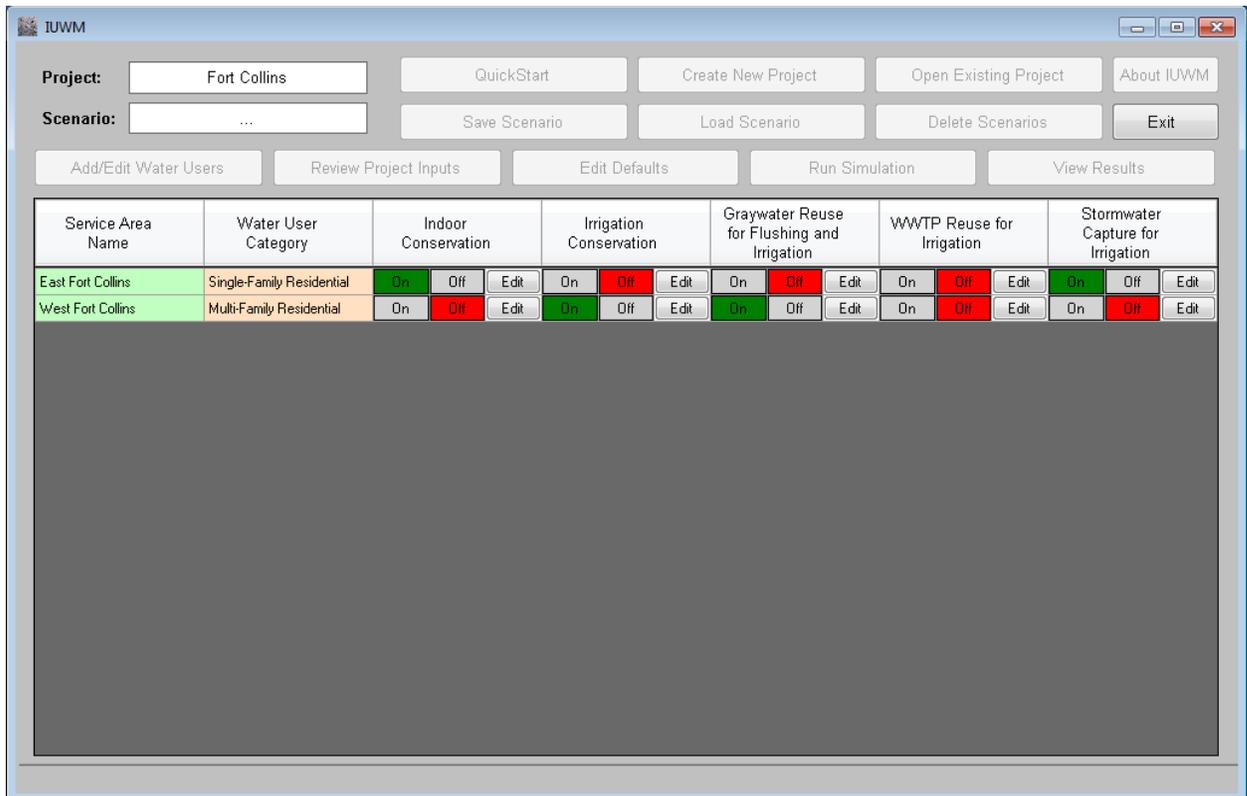


Figure 1-3 IUWM Main Interface

IUWM maintains a mass balance during simulation to record indoor end-use demands, irrigation demand, and wastewater production. Water is delivered, reused, and delivered to wastewater treatment based on the water management practices that are applied. The result is simulation of an integrated urban water system (Figure 1-4).

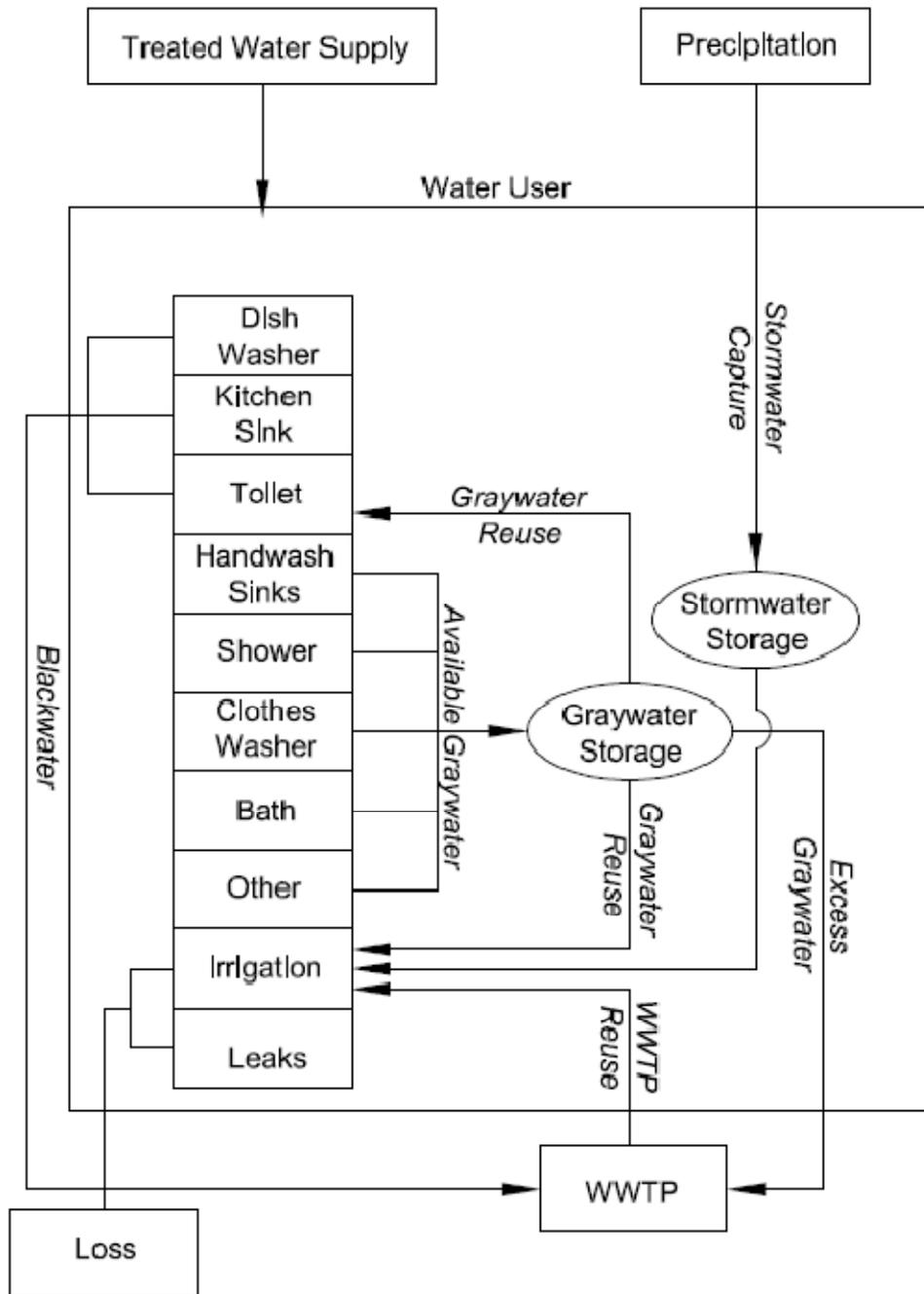


Figure 1-4 Depiction of the IUWM Integrated Water System

The integrated approach applied by IUWM considers hydrologic conditions in determination of irrigation demands and the effectiveness of water management practices.

Irrigation demand is based on evapotranspiration (ET) data and adjusted in terms of ET based

demand that is met. In the case of the included stormwater capture for irrigation practice, daily rainfall data are used to determine the volume of runoff available for capture.

A hierarchy of the water management practices exists and each practice respects the impacts of the others in maintaining the mass balance calculations in the model. For instance, household graywater available for capture will be impacted by the implementation of an indoor water conservation campaign that includes high efficiency fixtures and low flow appliances. Details of the calculations and order of operations in the model are included in section 2.3.

### 1.2.1 Water Management Practices

Five water management practices are included in IUWM. Each practice can be applied to each water user category separately or in combination. The practices selected for inclusion in the model were selected based on available technology and apparent interest level of water managers and urban planners.

#### 1.2.1.1 Indoor Conservation

Indoor water conservation can be achieved through encouraging users to adjust use patterns and/or through modification of fixtures and appliances. Conservation campaigns that raise public awareness of water issues can be quite effective in reducing total indoor demand and subsequent wastewater production. Additionally, installation of new high water efficiency fixtures and low-flow appliances can produce notable water savings. Sponsorship of rebate programs from utilities can help encourage implementation of these water saving devices.

Indoor demand is separated into end-use categories: baths, clothes washers, dish washers, faucets, leaks, showers, toilets, and other domestic uses. IUWM allows the user to

adjust the demands of each end-use category. The adjusted demand is then used to calculate the potential savings and wastewater production.

#### 1.2.1.2 Irrigation Conservation

Promotion of irrigation water conservation may be one of the most cost effective methods of reducing treated water demands and resulting wastewater production. Irrigation conservation measures have moved beyond simple watering restriction policies. Automatic irrigation equipment is now capable of adjusting the application of irrigation water based on real time climatic conditions. Encouragement of low water use landscape and xeriscaping are also effective tools for reduction of irrigation demand. Currently, the model takes into account region specific ET based irrigation demand schedules and allows the user to either increase or reduce the percent of demand that is met through irrigation.

#### 1.2.1.3 Graywater Reuse for Toilet Flushing and Irrigation

The collection and reuse of graywater for irrigation and toilet flushing can be carried out at the household and/or community scale. Dual plumbing is added to a residence or building in order to separate graywater and blackwater. Blackwater consists of toilet and kitchen wastewater while graywater includes all other wastewater sources including bathroom sinks, bathtubs, showers, and clothes washers. Collected graywater is stored in a tank for later use, in either irrigation or toilet flushing applications. IUWM allows the user to specify whether graywater toilet flushing and/or graywater irrigation will be applied and at what level of adoption community-wide. Also specified is the graywater storage tank volume.

#### 1.2.1.4 Wastewater Treatment Plant (WWTP) Reuse for Irrigation

The use of reclaimed wastewater has increased in popularity in cities where supply of raw water is very limited. Rather than treating and discharging wastewater to surface waters, the treated wastewater is routed back to the community through a separate distribution network for non-potable uses, primarily irrigation. An increased per volume cost is necessary for delivery of WWTP effluent and is considered in the model. Therefore, it is necessary to weigh the increased costs against the potential savings as a result of reductions in potable water demand. IUWM evaluates reclaimed water reuse by measuring the volume of wastewater produced and allowing the user to specify what percentage of wastewater will be available for irrigation use.

#### 1.2.1.5 Stormwater Capture Reuse for Irrigation

The most common form of stormwater capture reuse at the residential level is the use of rain barrels or cisterns which capture and store roof runoff for later use for landscape irrigation. There are instances in which stormwater capture is a logical and effective method of reducing irrigation demands. IUWM allows flexibility for the user to determine the total storage volume that is available in order to simulate systems from ranging from residential rain barrels to community cisterns or wet detention basins. A user defined volume available for capture specifies the portion of water user area that is impervious and contributes runoff that can be stored.

#### 1.2.2 Selection of Input Data Format

Design of IUWM was guided by the availability and the most common formats of input data (e.g. demands, land area, and population density). Decisions regarding the measurement units that IUWM would accept for indoor and irrigation demands, hydrologic records, and cost data were made based on the format which was found to be most reliably

and readily available to the end-user. During development to the model, the research team met with the water service division of the City of Fort Collins to demonstrate the model and receive feedback. It was brought to attention in the meeting that while the utility measured demands in terms of individual accounts, it would be possible to estimate population figures based on public records.

### 1.2.3 Basic Procedure for Using the Model

This report includes both basic and detailed instructions for use of IUWM. The basic approach to use of the model is included as a Quickstart walkthrough guide presented in the report and duplicated as a walkthrough sequence in the application itself. This guide allows a new user to become acquainted with the basic steps for creating a project and running a simulation. These steps include:

1. Create a new project which represents the entire watershed area.
2. Add service areas with unique water user categories.
3. Apply multiple water management practices with unique parameters.
4. Save a scenario.
5. Run a simulation.
6. View the results of the simulation.
7. Create Additional Scenarios

The steps can be repeated in order to create multiple scenarios and sets of saved results in order to compare the efficacy of each combination of water management practices.

### 1.3 Organization of this Manual and Other Available Documentation

This report details the development, functionality, and application of IUWM. Review of this document provides the user of the model with a strong understanding of its

capabilities and a practical understanding of how the included water management practices may be best applied. Chapter 2 describes how IUWM achieves its mass balance functions and handles treated water, wastewater, and graywater. Review and explanation of the water management practices included in the model closes the chapter. Chapter 3 includes a short tutorial that allows a new user to quickly gain an understanding of the basic steps in using the model. This tutorial mirrors the Quickstart walkthrough which is available in the model itself. After completing the tutorial or the walkthrough, a new user should be comfortable with creating a project, running a simulation, and viewing and exporting results. Chapter 4 takes a closer look at the organization of the model and all of the available interfaces and explains their functions and use. The chapter also includes an explanation of how IUWM handles running and saving simulation results and covers the review, comparison, and export of simulation results. Chapter 5 includes the results of case study application of the model over a range of hydrologic conditions in different regions of the United States. Selected cities include: Fort Collins, CO, Orlando, FL, Philadelphia, PA, San Diego, CA, and Seattle, WA.

## CHAPTER 2

### IUWM COMPUTATIONAL METHODOLOGY

IUWM applies a series of mass balance equations to determine water demand, wastewater production based on user inputs. Potential savings are computed based upon daily input data. These calculations are performed during user defined simulation periods and the results are saved into database files. Output may be viewed within IUWM in a summarized form or exported to common file formats for further analysis.

#### 2.1 Model Organization

The model is scalable from a neighborhood to a metropolitan scale. Water user groups are divided into service areas and water user categories within each service area. A service area may be an individual neighborhood or a portion of a city. Water user categories are units within a service area and define the types of water users. Examples include single-family residential, commercial, and industrial areas. Each of these categories may be applied repeatedly within a project or service area with unique characteristics.

#### 2.2 Data

An exhaustive search was performed for demand data in residential and commercial/industrial and institutional (CII) settings. End-use data was sought for inclusion in the model in order to provide accurate estimates of available graywater. While demand data for residential end-use was found to be available, location of demand data for CII end-

use proved to be much more difficult. Acquisition of irrigation demand data was also difficult across all sectors. Before using the model, the user must possess enough knowledge of their water user area in order to adequately describe its unique water users, population, and typical land use. In many cases CII water user demands are particularly difficult to determine and must be addressed on a case by case basis. Residential population and land use data is much more readily available as it is often a matter of public record.

Information about the water user population density and land uses must also be added by the user. Specifically, in the case of residential water users, the total water user area, average lot/development size, percent of lot/development that is irrigated, and persons per lot/development must be included for each water user category added to the model. CII users require the same input units of occupancy in terms of square feet of finished floorspace.

#### 2.2.1 Residential Indoor Demands

Residential water users can generally be defined in two separate categories. Single-family residential water users are typically defined as standalone homes that have separate water meters. Multi-family residential housing is most often apartment complexes that do not have supply separation.

##### 2.2.1.1 Review of Available Residential Indoor Demand Data

The data search revealed the most comprehensive source of end-use demand data continues to be the Residential End-uses of Water Study (REUWS) (Mayer, P.; DeOreo, W., 1999) study funded by the American Water Works Association Research Foundation (AWWARF). While the research is somewhat dated, it remains the most comprehensive and widely used reference for residential indoor water use. The results of the study suggest that residential indoor demands are quite consistent across North America. Therefore, the

residential indoor demand data included in IUWM is based upon the average of the 12 sites included in the study (Table 2-1).

Table 2-1 Default Residential Demands Included in IUWM

Study Site	Toilet	Clothes Washer	Shower	Faucet	Leak	Other Domestic	Bath	Dishwasher	Indoor Total
Seattle	17.1	12.0	11.4	8.7	5.9	0.0	1.1	1.0	57.1
San Diego	15.8	16.3	9.0	10.8	4.6	0.3	0.5	0.9	58.3
Boulder	19.8	14.0	13.1	11.6	3.4	0.2	1.4	1.4	64.7
Lompoc	16.6	15.3	11.1	9.9	10.1	0.9	1.2	0.8	65.8
Tampa	16.7	14.2	10.2	12.0	10.8	0.3	1.1	0.6	65.8
Walnut Valley WD	18.0	14.1	11.7	12.3	7.6	2.3	1.0	0.8	67.8
Denver	21.1	15.6	12.9	10.5	5.8	0.5	1.6	1.2	69.3
Las Virgenes MWD	15.7	16.8	11.4	11.2	11.2	1.1	1.3	0.9	69.6
Waterloo & Cambridge	20.3	13.7	8.3	11.4	8.2	6.0	1.9	0.8	70.6
Phoenix	19.6	16.9	12.5	9.6	14.8	2.2	1.2	0.8	77.6
Scottsdale & Tempe	18.4	14.5	12.6	11.2	17.6	5.0	0.9	1.1	81.4
Eugene	22.9	17.1	15.1	11.9	13.6	0.1	1.5	1.4	83.5
12 Study Sites	18.5	15.0	11.6	10.9	9.5	1.6	1.2	1.0	69.3

\*Values from REUWS (1999)

The REUWS includes detailed information on how end-use data was collected and analyzed, how end-use estimates may be made, and includes exploration of the difficulties inherent in making predictions of end-use. There is also a thorough discussion on the variations on end-use from household to household and region to region found during the data collection period.

A series of equations are included in the REUWS in an attempt to explain variations in end-use and provide a model for estimation of indoor demands. While this empirical model may yield more accurate estimates of total demand, the data required (e.g. income

level, age groups, and implementation of conservation measures) is very site specific and not readily available for inclusion in IUWM.

#### 2.2.1.2 Residential Indoor Demand Data Included in the Model

Residential indoor demands for the single-family and multi-family water user category types have been included in the model. These demands are described in gallons per capita day (gpcd) and are divided into individual end-uses which include: bath, clothes washer, dishwasher, faucets, leaks and consumption, shower, toilet, and other domestic demand. These values were taken from REUWS and are identical to the average of the average of the twelve study sites included in Table 2-1.

It should be noted that the REUWS did not include multi-family residential properties in the research that led to the default demands included in IUWM. However, the same values applied to single-family residential have been included for multi-family residential as well. Multi-family developments are often large apartment complexes that do not meter water use on a residence unit basis. This presents challenges in determining the actual demands of multi-family water users. Therefore, the default demands should be applied to multi-family developments with caution. The user has the option of adjusting these default demands and should if it is felt that the default values do not adequately reflect their demands.

#### 2.2.1.3 Residential Indoor Demand Data Supplied by User

Data describing each water user category must be supplied by the user. These values include the total water user land area, the average lot or development land area, and average population per lot or development . The user must also specify the cost of potable water delivery and municipal WWTP cost in terms of dollars per 1000 gallons.

## 2.2.2 Commercial/Institutional and Industrial Indoor (CII) Demands

CII users include all water users that do not fall into a residential category. This obviously makes the definition of typical demands very difficult as each type of CII user is quite different. However, in some cases CII water use is very significant and any water management initiative must address CII demand in order to be effective.

### 2.2.2.1 Review of Available Commercial Indoor Demand Data

The search for demand data for CII water users was difficult and it was determined that these demands are generally highly variable. Furthermore, a standard unit of measure upon which to base demand data does not currently exist. Therefore, it was deemed infeasible to include default values for CII water use. Instead, it is the responsibility of the user to make informed decisions about the CII water users in their area.

A report accompanying the REUWS was determined to provide the most comprehensive source of available commercial/institutional (CI) data. This report is entitled the Commercial and Institutional End-uses of Water Study (CIEUWS) (Dziegielewski, 2000) and includes the results of an ambitious attempt to quantify water demands across multiple sectors. The report was limited to five specific user types and only 24 data collection sites, primarily in the southwestern portion of the United States. CI user types included: restaurants, hotels/motels, office buildings, supermarkets, and schools. The report concludes that large variations exist even within the same type of CI water user and presents ranges of predicted demand for each type of CI user. While the study used trace metering equipment to monitor end-uses, the authors were careful to present CI water use results in terms of total indoor demand (Table 2-2).

Table 2-2 Ranges of CI Total Water Demand

User Type	Indoor Demand	Unit of Measure
Restaurants	163 to 563	gallons per square foot per year
Hotels/Motels	109 to 153	gallons per day per occupied room
Office Buildings	9 to 40	gallons per square foot per year
Supermarkets	20.0 to 40.3	gallons per square foot per year
Schools	2.2 to 6.7	gallons per school day per student

\*Values from CIEUWS (2000)

It should be noted the values included in the above table are the results of the field study alone, were extracted from the CIEUWS, and are not default demand values endorsed by this report or the authors of the CIEUWS. These values do, however, provide a representation of the variation that exists among CI users. However, it is noted that the scope of the CIEUWS did not include industrial applications and includes commercial/intuitional users only. The large volumes used by some industrial water users would likely make definition of default water demands almost impossible.

In addition to the data collection field study included in CIEUWS, the authors provided a thorough review of existing data and reports. The material should be reviewed by any water manager seeking to estimate CII use in their area. The existing data provides further guidance on typical demands for hospitals, laundries, car washes, etc. and has served as the basis for the popular, but antiquated, IWR-MAIN demand forecasting model.

While the CIEUWS is the most cited source of CI information, it is also limited and now quite dated. While searching for CII data sources, many newer publications and reports were found citing other works which in turn were citing the dated CIEUWS data. Fortunately, work aimed at gaining a better understanding of the end-use demands of CII water users is ongoing (Aquacraft, 2009). The California Public Utilities Commission has

taken a great interest in water use and has selected Aquacraft Inc. to carry out a large study to gather demand data across all sectors including CII. The results of the study were expected in late 2010 and may provide a comprehensive update to Aquacraft's other publications, the REUWS and CIEUWS. When made available, the data values may be incorporated into IUWM.

Another difficult aspect of assigning demand data to CII users is a lack of standards for units applied in describing daily demands. This is quite evident through review of the CIEUWS in which demands are also described per employee, per transaction, and per meal served. Without a standard unit of measure for CII demand, development of a robust dataset is very difficult. Central to this issue is a lack of support data upon which to develop an understanding of how CII sectors use water and means through which to measure total use. Work towards solutions to these issues was found to be developing towards use of geographic information systems (GIS) used in conjunction with public records in order to derive use patterns (Morales, 2009).

While the method proposed by Morales is not an entirely new concept, it does suggest a new approach to calibrating CII demand models for local applications. The method promotes incorporation of the increasing availability of parcel level land use and water billing databases. These databases are used to determine CII water user type, account data, and the ratio of heated and effective areas. This data is then used to derive weighted water user coefficients that are applied to a formula for CII use (Figure 2-1).

	n	Avg. Heated Area (sf)	HA/EA	Avg. Monthly Water Use (gal)	Weighted Water User Coef. (gal/hsf/mo)	Total Heated Area (sf)	% Heated Area in Sector	Total Water Use (mg/mo)	% Water Use in Sector
Commercial	1,207	17,521	0.94	70,678	4.03	21,148,443	52.7	85.31	66.8
Industrial	154	43,681	0.90	57,260	1.31	6,726,925	16.8	8.82	6.9
Institutional	496	24,744	0.97	67,630	2.73	12,272,985	30.6	33.54	26.3
Total CII	1,857	21,620	0.94	68,751	3.18	40,148,353	100.0	127.67	100.0

$$(\# \text{ of accounts}) \left( \frac{\text{avg. effective area}}{\text{account}} \right) \left( \frac{HA}{EA} \right) \left( \frac{\text{gallons}}{\text{sf of HA*month}} \right) =$$

*Avg. Monthly CII Water Use*

\*From Morales (2009)

Figure 2-1 Sample of Morales Method for CII Demand Estimates

While the method holds promise, the databases necessary to carry out the procedure are not yet widely available. If datasets such as these are made available, the possibility of incorporation of GIS technology into a model such as IUWM would certainly be possible. This would allow the user to select portions of a map for inclusion in a study and the demands would be automatically populated from the GIS datasets. This would not, however, eliminate the issue of the lack of end-use data.

Second only to the CIEUWS, the Watersmart Guidebook produced by East Bay Municipal Utility District (EBMUD, 2008) is considered the most up to date guidance for determination of CII demands. Though the publication is titled as a guide for new businesses, it includes a collection of typical end-use demand distributions for a large selection of CII water user types (Table 2-3).

Table 2-3 Selection of Typical CII Demand Distributions

Office Buildings		Beverage Manufacturers	
Landscape	27 %	Process	45 %
Kitchen & Other	11 %	Product	46 %
Domestic and Restroom	34 %	Restrooms & Other	4 %
Cooling and Heating	28 %	Cooling and Heating	5 %
Schools		Commercial & Retail Centers	
Landscape	31 %	Landscape	38 %
Kitchen & Other	11 %	Kitchen & Other	15 %
Restrooms	44 %	Domestic and Restroom	26 %
Cooling & Heating	12 %	Cooling and Heating	21 %
Hospitals		Restaurant & Fast-Food Outlets	
Landscape	10 %	Landscape	5 %
Kitchen	7 %	Kitchen & Other	47 %
Domestic & Restroom	31 %	Domestic & Restrooms	33 %
Cooling & Heating	23 %	Cooling & Heating	2 %
Sterilizers X-Ray Process	17 %	Other	13 %
Laundry	6 %		
Other	5 %		

\*Values from EBMUD (2008)

The guidebook is written as a user friendly manual that includes recommendations for conservation and methods for determination of potential savings for many CII sectors.

However, suggested CII demand data is not offered by the publication.

#### 2.2.2.2 Commercial Indoor Demand Data Included in the Model

Due to the wide variability in CII demands, default values have not been included with IUWM.

#### 2.2.2.3 Commercial Indoor Demand Data Supplied by the User

The large variation in CII indoor demands requires that special attention be paid to each user area. While the CIEUWS report includes an ambitious attempt to quantify the water demands of CII users, it was determined that the results would not be sufficient for

inclusion in IUWM. For this reason, default indoor demands for CII water users were not included in IUWM and they must be added manually to the model. Units of gallons per square foot per day were selected to describe demands for CII water users.

### 2.2.3 Irrigation Demands

Quantifying irrigation demand was a difficult task. Empirical data upon which default demands can be based is not readily available. Further complicating matters, irrigation demand data varies greatly between regions and municipalities. While many water managers and utilities have estimates of what irrigation demand is in their urban area, it is not typically made public. Therefore, alternative methods of determining irrigation demands were also considered.

#### 2.2.3.1 Review of Available Irrigation Demand Data

A popular method for estimating urban irrigation demand is to compare seasonal demands and separate out irrigation from indoor demand (Dziegielewski, 1992). The lowest demand months are considered as zero irrigation months and these months are used as a datum to determine irrigation demands during months in which irrigation does occur. While this method is effective, many assumptions are made about seasonal use and steps must be taken to ensure that leaks and consumption are accounted for. Furthermore, the method is not practical for regions that irrigate year round and subsequently have among the highest total irrigation demands. More advanced approaches to quantifying irrigation demand are being developed to address these issues through use of improved water user data (Palenchar, 2009).

Another method of estimating irrigation demand is through use of ET. ET based demand may be adjusted by a percent satisfied factor and published values are widely available. For example, irrigation manufacturers such as Irritrol (Irritrol, 2011) provide

regional ET values via an internet interface. In lieu of use of published values, predictions of ET may be derived through use of an empirical equation that considers factors such as solar radiation, humidity, and/or wind speed.

#### 2.2.3.2 Irrigation Demand Data Included in the Model

Default values have been included in IUWM in order to help facilitate use of the model and provide the user with a basis for creating projects. The review of available data served as a basis for selection of the data included in the model. The selected method of determination of irrigation demands for IUWM was ET based demand. Many sources of ET values exist and their use as a predictor of need for irrigation is well established. In IUWM, values from the aforementioned Irritrol website were included. The user may adjust these values by selecting a monthly percentage value of ET to determine irrigation demand. For example, during the non-growing seasons, this percentage should be set to zero, while in known months of high irrigation demand the ET can be set to more than 100% of ET. The resulting demand (calculated as depth per day) is then used in conjunction with population and land use data provided by the user to estimate the volume of water required for irrigation over a one year period.

#### 2.2.3.3 Irrigation Demand Data Supplied by the User

The included ET values may be applicable to residential and CII water user categories. However, it should be noted that the ET values included are for lawn watering applications and other types of landscaping require very different ET values. It is the responsibility of the user to determine appropriate ET values. The user must also supply an average percent of each water user category that is irrigated.

The percent of ET based demand satisfied by irrigation should also be addressed by the user. Regions that experience regular rainfall and therefore do not require that ET demand be met by irrigation should be adjusted accordingly. IUWM allows creation of custom irrigation demand schedules in order to allow the user to provide demand data specific to their region.

#### 2.3.4 Hydrologic Data

IUWM requires input of hydrologic data in inches of daily rainfall. A hydrologic region must be defined in order to run a simulation. This hydrologic data is essential to the use of the stormwater capture water management practice. Note that the hydrologic record will not impact simulation results if stormwater capture is not applied.

##### 2.3.4.1 Review of Available Hydrologic Data

The collection of hydrologic data is a well established practice and data is widely available from many sources. Daily rainfall records in excess of ten years of length were found to be available for the vast majority of regions in the United States.

##### 2.3.4.2 Hydrologic Data Included in the Model

Hydrologic data in terms of daily depths (inches/day) was retrieved from the National Climatic Data Center (NCDC) and has been included in the model. Hydrologic data for the five cities used for the case study included in Chapter 5 of this report were selected for inclusion in the model. The user can either choose to use this built in data by choosing the city most similar to their area of interest, or can instead enter city specific data. The data was collected from 1/1/2000 to 12/31/2009 at or near airports locations where possible. Instances of trace precipitation were treated as zero values.

##### 2.3.4.3 Hydrologic Data Supplied by the User

The selection of the hydrologic data included in IUWM was based on the climatological differences in the regions in which the cities are located. Use of these included hydrologic records in place of actual data from the user's region may result in less accurate results than if region specific data is used. Therefore, IUWM provides the option of adding hydrologic data. Details on adding hydrologic data to the model have been included in this report in section 4.3.

### 2.3 Calculations

IUWM calculates demand and wastewater production figures on a daily basis for each water user group included in a project. The results of each day's calculations are added to a database which may be exported for viewing in a spreadsheet file. A series of conditional control flow statements determine whether or not a calculation occurs based upon which water management practices are applied.

The input units for each water user in IUWM are based upon the water user category that defines the user. For instance, the population of a single-family water user category is described by the average persons per lot while the population of a multi-family water user category is described in terms of average persons per development. The model is capable of handling these differences as the units for each water user category are relative within the category. For example, in the case of population, user area is described in terms of average lot size for single-family and average development size for multi-family. This section presents the calculations performed in the model with single-family residential units. Note that all calculations are performed on a per day time step and therefore the designation of per day has been omitted from variable definitions.

### 2.3.1 Base Calculations

Each simulation calculates base values for water demand, wastewater production, and costs on a daily time step period. These base values are indicative of conventional practices or business as usual. These calculations are independent of the application of the selected water management practices. The results of these calculations are used in comparison with the results from application of the selected water management practices to determine potential savings.

Base demand per water user (2.3.1-1) is the combination of all demands input by the user.

$$D_T = d_b + d_{cw} + d_{dw} + d_f + d_l + d_s + d_t + d_{od} \quad (2.3.1-1)$$

Where:  $D_T$  = total indoor water demand per person (gallons/person)

$d_b$  = bath demand (gallons/person)

$d_{cw}$  = clothes washer demand (gallons /person)

$d_{dw}$  = dish washer demand (gallons /person)

$d_f$  = faucet demand (gallons /person)

$d_l$  = leak demand (gallons /person)

$d_s$  = shower demand (gallons /person)

$d_t$  = toilet demand (gallons /person)

$d_{od}$  = other demand (gallons /person)

Base treated water demand is separated into indoor demand (Equation 2-2) and irrigation demand (2.3.1-2).

$$T_b = A/L * D_T * P \quad (2.3.1-2)$$

Where:  $T_b$  = base total indoor water demand (gallons)

$A$  = water user area (acres)

$L$  = lot size (acres)

$D_T$  = demand per person (gallons/person)

$P$  = persons per lot

Base irrigation demand (2.3.1-3) is calculated with the average monthly ET values input by the user, adjusted by an ET demand satisfaction factor, and multiplied by the portion of the water user category user area that is irrigated.

$$I_b = ET * ET_{\%} * A * A_{\%} \quad (2.3.1-3)$$

Where:  $I_b$  = base total irrigation demand (gallons)  
 $ET$  = evapotranspiration demand (in)  
 $ET_{\%}$  = percent of evapotranspiration demand satisfied (%)  
 $A$  = user area (acres)  
 $A_{\%}$  = percent of area irrigated (%)

Base wastewater production (2.3.1-4) is simply the base indoor reduced by the volume of water described as being demand as a result of leaks.

$$W_b = T_b - (A/L * d_l * P) \quad (2.3.1-4)$$

Where:  $W_b$  = base total wastewater production (gallons)  
 $D_T$  = total demand per person (gallons/person)  
 $A$  = water user area (acres)  
 $L$  = lot size (acres)  
 $d_l$  = leak demand (gallons)  
 $P$  = persons per lot

The cost of treated water (2.3.1-5) is calculated as the combined total of indoor and irrigation volume multiplied by the specified dollar per gallon rate.

$$C_T = (T_b + I_b) * c_t \quad (2.3.1-5)$$

Where:  $C_T$  = base total cost of treated water (dollars)  
 $T_b$  = base indoor demand (gallons)  
 $I_b$  = base irrigation demand (gallons)  
 $c_t$  = cost of treated water (dollars/gallons)

The cost of wastewater treatment is simply the base wastewater production value multiplied by the cost per gallon rate.

$$C_W = W_b * c_w \quad (2.3.1-6)$$

Where:  $C_W$  = base waste production (gallons)

$W_b$  = base waste production (gallons)

$c_w$  = cost of wastewater treatment (dollars/gallons)

### 2.3.2 Water Management Practices Calculations

In addition to the calculations of the base values, IUWM performs a series of calculations for the selected water management practices and their associated parameters. The order in which these calculations are carried out is important to maintaining the mass balance in the model. A hierarchy of water management practices is implemented and each management practice respects those that preceded it. The following sections detail the calculations included in each water management practice in the order in which they are applied in the model.

#### 2.3.2.1 Indoor Conservation Calculations

Indoor water demands are divided into the most common household end-use applications. This division allows conservation efforts to be applied to each end-use. IUWM uses the reduced end-use demand values input by the user to determine the reduced demand per water user (2.3.2-1).

$$D_r = d_{br} + d_{cwr} + d_{dwr} + d_{fr} + d_{lr} + d_{sr} + d_{tr} + d_{odr} \quad (2.3.2.1-1)$$

Where:  $D_r$  = reduced demand per person (gallons/person)  
 $d_{br}$  = reduced bath demand (gallons/person)  
 $d_{cwr}$  = reduced clothes washer demand (gallons /person)  
 $d_{dwr}$  = reduced dish washer demand (gallons /person)  
 $d_{fr}$  = reduced faucet demand (gallons /person)  
 $d_{lr}$  = reduced leak demand (gallons /person)  
 $d_{sr}$  = reduced shower demand (gallons /person)  
 $d_{tr}$  = reduced toilet demand (gallons /person)  
 $d_{od}$  = reduced other demand (gallons /person)

This reduced demand is then used to calculate the reduced treated indoor water demand (2.3.2-2) and wastewater production (2.3.2-3) in the same manner as the base indoor demand and wastewater production calculations.

$$T_{rc} = A/L * D_r * P \quad (2.3.2.1-2)$$

Where:  $T_{rc}$  = reduced total indoor demand after conservation  
 $A$  = water user area (acres)  
 $L$  = lot size (acres)  
 $D_r$  = reduced demand per person (gallons/person)  
 $P$  = persons per lot

$$W_r = T_{rc} - (A/L * d_{lr} * P) \quad (2.3.2.1-3)$$

Where:  $W_r$  = reduced total wastewater production after conservation (gallons)  
 $T_{rc}$  = reduced total indoor demand after conservation (gallons)  
 $A$  = water user area (acres)  
 $L$  = lot size (acres)  
 $d_{lr}$  = reduced leaks per person (gallons/person)  
 $P$  = persons per lot

### 2.3.2.2 Irrigation Conservation Calculations

Reduced irrigation demand (2.3.2-4) is calculated with a percent reduction of the base irrigation demand specified by the user.

$$I_r = I_b - (I_b * F_{\%}) \quad (2.3.2.2-4)$$

Where:  $I_r$  = reduced total irrigation demand after conservation (gallons)  
 $I_b$  = base irrigation demand (gallons)  
 $F_{\%}$  = percent reduction (%)

While this is a rudimentary approach, it allows the user to approximate what level of reduction may be realized through implementation of one or more irrigation conservation measures.

### 2.3.2.3 Graywater Reuse for Toilet Flushing and Irrigation Calculations

Calculations involving graywater reuse for toilet flushing and irrigation consider the division of wastewater into graywater and blackwater sources. For purposes of the model, blackwater is considered to be wastewater from toilets, dishwashers, and a user specified portion of faucet demand that accounts for kitchen faucet wastewater which is not suitable for graywater applications. Available graywater (2.3.2-4) is considered to be the sum of indoor demands less blackwater and leaks.

$$G_A = (d_{br} + d_{cwr} + (d_{fr} * f_f) + d_{sr}) A / L * P * p_{\%} \quad (2.3.2.3-4)$$

Where:  $G_A$  = total graywater available for capture (gallons)  
 $d_{br}$  = reduced bath demand (gallons/person)  
 $d_{cwr}$  = reduced clothes washer demand (gallons/person)  
 $d_{fr}$  = reduced faucet demand (gallons/person)  
 $f_f$  = fraction of faucets contributing to graywater (%)  
 $d_{sr}$  = reduced shower demand (gallons/person)  
 $A$  = water user area (acres)  
 $L$  = lot size (acres)  
 $P$  = persons per lot  
 $p_{\%}$  = percent implementing the practice (%)

Graywater storage capacity (2.3.2-5) is determined by the average graywater storage volume and percentage of the water user category selected by the user to apply the practice.

$$G_c = g_c * A / L * p_{\%} \quad (2.3.2.3-5)$$

Where:  $G_c$  = total graywater storage capacity (gallons)  
 $g_c$  = average graywater storage volume per lot (gallons)  
 $A$  = water user area (acres)  
 $L$  = lot size (acres)  
 $p_{\%}$  = percent implementing practice

Three separate storage capacities are considered for each water user category in order to reflect the portion of the population implementing graywater reuse for flushing only, graywater reuse for irrigation only, and graywater reuse for both flushing and irrigation.

Available graywater is routed to storage as long as the storage capacity determined in equation 2.3.2-5 is not exceeded. Graywater volumes in excess of the storage capacity are added to wastewater production. This ensures that treated water demand reductions are not in excess of graywater supply and that excess graywater is not removed from wastewater production.

Graywater flushing takes precedence over graywater irrigation in order of operations. The result is that flushing demands are satisfied prior to the release of graywater to satisfy irrigation demands. The rationale for this order of operations is that in the case that a homeowner, business owner, or multi-resident building owner has gone through the trouble of installing a system for reuse of graywater for toilet flushing, the priority would be to first meet toilet flushing demands. Excess graywater and then be used for irrigation in combination with treated water. Both practices are respective of indoor and irrigation conservation calculations.

Reduced indoor demand resulting from graywater reuse (2.3.2.3-6) for flushing is calculated by reducing the toilet demand by the volume of graywater available for flushing.

$$T_{rf} = T_{rc} - G_{sf} \quad (2.3.2.3-6)$$

Where:  $T_{rf}$  = reduced total indoor demand after conservation and graywater flushing (gallons)  
 $T_{rc}$  = reduced total indoor demand after conservation (gallons)  
 $G_{sf}$  = stored graywater (gallons)

Reduced irrigation demand from graywater reuse (2.3.2.3-7) for irrigation is calculated by reducing also results in reduced wastewater production (2.3.2.3-8).

$$I_{rg} = I_{rc} - G_{si} \quad (2.3.2.3-7)$$

Where:  $I_{rg}$  = reduced total irrigation demand after conservation and graywater irrigation (gallons)  
 $I_{rc}$  = reduced total irrigation demand after conservation (gallons)  
 $G_{si}$  = stored graywater after graywater flushing (gallons)

$$W_{rg} = W_r - (I_{rg} - I_r) \quad (2.3.2.3-8)$$

Where:  $W_r$  = wastewater reduced by conservation (gallons)  
 $I_{rg}$  = irrigation demand reduced by graywater reuse (gallons)  
 $I_r$  = irrigation demand reduced by conservation (gallons)

#### 2.3.2.4 Wastewater Treatment Plant (WWTP) Reuse Calculations

Calculations for reuse of wastewater treatment effluent in irrigation applications have a direct impact of irrigation demand based on the availability of wastewater specified by the user. Total wastewater production that may be captured is adjusted by indoor conservation and graywater applications prior to consideration in WWTP reuse applications. The volume of WWTP effluent available for irrigation is calculated as a percent of wastewater production available for reuse (2.3.2.4-1).

$$E_A = W_{rg} * E_{\%} \quad (2.3.2.4-1)$$

Where:  $E_A$  = total volume of WWTP effluent available for irrigation (gallons)  
 $W_{rg}$  = reduced total wastewater production after graywater reuse (gallons)  
 $E_{\%}$  = percent of effluent available for reuse (%)

This practice results in a reduction in irrigation demand (2.3.2.4-2) while not affecting wastewater production.

$$I_{rw} = I_{rg} - E_A \quad (2.3.2.4-2)$$

Where:  $I_{rw}$  = reduced total irrigation demand after conservation, graywater irrigation, and WWTP reuse for irrigation (gallons)  
 $I_{rg}$  = reduced total irrigation demand after conservation and graywater reuse for irrigation (gallons)  
 $E_A$  = total volume of WWTP effluent available for irrigation (gallons)

An additional cost per volume of WWTP effluent delivered specified by the user is applied to the total cost. This cost of WWTP delivery (2.3.2.4-3) is simply the volume of WWTP effluent used for irrigation multiplied by the cost for delivery per 1000 gallons.

$$C_E = E_U * c_e \quad (2.3.2.4-3)$$

Where:  $C_E$  = total cost of WWTP delivery (dollars/gallons)  
 $E_U$  = total volume of WWTP effluent used for irrigation (gallons)  
 $c_e$  = unit cost of WWTP effluent delivery (dollars/gallons)

### 2.3.2.5 Stormwater Capture for Irrigation Calculations

Use of stormwater capture for irrigation directly impacts treated water demands. Stormwater available for capture (2.3.2.5-1) is determined by the daily precipitation values, average lot size, and average portion of the lot that produces runoff available for capture.

$$H_A = R/12 * A * I_{\%} * p_{\%} \quad (2.3.2.5-1)$$

Where:  $H_A$  = total stormwater available for capture (acre-inches)

$R$  = depth of rainfall (inches)

$A$  = water user area (acres)

$I_{\%}$  = percent impervious (%)

$p_{\%}$  = percent implementing practice

Stormwater capture capacity (2.3.2.5-2) is calculated in a manner very similar to graywater reuse.

$$H_c = h_c * A/L * p_{\%} \quad (2.3.2.5-2)$$

Where:  $H_c$  = total stormwater storage capacity (gallons)

$h_c$  = average stormwater capture volume per lot (gallons)

$A$  = water user area (acres)

$L$  = lot size (acres)

$p_{\%}$  = percent implementing practice

The primary difference between stormwater capture for irrigation and graywater reuse for irrigation is that the volume available for capture is dictated by the hydrologic record. The user may choose to manipulate the model in order to model the capture volume as rain barrels, community cisterns, or wet detention basins.

The portion of area that produces runoff can be a representation of a roof, paved surface, or other impervious areas. The volume of stormwater available for irrigation is handled in a manner similar to graywater reuse for irrigation in that stormwater in excess of the maximum storage capacity is not available for capture. The reduced irrigation demand (2.3.2.5-3) is determined by subtracting the stormwater available for irrigation.

$$I_{rh} = I_{rw} - H_A \quad (2.3.2.5-3)$$

Where:  $I_{rh}$  = irrigation demand reduced by stormwater capture for irrigation (gallons/day)

$I_{rw}$  = irrigation demand reduced by WWTP reuse for irrigation (gallons)

$H_A$  = stormwater available for irrigation (gallons)

## 2.4 Outputs

The application annualizes and reduces the results to present the user with results in terms of millions of gallons per year (Mgal/yr) or millions of dollars per year (M\$/yr). The results of the calculations carried out in an IUWM simulation are stored in a Microsoft Database (.mdb) file. The user may view the database file directly with a database application such as Microsoft Access. IUWM also provides the option of exporting results to comma separated variable (.csv) and Microsoft Excel (.xls) file formats. Details of the export procedure are included in section 4.8.

## CHAPTER 3

### GETTING STARTED WITH IUWM

#### 3.1 Installing IUWM

IUWM has been designed to work on any version of Microsoft Windows XP/Vista/7 operating systems. The only requirement is the presence of the Microsoft .NET 2.0 framework which comes preinstalled on Vista and 7 computers and has been installed as a recommended update on the majority of XP computers. XP computers that do not already have the .NET 2.0 framework installed can be easily upgraded by visiting the Microsoft Update website.

Installation of IUWM should be performed by unpacking the compressed archive and extracting the contents to a temporary location. The contents include the user's manual and the installation files. The preferred installation method is through use the Microsoft Installer file named `iuwm_installer.msi`. Also included is an executable file named `iuwm_installer.exe` that may be used in some cases in the Microsoft Installer fails to start due to differences in operating systems. The installer provides the option of where to install IUWM (Figure 3-1).

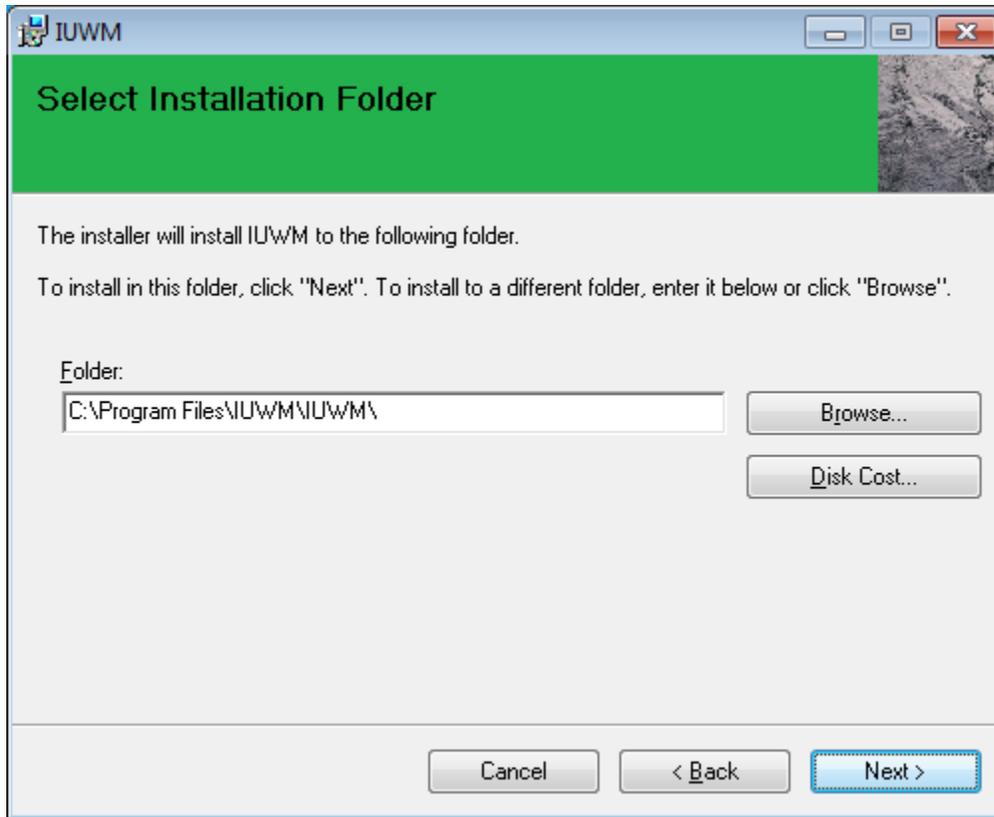


Figure 3-1 IUWM Installer Window

The default location is in 32-bit Program Files folder on the local hard drive. After installation, shortcuts to run or uninstall the application are added to the desktop. Uninstalls may be performed through use of the shortcut or through the windows operating system (Figure 3-2).



Figure 3-2 IUWM Shortcuts

Note that IUWM is a very minor installation and does not make any changes to the system registry. Uninstalls may also be performed through use of the Windows control panel.

### 3.2 Quickstart Utility

Included in IUWM is a *Quickstart* walkthrough utility which guides a new user through the steps of creating a new project, adding water users, applying running a simulation, and viewing results. The *Quickstart* is entered through clicking the **Quickstart** button on the *IUWM Main Interface* window (Figure 3-3).

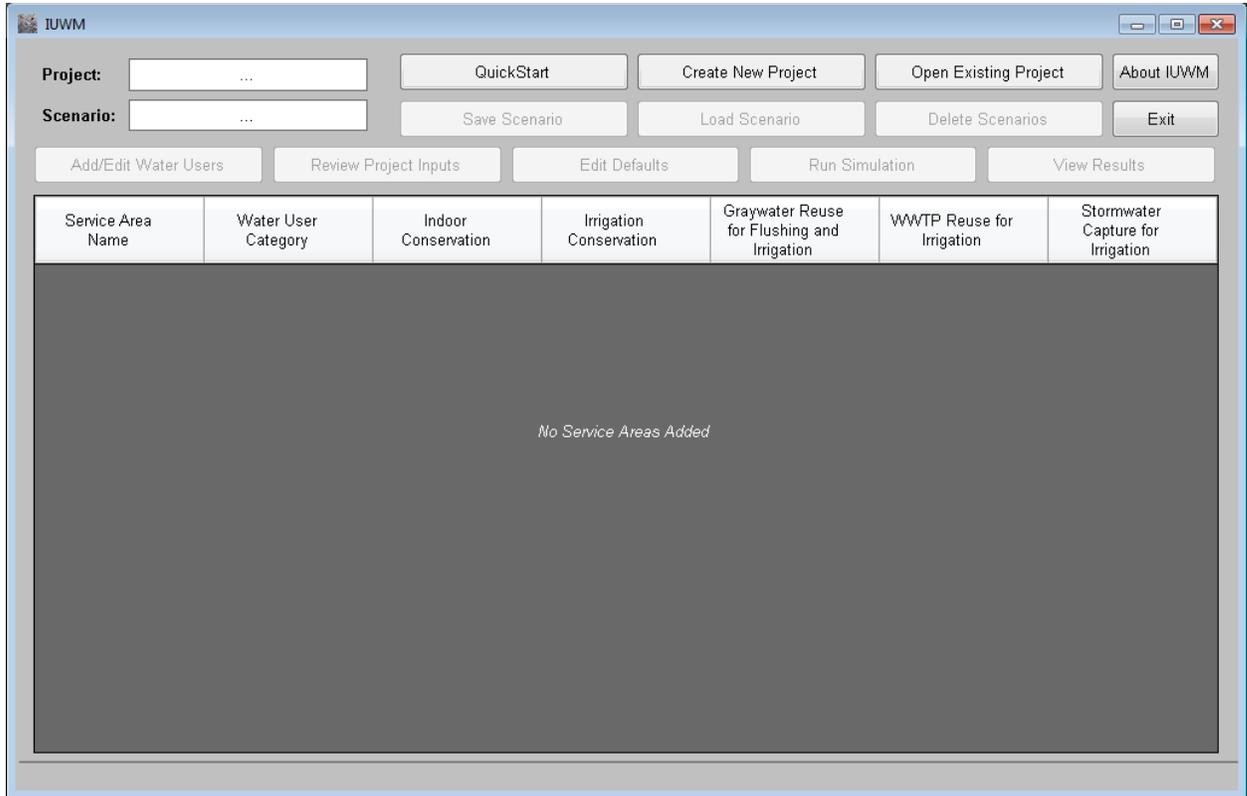


Figure 3-3 IUWM Main Interface Window

Each step in the walkthrough includes a dialog window with instructions to assist a new user in becoming familiar with the application (Figure 3-4).

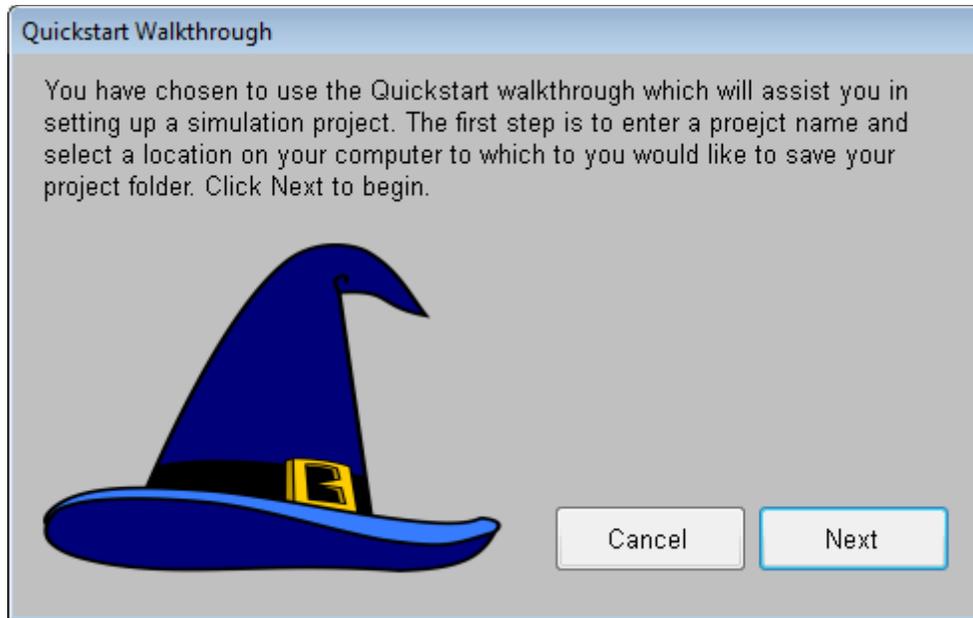


Figure 3-4 Quickstart Walkthrough Window

Clicking the **Next** button on each *Quickstart Walkthrough* window advances the user to the next step. This section describes each of the steps included in the walkthrough.

### 3.3 Step 1: Create a New Project

The first step in creating a new IUWM project is entering a project name in the *Create New Project* window (Figure 3-5).

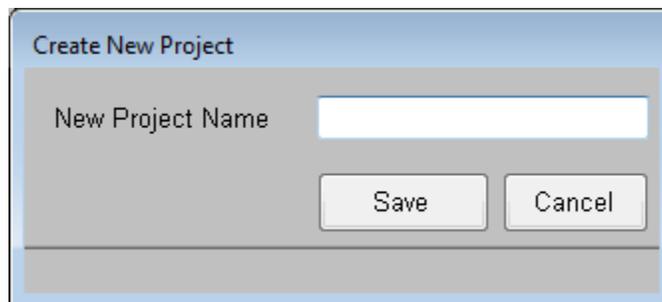


Figure 3-5 Create New Project Window

The project name is intended to identify the largest or entire area to be investigated. Suggested levels of delineation are watersheds, counties, or cities.

After clicking the **Save** button on the *Create New Project* window, the *Browse for Folder* window appears and prompts the user to select a location to save the new project (Figure 3-6).

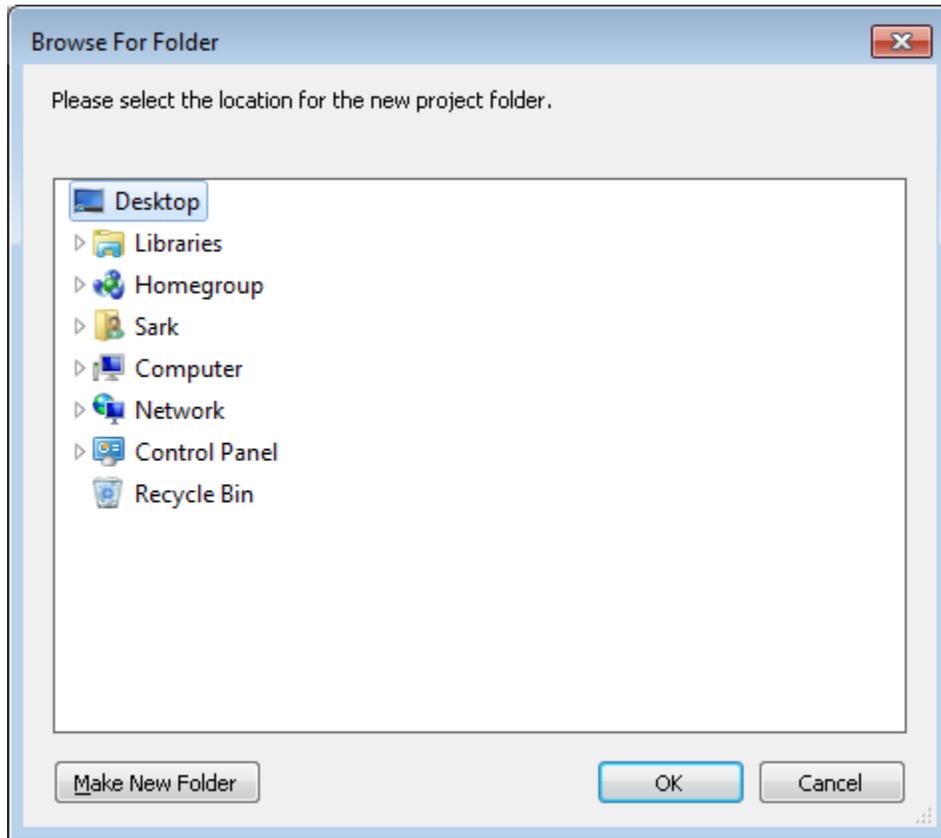


Figure 3-6 Browse for Folder Window

A project folder with the project name is added to the selected location. All files and databases related to the new project are stored within this folder.

After clicking the **OK** button on the *Browse for Folder* window, the *Define Project Defaults* window appears (Figure 3-7).

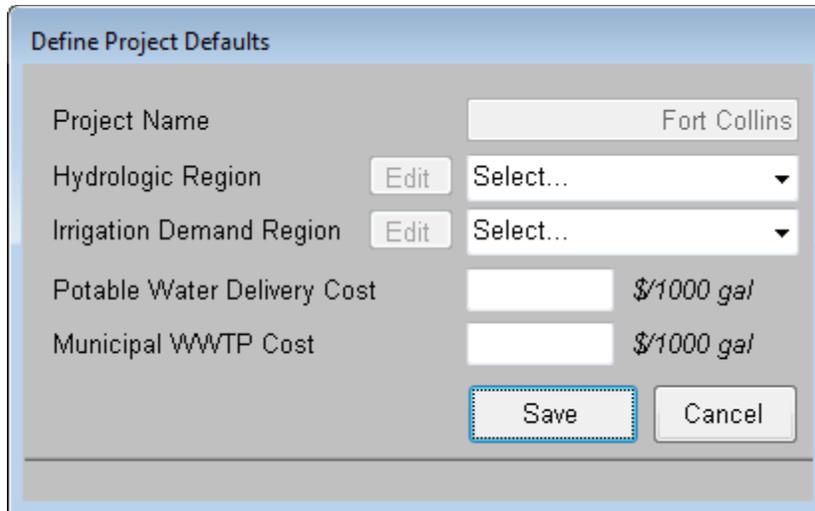


Figure 3-7 Define Project Defaults Window

Default hydrologic, irrigation, and cost data are input in this window. These defaults are then applied to each new water user added to the project. The default values may be changed later from the *IUWM Main Interface*. Details on changing default value assignments are included in section 4.4. It is important to note that with the exception of hydrologic region data, changing default values does not have retroactive effects on water user categories that have been previously added.

The Hydrologic Region and Irrigation Demand Region dropdown list boxes include default data for select cities (Fort Collins, Orlando, Philadelphia, San Diego, and Seattle). Section 2.4 describes the source of this data. In addition to the included default values, the user may chose to Create Custom Hydrology or Irrigation datasets. The process to create these custom datasets is included in section 4.4.

After default values have been selected, clicking the **Save** button on the *Define Project Defaults* window advances the walkthrough to the next *Quickstart Walkthrough* window (Figure 3-8).

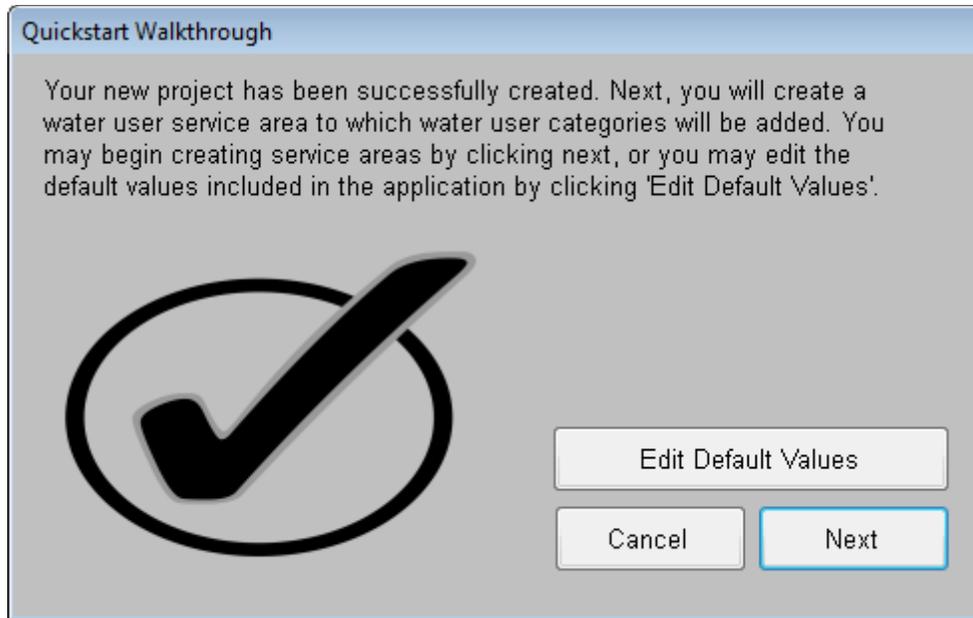


Figure 3-8 Quickstart Walkthrough Window

The option to edit default values is presented on this *Quickstart Walkthrough* window with the **Edit Default Values** button. Details on editing default values are included in section 4.4. Clicking the **Next** button completes the process of creating a new project, closes the *Quickstart Walkthrough* window and opens the *Create New Service Area* window to begin the process of adding water users to the new project (Figure 3-9).

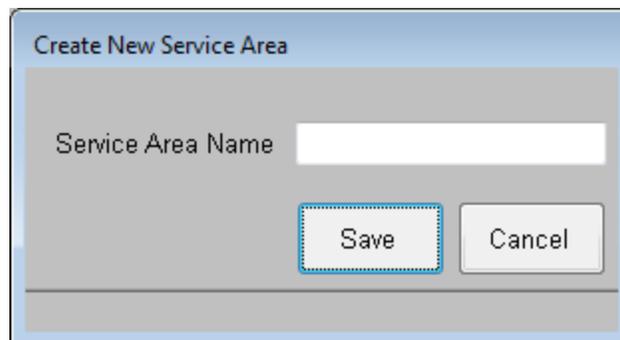


Figure 3-9 Create New Service Area Window

### 3.4 Step 2: Add Service Areas and Water User Categories

A typical IUWM project includes a collection of services areas that make up a watershed, county, or city. The first step in adding water users to a project is the input of a service area name in the *Create New Service Area* window.

After entering a name for the new service area and clicking **Create**, the *Add Water User Category* window appears and prompts the user to specify the details of the water user (Figure 3-10).

Field Name	Value / Unit
Service Area Name	West Fort Collins
Water User Category	Select...
Irrigation Demand Region	Fort Collins
Average Indoor Demand	[ ] gpcd
Water User Area	[ ] acres
Average Lot Size	[ ] acres
Average Percent of Area Irrigated	[ ] %
Average Persons per Lot	[ ]
Potable Water Delivery Cost	2 \$/1000 gal
Municipal WWTP Cost	3 \$/1000 gal

Figure 3-10 Add Water User Category Window

The irrigation demand region, potable water delivery cost, and municipal WWTP cost fields are automatically populated from the default values added during the creation of the project. Before the remaining fields can be filled, the user must select a water user category from the dropdown list box. The options included in the list box include: Single-Family

Residential, Multi-Family Residential, Commercial/Institutional, and Industrial. The option to create a custom category is also included in the list box. Details on adding a custom category are included in section 4.4.

Note that the units to the right of the fields on the *Add Water User Category* window change depending on the water user category selected. Selecting either single-family or multi-family residential populates the average indoor demand field and associated values with the default values included in IUWM. Information on these included defaults is included in section 2.4. Selecting either commercial/institutional or industrial changes average indoor demand values of zero, forcing the user to independently estimate this demand. The rationale for this is included in section 2.4. In short, demands for these types of water users vary greatly and reliable default values are not available.

Values for indoor demands may be added or edited by clicking on the **Edit** button to the left of the field. Performing this action is absolutely necessary if adding commercial/institutional or industrial categories. Details on editing the average indoor demand and associated values are included in Section 4.4.

The total size of the water user area is defined in acres for residential categories and in square feet for commercial/institutional or industrial categories. The average size of the lot, or development in the case of multi-family, is defined in terms of acreage. The average percent of area irrigated is used in conjunction with evapotranspiration values specified in the default irrigation demand region to determine the irrigation demand. The specified value for average persons per lot, or development in the case of multi-family, is used with other inputs to determine total indoor demand.

After successfully creating a new water user category, a dialog window prompts whether additional water user categories should be added to the new service area. Clicking the **Yes** button opens the *Add Water User Category* window. Clicking the **No** button ends the process of adding water user categories to the new service area and the next *Quickstart Walkthrough* window opens and provides the option of adding an additional service area with the **Create Another Service Area** button (Figure 3-11).

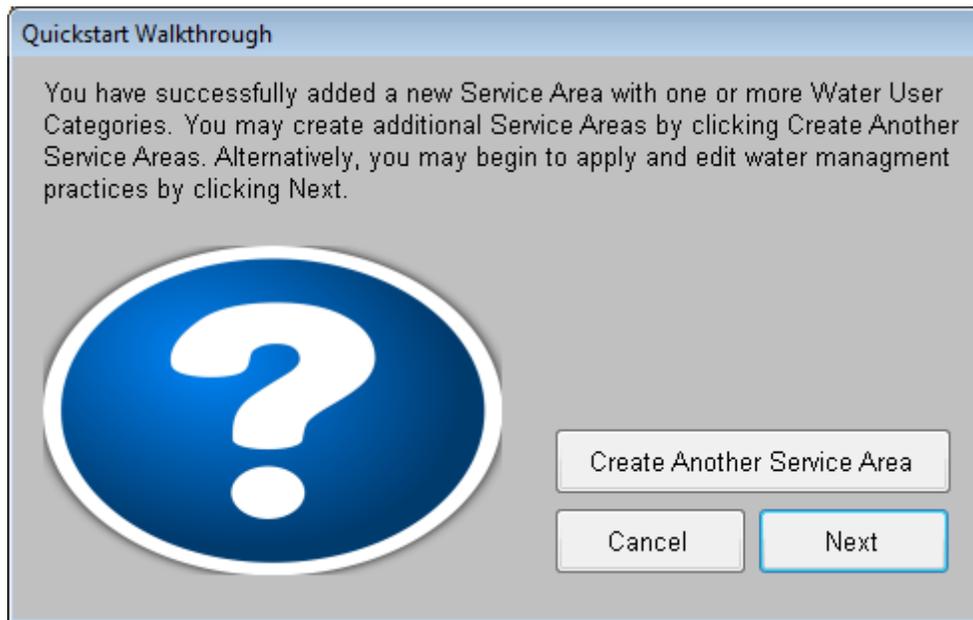


Figure 3-11 Quickstart Walkthrough Window

Of note is that changes can be made to water user categories at any time through use of the *Water User Browser* window which is accessed from the *IUWM Main Interface* window. Details of using the *Water User Browser* are included in section 4.2. Clicking the **Next** button opens the next *Quickstart Walkthrough* window (Figure 3-12).

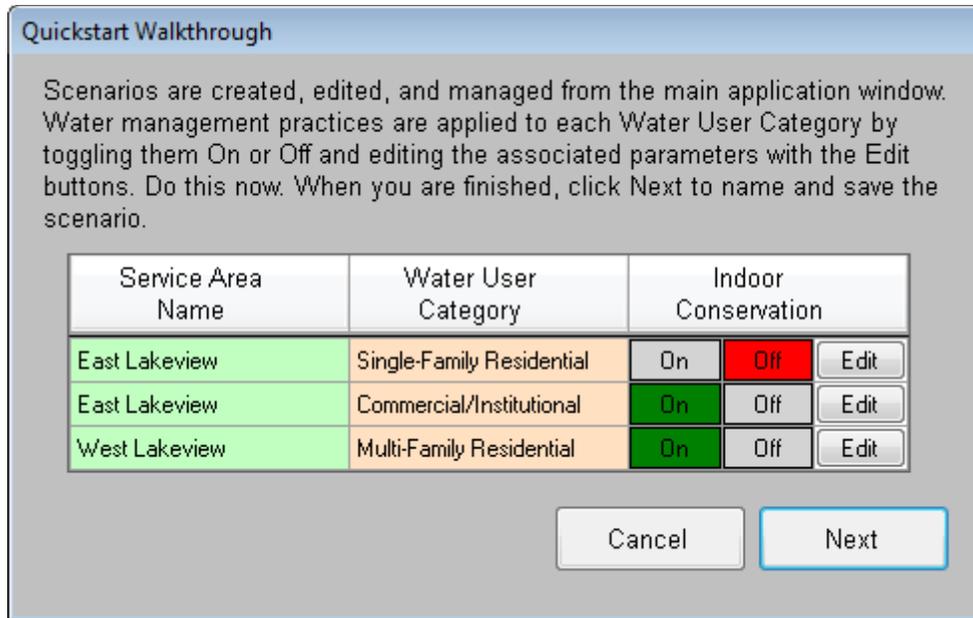


Figure 3-12 Quickstart Walkthrough Window

### 3.5 Step 3: Apply Water Management Practices

The function of this *Quickstart Walkthrough* window differs from previous *Quickstart Walkthrough* windows in that it allows the user to make changes to the *IUWM Main Interface* while it is open, thus providing guidance to the user as they work through applying water management practices for each user category. All other options on the *IUWM Main Interface* are locked during this process in the *Quickstart*. The user is now able to begin selecting which water management practices are to be applied to the individual water user categories.

Each of the available water management practices are displayed on the *IUWM Main Interface* with **On**, **Off**, and **Edit** buttons to the right of each water user category (Figure 3-13).

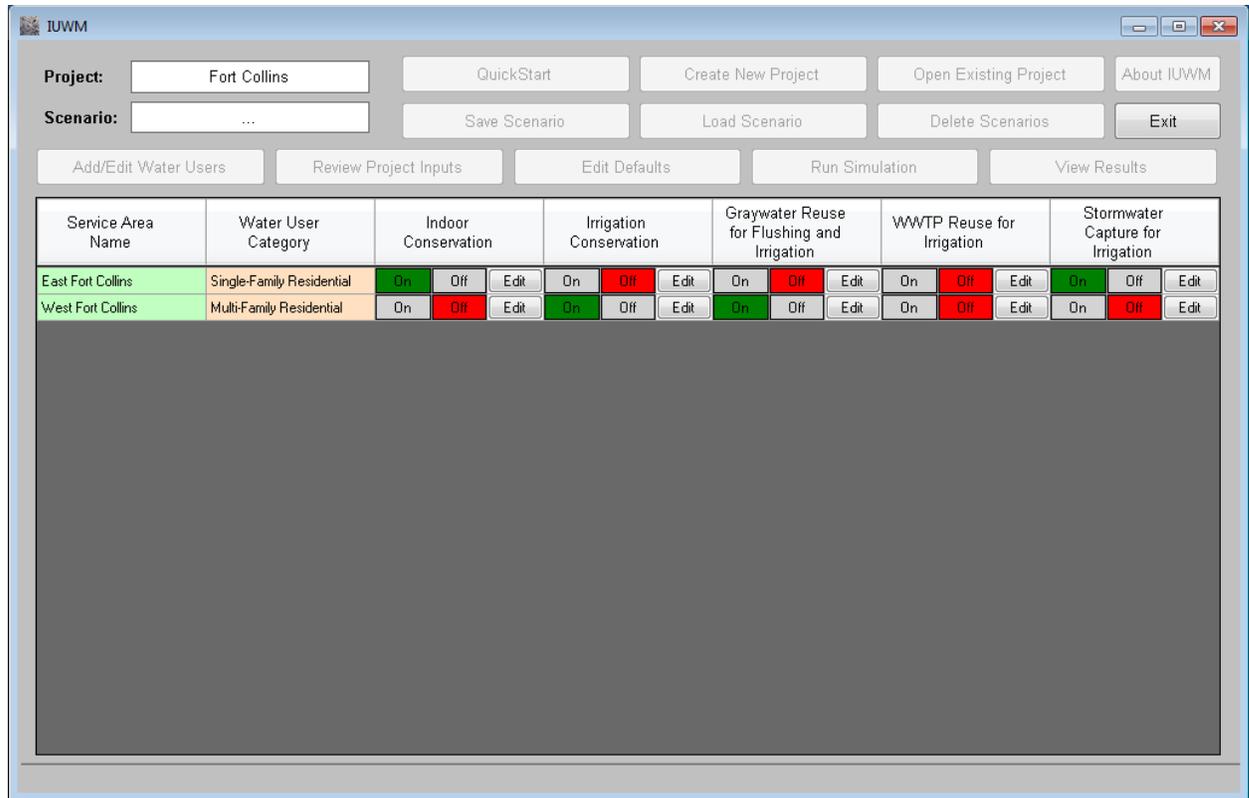


Figure 3-13 IUWM Main Interface

Practices are applied by toggling the **On** and **Off** buttons. Clicking the associated **Edit** button opens a window which includes the required parameter input for each practice. For example, clicking the **Edit** button below indoor conservation opens the *Edit Indoor Conservation Parameters* window (Figure 3-14).

**Edit Indoor Conservation Parameters**

**West Fort Collins - Multi-Family Residential**

	Base Demands (gpcd)	Reduced Demands (gpcd)	(Slide to Adjust)	Percent Reduction (%)
Low Flow Toilets	16.68	12.51	◀ [Slider] ▶	25
Low Flow Clothes Washer	14.3	14.30	◀ [Slider] ▶	0
Low Flow Shower Head	11.22	11.22	◀ [Slider] ▶	0
Low Flow Faucets	9.31	5.59	◀ [Slider] ▶	40
Low Flow Dishwasher	0.9	0.90	◀ [Slider] ▶	0
Reduced Capacity Bathtubs	1.16	1.16	◀ [Slider] ▶	0
Consumption/Leaks	8.78	8.78	◀ [Slider] ▶	0
Other Demands	0	0.00	◀ [Slider] ▶	0

Figure 3-14 Edit Indoor Conservation Parameters Window

Reduced demands are adjusted in this window through either typing a new value in the field or using the slider bar. It is important to note that changes made to each set of water management practice parameters apply only to the water user category noted at the top of the current window. Details of each of the water management practice parameters windows are covered in detail section 4.3.

After the desired water management practices have been applied and their parameters have been adjusted, the user must return to the *Quickstart Walkthrough* to proceed. Clicking the **Next** button closes the *Quickstart Walkthrough* window and the user is prompted to input a scenario name on the *Save Scenario* window (Figure 3-15) in order to save the current IUWM configuration.

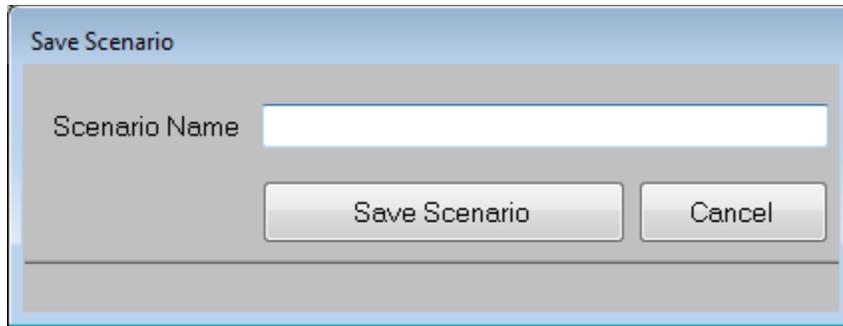


Figure 3-15 Save Scenario Window

#### 3.6 Step 4: Save Model Setup as a Scenario

IUWM requires that at least one scenario be created and saved prior to running a simulation. Each scenario is a snapshot of the user data and water management practices that are currently loaded into IUWM. There is no limit to the number of scenarios that can be saved. This allows the user to later compare the results of the different scenarios. In order to maintain database integrity, special characters and spaces are not allowed to be used in scenario names.

After inputting a scenario name into the *Save Scenario* window and clicking the **Save Scenario** button, the final *Quickstart Walkthrough* window appears and notifies the user that they are ready to run a simulation (Figure 3-16).

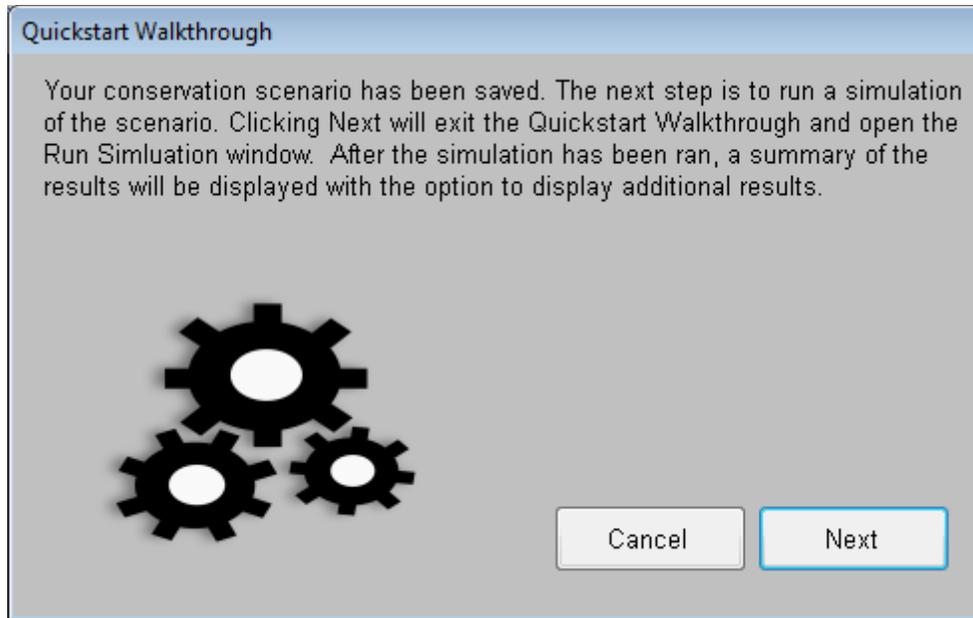


Figure 3-16 Quickstart Walkthrough Window

Clicking the **Next** button closes the *Quickstart Walkthrough* and opens the *Run Simulation* window (Figure 3-17).

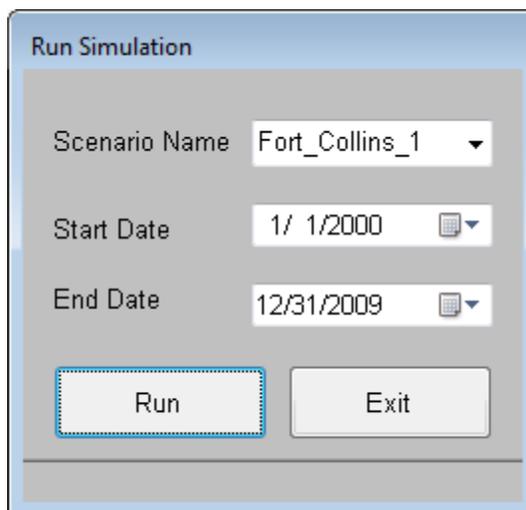


Figure 3-17 Run Simulation Window

### 3.7 Step 5: Run a Simulation

The *Run Simulation* window requires the user to select a Scenario from the dropdown list box. By default, the Scenario currently loaded into IUWM is selected. Other Scenarios

may be selected and simulated without altering the configuration of the currently loaded Scenario.

The user must also define the period through which the simulation should run. The length of the Simulation is only limited by the hydrologic data associated with the Scenario. By default, the Start and End Date values are populated with the start and end dates included in the associated hydrologic demand data. Dates outside the hydrologic record are rejected and the user is prompted to rectify the problem. All hydrologic regions included in IUWM have a 10 year time span. Longer simulations can be run with the addition of longer hydrologic data records. Details of the process for editing and creating custom hydrologic demand regions are included in section 4.4.

Clicking the **Run** button starts the simulation. Alternatively, clicking the **Exit** button closes the window and returns the user to the *IUWM Main Interface* window. The user is notified when the Simulation is complete and is prompted to click an **OK** button in order to close the *Run Simulation* window and view the results in the *Simulation Results Summary* window (Figure 3-18).

Simulation Results Summary		
	Base Values	Fort_Collins_1
Treated Indoor Water Demand (Mgal/yr)	462.44	402.93
Wastewater Production (Mgal/yr)	397.30	337.82
Treated Irrigation Demand (Mgal/yr)	403.35	403.35
Total Treated Water Cost (\$M/yr)	1.73	1.61
Wastewater Treatment Cost (\$M/yr)	1.19	1.01
WWTP Effluent Delivery Cost (\$M/yr)	0.00	0.00
Total Cost (\$M/yr)	2.92	2.63
Total Treated Water Savings (Mgal/yr)		59.52
Wastewater Reduction (Mgal/yr)		59.48
Total Scenario Cost Saving (\$M/yr)		0.30

Figure 3-18 Simulation Results Summary Window

### 3.8 Step 6: Review Simulation Results

The *Simulation Results Summary* window presents a summary of the current simulation results. The base values for each result are presented beside the results of the water management practice scenario named above the right hand column. Clicking the **More Results** button opens the *View Results* window which provides additional views of results. A full explanation of the *View Results* window has been included in section 4.6. Clicking on the **Export Summary** button allows the user to send the results summary values to a comma separated variable (.csv) file that may be viewed in a spreadsheet application such as Microsoft Excel or a text file viewer utility. Details on exporting results have been included in section 4.8.

### 3.9 Step 7: Create Additional Scenarios

Additional scenarios may be created at any time by clicking the **Save Scenario** button on the *IUWM Main Interface*. If an existing scenario is already loaded, IUWM prompts the user as to whether the or not it is okay to overwrite the current scenario (Figure 3-19).

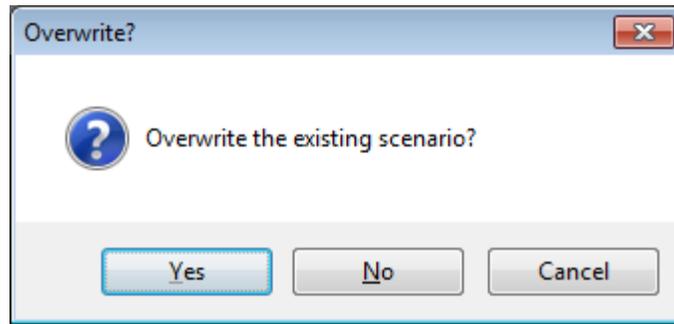


Figure 3-19 IUWM Overwrite Prompt

Clicking the **Yes** button results in the scenario being updated with the latest project inputs. Clicking the **No** button opens the *Save Scenario* window again to allow the user to enter a new scenario name. Existing scenarios may also be loaded or deleted from the *IUWM Main Interface*. Details on working with scenarios have been included in section 4.5.

## CHAPTER 4

### DETAILED MODEL FUNCTIONS

This chapter of the manual provides an expanded explanation of the features and functions in the model. It is intended as a supplement to the previous chapter and attempts to clarify and expand upon the upon the model capabilities. The *Quickstart Walkthrough* is not addressed in this chapter and an advanced approach to use of the model is introduced.

#### 4.1 Creating, Saving, and Opening IUWM Projects

Clicking the **Create New Project** button on the *IUWM Main Interface* prompts the user to select a name and save location for a new project folder (Figure 4-1). Default values for hydrologic region, irrigation demands, and cost data are also required. The new project is contained within a single folder with the name of the project. IUWM adds three Microsoft Access Database (.mdb) files to the folder. These files contain the default properties of the project in addition to the included hydrologic and irrigation data.

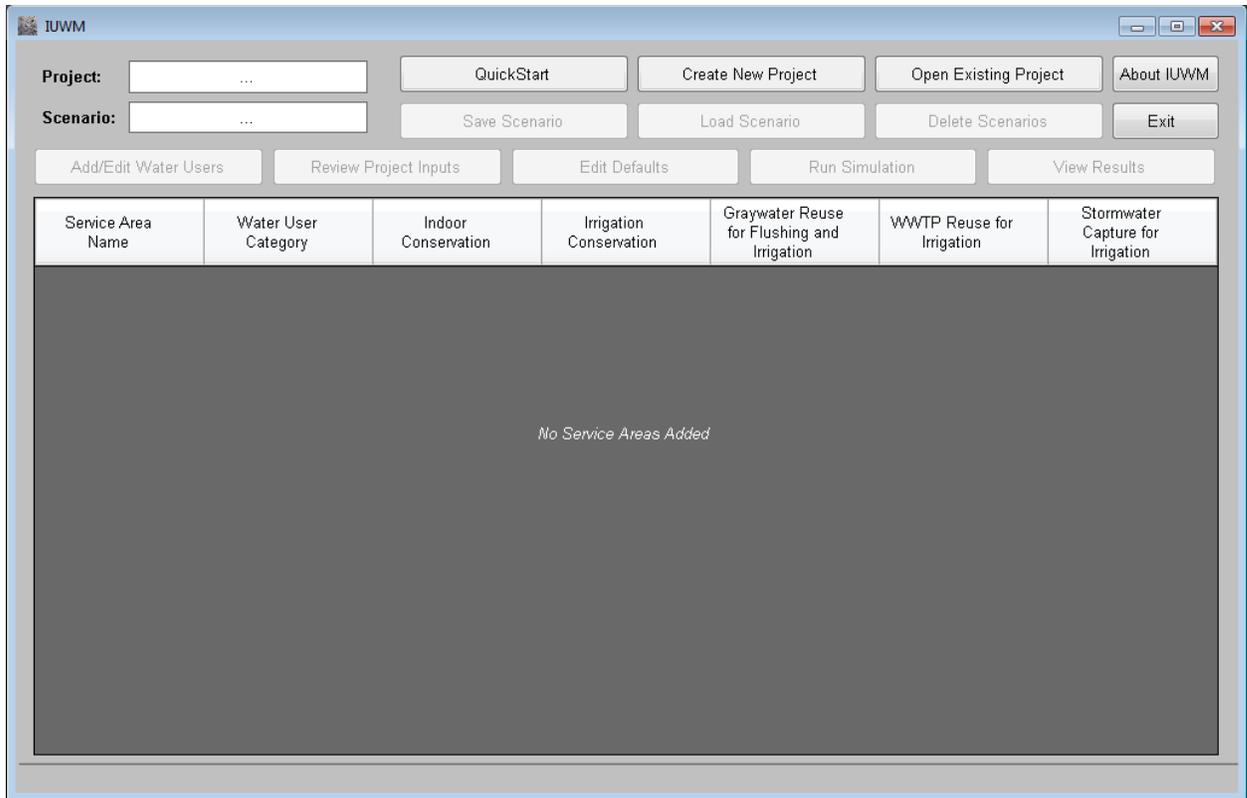


Figure 4-1 IUWM Main Interface

IUWM saves changes to a project in real time. Therefore, it is not necessary to save at the project level. However, it is necessary to save changes made to individual scenarios as they are adjusted. This is particularly important when making changes to scenarios and running simulations. A saved scenario is not updated until the user specifies that the existing scenario with the specified name is overwritten or a new scenario is created. Details of working with scenarios are included in section 4.4.

Opening a previously created IUWM project is achieved through clicking on the **Open Existing Project** button on the *IUWM Main Interface*. The user navigates to and selects the location of the IUWM project folder from the *Browse for Folder* window (Figure 4-2).

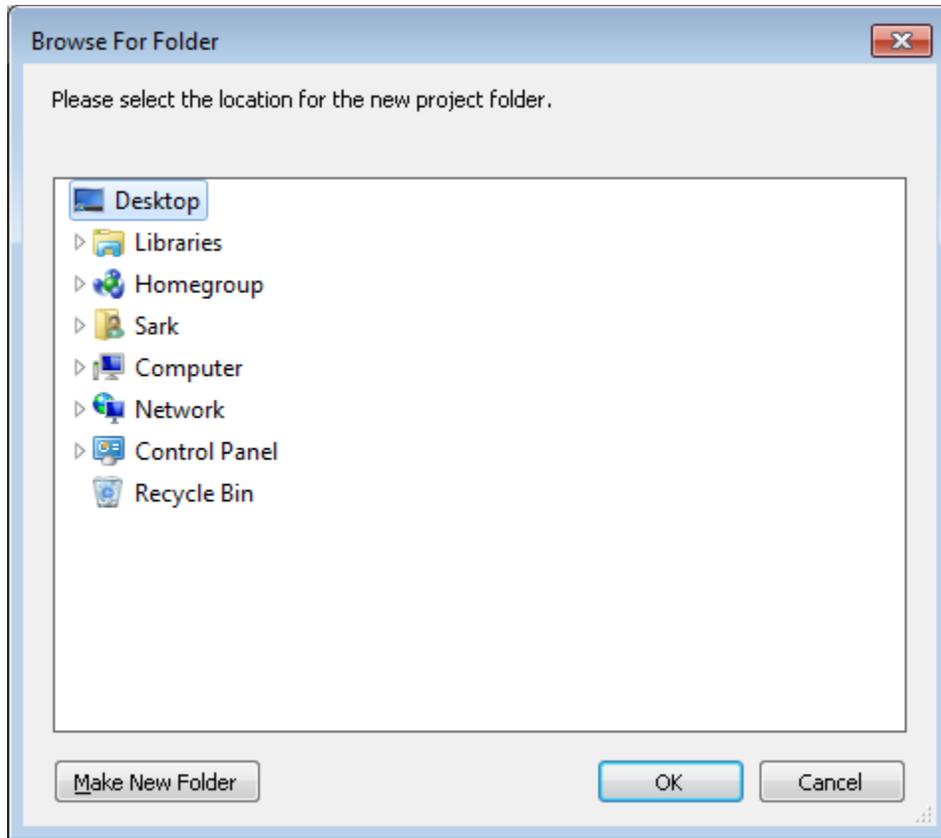


Figure 4-2 Browse for Folder Window

It is important to note that only one project may be open at a time in IUWM. The user is notified that the open project will be closed if they proceed with opening an existing project.

#### 4.2 Adding, Editing, and Deleting Water Users

After a project has been created or opened, the user may add water users to the project by clicking the **Add/Edit Water Users** button on the *IUWM Main Interface* to open the *Water User Browser* window (Figure 4-3).

The screenshot shows a software window titled "Water User Browser". At the top, there are two navigation buttons: "<< Previous Water User" and "Next Water User >>". To the right of these is a counter "0/0". Below the navigation are several data entry fields:

- Service Area Name:** A text input field with an "Add New Service Area" button to its right.
- Water User Category:** A text input field with an "Add New Water User Category" button to its right.
- Irrigation Demand Region:** A text input field with an "Edit" button to its left.
- Average Indoor Demand:** A text input field with an "Edit" button to its left and the unit "gpcd" to its right.
- Water User Area Size:** A text input field with the unit "acres" to its right.
- Average Lot Size:** A text input field with the unit "acres" to its right.
- Average Percent of Area Irrigated:** A text input field with the unit "%" to its right.
- Average Persons per Lot:** A text input field.
- Potable Water Delivery Cost:** A text input field with the unit "\$/1000 gal" to its right.
- Municipal WWTP Cost:** A text input field with the unit "\$/1000 gal" to its right.

At the bottom right of the window, there are two buttons: "Delete User" and "Exit".

Figure 4-3 Water User Browser Window

Clicking the **Add New Service Area** button opens the *Create New Service Area* window that was described in section 3.2. Once at least one service area has been added, the *Water User Browser* allows the user to make changes to existing water user categories. Water user categories may be reviewed through use of the **Previous Water User** and **Next Water User** buttons (Figure 4-4).

The screenshot shows a software window titled "Water User Browser". At the top, there are navigation buttons: "<< Previous Water User" (highlighted with a blue border), "Next Water User >>", and a page indicator "1/1". Below these are several data fields and buttons:

Service Area Name	East Fort Collins	Add New Service Area
Water User Category	Single-Family Residential	Add New Water User Category
Irrigation Demand Region	Fort Collins	
Average Indoor Demand	62.35 gpcd	Delete User
Water User Area Size	80000 acres	
Average Lot Size	0.25 acres	Exit
Average Percent of Area Irrigated	50 %	
Average Persons per Lot	3	
Potable Water Delivery Cost	2.5 \$/1000 gal	
Municipal WWTP Cost	3 \$/1000 gal	

Figure 4-4 Water User Browser Window

Changes made to water user categories are applied as soon as they are made. The **Add New Water User Category** button also becomes active and allows the user to add water user categories to an existing service area after at least one service area has been added.

#### 4.3 Applying and Editing Water Management Practices

A brief description of the procedure for applying and editing water management practices was included in section 3.5. This section reviews the windows associated with each of the water management practices and explains their inputs.

##### 4.3.1 Indoor Conservation

Clicking the **Edit** button to the right of any water user category below the indoor conservation heading opens the *Edit Indoor Conservation Parameters* window (Figure 4-5).

Edit Indoor Conservation Parameters

**East Fort Collins - Single-Family Residential**

	Base Demands (gpcd)	Reduced Demands (gpcd)	(Slide to Adjust)	Percent Reduction (%)
Low Flow Toilets	16.68	16.68	<input type="range"/>	<input type="text"/>
Low Flow Clothes Washer	14.3	14.3	<input type="range"/>	<input type="text"/>
Low Flow Shower Head	11.22	11.22	<input type="range"/>	<input type="text"/>
Low Flow Faucets	9.31	9.31	<input type="range"/>	<input type="text"/>
Low Flow Dishwasher	0.9	0.9	<input type="range"/>	<input type="text"/>
Reduced Capacity Bathtubs	1.16	1.16	<input type="range"/>	<input type="text"/>
Consumption/Leaks	8.78	8.78	<input type="range"/>	<input type="text"/>
Other Demands	0	0	<input type="range"/>	<input type="text"/>

Figure 4-5 Edit Indoor Conservation Parameters Window

This window displays the base demands for the selected water user category and allows the user to specify reduced demands. The reduced demands may be entered directly into the textbox or the slider to the right of the value may be used to select a percent reduction value. Note that the percent reduction column is not available for editing and is included only to display the level of reduction that has been specified. Clicking the **Save** button saves the reduced demand values to the selected water user category.

#### 4.3.2 Irrigation Conservation

Clicking the **Edit** button to the right of any water user category below the Irrigation Conservation heading opens the *Edit Irrigation Conservation Parameters* window (Figure 4-6).

**Edit Irrigation Conservation Parameters**

**East Fort Collins - Single-Family Residential**

Hydrologic Region: Fort Collins

Average Lot Size: 1 acres

Percent Demand Reduction: 0 %

Save Cancel

Figure 4-6 Edit Irrigation Conservation Parameters

The *Edit Irrigation Conservation Parameters* window allows the user to adjust the percent demand reduction. The hydrologic region and average lot size serve only to remind the user of the current inputs that influence irrigation demand. Clicking the **Save** button saves the percent by which irrigation demand will be reduced to the selected water user category.

#### 4.3.3 Graywater Reuse for Flushing and Irrigation

Clicking the **Edit** button to the right of any water user category below the Graywater Reuse for Flushing and Irrigation heading opens the *Edit Graywater Reuse Parameters* window (Figure 4-7).

**Edit Graywater Reuse Parameters**

**East Fort Collins - Single-Family Residential**

Portion of Faucet Water that is not Kitchen Wastewater (%) 33.3

Adoption of Graywater Flushing Alone (%) 0

Adoption of Graywater Irrigation Alone (%) 0

Adoption of Combined Graywater Flushing and Irrigation (%) 0

Average Graywater Storage Volume per Lot (gal) 0

Save Cancel

Figure 4-7 Edit Graywater Reuse Parameters Window

The portion of faucet water that is not kitchen wastewater must be specified on the *Edit Graywater Reuse Parameters* window. This value allows determination of graywater

that is produced by use at sinks. The default value is 33.3 percent. IUWM does not allow values above 100 percent.

Three classifications of graywater reuse are included in IUWM. The divisions are adoption of graywater flushing alone, adoption of graywater irrigation alone, and adoption of a combined graywater flushing and irrigation system. The user must specify what percent of the water user category falls into each of the three classifications. Stored graywater is first allocated to toilet flushing and excess is applied to irrigation. IUWM does not allow the total of the three classifications to be a sum greater than 100.

The average graywater storage volume must also be specified. The total storage volume defines the maximum volume of graywater that may be available in a given day. The stored volume is carried over from day to day if the available storage volume is not exceeded. Total wastewater production is adjusted based on the volume of graywater that is actually used. This ensures that graywater in excess of storage capacity is returned to the wastewater network.

Note that in the case of single-family residential, the average storage volume is per lot. This differs from multi-family residential average storage volumes which are described per development. Clicking the **Save** button saves the graywater reuse parameters to the selected water user category.

#### 4.3.4 WWTP Reuse for Irrigation

Clicking the **Edit** button to the right of any water user category below the WWTP Reuse for Irrigation heading opens the *Edit WWTP Reuse for Irrigation Parameters* window (Figure 4-8).

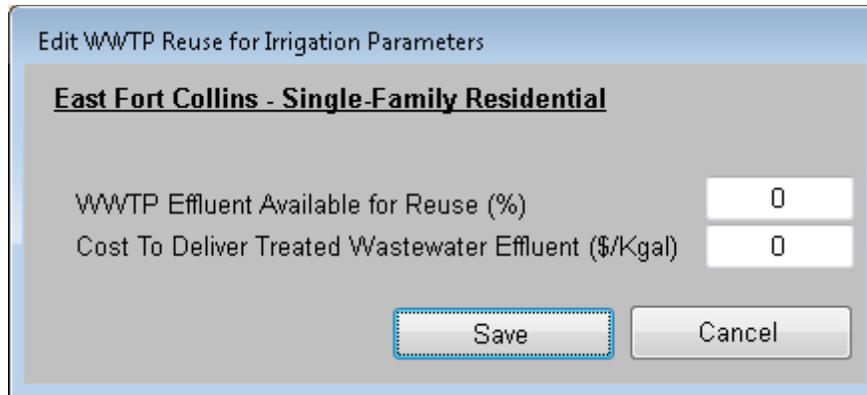


Figure 4-8 Edit WWTP Reuse for Irrigation Parameters Window

The percent of WWTP effluent that is available for reuse is specified on the *Edit WWTP Reuse for Irrigation Parameters* window. This value represents the amount of wastewater that could be treated to meet state regulations for reclaimed water and returned to users for irrigation applications. There is an additional cost associated with this water management practice and it must also be included. The cost is expressed per 1000 gallons of treated wastewater effluent delivered.

#### 4.3.5 Stormwater Capture for Irrigation

Clicking the **Edit** button to the right of any water user category below the Stormwater Capture for Irrigation heading opens the *Edit Stormwater Capture for Irrigation Parameters* window (Figure 4-9).

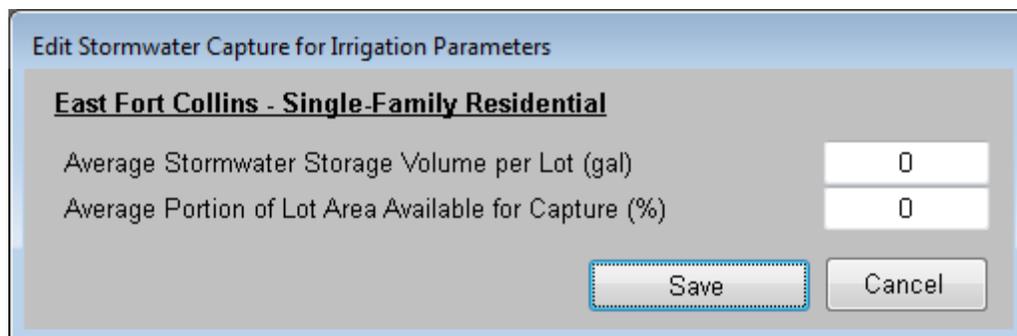


Figure 4-9 Edit Stormwater Capture Parameters Window

IUWM adjusts the labels on the *Stormwater Capture Parameters* window in a similar fashion to the changes to the *Edit Graywater Reuse Parameters* window. Single-family

residential water user categories require that the average stormwater storage volume be entered per lot, while multi-family residential water user categories are described on a per development basis. The average portion of the area available for capture is subject to the same change in units. This value represents that the portion of runoff that is produced by impervious surfaces or is otherwise available for capture.

#### 4.4 Editing Defaults and Adding Custom Data

The default options selected during creation of a new project may be altered at any time by clicking the **Edit Defaults** button on the *IUWM Main Interface*. Changes to default values are not retroactive except in the case of the hydrology assigned to a project. In other words, changing the default indoor demands does affect the indoor demand values assigned to already existing water user categories.

IUWM also allows for the addition of custom water user categories, hydrologic regions, and irrigation demand regions. This is achieved through selection of the ‘Create Custom’ selection from the dropdown boxes in each respective window. These custom additions to the model are based within the individual projects and can be recalled within the project in which they were created only.

##### 4.4.1 Editing Default Values

Making changes to the default values affects the project on a global level. However, it is important to note that changes to most default values do not affect existing water user categories. The exception to this is any change made to the default hydrology. Only a single hydrologic record may be applied to a given scenario. The hydrologic record may be altered clicking the **Hydrology** button on the *Edit Default Values* window (Figure 4-10). The

windows that open as a result of clicking any button on the *Edit Default Values* window are identical to the windows described in Chapter 3.



Figure 4-10 Edit Default Values Window

#### 4.4.2 Custom Water User Categories

Creating a custom water user category allows it be used repeatedly within the project in which it is created. Selecting 'Create Custom Category...' from the dropdown menu of the *Add Water User Category* window opens the *Create Custom Water User Category* window (Figure 4-11). The user must select a template for the new category in order to set the properties and units of the new custom category. The category is then assigned a name and created in the same manner as creating any other water user category. The new custom water user category is then added to the water user category dropdown list on the *Add New Water User Category* window.

Figure 4-11 Create Custom Water User Category Window

#### 4.4.3 Editing and Adding Custom Hydrologic Regions

The default hydrologic data included in IUWM may be edited at any time by selecting the **Hydrology** button on the *Edit Default Values* window. The *Edit Default Hydrology* window opens and the user is required to select the hydrology to be edited from the dropdown box (Figure 4-12).

Figure 4-12 Edit Default Hydrology Window

Clicking **Edit Hydrology** opens the *Edit/Add Hydrology* window with the current inputs displayed (Figure 4-13).

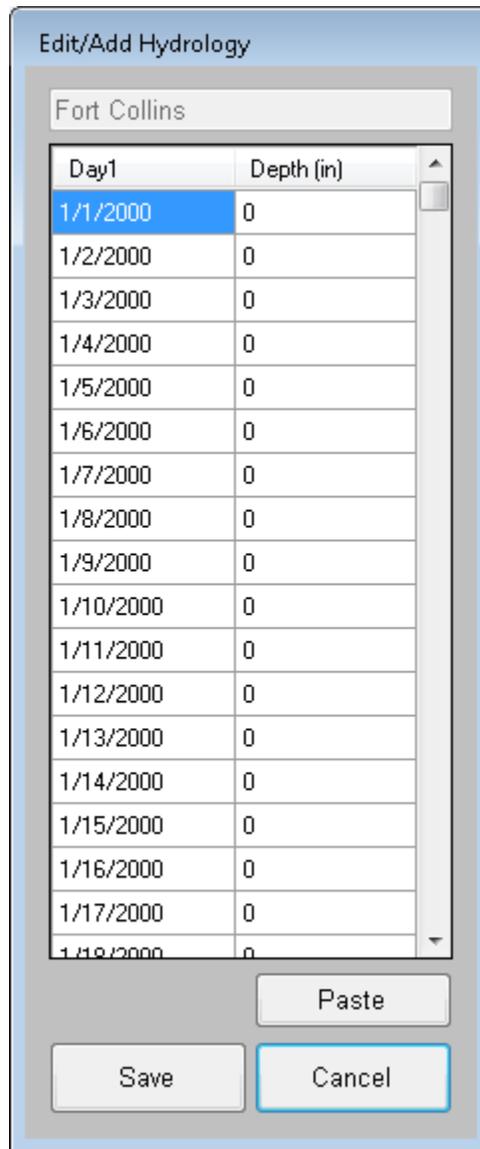


Figure 4-13 Edit/Add Hydrology Window

New hydrologic data can be added to IUWM by selecting 'Create Custom Hydrology...' from either the *Create New Project* window dropdown box or the *Edit Default Values* window dropdown box. The user is first required to select the start and end dates of the new hydrologic record from the *Select Hydrology Dates* window (Figure 4-14).

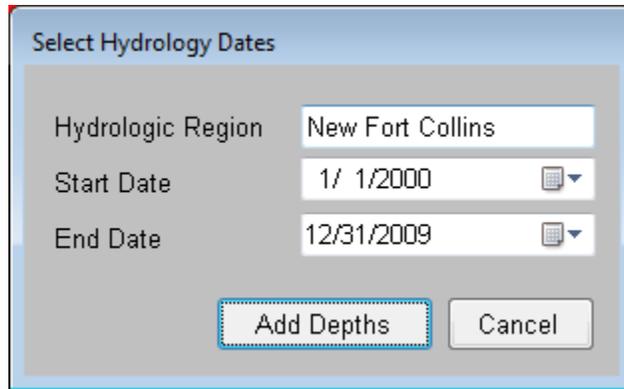


Figure 4-14 Select Hydrology Dates Window

Next, the user is presented with a blank column beside the selected dates on the *Edit/Add Hydrology* window into which the daily depth values (inches) are pasted (Figure 4-15).

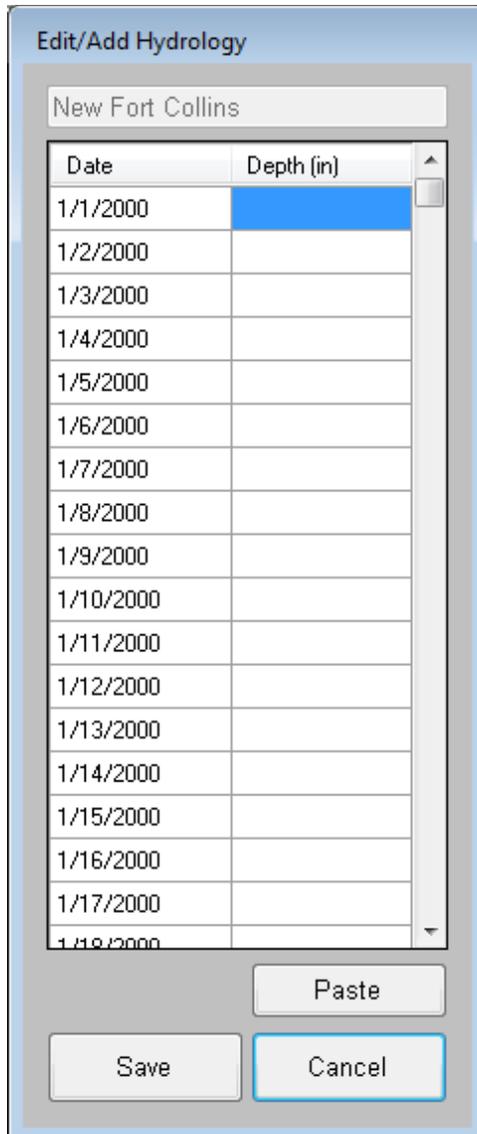
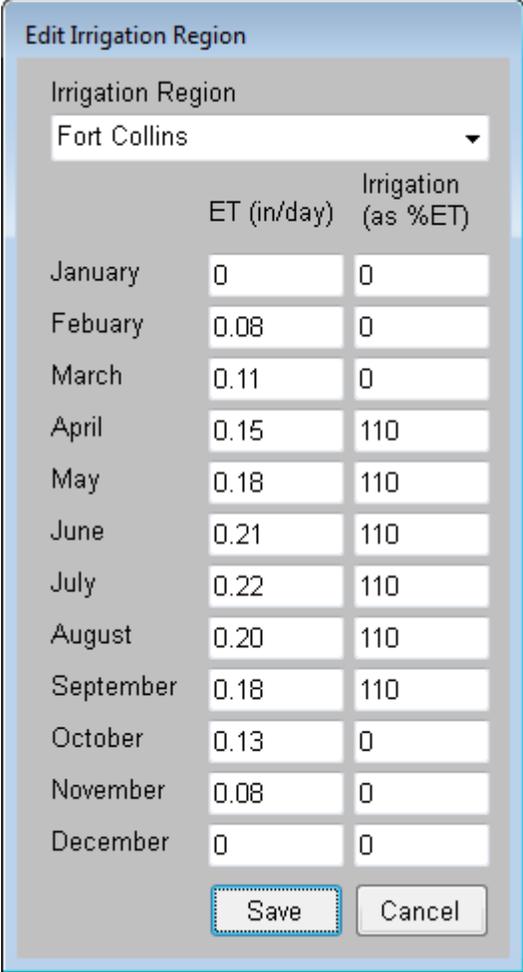


Figure 4-15 Add Custom Hydrology Window

The source of the embedded data is the NCDC. However, the data may be sourced or created in any fashion so long as the values are daily depths in inch increments. To create the custom hydrology, the user enters a name for the new hydrologic region, copies the desired data to the Windows system clipboard in typical fashion (e.g. Ctrl+C, right-click context menu, or menu option), and then clicks the **Paste** button on the Edit/Add Hydrology window or Ctrl+V on the keyboard.

#### 4.4.4 Editing and Adding Custom Irrigation Demand Regions

The default irrigation demands included in IUWM may be edited at any time by selecting the **Irrigation Demands** button on the *Edit Default Values* window. The *Edit Irrigation Region* window opens and the user is required to select the irrigation region to be edited from the dropdown box (Figure 4-16).



The screenshot shows a dialog box titled "Edit Irrigation Region". At the top, there is a dropdown menu labeled "Irrigation Region" with "Fort Collins" selected. Below this is a table with two columns: "ET (in/day)" and "Irrigation (as %ET)". The rows represent the months of the year from January to December. The "Irrigation" column shows 0% for winter months (Jan-Mar) and 110% for the rest of the year. At the bottom of the dialog are "Save" and "Cancel" buttons.

	ET (in/day)	Irrigation (as %ET)
January	0	0
February	0.08	0
March	0.11	0
April	0.15	110
May	0.18	110
June	0.21	110
July	0.22	110
August	0.20	110
September	0.18	110
October	0.13	0
November	0.08	0
December	0	0

Figure 4-16 Edit Irrigation Region Window

In the case of Fort Collins, irrigation does not typically occur in winter months from October through March. This is considered in IUWM through specifying zero irrigation as a percentage of ET (Figure 4-16). In all other months, one-hundred and ten percent irrigation as percent ET is specified since it is typical to irrigate at 110% of ET. In regions in which

irrigation occurs year round, each month would include some percentage applied to the irrigation column in the *Edit Irrigation Region* window.

New irrigation data can be added to IUWM by selecting ‘Create Custom Irrigation...’ from either the *Create New Project* window dropdown box or the *Edit Default Values* window dropdown box. The user is presented with a blank irrigation demand region window into which ET and Irrigation as % ET values are entered (Figure 4-17).

	ET (in/day)	Irrigation (as %ET)
January		
February		
March		
April		
May		
June		
July		
August		
September		
October		
November		
December		

Figure 4-17 Create Custom Irrigation Region Window

ET is most typically expressed in terms of inches per day. Published values are readily accessible and are often expressed as monthly averages, although daily values may also be retrieved. The values included in IUWM were retrieved from the website of a well established irrigation equipment manufacturer which maintains a database of ET values for

use with their products (Irritrol, 2011). The percentage of ET based irrigation demand that is satisfied may be set above one-hundred percent for known high demand months, below one-hundred percent for low demand months, or zero for months in which freeze conditions prevents irrigation from occurring.

#### 4.5 Saving, Loading, and Deleting Scenarios

IUWM was designed to facilitate analysis of water management practices. This is achieved through creation of water management scenarios which are applied to water user groups. Management practices are applied and edited on the *IUWM Main Interface*. After implementing the desired practices, it is necessary to save the scenario prior to running a simulation. Clicking **Save Scenario** button at any time after creating a project and adding at least one water user opens the *Save Scenario* window (Figure 4-18).

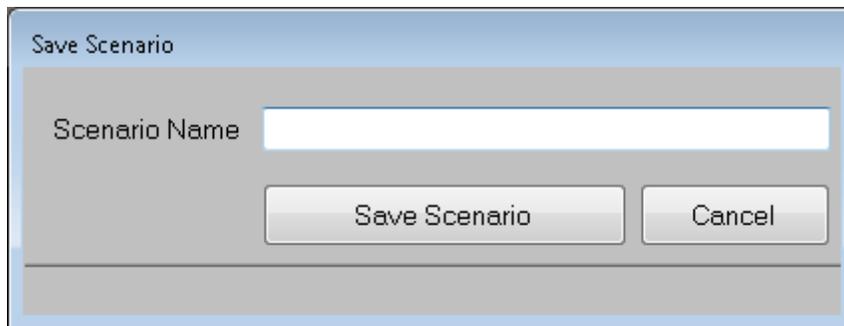


Figure 4-18 Save Scenario Window

A scenario name may be any length, but may not contain special characters in order to maintain database integrity. IUWM also adds underscores in place of spaces. This is a measure to maintain database integrity. After a scenario is saved, the name of the scenario is visible on the *IUWM Main Interface*. Note that IUWM allows overwriting of existing scenarios. If the user chooses not to overwrite an existing scenario, IUWM will prompt the user for a new name that does that does not conflict with the existing scenario name.

A saved scenario may be reloaded in IUWM at any time with the **Load Scenario** button on the *IUWM Main Interface*. Clicking the button displays the *Load Scenario* window (Figure 4-19).

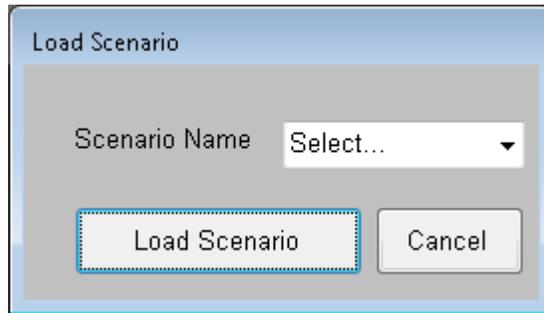


Figure 4-19 Load Scenario Window

Note that loading an existing scenario replaces the current inputs. IUWM prompts the user to save the current scenario before loading another.

IUWM also allows the user to delete scenarios that have been added to a project. Clicking the **Delete Scenarios** button on the *IUWM Main Interface* opens the *Delete Scenarios* window (Figure 4-20).

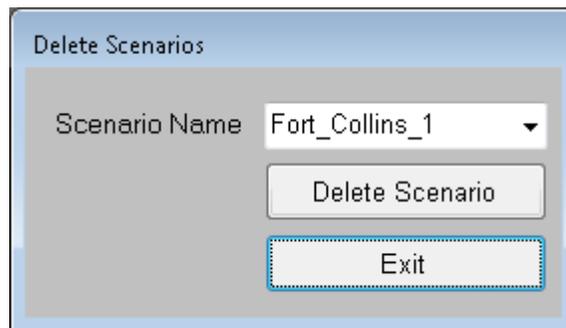


Figure 4-20 Delete Scenario Window

#### 4.6 Viewing and Results

Once a scenario has been saved, a simulation may be run by clicking **Run Simulation** on the *IUWM Main Interface*. This process was described in section 3.7. The *Simulation Results Summary* window appears when the simulation is complete. In addition to this results summary, it is possible to compare results side-by-side, create graphs, and export

results to spreadsheet formats. Clicking Export Summary on the results summary dialog creates a comma separated variable (.csv) file. Alternatively, clicking on the **More Results** button opens the *View Results* window that includes additional ways to view results (Figure 4-21).

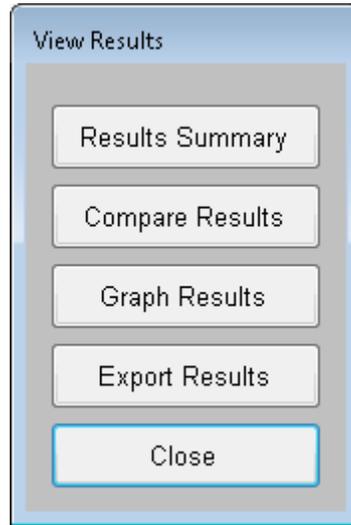


Figure 4-21 View Results Window

Clicking the **Compare Results** button opens the *Compare Simulation Results* (Figure 4-22).

	fc_all	fc_conservations	Select...	Select...	Select...
Treated Indoor Water Demand (Mgal/yr)	1821.6	1915.0			
Wastewater Production (Mgal/yr)	1451.8	1696.9			
Treated Irrigation Demand (Mgal/yr)	245.8	833.5			
Total Treated Water Cost (\$M/yr)	5.2	6.9			
Wastewater Treatment Cost (\$M/yr)	4.7	5.5			
WWTP Effluent Delivery Cost (\$M/yr)	0.4	0.0			
Total Cost (\$M/yr)	10.3	12.4			
Total Treated Water Savings (Mgal/yr)	2420.0	1738.9			
Wastewater Reduction (Mgal/yr)	1209.9	964.8			
Total Scenario Cost Saving (\$M/yr)	9.6	7.5			

Figure 4-22 Compare Simulation Results Window

Each dropdown box on this window allows the user to view another set of simulation results. Base values are omitted to prevent confusion of comparing incompatible results from scenarios in which the water user categories inputs differed. It is the responsibility of the user to understand the differences in inputs that produced the simulation results.

Simple bar graphs of treated demand, wastewater produced, and cost savings can be created with IUWM. Clicking on **Graph Results** on the *View Results* window opens the *Graph Simulation Results* window (Figure 4-23).

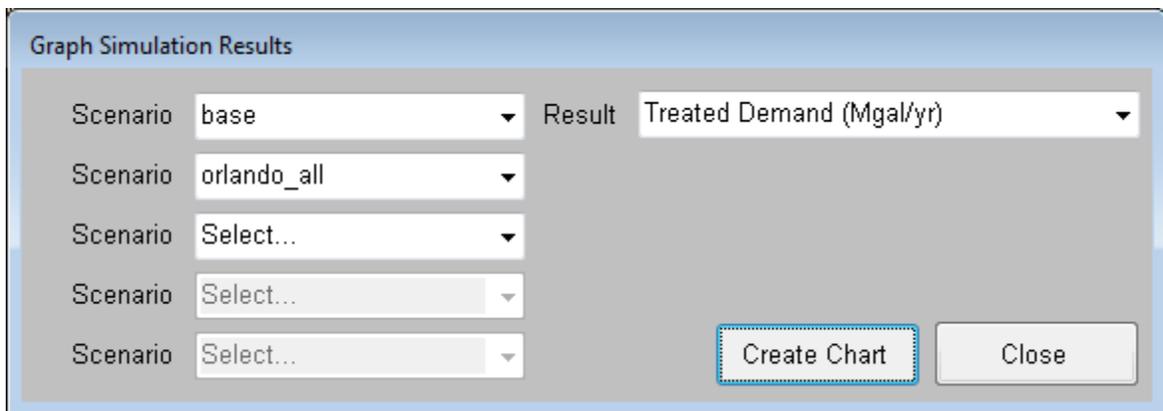


Figure 4-23 Graph Simulation Results Window

The chart includes the base and adjusted values for each scenario that was selected. After selecting the scenarios and result to be displayed, clicking **Create Chart** opens the *IUWM Results Chart* window (Figure 4-24).

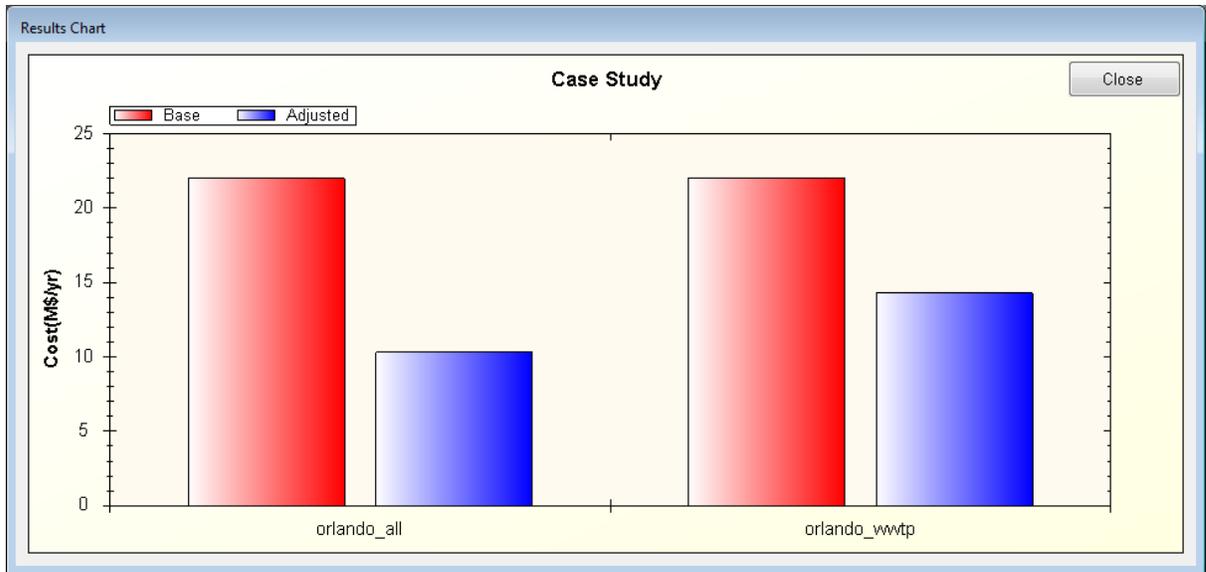


Figure 4-24 IUWM Results Chart

#### 4.7 Exporting Inputs and Results

Clicking **Export Results** on the *Compare Simulation Results* window or *View Results* window opens the *Export Results* window (Figure 4-25).

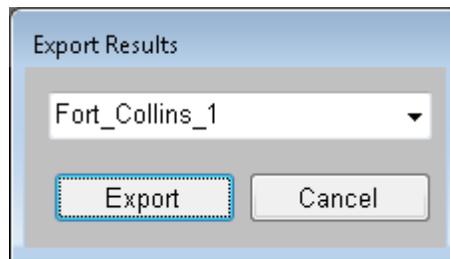


Figure 4-25 Export Results Window

IUWM can export the entire simulation record to a Microsoft Excel file (.xls). To perform this export, the user selects the results for export and the location to which the new file is to be saved.

IUWM can also export the inputs used in the project. This is achieved through clicking **Review Project Inputs** on the *IUWM Main Interface*. The *Simulation Inputs Summary* window opens with a summary of the current scenario inputs (Figure 4-26).

Service Area	Water User Category	Average Lot Size (acres)	Density (Persons per Lot or Sq. Feet per Lot)	Total Demand (gpcd or gal/sf/day)	Hyrdologic Region	Irrigation Demand Region	Potable Water Delivery Cost (\$/1000 gallons)	Municipal WWTP Cost (\$/1000 gallons)	Total User Area (acres)	Average Percent of Area Irrigated
Single Fami...	Single-Fam...	0.25	3	62.35	San Diego	San Diego	2.5	3.25	8000	50
Multi Fami...	Multi-Famil...	2.5	100	62.35	San Diego	San Diego	2.5	3.25	1000	30

Figure 4-26 Simulation Inputs Summary

Clicking **Export Inputs** on the *Simulation Inputs Summary* window opens the Export Inputs window (Figure 4-27).

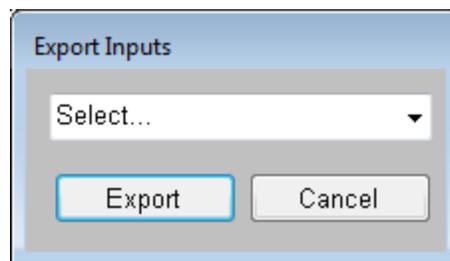


Figure 4-27 Export Results Window

This window functions in the same fashion as the *Export Results* window and produces a Microsoft Excel file (.xls) which includes the inputs summary in the location that the user selects.

## CHAPTER 5

### CASE STUDY APPLICATION

#### 5.1 Introduction

Several cities were selected to perform case study applications of IUWM. These case studies are intended to serve as example applications of IUWM and to showcase the capabilities of the application. Five water management practice scenarios have been applied to five cities and the resulting water and cost savings were reviewed. These scenarios are combinations of the water management practices included in IUWM and were selected as practical options for implementation. The inputs for the simulations have been simplified in order to focus on hydrologic and irrigation demand differences across different regions of the United States.

#### 5.2 Inputs

Many inputs in the case study were held constant in order to best identify the effectiveness of each management practice under varying hydrologic conditions. Population characteristics, land use, and cost inputs were identical for all five cities in each simulation. Only hydrologic and irrigation demand values differed between the selected cities.

##### 5.2.1 Selected Cities and Hydrologic Conditions

The five cities selected for this case study are: Seattle, San Diego, Fort Collins, Orlando, and Philadelphia. These cities were selected based upon geographic location as to provide a representation of various hydrologic conditions throughout the United States. Most

regions can identify with at least one of these cities in terms of climatic conditions and rainfall patterns. The ET rates applied in the case study are embedded in the model (Table 5-1).

Table 5-1 ET Values for Selected Cities  
**Fort Collins    Orlando    Philadelphia    San Diego    Seattle**

	<b>Fort Collins</b>	<b>Orlando</b>	<b>Philadelphia</b>	<b>San Diego</b>	<b>Seattle</b>
<b>January</b>	0.00	0.08	0.00	0.08	0.03
<b>February</b>	0.07	0.12	0.06	0.10	0.05
<b>March</b>	0.10	0.15	0.10	0.13	0.07
<b>April</b>	0.14	0.18	0.14	0.16	0.10
<b>May</b>	0.16	0.18	0.16	0.17	0.13
<b>June</b>	0.19	0.17	0.17	0.17	0.14
<b>July</b>	0.20	0.16	0.17	0.18	0.16
<b>August</b>	0.18	0.15	0.15	0.17	0.13
<b>September</b>	0.16	0.15	0.13	0.17	0.11
<b>October</b>	0.12	0.14	0.10	0.13	0.06
<b>November</b>	0.07	0.10	0.06	0.10	0.04
<b>December</b>	0.00	0.08	0.04	0.07	0.03

It was assumed that irrigation did not occur during winter months in cities which experience temperatures below freezing for extended periods. During all months in which irrigation did occur, irrigation demand estimates were made at 110% of ET (Table 5-2).

Table 5-2 Percent ET Values for Selected Cities  
**Fort Collins    Orlando    Philadelphia    San Diego    Seattle**

	<b>Fort Collins</b>	<b>Orlando</b>	<b>Philadelphia</b>	<b>San Diego</b>	<b>Seattle</b>
<b>January</b>	0	110	0	110	0
<b>February</b>	0	110	0	110	0
<b>March</b>	0	110	0	110	110
<b>April</b>	110	110	110	110	110
<b>May</b>	110	110	110	110	110
<b>June</b>	110	110	110	110	110
<b>July</b>	110	110	110	110	110
<b>August</b>	110	110	110	110	110
<b>September</b>	110	110	110	110	110
<b>October</b>	0	110	110	110	0
<b>November</b>	0	110	110	110	0
<b>December</b>	0	110	0	110	0

Rainfall depths available for stormwater capture in the case study were provided by the hydrologic records embedded in the model. These hydrologic records included ten years of daily precipitation totals retrieved from the NCDC database. This data allowed the representation of the varying hydrologic conditions between the five cities (Table 5-3).

Table 5-3 Average Precipitation Totals from NCDC Data

	<b>Fort Collins</b>	<b>Orlando</b>	<b>Philadelphia</b>	<b>San Diego</b>	<b>Seattle</b>
<b>January</b>	0.3	1.9	2.9	1.3	5.9
<b>February</b>	0.7	1.7	2.4	2.6	2.6
<b>March</b>	1.9	2.3	3.7	0.8	3.5
<b>April</b>	1.8	2.1	3.9	0.6	2.5
<b>May</b>	2.2	4.0	3.4	0.1	2.0
<b>June</b>	1.2	9.0	4.9	0.0	1.4
<b>July</b>	1.5	7.6	3.8	0.0	0.5
<b>August</b>	1.0	7.7	3.6	0.0	1.1
<b>September</b>	1.5	6.4	3.9	0.0	1.4
<b>October</b>	0.5	3.3	4.2	0.8	3.4
<b>November</b>	0.7	1.4	3.0	0.6	6.6
<b>December</b>	0.2	3.0	4.2	1.4	5.3
<b>Total</b>	13.7	50.4	43.8	8.3	36.2

### 5.2.2 Service Area and Water User Categories Input

The service area and water user category inputs for the five cities were simplified in order to focus attention on the efficacy of each of the water management practices under varying hydrologic conditions. Only two service areas were added to the case study project. These service areas consisted of a single-family residential area and a multi-family residential area. The inputs for the service areas and water user categories in the case study were the same for each city (Table 5-4 and Table 5-5).

Table 5-4 Single-Family Residential Service Area Input

<b>Average Indoor Demand</b>	69.3	<i>gpcd</i>
<i>Bath Demand</i>	1.2	<i>gpcd</i>
<i>Clothes Washer Demand</i>	15.0	<i>gpcd</i>
<i>Dish Washer Demand</i>	1.0	<i>gpcd</i>
<i>Faucet Demand</i>	10.9	<i>gpcd</i>
<i>Leaks</i>	9.5	<i>gpcd</i>
<i>Shower Demand</i>	11.6	<i>gpcd</i>
<i>Toilet Demand</i>	18.5	<i>gpcd</i>
<i>Other Domestic</i>	1.6	<i>gpcd</i>
<b>Water User Area Size</b>	8000	<i>acres</i>
<b>Average Lot Size</b>	0.25	<i>acres</i>
<b>Average Percent of Area Irrigated</b>	50	<i>%</i>
<b>Average Persons per Lot</b>	3	
<b>Potable Water Delivery Cost</b>	2.50	<i>\$/1000 gal</i>
<b>Municipal WWTP Cost</b>	3.25	<i>\$/1000 gal</i>

Table 5-5 Multi-Family Residential Service Area Input

<b>Average Indoor Demand</b>	69.3	<i>gpcd</i>
<i>Bath Demand</i>	1.2	<i>gpcd</i>
<i>Clothes Washer Demand</i>	15.0	<i>gpcd</i>
<i>Dish Washer Demand</i>	1.0	<i>gpcd</i>
<i>Faucet Demand</i>	10.9	<i>gpcd</i>
<i>Leaks Demand</i>	9.5	<i>gpcd</i>
<i>Shower Demand</i>	11.6	<i>gpcd</i>
<i>Toilet Demand</i>	18.5	<i>gpcd</i>
<i>Other Domestic</i>	1.6	<i>gpcd</i>
<b>Water User Area Size</b>	1000	<i>acres</i>
<b>Average Development Size</b>	2.5	<i>acres</i>
<b>Average Percent of Area Irrigated</b>	30	<i>%</i>
<b>Average Persons per Development</b>	100	
<b>Potable Water Delivery Cost</b>	2.50	<i>\$/1000 gal</i>
<b>Municipal WWTP Cost</b>	3.25	<i>\$/1000 gal</i>

The result of the use of identical inputs was that the case study compared the effectiveness of the water management practices in identical service areas under varying only hydrologic conditions.

### 5.2.3 Water Management Practice Parameters

The values selected for the water management practice parameters applied to the service areas were identical for each of the five cities.

#### 5.2.3.1 Indoor Conservation

The values selected for indoor conservation were based upon published potential savings values for low-flow appliances and fixtures (Vickers, 2001). Percent reductions (Table 5-6) were applied to the end-use demands published in the REUWS and the resulting values became the new demands under the indoor conservation practice (Table 5-7).

Table 5-6 Percent Reduction of Indoor Demands

<b>Average Indoor Demand</b>	35	%
<i>Bath Demand</i>	0	%
<i>Clothes Washer Demand</i>	33	%
<i>Dish Washer Demand</i>	30	%
<i>Faucet Demand</i>	1	%
<i>Leaks/Consumed Demand</i>	58	%
<i>Shower Demand</i>	24	%
<i>Toilet Demand</i>	56	%
<i>Other Demand</i>	0	%

Table 5-7 Reduced Demands with Indoor Conservation

<b>Average Indoor Demand</b>	45.3	gpcd
<i>Bath Demand</i>	1.2	gpcd
<i>Clothes Washer Demand</i>	10.0	gpcd
<i>Dish Washer Demand</i>	0.7	gpcd
<i>Faucet Demand</i>	10.8	gpcd
<i>Leaks Demand</i>	4.0	gpcd
<i>Shower Demand</i>	8.8	gpcd
<i>Toilet Demand</i>	8.2	gpcd
<i>Other Domestic</i>	1.6	gpcd

#### 5.2.3.2 Irrigation Conservation

Irrigation conservation was set at a 25 percent reduction in demand for each of the five cities. This would represent a dramatic, but reasonable, reduction in irrigation demand

and was based on potential savings published by the EPA sponsored WaterSense program (WaterSense, 2011). The program suggests that switching to drip irrigation can save between 20 and 50 percent. Therefore, a 25 percent reduction seems reasonable if conservation campaigns and watering restrictions were combined.

#### 5.2.3.3 Graywater Reuse for Flushing and Irrigation

Graywater reuse parameters were set to simulate 50 percent of the population implementing some form of the water management practice. Implementation was broken into three groups which included adoption of graywater flushing alone (10 percent), adoption of graywater irrigation alone (30 percent), and adoption of combined graywater flushing and irrigation (10 percent). The portion of faucet water that was not kitchen wastewater (and therefore available for graywater reuse) was set at 33.3 percent.

Each single-family residence participating in some form of graywater reuse was assumed to have an average storage volume of 150 gallons. This differed from the storage volume assigned to multi-family due to multi-family category size being defined in terms of developments instead of lots. Therefore, each multi-family development was assumed to have a system of common storage volumes that would provide an average storage capacity of 5000 gallons per development.

#### 5.2.3.4 Wastewater Treatment Plant (WWTP) Reuse for Irrigation

It was assumed that 90 percent of wastewater delivered to treatment facilities would be available for reuse. It should be noted that a large municipal improvement project would be necessary in order to develop the infrastructure to deliver recycled wastewater to residential areas as would be necessary for the service area configuration in this case study. The cost of this infrastructure is not included in the simulation. Instead, a per volume cost of

\$1.90 per 1000 gallons delivered is considered as an added cost in exchange for treated water demand reduction.

#### 5.2.3.5 Stormwater Capture for Irrigation

Stormwater capture for irrigation was modeled with an average storage capacity of 240 gallons per single-family residence. This would be the equivalent of four, 60 gallon rain barrels for each single-family residence in the service area. It was assumed that an average single-family residence would have an impervious area that would allow capture of 15 percent of the available runoff.

In the case of multi-family residences, the use of rain barrels is often not a feasible alternative. However, the use of community cisterns or construction of wet detention basins can provide very large storage volumes. Plastic cisterns as large as 10,000 gallons are readily available in most areas and constructed community wet detention basins can provide hundreds of thousands of gallons of storage capacity. Therefore, an average capacity of 40,000 gallons per development was assumed a reasonable estimate of potential storage capacity. It was assumed that 15 percent of the land area of each development would produce runoff available for capture.

### 5.3 Case Study Scenarios

Each of the water management practices were applied to each city individually. This application allowed examination of the efficacy of the included water management practices in varying hydrologic regions. The scenarios were identified as:

1. Indoor Conservation
2. Irrigation Conservation
3. Graywater Reuse for Flushing and Irrigation

4. WWTP Reuse for Irrigation
5. Stormwater Capture for Irrigation

Details of the water management practices were discussed in subsection 1.3 and their associated calculations were addressed in subsection 2.5. Adjustment of water management practice parameters was covered in section 4.3.

#### 5.4 Results

A simulation was run for each scenario applied to each city. The results of each simulation were reviewed within IUWM and also exported to a spreadsheet for comparison and analysis.

##### 5.4.1 Fort Collins

The city of Fort Collins could realize the greatest treated water savings from indoor conservation, irrigation conservation, and WWTP reuse for irrigation. Treated water savings were greatest with the application of WWTP reuse for irrigation with a reduction of 16 percent (Figure 5-1).

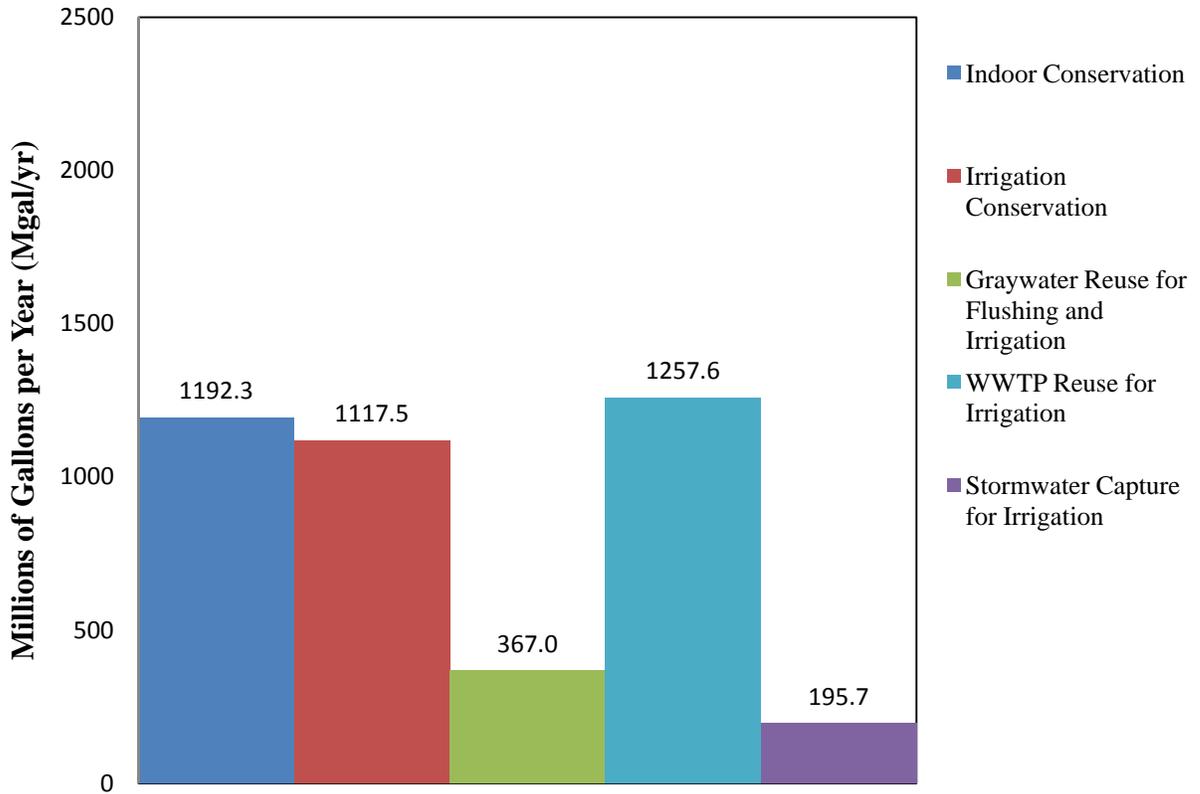


Figure 5-1 Fort Collins Treated Water Savings

While both indoor conservation and graywater reuse for flushing and irrigation resulted in notable wastewater reductions, the potential savings of indoor conservation were nearly triple those of graywater reuse for flushing and irrigation (Figure 5-2). Other scenarios result in no wastewater reduction and therefore are not included in graph indicating wastewater reduction throughout the report.

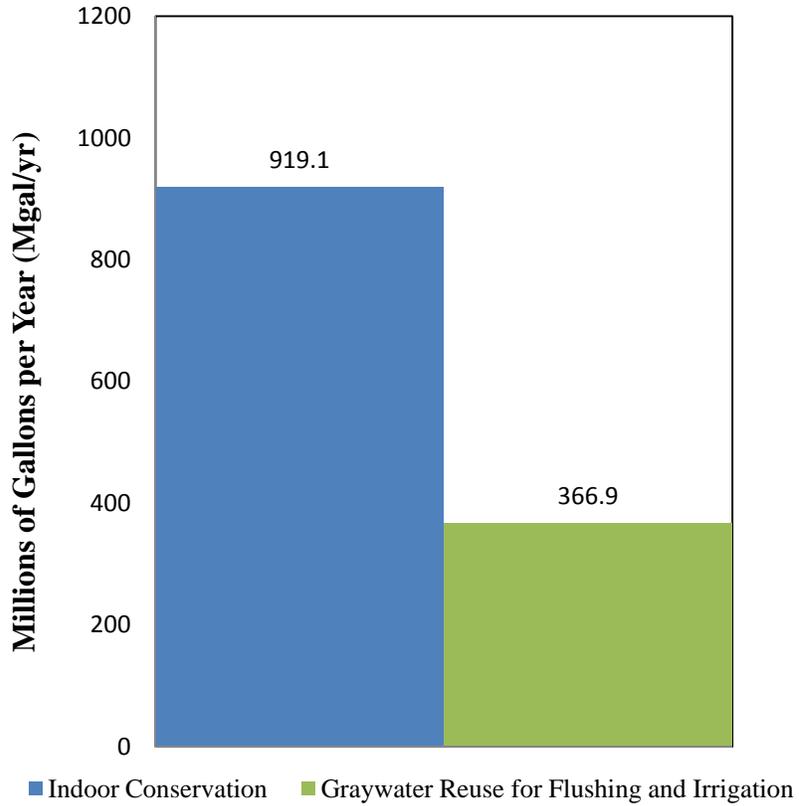


Figure 5-2 Fort Collins Wastewater Reduction

Aside from indoor conservation, the total cost savings for Fort Collins were highest with the application of irrigation conservation. Graywater reuse for flushing and irrigation also demonstrated strong potential for cost savings (Figure 5-3).

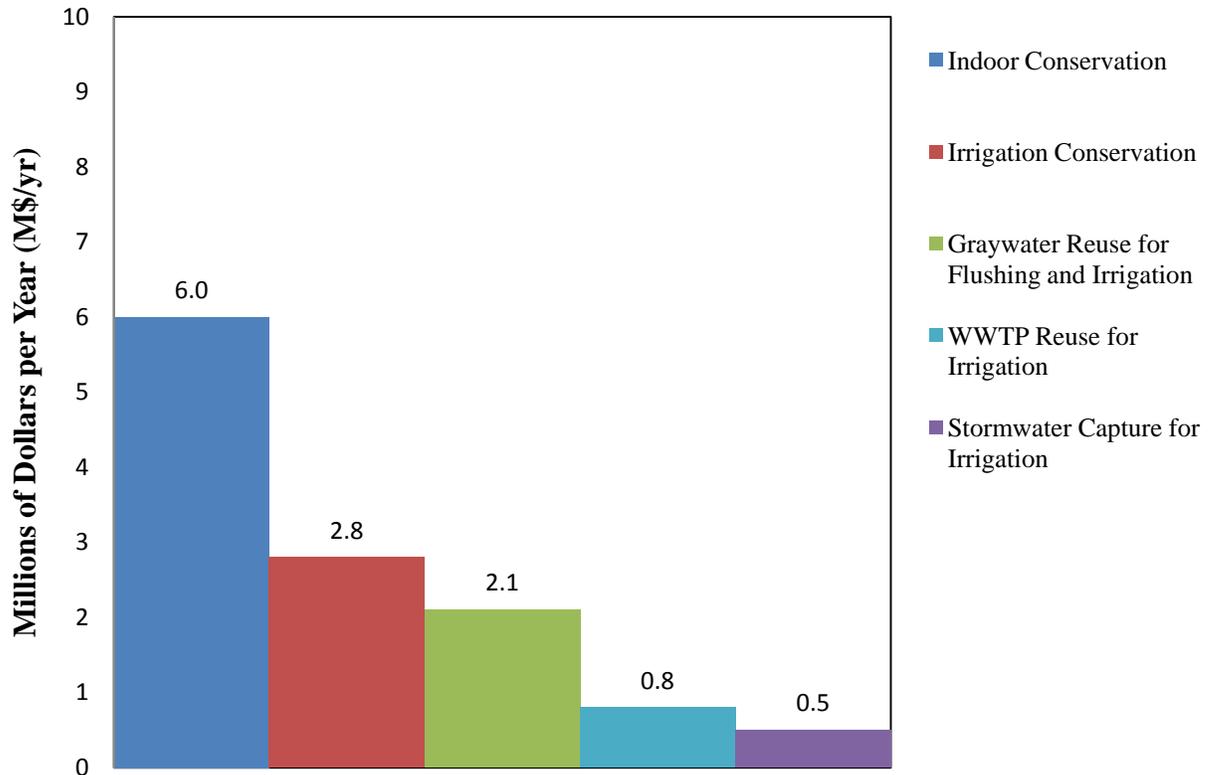


Figure 5-3 Fort Collins Total Cost Savings

#### 5.4.2 Orlando

Orlando is noted to have exhibited the greatest potential savings on treated water demand among the five cities included in the case study. Orlando could realize the greatest savings benefits from indoor conservation, irrigation conservation, and WWTP reuse for irrigation. Treated water savings were greatest with the application of WWTP reuse for irrigation with a reduction of 24 percent (Figure 5-4).

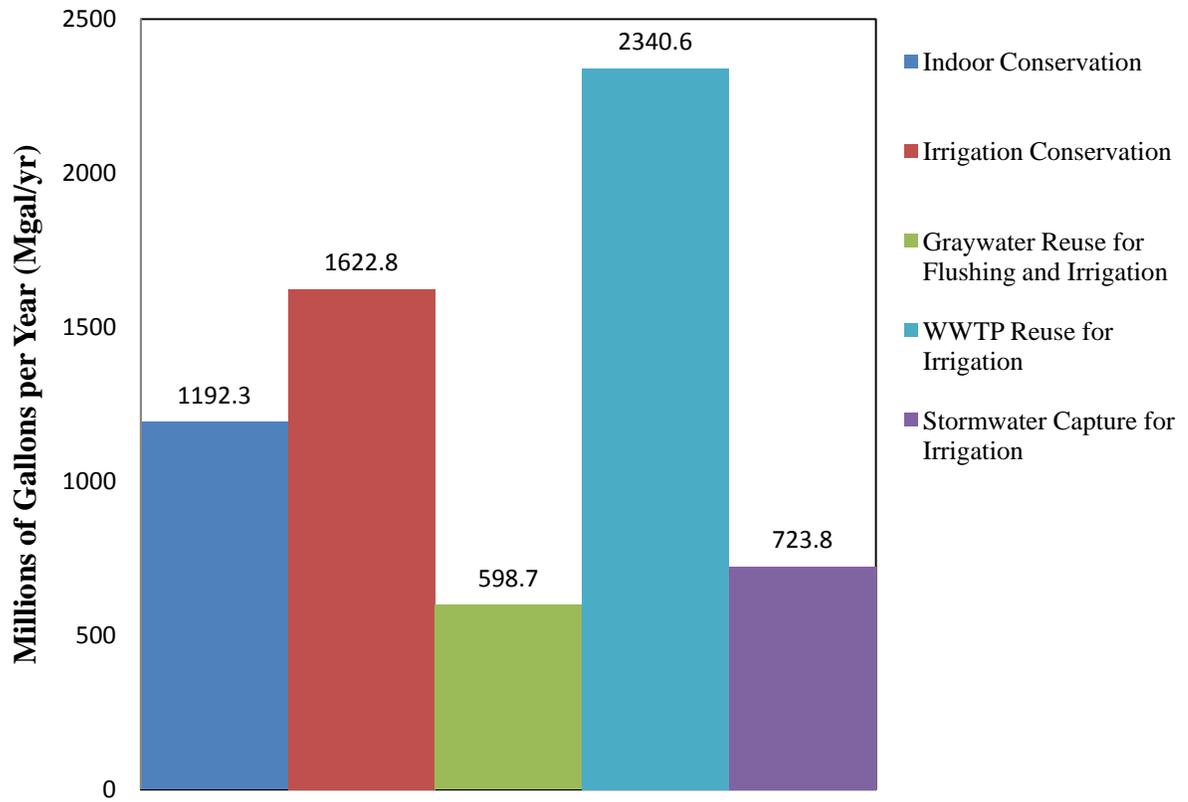


Figure 5-4 Orlando Treated Water Savings

While still falling short of the potential wastewater reductions of indoor conservation, graywater reuse for flushing and irrigation performed very well in application to the city of Orlando (Figure 5-5).

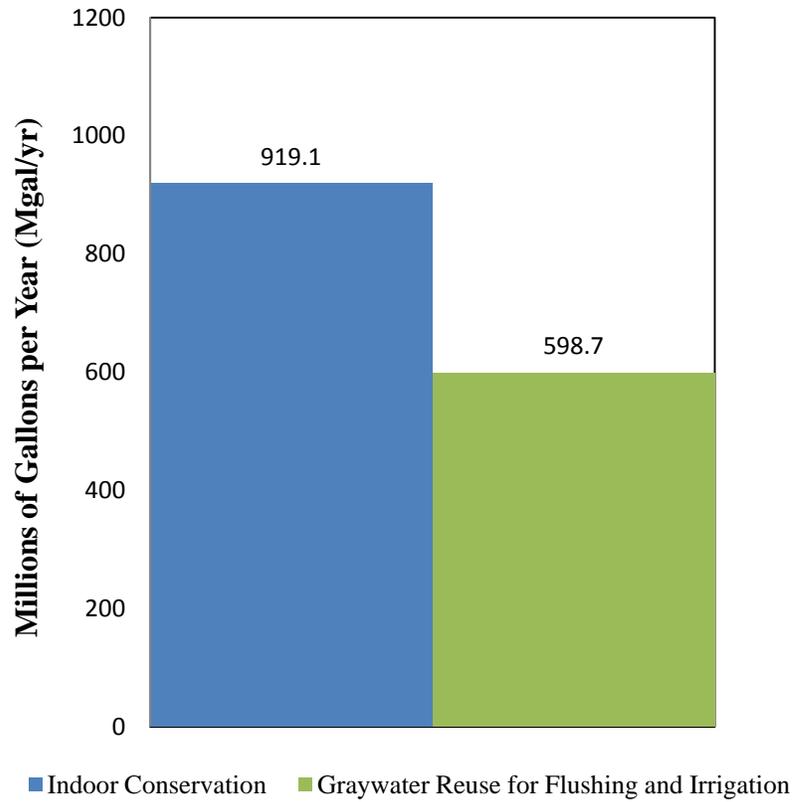


Figure 5-5 Orlando Wastewater Reduction

Aside from indoor conservation, the total cost savings for Orlando were highest with the application of irrigation conservation. Graywater reuse for flushing and irrigation also demonstrated strong potential for cost savings nearly equivalent cost savings (Figure 5-6).

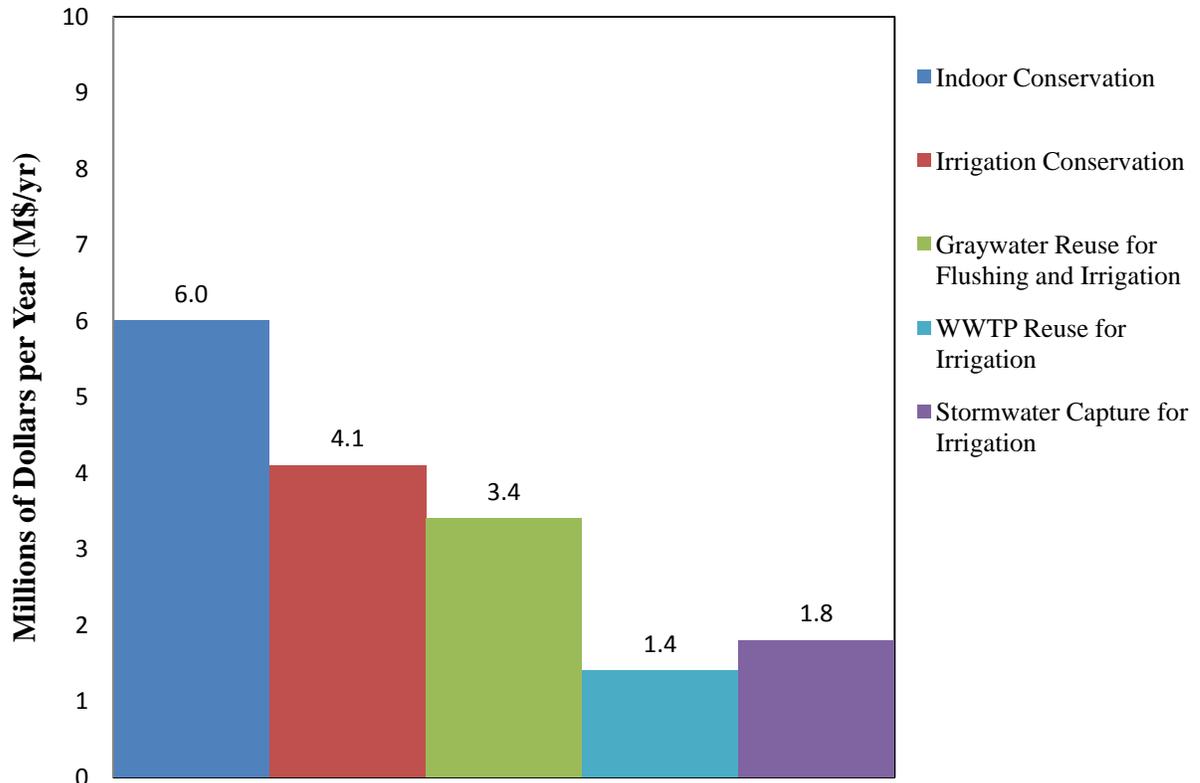


Figure 5-6 Orlando Total Cost Savings

### 5.4.3 Philadelphia

Philadelphia could realize the greatest savings benefits from indoor conservation, irrigation conservation, and WWTP reuse for irrigation. Treated water savings were greatest with the application of WWTP reuse for irrigation with a reduction of 20 percent (Figure 5-7).

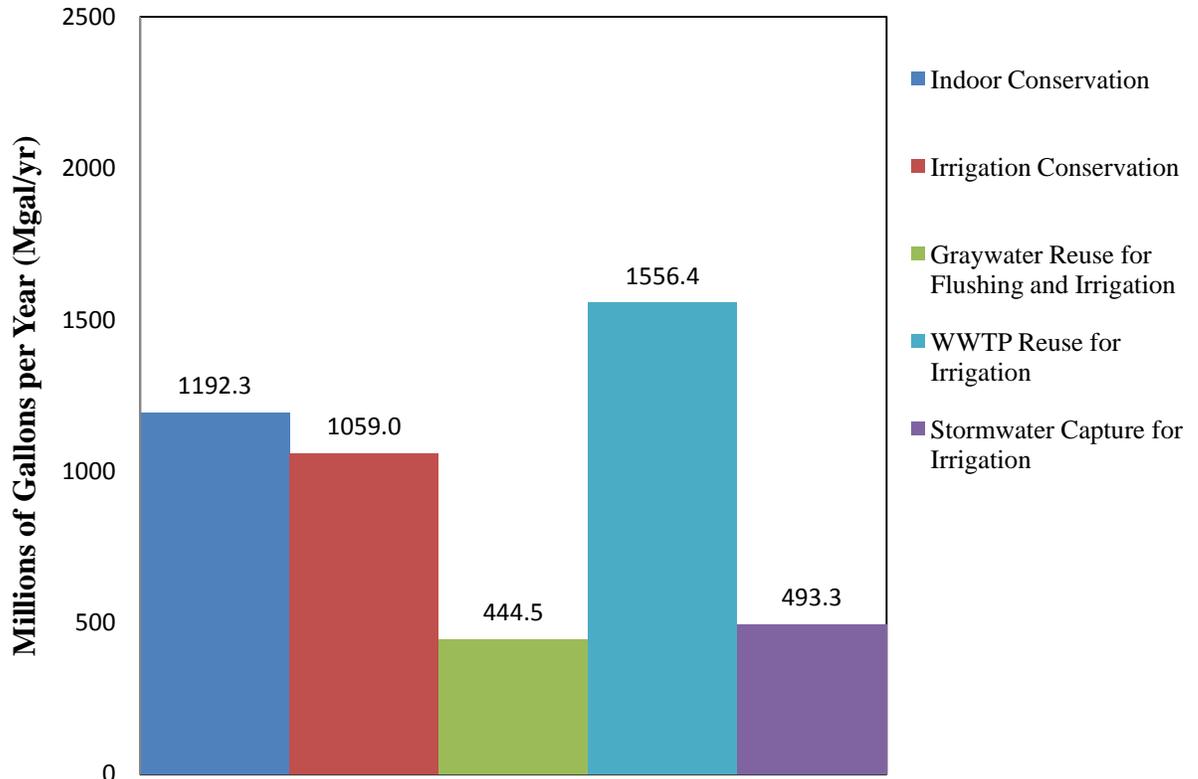


Figure 5-7 Philadelphia Treated Water Savings

Graywater reuse for flushing and irrigation would result in a wastewater reduction half that of indoor conservation in the case of Philadelphia (Figure 5-8).

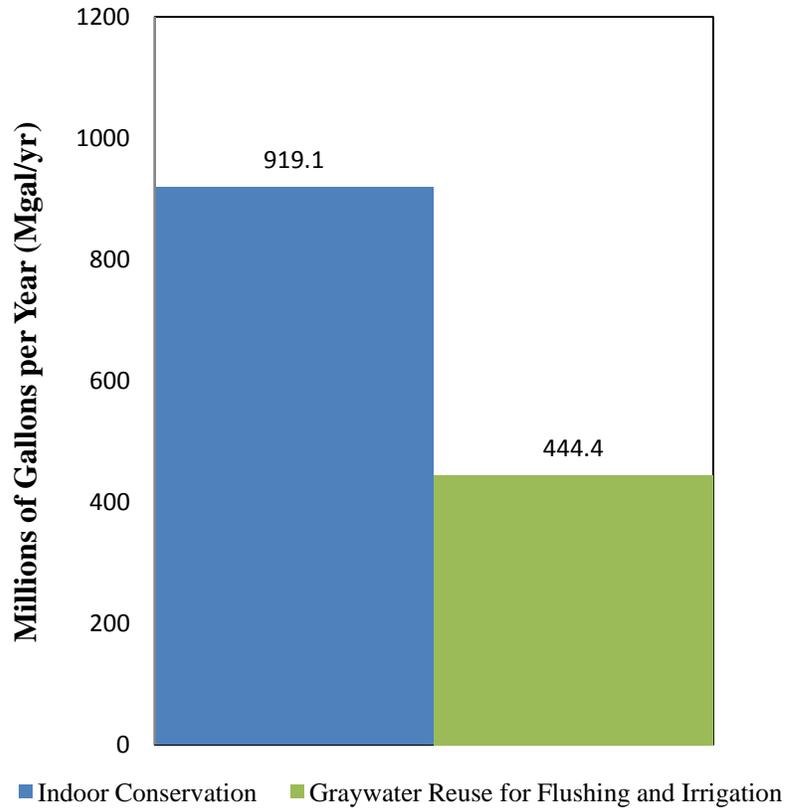


Figure 5-8 Philadelphia Wastewater Reduction

Aside from indoor conservation, the total cost savings for Philadelphia were greatest with irrigation conservation and graywater reuse for flushing and irrigation. The savings from these two practices were equivalent with the potential for a 9 percent cost reduction each (Figure 5-9).

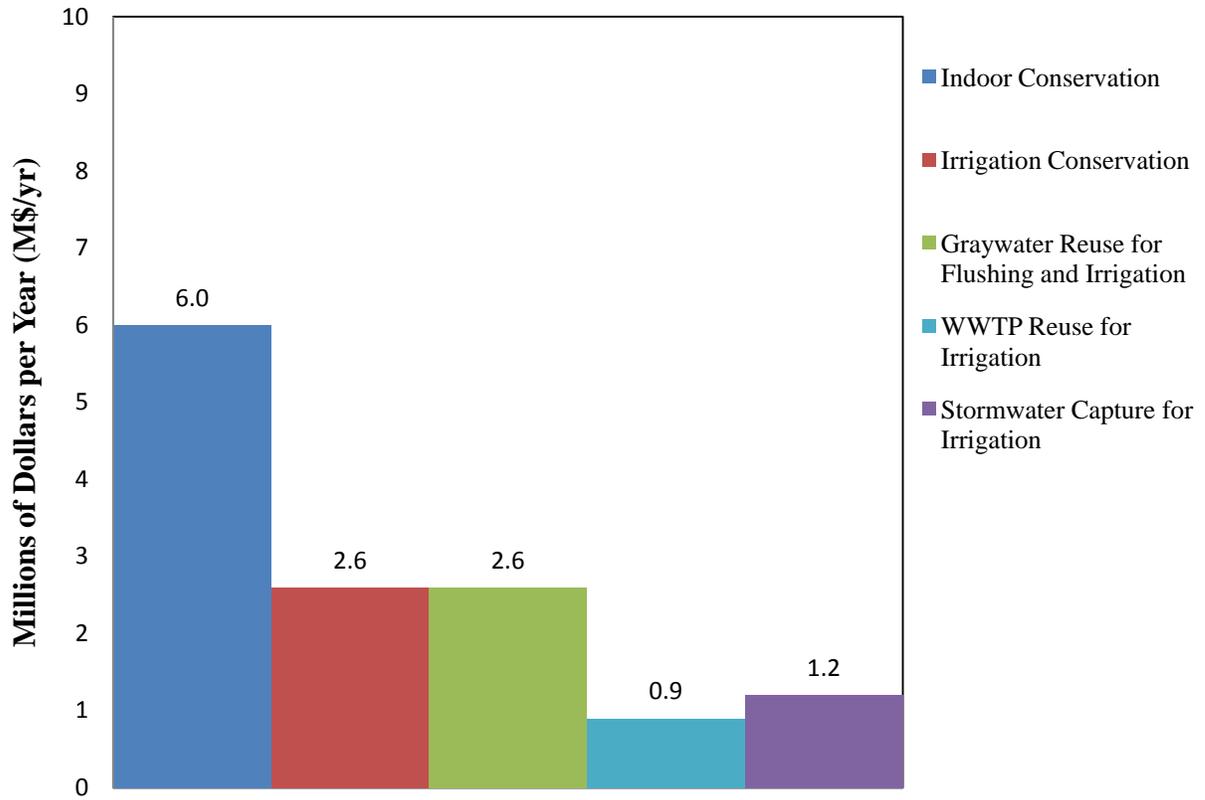


Figure 5-9 Philadelphia Total Cost Savings

#### 5.4.4 San Diego

San Diego could realize the greatest treated water savings from indoor conservation, irrigation conservation, and WWTP reuse for irrigation. Treated water savings were greatest with the application of WWTP reuse for irrigation with a reduction of 24 percent (Figure 5-10).

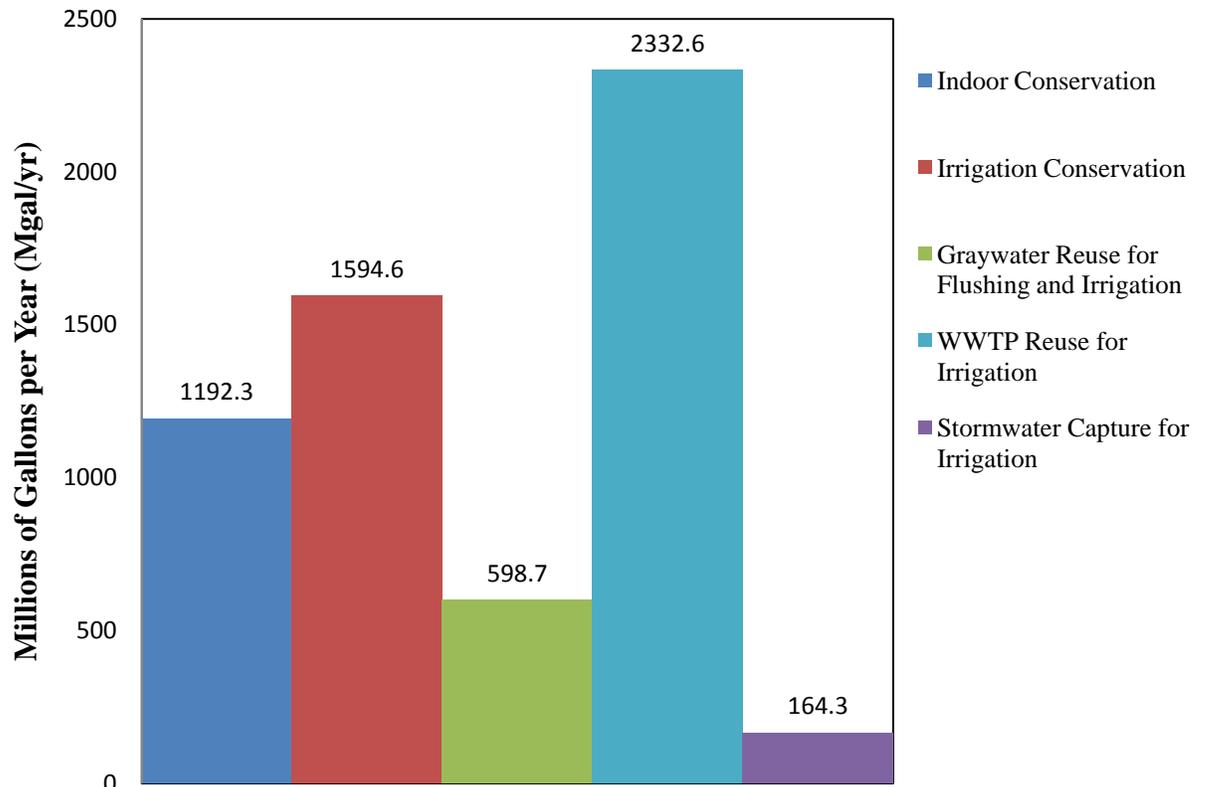


Figure 5-10 San Diego Treated Water Savings

San Diego exhibited a strong response to the application of graywater reuse for flushing and irrigation. Reductions in wastewater were nearly as great as those in Orlando (Figure 5-11).

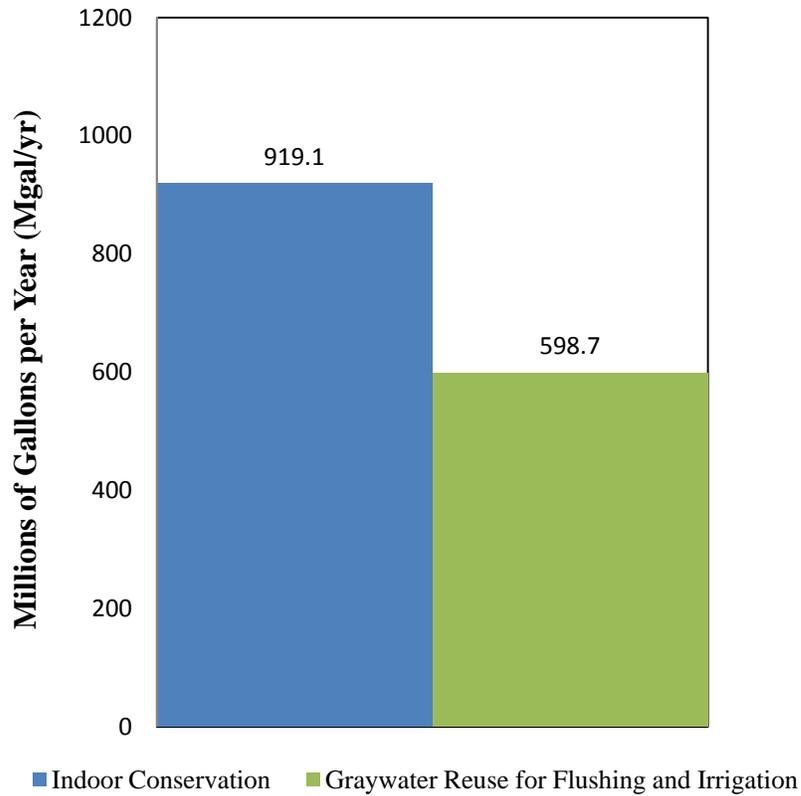


Figure 5-11 San Diego Wastewater Reduction

The total cost savings for San Diego were highest with the application of indoor conservation irrigation conservation. Application of graywater reuse for flushing and irrigation also demonstrated a strong potential while stormwater capture for irrigation provided little cost savings benefit (Figure 5-12), likely a result of the limited rainfall in the area.

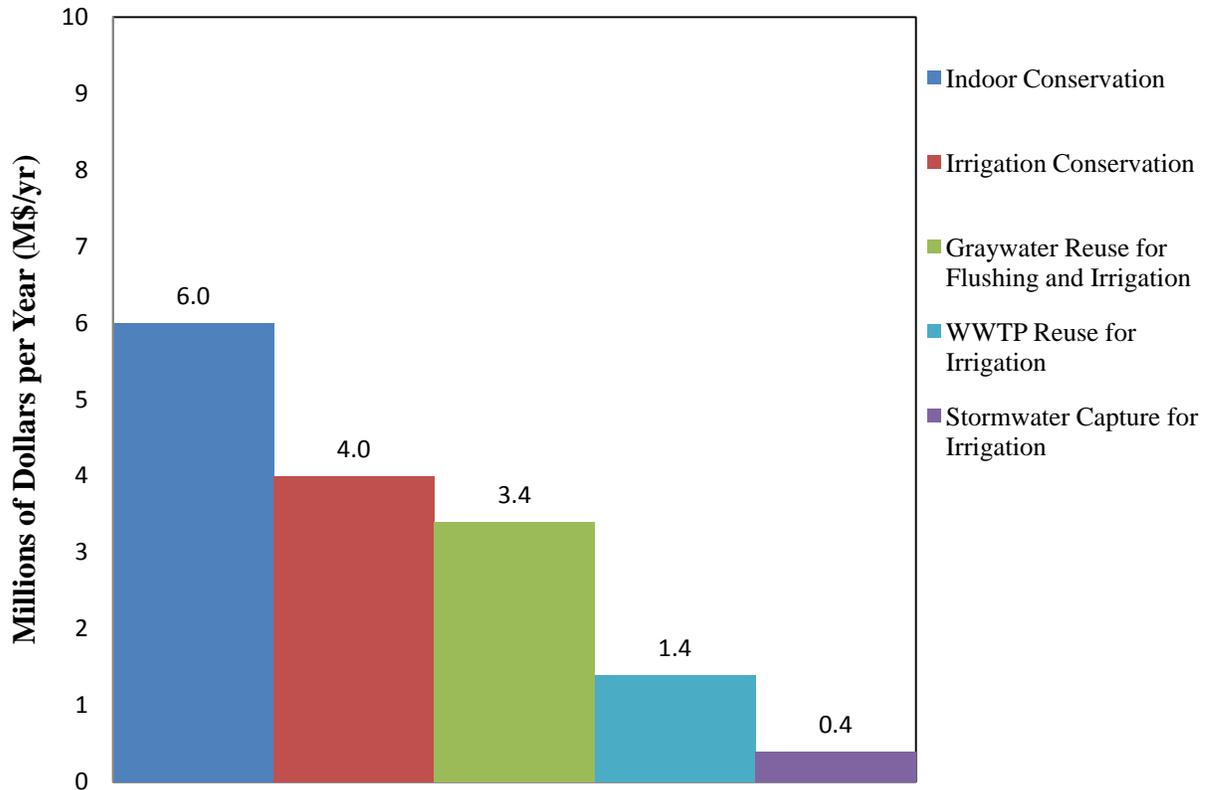


Figure 5-12 San Diego Total Cost Savings

#### 5.4.5 Seattle

Seattle could realize the greatest treated water demand savings from indoor conservation and WWTP reuse for irrigation. Treated water savings were greatest with the application of WWTP reuse for irrigation with a reduction of 20 percent (Figure 5-13).

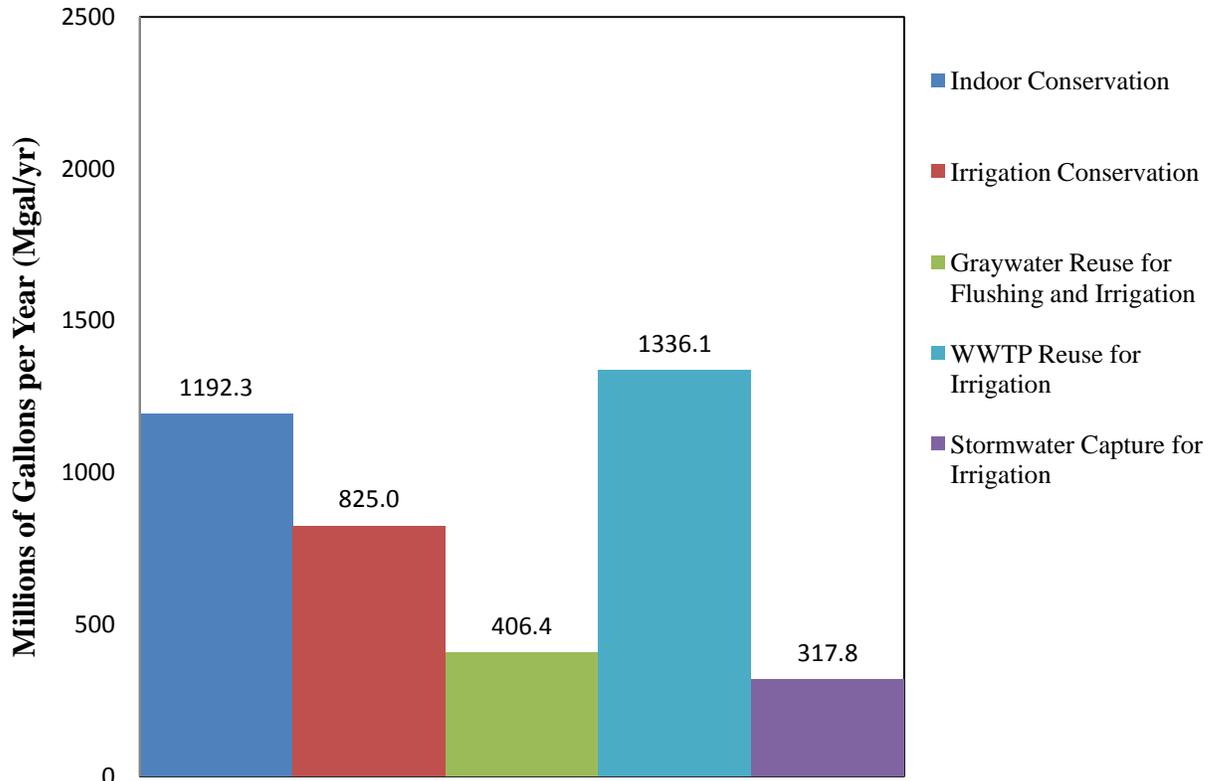


Figure 5-13 Seattle Treated Water Savings

The impact of graywater reuse for flushing and irrigation was less than half that of indoor conservation for Seattle (Figure 5-14).

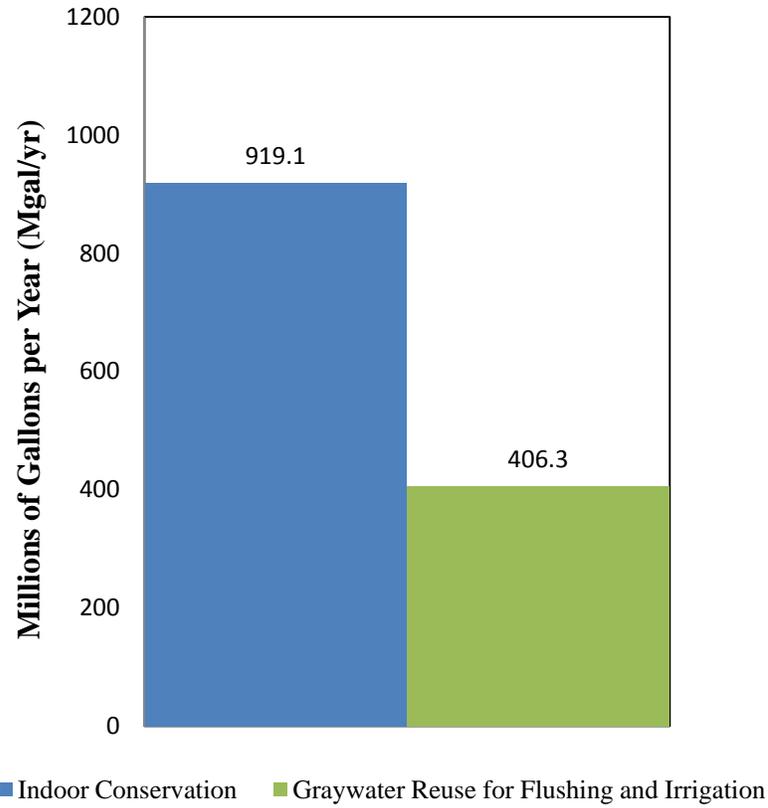


Figure 5-14 Seattle Wastewater Reduction

The total cost savings for Seattle were highest with the application of graywater reuse for flushing and irrigation (Figure 5-15). The city could potentially realize a 9 percent reduction in total costs.

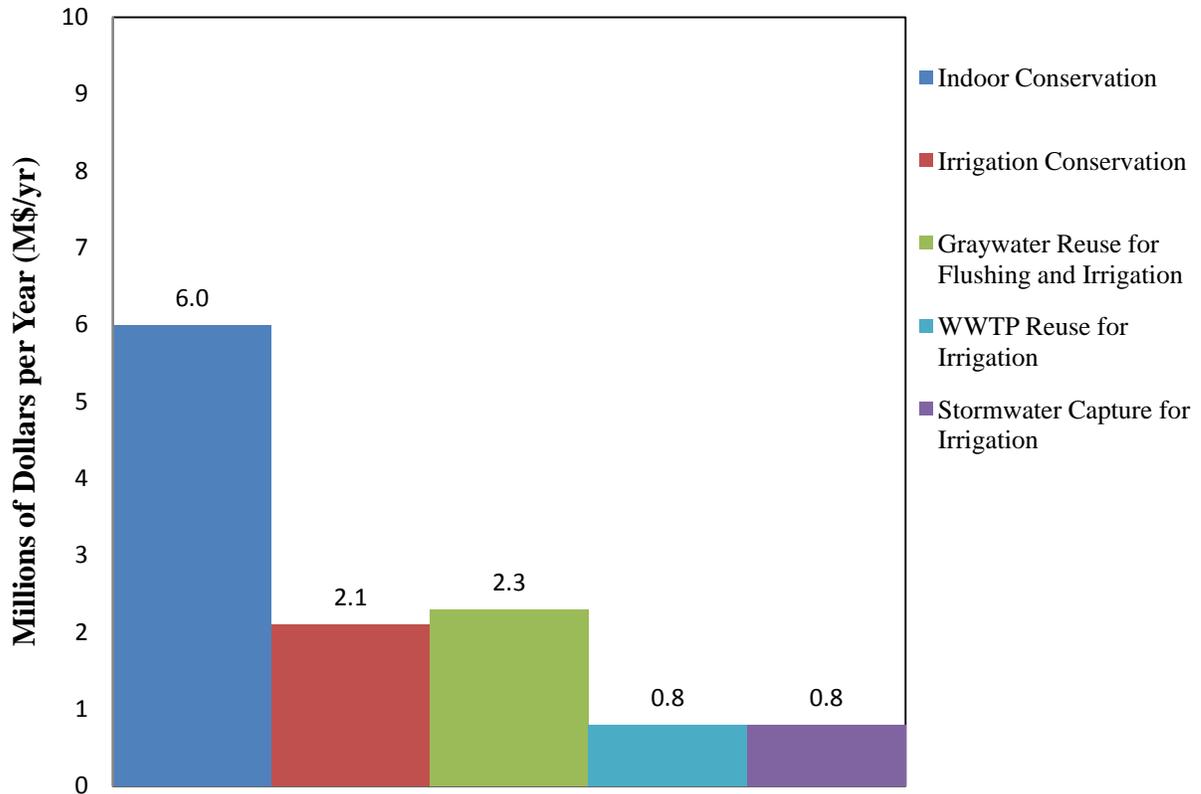


Figure 5-15 Seattle Total Cost Savings

### 5.5 Discussion

The results of the all simulations were relatively similar without any large variations in terms of scenarios which showed the largest water and cost savings. This was to be expected as identical city characteristics and water management practice parameters were applied so as to isolate and highlight the impact of hydrologic region differences. Subtle differences in the results of the scenarios were exhibited and differences between potential savings were apparent when comparing the application of water management practices. The use of city characteristics that better represented each city would certainly have a dramatic effect on the results. For instance, a city with a large percentage of multi-family developments would exhibit greater potential savings with practices that favor such development.

### 5.5.1 Indoor Conservation Simulation

Traditional conservation practices such as encouraging reduced consumption through public awareness campaigns have been joined by the advent of low flow fixtures and appliances and advanced irrigation technologies. It should be noted that there is some question as to how to identify water users that are already using water efficient installations. However, this is outside the scope of this case study and is a question for those determining how current water use patterns have already been impacted by low flow devices. For purposes of the case study, it was assumed that all water user groups implementing indoor conservation were capable of realizing the full savings benefit.

Because indoor water demands were assumed to be the same in all cities evaluated, the results of application of indoor conservation were identical for each city. Each city would potentially realize 9 million dollars per year in cost savings, 1192 millions of gallons per year in treated water savings, and 919 millions of gallons per year in wastewater reductions. However, the impact on irrigation demands of each city varied with hydrologic conditions and therefore the savings as a percentage of the total costs and demands varied as well. Comparison of the percent savings from this scenario revealed clear differences in the potential of indoor conservation for the five cities (Table 5-8).

Table 5-8 Potential Savings from Indoor Conservation

	<b>Fort Collins</b>	<b>Orlando</b>	<b>Philadelphia</b>	<b>San Diego</b>	<b>Seattle</b>
<b>Total Scenario Cost Saving (%)</b>	20	17	21	18	23
<b>Total Treated Water Savings (%)</b>	15	12	16	12	18

The potential of indoor conservation methods should not be overlooked in any water management plan. The application of other waste management plans could compliment indoor conservation and help maximize potential savings. In addition, installation of water savings devices does not require costly infrastructure changes.

### 5.5.2 Irrigation Conservation Simulation

As expected, cities with the greatest irrigation demand were found to receive the greatest benefit from irrigation conservation, Orlando and San Diego (Figure 5-16).

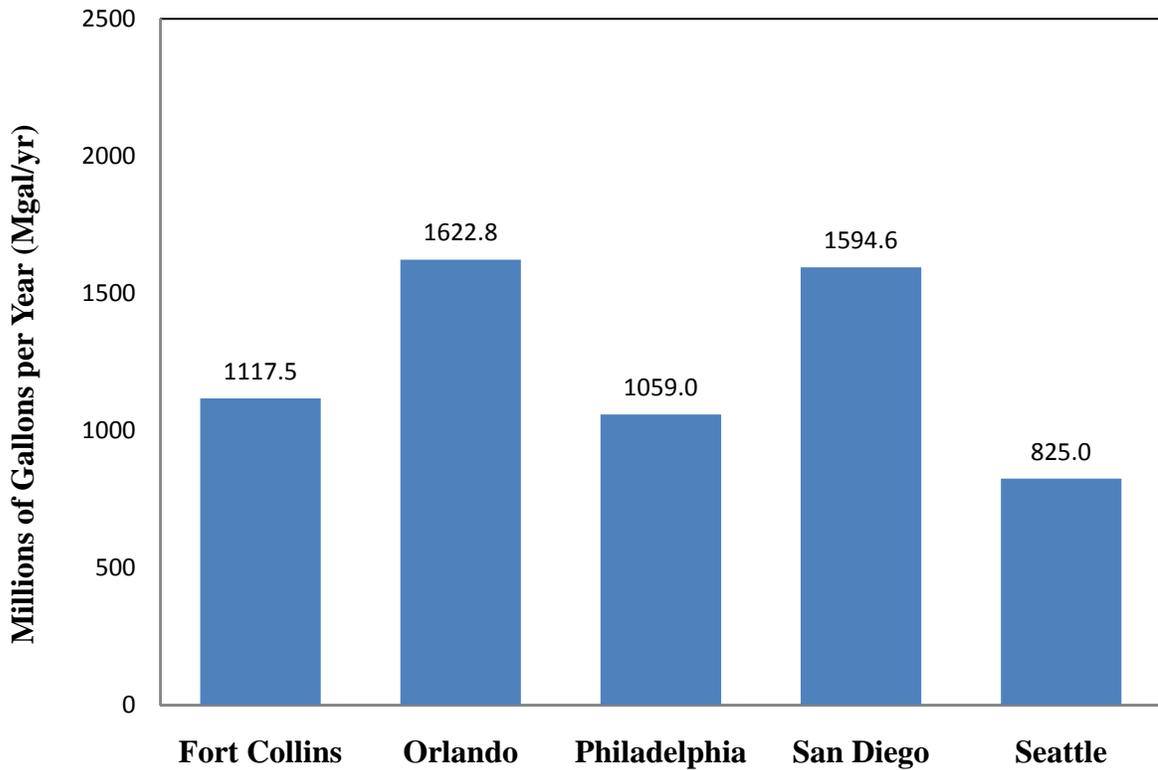


Figure 5-16 Irrigation Conservation Treated Water Savings Comparison

The greatest potential for total cost savings was observed in the cases of Orlando and San Diego (Figure 5-17).

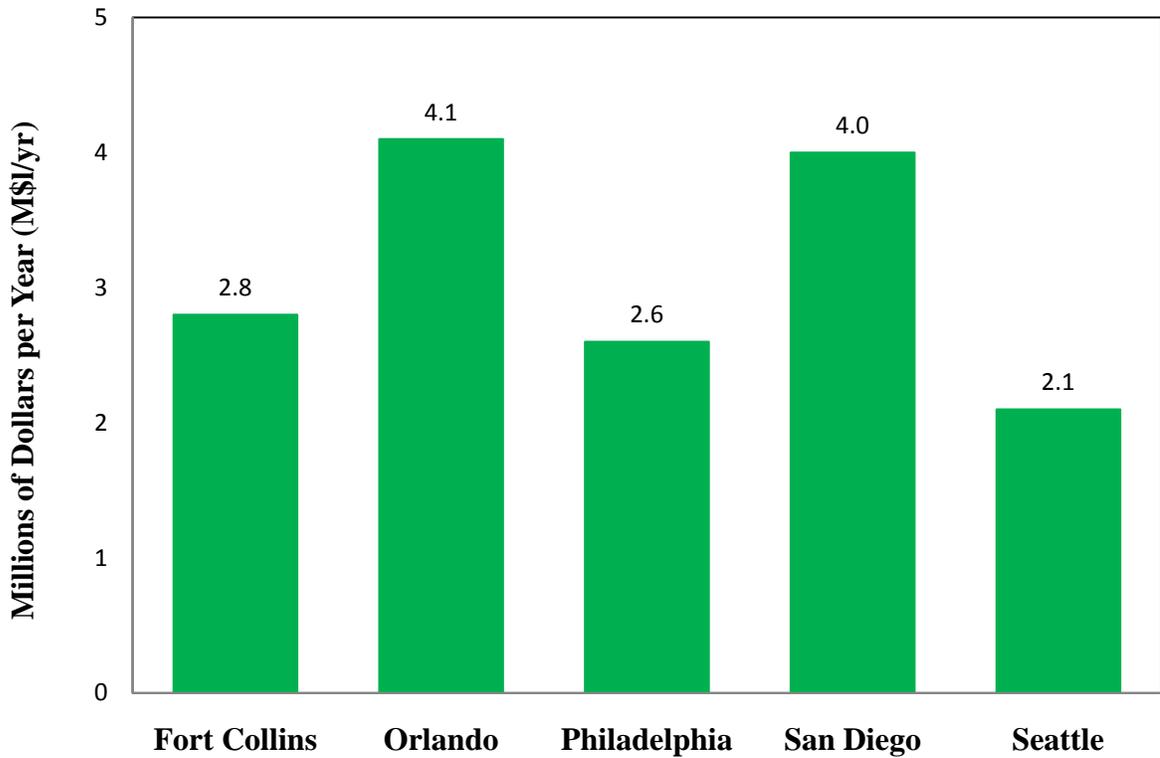


Figure 5-17 Irrigation Conservation Total Cost Savings Comparison

Comparison of the percent savings from this scenario reveals clear differences in the potential of each water management practice for the five cities (Table 5-9).

Table 5-9 Potential Savings from Irrigation Conservation

	Fort Collins	Orlando	Philadelphia	San Diego	Seattle
<b>Total Scenario Cost Saving (%)</b>	10	12	9	12	8
<b>Total Treated Water Savings (%)</b>	14	16	14	16	12

### 5.5.3 Graywater Reuse for Flushing and Irrigation Simulation

For graywater reuse, treated water savings were quite even between the five cities (Figure 5-18).

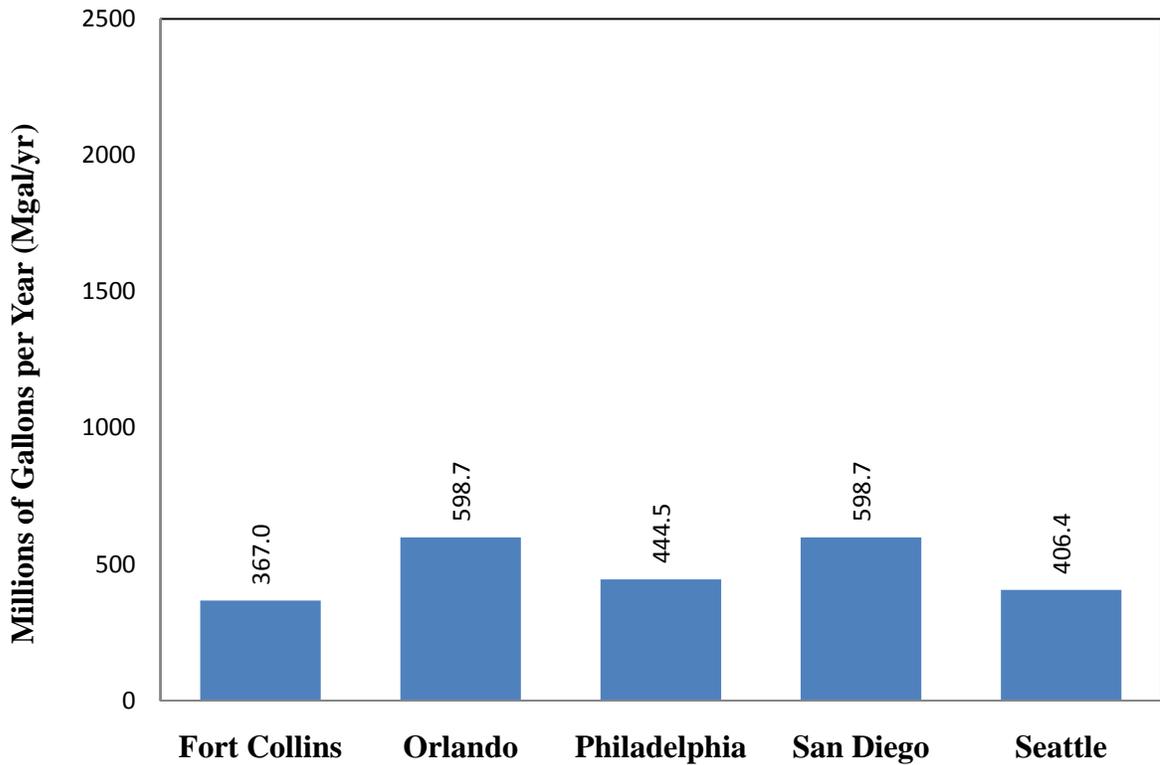


Figure 5-18 Graywater Reuse Treated Water Savings Comparison

As modeled, graywater reuse would occur at the household level with no definite costs to the municipality. However, some subsidy to help encourage homeowners to invest in the idea and necessary infrastructure for graywater reuse may be necessary to realize the potential savings. While the greatest potential for total cost savings was seen in the cases of Orlando and San Diego where irrigation demand is highest and year round, other regions experienced notable cost savings. This is the result of the application of graywater flushing which is not reliant on seasonal changes (Figure 5-19).

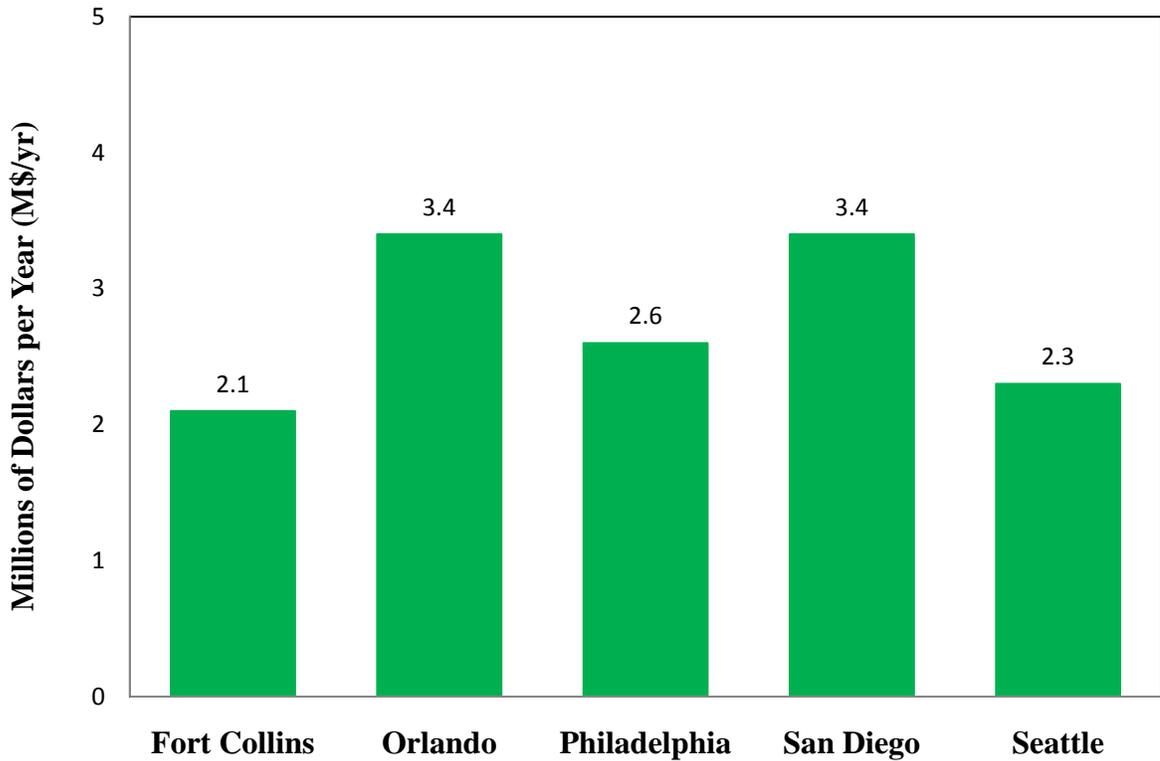


Figure 5-19 Graywater Reuse Total Cost Savings Comparison

Comparison of the percent savings from this scenario reveals clear differences in the potential of the water management practice for each of the five cities (Table 5-10).

Table 5-10 Potential Savings from Graywater Reuse for Flushing and Irrigation

	Fort Collins	Orlando	Philadelphia	San Diego	Seattle
<b>Total Scenario Cost Saving (%)</b>	7	10	9	10	9
<b>Total Treated Water Savings (%)</b>	5	6	6	6	6

#### 5.5.4 WWTP Reuse for Irrigation Simulation

The potential treated water savings observed with WWTP reuse for irrigation were the greatest among all five water management practices with Orlando and San Diego experiencing the greatest benefits (Figure 5-20).

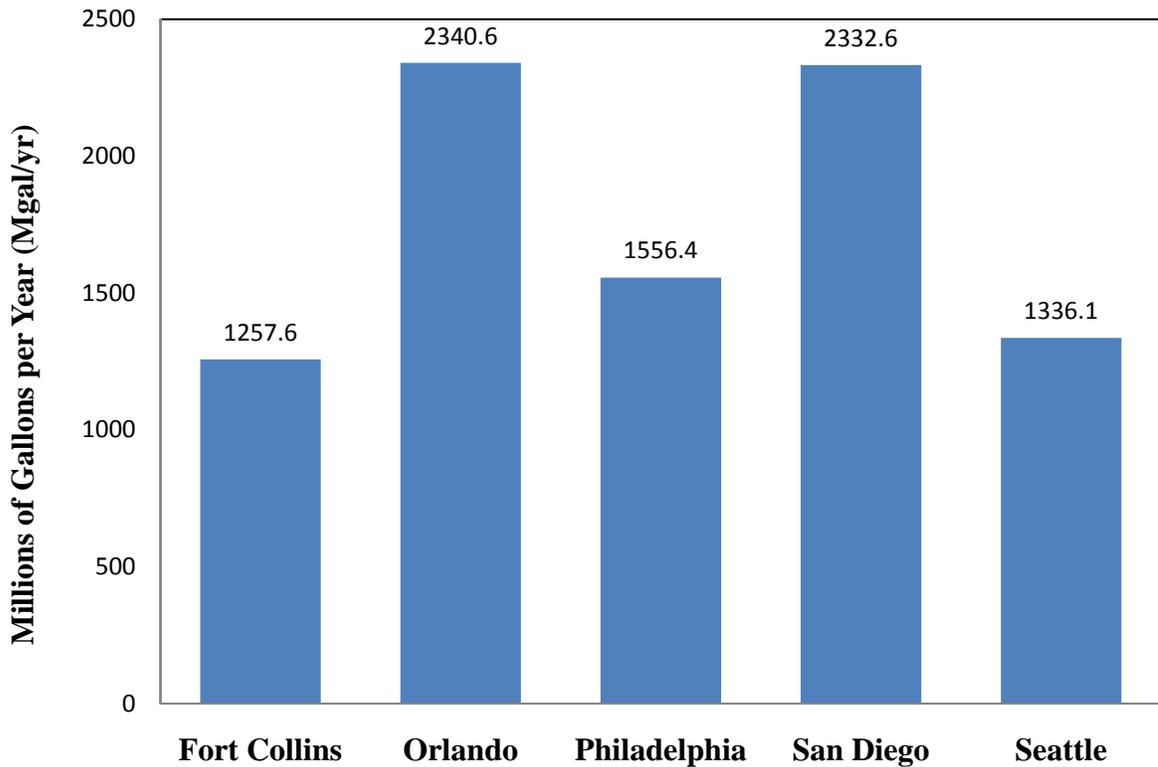


Figure 5-20 WWTP Reuse for Irrigation Treated Water Savings Comparison

It should be noted that the cost of delivery of WWTP effluent was minimal ( \$1.99 per 1000 gallons) and the volume available was very high (90%). In reality, the cost of delivery is highly variable from region to region and the infrastructure necessary to create a delivery system may be masked by government subsidies.

The added cost of delivery incorporated into the simulation reduced the overall impact to total cost. So while the potential treated water savings are significant, the total cost savings were diminished. Total cost savings between the five cities were nearly equivalent (Figure 5-23).

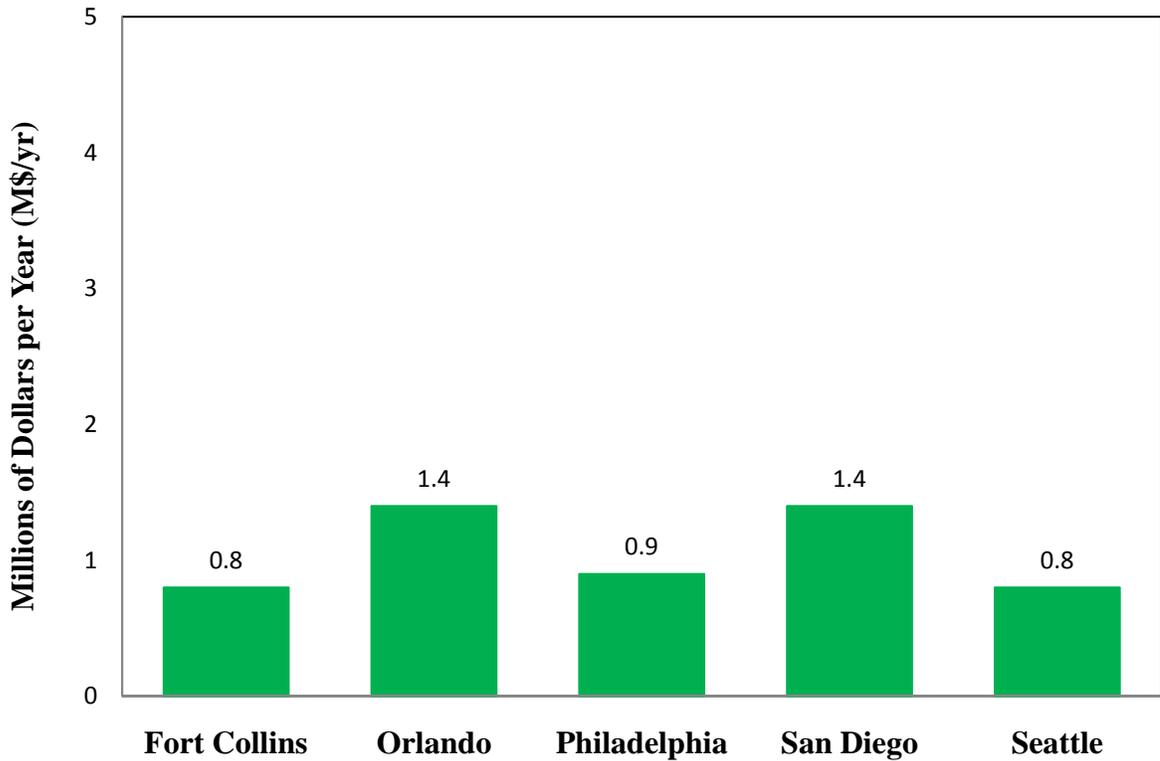


Figure 5-21 WWTP Reuse for Irrigation Total Cost Savings Comparison

Comparison of the percent savings from this scenario reveals clear differences in the potential of WWTP reuse for each of the five cities (Table 5-11).

Table 5-11 Potential Savings from WWTP Reuse for Irrigation

	Fort Collins	Orlando	Philadelphia	San Diego	Seattle
<b>Total Scenario Cost Saving (%)</b>	2	4	3	4	3
<b>Total Treated Water Savings (%)</b>	16	24	20	24	20

### 5.5.5 Stormwater Capture for Irrigation Simulation

The effectiveness of stormwater capture as a water management practice is dependent on the available storage volume. The volume of 240 gallons applied to the single-family residence user category does not allow for realization of the full potential of the practice. An

option for improved performance of the practice in single-family residential settings would be the use of community cisterns or wet detention basins such as those applied to the multi-family water user category which provide ample supply for stormwater capture and irrigation use.

Orlando stood out as the city with the greatest potential for treated water savings (Figure 5-22). Wastewater production was again unaffected.

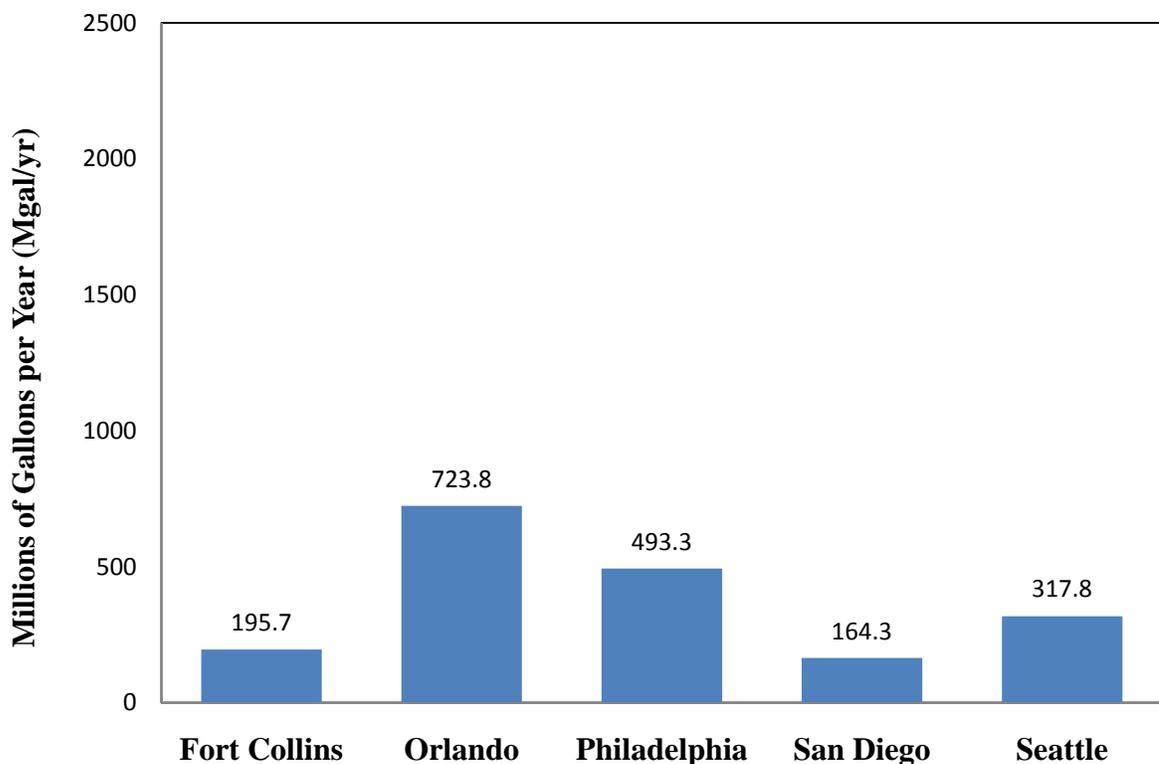


Figure 5-22 Stormwater Capture for Irrigation Treated Water Savings Comparison

Total cost savings for the scenario were the lowest of the five (Figure 5-23).

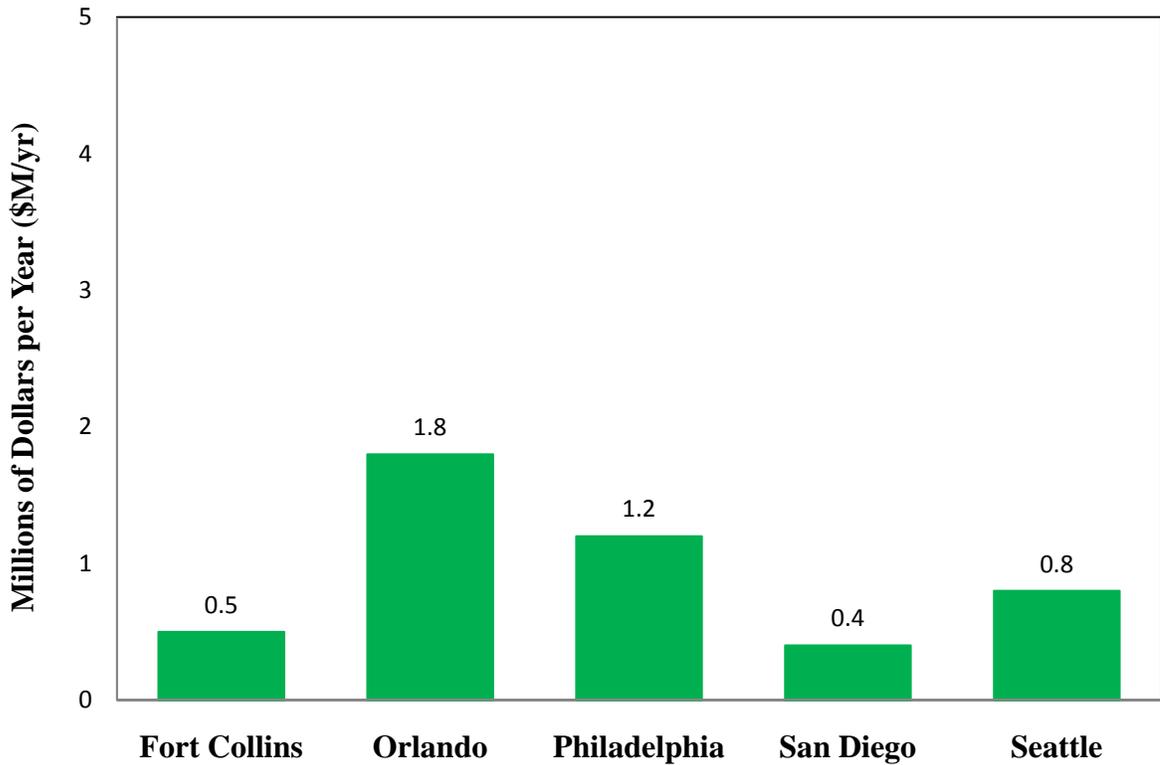


Figure 5-23 Stormwater Capture for Irrigation Total Cost Savings Comparison

Comparison of the percent savings from this scenario reveals clear differences in the potential of each water management practice for the five cities (Table 5-12).

Table 5-12 Potential Savings from Stormwater Capture for Irrigation

	Fort Collins	Orlando	Philadelphia	San Diego	Seattle
<b>Total Scenario Cost Saving (%)</b>	2	5	4	1	3
<b>Total Treated Water Savings (%)</b>	2	7	6	2	5

Orlando still fared well in terms of potential savings as a result of high availability of stormwater for capture and a year-round irrigation schedule. Simulations of the scenario

applied to Fort Collins and San Diego resulted in the lowest total cost savings due to hydrologic conditions which produce smaller volumes of stormwater.

Rainfall events often produce far more runoff than may be captured with by the limited storage capacity provided by four rain barrels. This is especially true in regions which experience large precipitation events followed by relatively dry periods.

Additional simulations were performed to explore the possibilities of increased savings and cost reduction with larger stormwater capture storage volumes. It was found that a storage volume of 720 gallons maximized the potential for savings in all five cities (Table 5-13).

Table 5-13 Results of Increased Stormwater Capture Storage Volume

	<b>Fort Collins</b>	<b>Orlando</b>	<b>Philadelphia</b>	<b>San Diego</b>	<b>Seattle</b>
<b>Total Scenario Cost Saving (%)</b>	2	9	7	2	4
<b>Total Treated Water Savings (%)</b>	4	13	11	2	6

A storage volume of 720 gallons would represent a 3 fold in storage volume per household. While the use of rain barrels to attain this level of storage in a single-family residence setting is likely infeasible, the use of below ground cisterns or shared wet detention basin storage on the subdivision level could make storage volumes of this size a reality. The use of wet detention basins as an amenity of the development while also reducing irrigation costs and providing stormwater detention capacity may be a wise investment and preferable to the expense of placing a cistern and pump system for each residence.

## 5.6 Conclusions

IUWM is capable of providing estimates of the potential for water and cost savings based upon user input. While this case study made broad assumptions about unit costs for water and wastewater treatment while also generalizing the characteristics of the five cities included, the goal of demonstrating the capabilities of the model was achieved. These assumptions were made to review performance of the model under varying hydrologic conditions alone. It is evident from the results that the differences in regional hydrology should influence decisions about which water management practices are most efficient. Results showed an impact of rainfall and irrigation demand on water savings achieved through application of water conservation practices, particularly those scenarios which reduce treated irrigation demand. Aside from indoor and irrigation conservation practices, graywater reuse resulted in the largest cost savings in all cities. This is attributable to the reduced wastewater production associated with this practice. While most scenarios resulted in higher savings on treated water demand than graywater, the overall cost benefit of this scenario was generally notable, due to decreased generation of wastewater. While treated wastewater reuse for irrigation generally resulted in the most treated water savings, cost savings were not realized due to high costs for supply of treated wastewater back to the user.

An improved dataset of demands and city characteristics would greatly enhance the results of the model case study. As with any model, the level of detail and accuracy of the results are a reflection of the detail and accuracy of the user input. As research and data collection in the areas of water reuse and conservation continue, improved availability of data will enhance the usefulness of IUWM. Further improvements to the current application may include the inclusion of CII demand data, improved irrigation demand handling, and

enhancements to the water management practices. One critical component required to enhance IUWM is inclusion of infrastructure requirements and associated whole life costs. Future versions of IUWM should include enhanced economic analysis capabilities and the possibility of geographic information system integration.

## REFERENCES

Aquacraft (2009). Embedded Energy in Water Study 3: End-use Water Demand Profile Final Research Plan. Aquacraft, Inc.

C.K. Makropoulos, et al. (2008), Decision Support for Sustainable Option Selection in Integrated Urban Water Management, *Environmental Modelling and Software* 23, 1448-1460

Dziegielewski, B., Opitz, E., Kiefer, J., and Baumann, D. (1993). Evaluation of Urban Water Conservation Programs: A Procedures Manual. California Urban Water Agencies.

Dziegielewski, B (2000). Commercial and Institutional End-uses of Water. American Water Works Association.

EBMUD (2008). Watersmart Guidebook: A Water-Use Efficiency Plan-Review Guide for New Businesses. East Bay Municipal Utility District

Irritrol. (2011). Historic ET.  
<http://www.rainmaster.com/historicET.asp>

Jokerst, A.W. (2010), An Evaluation of Graywater Reuse Utilizing a Constructed Wetland Treatment System, ASCE

Lekkas, D.F., Manoli, E., Assimacopoulos, D. (2008), Integrated Urban Water Modelling Using the Aquacycle Model, *Global Nest Journal*, Vol 10, No 3, 310-319

Mayer, P., DeOreo, W. (1999). Residential End-uses of Water, American Water Works Association.

Morales, M., Martin, J, Heaney, J. (2009). Methods for Estimating Commercial, Industrial and Institutional Water Use. University of Florida.

O'Connor, T., Rodrigo, D., Cannan, A. (2010), Total Water Management: The New Paradigm for Urban Water Resources Planning, ASCE

Palenchar, P., Friedman, K., Heaney, J. (2009). Hydrograph Separation of Indoor and Outdoor Billed Water Use in Florida's Single Family Residential Sector. University of Florida.

SelectWater Website – WaterCress Download Page (2011)  
<http://www.watersselect.com.au/watercress/watercress.html>

US Dept of Energy Website – Energy Efficiency & Renewable Energy (2011)  
[http://apps1.eere.energy.gov/buildings/tools\\_directory/software.cfm/ID=74/pagename=alpha\\_list](http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=74/pagename=alpha_list)

USEPA. (2004). Guidelines for Water Reuse. Report EPA/625/R-04/108. U.S. Environmental Protection Agency

USEPA. (2010). Sustainable Infrastructure for Water and Wastewater.  
<http://water.epa.gov/infrastructure/sustain/basicinformation.cfm>

WaterSense Website. (2011)  
[http://www.epa.gov/WaterSense/water\\_efficiency/what\\_you\\_can\\_do.html](http://www.epa.gov/WaterSense/water_efficiency/what_you_can_do.html)

Vickers, Amy (2001). Handbook of Water Use and Conservation. Waterplow Press.