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EVALUATING THE IMPACTS OF WATER CONSERVATION POLICIES ON

WATER DEMAND, AVAILABILITY AND OUTDOOR WATER

USE IN THE LAS VEGAS VALLEY

by

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Bachelor of Engineering
NED University of Engineering & Technology,
Karachi, Pakistan
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A thesis submitted in partial fulfillment of
the requirements for the

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ABSTRACT

Evaluating the Impacts of Water Conservation Policies on Water Demand, Availability and Outdoor Water Use in the Las Vegas Valley

by

Kamal Qaiser

Dr. Sajjad Ahmad, Examination Committee Chair
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University of Nevada, Las Vegas

The Las Vegas Valley, located in the arid Southern Nevada region, with a growing population, limited water resources, and a prolonged drought, faces a challenge in meeting its future water needs. Southern Nevada Water Authority (SNWA), the main water management agency in the Valley, is focusing on water conservation to reduce water demand. Current water use is 945 lpcd (250 gpcd) which SNWA aims to reduce to 752 lpcd (199 gpcd) by 2035. Presently the indoor outdoor water use proportion is about 40:60 in the Valley. An important component of the Valley's supply are the return flow credits which SNWA gets for the Colorado river water, the main supply source, that they return back to the river. This return flow mainly comprises the flow from the wastewater treatment plants. The credits process allows SNWA to withdraw additional one unit of river water for every unit of treated river water returned. The objectives of this research are (i) evaluating the extent to

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which the present available water supply can fulfill the water demand in the Valley in the future. This involves assessing the impacts of various water conservation policies and population projections on water supply and demand in the Las Vegas Valley (ii) evaluating the magnitude and interrelationship of the different outdoor water use components, their response to water conservation policies and their potential for water savings. This involves quantifying outdoor water use in response to water conservation, estimating the effect of nitrate loading in reuse water on the quality of shallow groundwater, and evaluating the potential for water savings from turf replacement in the Valley.

To accomplish the research objectives, a water balance simulation model for the Valley has been developed, which documents the water cycle of the Valley and can be used to explore several what-if questions. System Dynamics (SD) modeling approach and software tool Stella are used to develop the model that runs the simulations from 1993 to 2035 while keeping track of demographics, water demands, and water supply. The model runs on an annual time step and is calibrated for a period from 1993 to 2008. Five different conservation policies are evaluated for both research objectives. The first policy considers the status quo situation by projecting the 2008 water use levels till 2035. The second policy explores the effect of conserving water only on the outdoor side. The third policy considers equal conservation both on the indoor and outdoor side while the fourth policy considers 67% outdoor and 33%

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indoor water use conservation. The fifth policy considers conserving water only on the indoor side.

The results from the model for the first objective reveal the importance of outdoor water conservation and present it as a key solution in addressing the water problems of the Valley. Water consumption decrease from 945 lpcd (250 gpcd) to 752 lpcd (199 gpcd) if met completely through outdoor conservation, generates the highest return flow credits and can potentially satisfy the Valley's water needs through 2035.

For the second objective the all outdoor conservation scenario gives the highest value of return flow credits and the least values for the components of outdoor water use. The impact of wastewater reuse specifically its nitrate loading, on the shallow groundwater aquifer points to a gradual deterioration in the groundwater quality with time. The model assesses the impact of replacing all convertible (non-golf course) turf with desert landscaping in the Las Vegas Valley on water savings, and determines that replacing the turf will result in a 59 lpcd (16 gpcd) decrease in the water demand. The results can be a guide in developing effective outdoor water conservation policies and the water balance model can be potentially used in helping policy makers make informed decisions on various water management issues.

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ACKNOWLEDGMENT

I would like to thank Mr. Walter Johnson, P.E., for guiding me and especially for providing me with a large collection of data related to the water system in the Valley, without which this research would not have been possible.

My advisors Dr. Sajjad Ahmad and Dr. Jacimaria Batista also deserve my appreciation for their time, advice and encouragement to help me complete this thesis in the face of near insurmountable odds. I am also grateful to Dr. Ahmad for putting those long hours with me towards the end.

CHAPTER 1

INTRODUCTION

1.1. Background

Las Vegas Valley (LVV), located in Southern Nevada, is a region facing complex water management issues. The LVV has experienced enormous growth in population, changes in land use and substantial economic activity based on tourism, all of which have contributed to a high water demand and high amounts of wastewater generation, over the last 20 years. The Valley's population is expected to be nearly 3.3 million in 2035 (CBER, 2009), which is a large increase from the present value i.e., about 2 million. Exacerbating this situation is the severe drought gripping the region (Piechota et al, 2004), as a result of which main reservoirs in the Colorado river system, the major water source for the Valley, have reached historically low levels (Barnett & Pearce, 2008). The Valley is also one of the driest and hottest places in the United States and generally averages less than 130 mm (5 in) of rain annually (Gorelow & Skrbac, 2009). Another complication is that the water and wastewater in the Valley are intrinsically linked as highly treated wastewater effluent is returned back through the Las Vegas Wash, to Lake Mead, the drinking water source for the Valley's residents. Return flow credit is given to Nevada when wastewater is returned to Lake Mead, thereby augmenting Nevada's water allocation from the Colorado River (SNWA, 2008). Though the return of treated wastewater adds to the water supply,

it is a major contributor of nutrients, total dissolved solids, pharmaceuticals and other yet unregulated pollutants to Lake Mead (Johnson et al, 2007). Also, the internal administrative structure of the Valley poses a hurdle. The Valley is composed of 6 main urban entities, the City of Henderson, the City of Las Vegas, the City of North Las Vegas, Boulder City, Nellis Air Force Base and the Clark County portion of Las Vegas Valley (CCN, 2008). Each unit has its own individual growth dynamics. This complicates development and implementation of various water management policies. Overall, the amalgamation of these factors builds a very complex and challenging case for water management in the Las Vegas Valley.

In response to the precarious water situation brought about by a growing population, limited water resources and prolonged drought, SNWA (Southern Nevada Water Authority), which manages the water system in the Las Vegas Valley, has, among other options, focused on reducing the per capita water demand. In 2005, the water authority adopted a per capita demand target of 926 lpcd (245 gpcd) by 2035. In 2009, the per capita demand target was revised down to 752 lpcd (199 gpcd) (SNWA, 2009). Landscape irrigation is the single largest water use in the Valley, and about 60% water distributed to the residents is used outdoors Any attempt to reduce water use will have impacts on return flow credits and outdoor water use components (evapotranspiration,

seepage to groundwater, excess irrigation runoff, seepage to the Las Vegas Wash).

1.2. Hypothesis And Objectives

Three main hypotheses of this research are:

- The present available water supply can fulfill the water demand in the Las Vegas Valley through water conservation till 2035.
- If total turf replacement with xeriscaping in the Valley occurs, then it can achieve a 193 lpcd (51 gpcd) reduction in the water demand
- If domestic use of treated wastewater which contains nitrates is implemented, it will result in potential contamination of the shallow groundwater aquifer of the Las Vegas Valley

Two main objectives of this research related to the hypotheses are:

- Evaluating the extent to which the present available water supply can fulfill the water demand in the Valley in the future. This will involve,
    - o Assessing the effect of various water conservation policies and population projections on water supply and demand in the Las Vegas Valley.
    - o Reviewing the effect of water reuse in conjunction with water conservation on the water system.

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- Evaluating the magnitude and interrelationship of the different outdoor water use components, their response to water conservation policies and their potential for water savings. This will involve,

  o Estimating the quantity of different outdoor water use components including evapotranspiration, excess irrigation runoff, infiltration to groundwater and infiltration to the Las Vegas Wash, in response to different water conservation policies and the effect on return flow credits in the Las Vegas Valley over the next 25 years.

  o Estimating the effect of nitrate loading in reuse water on the quality of the shallow groundwater in the Valley.

  o Evaluating the potential of turf (grass) replacement with xeriscaping for water savings in the Valley.

An integrated, interactive and detailed water balance model of the Las Vegas Valley is developed to address the research objectives. System Dynamics (SD) modeling approach and software tool Stella are used to develop the model that is capable of running the simulations up to 25 years into the future while keeping track of demographics, water demands, and water supply. In SD the structure of a system, the network of cause and effect relations between system elements, governs system behavior (Sterman, 2000). SD is a framework for seeing

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interrelationships, for seeing patterns of change rather than static snapshots, and for seeing processes rather than objects (Senge, 1990).

Although there have been several attempts (Stave 2003), such a comprehensive water balance model has not been developed for the Las Vegas valley; this research is an attempt to accomplish that. The model is used to evaluate the impacts of population growth, water conservation choices, and changes in return flow credits on the water supply and demand in the Valley, and the outdoor water use components.

1.3. Model Scope

The model comprises the various administrative entities in the Las Vegas Valley which are the City of Henderson, City of Las Vegas, City of North Las Vegas, Clark County Portion of the Valley, Nellis Air Force Base and Boulder City. The model also includes the water and wastewater treatment plants, various indoor and outdoor water uses and all major components of the water system in the Valley. So the model is a comprehensive and rigorous water mass balance of the Valley, very different from what any previous study has attempted to accomplish. The model tries to conceptually conform to the real system as much as possible.

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1.4. Research Tasks

To complete the objectives of this research, the following tasks were identified and accomplished.

Task 1. Data Collection:

Sources of information used in this study include CEBR (Council for Economics and Business Research, Sewer and Water Agency Committee (SWAC), Las Vegas Convention and Visitors Authority (LVCVA), Southern Nevada Water Authority (SNWA), Las Vegas Valley Water District (LVVWD), Clark County Regional Flood Control District, Bureau of Reclamation, Colorado River Commission, and water reclamation facilities (CCWRD, COLV, COH).

Task 2. Development of the Water Mass Balance model:

A system dynamics modeling tool, Stella, was used to model the water balance in the Las Vegas Valley. Stella's diagrams and animations allow for visualization of interrelationships among variables in the Valley's water system.

Task 3. Model Calibration and Validation:

The model built in Stella was calibrated and validated using the available data collected under Task 1. Calibration was performed for water quantity parameters using measured flows at water and wastewater treatment facilities.

Task 4. Model Simulations:

After calibration, the model was used to simulate various water conservation scenarios.

1.5. Significance

The key contributions of this research are through:

a) Providing a quantitative framework: It provides a quantitative tool for mass balance and for exploring different water and wastewater management policies.

b) Explaining the complex system: The decision framework captures the impacts of feedbacks; a concept vital in understanding the cause and effect relations.

1.6. Preview

The thesis follows a manuscript format and starts with this introduction. It is then followed by two manuscripts as chapters two and three. The first manuscript discusses the effects of five conservation policies with varying indoor and outdoor water proportions in meeting the SNWA target of 752 lpcd (199 gpcd) and different population projections on the water demand and supply situation in the Valley over the next 25 years. The second manuscript investigates the effect of different conservation policies on outdoor water use and its components. It also investigates the effectiveness of removing turf and converting it to

water efficient landscapes in the Valley and the impact of water reuse on the quality of shallow ground water. The two chapters are followed by the final chapter that includes conclusion and recommendations and suggestions for future research.

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CHAPTER 2

EVALUATING THE IMPACT OF WATER CONSERVATION ON WATER

DEMAND AND AVAILABILTY IN THE LAS VEGAS VALLEY

2.1. Abstract

The Las Vegas Valley, located in the arid Southern Nevada region, faces a challenge in meeting its future water needs with a growing population, prolonged drought and limited water resources. The Southern Nevada Water Authority (SNWA), the main water management agency for the Valley, is focusing on water conservation to reduce water demand. Current water use is 945 lpcd (250 gpcd) which SNWA aims to reduce to 752 lpcd (199 gpcd) by 2035. An important component of the Valley's supply are the return flow credits which the Valley gets for the Colorado River water, the main supply source, that they return back to the river. This return flow mainly is comprised of the flow from the wastewater treatment plants. The credits process allows the water authority to withdraw an additional one unit of river water for every unit of treated river water returned. This research focuses on evaluating the impacts of various conservation policies on water demand and supply by changing the indoor and outdoor water use patterns, and considers only the present available water supply to gauge the extent to which the present supply can fulfill the water demand. The water conservation target is simulated through different conservation policies with varying indoor and outdoor water use proportions along with different population

projection scenarios to evaluate their combined effect on the water supply and demand, including return flow credits in the Valley over the next 25 years. To accomplish this, a water balance simulation model for the Valley has been developed, which documents the water cycle of the Valley and can be used to explore several what-if questions. The model runs from 1993 to 2035 on an annual time step and is validated for a period from 1993 to 2008. The model is used to explore five policy scenarios: (i) the status quo situation by projecting the 2008 water use levels till 2035, (ii) the effect of conserving water only on the outdoor side, (iii) the policy considers 67% outdoor and 33% indoor water use conservation, (iv) the policy considers equal conservation both on the indoor and outdoor side (v) the effect of conserving water only on the indoor side. The results of this analysis reveal the importance of water conservation especially outdoor water conservation and present it as a key solution in alleviating the water problems of the Valley. Water consumption decrease from 945 lpcd (250 gpcd) to 752 lpcd (199 gpcd), generates the highest return flow credits and can potentially satisfy the Valley's water needs through 2035 if met completely through outdoor conservation.

Key Words: Water balance, water management, simulation modeling, water conservation, policy analysis, system dynamics, Las Vegas

2.2. Introduction

Sustainable water resources systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental and hydrological integrity (ASCE, 1998). This definition hints towards the complexity inherent in contemporary water resources management problems. Population growth, climate variability, regulatory requirements, and limited water resources, are components that make water resources problems difficult to solve. Also, water management plans usually stretch over long time spans to account for the growth in the future population. Matching the future's increasing water needs requires integrated management of surface and ground water. The environmental and social impacts of possible water resources solutions must be given serious deliberation. Also, government regulations about water quality should be kept in perspective, and public participation needs to be ensured (Simonovic, 2009). All of these factors converge and effect an increase in the complexity of the decision making process for water resources management.

Las Vegas Valley (LVV), in the southwest USA, is a region facing exactly these sort of complex water management issues. The LVV has experienced enormous growth in population, changes in land use and substantial increases in economic activity based on tourism, all of which have contributed to a higher water demand and higher amounts of

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wastewater generation, over the last 30 years. The Valley's population is expected to be nearly 3.3 million in 2035, which is a significant increase from the present population which is about 2 million. Exacerbating this situation is the severe drought gripping the region, as a result of which main reservoirs in the Colorado river system, the major water source for the Valley, have reached historically low levels (Barnett & Pearce, 2008). The Valley is also one of the driest and hottest places in the United States and generally averages less than 130 mm (5 in) of rain annually (Gorelow and Skrbac, 2009). Another complication is that the water and wastewater in the Valley are intrinsically linked as highly treated wastewater effluent is returned back to Lake Mead, the drinking water source for the Valley's residents. Return flow credit is given to Nevada when wastewater is returned to Lake Mead, thereby augmenting Nevada's water allocation from the Colorado River (SNWA, 2008). Though the return of treated wastewater adds to the water supply, it is a major contributor of nutrients, total dissolved solids, pharmaceuticals and other yet unregulated pollutants to Lake Mead (Johnson et al, 2007). The Valley is composed of six main urban entities, the City of Henderson, the City of Las Vegas, the City of North Las Vegas, Boulder City, Nellis Air Force Base and unincorporated areas of Clark County (CCN, 2008). Each unit has its own individual growth dynamics. This complicates development and implementation of various water management policies.

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Overall, the amalgamation of these factors builds a very complex and challenging case for water management in the LVV.

In response to the precarious water situation brought about by a growing population, limited water resources and prolonged drought, SNWA (Southern Nevada Water Authority), which manages the water system in the LVV, has undertaken various conservation measures and set lower targets for per capita water demand. In 2005, SNWA adopted a per capita demand target of 926 lpcd (245 gpcd) by 2035. In 2009, the per capita demand target was revised down significantly to 752 lpcd (199 gpcd) (SNWA, 2009). Through this research, the impacts of population growth, water conservation policies and changes in return flow credits on the water demand and supply situation in the Valley over the next 25 years are evaluated. For this purpose an integrated, interactive and detailed system dynamics based water balance model of the LVV is developed using available water and wastewater data. The model reduces complexity and permits exploration of the simultaneous impacts of population change, water conservation choices, changes in return flow credits, wastewater reuse and other similar factors. The hypothesis tested in this research is, the present available water supply can fulfill the water demand in the LVV through 2035 through water conservation.

The objectives related to the hypothesis are:

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- To capture and document the water cycle of the Las Vegas Valley, in a mass balance model.

- To explore different policy options regarding water conservation, and redistribution between indoor and outdoor water usage.

- To review the effect of water reuse in conjunction with water conservation on the water system.

- To assess the time period till which the existing water resources can meet the water demand.

The Valley's water system is discussed next, followed by an overview of the present water use trends. After that, the method section is presented, with results and conclusions coming in the end.

2.3. Las Vegas Valley Water System

The latitude and longitude for the Valley are 36° 5' N, 115° 10' W and the size of the Valley is about 1600 km² (618 mi²).The main source of water for the LVV is Lake Mead, replenished with Colorado River water, and currently accounting for 90% of the Valley's water supply (SNWA, 2009). The amount of water available for Southern Nevada from Lake Mead under the Colorado River Agreement is 370 million m³/yr (300,000 ac-ft/yr) plus the return flow credits obtained from returning the treated wastewater to Lake Mead. The rest of the water, about 10%, is obtained from ground water wells in the Valley.
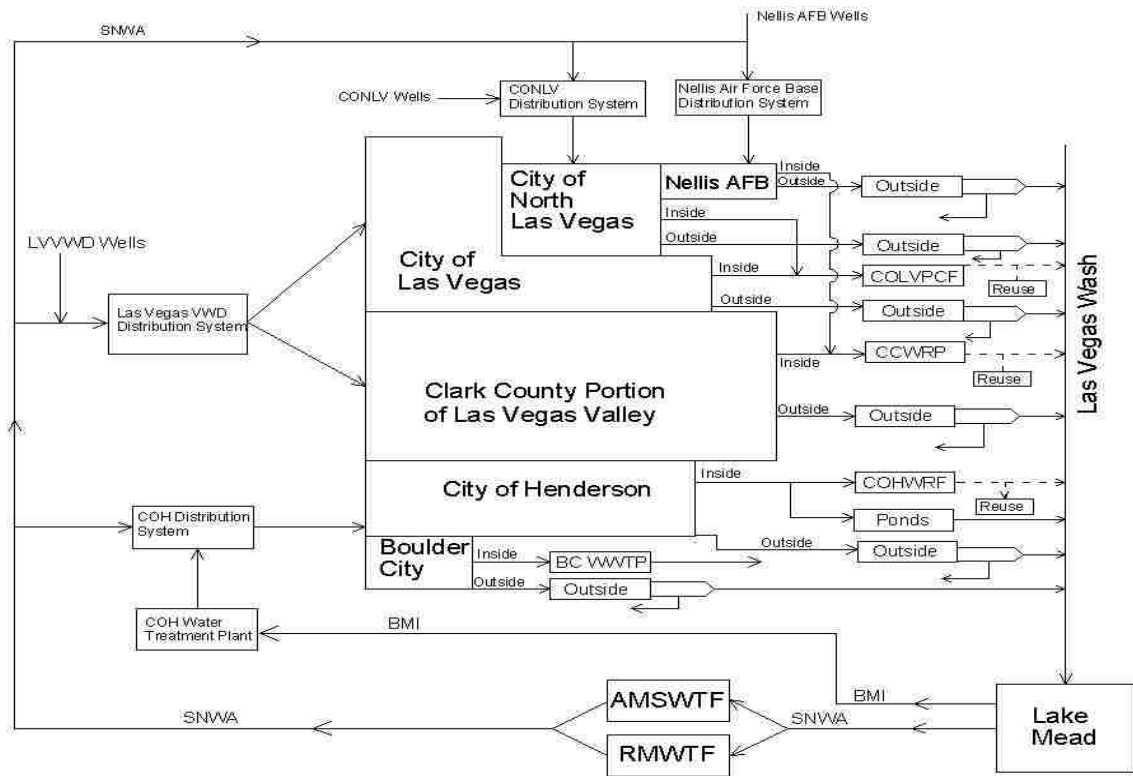
Figure 2.1. Schematic of Las Vegas Valley Water System

Figure 2.1 presents a schematic of the LVV water system. The model balance is created keeping this fundamental system in perspective. The LVV has two main water treatment plants, Alfred Merritt Smith Water Treatment Facility (AMSWTF) and River Mountains Water Treatment Facility (RMWTF), having a combined capacity of around 3.4 million m^3/day (900 MGD) (SNWA, 2010). In addition to these, the City of Henderson has a water treatment plant with a capacity of about 0.056 million m^3/day (15 MGD) (COH, 2009) that receives water from the Basic Management Inc. (BMI) pipeline which also supplies water to the BMI industries mainly for cooling purposes. The water is then supplied to the

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different administrative units in the Valley including the City of Henderson (COH), City of Las Vegas (COLV), City of North Las Vegas (CONLV), Clark County portion of Las Vegas Valley (CCPLVV), Boulder City (BC) and Nellis Air Force Base (NAFB). The portion of the water used indoor becomes wastewater and is treated to tertiary standards (e.g. including filtration and nutrient removal steps). There are three wastewater treatment plants, the City of Henderson Water Reclamation Facility (COHWRF), the Clark County Water Reclamation Plant (CCWRP) and the City of Las Vegas Water Pollution Control Facility (COLVWPCF). All three have a combined capacity of about 0.946 million m^3/day (250 MGD) (COH, 2009 and CCWRD, 2009). Most of the treated wastewater goes back to Lake Mead, through the Las Vegas Wash, while a small portion of the wastewater is reused for golf course irrigation. Also, stormwater in the Valley drains to Lake Mead. LVV has a relatively new and modern sewage and runoff collection system. The fate of outdoor water use is divided into four main components. A portion of the water used outdoors is lost to evapotranspiration, a portion seeps to the ground water, a portion becomes excess landscape irrigation flow and a portion seeps to the Las Vegas Wash. The excess irrigation flow is collected by the storm drainage system and ends up in the Las Vegas Wash.

The LVV gets return flow credits for the water it returns to Lake Mead which considerably enhances the available water supply. The

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computation method for the credits ensures Nevada gets credits only for those return flows, which have a signature of Colorado river, not for groundwater nor for storm water (LVWCAMP, 1999). The return flow credits are an important feedback in the Valley's water system. The role of the credits within the system is described by a causal loop diagram as shown in Figure 2.2. The Figure 2.2 is a positive loop which describes the self-reinforcing nature of return flow credits within the system. The more wastewater is generated, the more will be the return flow credits, and the higher will be the water supply resulting in more wastewater generated.
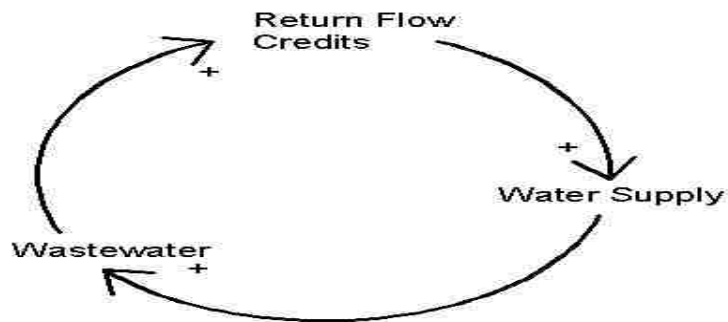
Figure 2.2. Causal Loop Showing Return Flow Credits

The equation 1 is used to calculate the return flow credits. It is developed from the description of the return flow credits process, and is basically an accounting technique outlined in the LVWCAMP (1999) report.

Return Flow Credits = Treated wastewater – [(groundwater wells portion of treated wastewater) - (wastewater reuse from groundwater wells) -

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(phreatophyte use from groundwater in the Las Vegas Wash)] + (Colorado river fraction*excess irrigation runoff) + (Colorado river fraction * seepage to Las Vegas Wash)   (1)

2.4. Current Water Use Pattern In The Las Vegas Valley

The water authority calculates the per capita water demand simply by dividing all the water supplied to Valley (residential, commercial, recreational etc.) by its permanent population. Even though the Valley has substantial transient population throughout the year, there is no separate calculation for the transient population's per capita demand, and it is represented in the per capita water demand for the Valley's resident population. As of 2008, Nellis Air Force Base and Boulder City have the highest per capita demand in the Valley, though they have the smallest populations. This trend has continued over the last twenty years. Nellis AFB had the highest per capita demand of 1890 lpcd (500 gpcd) while Boulder City is at 1572 lpcd (416 gpcd). The main population centers, the City of Henderson, City of Las Vegas, City of North Las Vegas, and the Clark County portion, in comparison have far lesser per capita demands. As of 2008, COH had 1055 lpcd (279 gpcd), COLV had 919 lpcd (243 gpcd), CONLV had 896 lpcd (237 gpcd) and Clark County portion had 919 lpcd (243 gpcd). Figure 2.3 shows (a) the water demand (b) the indoor outdoor distribution and (c) the per capita water demand in the Valley in 2008. The data for Fig.2.3 was collected from the Clark County SWAC (Sewage and Wastewater Advisory Committee) reports and

it also highlights that the different cities or entities in the Valley have their own diverse water use dynamics.

Presently the amount of wastewater reused in the Valley is 0.099 million m³/day (26 MGD). The amount of wastewater reused is projected to be 0.21 million m³/day (56 MGD) in 2020 (CCN, 2000).
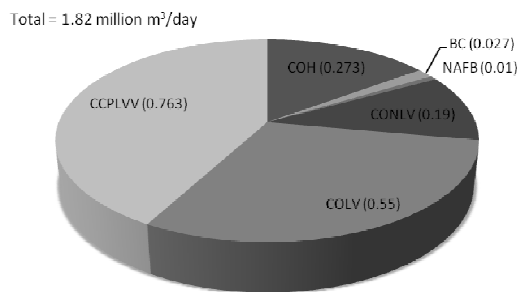
Figure 2.3a.Water Demand (Million m3/day) for Entities in 2008
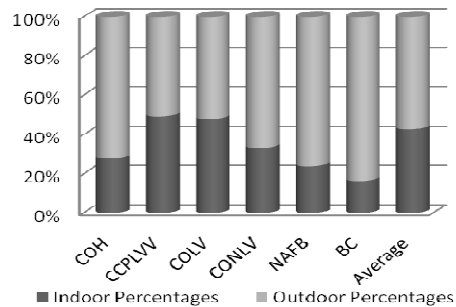
Figure 2.3b. Indoor Outdoor water use Percentages for Entities in 2008
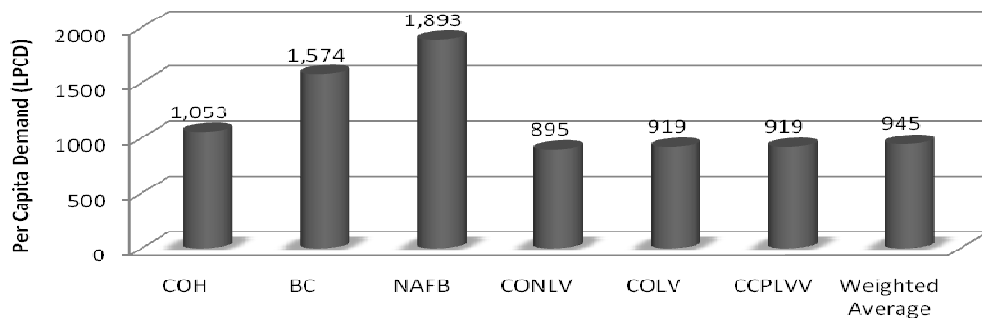
Figure 2.3c. Per Capita Demand for Entities in 2008

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2.5. Method

Water systems are sociotechnical systems i.e., technical systems with strong links to society. This makes them relevant for a systems thinking analysis, and the complexity can be reduced by applying systems thinking to study the working of the system (Grigg, 1996). Systems thinking is a conceptual framework for seeing interrelationships rather than things, for seeing patterns of change rather than static "snapshots." It is a discipline for seeing wholes (Senge, 1990). Systems thinking can be applied through system dynamics, which is a method used to understand how systems change over time. One feature that is common to all systems is that a system's structure determines its behavior. System dynamics links the behavior of a system to its underlying structure. It can be used to analyze how the structure of a physical, biological or any other system can lead to the behavior that the system exhibits. This is achieved by developing a model that can simulate and quantify the behavior of the system. The simulation of the model over time is considered essential to understanding the dynamics of the system (Simonovic, 2008). The water balance model developed in this research is based on system dynamics approach.

Simulation models play an important role in all aspects of water resources management. They are widely accepted within the water resources community and are usually designed to comprehend the response of a system under a particular set of conditions, and contribute

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to a better understanding of real world processes (Wurbs, 1997). Over the years many system dynamics simulation models have been developed for water resources management (Winz et al, 2008). They include a salinization model for irrigated lands by Seysel and Barlas (2001), a community based water planning model by Tidwell et al. (2004), a model for predicting floods from snowmelt by Li and Simonovic (2002), a reservoir operation model by Ahmad and Simonovic (2000), integrating system dynamics and GIS to develop a new approach for the simulation of water resource systems by Ahmad and Simonovic (2004), a flood evacuation emergency planning model by Simonovic and Ahmad (2005), a decision support system for flood management by Ahmad and Simonovic (2006), a model to increase public understanding of water policy options by Stave (2003), Watersim: an interactive water policy analysis tool for Phoenix, AZ by ASU-DCDC (2009), a model of a general large scale water supply system by Chung and Lansey (2009), a transboundary water resources management decision support system by Gastelum et. al (2009), and a simulation model to evaluate municipal water conservation policies by Ahmad and Prashar (2010).

The model developed is a comprehensive mass balance of the Valley's water system detailed in the earlier section. Data was collected for the model from various sources listed in Table 2.1. The population data was collected from the Center for Business and Economic Research (CBER-UNLV). Water supply and wastewater generated data was collected from

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Clark County Sewage and Wastewater Advisory Committee (SWAC) reports. Groundwater supply data was collected from the Nevada Division of Water Resources. Most of the outdoor water use data was collected from the Las Vegas Wash Comprehensive Adaptive Management Plan (LVWCAMP) report. There are various uncertainties associated with the measurement of flow data in the Las Vegas Wash which cause 95% of the daily discharges to be within 15% of the true value (LVWCAMP, 1999). Excess irrigation runoff and seepage to the Las Vegas Wash are not directly measured but estimated due to lack of flow data on main tributaries which makes definitive measurement of various components of flow difficult to achieve (LVWCAMP, 1999).

Table 2.1. Data Sources

Data Source	Model Component	Duration
CBER (Center for Business and Economic Research)	Population	2000-2035
SWAC (Clark County Sewage and Wastewater Advisory Committee)	Water Supply, Sewage Generation	1993-2008
Nevada Division of Water Resources	Groundwater	1993-2008
LVWCAMP (Las Vegas Wash Comprehensive Adaptive Management Plan	Seepage to the Las Vegas Wash	1992-1997
SNWA (Southern Nevada Water Authority)	Per Capita Water Demand	2009-2035

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The advantage of the model is that it allows exploration of various water policy scenarios. In-depth and focused scenario analysis on a particular administrative unit e.g., City of Henderson, can also be conducted. The model is built in Stella, a system dynamics modeling software, and facilitates easy user interaction. The model incorporates the six entities in the Valley. Water flow for a typical city in the model is shown in Figure 2.4.
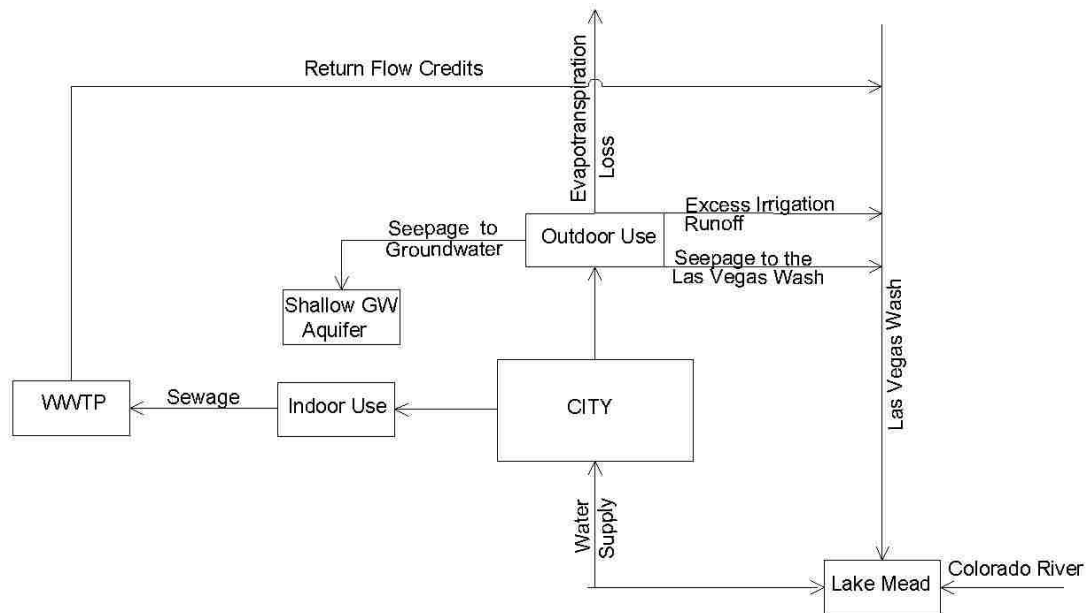
Figure 2.4. A portion of the water balance model showing a city system

The Figure 2.4 shows the division of water supplied to a city, into indoor and outdoor usage. The indoor water used eventually ends up in the wastewater treatment plants. The outdoor water used either gets evaporated, becomes excess irrigation runoff or seeps to groundwater or to the Las Vegas Wash.

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In this research, scenarios regarding population, per capita demand and water conservation measures and wastewater reuse are simulated. There has been some trepidation and apprehension in the local community that the Valley is running out of water. Various news reports and research papers have highlighted this issue (ABC, 2007) (LVS, 2008) (NYT, 2009) and (Swanson, 1996). There is no question that with an increasing population and limited water resources, the Valley faces a challenge in fulfilling its future water needs. In response to this dire situation, the water authority   has undertaken various conservation measures and set goals of lowering the per capita water demand. In 2005, SNWA adopted a per capita demand target of 926 lpcd (245 gpcd) by 2035. In 2009, the per capita demand target was revised down significantly to 752 lpcd (199 gpcd) (SNWA, 2009). SNWA also has plans for bringing additional water from the northern counties in Nevada, but that is not considered in this research, as the purpose is to evaluate the extent to which water conservation policies can potentially fulfill the water demand from the existing supply.

The population is multiplied by the per capita water demand to estimate the water demand for the Valley. The demand is then fulfilled by withdrawing water from Lake Mead and groundwater, which is then supplied to the entities in the Valley. The water is then divided into indoor and outdoor water use depending upon the indoor outdoor use proportions. The indoor use water ends up in the wastewater treatment

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plants from where the wastewater returns back to Lake Mead, and the Valley gets return flow credits. Some of the wastewater is also reused in the Valley.

The model is set up on an annual resolution and runs over a time span from 2009 to 2035. Historic run covers a period from 1993 to 2008 and future scenarios cover a period from 2009 to 2035. Different model validity tests were performed, to which the model responded satisfactorily. Validity tests including structure assessment, extreme condition tests, integration error, behavior reproduction and behavior anomaly tests were performed (Sterman, 2000). Different integration methods including Euler, 2nd order Runge-Kutta and 4th order Runge-Kutta were tested. There was no significant difference in the results, so the Euler method was selected as it is efficient in terms of computation time. Time step testing (varying the time step size) was also done and a delta time (dt) of 0.125 or (1/8) was used. CBER-UNLV projects that the population of the Valley will be about 3.23 million in 2035. The model is able to reproduce the population growth successfully following the same pattern as in the CBER-UNLV projection. The model was successful in replicating historic water demand with a percentage error of about 1 %. Figure 2.5a shows the comparison of the historic population to the model population while Figure 2.5b shows the comparison of the historic water demand to the actual water demand. Model equations are shown in Appendix A. A more detailed description of the equations for water

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distribution in a city, water demand and outdoor use components are given in Appendix B.
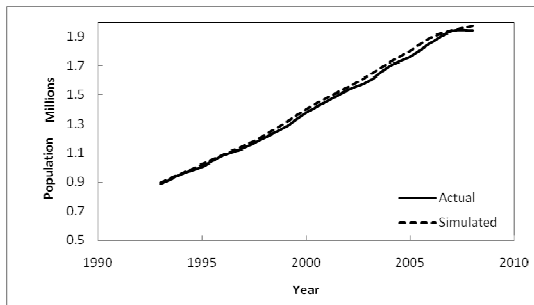
Figure 2.5a. Population comparison for historic data and model simulation
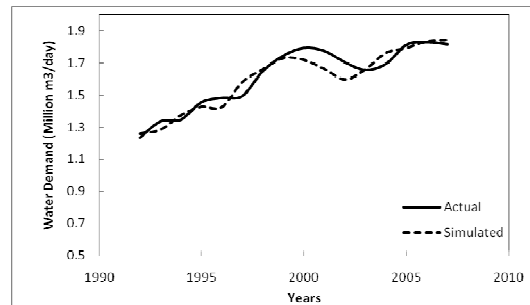
Figure 2.5b. Water Demand comparison for historic data and model simulation

Figure 2.6a shows the different CBER based population projections while Figure 2.6b shows the decrease in per capita demand for the different cities in the Valley. These data are used in all the scenarios.
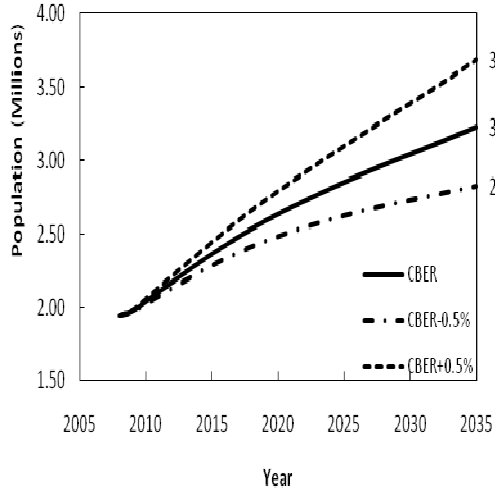
Figure 2.6a. Las Vegas Valley Population Projections 2008-2035
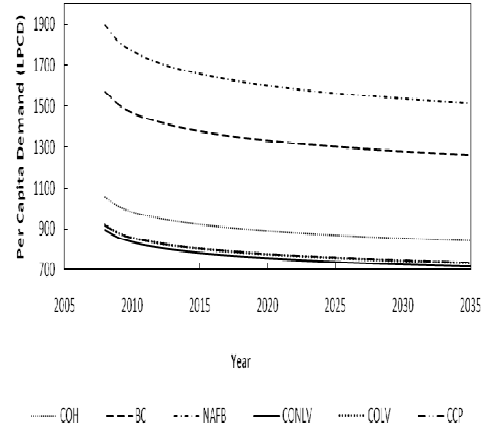
Figure 2.6b. Per Capita Water Demand for Entities in the Valley for 2008-2035

The decrease from the present demand to 752 lpcd (199 gpcd) in 2035 will not, necessarily occur in a linear fashion. Rather, as stringent conservation measures become implemented in the Valley, the harder it will be to achieve additional conservation gains. So, the conservation savings will be higher at the start, but as time passes the savings will start decreasing. This is referred to as demand hardening. In this research, it is assumed that the decrease in per capita water demand would follow a logarithmic pattern. Also, different cities have different per capita demands. All of them will not be at 752 lpcd (199 gpcd), rather some will be higher and some will be lower, but the weighted average will be 752 lpcd (199 gpcd). The decrease will be based on their 2008 water consumption levels.

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Using the SNWA per capita demand target of 752 lpcd (199 gpcd) in addition to CBER-UNLV Clark County population projections, various demand scenarios are created in which the effect of conservation measures are simulated by using different combinations of indoor and outdoor water use proportion. The demand projections are then compared with projected water supply available, to understand the effectiveness of the conservation measures, and to evaluate if the available supply can satisfy the demand in the future or when does the Valley run out of water.

2.6. Results

The research considers two main simulation options. The first option, considers water demand supply scenarios with only water conservation measures while the second option considers water demand and supply scenarios with both water conservation measures and wastewater reuse.

A total of five water demand supply scenarios are simulated and there results are summarized in Table 2.3. The first scenario uses the 2008 water use levels without any change at 945 lpcd (250 gpcd). The second scenario considers only outdoor water conservation to meet the 193 lpcd (51 gpcd) decrease. The third scenario considers 67% indoor and 33% outdoor water conservation to meet the 193 lpcd (51 gpcd decrease) while the fourth scenario considers 50% outdoor and 50% indoor water conservation. The fifth scenario meets the 193 lpcd (51 gpcd) decrease

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through indoor water conservation only. Every scenario has three sub scenarios with different population projections. There is a possibility that the CBER population projection, in reality, may be off the mark as from the 1970s through the mid 2000s, the Valley's population growth exceeded projections. It is a projection after all, and has its limitations. To get a better understanding of the impact of varying population on the water situation in LVV, the CBER projection is modified and three sub scenarios are created. The first sub scenario uses the CBER population projection as it is, and is referred to as the CBER subscenario with a population of 3.23 million in 2035. The second sub scenario decreases the CBER growth rates by 0.5%, and is referred to as the CBER-0.5% subscenario with a population of 2.83 million in 2035. This may be likely given the current economic downturn. The third subscenario increases the CBER growth rates by 0.5%, and is referred to as the CBER+0.5% subscenario with a population of 3.69 million in 2035. This may happen if the economy recovers and expands at a faster pace. CBER projections for population growth are for the Clark County. They are applied to the City of Henderson, City of Las Vegas, City of North Las Vegas and the unincorporated portions of Clark County. Boulder City and Nellis Air Force Base populations are assumed to remain at the 2008 level as these entities have experienced little or no population growth over the last 20 years.

1ST SCENARIO (Status Quo Projection):

The first scenario explores what would be the situation when no water conservation is implemented. The population keeps on growing however the per capita demand and and wastewater reuse remains at the 2008 levels i.e. 945 lpcd (250 gpcd) and is 0.099 million m^3/day (26 MGD) respectively. The results are shown in figure 2.7.

Scenario 1.1: (CBER Rate with no change):

With no conservation and increasing population, the 2008 status quo scenario is not a promising one. With no change in the CBER population forecast, the water demand exceeds the available supply in 2012. The demand supply deficit reaches 0.90 million m^3/day (238 MGD) in 2035.

Scenario 1.2: (CBER Rate-0.5%):

The situation does not improve much even with a lower population and the water demand exceeds the supply in 2012. The supply demand deficit is 0.52 million m^3/day (137 MGD) in 2035.

Scenario 1.3: (CBER Rate+0.5%):

The CBER projected growth rate is increased by 0.5% which results in the water supply being exceeded in 2011. The situation exacerbates and the demand supply gap increases to 1.34 million m^3/day (354 MGD) in 2035.

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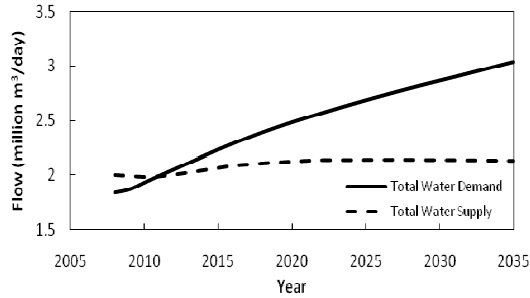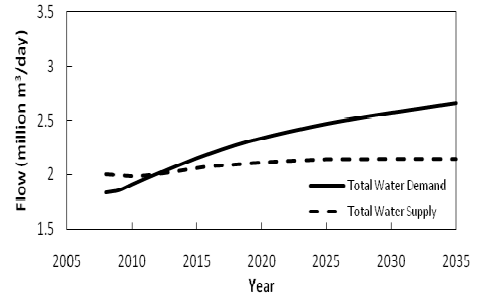
Fig.2.7a. (Scenario 1.1)   Fig.2.7b. (Scenario 1.2)
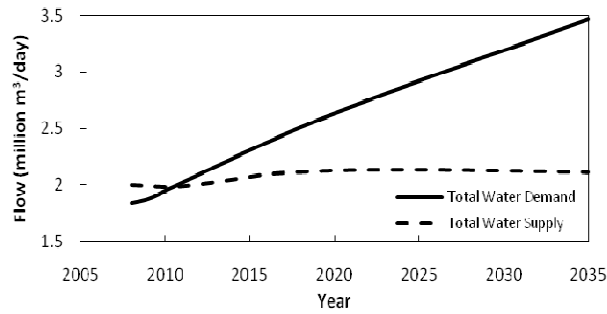
Fig.2.7c. (Scenario 1.3)

Figure 2.7. (Scenario 1) Total Demand Supply Graph with 2008 conditions and (a) CBER projection (Scenario 1.1) (b) CBER-0.5% projection (Scenario 1.2) (c) CBER+0.5% projection (Scenario 1.3)

The first scenario clearly points to a grave situation for the Valley in the next few years, as shown in figure 2.7. Given the limited water resources of the region, the need for water conservation measures is evident. Water needs to be conserved and its consumption reduced. This is very important for making the Valley water secure in the future.

The following scenarios evaluate the impacts of various water conservation goals and targets, and how they impact the Valley's water demand and supply situation in the future.

2ND SCENARIO (752 lpcd (199 gpcd) Target, Conservation 100% Outdoor Only)

The second scenario has two options or variations. The first option only explores the effect of the water authority's conservation target 752 lpcd (199 gpcd) in 2035 on the water demand and supply situation in the Valley. The second option uses the water authority conservation target of 752 lpcd (199 gpcd) in 2035, along with the wastewater reuse projection of 0.21 million m³/day (56 MGD), and explores what would be the effect of this policy. According to the water authority the water demand per person in 2008 in the LVV is 945 lpcd (250 gpcd). This amounts to a 20% reduction in the water demand which is to be met through conservation efforts. Most of water authority's previous conservation efforts have targeted the outdoor water use, so for this scenario it is assumed that all of the conservation would occur in the outdoor water use. Also, landscape irrigation is the single largest consumptive use in the Valley and the water authority has put a greater emphasis in promoting efficient outdoor water use (SNWA, 2009). Some methods for implementing outdoor conservation include incentives for promoting water efficient irrigation technologies and tougher regulations. The results are shown in figure 2.8.

Scenario 2.1: (CBER Rate with no change):

For the without reuse option, with strict outdoor conservation and a 752 lpcd (199 gpcd) target, the outcome becomes favorable compared to the status quo scenario. Keeping the CBER population with no change, the water demand never exceeds the available supply. The demand supply surplus is 0.07 million m³/day (18 MGD) in 2035 and the surplus water amounts to 3% of the water demand of 2035. The need to develop new water resources is delayed by more than 20 years.

The with reuse option has a similar result with the supply surplus being higher at about 0.106 million m³/day (28 MGD) in 2035, and the water demand is 0.11 million m³/day (30 MGD) lower than the first option.

Scenario 2.2: (CBER Rate-0.5%):

This scenario shows a very favorable outcome and the Valley does not run out of water resources. The return flow credits increase substantially compared to the slow growth in population. For the without reuse option the water supply surplus is about 0.23 million m³/day (61 MGD) in 2035, which is about 11% of the water demand in 2035, and the current water resources will last longer. For the second option considering reuse, the demand supply surplus increases to 0.27 million m³/day (71 MGD), and the water demand is 0.11 million m³/day (30 MGD) lower than the water conservation only option.

Scenario 2.3: (CBER Rate+0.5%):

The higher population results in the water supply being exceeded in 2023 for without reuse and 2028 for with reuse, despite the conservation measures. This scenario shows that the Valley is vulnerable to rapid population growth. The demand supply gap is 0.185 million m^3/day (49 MGD) in 2035 for without reuse and 0.1 million m^3/day (27 MGD) for with reuse.
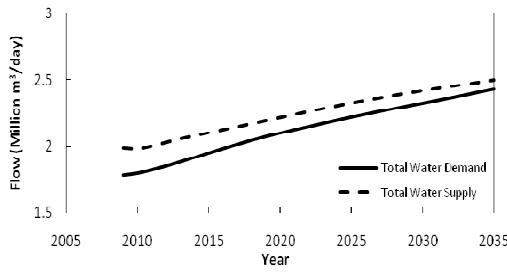
Fig.2.8a. (Scenario 2.1a)
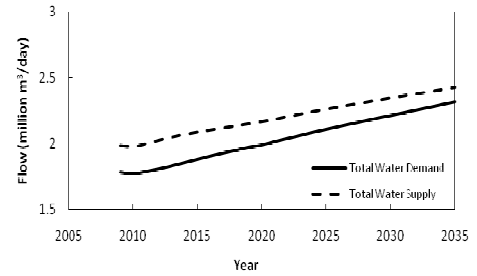
Fig.2.8b. (Scenario 2.1b)
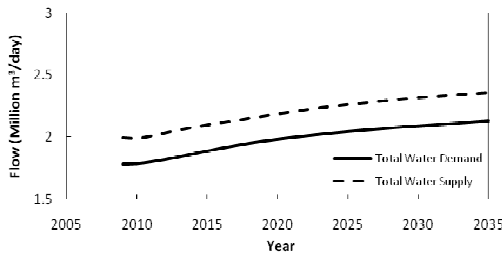
Fig.2.8c. (Scenario 2.2a)
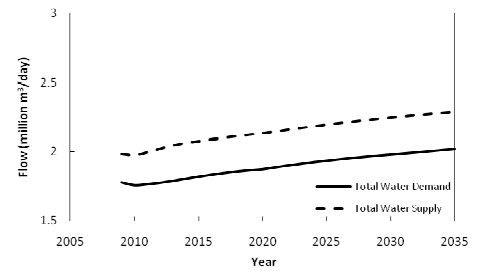
Fig.2.8d. (Scenario 2.2b)
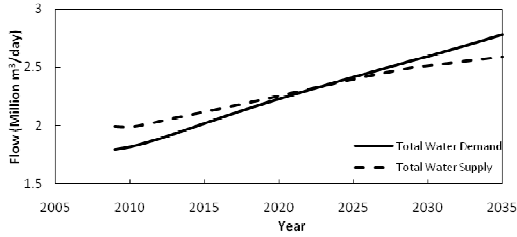
Fig.2.8e. (Scenario 2.3a)   Fig.2.8f. (Scenario 2.3b)
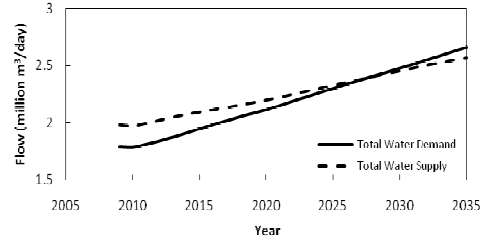
Figure 2.8. (Scenario 2) Total Demand Supply graphs at 752 lpcd (199 gpcd) 100% outdoor conservation scenario (a) with CBER projection but no Reuse (Scenario 2.1a) (b) with CBER projection and Reuse (Scenario 2.1b) (c) with CBER-0.5% projection but no Reuse (Scenario 2.2a) (d) with CBER-0.5% projection and Reuse (Scenario 2.2b) (e) with CBER+0.5% projection but no Reuse (Scenario 2.3a) (f) with CBER-0.5% projection and Reuse (Scenario 2.3b)

The second scenario clearly portrays the benefits of implementing stringent conservation measures in the Valley combined with a lower population. Only in 3rd sub scenario does the demand exceed the supply. The results lay out a very strong case for outdoor water conservation and show that it is a major solution in making the Valley water secure.

There is an appreciable difference between the two options for water demand supply comparisons if wastewater reuse is not considered or not. The with reuse option gives a higher surplus and it takes longer for the demand to exceed the supply under this option. Increasing reuse

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reduces the Colorado river consumptive demand and that means more Colorado river water is available for use in the future. Also, water demand is 0.11 million m³/day (30 MGD) higher when wastewater reuse is not considered. Considering wastewater reuse in tandem with water conservation measures reduces the per capita demand to 718 lpcd (190 gpcd) from 752 lpcd (199 gpcd) which is the target achieved by the water conservation only option.

3RD SCENARIO (752 lpcd (199 gpcd) Target, Conservation 67% Outdoor, 33% Indoor)

In this scenario, the 193 lpcd (51 gpcd) reduction is achieved through conserving water use in a proportion of 67% outdoors and 33% indoors. Considering that presently outdoor use is higher than the indoor use in the Valley, so a greater drop in outdoor use is more likely to occur in comparison to the indoor use. The results are shown in figure 2.9.

Scenario 3.1: (CBER Rate with no change):

The demand exceeds the supply in 2026 for the without reuse option and 2033 for the with reuse option. The demand supply gap is 0.13 million m³/day (34 MGD) for without reuse and 0.02 million m³/day (6 MGD) with reuse in 2035, which is noticeably less than the without reuse. In this scenario conservation efforts sustain the water supply for a considerable period.

Scenario 3.2: (CBER Rate-0.5%):

This scenario is encouraging as the demand does not exceed the supply in 2035. The surplus is 0.11 million m³/day (29 MGD) for without reuse and 0.15 million m³/day (40 MGD) for with reuse in 2035 and the extra water amounts to about 4.8% of the water demand for the without reuse option and 6.5% for the with reuse option. This scenario again shows the advantage of a smaller growth in population.

Scenario 3.3: (CBER Rate+0.5%):

Demand exceeds supply with a higher growth in population in 2018 for without reuse and 2021 for with reuse. The growth outstrips the available resources and the deficit grows to 0.45 million m³/day (119 MGD) for the without reuse option and 0.31 million m³/day (82 MGD) for the with reuse option. This scenario presents a dismal picture, and shows the limit of conservation compared to a fast rising water demand.
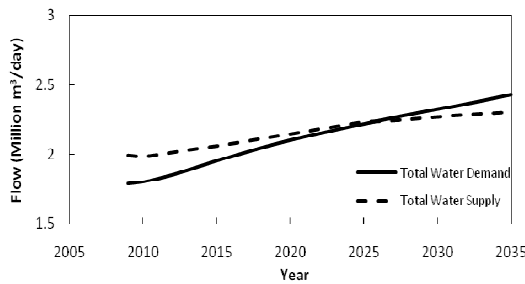

Fig.2.9a. (Scenario 3.1a)
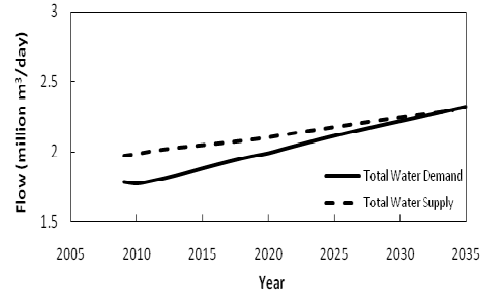

Fig.2.9b. (Scenario 3.1b)
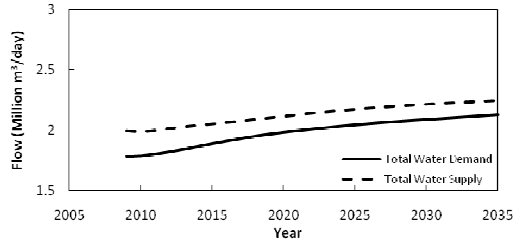
Fig.2.9c. (Scenario 3.2a)
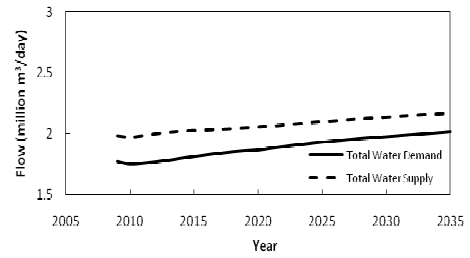
Fig.2.9d. (Scenario 3.2b)
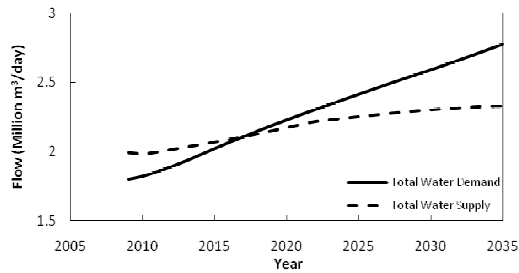
Fig.2.9e. (Scenario 3.3a)
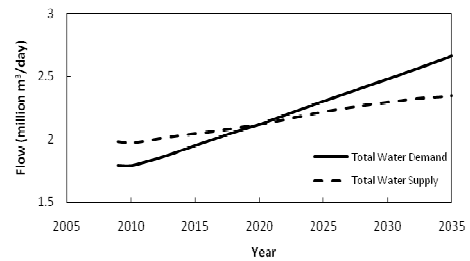
Fig.2.9f. (Scenario 3.3b)

Figure 2.9. (Scenario 3) Total Demand Supply graphs at 752 lpcd (199 gpcd) 67% outdoor 33% indoor conservation scenario (a) with CBER projection but no Reuse (Scenario 3.1a) (b) with CBER projection and Reuse (Scenario 3.1b) (c) with CBER-0.5% projection but no Reuse (Scenario 3.2a) (d) with CBER-0.5% projection and Reuse (Scenario 3.2b) (e) with CBER+0.5% projection but no Reuse (Scenario 3.3a) (f) with CBER-0.5% projection and Reuse (Scenario 3.3b)

This scenario demonstrates the limits of water conservation measures when the indoor use is also decreased and less conservation occurs in the outdoor use, in securing an adequate supply of water for the Valley in the future. It highlights the importance of return flow credits, and a decrease in their amount compared to the 2nd scenario makes the future

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grimmer, and amplifies the urgency for new sources of water. The with reuse option again results in appreciable differences in water demand compared to the without reuse option, and give a comparatively favorable result.

4TH SCENARIO (752 lpcd (199 gpcd) Target, Conservation 50% Outdoor and 50% Indoor Only)

This scenario considers the situation that the 193 lpcd (51 gpcd) reduction from 945 lpcd (250 gpcd) to 752 lpcd (199 gpcd) is achieved by conservation in the indoor and outdoor use equally i.e. 50:50. The indoor use may be curtailed by taking different measures like water pricing, promoting stricter building codes and water smart technologies, and public education programs. This scenario is more plausible as it would be very difficult to achieve water conservation solely with indoor or outdoor practices. The results are shown in figure 2.10.

Scenario 4.1: (CBER Rate with no change):

The demand exceeds the supply in 2021 for the without reuse option and 2025 for the with reuse option. This is a departure from the 2nd scenario in which the outdoor conservation effort generates enough return flow credits to create a favorable outcome. This is because the indoor conservation reduces the amount of return flow credits as less wastewater is generated. The demand supply gap is 0.25 million m³/day (66 MGD) in 2035 for the without reuse option and 0.13 million m³/day (34 MGD) in 2035 for the with reuse option.

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Scenario 4.2: (CBER Rate-0.5%):

With a reduced population the demand does not exceed the supply, and there is a surplus of 0.038 million m³/day (10 MGD) available for the without reuse option and 0.08 million m³/day (21 MGD) for the with reuse option. The surplus water is roughly 1.8% of the water demand in 2035 for the without reuse option and 3% for the with reuse option. In comparison to the 2nd scenario the demand supply surplus is very low, but still it averts the need for new water resources by more than two decades.

Scenario 4.3: (CBER Rate+0.5%):

Demand exceeds supply in 2016 for without reuse and 2017 for with reuse. The growth outstrips the available supply and the deficit grows to 0.59 million m³/day (156 MGD) for without reuse and 0.44 million m³/day (116 MGD) for with reuse. In comparison to the 2nd scenario, the situation is worse.
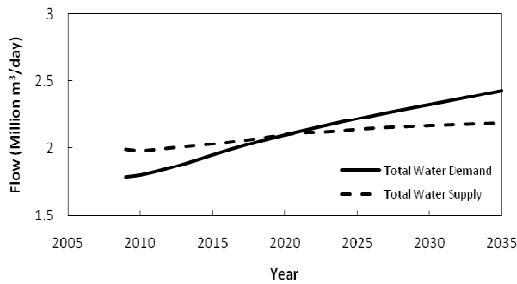
Fig.2.10a. (Scenario 4.1a)   Fig.2.10b. (Scenario 4.1b)
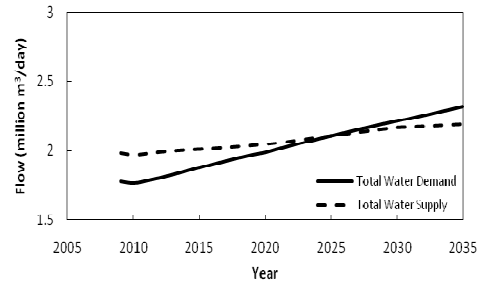
41
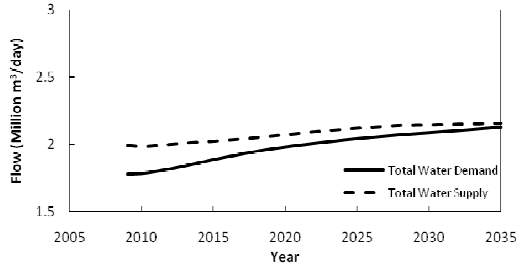
Fig.2.10c. (Scenario 4.2a)
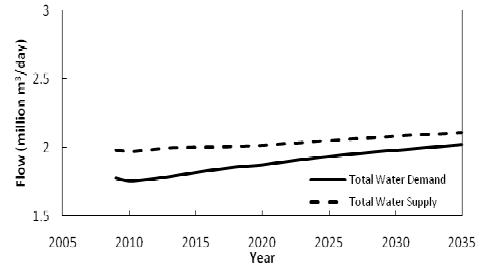
Fig.2.10d. (Scenario 4.2b)
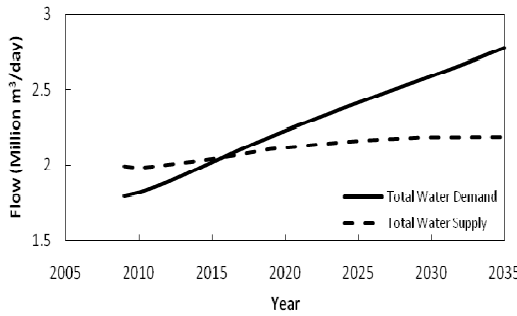
Fig.2.10e. (Scenario 4.3a)
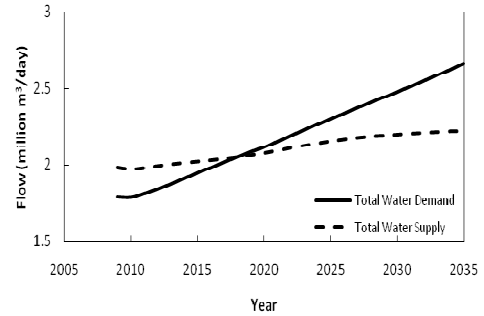
Fig.2.10f. (Scenario 4.3b)

Figure 2.10. (Scenario 4) Total Demand Supply graphs at 752 lpcd (199 gpcd) 50% outdoor 50% indoor conservation scenario (a) with CBER projection but no Reuse (Scenario 4.1a) (b) with CBER projection and Reuse (Scenario 4.1b) (c) with CBER-0.5% projection but no Reuse (Scenario 4.2a) (d) with CBER-0.5% projection and Reuse (Scenario 4.2b) (e) with CBER+0.5% projection but no Reuse (Scenario 4.3a) (f) with CBER-0.5% projection and Reuse (Scenario 4.3b)

Compared to the 3rd scenario, the equal outdoor and indoor conservation scenario results in a similar but less favorable outcome. The water conservation only option again results in a marginally worse condition compared to the water conservation plus wastewater reuse option.

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5TH SCENARIO (752 lpcd (199 gpcd) Target, 100% Indoor Conservation Only)

This scenario assumes all water conservation occurs in the indoor water use. A reduction in the indoor use ratios mean a reduction in return flow credits obtained, and ultimately less water supply available. Water authority's 752 lpcd (199 gpcd) target remains as it is, with the different population estimates, the water demand supply comparisons for this scenario are presented below in figure 2.11.

Scenario 5.1: (CBER Rate with no change):

The demand exceeds the supply in 2015 for the without reuse option and 2017 for with reuse option and the deficit becomes 0.55 million m³/day (145 MGD) in 2035 for without reuse and 0.43 million m³/day (114 MGD) for with reuse. Due to decrease in return flow credits compared to other scenarios, the demand supply curves interact earlier.

Scenario 5.2: (CBER Rate-0.5%):

The demand supply curves intersect in 2017 for the without reuse option and 20203 for the with reuse option. The deficit is 0.25 million m³/day (66 MGD) in 2035 for without reuse and 0.14 million m³/day (37 MGD) for with reuse, due to smaller population.

Scenario 5.3: (CBER Rate+0.5%):

The demand supply curves intersect in 2014 for the without reuse option and 2015 for the with reuse option due to the larger population and the demand supply deficit increases to 0.91 million m³/day (240

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MGD) for the without reuse option and 0.78 million m³/day (206 MGD) for the with reuse option. The deficit is more severe compared to the previous scenarios.
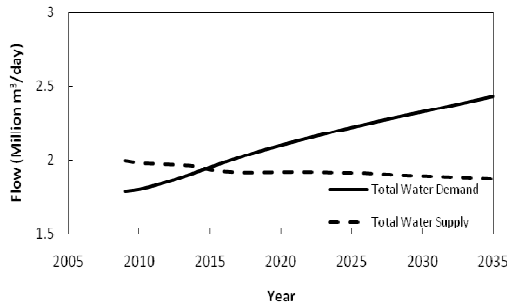


Fig.2.11a. (Scenario 5.1a)
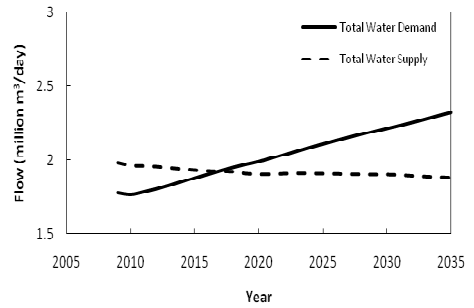
Fig.2.11b. (Scenario 5.1b)
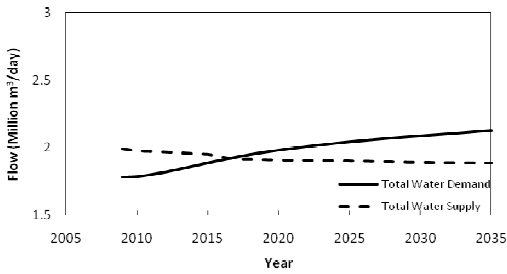
Fig.2.11c. (Scenario 5.2a)
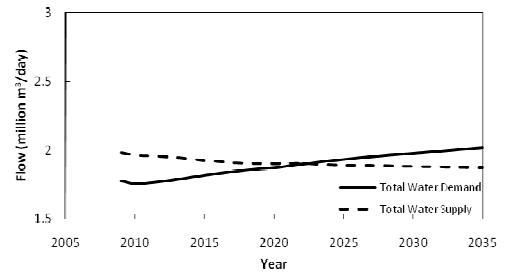
Fig.2.11d. (Scenario 5.2b)
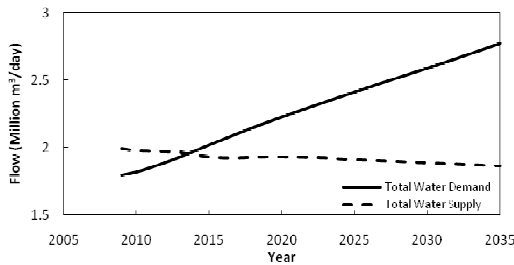
Fig.2.11e. (Scenario 5.3a)
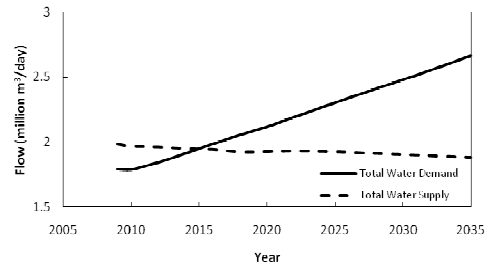
Fig.2.11f. (Scenario 5.3b)

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Figure 2.11. (Scenario 5) Total Demand Supply graphs at 752 lpcd (199 gpcd) 100% indoor conservation scenario (a) with CBER projection but no Reuse (Scenario 5.1a) (b) with CBER projection and Reuse (Scenario 5.1b) (c) with CBER-0.5% projection but no Reuse (Scenario 5.2a) (d) with CBER-0.5% projection and Reuse (Scenario 5.2b) (e) with CBER+0.5% projection but no Reuse (Scenario 5.3a) (f) with CBER-0.5% projection and Reuse (Scenario 5.3b)

This scenario shows that conserving indoor water use only translates into lesser return flow credits which subsequently means lesser water supply in the coming years. The future this scenario portrays is more harsh then the previous ones. It highlights the need for developing water conservation measures keeping in mind the effect on the return flow credits.

2.6.1. Return Flow Credits

Return flow credits are an integral component of water supply for the Valley. The various scenarios generate different amount of return flow credits. Table 2.2 presents the results of those simulations.

Table 2.2. Projected Return Flow Credits for Different Scenarios in 2035

Scenarios	Return Flow Credits (Million m³/day) in 2035	
	Option 1: Conservation Only	Option 2: Conservation+Reuse
Scenario 2.1 (Total outdoor conservation and CBER)	1.27	1.20
Scenario 2.2 (Total outdoor conservation and CBER-0.5%)	1.13	1.05
Scenario 2.3 (Total outdoor conservation and CBER+0.5%)	1.38	1.34
Scenario 3.1 (67% outdoor 33% indoor conservation and CBER)	1.11	1.06
Scenario 3.2 (67% outdoor 33% indoor conservation and CBER-0.5%)	1.01	0.93
Scenario 3.3 (67% outdoor 33% indoor conservation and CBER+0.5%)	1.15	1.12
Scenario 4.1 (50% outdoor 50% indoor conservation and CBER)	1.01	0.98
Scenario 4.2 (50% outdoor 50% indoor conservation and CBER-0.5%)	0.95	0.87
Scenario 4.3 (50% outdoor 50% indoor conservation and CBER+0.5%)	1.02	1.01
Scenario 5.1 (Total indoor conservation and CBER)	0.70	0.68
Scenario 5.2 (Total indoor conservation and CBER-0.5%)	0.71	0.67
Scenario 5.3 (Total indoor conservation and CBER+0.5%)	0.70	0.68

From Table 2.2 it is clear that the 100% outdoor conservation scenario generates the highest return flow credits. This is because only indoor water used ends up in the wastewater treatment plants resulting in return flow credits. To maximize return flow credits, policies targeting

outdoor water conservation would be effective. Also, the conservation only option results in higher return flow credits compared to conservation plus reuse option. This is because wastewater reuse leads to about a reduction of 0.11 million m³/day (30 MGD) in the demand resulting in lower return flow credits. But to keep things in perspective, pumping more water from Lake Mead increases the associated energy and infrastructure costs and leaves a larger carbon footprint. The water-energy nexus should be evaluated carefully before making any final conclusions.

2.6.2 Summary Of Results

Table 2.3 presents a summary of the different model simulations. The demand and supply results only of the year 2035 are presented and the critical year refers to the year in which the demand exceeds the supply. The table shows that scenario 2.1 is very favorable compared to other scenarios as it has the highest return flow credits and the supply is greater than demand.

Table 2.3. Summary of Results for different water conservation scenarios

Scenarios	Option 1: Water Conservation Only (Million m³/day)				Option 2: Water Conservation+Reuse (Million m³/day)			
	Demand in 2035	Supply in 2035	Deficit /Surpl -us	Critical Year	Demand in 2035	Supply in 2035	Deficit /Surpl -us	Critical Year
Scenario 1.1 (2008 level and CBER)	3.03	2.13	-0.90	2012				
Scenario 1.2 (2008 level % and CBER-0.5%)	2.66	2.14	-0.52	2012				
Scenario 1.3 (2008 level and CBER+0.5%)	3.46	2.12	-1.34	2011				
Scenario 2.1 (Total outdoor conservation and CBER)	2.43	2.50	0.07	-	2.32	2.43	0.11	-
Scenario 2.2 (Total outdoor conservation and CBER-0.5%)	2.13	2.36	0.23	-	2.02	2.29	0.27	-
Scenario 2.3 (Total outdoor conservation & CBER+0.5%)	2.78	2.59	-0.19	2023	2.66	2.56	-0.10	2028
Scenario 3.1 (67% outdoor 33% indoor conservation and CBER)	2.43	2.30	-0.13	2026	2.32	2.30	-0.02	2033
Scenario 3.2 (67% outdoor 33% indoor conservation and CBER-0.5%)	2.13	2.24	0.11	-	2.02	2.17	0.15	-
Scenario 3.3 (67% outdoor 33% indoor conservation & CBER+0.5%)	2.78	2.33	-0.45	2018	2.66	2.35	-0.40	2021
Scenario 4.1 (50% outdoor 50% indoor conservation and CBER)	2.43	2.18	-0.25	2021	2.32	2.19	-0.13	2025
Scenario 4.2 (50% outdoor 50% indoor conservation and CBER-0.5%)	2.13	2.16	0.03	-	2.02	2.10	0.08	-
Scenario 4.3 (50% outdoor 50% indoor conservation & CBER+0.5%)	2.78	2.19	-0.59	2016	2.66	2.22	-0.44	2017
Scenario 5.1 (Total indoor conservation and CBER)	2.43	1.88	-0.55	2015	2.32	1.89	-0.43	2017
Scenario 5.2 (Total indoor conservation and CBER-0.5%)	2.13	1.88	-0.25	2017	2.02	1.88	-0.14	2023
Scenario 5.3 (Total indoor conservation & CBER+0.5%)	2.78	1.87	-0.91	2014	2.66	1.88	-0.78	2015

2.7. Conclusion

It is clear that the Valley's water demand will likely reach its present available water supply in the near future. This research shows that water conservation focused on decreasing outdoor water use is a viable strategy for delaying an impending water crisis. Water consumption decrease from 945 lpcd (250 gpcd) to 752 lpcd (199 gpcd) if met completely through outdoor conservation as demonstrated in scenario 2.1, generates the highest return flow credits and can potentially satisfy the Valley's water needs through 2035, which proves that the hypothesis is true. This finding is consistent with Stave (2003) which also showed that outdoor water conservation is more effective than indoor conservation in LVV. Devitt et al (2008) demonstrated that a 20% reduction in outdoor water use is achievable if satellite based ET irrigation controllers are used in the Valley. This could be a possible strategy for achieving the water demand reduction through outdoor conservation.

Model assumptions for this study include (i) Nevada's share of Colorado River water stays stable and unchanged for the study period(ii) supply from ground water remains at the 2008 level throughout the study period (iii) the amount of wastewater reused is projected to be 0.21 million m³/day (56 MGD) in 2020 and then stays constant till the end of the simulation (CCN, 2000) (iv) the supply from Las Vegas Valley Water District to City of Las Vegas and Clark County portion is divided on the basis of their population as actual supply data was not available (v)

Leakages in the water system were assumed to be negligible (vi) The per capita demand decrease was assumed to occur in a logarithmic manner, as a result of demand hardening. If the per capita demand is decreased in any other manner, the results may be different.

In the simulation model, adaptive management is not considered when the Valley runs out of water e.g., in scenario 1. In reality water management agencies would respond to such situations by putting restriction on water use, utilizing emergency resources, by trading water, or developing new sources.

The water balance simulation model can potentially be a useful tool for water managers in the LVV to manage the water resources in a sustainable way. Though this paper focused on understanding the impact of various conservation policies, the model can be used to evaluate the impacts of other water management policies such as bringing additional water to the Valley and can potentially help the local and state agencies in making informed decisions by answering various what if type of questions.

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CHAPTER 3

EVALUATING THE IMPACT OF WATER CONSERVATION ON OUTDOOR WATER USE AND GROUND WATER QUALITY IN THE LAS VEGAS VALLEY

3.1. Abstract

Las Vegas Valley, located in Southern Nevada, with a growing population and limited water resources faces a challenge in meeting its future water needs. Southern Nevada Water Authority (SNWA), the main water management agency for the Valley, is focusing on water conservation practices to reduce water demand. Current water use is 945 lpcd (250 gpcd), which SNWA aims to reduce to 752 lpcd (199 gpcd) by 2035. Presently the indoor- outdoor water use proportion is about 40:60 in the Valley. An important component of the Valley's supply is the return flow credits that it gets for the Colorado River water. This return flow mainly is comprised of the flow from the Valley's three wastewater treatment plants. The credits process allows SNWA to withdraw an additional one unit volume of river water for every unit volume of treated river water returned.

The main objective of this research is to evaluate how the water used outdoors is distributed into different components of the Valley water cycle, their sensitivity to each other, and to estimate their quantity along with return flow credits in response to water conservation in the future. Other objectives include the investigation of the impact of water reuse on

the shallow groundwater quality and the extent of water savings achievable from replacing turf with xeriscaping in the Valley. For these purposes a water balance model for the Valley is developed that simulates the water cycle of the Valley and can be used to explore several what-if questions. The model runs from 1993 to 2035 on an annual time step and is validated for a period from 1993 to 2008.

The model is used to analyze the different components of outdoor water use under different water conservation policy scenarios for reducing water demand by 193 lpcd (51 gpcd) from 945 lpcd (250 gpcd) to 752 lpcd (199 gpcd) by 2035 and their effect on return flow credits. Five different conservation policies are evaluated. The first policy considers the status quo situation by projecting the 2008 water use levels till 2035. The second policy explores the effect of conserving water only in the outdoor use. The third policy considers 67% outdoor and 33% indoor water use conservation while the fourth policy considers 50% outdoor and 50% indoor conservation. The fifth policy considers conserving water only in the indoor use. The results from the analysis show that a substantial portion of the outdoor water use either evapotranspirates or infiltrates to the shallow groundwater, and infiltration to groundwater is most sensitive to evapotranspiration. The all outdoor conservation scenario gives the highest return flow credits and the least values for the components of outdoor water use. The impact of wastewater reuse, specifically its nitrate loading, on the

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shallow groundwater aquifer is studied and the results indicate a gradual deterioration in the groundwater's quality with time. The model assesses the impact of replacing all turf with desert landscaping in the Las Vegas Valley on water savings, and determines that replacing all convertible (non-golf course) turf will result in a 59 lpcd (16 gpcd) decrease in the water demand. The results can be a guide in developing effective outdoor water conservation policies and the water balance model can be used in helping policy makers make informed decisions on various water management issues.

Key Words: Water balance, simulation modeling, water conservation, policy analysis, outdoor water use, turf replacement, nitrates, wastewater reuse, shallow groundwater aquifer, Las Vegas Valley, system dynamics

3.2. Introduction

Rapid population growth and development in the urban areas of the Southwestern region of the United States have placed a high stress on the available water resources. The Southwest is located in a semi arid climatic region and as a consequence a substantial amount of water is used outdoors to maintain lawns and vegetation (Gleick, 2004). The Las Vegas Valley, located in the Southern Nevada region of the Southwest, is no exception and generally averages less than 130 mm (5 in) of rain annually. Daily daytime summer temperatures usually exceed 38 C (100

F) and are accompanied with very low humidity (Gorelow and Skrbac, 2009). The population of the Valley has nearly tripled over the last twenty years with the current population being about two million and is expected to be about 3.3 million by 2035 (CBER, 2009). The region is also experiencing a prolonged drought (Piechota et al, 2004), as a result of which Lake Mead, the major water source for the Valley, have reached alarmingly low levels (Barnett and Pearce, 2008). Landscape irrigation is the single largest water use in the Valley, and about 60% water distributed to the residents is used outdoors (SNWA, 2009). This is very different from the other parts of the US where total outdoor water use may range between 22-38% (Mayer and DeOreo, 1999).

In response to the precarious water situation brought about by a growing population, limited water resources and prolonged drought, Southern Nevada Water Authority (SNWA), which manages the water system in the Las Vegas Valley, has undertaken various conservation measures and set stricter targets for per capita water demand. In 2005, SNWA adopted a per capita demand target of 926 lpcd (245 gpcd) by 2035. In 2009, the per capita demand target was revised down to 752 lpcd (199 gpcd) (SNWA, 2009). Most of the conservation measures implemented have focused on outdoor water usage, an example of which is the Water Smart Landscapes Rebate in which SNWA pays a property owner for removing turf on his property and replacing it with desert friendly landscapes. Also wastewater reuse has grown over the years

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reaching 0.098 million m³/day (26 MGD) in 2008 and is projected to grow further to 0.21 million m³/day (56 MGD) in 2020 (CCN, 2000). Growing wastewater reuse decreases water demand but has potential quality implications for the groundwater present in the shallow aquifer in the Valley.

The main objective of this research is to evaluate how the water used outdoors is distributed into different components of the Valley water cycle, their sensitivity to each other, and to estimate their quantity in response to water conservation in the future. The effect of water conservation on return flow credits is also evaluated. This will help in understanding the overall impact of outdoor water use on the water system in the Valley, and in devising effective water conservation strategies. There are two goals identified by the water authority. One is to reach 752 lpcd (199 gpcd) in 2035 and the second is to increase wastewater reuse to 56 MGD by 2020. Two hypotheses are considered relative to these goals: (i) If total turf is replaced with xeriscaping in the Valley, then a 193 lpcd (51 gpcd) reduction in the water demand can be achieved, and (ii) If domestic use of treated wastewater containing nitrates is implemented, there will be potential contamination of the shallow groundwater aquifer of the Las Vegas Valley.

To accomplish this goal, a detailed urban water mass balance model based on system dynamics modeling is developed. An urban water balance shows the path in which the water flows between the source, the

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various uses and the wastewater generated in an urban context (Mitchell et al., 2001). The advantage of modeling an urban water balance is that it allows water managers to look towards the future and identify critical knowledge gaps. A water balance model allows investigation of various what if scenarios relating to sustainability and evaluation of different water conservation alternatives (Baker, 2009; Mitchell and Diaper, 2005). A number of water balance models have been developed over the years and used to evaluate solutions to various water related issues (Bin et al., 2008; Mitchell et al., 2008, Wang et al., 2008, Cleugh et al., 2005, Binder et al., 1997). Bin et al (2008) estimated landuse impacts on water balance of an urban region in Japan. Mitchell et al (2008) used a water balance modeling framework Aquacycle and analyzed the effects of urban design on the water balance. Wang et al (2008) used a water balance model to study the effects of trees on urban hydrology. Cleugh et al (2005) utilized a water balance model to study the impacts of suburban design on water use in Canberra, Australia. Binder et al (1997) created a water balance model for water management in developing countries.

The model developed in this research is a comprehensive water balance of the Valley, and allows an understanding of the complex interrelationships between various factors affecting this balance, and also facilitates analysis of different water conservation scenarios.

The Valley's water system is discussed next, followed by the method section. After that the results are presented and conclusions are drawn in the end.

3.3. Las Vegas Valley Water System

The main source of water for the Las Vegas Valley (LVV) is Lake Mead, replenished with Colorado River water, and currently accounting for 90% of the Valley's water supply (SNWA, 2009). The amount of water available for Southern Nevada from Lake Mead under the Colorado River Agreement is 370 million m^3/yr (300,000 ac-ft/yr) plus the return flow credits obtained from returning the treated wastewater to Lake Mead. The remaining 10% of the water is obtained from ground water wells in the Valley (SNWA, 2009). Figure 3.1a shows the position of the LVV within the United States of America. The latitude and longitude for the Valley are 36° 5' N, 115° 10' W and the size of the Valley is about 1600 km^2 (618 mi^2).

Figure 3.1a. Location of Las Vegas in the United States of America
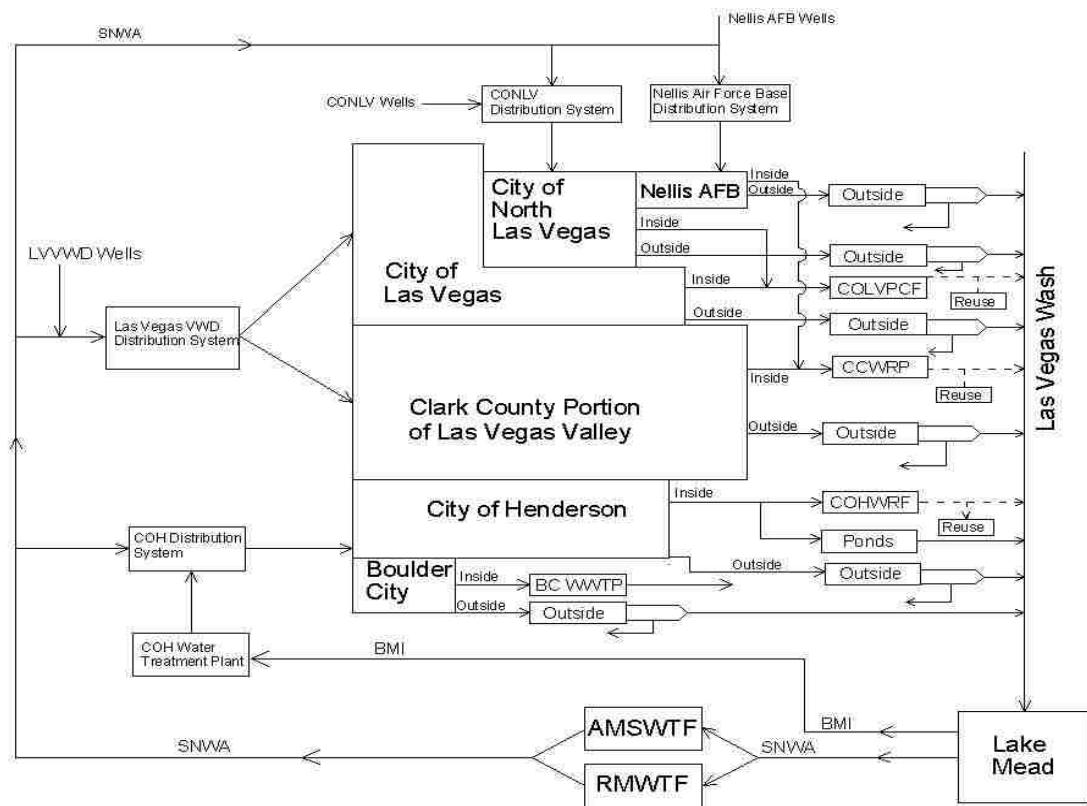
Figure 3.1b. Schematic of Las Vegas Valley Water System

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Figure 3.1b presents a schematic of the LVV water system. The valley has two main water treatment plants, Alfred Merritt Smith Water Treatment Facility (AMSWTF) and River Mountains Water Treatment Facility (RMWTF), having a combined capacity of about 3.4 million m³/day (900 MGD) (SNWA, 2008). In addition to these, the City of Henderson has a water treatment plant with a capacity of about 0.056 million m³/day (15 MGD) (COH, 2009) to which water is supplied from the BMI (Basic Management Inc.) pipeline which also supplies water to BMI industries mainly for cooling purposes. The water is then supplied to different administrative units in the Valley including the City of Henderson (COH), City of Las Vegas (COLV), City of North Las Vegas (CONLV), Clark County portion of LVV (CCPLVV), Boulder City (BC) and Nellis Air Force Base (NAFB). The portion of the water used indoor becomes wastewater and is treated to tertiary standards (e.g. including filtration and nutrient removal steps). There are three wastewater treatment plants: the City of Henderson Water Reclamation Facility (COHWRF), the Clark County Water Reclamation Plant (CCWRP) and the City of Las Vegas Water Pollution Control Facility (COLVWPCF). Together, all three have a combined capacity of about 0.946 million m³/day (250 MGD) (COH, 2009 and CCWRD, 2009). Most of the treated wastewater goes back to Lake Mead, through the Las Vegas Wash, while a small portion of the wastewater is reused for golf course irrigation. Also, stormwater in the Valley drains to Lake Mead. LVV has a relatively new

and modern, sewage and runoff collection system. The fate of outdoor water use is divided into four main components. A portion of the water used outdoors is lost to evapotranspiration, a portion seeps to the ground water, a portion becomes excess landscape irrigation flow and a portion seeps to the Las Vegas Wash. SNWA calculates the per capita water demand by dividing all of the water supplied to Valley by its permanent resident population. Though the Valley has a substantial number of tourists visiting throughout the year, their water demand is not separately calculated but is part the of water demand calculated for Valley residents.

The LVV gets return flow credits for the water it returns to Lake Mead, which considerably enhance the available water supply. The computation method for the credits ensures Nevada gets credits only for those return flows, which have a signature of Colorado river, not for groundwater nor for storm water (LVWCAMP, 1999). The return flow credits are an important feedback in the Valley's water system. The role of the credits within the system is described by a causal loop diagram as shown in Figure 3.2. Figure 3.2 is a positive loop which describes the self-reinforcing nature of return flow credits within the system. The more wastewater is generated, the greater will be the return flow credits, and the higher will be the water supply resulting in more wastewater generated.
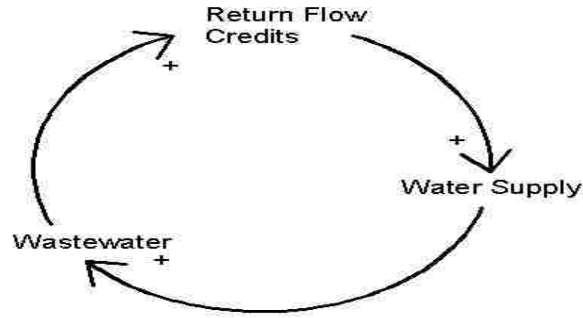
Figure 3.2. Causal Loop Showing Return Flow Credits

The equation 1 is used to calculate the return flow credits. It is developed from the description of the return flow credits process, and is basically an accounting approach outlined in the LVWCAMP (1999) report.

Return Flow Credits = Treated wastewater – [(groundwater wells portion of treated wastewater) - (wastewater reuse from groundwater wells) - (phreatophyte use from groundwater in the Las Vegas Wash)] + (Colorado river fraction*excess irrigation runoff) + (Colorado river fraction * seepage to Las Vegas Wash)   (1)

3.4. Method

Water systems are sociotechnical systems i.e., technical systems with strong links to society. This makes them relevant for systems thinking, and the complexity can be reduced by applying systems thinking to study the working of the system (Grigg, 1996). Systems thinking is a conceptual framework for seeing interrelationships rather than things,

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for seeing patterns of change rather than static "snapshots." It is a discipline for seeing wholes (Senge, 1990). Systems thinking can be applied through system dynamics, which is a method used to understand how systems change over time. One feature that is common to all systems is that a system's structure determines its behavior. System dynamics links the behavior of a system to its underlying structure. It can be used to analyze how the structure of a physical, biological or any other system can lead to the behavior that the system exhibits. This is achieved by developing a model that can simulate and quantify the behavior of the system. The simulation of the model over time is considered essential to understanding the dynamics of the system (Simonovic, 2008). The urban water balance model developed in this research is based on system dynamics approach.

Simulation models play an important role in all aspects of water resources management. They are widely accepted within the water resources community and are usually designed to comprehend the response of a system under a particular set of conditions, and contribute to a better understanding of real world processes (Wurbs, 1997). Over the years many system dynamics simulation models have been developed for water resources management (Winz et al, 2008). They include a salinization model for irrigated lands by Seysel and Barlas (2001), a community based water planning model by Tidwell et al. (2004), a model for predicting floods from snowmelt by Li and Simonovic (2002), a

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reservoir operation model by Ahmad and Simonovic (2000), integrating system dynamics and GIS to develop a new approach for the simulation of water resource systems by Ahmad and Simonovic (2004), a flood evacuation emergency planning model by Simonovic and Ahmad (2005), a decision support system for flood management by Ahmad and Simonovic (2006), a model to increase public understanding of water policy options by Stave (2003), Watersim: an interactive water policy analysis tool for Phoenix, AZ by ASU-DCDC (2009), a model of a general large scale water supply system by Chung and Lansey (2009), a transboundary water resources management decision support system by Gastelum et. al (2009), and a simulation model to evaluate municipal water conservation policies by Ahmad and Prashar (2010).

Most of the water used outdoors is used for landscape irrigation in the Valley (SNWA, 2006). The water used outdoors for landscape irrigation in the LVV is accounted for by the mass balance relationship shown in equation 2, which is modified from Mitchell et al (2008) and Oad et al (1997).

Water used for Outdoor Irrigation = ET + EIR + SGW+SLVW   (2)

Where ET is the Evapotranspiration, EIR is the excess irrigation runoff which drains into the storm water system in the Valley, SGW is the seepage to the ground water due to infiltration from irrigation, which

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in the case of LVV is actually a shallow groundwater aquifer, and SLVW is the seepage from the shallow groundwater to the Las Vegas Wash. The shallow groundwater aquifer is a reservoir where the infiltrating water is stored and only a minor fraction of it surfaces to Las Vegas Wash which is referred here as the seepage to Las Vegas Wash (LVWCAMP, 1999). SLVW is not a direct outdoor use component but it is used to quantify the seepage to the shallow ground water as no records are available for it, and also to calculate return flow credits. The shallow groundwater aquifer is different from the groundwater aquifer used as part of the water supply in the Valley. It is not used for drinking as its water quality is poor with total dissolved solids (TDS) exceeding acceptable drinking water standards, and is also not used for irrigation. The TDS in the shallow groundwater ranges from 1500 to about 7000 mg/l, which is well above the EPA's drinking water standard of 500 mg/l (LVWCAMP, 1999). A comparable situation occurs also elsewhere in the Southwest. Paul et al, 2007 describe the quality of shallow groundwater aquifer from seven study sites in the Southwest (Central Arizona Basins, Great Salt Lake Basins, Nevada Basin, Rio Grande Valley, Sacramento River Basin, San Joaquin-Tulare Basins and Southern California Basins) where it is also not used as a supply source, mainly because of quality concerns.

The shallow ground water aquifer which lies under most of the Valley is separated from the underlying aquifers by an impermeable clay or caliche layer. The groundwater flow generated by excessive landscape

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irrigation cannot pass through this geologic formation, and is held in storage in the shallow aquifer, or moves laterally down gradient (LVVWD, 1991). The shallow unconfined aquifer lies within 15 m (50 ft) of land surface (LVGMP, 2009), while the groundwater used as a water supply source for the Valley, comes from the aquifer which is about 300 m (984 ft) deep (Dettinger, 1987; Brothers and Katzer, 1988).

3.5. The Water Balance Model

The model is a comprehensive mass balance of the Valley's water system detailed in the earlier section. Data was collected for the model from various sources. The population data was collected from the Center for Business and Economic Research at the University of Nevada-Las Vegas (CBER-UNLV). Water supply and wastewater generated data was collected from Clark County Sewage and Wastewater Advisory Committee (SWAC) reports. Groundwater supply data was collected from the Nevada Division of Water Resources. Most of the outdoor water use data was collected from the Las Vegas Wash Comprehensive Adaptive Management Plan (LVWCAMP, 1999) report. There are various uncertainties associated with the measurement of flow data in the Las Vegas Wash which cause 95% of the daily discharge measurements to diverge from the true values as much as 15% (LVWCAMP, 1999). Excess irrigation runoff and seepage to the Las Vegas Wash are not directly measured but estimated due to lack of flow data on main tributaries which makes

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definitive measurement of various components of the balance difficult to achieve (LVWCAMP, 1999).

The model is set up on an annual temporal resolution and runs over a time span of 42 years from 1993 to 2035. The historic run covers a period from 1993 to 2008 and future scenarios cover a period from 2009 to 2035. Different model validity tests were done for a period of 1993 to 2008 including structure assessment, extreme condition tests, integration error, behavior reproduction and behavior anomaly tests were performed, to which the model responded satisfactorily and produced the expected logical outcomes (Sterman, 2000). Different integration methods including Euler, 2nd order Runge-Kutta and 4th order Runge-Kutta were tested. There was no significant variation in the results, so Euler method was selected as it is efficient in terms of computation time. Time step testing (making dt half) was also done and a delta time (dt) of 0.125 or (1/8) was used. The model was successful in replicating the historic water demand with an average error of about 1%. The water authority in the Valley has undertaken various water conservation measures and set goals for lowering the per capita water demand. In 2005, a per capita demand target of 926 lpcd (245 gpcd) by 2035 was adopted. In 2009, the per capita demand target was revised down to 752 lpcd (199 gpcd) (SNWA, 2009). Fig.3.3a shows the CBER based population projection while Fig.3.3b shows the logarithmic decrease in per capita demand for

the LVV from 946 lpcd (250 gpcd) to 752 lpcd (199 gpcd). This data is used in all the scenarios except the first one.

The advantage of the model is that it facilitates exploration of various water policy scenarios. It permits evaluation of the impact of population change, water conservation choices, changes in return flow credits and other similar impacts. In-depth and focused scenario analysis on a particular administrative unit e.g. City of Henderson, can also be conducted. The model is built in Stella, a system dynamics modeling software, and facilitates easy user interaction through a powerful control interface.
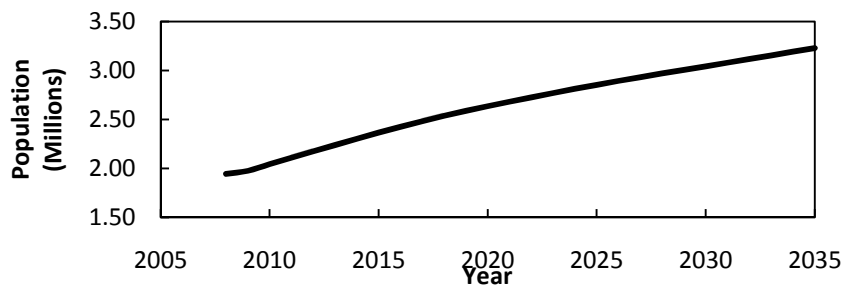
Figure 3.3a. Las Vegas Valley Population Projection 2008-2035
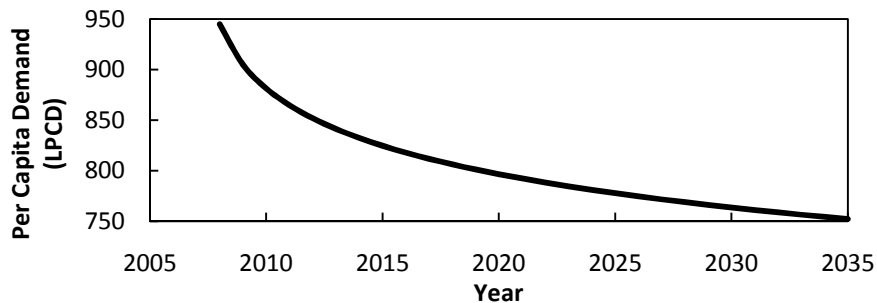
Figure 3.3b. Las Vegas Valley Per Capita Water Demand 2008-2035

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The total water used outdoors is estimated from the SWAC reports. The Potential evapotranspiration (PET) rate for the LVV available from UNCE (2002) and SNWA (2005), is about 225 cm/yr (90 in/yr). There are different types of plants and vegetation present in the LVV with different ET rates. However in this study the ET rates are assumed to be uniform for all vegetation types in the Valley. The amount of evapotranspiration loss is calculated by multiplying the PET with the total amount of vegetated land. Due to lack of spatial data, turf was the major type of vegetation considered, and trees had to be neglected. The data on excess irrigation runoff that reaches the storm water drainage system of the Valley is estimated from the LVWCAMP report. A portion of the shallow groundwater aquifer seeps to the Las Vegas Wash, the data for which is also available in the LVWCAMP. The amount of water infiltrating to the groundwater from outdoor irrigation is estimated by using equation 1, as the amount of infiltration to groundwater can be determined if the total amount of water used and other components like PET loss and excess irrigation runoff are estimated. Using the historical data, relationships were developed for the outdoor water use components and these relationship were used to estimate the components values in the future. The projected share of the different components of outdoor use is shown in Figure 3.4. In 2008, the values of outdoor use components as a percentage of the total water supply were evapotranspiration at 14%, seepage to groundwater at 36.4%, excess irrigation runoff at 3% and

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seepage to Las Vegas Wash at 3.8%. Evapotranspiration maybe higher than actually estimated due to lack of data regarding total vegetation area and its types in the Valley.
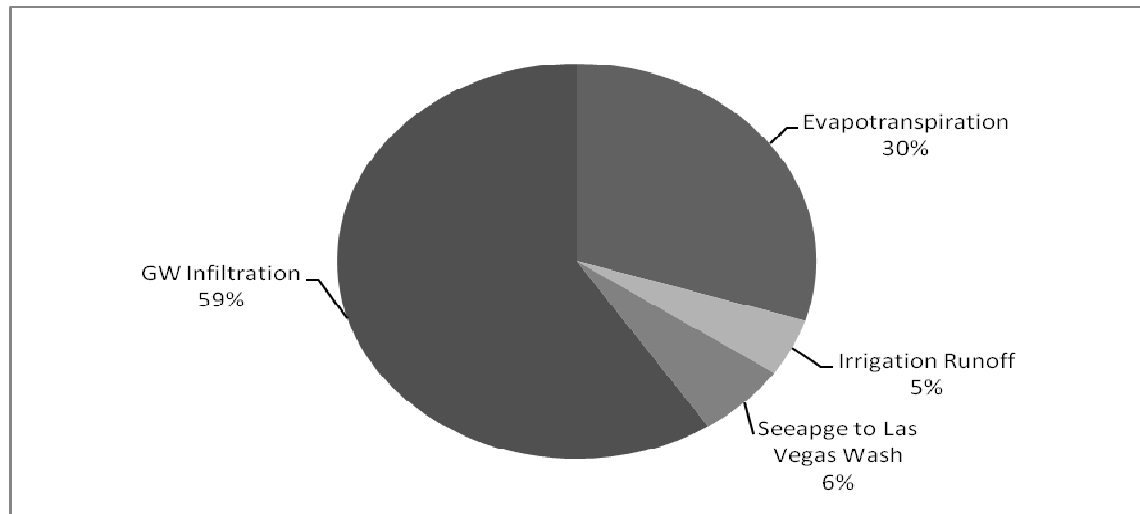
Figure 3.4. Projected Share of different components of Outdoor Use

3.6. Results

Five scenarios are simulated and their results are discussed. The first scenario uses the 2008 water use levels (945 lpcd) without any change. All subsequent scenarios assume that water demand will be 752 lpcd (199 gpcd) by 2035 according to SNWA's projection. The second scenario considers that all conservation is in the outdoor water use. The third scenario considers 67% outdoor water conservation and 33% indoor water conservation. The fourth scenario considers equal water conservation both in outdoor and indoor water use. The fifth scenario

considers all conservation in indoor water use only. An important assumption in all of the simulations is that the Valley does not run out of water from freshwater sources, and the supply is assumed to be infinitely large. There is a possibility that the water supply runs out for the different policy scenarios, which may give an inaccurate comparison of the quantity of outdoor water use components. To avoid this situation, supply is assumed to be infinitely large. Another important assumption is that the amount of wastewater reuse is projected to be 0.21 million m^3/day (56 MGD) in 2020 and will remain constant from 2020 until 2035 (CCN, 2000). Presently the amount of wastewater reused is 0.098 million m^3/day (26 MGD).

SCENARIO 1 (Status Quo Projection, 945 lpcd)

The first scenario explores what would be the amount of outdoor water use when no water conservation occurs. The population keeps on growing but the per capita demand and the indoor outdoor water use remains at the 2008 levels (i.e. 945 lpcd (250 gpcd) and roughly 60% outdoors and 40% indoors).

Figure 3.5 shows that in 2035 the amount of irrigation water seeping to the shallow groundwater aquifer becomes 1.02 million m^3/day (269 MGD). Also, evapotranspiration reaches 0.51 million m^3/day (136 MGD) while excess irrigation runoff and seepage to the Las Vegas Wash are 0.08 million m^3/day (21 MGD) and 0.11 million m^3/day (28 MGD), respectively.

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SCENARIO 2 (SNWA (752 lpcd 199 gpcd) Target, Conservation 100% Outdoor Only)

The second scenario uses the conservation target of 752 lpcd (199 gpcd) in 2035 and explores what would be the effects of this policy. According to the SNWA, the water demand per person in 2008 in the LVV is 945 lpcd (250 gpcd). The 752 lpcd (199 gpcd) figure amounts to a 20% reduction in the water demand, which is to be met in this scenario through outdoor conservation efforts only.

Figure 3.6 shows that comparatively less water is used outdoors than the first scenario as a result of conservation. In 2035, the amount of water seeping to the shallow groundwater aquifer is 0.68 million m^3/day (180 MGD) while evapotranspiration is 0.34 million m^3/day (91 MGD), which is 35% less than in the first scenario but still substantial. The seepage to the Las Vegas Wash and irrigation runoff are very small compared to the other two components.

SCENARIO 3 (SNWA 752 lpcd (199 gpcd) Target, Conservation 67% Outdoor 33% Indoor)

The third scenario assumes a greater portion of conservation, 67% occurs on the outdoor side, and a smaller 33% occurs on the indoor side. The SNWA conservation target of reducing water demand from 945 lpcd (250 gpcd) to 752 lpcd (199 gpcd) in 2035 is achieved through this policy.

Figure 3.7 shows the results for this scenario. Compared to scenario 2, evapotranspiration is 0.39 million m^3/day (90 MGD) versus 0.34

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million m³/day (79 MGD), and seepage to groundwater is about 0.089 million m³/day (23 MGD) higher. This is because more water ends up being used outdoors as compared to scenario 2.

SCENARIO 4 (SNWA 752 lpcd (199 gpcd) Target, 50% Outdoor Conservation 50% Indoor Conservation)

The fourth scenario assumes equal conservation on both the indoor and outdoor sides to achieve the conservation target of reducing water demand from 945 lpcd (250 gpcd) to 752 lpcd (199 gpcd) in 2035 and assesses the effect of this policy.

The results of this scenario are comparable to scenario 3 in which a 67% outdoor 33% indoor split was selected to achieve the conservation target. Figure 3.8 shows that evapotranspiration at 0.41 million m³/day (97 MGD) and seepage to groundwater at 0.82 million m³/day (193 MGD) are marginally higher than in scenario 3.

SCENARIO 5 (SNWA 752 lpcd (199 gpcd) Target, Conservation 100% Indoor Only)

The fifth scenario considers that to achieve a 20% reduction in water demand to 752 lpcd (199 gpcd) all water conservation occurs on the indoor side, and none on the outdoor side.

This scenario gives the highest values among all the conservation scenarios for the different components of outdoor use, as no conservation occurs in the outdoor use. Figure 3.9 shows that seepage to groundwater

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rises to 0.95 million m³/day (225 MGD) and the evapotranspiration loss reaches 0.48 million m³/day (114 MGD).
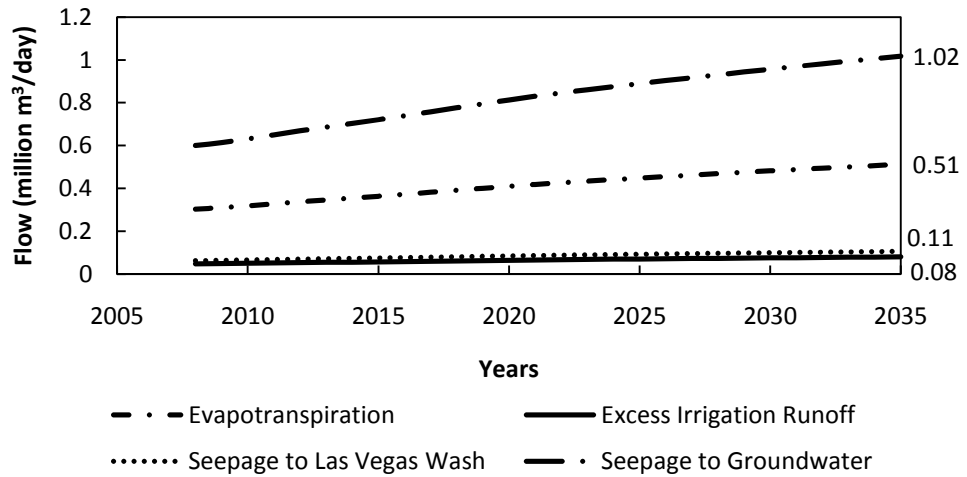
Figure 3.5. 945 lpcd Status Quo Scenario
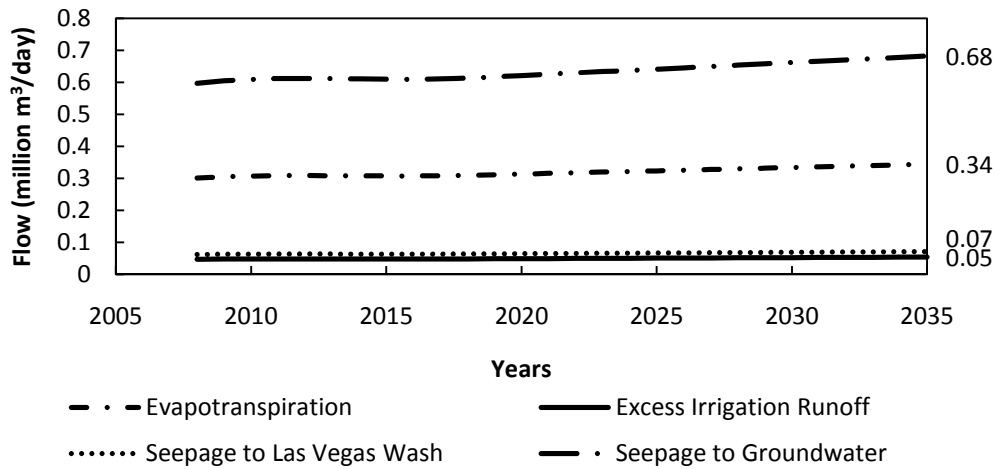
Figure 3.6. 752 lpcd, Outdoor Conservation Only Scenario

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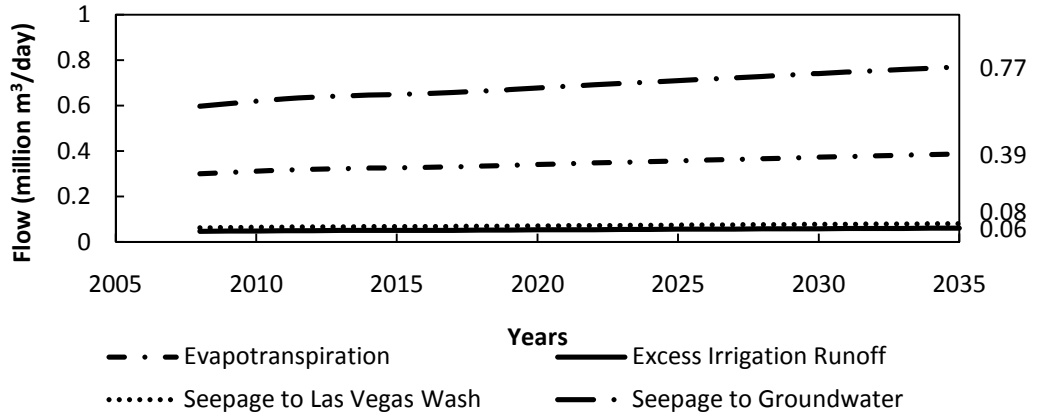
Figure 3.7. 752 lpcd, 67% Outdoor 33% Indoor Conservation Scenario
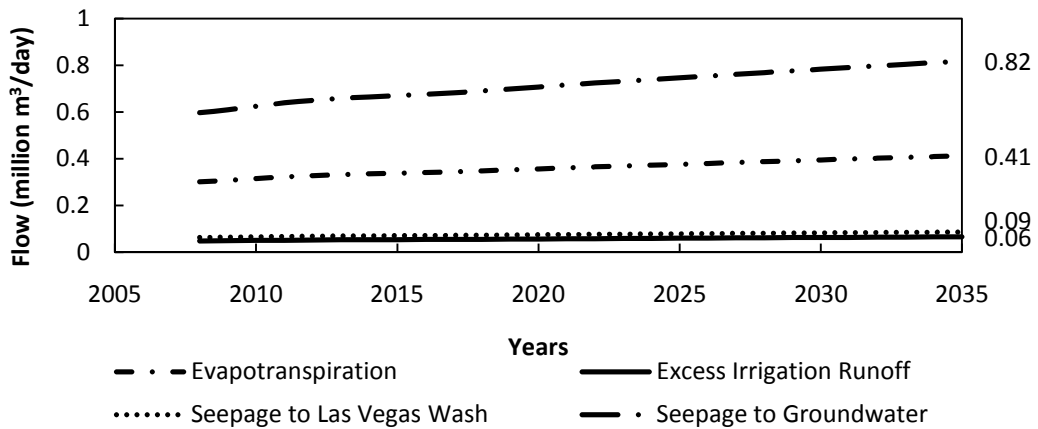
Figure 3.8. 752 lpcd, 50% Outdoor 50% Indoor Conservation Scenario
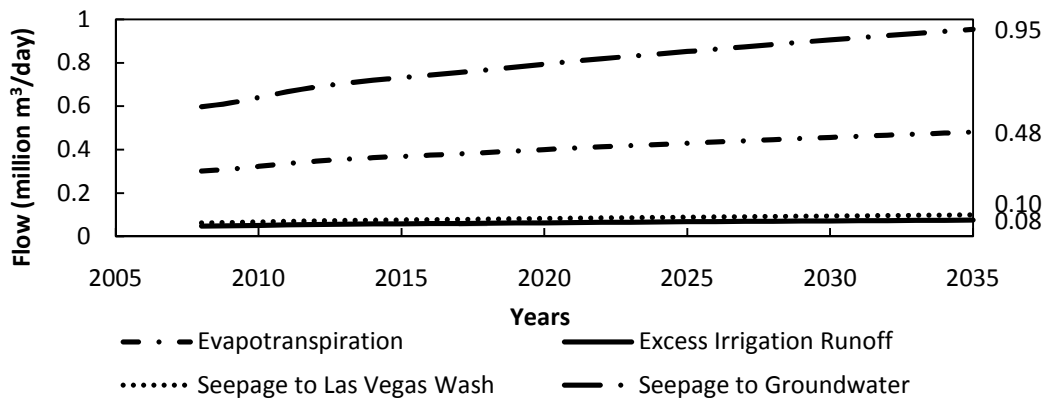
Figure 3.9. 752 lpcd, Indoor Conservation Only Scenario

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Table 3.1 presents a summary of the different model simulations. The values of the components of outdoor use for only the year 2035 are presented. The table shows that scenario 2 is very favorable compared to other scenarios, as it has the lowest values for evapotranspiration and groundwater infiltration.

Table 3.1. Outdoor Water Use Components in 2035

Year 2035	Evapotranspiration (million m³/day)	Excess Irrigation Runoff (million m³/day)	Seepage to Groundwater (million m³/day)	Seepage to LV Wash (million m³/day)	Total Outdoor Use (million m³/day)
Scenario 1 (2008 level)	0.513	0.081	1.018	0.106	1.72
Scenario 2 (Total outdoor conservation)	0.344	0.054	0.682	0.071	1.15
Scenario 3 (67% outdoor 33% indoor conservation)	0.388	0.061	0.771	0.080	1.30
Scenario 4 (50% outdoor 50% indoor conservation)	0.412	0.065	0.818	0.085	1.38
Scenario 5 (Total indoor conservation)	0.481	0.076	0.955	0.100	1.61

3.6.1. Return Flow Credits

Return flow credits are an integral part of the water resources for the Valley. The various scenarios generate different amount of return flow credits. Table 3.2 presents the results for all water conservation scenarios.

Table 3.2. Projected Return Flow Credits for Different Conservation Scenarios in 2035

Year 2035	Total Supply (million m³/day)	Total Indoor (million m³/day)	Total Outdoor (million m³/day)	Return Flow Credits (million m³/day)
Scenario 2 (Total outdoor conservation)	2.32	1.17	1.15	1.20
Scenario 3 (67% outdoor 33% indoor conservation)	2.32	1.01	1.30	1.07
Scenario 4 (50% outdoor 50% indoor conservation)	2.32	0.94	1.38	0.99
Scenario 5 (Total indoor conservation)	2.32	0.71	1.61	0.79

From Table 3.2 it is clear that the total outdoor conservation scenario generates the highest return flow credits. This is because only indoor water used ends up in the wastewater treatment plants resulting in return flow credits. To maximize return flow credits, policies targeting outdoor water conservation would be more effective.

3.6.2. Sensitivity Analysis

A sensitivity analysis was performed to gauge which variable has the most effect on infiltration to the shallow groundwater aquifer. A univariate sensitivity analysis is performed by varying the variables evapotranspiration, excess irrigation runoff and seepage to the Las Vegas Wash. The change in the variables ranges from -10% to +10% and the analysis is done only for Scenario 2 and results are reported for the final year i.e., 2035. Table 3.3 shows the result for the sensitivity analysis.

Table 3.3. Sensitivity of Groundwater Seepage

	Base Value	Evapotranspiration		Excess Irrigation Runoff		Seepage to LV Wash	
2035	Scenario 2	-10%	10%	-10%	10%	-10%	10%
Seepage to Groundwater (million m³/day)	0.595	0.613	0.577	0.598	0.592	0.599	0.592

The results of the sensitivity analysis indicate that the seepage to groundwater is more sensitive to evapotranspiration as compared to the other variables.

3.6.3. Nitrates In Reuse Water

The amount of treated wastewater to be reused is projected to be 0.21 million m^3/day (56 MGD) in 2020 (CCN, 2000). Presently the amount of wastewater reused is 0.098 million m^3/day (26 MGD) and it is used mainly for golf course irrigation. This reuse water is of lesser quality than the drinking water supplied to the Valley and had an average concentration of 14 mg/l of nitrates as N (NDEP, 2006). The nitrate loading analysis presented here considered the potential water quality implications if wastewater reuse in the future is used for residential outdoor irrigation by determining the amount of nitrates in the reuse water coming in contact with the vegetation.

Residential outdoor use is one of the largest consumptive uses in the Valley. Utilization of wastewater for outdoor use would reduce the demand for potable water. Major hindrances for residential wastewater reuse in LVV include the infrastructure costs for dual plumbing, local laws which bar wastewater reuse and the need for public education for proper reuse management. However, domestic wastewater reuse policies have been implemented in Florida and California (Asano et al, 2007). It is assumed that the concentration of nitrates in reuse water stays the same

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from the time it exits the treatment plant to the time it comes in contact with vegetation.

The concentration of nitrates was multiplied by volume of reuse water minus the excess irrigation runoff to get the total nitrate loading conveyed in the reuse water. How much of this loading ends up in the groundwater depends on the plant uptake rates and soil retention. Since nitrate ions are among the most weakly retained anions in soils (Bohn et al., 2001), they are capable of passing through the soil and reaching the groundwater with little retention taking place. Plant uptake rates may vary depending upon the level of lawn management taking place. (Bowman et al., 2006) shows that bermuda grass, which is the most prevalent type of turf in the Southwest US, has a very high nitrate uptake rate, upto 97%, of the applied amount if proper management occurs. However, it is probably safe to assume that for domestic properties (i.e. homes), such high levels of turf management would probably not be achieved Valley wide. Considering this, two scenarios representing varying degrees of management were created. The first one considers the nitrate uptake rate to be at 70% of the applied amount assuming a medium level of management while the second scenario considers the nitrate uptake rate to be at 40% of the applied amount assuming the management level to be poor. Five percent of the reuse water becomes excess irrigation runoff as indicated in Figure 3.4. The

mass balance model is utilized and a deterministic evaluation is conducted. The equations for the nitrate mass balance are,

Nitrate Loading (kg/day) = [Domestic Reuse Portion*(1- Excess Irrigation Runoff Percentage)(million m3/day)]*Nitrate Concentration(mg/l)*1000

Loading to Groundwater (kg/day) = Nitrate Loading – (Nitrate Loading*Nitrate Uptake Rate)

Table 3.4. Mass of Nitrate in Reuse Water

Year	Water Reuse increases to 0.21 million m³/day (56 MGD) in 2020			Loading to Groundwater under Nitrate Uptake Scenarios	
	Reuse Water Volume (Million m³/day)	Domestic Reuse Portion (Million m³/day)	Nitrate Loading (kg/day)	Loading to Groundwater under 70% scenario (kg/day)	Loading to Groundwater under 40% scenario (kg/day)
2008	0.10		-	-	-
2009	0.11	0.0062	82	25	49
2010	0.13	0.0313	416	125	250
2015	0.17	0.0712	953	286	572
2020	0.21	0.112	1490	447	894

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The application rate for turf in the Valley is approximately 3 m/yr (10 ft/yr) (SNWA, 2005). With this application rate and the volume of domestic reuse water which is 0.11 million m^3/day (29.6 MGD) in 2020, about 13.38 km^2 (3,316 acres) of turf can be potentially irrigated in LVV. Similarly, the application rate for xeriscaped area is approximately 0.7 m/yr (2.3 ft/yr) (SNWA, 2205), with which about 58.3 km^2 (14,417 acres) can be potentially irrigated in LVV in 2020. Devitt et al. (1992) reported nitrogen fertilization of about 6,793 kg/km^2/yr (27.5 kg/acre/yr) for low fertility turfgrass systems (e.g. parks) and 35,568 kg/km^2/yr (144 kg/acre/yr) for high fertility systems (e.g golf courses) (Devitt et al, 1992). Considering the application rate of xeriscaping, the nitrate loading in the reuse water will be 9633 kg/km^2/yr (39 kg/ac/yr), while for turf the nitrate loading would amount to 42,731 kg/km^2/yr (173 kg/ac/yr), which is high compared to the typical nitrate application rate. This means that reuse water will have enough nitrate loading to substantially decrease the use of traditional fertilizer application or avoid its use altogether. Also Leaching Fraction (LF = Drainage Volume/Irrigation Volume) with a ET of 2.29 m (7.5 ft) and an application rate of 3m/yr (10 ft/yr) is estimated as 0.25 for turf and for xeriscaping with an application rate of 0.7 m/yr (2.3 ft/yr), its 0. This gives a nitrate concentration of 16.25 mg/l under uptake scenario 1 and 32.5 mg/l under uptake scenario 2 for the water applied to turf draining to groundwater.

It is possible that the shallow groundwater aquifer may become a viable water resource in the future as it is estimated that more than 0.338 million m³/day (89 MGD) infiltrate to the shallow groundwater aquifer in the Valley (LVGMP, 2009). This analysis highlights the water quality issues facing the aquifer which may hinder its attractiveness as a resource in the future. The analysis indicates a high amount of nitrate loading in the reuse water with the loading increasing with the increase in water reuse from 82 kg/day in 2008 to 1490 kg/day in 2020, as shown in Table 3.4. A major portion of this nitrate loading may reach the shallow groundwater aquifer, depending upon the level of turf management occurring among residential users. Already the TDS in the shallow groundwater aquifer ranges from 1500 to about 7000 mg/l and coupled with high nitrate levels, the cost of treating water from the shallow groundwater aquifer in the future may become exorbitant. To overcome this outcome, the public would need to be educated about proper nitrate management in order to avoid over fertilizing by accounting for the nitrates from reuse water.

3.6.4. Achieving Water Conservation Through Turf Conversion

Considering the water supply situation in the future, the limited water resources and the growing population, SNWA started a landscape conversion program for removing turf (grass) and replacing it with xeriscaping (desert friendly landscape). Currently the water authority

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offers property owners up to $1.50 per square foot of turf removed and replaced with xeriscaping (SNWA, 2010).

The model is used to estimate water savings resulting from turf reduction in the LVV by creating a scenario in which the existing (non-golf course) turf is replaced with desert landscaping under the Water Smart Landscape program (SNWA, 2010). The potential for meeting the SNWA target of 752 lpcd (199 gpcd) in 2035, through turf reduction is also evaluated.

From 2000 to 2008, the SNWA landscape conversion program has successfully replaced 7.55 km^2 (1865 acres), resulting in water savings of about 0.05 million m^3/day (13 MGD) (Hidden Oasis, 2008). The highest saving in a year is 0.02 million m^3/day (5.23 MGD) in 2004 with 3.17 km^2 (785 acres) being converted. The next highest year is 2005 with 1.44 km^2 (356 acres) converted.

The essential information required to make this assessment includes the total amount of turf in the Valley and the amount of water saved per unit area of turf conversion. The amount of turf present in the Valley in 2008 is 40.58 km^2 (10028 acres) (Judy Brandt, 2009) out of which 21.45 km^2 (5300 acres) is golf course turf (verbal communication with Dr. Dale Devitt, UNLV). This leaves the area of convertible turf at 19.13 km^2 (4728 acres). Turf is an integral part of golf courses and it is safe to consider that golf course turf will not be xeriscaped. The quantity of water saved per unit turf conversion to xeriscaping is 0.57 liters/ft^2/day (0.1528

gallons/ft²/day) (SNWA, 2005). An important assumption is that the growth in turf area is considered negligible in the future, which is reasonable as new building regulations require xeriscaping. The reduction of water demand from 945 lpcd (250 gpcd) to 752 lpcd (199 gpcd) in 2035 in this case is assumed to be met in a linear fashion. Using these values and the SNWA goal, the analysis is completed, and the results are presented in Table 3.5. The procedure for the analysis is to divide the per capita demand change by the value for water saved per unit turf reduction to get area per capita, and multiply this by the population to get the area that needs to be converted.

Table 3.5. Turf Reduction Analysis

	Per Capita Demand Change (lpcd)	Turf Reduction (km²)	Remaining Turf Area (km²)
2008	945		19.1
2009	937	2.30	16.8
2010	929	2.38	14.5
2011	922	2.45	12.0
2012	915	2.52	9.5
2013	907	2.60	6.9
2014	900	2.67	4.2
2015	893	2.74	1.5
2016	886	2.80	-1.3
2020	858	3.03	-13.1
2025	822	3.28	-29.0
2030	787	3.49	-46.1
2035	752	3.70	-64.2

The results show that the Valley converts all turf area in 2016 with an overall per capita demand reduction of about 59 lpcd (16 gpcd). To achieve a 193 lpcd (51 gpcd) reduction an additional 64 km² (15865 acres) would have to be available to be xeriscaped. Thus, turf conversion as a water conservation measure alone, does not meet the SNWA's target.

3.7. Conclusion

The mass balance model reveals some interesting results. A fairly large amount of water is being lost outdoors mainly due to infiltration to the shallow groundwater aquifer, and to evapotranspiration. A sensitivity analysis revealed that seepage to groundwater is most sensitive to evapotranspiration. Most of the water infiltrating to the shallow groundwater aquifer is being stored there and can be termed as a possible future water resource for the Valley. It is estimated that more than 0.38 million m³/day (100 MGD) infiltrates to the groundwater over the next 25 years, which is similar to the projection of 0.34 million m³/day (89 MGD) from the Las Vegas Groundwater Management Program and also similar to the projection of 120 MGD by Johnson et al. (2007). It is also possible that in the future the increasing shallow aquifer may start coming into contact with foundations and high rise buildings and start surfacing at some low lying points in the Valley, becoming a negative feedback. To evaluate this, data about the volume and capacity of the shallow aquifer would be required which was not available. The

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analysis highlights the importance of outdoor conservation in minimizing the water losses, and the need for adopting conservation measures. The all outdoor conservation scenario has the lowest outdoor usage and the highest return flow credits, and hence policy wise it is deemed the most appropriate. The first hypothesis is proved negative as the limitation of turf removal as a water conservation measure is shown and it cannot be solely relied upon to achieve the desired conservation goal for the Valley, but can used in conjunction with other policies. The second hypothesis is most probably positive as increase in water reuse will decrease the quality of the shallow groundwater with respect to nitrates and it may prove a hindrance to its development as a resource in the future.

It may seem wasteful that a substantial portion of outdoor water gets evapotranspirated and infiltrates to the shallow groundwater. However, it is also possible that this water use has an ecological function. It may sustain a higher amount and quality of vegetation and may lessen the urban heat island effect. Conserving outdoor water usage may change the present relationship between humans and the environment in the Valley, and a conservation policy should be developed keeping this in perspective.

A few assumptions were made in this study. They include calculating evapotranspiration for area covered by turf only, neglecting trees as relevant data was not available, and assuming the evapotranspiration rate and water quantity saved per unit turf reduction are not impacted

by climate change. Also, the turf area estimate is subject to error. Any leakages in the water system were also assumed to be negligible. The need for these assumptions also highlighted some critical knowledge gaps in the urban water balance model as a result of the modeling exercise. These gaps also include data about the volume of the shallow groundwater aquifer, for which no estimate is available, the absence of detailed land use information, especially regarding vegetation, and lack of information about fate and transport processes for contaminants in reuse water.

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CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

Simulation models play an important role in all aspects of water resources management. They are widely accepted within the water resources community and are usually designed to comprehend the response of a system under a particular set of conditions, and contribute to a better understanding of real world processes. To accomplish the objectives of this research, a water mass balance simulation model is created which captures and documents the water cycle of the Las Vegas Valley. The model can be used in helping policy makers make informed decisions by answering several what if questions. The main conclusions of this research are,

• The simultaneous effect of four different water conservation policies and three different population projections were assessed for achieving the SNWA target of 752 lpcd (199 gpcd), on the water supply and demand situation, by creating different outdoor and indoor water use scenarios. The conserving all outdoor water use scenario is found to be the most appropriate option for meeting that goal through 2035 keeping in view the water availability.

• The conserving all outdoor water use scenario, gives the highest volume of return flow credits among the different conservation scenarios.

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- The effect of water reuse in conjunction with and without water conservation was analyzed. Including water reuse decreases the water demand but also decreases the return flow credits, which means a decrease in the available water supply. On the other hand it also means a reduction in the energy requirement for pumping water. This possibility of decrease in energy consumption is not addressed in this research.

- Various demand supply comparisons were done for the different conservation scenarios and the 100% outdoor conservation scenario can fulfill the Valley's water demand through 2035 with still a surplus of 0.05 million m³/day (13 MGD).

- Two entities in the Valley, Nellis Air Force Base and Boulder City have abnormally high per capita water use at 1890 lpcd (500 gpcd) and 1572 lpcd (416 gpcd), respectively.

- The different components of outdoor use including evapotranspiration, excess irrigation runoff, infiltration to groundwater and infiltration to the Las Vegas Wash were simulated and projected in the future and the impact of different water conservation policies on them was analyzed. Infiltration to groundwater will increase the volume of shallow groundwater aquifer with more than 0.37 million m³/day (100 MGD) infiltrating to it every year and it may become a viable water resource in the future.

- Nitrate loading in reclaimed water used for irrigation will contaminate the shallow groundwater aquifer and will increase the cost of treating the shallow groundwater the cost of which was not addressed in this research. In 2008, the nitrate loading in reuse is estimated to be about 800 kg which increases to about 1750 kg if the volume of reuse water is 0.21 million m^3/day (56 MGD) in 2035. The loading increases with increase in wastewater reuse.

- Even if all convertible (non-golf course) turf in the Valley is converted to xeriscaping (desert landscape), it cannot meet the SNWA target of 752 lpcd (199 gpcd), based on present estimates of turf area in the Valley. A maximum of 50 lpcd (16 gpcd) reduction in water demand can be achieved.

4.2. Recommendations

Some recommendations from this research are,

- The conserving all outdoor water use scenario appears to be the most suitable option and is recommended for adoption as a policy.

- There is a potential for substantial water savings in outdoor water usage as a considerable amount of water, more than 0.37 million m^3/day (100 MGD) valley wide, infiltrates to the shallow groundwater aquifer. This potential water saving should be further explored.

- The abnormally high per capita water use for Nellis Air Force Base and Boulder City, compared to other entities in the Valley, presents

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an avenue for water savings, which should be examined further. If possible, steps should be taken to bring them in line with other entities.

- Since turf conversion has its limits, the water usage by large trees and bushes, though not evaluated in this research, should be investigated to evaluate their attractiveness for a program similar to turf conversion.

4.3. Future Work

Based on the research conducted, some recommendations for future work are given which could extend and improve the research work presented in the thesis.

- The water balance model could be linked to climate change models to ascertain inputs for the calculation of future evapotranspiration rates and its effect on water use.

- A detailed land use model for the Valley needs to be built and linked to the water balance model to accurately predict future outdoor water use.

- The size of the shallow groundwater aquifer needs to be estimated and incorporated in the model. This will improve the analysis of infiltration to the shallow groundwater part.

- Adding a water energy nexus section in the model which describes the energy required for pumping the water into the water system and its associated carbon footprint, will enhance the usefulness of the model.

- Detailed per capita water demand breakup into individual consumption components like flushing, laundry, bathing etc. will also increase the utility of the model.

APPENDIX A

MODEL EQUATIONS

Boulder City

BC_WWTP(t) = BC_WWTP(t - dt) + (BC_Sewage - Effluent_to_Desert) * dt

INIT BC_WWTP = 1

INFLOWS:

BC_Sewage = Boulder_City__Indoor*BC_Sewage_Ratio

OUTFLOWS:

Effluent_to_Desert = BC_WWTP*BC_Effluent_Ratio

Boulder_City(t) = Boulder_City(t - dt) + (Boulder_City_Supply -

To_Boulder_City_Indoor - To_Boulder_City_Outdoor) * dt

INIT Boulder_City = 5

INFLOWS:

Boulder_City_Supply (Not in a sector)

OUTFLOWS:

To_Boulder_City_Indoor = Boulder_City*BC_Indoor__Fraction

To_Boulder_City_Outdoor = Boulder_City*BC_Outdoor_Fraction

Boulder_City_Outdoor(t) = Boulder_City_Outdoor(t - dt) +

(To_Boulder_City_Outdoor - Total_BC_Outdoor) * dt

INIT Boulder_City_Outdoor = 5

INFLOWS:

To_Boulder_City_Outdoor = Boulder_City*BC_Outdoor_Fraction

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OUTFLOWS:

Total_BC_Outdoor (Not in a sector)

Boulder_City__Indoor(t) = Boulder_City__Indoor(t - dt) +

(To_Boulder_City_Indoor - BC_Sewage) * dt

INIT Boulder_City__Indoor = 1

INFLOWS:

To_Boulder_City_Indoor = Boulder_City*BC_Indoor__Fraction

OUTFLOWS:

BC_Sewage = Boulder_City__Indoor*BC_Sewage_Ratio

BC_Effluent_Ratio = 1

BC_Indoor_Linear = IF(TIME > 2008)

THEN(0.165+RAMP(BC__Future,2008)) ELSE(BC_Indoor__Historic)

BC_Indoor__Fraction = IF(Indoor_Outdoor_Choice = 1)

THEN(BC_Indoor_LN_1) ELSE IF(Indoor_Outdoor_Choice = 2)

THEN(BC_Indoor_50%_LN) ELSE IF(Indoor_Outdoor_Choice = 3)

THEN(BC_Indoor_LN_3) ELSE IF(Indoor_Outdoor_Choice = 4)

THEN(BC_Indoor_Linear) ELSE IF(Indoor_Outdoor_Choice = 5)

THEN(BC_Indoor_LN_33%) ELSE(0)

BC_Outdoor_Fraction = IF(Indoor_Outdoor_Choice = 1)

THEN(BC_Outdoor_LN_1) ELSE IF(Indoor_Outdoor_Choice = 2)

THEN(BC_Outdoor_50%_LN) ELSE IF(Indoor_Outdoor_Choice = 3)

THEN(BC_Outdoor_LN_3) ELSE IF(Indoor_Outdoor_Choice = 4)

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THEN(BC_Outdoor_Linear) ELSE IF(Indoor_Outdoor_Choice = 5)

THEN(BC_Outdoor_LN_66%) ELSE(0)

BC_Outdoor_Linear = IF(TIME > 2008) THEN(0.835-

RAMP(BC__Future,2008)) ELSE(BC_Outdoor_Historic)

BC_Sewage_Ratio = 1

BC__Future = (0.835-(0.835-(0.835*Future_Rate)))/27

BC_Indoor_50%_LN = GRAPH(TIME)

(1993, 0.2), (1994, 0.189), (1995, 0.195), (1996, 0.176), (1997, 0.186),

(1998, 0.191), (1999, 0.141), (2000, 0.117), (2001, 0.124), (2002, 0.097),

(2003, 0.129), (2004, 0.178), (2005, 0.182), (2006, 0.152), (2007, 0.153),

(2008, 0.165), (2009, 0.18), (2010, 0.188), (2011, 0.194), (2012, 0.198),

(2013, 0.202), (2014, 0.205), (2015, 0.208), (2016, 0.21), (2017, 0.212),

(2018, 0.214), (2019, 0.216), (2020, 0.217), (2021, 0.219), (2022, 0.22),

(2023, 0.221), (2024, 0.223), (2025, 0.224), (2026, 0.225), (2027, 0.226),

(2028, 0.227), (2029, 0.228), (2030, 0.229), (2031, 0.23), (2032, 0.23),

(2033, 0.231), (2034, 0.232), (2035, 0.233)

BC_Indoor_LN_1 = GRAPH(TIME)

(1993, 0.2), (1994, 0.189), (1995, 0.195), (1996, 0.176), (1997, 0.186),

(1998, 0.191), (1999, 0.141), (2000, 0.117), (2001, 0.124), (2002, 0.097),

(2003, 0.129), (2004, 0.178), (2005, 0.182), (2006, 0.152), (2007, 0.153),

(2008, 0.165), (2009, 0.2), (2010, 0.22), (2011, 0.235), (2012, 0.246),

(2013, 0.255), (2014, 0.263), (2015, 0.269), (2016, 0.275), (2017, 0.281),

(2018, 0.285), (2019, 0.29), (2020, 0.294), (2021, 0.297), (2022, 0.301),

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(2023, 0.304), (2024, 0.307), (2025, 0.31), (2026, 0.313), (2027, 0.315),

(2028, 0.318), (2029, 0.32), (2030, 0.322), (2031, 0.324), (2032, 0.326),

(2033, 0.328), (2034, 0.33), (2035, 0.332)

BC_Indoor_LN_3 = GRAPH(TIME)

(1993, 0.2), (1994, 0.189), (1995, 0.195), (1996, 0.176), (1997, 0.186),

(1998, 0.191), (1999, 0.141), (2000, 0.117), (2001, 0.124), (2002,

0.0968), (2003, 0.129), (2004, 0.178), (2005, 0.182), (2006, 0.152),

(2007, 0.153), (2008, 0.165), (2009, 0.158), (2010, 0.154), (2011, 0.152),

(2012, 0.149), (2013, 0.147), (2014, 0.146), (2015, 0.145), (2016, 0.143),

(2017, 0.142), (2018, 0.141), (2019, 0.141), (2020, 0.14), (2021, 0.139),

(2022, 0.138), (2023, 0.138), (2024, 0.137), (2025, 0.136), (2026, 0.136),

(2027, 0.135), (2028, 0.135), (2029, 0.134), (2030, 0.134), (2031, 0.134),

(2032, 0.133), (2033, 0.133), (2034, 0.132), (2035, 0.132)

BC_Indoor_LN_33% = GRAPH(TIME)

(1993, 0.2), (1994, 0.189), (1995, 0.195), (1996, 0.176), (1997, 0.186),

(1998, 0.191), (1999, 0.141), (2000, 0.117), (2001, 0.124), (2002, 0.097),

(2003, 0.129), (2004, 0.178), (2005, 0.182), (2006, 0.152), (2007, 0.153),

(2008, 0.165), (2009, 0.186), (2010, 0.199), (2011, 0.207), (2012, 0.214),

(2013, 0.22), (2014, 0.225), (2015, 0.229), (2016, 0.232), (2017, 0.235),

(2018, 0.238), (2019, 0.241), (2020, 0.243), (2021, 0.246), (2022, 0.248),

(2023, 0.25), (2024, 0.252), (2025, 0.253), (2026, 0.255), (2027, 0.257),

(2028, 0.258), (2029, 0.26), (2030, 0.261), (2031, 0.262), (2032, 0.263),

(2033, 0.265), (2034, 0.266), (2035, 0.267)

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BC_Indoor__Historic = GRAPH(TIME)

(1993, 0.2), (1994, 0.189), (1995, 0.195), (1996, 0.176), (1997, 0.186),

(1998, 0.191), (1999, 0.141), (2000, 0.117), (2001, 0.124), (2002,

0.0968), (2003, 0.129), (2004, 0.178), (2005, 0.182), (2006, 0.152),

(2007, 0.153), (2008, 0.165), (2009, 0.00), (2010, 0.00), (2011, 0.00),

(2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017,

0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00),

(2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028,

0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00),

(2034, 0.00), (2035, 0.00)

BC_Outdoor_Historic = GRAPH(TIME)

(1993, 0.8), (1994, 0.811), (1995, 0.805), (1996, 0.824), (1997, 0.814),

(1998, 0.809), (1999, 0.859), (2000, 0.883), (2001, 0.876), (2002, 0.903),

(2003, 0.871), (2004, 0.822), (2005, 0.818), (2006, 0.848), (2007, 0.847),

(2008, 0.835), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00),

(2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018,

0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00),

(2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029,

0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00),

(2035, 0.00)

BC_Outdoor_LN_1 = GRAPH(TIME)

(1993, 0.8), (1994, 0.811), (1995, 0.805), (1996, 0.824), (1997, 0.814),

(1998, 0.809), (1999, 0.859), (2000, 0.883), (2001, 0.876), (2002, 0.903),

(2003, 0.871), (2004, 0.822), (2005, 0.818), (2006, 0.848), (2007, 0.847),

(2008, 0.835), (2009, 0.8), (2010, 0.78), (2011, 0.765), (2012, 0.754),

(2013, 0.745), (2014, 0.737), (2015, 0.731), (2016, 0.725), (2017, 0.719),

(2018, 0.715), (2019, 0.71), (2020, 0.706), (2021, 0.703), (2022, 0.699),

(2023, 0.696), (2024, 0.693), (2025, 0.69), (2026, 0.687), (2027, 0.685),

(2028, 0.682), (2029, 0.68), (2030, 0.678), (2031, 0.676), (2032, 0.674),

(2033, 0.672), (2034, 0.67), (2035, 0.668)

BC_Outdoor_LN_3 = GRAPH(TIME)

(1993, 0.8), (1994, 0.811), (1995, 0.805), (1996, 0.824), (1997, 0.814),

(1998, 0.809), (1999, 0.859), (2000, 0.883), (2001, 0.876), (2002, 0.903),

(2003, 0.871), (2004, 0.822), (2005, 0.818), (2006, 0.848), (2007, 0.847),

(2008, 0.835), (2009, 0.842), (2010, 0.846), (2011, 0.848), (2012, 0.851),

(2013, 0.853), (2014, 0.854), (2015, 0.855), (2016, 0.857), (2017, 0.858),

(2018, 0.859), (2019, 0.859), (2020, 0.86), (2021, 0.861), (2022, 0.862),

(2023, 0.862), (2024, 0.863), (2025, 0.864), (2026, 0.864), (2027, 0.865),

(2028, 0.865), (2029, 0.866), (2030, 0.866), (2031, 0.866), (2032, 0.867),

(2033, 0.867), (2034, 0.868), (2035, 0.868)

City of Las Vegas

COLV(t) = COLV(t - dt) + (To_COLV - To_COLV_Outdoor -

To_COLV_Indoor) * dt

INIT COLV = 100

INFLOWS:

To_COLV (Not in a sector)

OUTFLOWS:

To_COLV_Outdoor = COLV*COLV_Outdoor_Fraction

To_COLV_Indoor = COLV*COLV_Indoor_Fraction

COLV_Indoor(t) = COLV_Indoor(t - dt) + (To_COLV_Indoor -

COLV_Sewage) * dt

INIT COLV_Indoor = Initial_City_In_Out_Outdoor_Stocks

INFLOWS:

To_COLV_Indoor = COLV*COLV_Indoor_Fraction

OUTFLOWS:

COLV_Sewage = COLV_Indoor*COLV_Sewage_Ratio

COLV_Outdoor(t) = COLV_Outdoor(t - dt) + (To_COLV_Outdoor -

Total_COLV_Outdoor) * dt

INIT COLV_Outdoor = Initial_City_In_Out_Outdoor_Stocks

INFLOWS:

To_COLV_Outdoor = COLV*COLV_Outdoor_Fraction

OUTFLOWS:

Total_COLV_Outdoor = COLV_Outdoor*COLV_Outdoor_Rate

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COLV_WWTP(t) = COLV_WWTP(t - dt) + (COLV_Sewage +

CONLV__Sewage_to_COLV + Nellis_AFB_Sewage_to__COLV_WWTP -

COLV_WWTP__Effluent_to_Wash - COLV_Effluent__to_RP) * dt

INIT COLV_WWTP = 40

INFLOWS:

COLV_Sewage = COLV_Indoor*COLV_Sewage_Ratio

CONLV__Sewage_to_COLV = (CONLV_Indoor*CONLV_Sewage_Ratio)-5

Nellis_AFB_Sewage_to__COLV_WWTP   (IN SECTOR: City of North

Las Vegas)

OUTFLOWS:

COLV_WWTP__Effluent_to_Wash (Not in a sector)

COLV_Effluent__to_RP (Not in a sector)

Yearly_GW = GW*Yearly_GW_ratio

OUTFLOW FROM: GW(Not in a sector)

COLV_Evaporation_Fraction = 0.236321684

COLV_Fraction_Runoff = 0.043818654

COLV_Fraction__Seeping_to_GW = 0.662034159

COLV_Future = (0.52-(0.52-(0.52*Future_Rate)))/27

COLV_Indoor_Fraction = IF(Indoor_Outdoor_Choice = 1)

THEN(COLV_Indoor_LN_1) ELSE IF(Indoor_Outdoor_Choice = 2)

THEN(COLV_Indoor_50%_LN) ELSE IF(Indoor_Outdoor_Choice = 3)

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THEN(COLV_Indoor_LN_3) ELSE IF(Indoor_Outdoor_Choice = 4)

THEN(COLV_Indoor_Linear) ELSE IF(Indoor_Outdoor_Choice = 5)

THEN(COLV_Indoor_LN_33%) ELSE(0)

COLV_Indoor_Linear = IF(TIME > 2008)

THEN(0.48+RAMP(COLV_Future,2008)) ELSE(COLV_Indoor__Historic)

COLV_Outdoor_Fraction = IF(Indoor_Outdoor_Choice = 1)

THEN(COLV_Outdoor_LN_1) ELSE IF(Indoor_Outdoor_Choice = 2)

THEN(COLV_Outdoor_50%_LN) ELSE IF(Indoor_Outdoor_Choice = 3)

THEN(COLV_Outdoor_LN_3) ELSE IF(Indoor_Outdoor_Choice = 4)

THEN(COLV_Outdoor_Linear) ELSE IF(Indoor_Outdoor_Choice = 5)

THEN(COLV_Outdoor_LN_66%) ELSE(0)

COLV_Outdoor_Linear = IF(TIME > 2008) THEN(0.52-

RAMP(COLV_Future,2008)) ELSE(COLV_Outdoor_Historic)

COLV_Outdoor_Rate = 1

COLV_Sewage_Ratio = 1

COLV__Fraction__Seeping_to_Wash = 0.057825504

CONLV__Fraction__Seeping_to_Wash = 0.057825504

Fraction__COLV_RP = 1

Nellis_AFB_Fraction_Seeping_to_Wash = 0.057825504

Sum_COLV__Outdoor_Fraction =

COLV_Evaporation_Fraction+COLV_Fraction_Runoff+COLV_Fraction__Se

eping_to_GW+COLV__Fraction__Seeping_to_Wash

COLV_Indoor_50%_LN = GRAPH(TIME)

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(1993, 0.38), (1994, 0.373), (1995, 0.38), (1996, 0.37), (1997, 0.367),

(1998, 0.374), (1999, 0.357), (2000, 0.36), (2001, 0.377), (2002, 0.413),

(2003, 0.444), (2004, 0.484), (2005, 0.492), (2006, 0.475), (2007, 0.481),

(2008, 0.48), (2009, 0.481), (2010, 0.481), (2011, 0.481), (2012, 0.482),

(2013, 0.482), (2014, 0.482), (2015, 0.482), (2016, 0.482), (2017, 0.482),

(2018, 0.482), (2019, 0.482), (2020, 0.483), (2021, 0.483), (2022, 0.483),

(2023, 0.483), (2024, 0.483), (2025, 0.483), (2026, 0.483), (2027, 0.483),

(2028, 0.483), (2029, 0.483), (2030, 0.483), (2031, 0.483), (2032, 0.483),

(2033, 0.483), (2034, 0.483), (2035, 0.483)

COLV_Indoor_LN_1 = GRAPH(TIME)

(1993, 0.38), (1994, 0.373), (1995, 0.38), (1996, 0.37), (1997, 0.367),

(1998, 0.374), (1999, 0.357), (2000, 0.36), (2001, 0.377), (2002, 0.413),

(2003, 0.444), (2004, 0.484), (2005, 0.492), (2006, 0.475), (2007, 0.481),

(2008, 0.48), (2009, 0.502), (2010, 0.514), (2011, 0.523), (2012, 0.53),

(2013, 0.536), (2014, 0.541), (2015, 0.545), (2016, 0.549), (2017, 0.552),

(2018, 0.555), (2019, 0.558), (2020, 0.56), (2021, 0.562), (2022, 0.565),

(2023, 0.567), (2024, 0.568), (2025, 0.57), (2026, 0.572), (2027, 0.574),

(2028, 0.575), (2029, 0.577), (2030, 0.578), (2031, 0.579), (2032, 0.581),

(2033, 0.582), (2034, 0.583), (2035, 0.584)

COLV_Indoor_LN_3 = GRAPH(TIME)

(1993, 0.38), (1994, 0.373), (1995, 0.38), (1996, 0.37), (1997, 0.367),

(1998, 0.374), (1999, 0.357), (2000, 0.36), (2001, 0.377), (2002, 0.413),

(2003, 0.444), (2004, 0.484), (2005, 0.492), (2006, 0.475), (2007, 0.481),

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(2008, 0.48), (2009, 0.46), (2010, 0.448), (2011, 0.44), (2012, 0.433),

(2013, 0.428), (2014, 0.424), (2015, 0.42), (2016, 0.416), (2017, 0.413),

(2018, 0.411), (2019, 0.408), (2020, 0.406), (2021, 0.404), (2022, 0.402),

(2023, 0.4), (2024, 0.398), (2025, 0.396), (2026, 0.395), (2027, 0.393),

(2028, 0.392), (2029, 0.39), (2030, 0.389), (2031, 0.388), (2032, 0.387),

(2033, 0.386), (2034, 0.385), (2035, 0.383)

COLV_Indoor_LN_33% = GRAPH(TIME)

(1993, 0.38), (1994, 0.373), (1995, 0.38), (1996, 0.37), (1997, 0.367),

(1998, 0.374), (1999, 0.357), (2000, 0.36), (2001, 0.377), (2002, 0.413),

(2003, 0.444), (2004, 0.484), (2005, 0.492), (2006, 0.475), (2007, 0.481),

(2008, 0.48), (2009, 0.488), (2010, 0.492), (2011, 0.496), (2012, 0.498),

(2013, 0.5), (2014, 0.502), (2015, 0.503), (2016, 0.505), (2017, 0.506),

(2018, 0.507), (2019, 0.508), (2020, 0.509), (2021, 0.51), (2022, 0.511),

(2023, 0.511), (2024, 0.512), (2025, 0.513), (2026, 0.513), (2027, 0.514),

(2028, 0.514), (2029, 0.515), (2030, 0.515), (2031, 0.516), (2032, 0.516),

(2033, 0.517), (2034, 0.517), (2035, 0.518)

COLV_Indoor__Historic = GRAPH(TIME)

(1993, 0.38), (1994, 0.373), (1995, 0.38), (1996, 0.37), (1997, 0.367),

(1998, 0.374), (1999, 0.357), (2000, 0.36), (2001, 0.377), (2002, 0.413),

(2003, 0.444), (2004, 0.484), (2005, 0.492), (2006, 0.475), (2007, 0.481),

(2008, 0.48), (2009, 0.48), (2010, 0.48), (2011, 0.48), (2012, 0.48), (2013,

0.48), (2014, 0.48), (2015, 0.48), (2016, 0.48), (2017, 0.48), (2018, 0.48),

(2019, 0.48), (2020, 0.48), (2021, 0.48), (2022, 0.48), (2023, 0.48), (2024,

111

0.48), (2025, 0.48), (2026, 0.48), (2027, 0.48), (2028, 0.48), (2029, 0.48),

(2030, 0.48), (2031, 0.48), (2032, 0.48), (2033, 0.48), (2034, 0.48), (2035,

0.48)

COLV_Outdoor_50%_LN = GRAPH(TIME)

(1993, 0.62), (1994, 0.627), (1995, 0.62), (1996, 0.63), (1997, 0.633),

(1998, 0.626), (1999, 0.643), (2000, 0.64), (2001, 0.623), (2002, 0.587),

(2003, 0.556), (2004, 0.516), (2005, 0.508), (2006, 0.525), (2007, 0.519),

(2008, 0.52), (2009, 0.519), (2010, 0.519), (2011, 0.519), (2012, 0.518),

(2013, 0.518), (2014, 0.518), (2015, 0.518), (2016, 0.518), (2017, 0.518),

(2018, 0.518), (2019, 0.518), (2020, 0.517), (2021, 0.517), (2022, 0.517),

(2023, 0.517), (2024, 0.517), (2025, 0.517), (2026, 0.517), (2027, 0.517),

(2028, 0.517), (2029, 0.517), (2030, 0.517), (2031, 0.517), (2032, 0.517),

(2033, 0.517), (2034, 0.517), (2035, 0.517)

COLV_Outdoor_Historic = GRAPH(TIME)

(1993, 0.62), (1994, 0.627), (1995, 0.62), (1996, 0.63), (1997, 0.633),

(1998, 0.626), (1999, 0.643), (2000, 0.64), (2001, 0.623), (2002, 0.587),

(2003, 0.556), (2004, 0.516), (2005, 0.508), (2006, 0.525), (2007, 0.519),

(2008, 0.52), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013,

0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00),

(2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024,

0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00),

(2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035,

0.00)

COLV_Outdoor_LN_1 = GRAPH(TIME)

(1993, 0.62), (1994, 0.627), (1995, 0.62), (1996, 0.63), (1997, 0.633),

(1998, 0.626), (1999, 0.643), (2000, 0.64), (2001, 0.623), (2002, 0.587),

(2003, 0.556), (2004, 0.516), (2005, 0.508), (2006, 0.525), (2007, 0.519),

(2008, 0.52), (2009, 0.498), (2010, 0.486), (2011, 0.477), (2012, 0.47),

(2013, 0.464), (2014, 0.459), (2015, 0.455), (2016, 0.451), (2017, 0.448),

(2018, 0.445), (2019, 0.442), (2020, 0.44), (2021, 0.438), (2022, 0.435),

(2023, 0.433), (2024, 0.432), (2025, 0.43), (2026, 0.428), (2027, 0.426),

(2028, 0.425), (2029, 0.423), (2030, 0.422), (2031, 0.421), (2032, 0.419),

(2033, 0.418), (2034, 0.417), (2035, 0.416)

COLV_Outdoor_LN_3 = GRAPH(TIME)

(1993, 0.62), (1994, 0.627), (1995, 0.62), (1996, 0.63), (1997, 0.633),

(1998, 0.626), (1999, 0.643), (2000, 0.64), (2001, 0.623), (2002, 0.587),

(2003, 0.556), (2004, 0.516), (2005, 0.508), (2006, 0.525), (2007, 0.519),

(2008, 0.52), (2009, 0.54), (2010, 0.552), (2011, 0.56), (2012, 0.567),

(2013, 0.572), (2014, 0.576), (2015, 0.58), (2016, 0.584), (2017, 0.587),

(2018, 0.589), (2019, 0.592), (2020, 0.594), (2021, 0.596), (2022, 0.598),

(2023, 0.6), (2024, 0.602), (2025, 0.604), (2026, 0.605), (2027, 0.607),

(2028, 0.608), (2029, 0.61), (2030, 0.611), (2031, 0.612), (2032, 0.613),

(2033, 0.614), (2034, 0.615), (2035, 0.617)

COLV_Outdoor_LN_66% = GRAPH(TIME)

(1993, 0.62), (1994, 0.627), (1995, 0.62), (1996, 0.63), (1997, 0.633),

(1998, 0.626), (1999, 0.643), (2000, 0.64), (2001, 0.623), (2002, 0.587),

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(2003, 0.556), (2004, 0.516), (2005, 0.508), (2006, 0.525), (2007, 0.519),

(2008, 0.52), (2009, 0.512), (2010, 0.508), (2011, 0.504), (2012, 0.502),

(2013, 0.5), (2014, 0.498), (2015, 0.497), (2016, 0.495), (2017, 0.494),

(2018, 0.493), (2019, 0.492), (2020, 0.491), (2021, 0.49), (2022, 0.489),

(2023, 0.489), (2024, 0.488), (2025, 0.487), (2026, 0.487), (2027, 0.486),

(2028, 0.486), (2029, 0.485), (2030, 0.485), (2031, 0.484), (2032, 0.484),

(2033, 0.483), (2034, 0.483), (2035, 0.482)

COLV_WWTP__Efluent_Fraction = GRAPH(TIME)

(1992, 0.934), (1993, 0.938), (1994, 0.944), (1995, 0.945), (1996, 0.998),

(1997, 0.993), (1998, 0.989), (1999, 0.942), (2000, 0.937), (2001, 0.915),

(2002, 0.91), (2003, 0.923), (2004, 0.931), (2005, 0.925), (2006, 0.932),

(2007, 0.929), (2008, 0.89)

COLV_WWTP__Fraction_to_Reuse = GRAPH(TIME)

(1992, 0.0658), (1993, 0.0623), (1994, 0.0559), (1995, 0.0546), (1996,

0.00229), (1997, 0.00708), (1998, 0.0107), (1999, 0.0579), (2000,

0.0634), (2001, 0.0847), (2002, 0.0899), (2003, 0.0773), (2004, 0.0687),

(2005, 0.0751), (2006, 0.068), (2007, 0.0707), (2008, 0.11)

City of North Las Vegas

CONLV(t) = CONLV(t - dt) + (To_CONLV - To_CONLV__Outdoor -

To_CONLV_Indoor) * dt

INIT CONLV = 30

INFLOWS:

To_CONLV (Not in a sector)

OUTFLOWS:

To_CONLV__Outdoor = CONLV*CNLV_Outdoor_Fraction

To_CONLV_Indoor = CONLV*CNLV_Indoor_Fraction

CONLV_Indoor(t) = CONLV_Indoor(t - dt) + (To_CONLV_Indoor -

CONLV__Sewage_to_COLV - CONLV_Sewage - Sunrise_Manor_Sewage) *

dt

INIT CONLV_Indoor = 10

INFLOWS:

To_CONLV_Indoor = CONLV*CNLV_Indoor_Fraction

OUTFLOWS:

CONLV__Sewage_to_COLV   (IN SECTOR: City of Las Vegas)

CONLV_Sewage = CONLV_Indoor*CONLV__WW_Ratio

Sunrise_Manor_Sewage (IN SECTOR: Clark County Portion)

CONLV_Outdoor(t) = CONLV_Outdoor(t - dt) + (To_CONLV__Outdoor -

Total_CONLV_Outdoor) * dt

INIT CONLV_Outdoor = 10

INFLOWS:

To_CONLV__Outdoor = CONLV*CNLV_Outdoor_Fraction

OUTFLOWS:

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Total_CONLV_Outdoor (Not in a sector)

CONLV_WWTP(t) = CONLV_WWTP(t - dt) + (CONLV_Sewage -

CONLV_Effluent__to_Reuse) * dt

INIT CONLV_WWTP = 0

INFLOWS:

CONLV_Sewage = CONLV_Indoor*CONLV__WW_Ratio

OUTFLOWS:

CONLV_Effluent__to_Reuse =

CONLV_WWTP*Ratio_CONLV__WWTP_to_Reuse

Nellis_AFB_Sewage_to__COLV_WWTP =

Nellis_AFB_Indoor*Nellis_AFB_COLV__Sewage_Ratio

OUTFLOW FROM: Nellis_AFB_Indoor   (IN SECTOR: Nellis Air Force

Base)

INFLOW TO: COLV_WWTP   (IN SECTOR: City of Las Vegas)

CNLV_Future = (0.666-(0.666-(0.666*Future_Rate)))/27

CNLV_Indoor_Fraction = IF(Indoor_Outdoor_Choice = 1)

THEN(CONLV_Indoor_LN_1) ELSE IF(Indoor_Outdoor_Choice = 2)

THEN(CONLV_Indoor_50%_LN) ELSE IF(Indoor_Outdoor_Choice = 3)

THEN(CONLV_Indoor_LN_3) ELSE IF(Indoor_Outdoor_Choice = 4)

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THEN(CNLV_Indoor_Linear) ELSE IF(Indoor_Outdoor_Choice = 5)

THEN(CONLV_Indoor_LN_33%) ELSE(0)

CNLV_Indoor_Linear = IF(TIME > 2008)

THEN(0.334+RAMP(CNLV_Future,2008)) ELSE(CNLV_Indoor__Historic)

CNLV_Outdoor_Fraction = IF(Indoor_Outdoor_Choice = 1)

THEN(CONLV_Outdoor_LN_1) ELSE IF(Indoor_Outdoor_Choice = 2)

THEN(CONLV_Outdoor_50%_LN) ELSE IF(Indoor_Outdoor_Choice = 3)

THEN(CONLV_Outdoor_LN_3) ELSE IF(Indoor_Outdoor_Choice = 4)

THEN(CNLV_Outdoor_Linear) ELSE IF(Indoor_Outdoor_Choice = 5)

THEN(CONLV_Outdoor_LN_66%) ELSE(0)

CNLV_Outdoor_Linear = IF(TIME > 2008) THEN(0.666-

RAMP(CNLV_Future,2008)) ELSE(CNLV_Outdoor_Historic)

CONLV_Fraction__Seeping_to_GW = 0.662034159

CONLV_Sewage_Ratio = 1

CONLV__WW_Ratio = 0

Nellis_AFB_COLV__Sewage_Ratio = 0

Nellis_AFB_Evaporation_Fraction = 0.236

Ratio_CONLV__WWTP_to_Reuse = 1

Sum_CONLV_Outdoor_Fraction =

CONLV_Evaporation_Fraction+CONLV_Fraction_Runoff+CONLV_Fraction

__Seeping_to_GW+CONLV__Fraction__Seeping_to_Wash

Sum_CONLV__Indoor_Fraction =

CONLV_Sewage_Ratio+CONLV__WW_Ratio

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CNLV_Indoor__Historic = GRAPH(TIME)

(1993, 0.242), (1994, 0.226), (1995, 0.216), (1996, 0.251), (1997, 0.296),

(1998, 0.306), (1999, 0.345), (2000, 0.31), (2001, 0.29), (2002, 0.284),

(2003, 0.29), (2004, 0.321), (2005, 0.319), (2006, 0.302), (2007, 0.326),

(2008, 0.334), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00),

(2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018,

0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00),

(2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029,

0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00),

(2035, 0.00)

CNLV_Outdoor_Historic = GRAPH(TIME)

(1993, 0.758), (1994, 0.774), (1995, 0.784), (1996, 0.749), (1997, 0.704),

(1998, 0.694), (1999, 0.655), (2000, 0.69), (2001, 0.71), (2002, 0.716),

(2003, 0.71), (2004, 0.679), (2005, 0.681), (2006, 0.698), (2007, 0.674),

(2008, 0.666), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00),

(2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018,

0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00),

(2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029,

0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00),

(2035, 0.00)

CONLV_Indoor_50%_LN = GRAPH(TIME)

(1993, 0.242), (1994, 0.226), (1995, 0.216), (1996, 0.251), (1997, 0.296),

(1998, 0.306), (1999, 0.345), (2000, 0.31), (2001, 0.29), (2002, 0.284),

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(2003, 0.29), (2004, 0.321), (2005, 0.319), (2006, 0.302), (2007, 0.326),

(2008, 0.334), (2009, 0.341), (2010, 0.345), (2011, 0.348), (2012, 0.35),

(2013, 0.352), (2014, 0.353), (2015, 0.355), (2016, 0.356), (2017, 0.357),

(2018, 0.358), (2019, 0.359), (2020, 0.36), (2021, 0.36), (2022, 0.361),

(2023, 0.362), (2024, 0.362), (2025, 0.363), (2026, 0.363), (2027, 0.364),

(2028, 0.364), (2029, 0.365), (2030, 0.365), (2031, 0.366), (2032, 0.366),

(2033, 0.367), (2034, 0.367), (2035, 0.367)

CONLV_Indoor_LN_1 = GRAPH(TIME)

(1993, 0.242), (1994, 0.226), (1995, 0.216), (1996, 0.251), (1997, 0.296),

(1998, 0.306), (1999, 0.345), (2000, 0.31), (2001, 0.29), (2002, 0.284),

(2003, 0.29), (2004, 0.321), (2005, 0.319), (2006, 0.302), (2007, 0.326),

(2008, 0.334), (2009, 0.361), (2010, 0.378), (2011, 0.389), (2012, 0.398),

(2013, 0.405), (2014, 0.411), (2015, 0.417), (2016, 0.421), (2017, 0.426),

(2018, 0.43), (2019, 0.433), (2020, 0.436), (2021, 0.439), (2022, 0.442),

(2023, 0.445), (2024, 0.447), (2025, 0.449), (2026, 0.451), (2027, 0.453),

(2028, 0.455), (2029, 0.457), (2030, 0.459), (2031, 0.461), (2032, 0.462),

(2033, 0.464), (2034, 0.465), (2035, 0.467)

CONLV_Indoor_LN_3 = GRAPH(TIME)

(1993, 0.242), (1994, 0.226), (1995, 0.216), (1996, 0.251), (1997, 0.296),

(1998, 0.306), (1999, 0.345), (2000, 0.31), (2001, 0.29), (2002, 0.284),

(2003, 0.29), (2004, 0.321), (2005, 0.319), (2006, 0.302), (2007, 0.326),

(2008, 0.334), (2009, 0.32), (2010, 0.312), (2011, 0.306), (2012, 0.301),

(2013, 0.298), (2014, 0.295), (2015, 0.292), (2016, 0.29), (2017, 0.288),

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(2018, 0.286), (2019, 0.284), (2020, 0.282), (2021, 0.281), (2022, 0.279),

(2023, 0.278), (2024, 0.277), (2025, 0.276), (2026, 0.275), (2027, 0.274),

(2028, 0.273), (2029, 0.272), (2030, 0.271), (2031, 0.27), (2032, 0.269),

(2033, 0.268), (2034, 0.268), (2035, 0.267)

CONLV_Indoor_LN_33% = GRAPH(TIME)

(1993, 0.242), (1994, 0.226), (1995, 0.216), (1996, 0.251), (1997, 0.296),

(1998, 0.306), (1999, 0.345), (2000, 0.31), (2001, 0.29), (2002, 0.284),

(2003, 0.29), (2004, 0.321), (2005, 0.319), (2006, 0.302), (2007, 0.326),

(2008, 0.334), (2009, 0.348), (2010, 0.357), (2011, 0.362), (2012, 0.367),

(2013, 0.371), (2014, 0.374), (2015, 0.377), (2016, 0.379), (2017, 0.381),

(2018, 0.383), (2019, 0.385), (2020, 0.387), (2021, 0.388), (2022, 0.39),

(2023, 0.391), (2024, 0.392), (2025, 0.393), (2026, 0.394), (2027, 0.395),

(2028, 0.396), (2029, 0.397), (2030, 0.398), (2031, 0.399), (2032, 0.4),

(2033, 0.401), (2034, 0.402), (2035, 0.402)

CONLV_Outdoor_50%_LN = GRAPH(TIME)

(1993, 0.758), (1994, 0.774), (1995, 0.784), (1996, 0.749), (1997, 0.704),

(1998, 0.694), (1999, 0.655), (2000, 0.69), (2001, 0.71), (2002, 0.716),

(2003, 0.71), (2004, 0.679), (2005, 0.681), (2006, 0.698), (2007, 0.674),

(2008, 0.666), (2009, 0.659), (2010, 0.655), (2011, 0.652), (2012, 0.65),

(2013, 0.648), (2014, 0.647), (2015, 0.645), (2016, 0.644), (2017, 0.643),

(2018, 0.642), (2019, 0.641), (2020, 0.64), (2021, 0.64), (2022, 0.639),

(2023, 0.638), (2024, 0.638), (2025, 0.637), (2026, 0.637), (2027, 0.636),

(2028, 0.636), (2029, 0.635), (2030, 0.635), (2031, 0.634), (2032, 0.634),

(2033, 0.633), (2034, 0.633), (2035, 0.633)

CONLV_Outdoor_LN_1 = GRAPH(TIME)

(1993, 0.758), (1994, 0.774), (1995, 0.784), (1996, 0.749), (1997, 0.704),

(1998, 0.694), (1999, 0.655), (2000, 0.69), (2001, 0.71), (2002, 0.716),

(2003, 0.71), (2004, 0.679), (2005, 0.681), (2006, 0.698), (2007, 0.674),

(2008, 0.666), (2009, 0.639), (2010, 0.622), (2011, 0.611), (2012, 0.602),

(2013, 0.595), (2014, 0.589), (2015, 0.583), (2016, 0.579), (2017, 0.574),

(2018, 0.57), (2019, 0.567), (2020, 0.564), (2021, 0.561), (2022, 0.558),

(2023, 0.555), (2024, 0.553), (2025, 0.551), (2026, 0.549), (2027, 0.547),

(2028, 0.545), (2029, 0.543), (2030, 0.541), (2031, 0.539), (2032, 0.538),

(2033, 0.536), (2034, 0.535), (2035, 0.533)

CONLV_Outdoor_LN_3 = GRAPH(TIME)

(1993, 0.758), (1994, 0.774), (1995, 0.784), (1996, 0.749), (1997, 0.704),

(1998, 0.694), (1999, 0.655), (2000, 0.69), (2001, 0.71), (2002, 0.716),

(2003, 0.71), (2004, 0.679), (2005, 0.681), (2006, 0.698), (2007, 0.674),

(2008, 0.666), (2009, 0.68), (2010, 0.688), (2011, 0.694), (2012, 0.699),

(2013, 0.702), (2014, 0.705), (2015, 0.708), (2016, 0.71), (2017, 0.712),

(2018, 0.714), (2019, 0.716), (2020, 0.718), (2021, 0.719), (2022, 0.721),

(2023, 0.722), (2024, 0.723), (2025, 0.724), (2026, 0.725), (2027, 0.726),

(2028, 0.727), (2029, 0.728), (2030, 0.729), (2031, 0.73), (2032, 0.731),

(2033, 0.732), (2034, 0.732), (2035, 0.733)

CONLV_Outdoor_LN_66% = GRAPH(TIME)

(1993, 0.758), (1994, 0.774), (1995, 0.784), (1996, 0.749), (1997, 0.704),

(1998, 0.694), (1999, 0.655), (2000, 0.69), (2001, 0.71), (2002, 0.716),

(2003, 0.71), (2004, 0.679), (2005, 0.681), (2006, 0.698), (2007, 0.674),

(2008, 0.666), (2009, 0.652), (2010, 0.643), (2011, 0.638), (2012, 0.633),

(2013, 0.629), (2014, 0.626), (2015, 0.623), (2016, 0.621), (2017, 0.619),

(2018, 0.617), (2019, 0.615), (2020, 0.613), (2021, 0.612), (2022, 0.61),

(2023, 0.609), (2024, 0.608), (2025, 0.607), (2026, 0.606), (2027, 0.605),

(2028, 0.604), (2029, 0.603), (2030, 0.602), (2031, 0.601), (2032, 0.6),

(2033, 0.599), (2034, 0.598), (2035, 0.598)

Clark County Portion

CCWRP(t) = CCWRP(t - dt) + (Clark_County__LVV_Sewage +

Nellis_AFB_Sewage_to_CCWRP + Sunrise_Manor_Sewage -

CCWRP_Effluent_to_Wash - CCWRP_to_DBRP - CCWRP_to_Reuse -

CCWRP__to_ERP) * dt

INIT CCWRP = 57

INFLOWS:

Clark_County__LVV_Sewage =

Clark_County__LVV_Indoor*CCLVV_Sewage_Ratio

Nellis_AFB_Sewage_to_CCWRP   (IN SECTOR: Nellis Air Force Base)

Sunrise_Manor_Sewage = 5

OUTFLOWS:

CCWRP_Effluent_to_Wash (Not in a sector)

CCWRP_to_DBRP = GRAPH(TIME)

(1993, 0.00), (1994, 0.00), (1995, 0.00), (1996, 0.00), (1997, 0.00), (1998, 0.00), (1999, 0.00), (2000, 0.00), (2001, 0.00), (2002, 0.00), (2003, 0.52), (2004, 2.43), (2005, 2.64), (2006, 2.85), (2007, 2.98), (2008, 3.44), (2009, 3.57), (2010, 3.70), (2011, 3.83), (2012, 3.96), (2013, 4.09), (2014, 4.22), (2015, 4.35), (2016, 4.48), (2017, 4.61), (2018, 4.74), (2019, 4.87), (2020, 5.00), (2021, 5.00), (2022, 5.00), (2023, 5.00), (2024, 5.00), (2025, 5.00), (2026, 5.00), (2027, 5.00), (2028, 5.00), (2029, 5.00), (2030, 5.00), (2031, 5.00), (2032, 5.00), (2033, 5.00), (2034, 5.00), (2035, 5.00)

CCWRP_to_Reuse = GRAPH(TIME)

(1993, 2.03), (1994, 3.72), (1995, 4.24), (1996, 6.04), (1997, 6.40), (1998, 5.81), (1999, 4.81), (2000, 5.22), (2001, 5.11), (2002, 5.43), (2003, 5.22), (2004, 6.22), (2005, 7.65), (2006, 7.97), (2007, 8.22), (2008, 7.08), (2009, 7.32), (2010, 7.56), (2011, 7.81), (2012, 8.05), (2013, 8.29), (2014, 8.54), (2015, 8.78), (2016, 9.03), (2017, 9.27), (2018, 9.51), (2019, 9.76), (2020, 10.0), (2021, 10.0), (2022, 10.0), (2023, 10.0), (2024, 10.0), (2025, 10.0), (2026, 10.0), (2027, 10.0), (2028, 10.0), (2029, 10.0), (2030, 10.0), (2031, 10.0), (2032, 10.0), (2033, 10.0), (2034, 10.0), (2035, 10.0)

CCWRP__to_ERP = GRAPH(TIME)

(1993, 0.00), (1994, 0.00), (1995, 0.00), (1996, 0.00), (1997, 0.00), (1998, 0.00), (1999, 0.00), (2000, 0.00), (2001, 0.00), (2002, 0.00), (2003, 0.00), (2004, 0.00), (2005, 0.00), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2009,

10.0), (2010, 10.0), (2011, 10.0), (2012, 10.0), (2013, 10.0), (2014, 10.0), (2015, 10.0), (2016, 10.0), (2017, 10.0), (2018, 10.0), (2019, 10.0), (2020, 10.0), (2021, 10.0), (2022, 10.0), (2023, 10.0), (2024, 10.0), (2025, 10.0), (2026, 10.0), (2027, 10.0), (2028, 10.0), (2029, 10.0), (2030, 10.0), (2031, 10.0), (2032, 10.0), (2033, 10.0), (2034, 10.0), (2035, 10.0)

Clark_County_LVV(t) = Clark_County_LVV(t - dt) +

(To_Clark_County_LVV - To_Clark_County_LVV_Outdoor -

To_Clark_County__LVV_Indoor) * dt

INIT Clark_County_LVV = 130

INFLOWS:

To_Clark_County_LVV (Not in a sector)

OUTFLOWS:

To_Clark_County_LVV_Outdoor =

Clark_County_LVV*CCLVV_Outdoor_Fraction

To_Clark_County__LVV_Indoor =

Clark_County_LVV*CCLVV_Indoor_Fraction

Clark_County__LVV_Indoor(t) = Clark_County__LVV_Indoor(t - dt) +

(To_Clark_County__LVV_Indoor - Clark_County__LVV_Sewage) * dt

INIT Clark_County__LVV_Indoor = 60

INFLOWS:

To_Clark_County__LVV_Indoor =

Clark_County_LVV*CCLVV_Indoor_Fraction

OUTFLOWS:

Clark_County__LVV_Sewage =

Clark_County__LVV_Indoor*CCLVV_Sewage_Ratio

Clark_County__LVV__Outdoor(t) = Clark_County__LVV__Outdoor(t - dt) +

(To_Clark_County_LVV_Outdoor - Total_CCPLVV_Outdoor) * dt

INIT Clark_County__LVV__Outdoor = Initial_City_In_Out_Outdoor_Stocks

INFLOWS:

To_Clark_County_LVV_Outdoor =

Clark_County_LVV*CCLVV_Outdoor_Fraction

OUTFLOWS:

Total_CCPLVV_Outdoor (Not in a sector)

Desert_Breeze__Reclamation_Plant(t) =

Desert_Breeze__Reclamation_Plant(t - dt) + (CCWRP_to_DBRP -

DBRP_to_Reuse) * dt

INIT Desert_Breeze__Reclamation_Plant =

Initial_Reclamation_Plants_Human_Use_Ponds

INFLOWS:

CCWRP_to_DBRP = GRAPH(TIME)

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(1993, 0.00), (1994, 0.00), (1995, 0.00), (1996, 0.00), (1997, 0.00), (1998, 0.00), (1999, 0.00), (2000, 0.00), (2001, 0.00), (2002, 0.00), (2003, 0.52), (2004, 2.43), (2005, 2.64), (2006, 2.85), (2007, 2.98), (2008, 3.44), (2009, 3.57), (2010, 3.70), (2011, 3.83), (2012, 3.96), (2013, 4.09), (2014, 4.22), (2015, 4.35), (2016, 4.48), (2017, 4.61), (2018, 4.74), (2019, 4.87), (2020, 5.00), (2021, 5.00), (2022, 5.00), (2023, 5.00), (2024, 5.00), (2025, 5.00), (2026, 5.00), (2027, 5.00), (2028, 5.00), (2029, 5.00), (2030, 5.00), (2031, 5.00), (2032, 5.00), (2033, 5.00), (2034, 5.00), (2035, 5.00)

OUTFLOWS:

DBRP_to_Reuse =

Desert_Breeze__Reclamation_Plant*DBRP_Fraction__to_Reuse

Enterprise__Reuse_Plant(t) = Enterprise__Reuse_Plant(t - dt) +

(CCWRP__to_ERP - ERP_to__Reuse) * dt

INIT Enterprise__Reuse_Plant =

Initial_Reclamation_Plants_Human_Use_Ponds

INFLOWS:

CCWRP__to_ERP = GRAPH(TIME)

(1993, 0.00), (1994, 0.00), (1995, 0.00), (1996, 0.00), (1997, 0.00), (1998, 0.00), (1999, 0.00), (2000, 0.00), (2001, 0.00), (2002, 0.00), (2003, 0.00), (2004, 0.00), (2005, 0.00), (2006, 0.00), (2007, 0.00), (2008, 0.00), (2009, 10.0), (2010, 10.0), (2011, 10.0), (2012, 10.0), (2013, 10.0), (2014, 10.0), (2015, 10.0), (2016, 10.0), (2017, 10.0), (2018, 10.0), (2019, 10.0), (2020,

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10.0), (2021, 10.0), (2022, 10.0), (2023, 10.0), (2024, 10.0), (2025, 10.0),

(2026, 10.0), (2027, 10.0), (2028, 10.0), (2029, 10.0), (2030, 10.0), (2031,

10.0), (2032, 10.0), (2033, 10.0), (2034, 10.0), (2035, 10.0)

OUTFLOWS:

ERP_to__Reuse = Enterprise__Reuse_Plant*ERP_Fraction_to_Reuse

COH_Ponds__seepage_to_Wash =

COH_Ponds*Ponds_Wash__Seepage_Ratio

OUTFLOW FROM: COH_Ponds(Not in a sector)

INFLOW TO: Las_Vegas_Wash(Not in a sector)

CCLVV_Evaporation_Fraction = 0.236321684

CCLVV_Fraction__Seeping_to_GW = 0.662034159

CCLVV_Future = (0.507-(0.507-(0.507*Future_Rate)))/27

CCLVV_Indoor_Fraction = IF(Indoor_Outdoor_Choice = 1)

THEN(CCLVV_Indoor_LN_1) ELSE IF(Indoor_Outdoor_Choice = 2)

THEN(CCLVVIndoor_50%_LN) ELSE IF(Indoor_Outdoor_Choice = 3)

THEN(CCLVV_Indoor_LN_3) ELSE IF(Indoor_Outdoor_Choice = 4)

THEN(CCLVV_Indoor__Linear) ELSE IF(Indoor_Outdoor_Choice = 5)

THEN(CCPLV_Indoor_LN_33%) ELSE(0)

CCLVV_Indoor__Linear = IF(TIME > 2008)

THEN(0.493+RAMP(CCLVV_Future, 2008))

ELSE(CCLVV_Indoor__Historic)

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CCLVV_Outdoor_Fraction = IF(Indoor_Outdoor_Choice = 1)

THEN(CCLVV_Outdoor_LN_1) ELSE IF(Indoor_Outdoor_Choice = 2)

THEN(CCLVV_Outdoor_50%_LN) ELSE IF(Indoor_Outdoor_Choice = 3)

THEN(CCLVV_Outdoor_LN_3) ELSE IF(Indoor_Outdoor_Choice = 4)

THEN(CCLVV_Outdoor_Linear) ELSE IF(Indoor_Outdoor_Choice = 5)

THEN(CCLVV_Outdoor_LN_66%) ELSE(0)

CCLVV_Outdoor_Linear = IF(TIME > 2008) THEN(0.507-

RAMP(CCLVV_Future,2008)) ELSE(CCLVV_Outdoor_Historic)

CCLVV_Sewage_Ratio = 1

CCLVV__Fraction_Runoff = 0.043818654

CCLVV__Fraction__Seeping_to_Wash = 0.057825504

ERP_Fraction_to_Reuse = 0

Sewage_Fraction_to_ERP = 0

Sum_CCLVV__Indoor_Fraction =

CCWRP_Fraction_to_Reuse+CCWRP_Wash_Fraction+Sewage_Fraction_to

_DBRP+Sewage_Fraction_to_ERP

Sum_CCLVV__Outdoor_Fraction =

CCLVV_Evaporation_Fraction+CCLVV_Fraction__Seeping_to_GW+CCLVV

__Fraction_Runoff+CCLVV__Fraction__Seeping_to_Wash

CCLVVIndoor_50%_LN = GRAPH(TIME)

(1993, 0.412), (1994, 0.428), (1995, 0.456), (1996, 0.481), (1997, 0.439),

(1998, 0.452), (1999, 0.463), (2000, 0.434), (2001, 0.427), (2002, 0.441),

(2003, 0.485), (2004, 0.516), (2005, 0.537), (2006, 0.513), (2007, 0.504),

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(2008, 0.493), (2009, 0.493), (2010, 0.493), (2011, 0.493), (2012, 0.494),

(2013, 0.494), (2014, 0.494), (2015, 0.494), (2016, 0.494), (2017, 0.494),

(2018, 0.494), (2019, 0.494), (2020, 0.494), (2021, 0.494), (2022, 0.494),

(2023, 0.494), (2024, 0.494), (2025, 0.494), (2026, 0.494), (2027, 0.494),

(2028, 0.494), (2029, 0.494), (2030, 0.494), (2031, 0.494), (2032, 0.494),

(2033, 0.494), (2034, 0.494), (2035, 0.494)

CCLVV_Indoor_LN_1 = GRAPH(TIME)

(1993, 0.412), (1994, 0.428), (1995, 0.456), (1996, 0.481), (1997, 0.439),

(1998, 0.452), (1999, 0.463), (2000, 0.434), (2001, 0.427), (2002, 0.441),

(2003, 0.485), (2004, 0.516), (2005, 0.537), (2006, 0.513), (2007, 0.504),

(2008, 0.493), (2009, 0.514), (2010, 0.526), (2011, 0.535), (2012, 0.542),

(2013, 0.547), (2014, 0.552), (2015, 0.556), (2016, 0.56), (2017, 0.563),

(2018, 0.566), (2019, 0.568), (2020, 0.571), (2021, 0.573), (2022, 0.575),

(2023, 0.577), (2024, 0.579), (2025, 0.581), (2026, 0.582), (2027, 0.584),

(2028, 0.585), (2029, 0.587), (2030, 0.588), (2031, 0.589), (2032, 0.591),

(2033, 0.592), (2034, 0.593), (2035, 0.594)

CCLVV_Indoor_LN_3 = GRAPH(TIME)

(1993, 0.412), (1994, 0.428), (1995, 0.456), (1996, 0.481), (1997, 0.439),

(1998, 0.452), (1999, 0.463), (2000, 0.434), (2001, 0.427), (2002, 0.441),

(2003, 0.485), (2004, 0.516), (2005, 0.537), (2006, 0.513), (2007, 0.504),

(2008, 0.493), (2009, 0.472), (2010, 0.46), (2011, 0.452), (2012, 0.445),

(2013, 0.439), (2014, 0.435), (2015, 0.431), (2016, 0.427), (2017, 0.424),

(2018, 0.421), (2019, 0.419), (2020, 0.416), (2021, 0.414), (2022, 0.412),

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(2023, 0.41), (2024, 0.408), (2025, 0.406), (2026, 0.405), (2027, 0.403),

(2028, 0.402), (2029, 0.4), (2030, 0.399), (2031, 0.398), (2032, 0.397),

(2033, 0.395), (2034, 0.394), (2035, 0.393)

CCLVV_Indoor__Historic = GRAPH(TIME)

(1993, 0.412), (1994, 0.428), (1995, 0.456), (1996, 0.481), (1997, 0.439),

(1998, 0.452), (1999, 0.463), (2000, 0.434), (2001, 0.427), (2002, 0.441),

(2003, 0.485), (2004, 0.516), (2005, 0.537), (2006, 0.513), (2007, 0.504),

(2008, 0.493), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00),

(2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018,

0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00),

(2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029,

0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00),

(2035, 0.00)

CCLVV_Outdoor_50%_LN = GRAPH(TIME)

(1993, 0.588), (1994, 0.572), (1995, 0.544), (1996, 0.519), (1997, 0.561),

(1998, 0.548), (1999, 0.537), (2000, 0.566), (2001, 0.573), (2002, 0.559),

(2003, 0.515), (2004, 0.484), (2005, 0.463), (2006, 0.487), (2007, 0.496),

(2008, 0.507), (2009, 0.507), (2010, 0.507), (2011, 0.507), (2012, 0.506),

(2013, 0.506), (2014, 0.506), (2015, 0.506), (2016, 0.506), (2017, 0.506),

(2018, 0.506), (2019, 0.506), (2020, 0.506), (2021, 0.506), (2022, 0.506),

(2023, 0.506), (2024, 0.506), (2025, 0.506), (2026, 0.506), (2027, 0.506),

(2028, 0.506), (2029, 0.506), (2030, 0.506), (2031, 0.506), (2032, 0.506),

(2033, 0.506), (2034, 0.506), (2035, 0.506)

CCLVV_Outdoor_Historic = GRAPH(TIME)

(1993, 0.588), (1994, 0.572), (1995, 0.544), (1996, 0.519), (1997, 0.561),

(1998, 0.548), (1999, 0.537), (2000, 0.566), (2001, 0.573), (2002, 0.559),

(2003, 0.515), (2004, 0.484), (2005, 0.463), (2006, 0.487), (2007, 0.496),

(2008, 0.507), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00),

(2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018,

0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00),

(2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029,

0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00),

(2035, 0.00)

CCLVV_Outdoor_LN_1 = GRAPH(TIME)

(1993, 0.588), (1994, 0.572), (1995, 0.544), (1996, 0.519), (1997, 0.561),

(1998, 0.548), (1999, 0.537), (2000, 0.566), (2001, 0.573), (2002, 0.559),

(2003, 0.515), (2004, 0.484), (2005, 0.463), (2006, 0.487), (2007, 0.496),

(2008, 0.507), (2009, 0.486), (2010, 0.474), (2011, 0.465), (2012, 0.458),

(2013, 0.453), (2014, 0.448), (2015, 0.444), (2016, 0.44), (2017, 0.437),

(2018, 0.434), (2019, 0.432), (2020, 0.429), (2021, 0.427), (2022, 0.425),

(2023, 0.423), (2024, 0.421), (2025, 0.419), (2026, 0.418), (2027, 0.416),

(2028, 0.415), (2029, 0.413), (2030, 0.412), (2031, 0.411), (2032, 0.409),

(2033, 0.408), (2034, 0.407), (2035, 0.406)

CCLVV_Outdoor_LN_3 = GRAPH(TIME)

(1993, 0.588), (1994, 0.572), (1995, 0.544), (1996, 0.519), (1997, 0.561),

(1998, 0.548), (1999, 0.537), (2000, 0.566), (2001, 0.573), (2002, 0.559),

(2003, 0.515), (2004, 0.484), (2005, 0.463), (2006, 0.487), (2007, 0.496),

(2008, 0.507), (2009, 0.528), (2010, 0.54), (2011, 0.548), (2012, 0.555),

(2013, 0.561), (2014, 0.565), (2015, 0.569), (2016, 0.573), (2017, 0.576),

(2018, 0.579), (2019, 0.581), (2020, 0.584), (2021, 0.586), (2022, 0.588),

(2023, 0.59), (2024, 0.592), (2025, 0.594), (2026, 0.595), (2027, 0.597),

(2028, 0.598), (2029, 0.6), (2030, 0.601), (2031, 0.602), (2032, 0.603),

(2033, 0.605), (2034, 0.606), (2035, 0.607)

CCLVV_Outdoor_LN_66% = GRAPH(TIME)

(1993, 0.588), (1994, 0.572), (1995, 0.544), (1996, 0.519), (1997, 0.561),

(1998, 0.548), (1999, 0.537), (2000, 0.566), (2001, 0.573), (2002, 0.559),

(2003, 0.515), (2004, 0.484), (2005, 0.463), (2006, 0.487), (2007, 0.496),

(2008, 0.507), (2009, 0.499), (2010, 0.495), (2011, 0.492), (2012, 0.489),

(2013, 0.487), (2014, 0.486), (2015, 0.484), (2016, 0.483), (2017, 0.482),

(2018, 0.481), (2019, 0.48), (2020, 0.479), (2021, 0.478), (2022, 0.477),

(2023, 0.477), (2024, 0.476), (2025, 0.475), (2026, 0.475), (2027, 0.474),

(2028, 0.474), (2029, 0.473), (2030, 0.473), (2031, 0.472), (2032, 0.472),

(2033, 0.471), (2034, 0.471), (2035, 0.471)

CCPLV_Indoor_LN_33% = GRAPH(TIME)

(1993, 0.412), (1994, 0.428), (1995, 0.456), (1996, 0.481), (1997, 0.439),

(1998, 0.452), (1999, 0.463), (2000, 0.434), (2001, 0.427), (2002, 0.441),

(2003, 0.485), (2004, 0.516), (2005, 0.537), (2006, 0.513), (2007, 0.504),

(2008, 0.493), (2009, 0.501), (2010, 0.505), (2011, 0.508), (2012, 0.511),

(2013, 0.513), (2014, 0.514), (2015, 0.516), (2016, 0.517), (2017, 0.518),

(2018, 0.519), (2019, 0.52), (2020, 0.521), (2021, 0.522), (2022, 0.523),

(2023, 0.523), (2024, 0.524), (2025, 0.525), (2026, 0.525), (2027, 0.526),

(2028, 0.526), (2029, 0.527), (2030, 0.527), (2031, 0.528), (2032, 0.528),

(2033, 0.529), (2034, 0.529), (2035, 0.529)

CCWRP_Fraction_to_Reuse = GRAPH(TIME)

(1992, 0.0284), (1993, 0.0354), (1994, 0.0595), (1995, 0.064), (1996, 0.0822), (1997, 0.0921), (1998, 0.0809), (1999, 0.0593), (2000, 0.0656), (2001, 0.0627), (2002, 0.0657), (2003, 0.0594), (2004, 0.0679), (2005, 0.078), (2006, 0.0797), (2007, 0.0819), (2008, 0.0711), (2009, 0.0711), (2010, 0.0711), (2011, 0.0711), (2012, 0.0711), (2013, 0.0711), (2014, 0.0711), (2015, 0.0711), (2016, 0.0711), (2017, 0.0711), (2018, 0.0711), (2019, 0.0711), (2020, 0.0711), (2021, 0.0711), (2022, 0.0711), (2023, 0.0711), (2024, 0.0711), (2025, 0.0711), (2026, 0.0711), (2027, 0.0711), (2028, 0.0711), (2029, 0.0711), (2030, 0.0711), (2031, 0.0711), (2032, 0.0711), (2033, 0.0711), (2034, 0.0711), (2035, 0.0711)

CCWRP_Wash_Fraction = GRAPH(TIME)

(1992, 0.972), (1993, 0.965), (1994, 0.941), (1995, 0.936), (1996, 0.918), (1997, 0.908), (1998, 0.919), (1999, 0.941), (2000, 0.934), (2001, 0.937), (2002, 0.934), (2003, 0.935), (2004, 0.906), (2005, 0.895), (2006, 0.892), (2007, 0.888), (2008, 0.894), (2009, 0.894), (2010, 0.894), (2011, 0.894), (2012, 0.894), (2013, 0.894), (2014, 0.894), (2015, 0.894), (2016, 0.894), (2017, 0.894), (2018, 0.894), (2019, 0.894), (2020, 0.894), (2021, 0.894), (2022, 0.894), (2023, 0.894), (2024, 0.894), (2025, 0.894), (2026, 0.894),

(2027, 0.894), (2028, 0.894), (2029, 0.894), (2030, 0.894), (2031, 0.894),

(2032, 0.894), (2033, 0.894), (2034, 0.894), (2035, 0.894)

DBRP_Fraction__to_Reuse = GRAPH(TIME)

(1992, 0.00), (1993, 0.00), (1994, 0.00), (1995, 0.00), (1996, 0.00), (1997,

0.00), (1998, 0.00), (1999, 0.00), (2000, 0.00), (2001, 0.00), (2002, 0.00),

(2003, 0.00591), (2004, 0.0265), (2005, 0.0269), (2006, 0.0285), (2007,

0.0297), (2008, 0.0345)

Sewage_Fraction_to_DBRP = GRAPH(TIME)

(1992, 0.00), (1993, 0.00), (1994, 0.00), (1995, 0.00), (1996, 0.00), (1997,

0.00), (1998, 0.00), (1999, 0.00), (2000, 0.00), (2001, 0.00), (2002, 0.00),

(2003, 0.00591), (2004, 0.0265), (2005, 0.0269), (2006, 0.0285), (2007,

0.0297), (2008, 0.0345), (2009, 0.0345), (2010, 0.0345), (2011, 0.0345),

(2012, 0.0345), (2013, 0.0345), (2014, 0.0345), (2015, 0.0345), (2016,

0.0345), (2017, 0.0345), (2018, 0.0345), (2019, 0.0345), (2020, 0.0345),

(2021, 0.0345), (2022, 0.0345), (2023, 0.0345), (2024, 0.0345), (2025,

0.0345), (2026, 0.0345), (2027, 0.0345), (2028, 0.0345), (2029, 0.0345),

(2030, 0.0345), (2031, 0.0345), (2032, 0.0345), (2033, 0.0345), (2034,

0.0345), (2035, 0.0345)

Demand Sector

Pop_Stock[City_of_Henderson_Net_In](t) =

Pop_Stock[City_of_Henderson_Net_In](t - dt) +

(Population_In[City_of_Henderson_Net_In]) * dt

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INIT Pop_Stock[City_of_Henderson_Net_In] = 86531

Pop_Stock[City_of_Las_Vegas_Net_In](t) =

Pop_Stock[City_of_Las_Vegas_Net_In](t - dt) +

(Population_In[City_of_Las_Vegas_Net_In]) * dt

INIT Pop_Stock[City_of_Las_Vegas_Net_In] = 311593

Pop_Stock[Clark_County_Portion_Net_In](t) =

Pop_Stock[Clark_County_Portion_Net_In](t - dt) +

(Population_In[Clark_County_Portion_Net_In]) * dt

INIT Pop_Stock[Clark_County_Portion_Net_In] = 368356

Pop_Stock[City_of_North_Las_Vegas_Net_In](t) =

Pop_Stock[City_of_North_Las_Vegas_Net_In](t - dt) +

(Population_In[City_of_North_Las_Vegas_Net_In]) * dt

INIT Pop_Stock[City_of_North_Las_Vegas_Net_In] = 55615

Pop_Stock[Nellis_AFB_Net_In](t) = Pop_Stock[Nellis_AFB_Net_In](t - dt) +

(Population_In[Nellis_AFB_Net_In]) * dt

INIT Pop_Stock[Nellis_AFB_Net_In] = 7476

Pop_Stock[Boulder_City_Net_In](t) = Pop_Stock[Boulder_City_Net_In](t -

dt) + (Population_In[Boulder_City_Net_In]) * dt

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INIT Pop_Stock[Boulder_City_Net_In] = 13213

INFLOWS:

Population_In[Cities] = Scenario_Rate[Cities]*Pop_Stock[Cities]

Adjusted__Withdrawl = Withdrawing_Water-

Consumptive_use_Exceedence

Average_per_capita_199_gpcd_natural_log[Cities] = TIME

CBER_Rate[Cities] = TIME

CBER_Rate_Change[City_of_Henderson_Net_In] = 0

CBER_Rate_Change[City_of_Las_Vegas_Net_In] = 0

CBER_Rate_Change[Clark_County_Portion_Net_In] = 0

CBER_Rate_Change[City_of_North_Las_Vegas_Net_In] = 0

CBER_Rate_Change[Nellis_AFB_Net_In] = 0

CBER_Rate_Change[Boulder_City_Net_In] = 0

Consumptive_use_Exceedence = IF(Colorado_river__Outdoor_Portion-

Colorado_river) <= 0 THEN(0) ELSE(Colorado_river__Outdoor_Portion-

Colorado_river)

Demand_Reduction_due_to_Reuse[Cities] = TIME

new_per_capita__demand_linear[Cities] = TIME

Per_capita_199__gpcd_natural_log[Cities] = TIME

Per_capita_demand_choice = 4

Per_capita_demand__2008_level[Cities] = TIME

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Reuse_Adjusted_Water_Demand[Cities] = Water_Demand[Cities]-

Demand_Reduction_due_to_Reuse[Cities]

Scenario_Rate[Cities] = IF(TIME > 2008)

THEN(CBER_Rate[Cities]+CBER_Rate_Change[Cities])

ELSE(CBER_Rate[Cities])

Total_Population = ARRAYSUM(Pop_Stock[*])

Water_Demand[Cities] = IF(Per_capita_demand_choice = 1)

THEN(Pop_Stock[Cities]*Per_capita_199__gpcd_natural_log[Cities]/10000

00) ELSE IF(Per_capita_demand_choice = 2)

THEN(Pop_Stock[Cities]*Per_capita_demand__2008_level[Cities]/1000000

) ELSE IF(Per_capita_demand_choice = 3)

THEN(Pop_Stock[Cities]*new_per_capita__demand_linear[Cities]/100000

0) ELSE IF(Per_capita_demand_choice = 4)

THEN(Pop_Stock[Cities]*Average_per_capita_199_gpcd_natural_log[Cities]

/1000000) ELSE(0)

Withdrawing_Water = IF((ARRAYSUM(Reuse_Adjusted_Water_Demand[*]))

< (Colorado_river+LV_Wash_Outflow+Total_Wells_Supply))

THEN((ARRAYSUM(Reuse_Adjusted_Water_Demand[*]))-

(Total_Wells_Supply)) ELSE(Colorado_river+LV_Wash_Outflow)

Average_per_capita_199_gpcd_natural_log[Cities] = TIME

CBER_Rate[Cities] = TIME

Demand_Reduction_due_to_Reuse[Cities] = TIME

new_per_capita__demand_linear[Cities] = TIME

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Per_capita_199__gpcd_natural_log[Cities] = TIME

Per_capita_demand__2008_level[Cities] = TIME

Nellis Air Force Base

Nellis_AFB(t) = Nellis_AFB(t - dt) + (To_Nellis_AFB -

To_Nellis_AFB__Outdoor - To_Nellis_AFB__Indoor) * dt

INIT Nellis_AFB = 5

INFLOWS:

To_Nellis_AFB =

Nellis_AFB__Distribution_System*Nellis_AFB__Supply_Ratio

OUTFLOWS:

To_Nellis_AFB__Outdoor = Nellis_AFB*NAFB_Outdoor__Fraction

To_Nellis_AFB__Indoor = Nellis_AFB*NAFB_Indoor_Fraction

Nellis_AFB_Indoor(t) = Nellis_AFB_Indoor(t - dt) + (To_Nellis_AFB__Indoor

- Nellis_AFB_Sewage_to_CCWRP - To_Nellis_AFB__Ponds -

Nellis_AFB_Sewage_to__COLV_WWTP) * dt

INIT Nellis_AFB_Indoor = 2

INFLOWS:

To_Nellis_AFB__Indoor = Nellis_AFB*NAFB_Indoor_Fraction

OUTFLOWS:

Nellis_AFB_Sewage_to_CCWRP =

Nellis_AFB_Indoor*Nellis_AFB_CCWRP_Sewage_Ratio

To_Nellis_AFB__Ponds = Nellis_AFB_Indoor*Nellis_AFB__Ponds_Ratio

Nellis_AFB_Sewage_to__COLV_WWTP   (IN SECTOR: City of North

Las Vegas)

Nellis_AFB_Outdoor(t) = Nellis_AFB_Outdoor(t - dt) +

(To_Nellis_AFB__Outdoor - Total_NAFB_Outdoor) * dt

INIT Nellis_AFB_Outdoor = 2

INFLOWS:

To_Nellis_AFB__Outdoor = Nellis_AFB*NAFB_Outdoor__Fraction

OUTFLOWS:

Total_NAFB_Outdoor (Not in a sector)

Nellis_AFB_Ponds(t) = Nellis_AFB_Ponds(t - dt) + (To_Nellis_AFB__Ponds)

* dt

INIT Nellis_AFB_Ponds = Initial_Reclamation_Plants_Human_Use_Ponds

INFLOWS:

To_Nellis_AFB__Ponds = Nellis_AFB_Indoor*Nellis_AFB__Ponds_Ratio

NAFB_Future = (0.761-(0.761-(0.761*Future_Rate)))/27

NAFB_Indoor_Fraction = IF(Indoor_Outdoor_Choice = 1)

THEN(NAFB_Indoor_LN_1) ELSE IF(Indoor_Outdoor_Choice = 2)

THEN(NAFB_Indoor_50%_LN) ELSE IF(Indoor_Outdoor_Choice = 3)

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THEN(NAFB_Indoor_LN_3) ELSE IF(Indoor_Outdoor_Choice = 4)

THEN(NAFB_Indoor_Linear) ELSE IF(Indoor_Outdoor_Choice = 5)

THEN(NAFB_Indoor_LN_33%) ELSE(0)

NAFB_Indoor_Linear = IF(TIME > 2008)

THEN(0.239+RAMP(NAFB_Future,2008)) ELSE(NAFB_Indoor__Historic)

NAFB_Outdoor_Linear = IF(TIME > 2008) THEN(0.761-

RAMP(NAFB_Future,2008)) ELSE(NAFB_Outdoor_Historic)

NAFB_Outdoor__Fraction = IF(Indoor_Outdoor_Choice =1)

THEN(NAFB_Outdoor_LN_1) ELSE IF(Indoor_Outdoor_Choice = 2)

THEN(NAFB_Outdoor_50%_LN) ELSE IF(Indoor_Outdoor_Choice = 3)

THEN(NAFB_Outdoor_LN_3) ELSE IF(Indoor_Outdoor_Choice = 4)

THEN(NAFB_Outdoor_Linear) ELSE IF(Indoor_Outdoor_Choice = 5)

THEN(NAFB_Outdoor_LN_66%) ELSE(0)

Nellis_AFB_CCWRP_Sewage_Ratio = 1

Nellis_AFB_Fraction_Runoff = 0.043818654

Nellis_AFB_Fraction__Seeping_to_GW = 0.662034159

Nellis_AFB__Ponds_Ratio = 0

Nellis_AFB__Supply_Ratio = 1

Sum_Nellis_AFB__Indoor_Fraction =

Nellis_AFB_CCWRP_Sewage_Ratio+Nellis_AFB__Ponds_Ratio+Nellis_AFB_

COLV__Sewage_Ratio

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Sum_Nellis_AFB__Outdoor_Fraction =

Nellis_AFB_Fraction_Runoff+Nellis_AFB_Evaporation_Fraction+Nellis_AF

B_Fraction_Seeping_to_Wash+Nellis_AFB_Fraction__Seeping_to_GW

NAFB_Indoor_50%_LN = GRAPH(TIME)

(1993, 0.318), (1994, 0.19), (1995, 0.21), (1996, 0.18), (1997, 0.19),

(1998, 0.233), (1999, 0.2), (2000, 0.225), (2001, 0.23), (2002, 0.193),

(2003, 0.248), (2004, 0.266), (2005, 0.218), (2006, 0.204), (2007, 0.209),

(2008, 0.239), (2009, 0.251), (2010, 0.258), (2011, 0.262), (2012, 0.266),

(2013, 0.269), (2014, 0.271), (2015, 0.273), (2016, 0.275), (2017, 0.277),

(2018, 0.278), (2019, 0.28), (2020, 0.281), (2021, 0.282), (2022, 0.283),

(2023, 0.284), (2024, 0.285), (2025, 0.286), (2026, 0.287), (2027, 0.288),

(2028, 0.289), (2029, 0.289), (2030, 0.29), (2031, 0.291), (2032, 0.292),

(2033, 0.292), (2034, 0.293), (2035, 0.293)

NAFB_Indoor_LN_1 = GRAPH(TIME)

(1993, 0.318), (1994, 0.19), (1995, 0.21), (1996, 0.18), (1997, 0.19),

(1998, 0.233), (1999, 0.2), (2000, 0.225), (2001, 0.23), (2002, 0.193),

(2003, 0.248), (2004, 0.266), (2005, 0.218), (2006, 0.204), (2007, 0.209),

(2008, 0.239), (2009, 0.271), (2010, 0.289), (2011, 0.302), (2012, 0.313),

(2013, 0.321), (2014, 0.328), (2015, 0.334), (2016, 0.339), (2017, 0.344),

(2018, 0.348), (2019, 0.352), (2020, 0.356), (2021, 0.359), (2022, 0.362),

(2023, 0.365), (2024, 0.368), (2025, 0.371), (2026, 0.373), (2027, 0.375),

(2028, 0.378), (2029, 0.38), (2030, 0.382), (2031, 0.384), (2032, 0.386),

(2033, 0.387), (2034, 0.389), (2035, 0.391)

NAFB_Indoor_LN_3 = GRAPH(TIME)

(1993, 0.318), (1994, 0.19), (1995, 0.21), (1996, 0.18), (1997, 0.19),

(1998, 0.233), (1999, 0.2), (2000, 0.225), (2001, 0.23), (2002, 0.193),

(2003, 0.248), (2004, 0.266), (2005, 0.218), (2006, 0.204), (2007, 0.209),

(2008, 0.239), (2009, 0.23), (2010, 0.224), (2011, 0.22), (2012, 0.217),

(2013, 0.214), (2014, 0.212), (2015, 0.21), (2016, 0.209), (2017, 0.207),

(2018, 0.206), (2019, 0.205), (2020, 0.203), (2021, 0.202), (2022, 0.201),

(2023, 0.201), (2024, 0.2), (2025, 0.199), (2026, 0.198), (2027, 0.197),

(2028, 0.197), (2029, 0.196), (2030, 0.196), (2031, 0.195), (2032, 0.194),

(2033, 0.194), (2034, 0.193), (2035, 0.193)

NAFB_Indoor_LN_33% = GRAPH(TIME)

(1993, 0.318), (1994, 0.19), (1995, 0.21), (1996, 0.18), (1997, 0.19),

(1998, 0.233), (1999, 0.2), (2000, 0.225), (2001, 0.23), (2002, 0.193),

(2003, 0.248), (2004, 0.266), (2005, 0.218), (2006, 0.204), (2007, 0.209),

(2008, 0.239), (2009, 0.257), (2010, 0.268), (2011, 0.275), (2012, 0.28),

(2013, 0.285), (2014, 0.289), (2015, 0.292), (2016, 0.295), (2017, 0.298),

(2018, 0.3), (2019, 0.302), (2020, 0.305), (2021, 0.306), (2022, 0.308),

(2023, 0.31), (2024, 0.311), (2025, 0.313), (2026, 0.314), (2027, 0.315),

(2028, 0.317), (2029, 0.318), (2030, 0.319), (2031, 0.32), (2032, 0.321),

(2033, 0.322), (2034, 0.323), (2035, 0.324)

NAFB_Indoor__Historic = GRAPH(TIME)

(1993, 0.318), (1994, 0.19), (1995, 0.21), (1996, 0.18), (1997, 0.19),

(1998, 0.233), (1999, 0.2), (2000, 0.225), (2001, 0.23), (2002, 0.193),

(2003, 0.248), (2004, 0.266), (2005, 0.218), (2006, 0.204), (2007, 0.209),

(2008, 0.239), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00),

(2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018,

0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00),

(2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029,

0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00),

(2035, 0.00)

NAFB_Outdoor_50%_LN = GRAPH(TIME)

(1993, 0.682), (1994, 0.81), (1995, 0.79), (1996, 0.82), (1997, 0.81),

(1998, 0.767), (1999, 0.8), (2000, 0.775), (2001, 0.77), (2002, 0.807),

(2003, 0.752), (2004, 0.734), (2005, 0.782), (2006, 0.796), (2007, 0.791),

(2008, 0.761), (2009, 0.749), (2010, 0.742), (2011, 0.738), (2012, 0.734),

(2013, 0.731), (2014, 0.729), (2015, 0.727), (2016, 0.725), (2017, 0.723),

(2018, 0.722), (2019, 0.72), (2020, 0.719), (2021, 0.718), (2022, 0.717),

(2023, 0.716), (2024, 0.715), (2025, 0.714), (2026, 0.713), (2027, 0.712),

(2028, 0.711), (2029, 0.711), (2030, 0.71), (2031, 0.709), (2032, 0.708),

(2033, 0.708), (2034, 0.707), (2035, 0.707)

NAFB_Outdoor_Historic = GRAPH(TIME)

(1993, 0.682), (1994, 0.81), (1995, 0.79), (1996, 0.82), (1997, 0.81),

(1998, 0.767), (1999, 0.8), (2000, 0.775), (2001, 0.77), (2002, 0.807),

(2003, 0.752), (2004, 0.734), (2005, 0.782), (2006, 0.796), (2007, 0.791),

(2008, 0.761), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00),

(2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018,

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0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00),

(2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029,

0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00),

(2035, 0.00)

NAFB_Outdoor_LN_1 = GRAPH(TIME)

(1993, 0.682), (1994, 0.81), (1995, 0.79), (1996, 0.82), (1997, 0.81),

(1998, 0.767), (1999, 0.8), (2000, 0.775), (2001, 0.77), (2002, 0.807),

(2003, 0.752), (2004, 0.734), (2005, 0.782), (2006, 0.796), (2007, 0.791),

(2008, 0.761), (2009, 0.729), (2010, 0.711), (2011, 0.698), (2012, 0.687),

(2013, 0.679), (2014, 0.672), (2015, 0.666), (2016, 0.661), (2017, 0.656),

(2018, 0.652), (2019, 0.648), (2020, 0.644), (2021, 0.641), (2022, 0.638),

(2023, 0.635), (2024, 0.632), (2025, 0.629), (2026, 0.627), (2027, 0.625),

(2028, 0.622), (2029, 0.62), (2030, 0.618), (2031, 0.616), (2032, 0.614),

(2033, 0.613), (2034, 0.611), (2035, 0.609)

NAFB_Outdoor_LN_3 = GRAPH(TIME)

(1993, 0.682), (1994, 0.81), (1995, 0.79), (1996, 0.82), (1997, 0.81),

(1998, 0.767), (1999, 0.8), (2000, 0.775), (2001, 0.77), (2002, 0.807),

(2003, 0.752), (2004, 0.734), (2005, 0.782), (2006, 0.796), (2007, 0.791),

(2008, 0.761), (2009, 0.77), (2010, 0.776), (2011, 0.78), (2012, 0.783),

(2013, 0.786), (2014, 0.788), (2015, 0.79), (2016, 0.791), (2017, 0.793),

(2018, 0.794), (2019, 0.795), (2020, 0.797), (2021, 0.798), (2022, 0.799),

(2023, 0.799), (2024, 0.8), (2025, 0.801), (2026, 0.802), (2027, 0.803),

(2028, 0.803), (2029, 0.804), (2030, 0.804), (2031, 0.805), (2032, 0.806),

(2033, 0.806), (2034, 0.807), (2035, 0.807)

NAFB_Outdoor_LN_66% = GRAPH(TIME)

(1993, 0.682), (1994, 0.81), (1995, 0.79), (1996, 0.82), (1997, 0.81),

(1998, 0.767), (1999, 0.8), (2000, 0.775), (2001, 0.77), (2002, 0.807),

(2003, 0.752), (2004, 0.734), (2005, 0.782), (2006, 0.796), (2007, 0.791),

(2008, 0.761), (2009, 0.743), (2010, 0.732), (2011, 0.725), (2012, 0.72),

(2013, 0.715), (2014, 0.711), (2015, 0.708), (2016, 0.705), (2017, 0.702),

(2018, 0.7), (2019, 0.698), (2020, 0.695), (2021, 0.694), (2022, 0.692),

(2023, 0.69), (2024, 0.689), (2025, 0.687), (2026, 0.686), (2027, 0.685),

(2028, 0.683), (2029, 0.682), (2030, 0.681), (2031, 0.68), (2032, 0.679),

(2033, 0.678), (2034, 0.677), (2035, 0.676)

Not in a sector

Alfred_Merrit_Smith_WTF(t) = Alfred_Merrit_Smith_WTF(t - dt) +

(AMSWTF__Withdrawl - AMSWTF__Supply) * dt

INIT Alfred_Merrit_Smith_WTF = 200

INFLOWS:

AMSWTF__Withdrawl = (Adjusted__Withdrawl/2)-(BMI_to_COH/2)

OUTFLOWS:

AMSWTF__Supply = Alfred_Merrit_Smith_WTF*AMSWTF__Efficiency

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BMI(t) = BMI(t - dt) + (BMI_Withdrawl - Cooling_Water - Lake_Las_Vegas

- BMI_to_COH) * dt

INIT BMI = 10

INFLOWS:

BMI_Withdrawl = GRAPH(TIME)

(1992, 14.5), (1993, 13.3), (1994, 16.7), (1995, 17.6), (1996, 19.6), (1997,

17.2), (1998, 18.3), (1999, 16.4), (2000, 17.7), (2001, 17.6), (2002, 17.6),

(2003, 14.7), (2004, 17.6), (2005, 17.2), (2006, 19.9), (2007, 18.7), (2008,

18.8), (2009, 18.8), (2010, 18.8), (2011, 18.8), (2012, 18.8), (2013, 18.8),

(2014, 18.8), (2015, 18.8), (2016, 18.8), (2017, 18.8), (2018, 18.8), (2019,

18.8), (2020, 18.8), (2021, 18.8), (2022, 18.8), (2023, 18.8), (2024, 18.8),

(2025, 18.8), (2026, 18.8), (2027, 18.8), (2028, 18.8), (2029, 18.8), (2030,

18.8), (2031, 18.8), (2032, 18.8), (2033, 18.8), (2034, 18.8), (2035, 18.8)

OUTFLOWS:

Cooling_Water = 6

Lake_Las_Vegas = 4

BMI_to_COH = BMI*BMI_to__COH_Ratio

Boulder_City_Distribution_System(t) =

Boulder_City_Distribution_System(t - dt) + (To_Boulder_City -

Boulder_City_Supply - Boulder_CIty_Leakage) * dt

INIT Boulder_City_Distribution_System = 5

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INFLOWS:

To_Boulder_City = Reuse_Adjusted_Water_Demand[Boulder_City_Net_In]

OUTFLOWS:

Boulder_City_Supply =

Boulder_City_Distribution_System*BC_Supply_Ratio

Boulder_CIty_Leakage =

Boulder_City_Distribution_System*BC_Leakage_Ratio

COH(t) = COH(t - dt) + (To_COH - To_COH_Outdoor - To_COH_Indoor) *

dt

INIT COH = Initial_City_In_Out_Outdoor_Stocks

INFLOWS:

To_COH = COH_Distribution_System*COH_Supply_Ratio

OUTFLOWS:

To_COH_Outdoor = COH*COH_Outdoor_Fraction

To_COH_Indoor = COH*COH_Indoor_Fraction

COH_Distribution_System(t) = COH_Distribution_System(t - dt) +

(To_COH_System_from_TW + COH_Supply_from_BMI - To_COH -

COH_Leakage) * dt

INIT COH_Distribution_System = 30

INFLOWS:

To_COH_System_from_TW =

Reuse_Adjusted_Water_Demand[City_of_Henderson_Net_In]-BMI_to_COH

COH_Supply_from_BMI = COH_WTP*COH_WTP__Efficiency

OUTFLOWS:

To_COH = COH_Distribution_System*COH_Supply_Ratio

COH_Leakage = COH_Distribution_System*COH_Leakage__Ratio

COH_Indoor(t) = COH_Indoor(t - dt) + (To_COH_Indoor - COH__Sewage) *

dt

INIT COH_Indoor = 15

INFLOWS:

To_COH_Indoor = COH*COH_Indoor_Fraction

OUTFLOWS:

COH__Sewage = COH_Indoor*COH_Sewage__Ratio

COH_Outdoor(t) = COH_Outdoor(t - dt) + (To_COH_Outdoor -

Total_COH_Outdoor) * dt

INIT COH_Outdoor = Initial_City_In_Out_Outdoor_Stocks

INFLOWS:

To_COH_Outdoor = COH*COH_Outdoor_Fraction

OUTFLOWS:

Total_COH_Outdoor = COH_Outdoor*COH_Outdoor__Rate

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COH_Ponds(t) = COH_Ponds(t - dt) + (COH_Effluent__to_Ponds -

COH_Ponds__seepage_to_Wash) * dt

INIT COH_Ponds = Initial_Reclamation_Plants_Human_Use_Ponds

INFLOWS:

COH_Effluent__to_Ponds = GRAPH(TIME)

(1993, 3.69), (1994, 3.28), (1995, 5.08), (1996, 4.85), (1997, 1.99), (1998,

2.54), (1999, 1.13), (2000, 4.73), (2001, 5.07), (2002, 4.93), (2003, 6.46),

(2004, 5.49), (2005, 3.14), (2006, 2.94), (2007, 1.60), (2008, 1.50), (2009,

1.50), (2010, 1.50), (2011, 1.50), (2012, 1.50), (2013, 1.50), (2014, 1.50),

(2015, 1.50), (2016, 1.50), (2017, 1.50), (2018, 1.50), (2019, 1.50), (2020,

1.50), (2021, 1.50), (2022, 1.50), (2023, 1.50), (2024, 1.50), (2025, 1.50),

(2026, 1.50), (2027, 1.50), (2028, 1.50), (2029, 1.50), (2030, 1.50), (2031,

1.50), (2032, 1.50), (2033, 1.50), (2034, 1.50), (2035, 1.50)

OUTFLOWS:

COH_Ponds__seepage_to_Wash   (IN SECTOR: Clark County Portion)

COH_WTP(t) = COH_WTP(t - dt) + (BMI_to_COH - COH_Supply_from_BMI)

* dt

INIT COH_WTP = 10

INFLOWS:

BMI_to_COH = BMI*BMI_to__COH_Ratio

OUTFLOWS:

149

COH_Supply_from_BMI = COH_WTP*COH_WTP__Efficiency

COH_WWTP(t) = COH_WWTP(t - dt) + (COH__Sewage -

COH_Effluent__to_Ponds - COH_WWTP__Effluent_to_Wash -

COH_Effluent__to_Reuse) * dt

INIT COH_WWTP = 8

INFLOWS:

COH__Sewage = COH_Indoor*COH_Sewage__Ratio

OUTFLOWS:

COH_Effluent__to_Ponds = GRAPH(TIME)

(1993, 3.69), (1994, 3.28), (1995, 5.08), (1996, 4.85), (1997, 1.99), (1998,

2.54), (1999, 1.13), (2000, 4.73), (2001, 5.07), (2002, 4.93), (2003, 6.46),

(2004, 5.49), (2005, 3.14), (2006, 2.94), (2007, 1.60), (2008, 1.50), (2009,

1.50), (2010, 1.50), (2011, 1.50), (2012, 1.50), (2013, 1.50), (2014, 1.50),

(2015, 1.50), (2016, 1.50), (2017, 1.50), (2018, 1.50), (2019, 1.50), (2020,

1.50), (2021, 1.50), (2022, 1.50), (2023, 1.50), (2024, 1.50), (2025, 1.50),

(2026, 1.50), (2027, 1.50), (2028, 1.50), (2029, 1.50), (2030, 1.50), (2031,

1.50), (2032, 1.50), (2033, 1.50), (2034, 1.50), (2035, 1.50)

COH_WWTP__Effluent_to_Wash = COH_WWTP-COH_Effluent__to_Ponds-

COH_Effluent__to_Reuse

COH_Effluent__to_Reuse = GRAPH(TIME)

(1993, 1.92), (1994, 2.19), (1995, 2.61), (1996, 3.08), (1997, 2.90), (1998,

6.17), (1999, 5.74), (2000, 6.72), (2001, 6.91), (2002, 8.43), (2003, 7.48),

(2004, 6.99), (2005, 6.61), (2006, 7.13), (2007, 7.42), (2008, 8.20), (2009, 9.18), (2010, 10.2), (2011, 11.1), (2012, 12.1), (2013, 13.1), (2014, 14.1), (2015, 15.1), (2016, 16.1), (2017, 17.0), (2018, 18.0), (2019, 19.0), (2020, 20.0), (2021, 20.0), (2022, 20.0), (2023, 20.0), (2024, 20.0), (2025, 20.0), (2026, 20.0), (2027, 20.0), (2028, 20.0), (2029, 20.0), (2030, 20.0), (2031, 20.0), (2032, 20.0), (2033, 20.0), (2034, 20.0), (2035, 20.0)

COLV_RP(t) = COLV_RP(t - dt) + (COLV_Effluent__to_RP - COLV_RP_Flow) * dt

INIT COLV_RP = 0

INFLOWS:

COLV_Effluent__to_RP = GRAPH(TIME)

(1993, 2.82), (1994, 2.65), (1995, 2.65), (1996, 0.12), (1997, 0.36), (1998, 0.56), (1999, 3.19), (2000, 3.68), (2001, 5.11), (2002, 5.63), (2003, 4.95), (2004, 4.62), (2005, 5.22), (2006, 4.71), (2007, 4.89), (2008, 7.70), (2009, 7.98), (2010, 8.25), (2011, 8.53), (2012, 8.80), (2013, 9.08), (2014, 9.35), (2015, 9.63), (2016, 9.90), (2017, 10.2), (2018, 10.5), (2019, 10.7), (2020, 11.0), (2021, 11.0), (2022, 11.0), (2023, 11.0), (2024, 11.0), (2025, 11.0), (2026, 11.0), (2027, 11.0), (2028, 11.0), (2029, 11.0), (2030, 11.0), (2031, 11.0), (2032, 11.0), (2033, 11.0), (2034, 11.0), (2035, 11.0)

OUTFLOWS:

COLV_RP_Flow = COLV_RP*Fraction__COLV_RP

CONLV_Distribution_System(t) = CONLV_Distribution_System(t - dt) +

(To_CONLV_System + CONLV_Wells - To_CONLV - CONLV_Leakage) * dt

INIT CONLV_Distribution_System = 25

INFLOWS:

To_CONLV_System =

Reuse_Adjusted_Water_Demand[City_of_North_Las_Vegas_Net_In]-

CONLV_Wells

CONLV_Wells = GRAPH(TIME*Well_Testing)

(1992, 5.35), (1993, 5.85), (1994, 4.20), (1995, 4.91), (1996, 7.26), (1997,

7.31), (1998, 7.28), (1999, 6.16), (2000, 7.17), (2001, 7.83), (2002, 7.71),

(2003, 6.95), (2004, 4.98), (2005, 4.39), (2006, 4.36), (2007, 3.83), (2008,

4.72), (2009, 4.72), (2010, 4.72), (2011, 4.72), (2012, 4.72), (2013, 4.72),

(2014, 4.72), (2015, 4.72), (2016, 4.72), (2017, 4.72), (2018, 4.72), (2019,

4.72), (2020, 4.72), (2021, 4.72), (2022, 4.72), (2023, 4.72), (2024, 4.72),

(2025, 4.72), (2026, 4.72), (2027, 4.72), (2028, 4.72), (2029, 4.72), (2030,

4.72), (2031, 4.72), (2032, 4.72), (2033, 4.72), (2034, 4.72), (2035, 4.72)

OUTFLOWS:

To_CONLV = CONLV_Distribution_System*CONLV__Supply_ratio

CONLV_Leakage = CONLV_Distribution_System*CONLV_Leakage__Ratio

GW(t) = GW(t - dt) + (Runoff_Seepage__to_GW + Reuse_Seepage_to_GW +

Total_GW_from_outdoor_Use - Yearly_GW) * dt

INIT GW = Initial_City_In_Out_Outdoor_Stocks

INFLOWS:

Runoff_Seepage__to_GW =

Urban_Runoff_System*Runoff_Fraction_to_GW

Reuse_Seepage_to_GW = Reuse_sites*Fraction_Reuse__to_GW

Total_GW_from_outdoor_Use =

Total_Outdoor_Use*Total_GW_Fraction_from_outdoor_use

OUTFLOWS:

Yearly_GW (IN SECTOR: City of Las Vegas)

Lake_Mead(t) = Lake_Mead(t - dt) + (Colorado_river + LV_Wash_Outflow +

Cooling_Water - AMSWTF__Withdrawl - RMWTF__Withdrawl_ -

BMI_Withdrawl) * dt

INIT Lake_Mead = 8500

INFLOWS:

Colorado_river = 264

LV_Wash_Outflow = (Las_Vegas_Wash-

(Final_Fraction_GW_in_LV_Wash*Las_Vegas_Wash))-Precipitation

Cooling_Water = 6

OUTFLOWS:

AMSWTF__Withdrawl = (Adjusted__Withdrawl/2)-(BMI_to_COH/2)

RMWTF__Withdrawl_ = (Adjusted__Withdrawl/2)-(BMI_to_COH/2)

BMI_Withdrawl = GRAPH(TIME)

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(1992, 14.5), (1993, 13.3), (1994, 16.7), (1995, 17.6), (1996, 19.6), (1997, 17.2), (1998, 18.3), (1999, 16.4), (2000, 17.7), (2001, 17.6), (2002, 17.6), (2003, 14.7), (2004, 17.6), (2005, 17.2), (2006, 19.9), (2007, 18.7), (2008, 18.8), (2009, 18.8), (2010, 18.8), (2011, 18.8), (2012, 18.8), (2013, 18.8), (2014, 18.8), (2015, 18.8), (2016, 18.8), (2017, 18.8), (2018, 18.8), (2019, 18.8), (2020, 18.8), (2021, 18.8), (2022, 18.8), (2023, 18.8), (2024, 18.8), (2025, 18.8), (2026, 18.8), (2027, 18.8), (2028, 18.8), (2029, 18.8), (2030, 18.8), (2031, 18.8), (2032, 18.8), (2033, 18.8), (2034, 18.8), (2035, 18.8)

Las_Vegas_Wash(t) = Las_Vegas_Wash(t - dt) + (COH_Ponds__seepage_to_Wash + Runoff_to_LV_Wash + Precipitation + COLV_WWTP__Effluent_to_Wash + CCWRP_Effluent_to_Wash + COH_WWTP__Effluent_to_Wash + RFC_from_LV_Wash_Seepage - LV_Wash_Outflow) * dt

INIT Las_Vegas_Wash = Initial_City_In_Out_Outdoor_Stocks

INFLOWS:

COH_Ponds__seepage_to_Wash   (IN SECTOR: Clark County Portion)

Runoff_to_LV_Wash = Urban_Runoff_System-1.16

Precipitation = 6

COLV_WWTP__Effluent_to_Wash = COLV_WWTP-COLV_Effluent__to_RP

CCWRP_Effluent_to_Wash = CCWRP-CCWRP_to_DBRP-CCWRP_to_Reuse-CCWRP__to_ERP

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COH_WWTP__Effluent_to_Wash = COH_WWTP-COH_Effluent__to_Ponds-

COH_Effluent__to_Reuse

RFC_from_LV_Wash_Seepage =

Total_LV_Wash_seepage__from_Outside_Use-1.56

OUTFLOWS:

LV_Wash_Outflow = (Las_Vegas_Wash-

(Final_Fraction_GW_in_LV_Wash*Las_Vegas_Wash))-Precipitation

LVVWD_Distribution__System(t) = LVVWD_Distribution__System(t - dt) +

(To_LVVWD_System + LVVWD_Wells - To_Clark_County_LVV - To_COLV

- LVVWD_Leakage) * dt

INIT LVVWD_Distribution__System = 200

INFLOWS:

To_LVVWD_System =

(Reuse_Adjusted_Water_Demand[City_of_Las_Vegas_Net_In]+Reuse_Adju

sted_Water_Demand[Clark_County_Portion_Net_In])-LVVWD_Wells

LVVWD_Wells = GRAPH(TIME*Well_Testing)

(1992, 54.5), (1993, 53.4), (1994, 56.5), (1995, 56.4), (1996, 58.1), (1997,

59.2), (1998, 57.0), (1999, 57.6), (2000, 56.7), (2001, 60.5), (2002, 59.3),

(2003, 57.8), (2004, 59.5), (2005, 50.1), (2006, 54.9), (2007, 57.9), (2008,

57.6), (2009, 57.6), (2010, 57.6), (2011, 57.6), (2012, 57.6), (2013, 57.6),

(2014, 57.6), (2015, 57.6), (2016, 57.6), (2017, 57.6), (2018, 57.6), (2019,

57.6), (2020, 57.6), (2021, 57.6), (2022, 57.6), (2023, 57.6), (2024, 57.6),

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(2025, 57.6), (2026, 57.6), (2027, 57.6), (2028, 57.6), (2029, 57.6), (2030, 57.6), (2031, 57.6), (2032, 57.6), (2033, 57.6), (2034, 57.6), (2035, 57.6)

OUTFLOWS:

To_Clark_County_LVV =

LVVWD_Distribution__System*CCLVV__Supply_Ratio

To_COLV = LVVWD_Distribution__System*COLV_Supply_Ratio

LVVWD_Leakage = LVVWD_Distribution__System*LVVWD_Leakage_Ratio

Nellis_AFB__Distribution_System(t) = Nellis_AFB__Distribution_System(t - dt) + (To_Nellis_AFB_System + Nellis_AFB_Wells - To_Nellis_AFB - Nellis_AFB_Leakage) * dt

INIT Nellis_AFB__Distribution_System = 1

INFLOWS:

To_Nellis_AFB_System =

Reuse_Adjusted_Water_Demand[Nellis_AFB_Net_In]-Nellis_AFB_Wells

Nellis_AFB_Wells = GRAPH(TIME*Well_Testing)

(1992, 0.835), (1993, 0.873), (1994, 0.821), (1995, 0.728), (1996, 0.91), (1997, 1.02), (1998, 0.897), (1999, 1.37), (2000, 1.86), (2001, 2.11), (2002, 1.97), (2003, 1.75), (2004, 1.62), (2005, 1.11), (2006, 1.03), (2007, 1.25), (2008, 0.586), (2009, 0.586), (2010, 0.586), (2011, 0.586), (2012, 0.586), (2013, 0.586), (2014, 0.586), (2015, 0.586), (2016, 0.586), (2017, 0.586), (2018, 0.586), (2019, 0.586), (2020, 0.586), (2021, 0.586), (2022, 0.586), (2023, 0.586), (2024, 0.586), (2025, 0.586), (2026, 0.586), (2027,

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0.586), (2028, 0.586), (2029, 0.586), (2030, 0.586), (2031, 0.586), (2032, 0.586), (2033, 0.586), (2034, 0.586), (2035, 0.586)

OUTFLOWS:

To_Nellis_AFB   (IN SECTOR: Nellis Air Force Base)

Nellis_AFB_Leakage =

Nellis_AFB__Distribution_System*Nellis_AFB_Leakage_Ratio

Outdoor_Evaporation(t) = Outdoor_Evaporation(t - dt) +

(Reuse_to_Evaporation + Total_Outdoor__Evap_fraction - Yearly_Evap) *

dt

INIT Outdoor_Evaporation = Initial_City_In_Out_Outdoor_Stocks

INFLOWS:

Reuse_to_Evaporation = Reuse_sites*Fraction_Reuse__to_Evaporation

Total_Outdoor__Evap_fraction =

Total_Outdoor_Use*Evaporation_Fraction

OUTFLOWS:

Yearly_Evap = Outdoor_Evaporation*Yearly_Evap_Ratio

Reuse_sites(t) = Reuse_sites(t - dt) + (ERP_to__Reuse + DBRP_to_Reuse +

CONLV_Effluent__to_Reuse + COH_Effluent__to_Reuse + COLV_RP_Flow

+ CCWRP_to_Reuse - Reuse_Seepage_to_GW - Reuse_to_Evaporation -

Urban_runoff__from_Reuse_sites -

Seeapge_to_LV_Wash_from_Reuse_sites) * dt

INIT Reuse_sites = Initial_City_In_Out_Outdoor_Stocks

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INFLOWS:

ERP_to__Reuse   (IN SECTOR: Clark County Portion)

DBRP_to_Reuse   (IN SECTOR: Clark County Portion)

CONLV_Effluent__to_Reuse   (IN SECTOR: City of North Las Vegas)

COH_Effluent__to_Reuse = GRAPH(TIME)

(1993, 1.92), (1994, 2.19), (1995, 2.61), (1996, 3.08), (1997, 2.90), (1998, 6.17), (1999, 5.74), (2000, 6.72), (2001, 6.91), (2002, 8.43), (2003, 7.48), (2004, 6.99), (2005, 6.61), (2006, 7.13), (2007, 7.42), (2008, 8.20), (2009, 9.18), (2010, 10.2), (2011, 11.1), (2012, 12.1), (2013, 13.1), (2014, 14.1), (2015, 15.1), (2016, 16.1), (2017, 17.0), (2018, 18.0), (2019, 19.0), (2020, 20.0), (2021, 20.0), (2022, 20.0), (2023, 20.0), (2024, 20.0), (2025, 20.0), (2026, 20.0), (2027, 20.0), (2028, 20.0), (2029, 20.0), (2030, 20.0), (2031, 20.0), (2032, 20.0), (2033, 20.0), (2034, 20.0), (2035, 20.0)

COLV_RP_Flow = COLV_RP*Fraction__COLV_RP

CCWRP_to_Reuse (IN SECTOR: Clark County Portion)

OUTFLOWS:

Reuse_Seepage_to_GW = Reuse_sites*Fraction_Reuse__to_GW

Reuse_to_Evaporation = Reuse_sites*Fraction_Reuse__to_Evaporation

Urban_runoff__from_Reuse_sites =

Reuse_sites*Ratio_Runoff__from_Reuse_sites

Seeapge_to_LV_Wash_from_Reuse_sites =

Reuse_sites*Ratio_Seepage_to_LV_Wash_from_Reuse_Sites

158

River_Mountains_WTF(t) = River_Mountains_WTF(t - dt) +

(RMWTF__Withdrawl_ - RMWTF__Supply) * dt

INIT River_Mountains_WTF = 200

INFLOWS:

RMWTF__Withdrawl_ = (Adjusted__Withdrawl/2)-(BMI_to_COH/2)

OUTFLOWS:

RMWTF__Supply = River_Mountains_WTF*RMWTF_Efficiency

Total_LV_Wash_seepage__from_Outside_Use(t) =

Total_LV_Wash_seepage__from_Outside_Use(t - dt) +

(Seepage_to_LV_Wash + Seeapge_to_LV_Wash_from_Reuse_sites -

RFC_from_LV_Wash_Seepage) * dt

INIT Total_LV_Wash_seepage__from_Outside_Use = 5

INFLOWS:

Seepage_to_LV_Wash =

Total_Outdoor_Use*Seepage_to_LV_Wash_to_Outside_Use_fraction

Seeapge_to_LV_Wash_from_Reuse_sites =

Reuse_sites*Ratio_Seepage_to_LV_Wash_from_Reuse_Sites

OUTFLOWS:

RFC_from_LV_Wash_Seepage =

Total_LV_Wash_seepage__from_Outside_Use-1.56

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Total_Outdoor_Use(t) = Total_Outdoor_Use(t - dt) + (Total_COH_Outdoor

+ Total_CCPLVV_Outdoor + Total_COLV_Outdoor +

Total_CONLV_Outdoor + Total_NAFB_Outdoor + Total_BC_Outdoor -

Total_Urban__runoff_from_Outside_Use - Total_Outdoor__Evap_fraction -

Total_GW_from_outdoor_Use - Seepage_to_LV_Wash) * dt

INIT Total_Outdoor_Use = 0

INFLOWS:

Total_COH_Outdoor = COH_Outdoor*COH_Outdoor__Rate

Total_CCPLVV_Outdoor =

Clark_County__LVV__Outdoor*CCPLVV_Outdoor__Rate

Total_COLV_Outdoor   (IN SECTOR: City of Las Vegas)

Total_CONLV_Outdoor = CONLV_Outdoor*CONLV_Outdoor_Rate

Total_NAFB_Outdoor = Nellis_AFB_Outdoor*NAFB_Outdoor__Rate

Total_BC_Outdoor = Boulder_City_Outdoor*BC_Outdoor_Rate

OUTFLOWS:

Total_Urban__runoff_from_Outside_Use =

Urban_Runoff_to_Outside_Use_fraction*Total_Outdoor_Use

Total_Outdoor__Evap_fraction =

Total_Outdoor_Use*Evaporation_Fraction

Total_GW_from_outdoor_Use =

Total_Outdoor_Use*Total_GW_Fraction_from_outdoor_use

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Seepage_to_LV_Wash =

Total_Outdoor_Use*Seepage_to_LV_Wash_to_Outside_Use_fraction

Treated_Water(t) = Treated_Water(t - dt) + (AMSWTF__Supply +

RMWTF__Supply - To_CONLV_System - To_LVVWD_System -

To_Nellis_AFB_System - To_COH_System_from_TW - To_Boulder_City) *

dt

INIT Treated_Water = 230

INFLOWS:

AMSWTF__Supply = Alfred_Merrit_Smith_WTF*AMSWTF__Efficiency

RMWTF__Supply = River_Mountains_WTF*RMWTF_Efficiency

OUTFLOWS:

To_CONLV_System =

Reuse_Adjusted_Water_Demand[City_of_North_Las_Vegas_Net_In]-

CONLV_Wells

To_LVVWD_System =

(Reuse_Adjusted_Water_Demand[City_of_Las_Vegas_Net_In]+Reuse_Adju

sted_Water_Demand[Clark_County_Portion_Net_In])-LVVWD_Wells

To_Nellis_AFB_System =

Reuse_Adjusted_Water_Demand[Nellis_AFB_Net_In]-Nellis_AFB_Wells

To_COH_System_from_TW =

Reuse_Adjusted_Water_Demand[City_of_Henderson_Net_In]-BMI_to_COH

To_Boulder_City = Reuse_Adjusted_Water_Demand[Boulder_City_Net_In]

161

Urban_Runoff_System(t) = Urban_Runoff_System(t - dt) +

(Total_Urban__runoff_from_Outside_Use +

Urban_runoff__from_Reuse_sites - Runoff__Evaporation_Loss -

Runoff_Seepage__to_GW - Runoff_to_LV_Wash) * dt

INIT Urban_Runoff_System = 3

INFLOWS:

Total_Urban__runoff_from_Outside_Use =

Urban_Runoff_to_Outside_Use_fraction*Total_Outdoor_Use

Urban_runoff__from_Reuse_sites =

Reuse_sites*Ratio_Runoff__from_Reuse_sites

OUTFLOWS:

Runoff__Evaporation_Loss =

Urban_Runoff_System*Runoff_Fraction_Evaporating

Runoff_Seepage__to_GW =

Urban_Runoff_System*Runoff_Fraction_to_GW

Runoff_to_LV_Wash = Urban_Runoff_System-1.16

AMSWTF__Efficiency = 1

BC_Evaporation_Fraction = 0.236321684

BC_Fraction_Runoff = 0.043818654

BC_Fraction_Seeping_to_GW = 0.662034159

BC_Fraction_Seeping_to_Wash = 0.057825504

BC_Leakage_Ratio = 0

162

BC_Outdoor_Rate = 1

BC_Supply_Ratio = 1

BMI_to__COH_Ratio = 1

CCPLVV_Outdoor__Rate = 1

COH_Evaporation__Fraction = 0.236321684

COH_Fraction__Runoff = 0.043818654

COH_Fraction__Seeping_to_GW = 0.662034159

COH_Fraction__Seeping_to_Wash = 0.057825504

COH_Future = (0.72-(.72-(0.72*Future_Rate)))/26

COH_Indoor_Fraction = IF(Indoor_Outdoor_Choice = 1)

THEN(COH_Indoor_LN_1) ELSE IF(Indoor_Outdoor_Choice = 2)

THEN(COH_Indoor_50%_LN) ELSE IF(Indoor_Outdoor_Choice = 3)

THEN(COH_Indoor_LN_3) ELSE IF(Indoor_Outdoor_Choice = 4)

THEN(COH_Indoor_Linear) ELSE IF(Indoor_Outdoor_Choice = 5)

THEN(COH_Indoor_LN_33%) ELSE(0)

COH_Indoor_Linear = IF(TIME > 2008)

THEN(0.27+RAMP(COH_Future,2008)) ELSE(COH_Indoor_Historic)

COH_Leakage__Ratio = 0

COH_Outdoor_Fraction = IF(Indoor_Outdoor_Choice = 1)

THEN(COH_Outdoor_LN_1) ELSE IF(Indoor_Outdoor_Choice = 2)

THEN(COH_Outdoor_50%_LN) ELSE IF(Indoor_Outdoor_Choice = 3)

THEN(COH_Outdoor_LN_3) ELSE IF(Indoor_Outdoor_Choice = 4)

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THEN(COH_Outdoor_Linear) ELSE IF(Indoor_Outdoor_Choice = 5)

THEN(COH_Outdoor_LN_66%) ELSE(0)

COH_Outdoor_Linear = IF(TIME > 2008) THEN(0.73-

RAMP(COH_Future,2008)) ELSE(COH_Outdoor_Historic)

COH_Outdoor__Rate = 1

COH_Reuse_Ratio = 1-COH_Ponds_Ratio-COH_WWTP__Effluent_Fraction

COH_Sewage__Ratio = 1

COH_Supply_Ratio = 1

COH_WTP__Efficiency = 1

Colorado_river__Outdoor_Portion = Total_Outdoor_Supply-

(Total_Wells_Supply*(Total_Outdoor_Supply/(Total_Outdoor_Supply+Tota

l_Indoor__Supply_)))

CONLV_Evaporation_Fraction = 0.236321684

CONLV_Fraction_Runoff = 0.043818654

CONLV_Leakage__Ratio = 0

CONLV_Outdoor_Rate = 1

CONLV__Supply_ratio = 1

Evaporation_Fraction = 0.298636016

Final_Fraction_GW_in_LV_Wash =

Initial_Fraction_GW__in_LV_Wash/Total_Treated_Eflluent_to_Wash

Fraction_Reuse__to_Evaporation = 0.298636016

Fraction_Reuse__to_GW = 0.592483735

Future_Rate = 0

Indoor_Outdoor_Choice = 3

Initial_City_In_Out_Outdoor_Stocks = 50

Initial_Distribution_System = 50

Initial_Fraction_GW__in_LV_Wash =

(Ratio_GW__to_Supply*Total_Treated_Eflluent_to_Wash)-17

Initial_Reclamation_Plants_Human_Use_Ponds = 10

Initial_WTP = 100

Initial_WWTPs = 50

LVVWD_Leakage_Ratio = 0

NAFB_Outdoor__Rate = 1

Nellis_AFB_Leakage_Ratio = 0

Ponds_Wash__Seepage_Ratio = 0.9

Ratio_GW__to_Supply = Total_Wells_Supply/Sum_Distribution

Ratio_Runoff__from_Reuse_sites = 0.047017014

Ratio_Seepage_to_LV_Wash_from_Reuse_Sites = 0.061863235

RMWTF_Efficiency = 1

Runoff_Fraction_Evaporating = 0.0144

Runoff_Fraction_to_GW = 0.008

Seepage_to_LV_Wash_to_Outside_Use_fraction = 0.061863235

Sum_BC__Outdoor_Fraction =

BC_Evaporation_Fraction+BC_Fraction_Runoff+BC_Fraction_Seeping_to_

GW+BC_Fraction_Seeping_to_Wash

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Sum_COH_Outdoor__Fractions =

COH_Evaporation__Fraction+COH_Fraction__Runoff+COH_Fraction__Seeping_to_GW+COH_Fraction__Seeping_to_Wash

Sum_COH__Effluent_Fraction =

COH_Ponds_Ratio+COH_Reuse_Ratio+COH_WWTP__Effluent_Fraction

Sum_CONLV_Indoor_Use = CONLV_Sewage+CONLV__Sewage_to_COLV

Sum_Distribution =

To_COH+To_Nellis_AFB+To_Clark_County_LVV+To_COLV+To_CONLV+To_Boulder_City

Sum_Nellis_AFB_Indoor_Use =

Nellis_AFB_Sewage_to_CCWRP+Nellis_AFB_Sewage_to__COLV_WWTP+To_Nellis_AFB__Ponds

Sum_Supply =

AMSWTF__Supply+RMWTF__Supply+COH_Supply_from_BMI

Sum_Water_Available =

Colorado_river+LV_Wash_Outflow+Total_Wells_Supply-Consumptive_use_Exceedence

Sum_Water_Demand = ARRAYSUM(Reuse_Adjusted_Water_Demand[*])

Total_GW_Fraction_from_outdoor_use = 0.592483735

Total_Indoor__Supply_ =

To_Boulder_City_Indoor+To_Clark_County__LVV_Indoor+To_COH_Indoor+To_COLV_Indoor+To_CONLV_Indoor+To_Nellis_AFB__Indoor

Total_Outdoor_Supply =

To_Boulder_City_Outdoor+To_Clark_County_LVV_Outdoor+To_COH_Outdoor+To_COLV_Outdoor+To_CONLV__Outdoor+To_Nellis_AFB__Outdoor

Total_Reuse =

CCWRP_to_DBRP+CCWRP_to_Reuse+CCWRP__to_ERP+COH_Effluent__to_Reuse+COLV_Effluent__to_RP

Total_Sewage =

BC_Sewage+Clark_County__LVV_Sewage+COH__Sewage+COLV_Sewage+CONLV_Sewage+Nellis_AFB_Sewage_to_CCWRP+Nellis_AFB_Sewage_to__COLV_WWTP+Sunrise_Manor_Sewage+CONLV__Sewage_to_COLV

Total_Treated_Eflluent_to_Wash =

CCWRP_Effluent_to_Wash+COLV_WWTP__Effluent_to_Wash+COH_WWTP__Effluent_to_Wash

Total_Water_Supply =

COH_Distribution_System+CONLV_Distribution_System+LVVWD_Distribution__System+Nellis_AFB__Distribution_System+Boulder_City_Distribution_System

Total_Wells_Supply = CONLV_Wells+LVVWD_Wells+Nellis_AFB_Wells

Total_WWTP_Influent = CCWRP+COH_WWTP+COLV_WWTP+BC_WWTP

Urban_Runoff_to_Outside_Use_fraction = 0.047017014

Well_Testing = 0

Yearly_Evap_Ratio = 1

Yearly_GW_ratio = 1

BC_Outdoor_50%_LN = GRAPH(TIME)

(1993, 0.8), (1994, 0.811), (1995, 0.805), (1996, 0.824), (1997, 0.814),

(1998, 0.809), (1999, 0.859), (2000, 0.883), (2001, 0.876), (2002, 0.903),

(2003, 0.871), (2004, 0.822), (2005, 0.818), (2006, 0.848), (2007, 0.847),

(2008, 0.835), (2009, 0.82), (2010, 0.812), (2011, 0.806), (2012, 0.802),

(2013, 0.798), (2014, 0.795), (2015, 0.792), (2016, 0.79), (2017, 0.788),

(2018, 0.786), (2019, 0.784), (2020, 0.783), (2021, 0.781), (2022, 0.78),

(2023, 0.779), (2024, 0.777), (2025, 0.776), (2026, 0.775), (2027, 0.774),

(2028, 0.773), (2029, 0.772), (2030, 0.771), (2031, 0.77), (2032, 0.77),

(2033, 0.769), (2034, 0.768), (2035, 0.767)

BC_Outdoor_LN_66% = GRAPH(TIME)

(1993, 0.8), (1994, 0.811), (1995, 0.805), (1996, 0.824), (1997, 0.814),

(1998, 0.809), (1999, 0.859), (2000, 0.883), (2001, 0.876), (2002, 0.903),

(2003, 0.871), (2004, 0.822), (2005, 0.818), (2006, 0.848), (2007, 0.847),

(2008, 0.835), (2009, 0.814), (2010, 0.801), (2011, 0.793), (2012, 0.786),

(2013, 0.78), (2014, 0.775), (2015, 0.771), (2016, 0.768), (2017, 0.765),

(2018, 0.762), (2019, 0.759), (2020, 0.757), (2021, 0.754), (2022, 0.752),

(2023, 0.75), (2024, 0.748), (2025, 0.747), (2026, 0.745), (2027, 0.743),

(2028, 0.742), (2029, 0.74), (2030, 0.739), (2031, 0.738), (2032, 0.737),

(2033, 0.735), (2034, 0.734), (2035, 0.733)

CCLVV__Supply_Ratio = GRAPH(TIME)

(1992, 0.547), (1993, 0.541), (1994, 0.537), (1995, 0.533), (1996, 0.53),

(1997, 0.532), (1998, 0.532), (1999, 0.533), (2000, 0.533), (2001, 0.546),

(2002, 0.554), (2003, 0.558), (2004, 0.562), (2005, 0.564), (2006, 0.573), (2007, 0.581), (2008, 0.58)

COH_Indoor_50%_LN = GRAPH(TIME)

(1993, 0.33), (1994, 0.27), (1995, 0.3), (1996, 0.26), (1997, 0.3), (1998, 0.31), (1999, 0.31), (2000, 0.31), (2001, 0.31), (2002, 0.31), (2003, 0.36), (2004, 0.32), (2005, 0.3), (2006, 0.27), (2007, 0.27), (2008, 0.28), (2009, 0.289), (2010, 0.294), (2011, 0.298), (2012, 0.301), (2013, 0.303), (2014, 0.305), (2015, 0.307), (2016, 0.309), (2017, 0.31), (2018, 0.311), (2019, 0.312), (2020, 0.313), (2021, 0.314), (2022, 0.315), (2023, 0.316), (2024, 0.317), (2025, 0.318), (2026, 0.318), (2027, 0.319), (2028, 0.32), (2029, 0.32), (2030, 0.321), (2031, 0.321), (2032, 0.322), (2033, 0.322), (2034, 0.323), (2035, 0.323)

COH_Indoor_Historic = GRAPH(TIME)

(1993, 0.33), (1994, 0.27), (1995, 0.3), (1996, 0.26), (1997, 0.3), (1998, 0.31), (1999, 0.31), (2000, 0.31), (2001, 0.31), (2002, 0.31), (2003, 0.36), (2004, 0.32), (2005, 0.3), (2006, 0.27), (2007, 0.27), (2008, 0.28), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00)

COH_Indoor_LN_1 = GRAPH(TIME)

(1993, 0.33), (1994, 0.27), (1995, 0.3), (1996, 0.26), (1997, 0.3), (1998, 0.31), (1999, 0.31), (2000, 0.31), (2001, 0.31), (2002, 0.31), (2003, 0.36), (2004, 0.32), (2005, 0.3), (2006, 0.27), (2007, 0.27), (2008, 0.28), (2009, 0.31), (2010, 0.327), (2011, 0.34), (2012, 0.35), (2013, 0.357), (2014, 0.364), (2015, 0.37), (2016, 0.375), (2017, 0.379), (2018, 0.384), (2019, 0.387), (2020, 0.391), (2021, 0.394), (2022, 0.397), (2023, 0.4), (2024, 0.402), (2025, 0.405), (2026, 0.407), (2027, 0.409), (2028, 0.412), (2029, 0.414), (2030, 0.415), (2031, 0.417), (2032, 0.419), (2033, 0.421), (2034, 0.422), (2035, 0.424)

COH_Indoor_LN_3 = GRAPH(TIME)

(1993, 0.33), (1994, 0.27), (1995, 0.3), (1996, 0.26), (1997, 0.3), (1998, 0.31), (1999, 0.31), (2000, 0.31), (2001, 0.31), (2002, 0.31), (2003, 0.36), (2004, 0.32), (2005, 0.3), (2006, 0.27), (2007, 0.27), (2008, 0.28), (2009, 0.268), (2010, 0.261), (2011, 0.256), (2012, 0.253), (2013, 0.25), (2014, 0.247), (2015, 0.245), (2016, 0.243), (2017, 0.241), (2018, 0.239), (2019, 0.238), (2020, 0.236), (2021, 0.235), (2022, 0.234), (2023, 0.233), (2024, 0.232), (2025, 0.231), (2026, 0.23), (2027, 0.229), (2028, 0.228), (2029, 0.227), (2030, 0.227), (2031, 0.226), (2032, 0.225), (2033, 0.225), (2034, 0.224), (2035, 0.223)

COH_Indoor_LN_33% = GRAPH(TIME)

(1993, 0.33), (1994, 0.27), (1995, 0.3), (1996, 0.26), (1997, 0.3), (1998, 0.31), (1999, 0.31), (2000, 0.31), (2001, 0.31), (2002, 0.31), (2003, 0.36), (2004, 0.32), (2005, 0.3), (2006, 0.27), (2007, 0.27), (2008, 0.28), (2009,

0.296), (2010, 0.306), (2011, 0.312), (2012, 0.318), (2013, 0.322), (2014, 0.326), (2015, 0.329), (2016, 0.331), (2017, 0.334), (2018, 0.336), (2019, 0.338), (2020, 0.34), (2021, 0.342), (2022, 0.343), (2023, 0.345), (2024, 0.346), (2025, 0.348), (2026, 0.349), (2027, 0.35), (2028, 0.351), (2029, 0.352), (2030, 0.353), (2031, 0.354), (2032, 0.355), (2033, 0.356), (2034, 0.357), (2035, 0.358)

COH_Outdoor_50%_LN = GRAPH(TIME)

(1993, 0.67), (1994, 0.73), (1995, 0.7), (1996, 0.74), (1997, 0.7), (1998, 0.69), (1999, 0.69), (2000, 0.69), (2001, 0.69), (2002, 0.69), (2003, 0.64), (2004, 0.68), (2005, 0.7), (2006, 0.73), (2007, 0.73), (2008, 0.72), (2009, 0.711), (2010, 0.706), (2011, 0.702), (2012, 0.699), (2013, 0.697), (2014, 0.695), (2015, 0.693), (2016, 0.691), (2017, 0.69), (2018, 0.689), (2019, 0.688), (2020, 0.687), (2021, 0.686), (2022, 0.685), (2023, 0.684), (2024, 0.683), (2025, 0.682), (2026, 0.682), (2027, 0.681), (2028, 0.68), (2029, 0.68), (2030, 0.679), (2031, 0.679), (2032, 0.678), (2033, 0.678), (2034, 0.677), (2035, 0.677)

COH_Outdoor_Historic = GRAPH(TIME)

(1993, 0.67), (1994, 0.73), (1995, 0.7), (1996, 0.74), (1997, 0.7), (1998, 0.69), (1999, 0.69), (2000, 0.69), (2001, 0.69), (2002, 0.69), (2003, 0.64), (2004, 0.68), (2005, 0.7), (2006, 0.73), (2007, 0.73), (2008, 0.72), (2009, 0.00), (2010, 0.00), (2011, 0.00), (2012, 0.00), (2013, 0.00), (2014, 0.00), (2015, 0.00), (2016, 0.00), (2017, 0.00), (2018, 0.00), (2019, 0.00), (2020, 0.00), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00),

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(2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00)

COH_Outdoor_LN_1 = GRAPH(TIME)

(1993, 0.67), (1994, 0.73), (1995, 0.7), (1996, 0.74), (1997, 0.7), (1998, 0.69), (1999, 0.69), (2000, 0.69), (2001, 0.69), (2002, 0.69), (2003, 0.64), (2004, 0.68), (2005, 0.7), (2006, 0.73), (2007, 0.73), (2008, 0.72), (2009, 0.69), (2010, 0.673), (2011, 0.66), (2012, 0.65), (2013, 0.643), (2014, 0.636), (2015, 0.63), (2016, 0.625), (2017, 0.621), (2018, 0.616), (2019, 0.613), (2020, 0.609), (2021, 0.606), (2022, 0.603), (2023, 0.6), (2024, 0.598), (2025, 0.595), (2026, 0.593), (2027, 0.591), (2028, 0.588), (2029, 0.586), (2030, 0.585), (2031, 0.583), (2032, 0.581), (2033, 0.579), (2034, 0.578), (2035, 0.576)

COH_Outdoor_LN_3 = GRAPH(TIME)

(1993, 0.67), (1994, 0.73), (1995, 0.7), (1996, 0.74), (1997, 0.7), (1998, 0.69), (1999, 0.69), (2000, 0.69), (2001, 0.69), (2002, 0.69), (2003, 0.64), (2004, 0.68), (2005, 0.7), (2006, 0.73), (2007, 0.73), (2008, 0.72), (2009, 0.732), (2010, 0.739), (2011, 0.744), (2012, 0.747), (2013, 0.75), (2014, 0.753), (2015, 0.755), (2016, 0.757), (2017, 0.759), (2018, 0.761), (2019, 0.762), (2020, 0.764), (2021, 0.765), (2022, 0.766), (2023, 0.767), (2024, 0.768), (2025, 0.769), (2026, 0.77), (2027, 0.771), (2028, 0.772), (2029, 0.773), (2030, 0.773), (2031, 0.774), (2032, 0.775), (2033, 0.775), (2034, 0.776), (2035, 0.777)

COH_Outdoor_LN_66% = GRAPH(TIME)

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(1993, 0.67), (1994, 0.73), (1995, 0.7), (1996, 0.74), (1997, 0.7), (1998, 0.69), (1999, 0.69), (2000, 0.69), (2001, 0.69), (2002, 0.69), (2003, 0.64), (2004, 0.68), (2005, 0.7), (2006, 0.73), (2007, 0.73), (2008, 0.72), (2009, 0.704), (2010, 0.694), (2011, 0.688), (2012, 0.682), (2013, 0.678), (2014, 0.674), (2015, 0.671), (2016, 0.669), (2017, 0.666), (2018, 0.664), (2019, 0.662), (2020, 0.66), (2021, 0.658), (2022, 0.657), (2023, 0.655), (2024, 0.654), (2025, 0.652), (2026, 0.651), (2027, 0.65), (2028, 0.649), (2029, 0.648), (2030, 0.647), (2031, 0.646), (2032, 0.645), (2033, 0.644), (2034, 0.643), (2035, 0.642)

COH_Ponds_Ratio = GRAPH(TIME)

(1992, 0.849), (1993, 0.45), (1994, 0.367), (1995, 0.513), (1996, 0.444), (1997, 0.161), (1998, 0.171), (1999, 0.0719), (2000, 0.278), (2001, 0.275), (2002, 0.261), (2003, 0.305), (2004, 0.259), (2005, 0.152), (2006, 0.145), (2007, 0.0774), (2008, 0.0743), (2009, 0.0706), (2010, 0.0672), (2011, 0.0642), (2012, 0.0614), (2013, 0.0589), (2014, 0.0565), (2015, 0.0544), (2016, 0.0525), (2017, 0.0507), (2018, 0.0491), (2019, 0.0477), (2020, 0.0464), (2021, 0.0452), (2022, 0.0441), (2023, 0.043), (2024, 0.042), (2025, 0.0411), (2026, 0.0403), (2027, 0.0395), (2028, 0.0387), (2029, 0.0381), (2030, 0.0374), (2031, 0.0368), (2032, 0.0362), (2033, 0.0356), (2034, 0.035), (2035, 0.0346)

COH_WWTP__Effluent_Fraction = GRAPH(TIME)

(1992, 0.151), (1993, 0.316), (1994, 0.387), (1995, 0.224), (1996, 0.274), (1997, 0.605), (1998, 0.414), (1999, 0.563), (2000, 0.328), (2001, 0.35),

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(2002, 0.294), (2003, 0.343), (2004, 0.411), (2005, 0.527), (2006, 0.504),

(2007, 0.564), (2008, 0.54), (2009, 0.543), (2010, 0.547), (2011, 0.55),

(2012, 0.553), (2013, 0.438), (2014, 0.44), (2015, 0.443), (2016, 0.445),

(2017, 0.446), (2018, 0.448), (2019, 0.449), (2020, 0.451), (2021, 0.452),

(2022, 0.453), (2023, 0.454), (2024, 0.455), (2025, 0.456), (2026, 0.457),

(2027, 0.458), (2028, 0.458), (2029, 0.459), (2030, 0.46), (2031, 0.46),

(2032, 0.461), (2033, 0.461), (2034, 0.462), (2035, 0.462)

COLV_Supply_Ratio = GRAPH(TIME)

(1992, 0.453), (1993, 0.459), (1994, 0.463), (1995, 0.467), (1996, 0.47),

(1997, 0.468), (1998, 0.468), (1999, 0.467), (2000, 0.467), (2001, 0.454),

(2002, 0.446), (2003, 0.442), (2004, 0.438), (2005, 0.436), (2006, 0.427),

(2007, 0.419), (2008, 0.42)

CONLV_upon_TW = GRAPH(TIME)

(1992, 0.089), (1993, 0.0834), (1994, 0.0909), (1995, 0.097), (1996,
0.0971), (1997, 0.0938), (1998, 0.0917), (1999, 0.0881), (2000, 0.0897),
(2001, 0.0909), (2002, 0.0947), (2003, 0.102), (2004, 0.104), (2005,
0.104), (2006, 0.111), (2007, 0.111), (2008, 0.107)

APPENDIX B

DESCRIPTION OF EQUATIONS FOR A CITY, DEMAND AND OUTDOOR

COMPONENTS SECTIONS

The equations for a city (City of Las Vegas), water demand and outdoor components sections are shown here for easier comprehension. The equations are the same for the other cities. All units are in MGD unless otherwise stated.

This equation is used for distributing the supply between indoor and outdoor uses. All water is distributed to either indoor or outdoor use.

COLV(t) = COLV(t - dt) + (To_COLV - To_COLV_Outdoor - To_COLV_Indoor) * dt

Where,

COLV(t) = City of Las Vegas at time step (t)

COLV(t - dt) = City of Las Vegas at new time step minus the previous time step

To COLV = Water Supply to City of Las Vegas

To COLV Outdoor = Outdoor Water Use in City of Las Vegas

To COLV Indoor = Indoor Water Use in City of Las Vegas

These equations determine the amount of indoor and outdoor use

To_COLV_Outdoor = COLV*COLV_Outdoor_Fraction

To_COLV_Indoor = COLV*COLV_Indoor_Fraction

Where,

COLV Outdoor Fraction = Fraction of water going to Outdoor Water Use, determined by conservation scenarios

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COLV Indoor Fraction = Fraction of water going to Indoor Water Use, determined by conservation scenarios

This equation converts the indoor water use to wastewater. All indoor use becomes sewage.

COLV_Indoor(t) = COLV_Indoor(t - dt) + (To_COLV_Indoor - COLV_Sewage) * dt

Where,

COLV Indoor = Indoor Water Use

COLV Sewage = Wastewater generated from indoor use in City of Las Vegas

This equation shows division of the wastewater reaching the wastewater treatment plant into treated wastewater either going to Las Vegas Wash or to reuse sites.

COLV_WWTP(t) = COLV_WWTP(t - dt) + (COLV_Sewage + CONLV__Sewage_to_COLV + Nellis_AFB_Sewage_to__COLV_WWTP - COLV_WWTP__Effluent_to_Wash - COLV_Effluent__to_RS) * dt

Where,

COLV WWTP = City of Las Vegas Waste Water Treatment Plant

CONLV Sewage to COLV = City of North Las Vegas wastewater to COLV WWTP

Nellis AFB Sewage to COLV WWTP = Nellis Air Force Base Sewage to
COLV WWTP

COLV WWTP Effluent to Wash = Fraction of COLV WWTP treated
wastewater going to Las Vegas Wash

COLV Effluent to RS = COLV Effluent to Reuse Sites

The IF THEN ELSE conditions assist in choosing the conservation
scenario. The value in the indoor outdoor choice, decides which scenario
is selected.

COLV_Indoor_Fraction = IF(Indoor_Outdoor_Choice = 1)
THEN(COLV_Indoor_LN_1 "Scenario 2")
ELSE IF(Indoor_Outdoor_Choice = 2) THEN(COLV_Indoor_50%_LN
"Scenario 4")   ELSE IF(Indoor_Outdoor_Choice = 3)
THEN(COLV_Indoor_LN_3 "Scenario 5")   ELSE
IF(Indoor_Outdoor_Choice = 4) THEN(COLV_Indoor_Linear "Scenario 1")
ELSE IF(Indoor_Outdoor_Choice = 5) THEN(COLV_Indoor_LN_33%
"Scenario 3") ELSE(0)

COLV_Outdoor_Fraction = IF(Indoor_Outdoor_Choice = 1)
THEN(COLV_Outdoor_LN_1 "Scenario 2")
ELSE IF(Indoor_Outdoor_Choice = 2) THEN(COLV_Outdoor_50%_LN
"Scenario 4")   ELSE IF(Indoor_Outdoor_Choice = 3)
THEN(COLV_Outdoor_LN_3 "Scenario 5")   ELSE

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IF(Indoor_Outdoor_Choice = 4) THEN(COLV_Outdoor_Linear "Scenario
1") ELSE IF(Indoor_Outdoor_Choice = 5) THEN(COLV_Outdoor_LN_66%
"Scenario 3") ELSE(0)

The following graphs show the indoor and outdoor fractions under
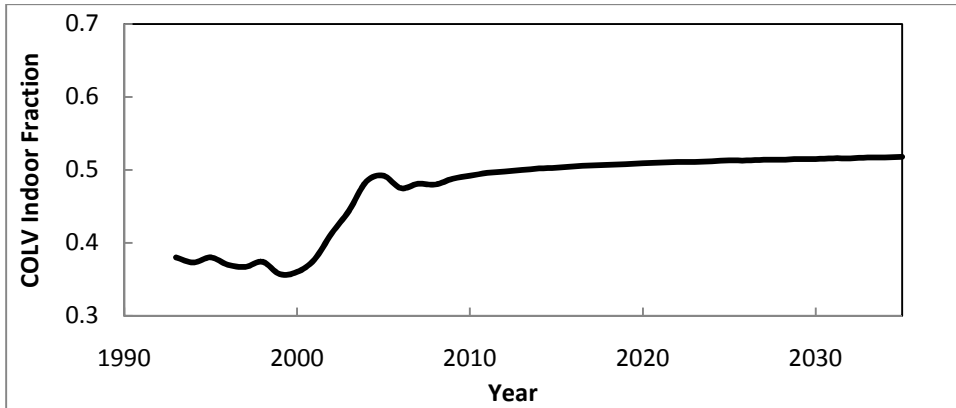different conservation scenarios for COLV.
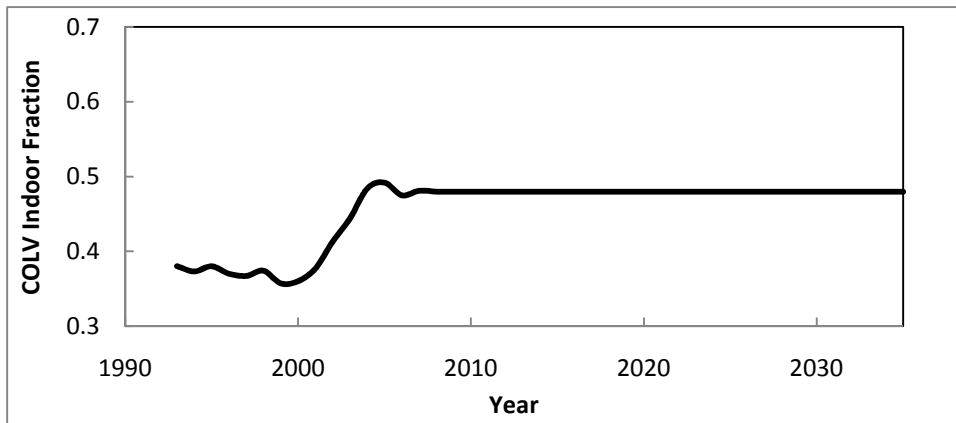
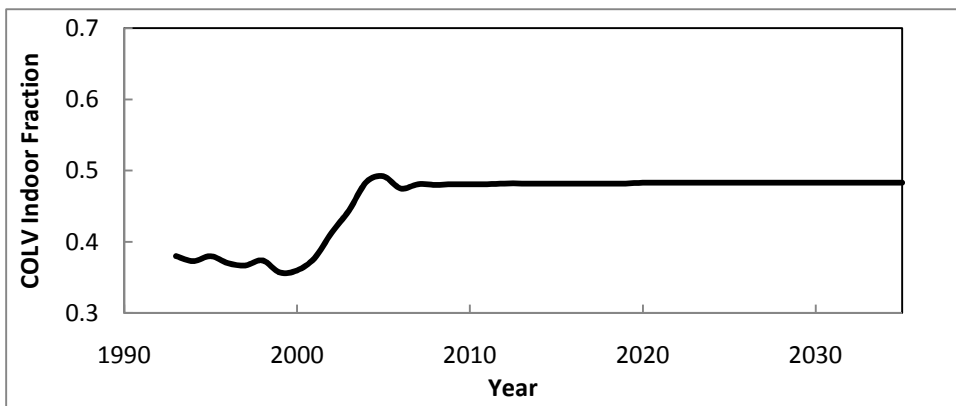COLV_Indoor__Status_Quo = GRAPH(TIME) "Scenario 1" Status Quo

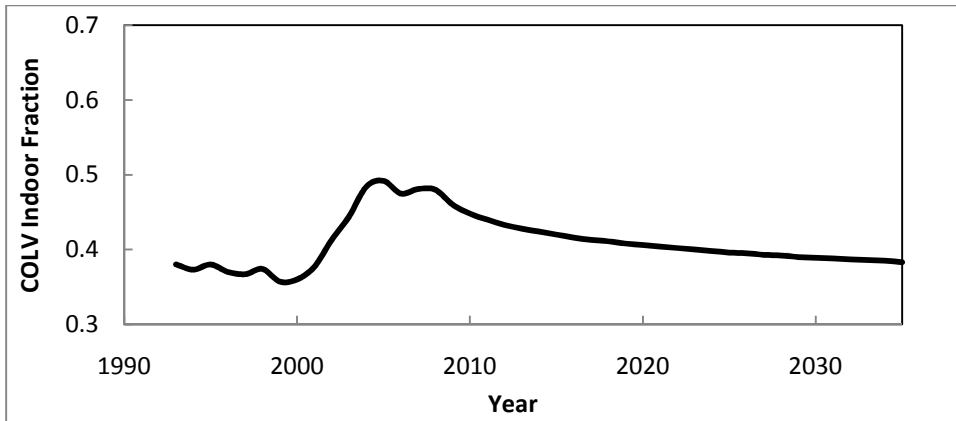COLV_Indoor_LN_1 = GRAPH(TIME) "Scenario 2" Total outdoor
conservation

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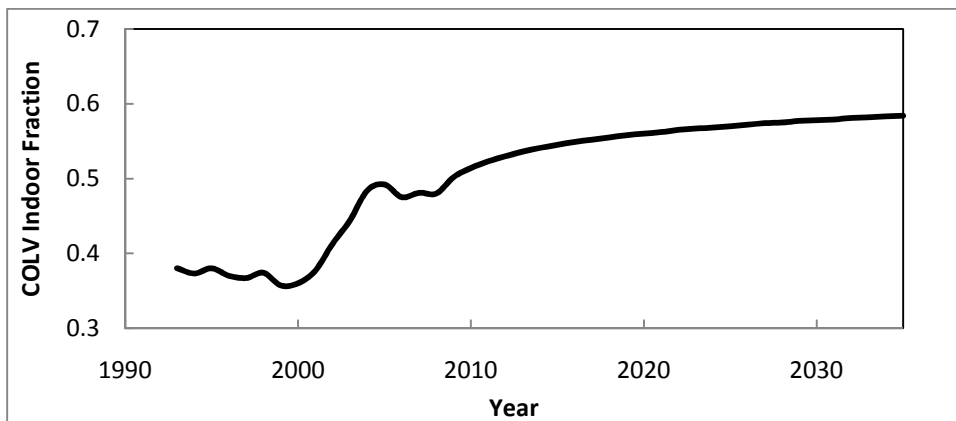
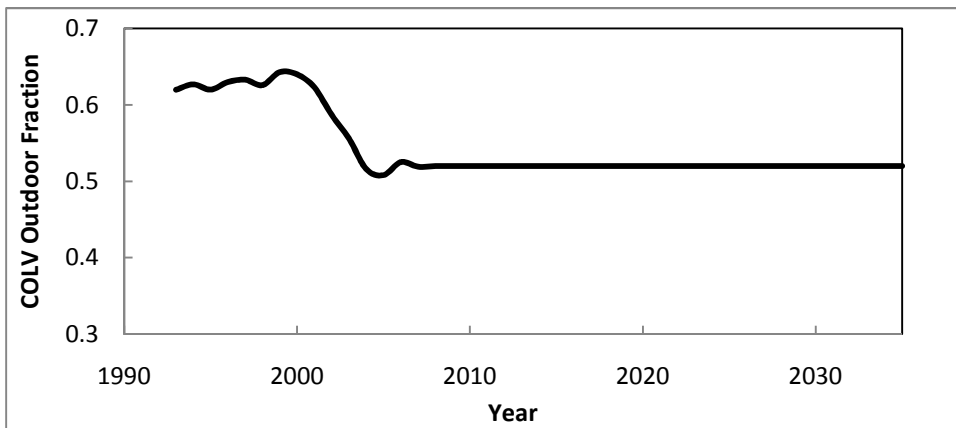COLV_Indoor_LN_33% = GRAPH(TIME) "Scenario 3" 67% outdoor 33%

Indoor conservation

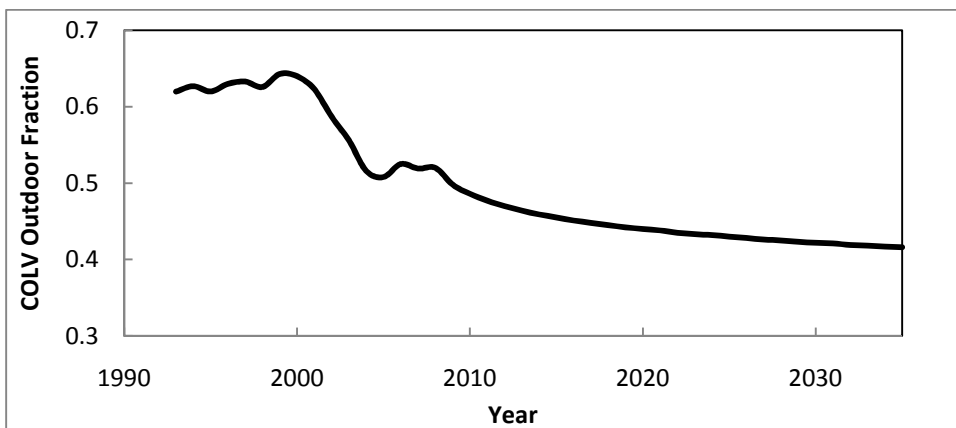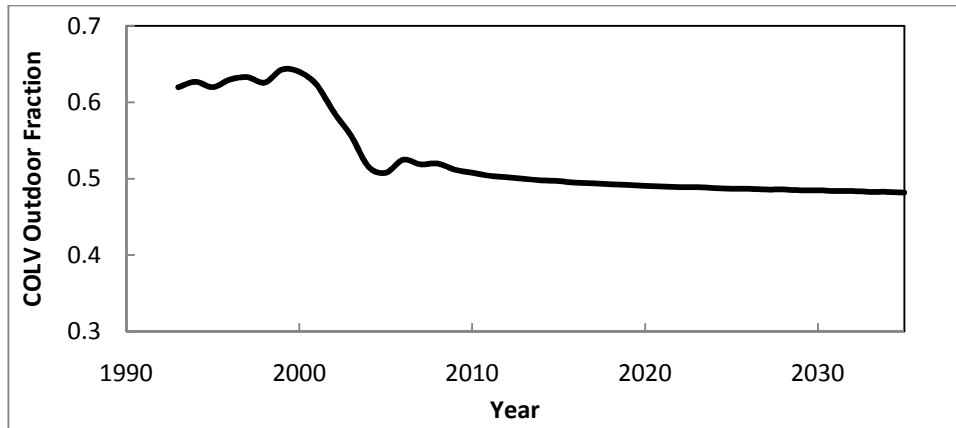COLV_Indoor_50%_LN = GRAPH(TIME) "Scenario 4" Equal outdoor

indoor conservation

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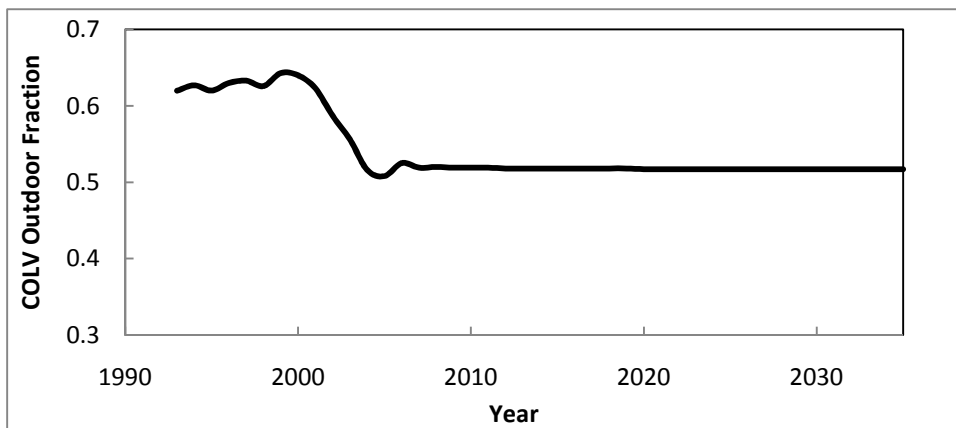COLV_Indoor_LN_3 = GRAPH(TIME) "Scenario 5" Total indoor

conservation

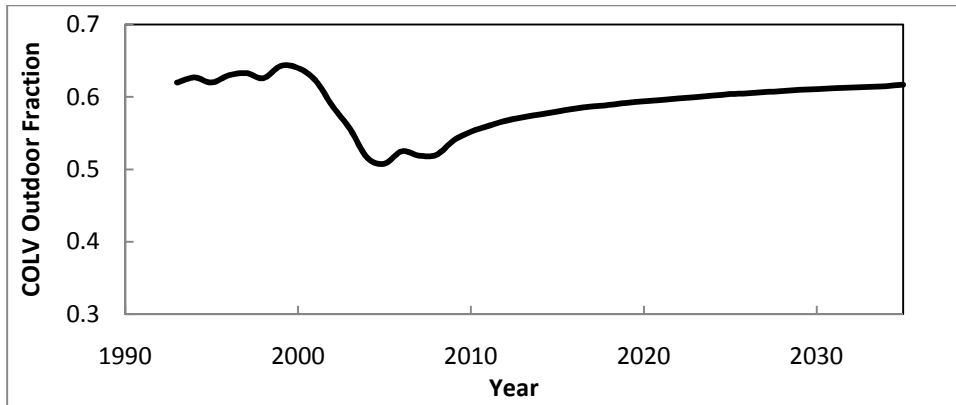COLV_Outdoor_Status_Quo = GRAPH(TIME) "Scenario 1" Status Quo

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COLV_Outdoor_LN_1 = GRAPH(TIME) "Scenario 2" Total outdoor
conservation

COLV_Outdoor_LN_66% = GRAPH(TIME) "Scenario 3" 67% outdoor 33%
Indoor conservation

COLV_Outdoor_50%_LN = GRAPH(TIME) "Scenario 4" Equal outdoor
indoor conservation

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COLV_Outdoor_LN_3 = GRAPH(TIME) "Scenario 5" Total indoor

conservation

Demand Section

This equation is used to calculate the population.

Population_In[Cities] = Scenario_Rate[Cities]*Pop_Stock[Cities]

Where,

Population_In[Cities] = Adjusted total population accounting for CBER,

CBER-0.5%, CBER+0.5% scenarios

Pop Stock[Cities] = Initial Population of Cities

Scenario_Rate[Cities] = IF(TIME > 2008)

THEN(CBER_Rate[Cities]+CBER_Rate_Change[Cities])

ELSE(CBER_Rate[Cities])

Where,

Scenario_Rate[Cities] = Population Growth Rate of cities

CBER_Rate[Cities] = CBER Population Projection

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CBER_Rate_Change[Cities] = Either 0%, -0.5% or +0.5%

This equation calculates the total water demand and accounts for the demand decrease due to water reuse. This equation is also used to select either the 2008 per capita demand for cities for scenario 1, or the average 199 gpcd demand for cities for scenarios 2, 3, 4 and 5

Reuse Adjusted_Water_Demand[Cities] = Water_Demand[Cities]-Total Reuse[Cities]

Where,

Reuse Adjusted_Water_Demand[Cities] = Final Reuse Adjusted Water Demand of a city

Total_Reuse[Cities] = Total Reuse Water in Cities

Water_Demand[Cities] (gpcd)= IF(Per_capita_demand_choice = 1) THEN(Pop_Stock[Cities]*Per_capita_demand__2008_level[Cities]/1000000) ELSE IF(Per_capita_demand_choice = 2) THEN Average_per_capita_199_gpcd_natural_log[Cities]/1000000) ELSE(0)

This equation is used to check if water demand exceeds the available supply

 Withdrawing_Water = IF((ARRAYSUM(Reuse Adjusted_Water_Demand[*])) < (Colorado_river+RFC+Total_Wells_Supply)) THEN((ARRAYSUM(Reuse Adjusted_Water_Demand[*]))-(Total_Wells_Supply)) ELSE(Colorado_river+RFC)

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Where,

Withdrawing_Water = Final Amount of Water Withdrawn from Lake Mead

ARRAYSUM(Reuse Adjusted_Water_Demand[*] = Sum of Reuse Adjusted

Water Demand of Cities

Colorado_river = Colorado river Share

RFC = Return flow Credits

Total Wells Supply = Water supply from Groundwater wells

Outdoor Use Components

These are the equations for the different outdoor use components in the

Valley.

Excess_Irrigation_runoff_ = Runoff_fraction*Total_Outdoor_Use

Total_Outdoor__Evaporation_ = Total_Outdoor_Use*Evaporation_Fraction

Seepage_to_Shallow_Groundwater = Total_Outdoor_Use* GW_Fraction_

Seepage_to_LV_Wash   =

Total_Outdoor_Use*Seepage_to_LV_Wash_fraction

Where,

Total Outdoor Use = Total Outdoor use in the Valley

VITA

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