RECLAMATION

Managing Water in the West

Los Angeles Basin Stormwater Conservation Study

Task 3.2 Hydrologic Modeling Report

U.S. Department of the Interior
Bureau of Reclamation

County of Los Angeles
Department of Public Works

Los Angeles County
Flood Control District

December 2013

Mission Statements

The mission of the County of Los Angeles Department of Public Works is to provide public infrastructure and municipal services to protect and enrich the daily lives of over 10 million people in Los Angeles County.

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover Photo: Morris Dam along the San Gabriel River, Los Angeles County, California.

Los Angeles Basin Stormwater Conservation Study

Task 3.2. Hydrologic Modeling Report

December 2013

Prepared by:

County of Los Angeles Department of Public Works
Los Angeles County Flood Control District
Watershed Management Division
Lee Alexanderson, Associate Civil Engineer
Daniel Bradbury, Senior Civil Engineering Assistant

Peer Reviewed by:

Taejin Moon, Civil Engineer

This page intentionally left blank.

Contents

Figures

Tables

Appendix

Acronyms and Abbreviations

af	acre-foot (1 af = 43,560 ft^3)
ALERT	Automatic Local Evaluation in Real-Time
cfs	cubic feet per second
CMIP3-BCSD	Bias Correction and Spatial Disaggregation Coupled Model Intercomparision Project, Phase 3
CMIP5-BCSD	Bias Correction and Spatial Disaggregation Coupled Model Intercomparision Project, Phase 5
CMIP5-BCCA	Bias Correction Constructed Analogue Coupled Model Intercomparision Project, Phase 5
F-Table	Hydrologic Function Table
GIS	Geographic Information System
LA Basin Study	Los Angeles Basin Stormwater Conservation Study
LACDPW	Los Angeles County Department of Public Works
LACFCD	Los Angeles County Flood Control District
LID	Low Impact Development
LSPC	Loading Simulation Program in C++
MWD	Metropolitan Water District of Southern California
RCP	Representative Concentration Pathway
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RO	Total rate of outflow from a subwatershed (LSPC output metric)
VOL	Total volume in a subwatershed (LSPC output metric)
WMMS	Watershed Management Modeling System
WRD	Water Replenishment District of Southern California

Glossary

Basin Study Watersheds (Study Area): The Los Angeles River, San Gabriel River, Ballona Creek, South Santa Monica Bay, North Santa Monica Bay, Malibu Creek, and Dominguez Channel/Los Angeles Harbor watersheds.

Climate Projection: Climate conditions and meteorological parameters (e.g. temperature and precipitation) corresponding to a single global climate model simulation of future climate conditions under a given emissions scenario and initial condition.

Ensemble Mean: The average of all datasets. The projected weather or hydrologic data derived from a specific global climate model, downscaling technique, and or emissions pathway are averaged to analyze the general trend.

F-Table: Operation guidelines for water conservation or flood control facilities that are represented by a generalized volume versus discharge curve. F-Tables control the discharge rate at specific volumes within the hydrologic model.

Historic Hydrology: Period of historic record encompassing water years 1987 through 2000.

Land Use: A specific use assigned to a particular land area with a known impervious surface area.

LSPC: (Loading Simulation Program in C++) Calculates and produces hydrologic output time series data for a specific set of subwatersheds and based on a specific dataset of weather files. LSPC is the hydrologic simulation program under the Watershed Management Modeling System (WMMS).

Maximum Flow Rate: The maximum one-hour flow rate attained at a specific discharge location (reported in cubic feet per second [cfs]).

Meteorological Inputs: Observed historic records or computer-generated projections of precipitation and evapotranspiration.

Projected Hydrology: Future period encompassing water years 2012 through 2095.

Run: Performance of a single hydrologic modeling setup using an individual climate change scenario.

Simulation: Equivalent to Run (used interchangeably).

Stormwater (Available): The amount stormwater runoff that passes out of a subwatershed which can potentially be captured within itself at upstream locations (reported in acre-feet [af]).

Stormwater Capture (% Capture): The ratio of Recharge to Total Stormwater for the sub-watershed.

Stormwater (Recharge): The total amount of stormwater infiltrated within a subwatershed with contributions from all water conservation facilities (reported in acre-feet [af]).

Stormwater (Total): The total amount of stormwater within a subwatershed system. It is the sum of Recharge and Available (reported in acre-feet [af]).

Subbasin: A simplified groundwater basin within WMMS to account for the amount of water recharged at each of the spreading facilities, rubber dams, or soft bottom channels.

Subwatershed: A sub-division of a larger watershed. Smallest area unit in WMMS.

Total Flow Volume: The total volume of stormwater that discharges through a certain location (reported as an annual average in acre-feet [af]).

Watershed (Drainage Area): Surface drainage area upstream of a specified point on a watercourse. A geographical portion of the Earth's surface from which water drains or runs off to a single point.

Water Year: The 12-month period between October 1st through September 30th for any given year. Water years are written as the ending year (i.e., water year 1986-87 is written as 1987).

Executive Summary

The Los Angeles County Flood Control District (LACFCD) partnered with the U.S. Department of the Interior, Bureau of Reclamation (Reclamation) to collaborate on the Los Angeles Basin Stormwater Conservation Study (LA Basin Study). The purpose of the LA Basin Study is to investigate long-range water conservation and flood control impacts caused by projected changes in climate conditions and population in the Los Angeles region. The LA Basin Study will recommend potential modifications or changes in the operation of the existing stormwater capture systems, and the development of new facilities that could help resolve future water supply and flood control issues. These recommendations will be developed by identifying alternatives and conducting trade-off analyses.

For Task 3, Downscaled Climate Change and Hydrologic Modeling of the LA Basin Study, Reclamation developed downscaled climate change projections, while LACFCD applied these projections to generate the future hydrology. LACFCD utilized the Watershed Management Modeling System (WMMS) to perform the hydrologic modeling for the LA Basin Study. This report summarizes the data, methods, and results of the historic and future hydrologic modeling.

The purpose of Task 3.2, Hydrologic Modeling is to simulate hydrology with respect to climate change for the Los Angeles River, San Gabriel River, Ballona Creek, South Santa Monica Bay, North Santa Monica Bay, Malibu Creek, and Dominguez Channel/Los Angeles Harbor watersheds (Basin Study Watersheds). This study incorporates the entire watershed boundaries, including where they extend outside of Los Angeles County. The following sub-tasks were identified to achieve this objective:

- Historic Hydrologic Modeling (Water Year 1987 through 2000)
    - Determine baseline scenario modeling assumptions
    - Prepare WMMS to simulate baseline scenario
    - Perform WMMS baseline simulations
    - Analyze and summarize WMMS results

- Projected Hydrologic Modeling (Water Year 2012 through 2095)
    - Determine future scenario modeling assumptions
    - Prepare WMMS to simulate future scenarios
    - Perform WMMS simulations
    - Analyze and summarize WMMS results

Historic & Projected Hydrology

The Historic Hydrology used an observed set of precipitation and evaporation records to produce the baseline conditions within WMMS. Similarly, the Projected Hydrology was also simulated in WMMS using the climate change projections developed by Reclamation. Three groups of climate change projections were developed from two major global climate datasets: CMIP3 and CMIP5, and with two downscaling techniques: BCSD and BCCA. The downscaling techniques are used to bring the coarser 200 kilometer resolution global climate datasets down to a more refined 12 kilometer resolution for use on a local scale in the LA Basin Study. CMIP3 was not investigated with the BCCA downscaling technique due to the large number of additional WMMS runs needed (approximately 30 to 40), which would have impacted the study schedule greatly to process and analyze.

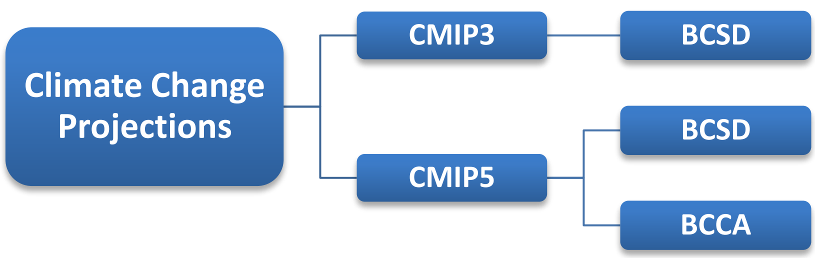


Figure ES-1. The LA Basin Study Climate Projections

WMMS produced hydrologic outputs of stormwater runoff and total stormwater volume stored for all LACFCD facilities, including dams and reservoirs, spreading grounds, stream gaging stations, and other hydrologic points of interest. The Projected Hydrology was then compared against the Historic Hydrology baseline to examine the impacts on water conservation and flood control due to the projected climate change.

Projected Changes to Stormwater Runoff

Figure ES-2 shows the percent change from the historic baseline in average stormwater runoff over the course of the century for all climate projections. It is important to recognize that for stormwater runoff there is a very high variability within the projections. Inspection of the ensemble mean, or total average across all projections, indicates that there is the potential for increased stormwater runoff. Additionally, analysis of LACFCD water conservation facilities shows a similar tendency for total stormwater recharge. However, reduced runoff is still observed in several projections.

The range of projected stormwater runoff is encompassed between the lower and upper bounds of the variability, with the ensemble mean used only to show the central tendency of all the projections combined.

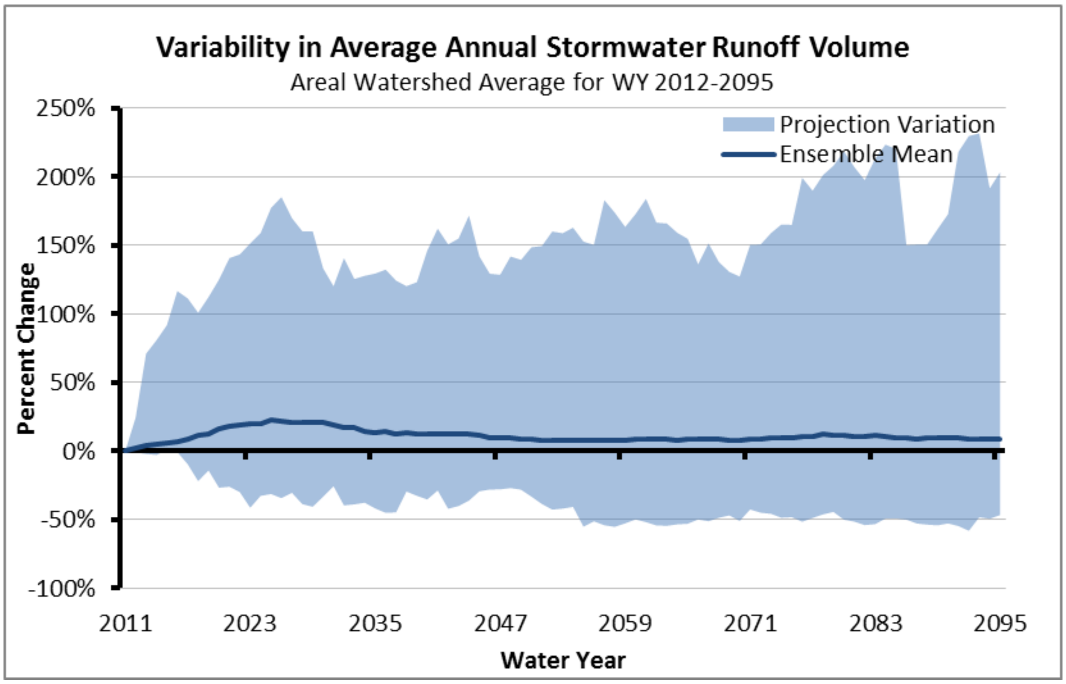


Figure ES-2. Projected Change in Average Annual Stormwater Runoff

Note: *Projection variation in Figure ES-2 represents only variability among the average annual runoff, not the variation in extreme wet and dry years.*

Projected Changes to Flood Flows

After comparing all hydrologic projections, there appears to be a high potential for increased peak flow rates when compared to the historic baseline. Figure ES-3 shows a similar trend as compared to the future projections of stormwater runoff. Overall, the vast majority of projections indicate a general increase in peak flood flow rates. However, as with stormwater runoff, the possible range of projections may be encompassed anywhere between the lower and upper bounds of the variability.

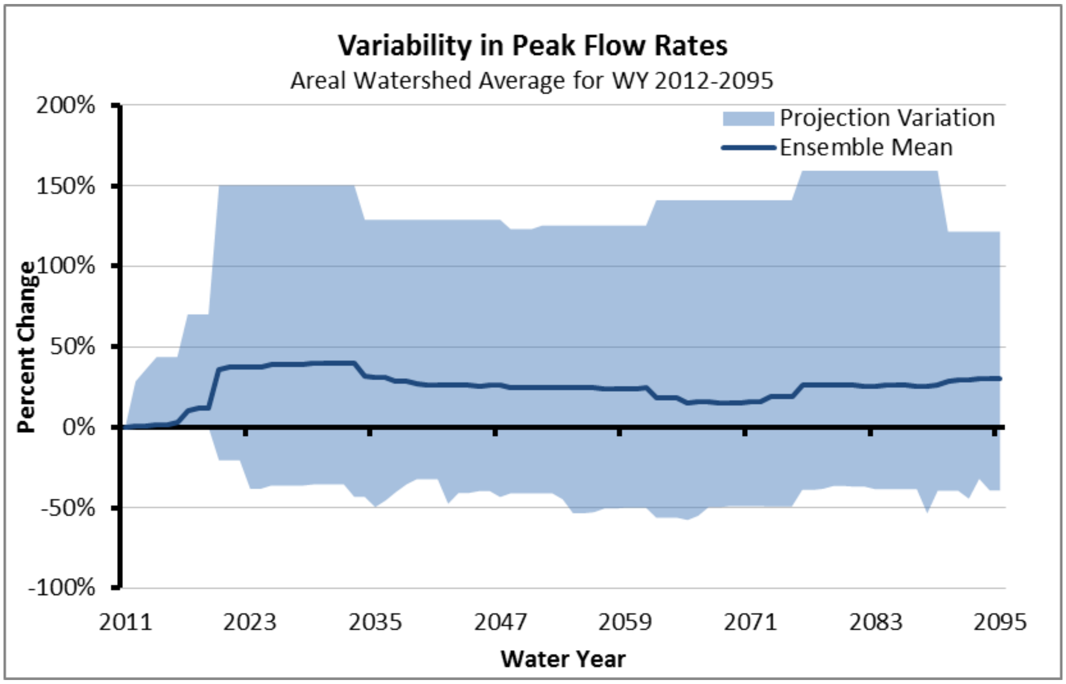


Figure ES-3. Projected Change in Peak Flow Rates

1. Introduction

1.1. Study Purpose

The purpose of the Los Angeles Basin Stormwater Conservation Study (LA Basin Study) is to study long-term water conservation and flood control impacts from projected climate conditions and population changes in the Los Angeles Basin. The LA Basin Study will recommend potential changes to the operation of stormwater capture systems, modifications to existing facilities, and development of new facilities that could help resolve future water supply and flood control issues. The recommendations will be developed through identifying alternatives and conducting trade-off analyses.

1.2. Study Background

The Los Angeles County Flood Control District (LACFCD) has been considering the possibility of large-scale enhancement of the LACFCD's water conservation capabilities through the study of long-term projected needs and future climate conditions. Informal discussions occurred between LACFCD and several major water agencies on the same subject. As a result, this interest was the driving force for creating a partnership between the LACFCD and U.S. Department of the Interior, Bureau of Reclamation (Reclamation) under the Basin Studies Program (Reclamation 2009).

The LA Basin Study will utilize the latest climate science and hydrologic modeling tools to create a vision of the near-term and long-term future of stormwater capture in Los Angeles County. The LA Basin Study will offer the opportunity for multiple water management agencies to participate in a collaborative process to plan for future local water supply scenarios. The LA Basin Study will examine opportunities to enhance existing LACFCD and LA Basin Study partner facilities and operations and develop new facilities to demonstrate direct benefits to water agencies and local communities.

The LA Basin Study will utilize, to the greatest extent practicable, existing information on the availability and suitability of various open space and underdeveloped parcel opportunities as infiltration sites. The LA Basin Study will evaluate potential infiltration sites for soil characteristics, groundwater basin condition, conveyance/diversion/outlet requirements, site remediation requirements, property valuation and availability, environmental impact, regulatory requirements, community impact, multiuse potential, and other factors deemed necessary to assess a potential site.

The LA Basin Study will consider technical viability of implementing innovative facility concepts that show a prospective for increasing infiltrative capacity to recharge groundwater. A trade-off analysis will be conducted to evaluate the regional impacts and the economic costs and benefits of the various stormwater capture alternatives. Additionally, the study will look at the costs of attaining different goals through a cost-effectiveness analysis. The final outcome and recommendations of the LA Basin Study concept development and trade-off analyses will serve as a guiding document for further local water supply development planning, financing strategy, and policy adoption at the LACFCD and other LA Basin Study partners.

1.3. Description of Study Area

The Los Angeles River, San Gabriel River, South Santa Monica Bay, North Santa Monica Bay, Ballona Creek, Malibu Creek, and Dominguez Channel/Los Angeles Harbor watersheds (Basin Study Watersheds) are the focus of this LA Basin Study, and are shown in Figure 1. This study incorporates the entire watershed boundaries, including where they extend beyond the County of Los Angeles.

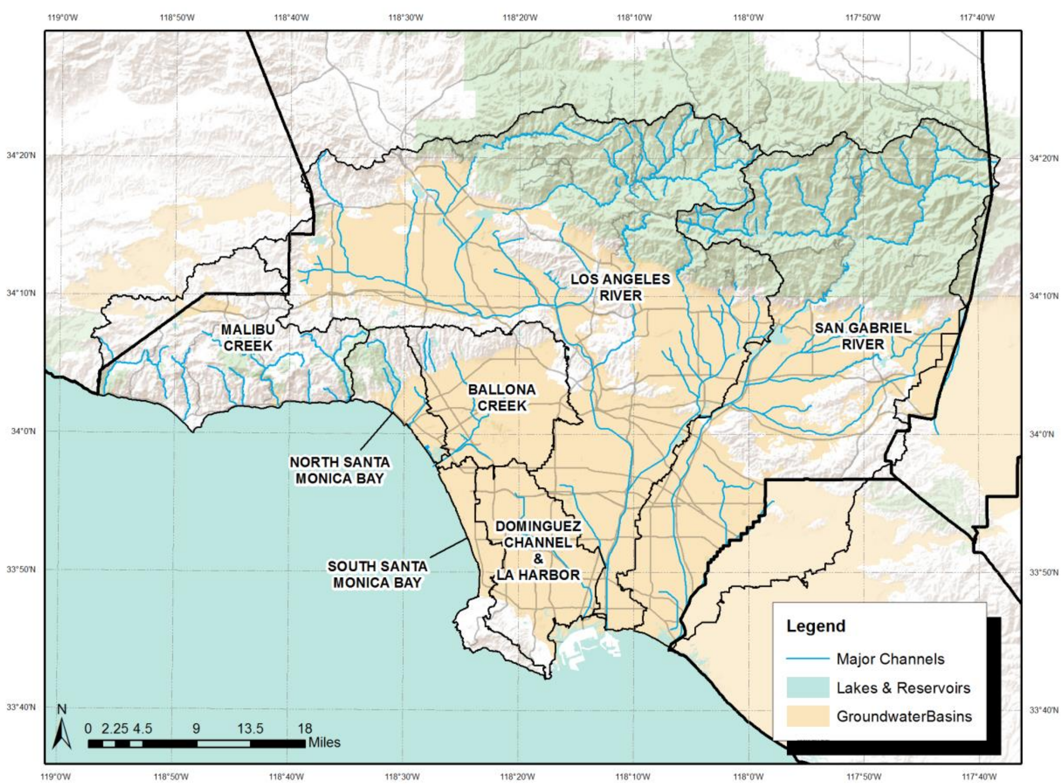


Figure 1. Los Angeles Basin Stormwater Conservation Study Watersheds

The LA Basin Study area includes several large groundwater basins, including the Central Basin, Main San Gabriel Basin, Raymond Basin, San Fernando Valley Basin, Six Basins, and West Coast Basin (Figure 2). The LACFCD's 14 major dams and reservoirs (Figure 3) are located in the front range of the San Gabriel Mountains stretching more than 40 miles from the San Fernando Valley on the west to the eastern edge of the San Gabriel Valley (Los Angeles County Department of Public Works [LACDPW] 2013). The largely undeveloped watershed area upstream of the LACFCD dams is approximately 400 square miles and the majority of it is within the Angeles National Forest. Spreading grounds—which serve to infiltrate stormwater runoff—are located in areas of high permeability downstream from the LACFCD dams. Rubber dams are located within the natural bottom portions of a river and help to retain and percolate stormwater through the river bottom.

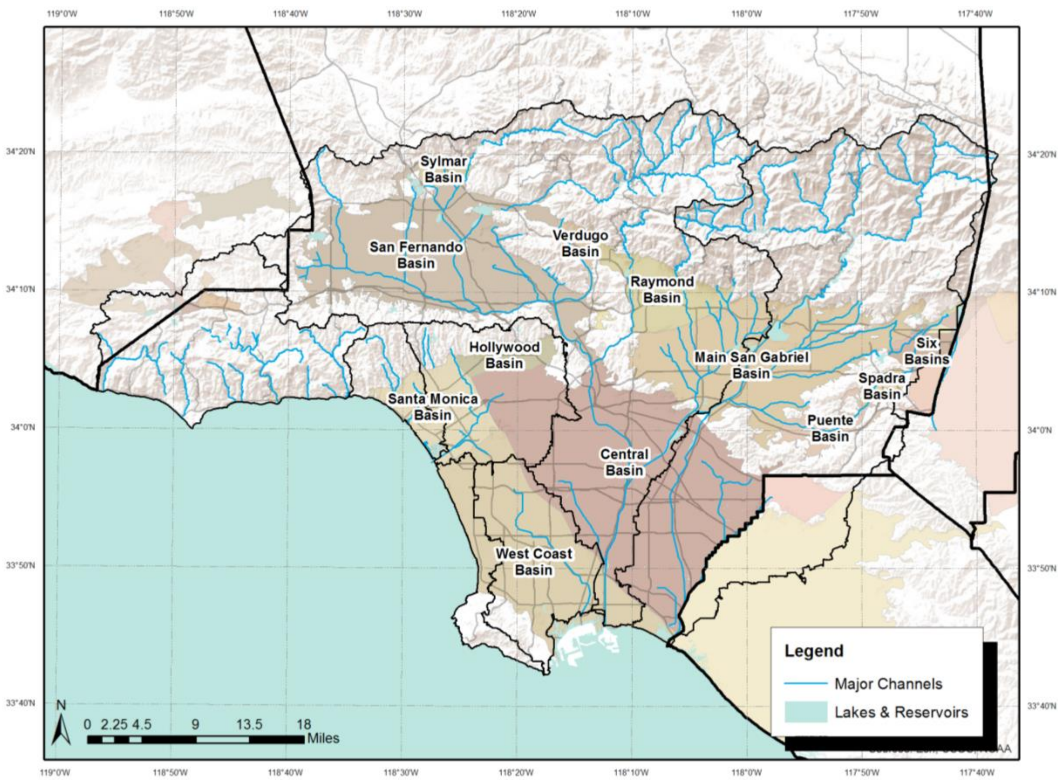


Figure 2. LA Basin Study Major Groundwater Basins

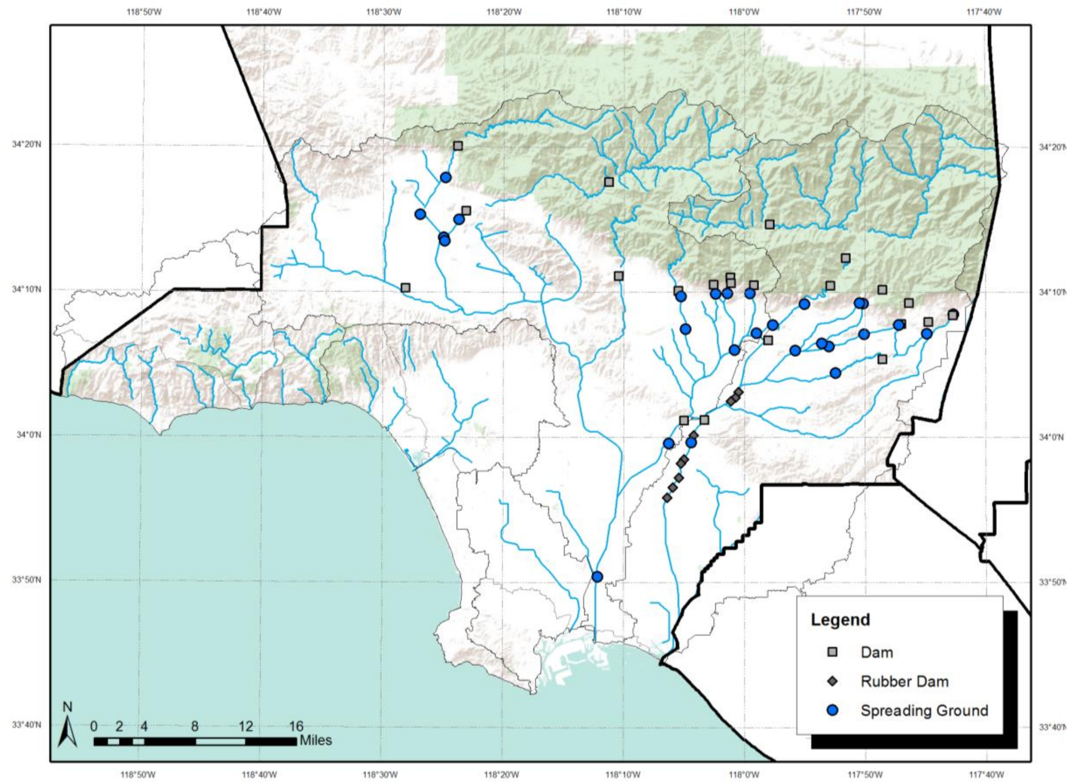


Figure 3. LACFCD Flood Control and Water Conservation Facilities

The Basin Study Watersheds include more than 9 million people and cover approximately 1,900 square miles. More than 95 percent of Los Angeles County's population resides within the LA Basin Study area. This population concentration also accounts for more than one-fourth of the State of California's population. Presently, California's population is 37.3 million people and the County of Los Angeles' population is nearly 9.8 million. By 2050, the populations of California and the County of Los Angeles are projected to reach approximately 50.3 million and 11.4 million, respectively.

According to the California Department of Finance, the State's population as a whole is projected to increase by more than 34 percent, while Los Angeles County's is projected to increase by approximately 16 percent (Department of Finance 2013). Projected larger population growth rates outside of Los Angeles County indicate there will be enormous pressure and competition for imported sources of water and the need for increased development of local water supply sources. At present, Los Angeles County accounts for the largest amount of water demand of any urbanized county in California. Total water usage within the Los Angeles County portion of the Metropolitan Water District of Southern California (MWD) service area—an area wholly served by the LACFCD—exceeded 1.54 million acre-feet in fiscal year 2011-12 (MWD 2012).

1.4. Hydrology Model Used for Study

The Watershed Management Modeling System (WMMS) was used for the historic and projected hydrologic modeling of all Basin Study Watersheds and subwatersheds. The underlying software in WMMS which performs the actual hydrologic simulations is known as the Loading Simulation Program in C++ (LSPC). LSPC simulated and provided continuous hourly runoff and volume outputs at all facilities, watersheds, and subwatersheds targeted for the LA Basin Study.

1.5. Hydrology Model Description

WMMS is a comprehensive computer based decision support system for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. The model combines the Hydrological Simulation Program-Fortran (HSPF) with a watershed-scale nonpoint source pollutant model to create a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions.

WMMS can produce a time history of runoff flow rates, sediment loads, as well as water quantity and quality at any point in a watershed. The model simulates three sediment types (sand, silt, and clay). As a note, the LA Basin Study targeted only outputs of stormwater flow rate and volume. Water quality and sediment transfer were not investigated.

The model was peer-reviewed by the U.S. Environmental Protection Agency, internally at LACFCD, and by local stakeholders. WMMS employs kinematic wave routing within the channel and river network and assumes one-directional, well-mixed flow inside the fixed channel configurations (Tetra Tech 2010).

WMMS was developed to evaluate the watershed input and timing of flow and mass into the channel and river network, and has the capability of running multiple combinations of runoff scenarios that will be based on the projected changes in rainfall patterns and varied watershed conditions. For production of the simulation file, LSPC has been integrated into a Geographic Information System (GIS) interface via MapWindow to allow users to quickly create any number of hydrologic runs (Figure 4).

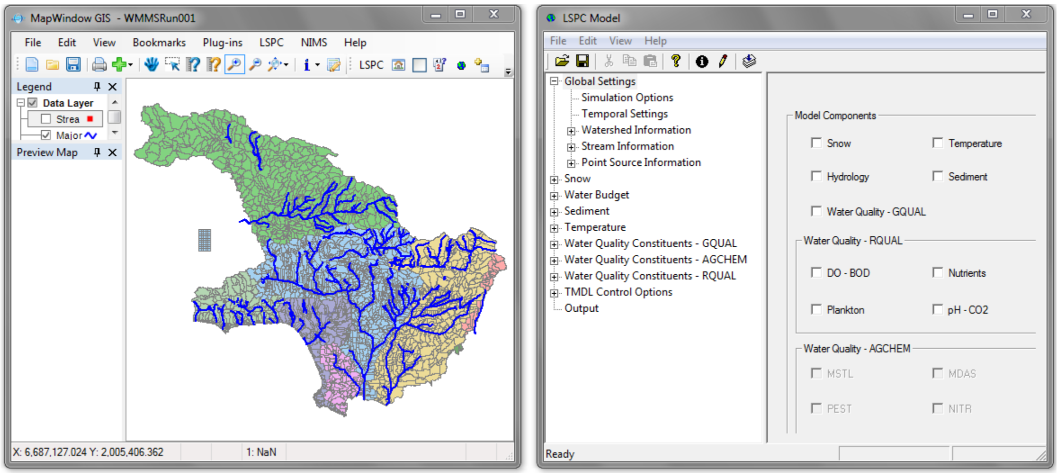


Figure 4. MapWindow GIS User Interface (Left) & LSPC User Interface (Right)

1.6. Summary of Procedures

The LA Basin Study utilizes LSPC to perform all of the hydrology modeling simulations, which is capable of simulating hydrology for all of the Basin Study Watersheds, including their subwatersheds, for historic meteorological records and the extended projected climate change scenarios.

The two main inputs into LSPC were precipitation and evapotranspiration data (Meteorological Inputs). In order for LSPC to run, the Meteorological Inputs were formatted to a time step of one-hour. WMMS comes pre-loaded with historic Meteorological Inputs for the County of Los Angeles. Continuous records from 134 precipitation gages and 17 evaporation stations are included in WMMS and provide data from January 1, 1986 to April 30, 2012. At the start of a model simulation, it was recommended to ignore an initial period of hydrologic output results in order to build up antecedent conditions within the Basin Study Watersheds. Thus, as the model initially started “dry,” reservoirs and channels needed to have some operational demand before the start of the output. Therefore, the hydrologic output range from October 1, 1986 to September 30, 2000 (water years 1987 through 2000) was considered to be the foundation for the baseline conditions (Historic Hydrology).

In addition to the historic Meteorological Inputs, the WMMS database was also pre-populated with the subwatershed network of Basin Study Watersheds, which totaled 2,221 subwatersheds. LSPC calculated hydrologic outputs of mean-hourly total runoff (RO) and total volume (VOL) for each subwatershed. Certain subwatersheds within the network contained important water supply and conservation infrastructure such as dams, spreading grounds, rubber dams, or stream gaging stations that were important to analyze. For the Historic Hydrology, 210 of these sites were targeted for analysis and resulted in 210 separate hourly output files of RO and VOL.

To simulate the future hydrologic conditions within the Basin Study Watersheds, the historic Meteorological Inputs were augmented using climate change procedures conducted by Reclamation from the companion Los Angeles Basin Stormwater Conservation Study: Task 3.1. Downscaled Climate Change Report (Reclamation, 2013). This augmentation developed 47 sets of projected Meteorological Inputs for all of the 134 precipitation gages and 17 evaporation stations. The future climate period spans from water years 2012 through 2095. The three climate change projections generated by Reclamation are as follows:

- **CMIP3-BCSD:** Bias Correction and Spatially Disaggregated Coupled Model Intercomparision, Project Phase 3 (5 Meteorological Input sets)
- **CMIP5-BCSD:** Bias Correction and Spatially Disaggregated Coupled Model Intercomparision, Project Phase 5 (5 Meteorological Input sets)
- **CMIP5-BCCA:** Bias Correction Constructed Analogues Coupled Model Intercomparision, Project Phase 5 (37 Meteorological Input sets)

Figure 5 shows the relationship between the climate change projections and their individual scenarios that were utilized in the LA Basin Study.

The future hydrology (Projected Hydrology) was simulated by running the 47 climate change projections for the 210 target subwatersheds. The Projected Hydrology produced 47 sets of climate-adjusted hydrologic outputs, with each set containing hourly output files of RO and VOL for the 210 individual target subwatersheds.

To further supplement the Projected Hydrology, the potential influence of widespread Low Impact Development (LID) was analyzed at a macro level. The impacts of LID implementation were investigated to determine whether or not more stormwater could be captured and if there was any significant effect on the peak flow rate during storm events. After an initial investigation of sources pertaining to LID and/or its implementation, it was determined that there is currently no defined method or tool to estimate the future implementation rate. Therefore, the LA Basin Study assumed reasonable LID implementation rates for use in these hydrology projections (refer to Methodology in Section 2.1.4).

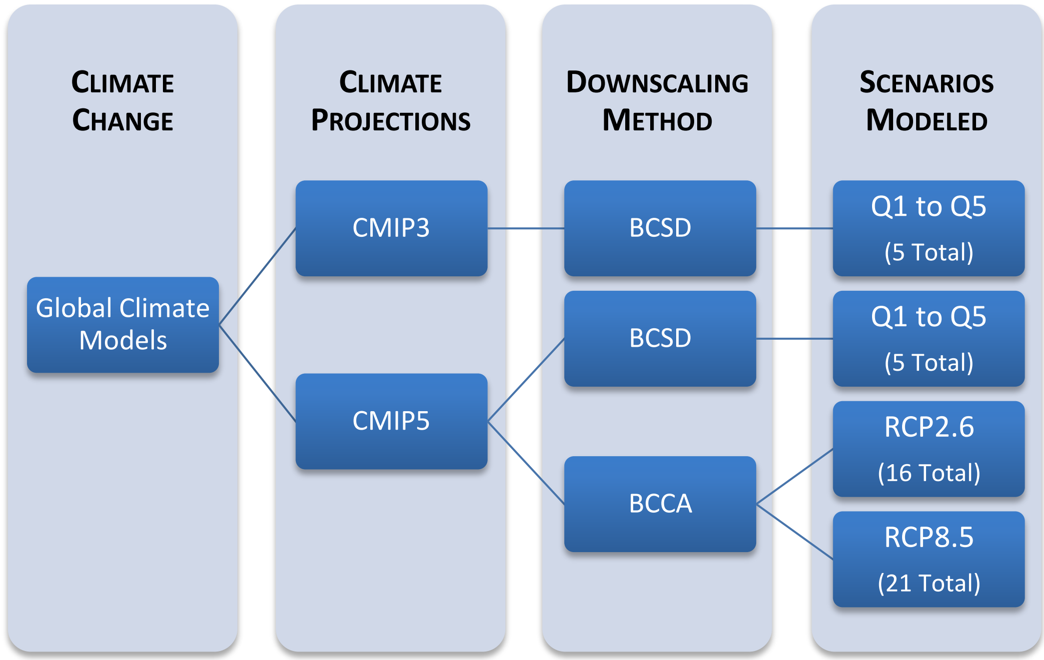


Figure 5. Climate Change Projections Used in the LA Basin Study

The estimated effect of LID was incorporated into the hydrologic model by adjusting pervious land areas within the WMMS land use database. LID act to capture and infiltrate stormwater runoff; therefore, a very approximate relationship between LID and pervious surface areas was developed. The reduced stormwater volumes coarsely reflect that amount of water that could potentially be captured by LID. The Projected Hydrology simulated an additional 10 hydrology runs for LID implementation using the five CMIP3-BCSD and five CMIP5-BCSD ensemble scenarios.

For the 58 total hydrology simulations shown in Figure 6, the results outputted mean-hourly RO and VOL values at each of the 210 target subwatersheds. The hydrologic results were post-processed and analyzed in order to develop metrics that are more consistent with the typical values used for planning purposes. The RO and VOL outputs were processed as shown in Figure 7.

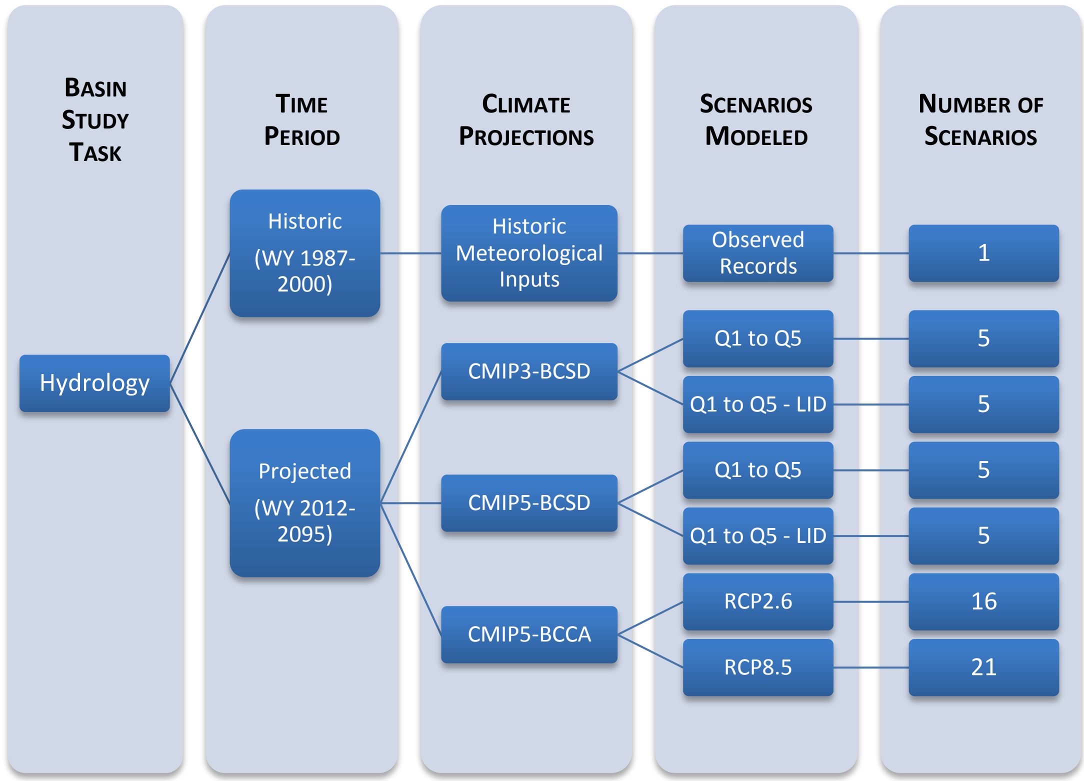


Figure 6. Hierarchy of the 58 Hydrology Simulations

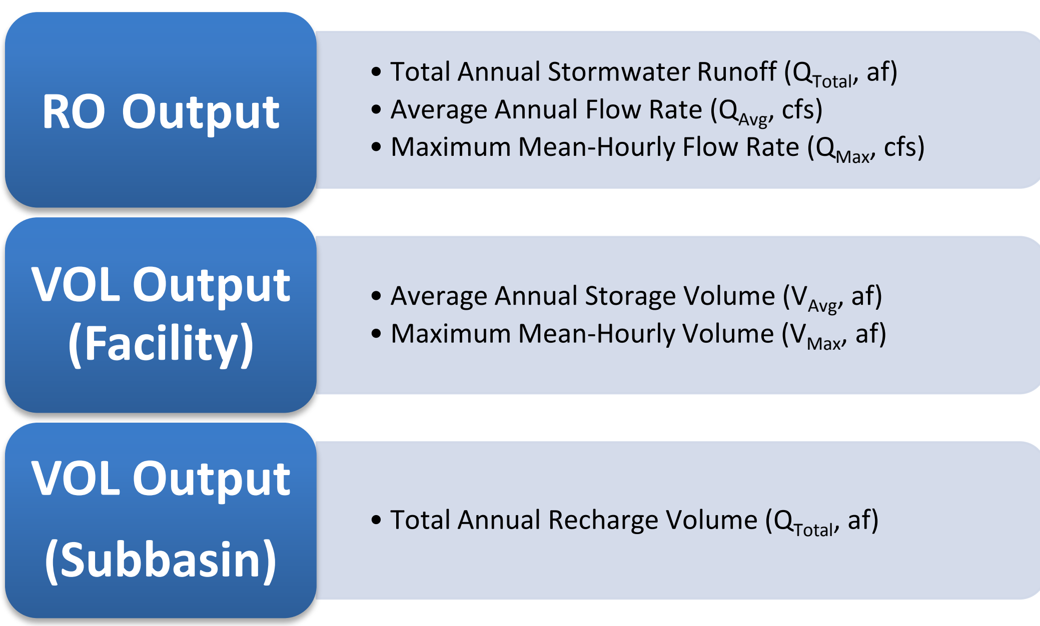


Figure 7. Analysis Performed on Raw RO and VOL Output Results

2. Methodology

The main purpose of LA Basin Study Task 3.2 is to use the meteorological inputs in WMMS to produce climate-adjusted hydrologic output projections. WMMS utilized the meteorological inputs from CMIP3-BCSD, CMIP5-BCSD, and CMIP5-BCCA to create these hydrologic projections.

This section details the procedures followed in order to prepare the WMMS model and analyze the resulting hydrology projections.

Section 2.1. describes the preparations needed to run WMMS.

Section 2.2. describes the meteorological input files necessary to run the simulations and the hydrology projection outputs created by the WMMS simulation.

Section 2.3. describes how the raw output projections were processed.

Section 2.4. discusses the hydrologic analysis of the output projections.

2.1. Hydrology Model Preparation and Setup

This section discusses the methods used to set up WMMS and generate the hydrologic output values for the LA Basin Study.

Section 2.1.1. outlines the WMMS model assumptions.

Section 2.1.2. describes the calibration efforts.

Section 2.1.3. describes the meteorological input setup.

Section 2.1.4. discusses the incorporation of the LID implementation.

2.1.1. Model Assumptions

WMMS is a one-dimensional hydrologic model. In short, the runoff is generated from continuous precipitation and potential evapotranspiration records, and the runoff is then routed over time through each subwatershed to its designated downstream subwatershed(s) in a unidirectional approach. It is important to recognize that the model is not a hydraulic simulation program, as it cannot simulate hydraulic properties, such as changes in channel shape or channel slope, and it cannot simulate hydraulic jumps or other related phenomena. WMMS is simply a mass conservation program and is used to keep track of the total volume of water moving through the system.

A major assumption for spreading grounds (Figure 8) in WMMS is that all the runoff traveling into a subwatershed passes into that spreading ground. This idealistic generalization reduces complexity within the model and permits for much faster simulation times. However, as this assumption works well for reservoirs, it cannot address the full complexity of spreading ground operations. Effectively, this assumption removes the intricate nature of how most spreading facilities operate in reality. Spreading facilities are typically located adjacent to a river or stream, and flows coming into a spreading facility are limited by a forebay or other intake structure. With this generalization, however, the model assumes that the spreading grounds are in-line with a channel or river and would have to fill to maximum capacity before allowing any water to pass through downstream. This assumption ignores the incoming flow rates with respect to the intake capacity as well as the potential for increased turbidity during high flows. As this is a considerable assumption, a calibration effort was necessary to modify the recharge or percolation rates of each spreading facility so that the simulated annual average recharge volumes mimicked historic records.

Figure 8. Morris Dam (Left) and San Gabriel Canyon Spreading Ground (Right)

In WMMS, the weather handling assumed that individual precipitation gauges and evaporation stations represented large areas overlaying multiple subwatersheds. An interpolated Thiessen polygon mesh was constructed for both the precipitation gauges and the evaporation stations (Figure 9). The subwatersheds that were assigned to each polygon within the mesh, and hence an individual gage or station, were collected by the location of the centroid of the subwatershed that falls within the polygon boundary. As there were fewer evaporation stations than precipitation gauges, the polygon mesh was much less dense for the evaporation stations. Because of this, the evaporation distribution was not as refined as precipitation; however, the overall sensitivity of evaporation on the majority of the system is minimal. During the wet season when winter storm events occur, the pan measured evaporation rates diminish when compared to the summer rates, which in turn reduces the system sensitivity. Additionally, since storms typically fall and disperse quickly, and because temperatures during these days are generally cooler, evaporation will have a lesser impact on actual stormwater runoff volumes.

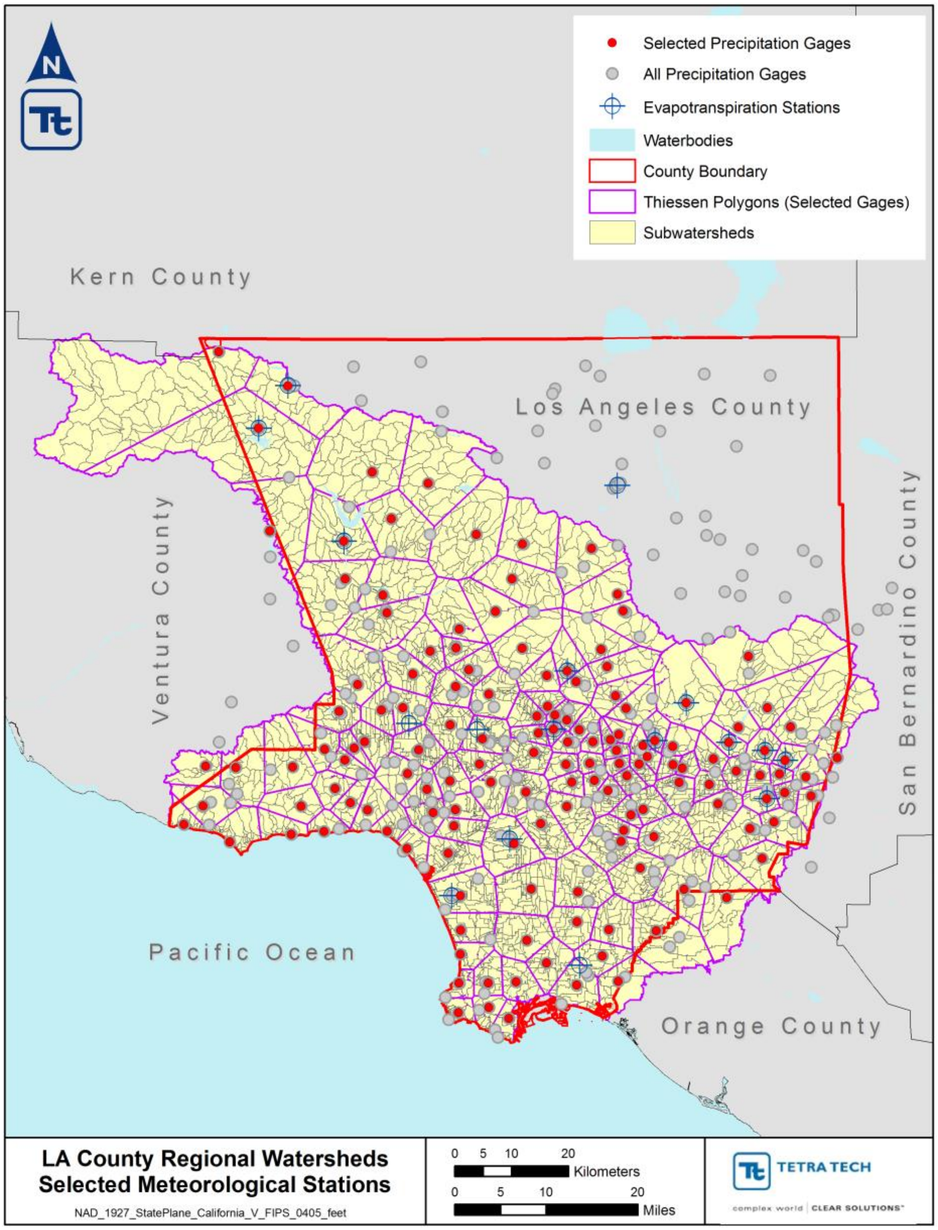


Figure 9. WMMS Precipitation Gage Thiessen Polygon Mesh

As an additional assumption, sources of all water within the system are comprised entirely from stormwater produced from precipitation falling within the Basin Study Watersheds. Imported or recycled water sources were removed from the model, including nuisance flow runoff from irrigation. Only potential stormwater recharge produced from the future hydrology projections was targeted, so it was necessary to remove these additional sources. This also prevented a co-mingling effect of water sources which would have made it difficult to decipher between the different quantities of water recharged. Typically, literature or reports on recharge quote all of these sources, so estimates provided in the LA Basin Study will be to some extent lower than observed normal as they are focused on recharge from stormwater runoff.

2.1.2. F-Table Correction and Calibration

2.1.2.1. Dam and Reservoirs

During the project planning phase of the LA Basin Study, WMMS was targeted to be the sole source for all hydrologic outputs. However, the model was originally developed for water quality purposes and was not intended for purely hydrologic studies. Subsequently, the model had to be optimized for this type of modeling situation that included future hydrology projections. One of the major changes applied to the model was a complete overhaul of the reservoir and spreading ground operation guidelines within the WMMS database. In WMMS, these operation guidelines are represented by generalized volume versus discharge curves called Hydrologic Function Tables (F-table). These F-tables control the dam discharge rate when a facility is at a specific storage volume. During simulation, the program interpolates the discharges between the user defined points for a continuous operations curve.

In WMMS, the original F-tables were greatly simplified for analysis of observed conditions. The F-tables set reservoir storage volumes to be infinitely large and were not associated with a dam discharge rate characteristic. Instead, discharges from reservoirs were controlled using a different mechanism. Within WMMS, there was a pre-established point source database that provides a time series of observed hourly discharge rates for all reservoirs. This point source database would draw from the F-table storage volumes and discharge flows from the facility according to the observed hourly discharge rates. This original setup was accurate for modeling observed flows or discharges during the historic period, but the setup proved problematic for conducting the projected hydrology. Since the day-to-day operations of each dam/reservoir cannot be known for the future climate and that dam operations are greatly influenced by immediate or impending weather conditions, the historic point source database discharge methodology could not be employed to model the facilities under future conditions.

In order for the F-tables to work with future hydrologic projections, they were further developed and refined to resolve the issue of WMMS being constrained to using historic point source discharges for the reservoirs. Observed historical data were obtained for reservoir storage volume linked with the water surface elevation and a corresponding dam discharge rate. The numerous pairs of water surface elevation and discharge rates were plotted to understand the general operations at each of the facilities. Next, a moving average of the paired data was generated to develop a discharge curve. This moving average line—or discharge curve—was then used to produce a best-fit constructed F-table curve for each facility. The constructed F-table curve signals the model to discharge at a certain rate as a function of water surface elevation. The refinement of the F-tables removed the limitation of discharging flows at a pre-established observed rate regardless of the storage volume impounded in the reservoir. The resulting F-tables could now be used for any period of interest—historic or future.

Figure 10 below shows the development of a F-table with the observed raw reservoir data points, the moving average line to depict a general discharge trend, and the best fit constructed F-table line for Morris Dam. Table 1 below shows the actual F-table for Morris Dam.

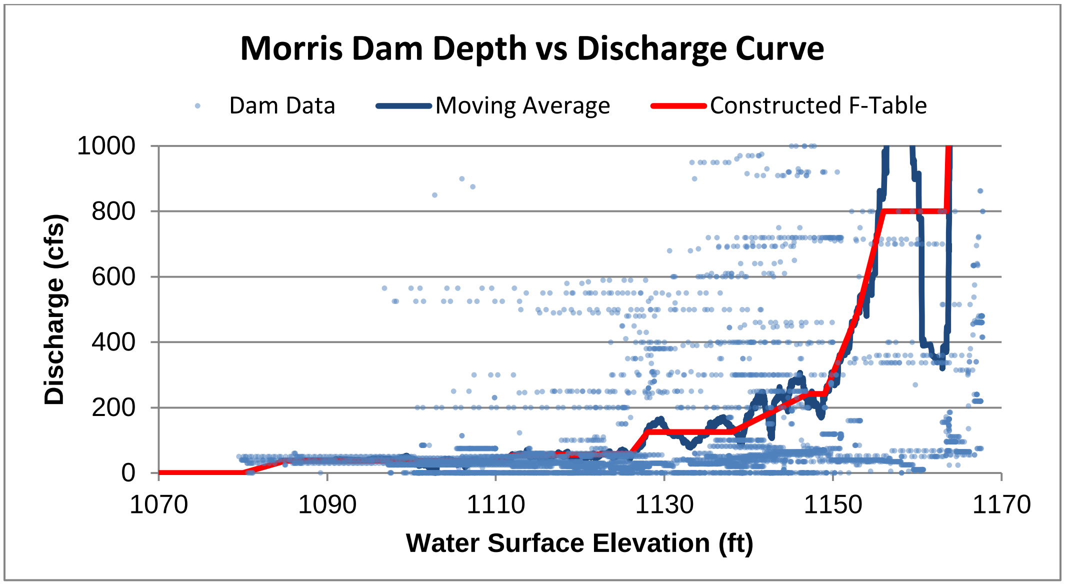


Figure 10. F-table Example for Morris Dam

Table 1. F-Table Database Entry for Morris Dam

Subwatershed ID	Depth (ft)	Area (acre)	Volume (ac-ft)	Discharge (cfs)
5270	0	0	0	0
5270	102	180	6,114	0
5270	107	191	6,795	37
5270	132	250	10,995	37
5270	134	256	11,413	54
5270	148	299	14,751	59
5270	150	305	15,264	125
5270	160	338	18,013	125
5270	169	368	20,721	242
5270	171	375	21,352	242
5270	175	388	22,648	495
5270	178	399	23,647	800
5270	186	425	26,261	800
5270	187	430	26,802	2,218
5270	189	437	27,534	2,281
5270	190	439	27,718	4,063

2.1.2.2. Spreading Facilities

Unlike the dams and reservoirs, the spreading facility calibration was much more involved. Spreading facilities are modeled within WMMS as a single subwatershed and, as stated earlier, all water generated in or traveling into the subwatershed is assumed to travel into the spreading facility. As this is a very general and idealistic assumption, special consideration was necessary for calibration.

For the spreading ground calibration effort, the most upstream facilities were targeted first (Figure 11). As each location's F-table was calibrated, the effort continued downstream until finally the most downstream facility was calibrated. The parameter adjusted during the calibration was the groundwater percolation discharge rate for each facility. As a limiting factor of the model, the percolation rate within WMMS is constant. It is important to note; however, that percolation rates are actually highly variable and that percolation is based on a number of factors, including silting, organics such as algae and ground water mounding. Because of this limitation within the model, it was necessary to develop an overall average percolation rate for each facility. This average percolation discharge rate was developed by matching WMMS recharge outputs with actual historic stormwater recharge data.

As a comparison baseline for each spreading ground, an upstream flow gage was first selected. At this selected upstream flow gage, the model output was then compared to historic record. A percent difference was then developed between the simulated flow and the historic flow. This determined how accurate the modeled flows were. Next, this percent difference was applied to the historic annual average recharge volume at the spreading facility being calibrated. This typically decreased the historic stormwater recharge volume, which was then used as a target recharge volume for the modeled recharge calibration.

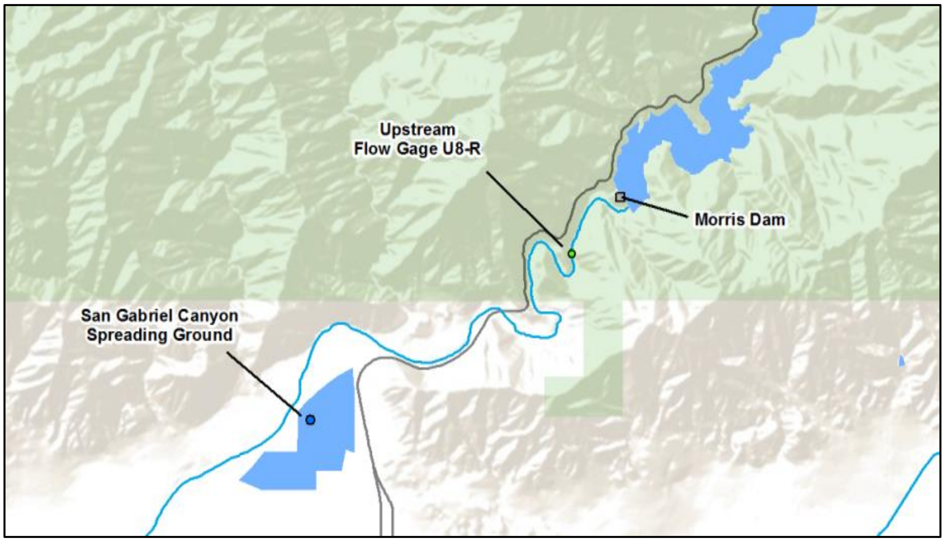


Figure 11. Example Schematic for Spreading Ground Calibration

The reason the historic records were modified with this percentage increase or decrease was to account for the difference in the amount of water within the system. The flood control system normally contains a large amount of other water sources, such as imported and recycled water, but these water sources were not added to the model and this left only stormwater present within the entire system. With this assumption, a large reduction in water within the system called for a change to the simulated recharge targets, so that an analogous recharge rate could be determined for each spreading facility.

Starting with an initial percolation rate at a spreading site, this percolation rate was then iteratively increased or decreased until the simulated recharge matched the modified historic recharge target. Figure 12 below provides an example procedure of how the calibration methodology was applied to the spreading facilities.

Example:

- Upstream gage U8-R below Morris Dam historically records 110 ac-ft of runoff annually
- San Gabriel Canyon Spreading Ground historically recharges 20 ac-ft of runoff annually
- WMMS simulates 100 ac-ft of runoff annually at U8-R

For the spreading ground calibration, the recharge target was decreased by a factor of 91% (100/110) of the historical recharge volume, or equivalent to 18.2 ac-ft of recharge. Within WMMS, the spreading ground percolation discharge rate was modified using an iterative process until the recharge target was reached. Once the target was reached, a check would be made to verify that the downstream flow gaging station behaved similarly and corresponded with the original factor of 91%. This verified that no more or less water was recharged or released between the gages as compared to historical data. This process was then repeated for all spreading facilities in the system.

Figure 12. Example Calibration for San Gabriel Canyon Spreading Ground

After an extensive update and calibration effort, the recharge and runoff numbers were found to match well with the annual average historic records. Comparisons of the historic and simulated results validate that the model is producing reasonably accurate values for urbanized watersheds.

For month-to-month operations, however, the spreading facilities were not as accurate. This divergence is related to the intricate nature of how water is conveyed throughout the entire system; with the demands for water to different areas within the Los Angeles County region influencing the annual recharge totals at each spreading facility. Additionally, it has been determined that for certain rural or largely non-urbanized regions such as the Malibu Creek watersheds, the model produces higher runoff than expected. This is largely due in part that the runoff coefficients were not calibrated specifically in this watershed during the creation of WMMS. Overall, calibration increased the accuracy of the model.

During the calibration effort, nearly all stream gaging stations within the system were used. It was difficult to calibrate to some of the gages, which may be due to the uncertainties within the gage measurement. Most gages within the system measure water depth and correlate the depth to an assumed channel velocity, which is an empirical relationship. Additionally, other sites have only high water metering, which loses data when dealing with smaller flows. For reference, Figure 13 shows the location of all LA Basin Study stream gaging stations.

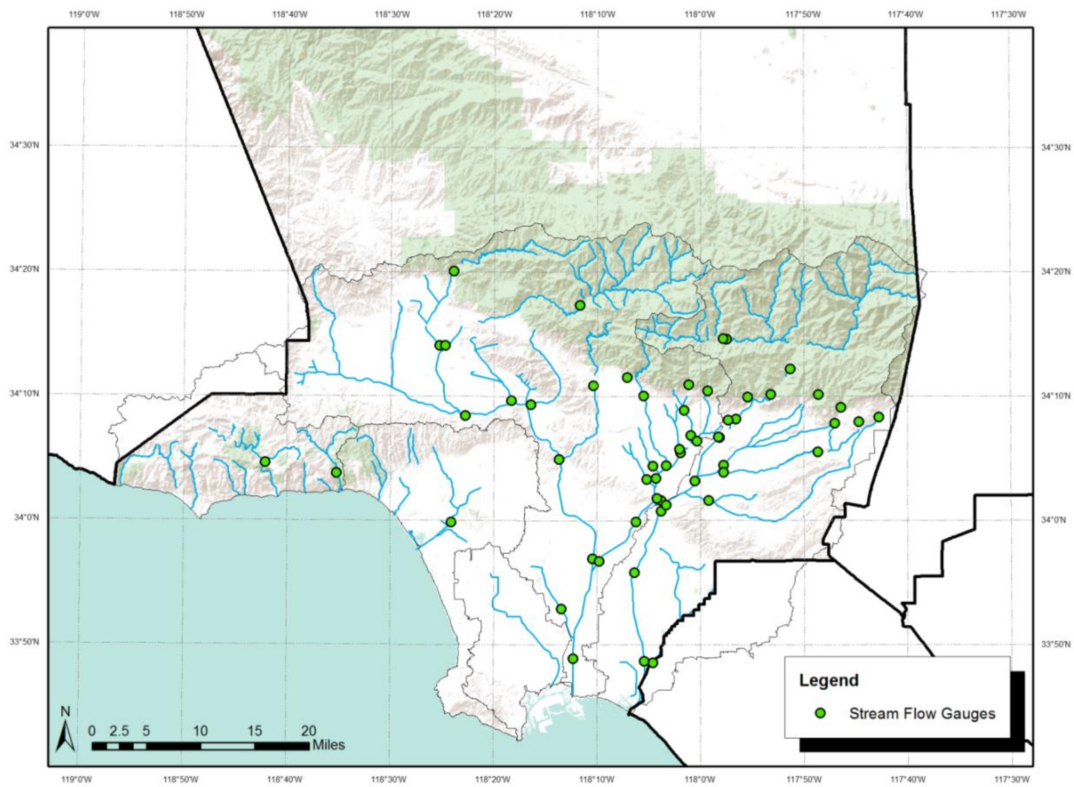


Figure 13. LA Basin Study Stream Gaging Stations

2.1.3. Meteorological Input Preparation

This section discusses the meteorological files used for input into WMMS as well as corrections made to the historical meteorological dataset to improve its suitability for a continuous simulation hydrology study.

2.1.3.1. Types of Meteorological Input

The WMMS program can work with a number of different meteorological inputs. However, the LA Basin Study's use of WMMS specifically uses precipitation and potential evapotranspiration as inputs into the model. In general, the meteorological inputs control the entire mass of water within the Basin Study Watersheds.

For the precipitation records used in WMMS, 134 precipitation gages were selected throughout the County of Los Angeles. The gage density is fairly uniform over most of the Basin Study Watersheds, with a slightly higher concentration near the base of the San Gabriel Mountains. Most of the gages that are utilized are owned and operated by Los Angeles County Department of Public Works (LACDPW), with only a few gages owned by other entities, such as the City of Los Angeles and other agencies. Figure 14 below shows the precipitation gage sites for the LA Basin Study. As a note, WMMS comprises many more gages within the Santa Clara River Watershed, but these gages were not required since they were beyond the LA Basin Study's boundary.

For the evaporation records used in WMMS, there are 15 evaporation stations located throughout the Basin Study Area. When compared to the precipitation gages, there are far fewer evaporation stations and the time step resolution for all sites is in daily increments. As the records were only in daily increments and since the LSPC requires hourly weather data, a standard evaporation curve was used to distribute the evaporation over a typical day (Tetra Tech 2010). For reference, the locations for evaporation sites can be found in Figure 15.

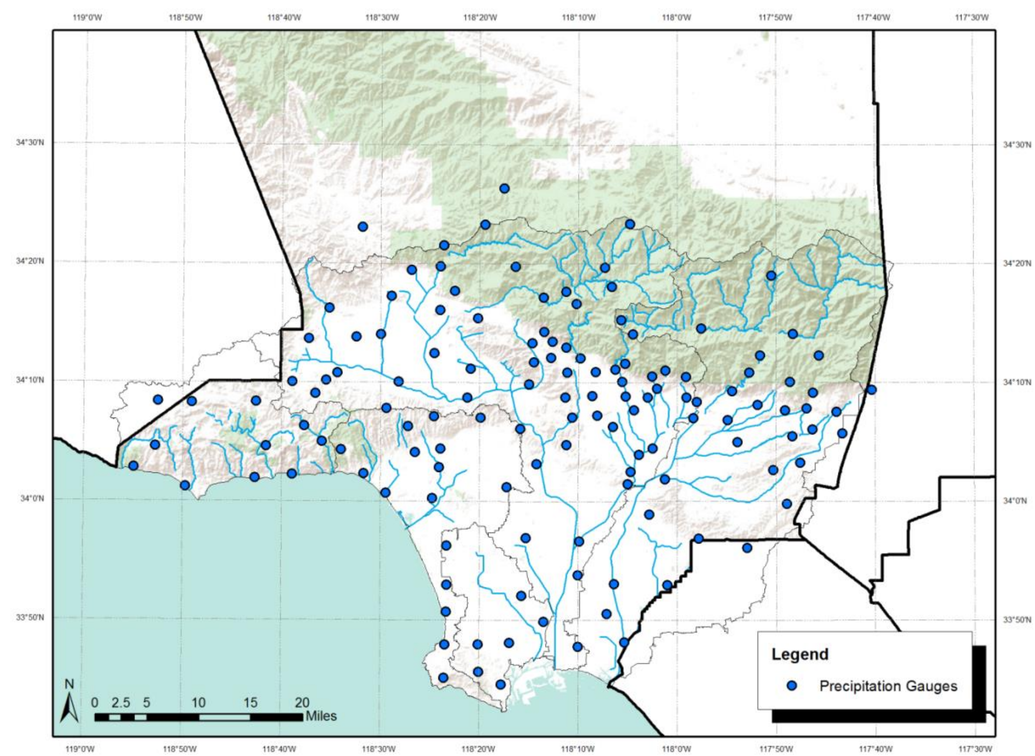


Figure 14. LA Basin Study Precipitation Gage Sites (134 total)

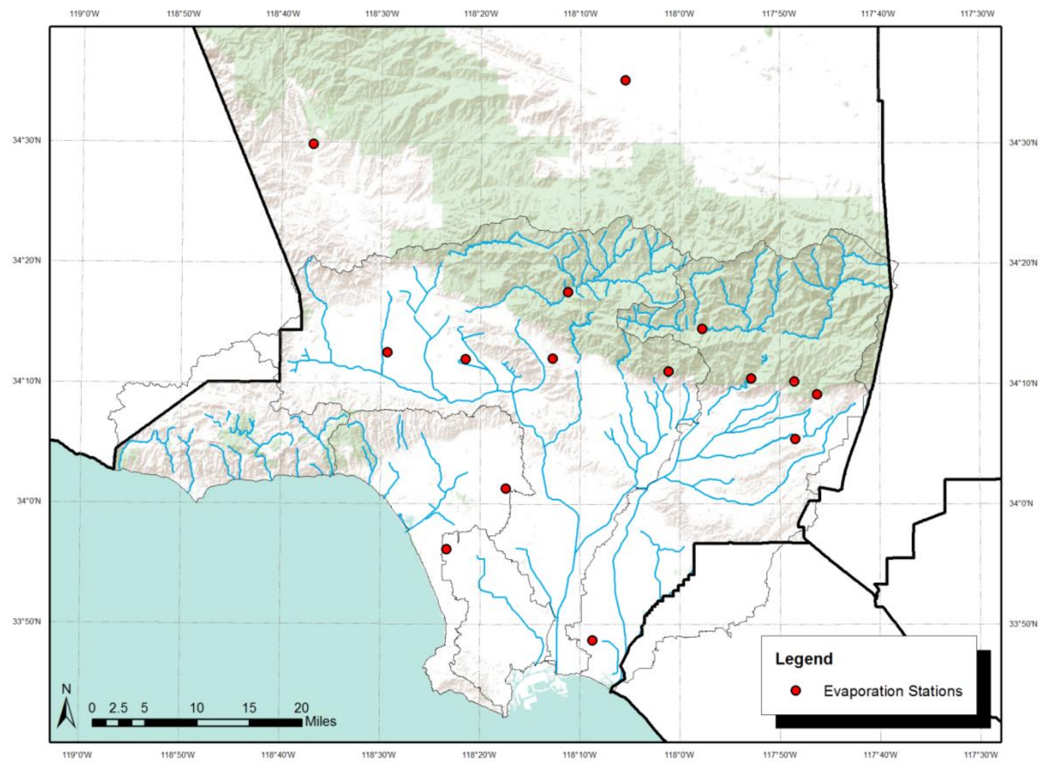


Figure 15. LA Basin Study Evaporation Station Sites (15 total)

2.1.3.2. Data Gaps

Initially, the meteorological inputs in WMMS spanned from 1986 through 2006. To make use of more recent records and to utilize an additional 5 years of water resources data, all meteorological inputs were appended to the end of the water year 2011. Soon after, it was determined that a number of the precipitation gage sites used in WMMS were no longer in service or decommissioned. Also, many of the gages had extremely long gaps in data either due to prolonged maintenance work, being offline due to malfunctions, or other issues. To rectify this problem, precipitation data had to be computed for these gaps. One of the customary practices for filling missing rainfall data is the normal ratio method (Tetra Tech 2010). This method utilizes station averages in addition to nearby working gages to produce the missing records.

Using the Normal Ratio Method:

$$P_A = \frac{1}{n}\left(\sum_{i=1}^{n} \frac{N_A}{N_i} P_i\right)$$

For:

- A is a precipitation station with data gaps

Where:

- P_A is the estimate for the impaired value at station A
- n is the number of surrounding index stations with unimpaired data at the same specific point in time
- N_A is the long-term average value at station A
- N_i is the long term average value at nearby index station i
- P_i is the observed value at nearby index station i

For each impaired value at station A, n consists of only the surrounding index stations with unimpaired data. This missing data can be in either daily or hourly time-steps. If the data was in hourly format, however, the nearest Automatic Local Evaluation in Real-Time (ALERT) or hourly precipitation gage site was used to distribute the amended rainfall.

2.1.3.3. High Precipitation Irregularities

After closely inspecting the compiled historic meteorological records, it was noticed that in certain circumstances a specific precipitation gage had an unusually high hourly precipitation record. This was determined to be attributed to the initial historic record compilation for WMMS; for when there were no nearby gauges with recorded precipitation (i.e., down for maintenance or malfunction), a rainfall distribution could not be determined for the daily to hourly disaggregation. On the occasions this happened, the entire daily rainfall total was assigned to a one-hour period. This ensured that the correct amount of runoff volume was generated, but an unintended consequence was that it could potentially cause an enormous—and unwarranted—spike in flow rates.

Identifying possible irregularities were based upon observed extra-tropical storms in the Los Angeles region and this provided the pattern for extracting any unusually high hourly precipitation records. The LACDPW 2006 Hydrology Manual states, "An analysis of the hourly distribution of large historical 24-hour events showed rainfall intensities increasing during the first 70 to 90 percent of the period and decreasing for the remaining time. Approximately 80 percent of the total 24-hour rainfall occurs within the same 70 to 90 percent of the period" (LACDPW 2006, p. 41). Therefore, for winter storms it is highly unusual, although not impossible, to see no precipitation leading up to a high hourly rainfall depth. Since the LA Basin Study only models wet season storm events, the storm patterns of summer monsoonal effects which may exhibit this behavior did not have to be considered in this analysis.

To resolve this issue, the following method was developed to initially determine the potential high precipitation irregularities and then distribute the rainfall totals over an hourly time step. Preliminary irregularities were identified by meeting both of the following criteria:

1. Any daily (24-hour) period with twenty-three hourly precipitation records all equaling 0.00 inches, and

2. The remaining hourly precipitation record was greater than 0.50 inches (subjective cutoff).

These potential high precipitation irregularities were initially identified using an automated detection algorithm. A manual review of the identified precipitation records followed to confirm whether or not these outliers were in fact daily precipitation totals incorrectly assigned to an hourly record or an actual precipitation event.

Once the high precipitation irregularities were identified and checked, these precipitation depths had to be distributed over a more representative timeframe. As mentioned earlier, since the nearby precipitation gages did not record any precipitation data, no real distribution could be applied to the high precipitation irregularity. It was decided to distribute these amounts over a constant rate for a specified duration so as to not adversely impact flow rates and artificially increase their magnitude. The duration in which to distribute the identified irregularity was based on a simplified correlation between recorded storm durations versus total precipitation produced. Table 2 summarizes how high precipitation irregularities ranging in values greater than 0.50 inches were disaggregated into a more typical hourly distribution.

Table 2. Total Precipitation and Storm Event Duration Correlation

Depth (Inches)	Duration (Hours)	Depth (Inches)	Duration (Hours)	Depth (Inches)	Duration (Hours)	Depth (Inches)	Duration (Hours)
0.5	5	**1.1**	10	**1.7**	15	**2.3**	21
0.6	5	**1.2**	11	**1.8**	16	**2.4**	22
0.7	6	**1.3**	12	**1.9**	17	**2.5**	23
0.8	7	**1.4**	13	**2.0**	18	**2.6**	23
0.9	8	**1.5**	14	**2.1**	19	**>2.7**	24
1.0	9	**1.6**	14	**2.2**	20		

After the precipitation irregularities were disaggregated into a more appropriate hourly distribution, they were then appended back into the historic precipitation records. If the unimpaired historic records for the previous day showed an evening storm event, then the corrected records were positioned in the early morning to reflect a continuation of the storm. Conversely, if the day after the corrected records showed an early morning storm event, then the corrected records were positioned in the late evening to create a continual storm event. Lastly, if the corrected records were bracketed by storm events in the preceding and ensuing days, then the precipitation was centered at noon.

The benefit of correcting the high precipitation irregularities allowed for the same amount of stormwater to be present within the system by not discarding those records and by not creating artificially high flow rates.

2.1.4. Low Impact Development Implementation Scenario

A preliminary evaluation of the potential impacts of widespread LID implementation across the urbanized portions of the Basin Study Watersheds was also assessed. This LID implementation scenario augmented the CMIP3-BCSD and CMIP5-BCSD Projected Hydrology by providing an additional two sets of scenarios for comparing stormwater runoff and conservation. Ultimately, the LA Basin Study would benefit from assessing the cumulative impacts of widespread LID implementation over the course of the future periods against the existing conditions of the urban landscape.

LID helps to reduce the impacts of development on stormwater runoff by retaining and infiltrating runoff on a site’s footprint. The infiltration of stormwater runoff helps to improve water quality as well as provide some supplemental stormwater recharge (Los Angeles County 2009). The intent of this effort was to perform a cursory review of how the LID implementation could affect stormwater capture and whether there was any significant effect on the peak flow rate during storm events.

There were two major challenges encountered during the LA Basin Study that had to be overcome in order to investigate the cursory impacts of widespread LID implementation:

1. Approximation of the LID implementation values

2. Simulation of the widespread LID effects in WMMS

These two challenges were resolved through the use of simplifying assumptions and knowledge of general LID characteristics.

2.1.4.1. Approximation of LID Implementation Values

In order to simulate the effects of LID for the LA Basin Study, the amount of LID being implemented needed to be approximated. As it was difficult to discern the extent of LID implementation by 2095, it was necessary to come up with an approximate yet reasonable assumption for the amount of future LID implementation.

After an initial investigation of sources pertaining to LID and/or its implementation, it was determined that there is currently no defined method or tool to estimate the future implementation rate. Nevertheless, research pertaining to this subject is starting to display signs of potential applications in future use (Water Replenishment District of Southern California [WRD] 2012). Generally, LID implementation is guided by ordinances that are legislated by individual cities; and these regulations are the product of addressing water quality permits. Another element that further complicates the understanding of LID implementation is that, not only can LID implementation occur in new developments, but also at existing properties as they get upgraded or retrofitted.

To estimate the level of LID implementation, a small working group of government agencies, water purveyors, and non-governmental organizations convened to deliberate estimates for an assumed future level of LID implementation. LID implementation percentages were estimated for different land uses for the year 2095 based upon speculations of potential widespread implementation over the span of the century. Within WMMS, the land use database contains nine urban land use categories as shown in Table 3 (Tetra Tech 2010).

Table 3. WMMS Land Use Categories

Urban Land Use Categories
High-Density Single-Family Residential
Low-Density Single-Family Residential, Moderate Slope
Low-Density Single-Family Residential, High Slope
Multi-Family Residential
Commercial
Institutional
Industrial
Transportation
Secondary Roads

The premise for relating LID implementation values to land uses was twofold. First, it allowed for the assumption that land uses which are highly regulated (e.g., industrial) are more likely to experience higher LID implementation rates. The reverse assumption was true for land uses that are not closely regulated (e.g., residential); meaning that they undergo less LID implementation. A limitation of this assumption was that LID regulations are in their infancy and may be significantly modified in the future.

Next, instead of attempting to quantify the total number or type of LID installed in different locations, this premise allowed for a uniform application of LID implementation via percentages. An assumed implementation percentage was easily applied across various land uses without the need to determine specific amounts of LID installed. However, a restriction of this applied percentage instead of quantified LID for specific locations was that this failed to capture whether or not the underlying soils conditions were favorable for infiltration, as well as if there was even enough available land area for implementation. Yet, applying LID implementation values to land uses did provide a reasonable and simplified framework for estimating the widespread implementation.

The LA Basin Study developed implementation values for LID as shown in Table 4. Again, these numbers were only a reasonable—not overly conservative nor overly optimistic—assumption of what potential implementation values could be since there are currently no data or tools available to accurately project LID implementation rates. For example, it was assumed that higher slope low-density residential would be harder to implement LID, thus the implementation rate was lower than the moderate slope low-density residential.

The individual LID implementation values presented below reflect the total percentage of land area for each WMMS land use that may have installed LID by 2095. To run the LID simulation scenarios for CMIP3-BCSD and CMIP5-BCSD, these LID implementation values were steadily increased. A value of zero percent was used as the baseline condition for all land uses during water years 1987 through 2000 and it was incrementally increased for each water year of the LA Basin Study's future period until the ultimate value was achieved in water year 2095 (Table 4). This reflects the general assumption that LID implementation will not be achieved quickly and that widespread installation would likely occur over a long period of time (WRD 2012, p. 10).

Table 4. Estimated LID Implementation Values

WMMS Land Use Description (Applied Only To Urban Uses)	**LID Implementation Value for 2095** (% Land Area)
High-Density Single-Family Residential	25%
Low-Density Single-Family Residential, Moderate Slope	20%
Low-Density Single-Family Residential, High Slope	5%
Multi-family Residential	25%
Commercial	35%
Institutional	80%
Industrial	60%
Transportation	65%
Secondary Roads	60%

2.1.4.2. Simulation of Widespread LID Effects

It was determined that the most practical approach to demonstrate the LID implementation relationship was through the WMMS land use database. However, once the LID implementation values were determined, they had to be applied to adequately characterize the effects of LID in WMMS.

For each subwatershed in WMMS, the land use database assigns land area and percent impervious for each of the different categories. This impervious land area value has a significant effect on the amount of runoff generated for the individual land uses. Therefore, to mimic the effects of widespread LID implementation, the impervious areas were manipulated to characterize the effects that LID implementation could have. This employed the coarse generalization that the impervious area could be decreased—a corresponding increase in pervious—to sufficiently replicate the effects of an LID by reducing the stormwater runoff volume equal to the LID capture volume.

LID is typically designed to capture, retain, and infiltrate stormwater volume from the 85^{th} percentile, 24-hour storm event or the 0.75-inch event, whichever is greater. In general, the 85^{th} percentile, 24-hour storm event precipitation depth is greater than 0.75 inches for the Basin Study Watersheds; therefore this analysis will only consider the 85^{th} percentile, 24-hour storm event threshold (LACDPW 2004). This requires that LID be capable of capturing the 85^{th} percentile volume, or in other words, the stormwater runoff volume generated by 85% of all storm events. The remaining 15% of storms are too large for the LID, and only a small portion of the volumes can be retained. Therefore, over the span of a year, LID should theoretically capture all the stormwater volume generated by 85% of the storm events and this characteristic was used in the analysis to determine an LID volume ratio. Consequently, the volume ratio that an LID was assumed to capture was taken as:

$$LID\ Volume\ Ratio = \frac{85^{\,th} Percentile\ Cumulative\ Volume}{100^{\,th}\ Percentile\ Cumulative\ Volume}$$

For each of the 134 precipitation gages, the historic 24-hour rain depths were ranked in order to determine their respective percentiles and then the volume ratio was calculated. The LID volume ratio across all gages was calculated to be 41%.

Figure 16 shows the storm percentile distribution ranked against the annual cumulative volume. For 85% of all storm events, the volume of rainfall produced corresponds to 41% of the total cumulative volume. Correspondingly, for the 85^{th} percentile storm event, the LID design threshold should theoretically capture 41% of the annual cumulative volume.

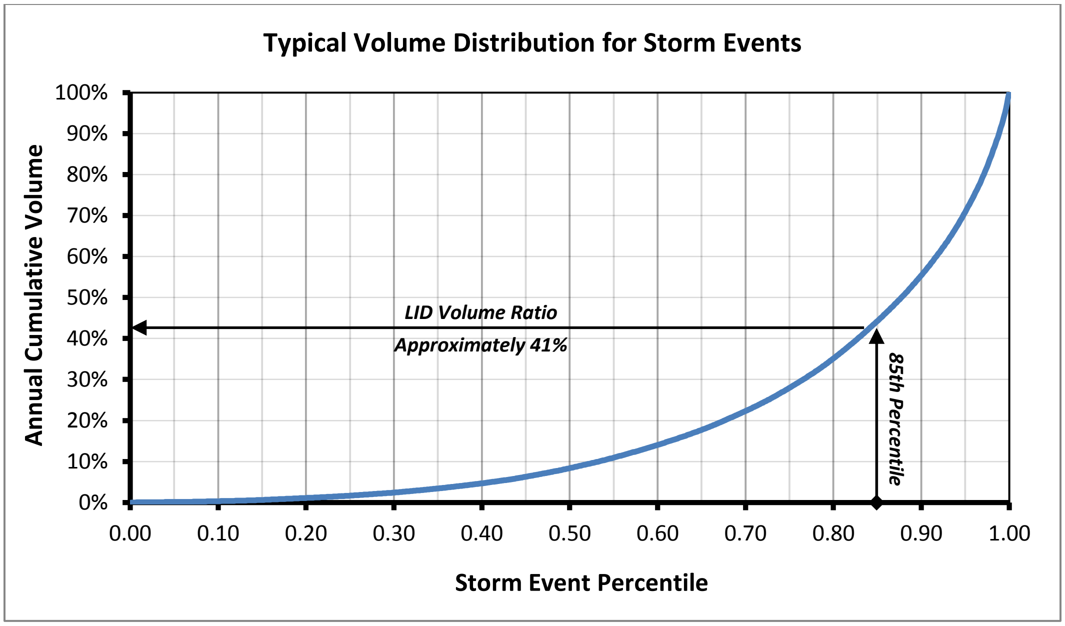


Figure 16. Storm Event Percentile Distribution

Based on the generalization that the impervious area could be transferred to pervious area to approximate the effects of widespread LID implementation in a subwatershed, reduction factors were applied to the WMMS land use database. The reduction factor applied the nine urban land uses combined the LID volume ratio (41%) and the estimated LID implementation value for the individual category as listed in Table 4.

The impervious percent reduction factor for any current water year was represented as:

$$Reduction\ Factor = \left(1 - 0.41\ \times LID\ Implementation\ Value\ \times \left(\frac{WY - 2012}{2095 - 2012}\right)\right)$$

This reduction factor was applied to the WMMS land use database for the nine urban land uses and increased incrementally with respect to the water year. The effect of factoring each urban land use area by the LID volume ratio of 41% approximated the stormwater volume reduction when the entire subwatershed had 100% LID implementation. Therefore, it was necessary to also apply the assumed LID implementation value from Table 4 and prorate it with the current water year to reflect the effective LID implementation value based upon the assumptions made in Section 2.1.4.1.

After the reduction factor was applied to the nine urban land uses, this resulted in a reduction in impervious land with the summation of the decrease applied as an increase to the pervious area. This maintained the same total area of the subwatershed and allowed for more pervious surface area which has similar characteristics to how LID behaves. When the hydrology simulations were performed, the reduced stormwater volumes approximately reflected that quantity of water that could be captured and infiltrated by LID.

The Projected Hydrology simulations with LID implementation were performed for both BCSD climate projections and were reported as CMIP3-BCSD-LID and CMIP5-BCSD-LID. These results were then analyzed and compared to the baseline condition of no LID implementation.

2.2. Hydrology Model Simulations

WMMS was selected to be the hydrologic modeling tool for the LA Basin Study. The study required analyzing water conservation capabilities and flood flows over hundreds of square miles within the Basin Study Watersheds. Additionally, the time period for the hydrology runs was immense—historic records were simulated to obtain baseline conditions and almost an entire century into the future was modeled. For those reasons, a powerful and efficient hydrologic model was necessary to complete the simulations over this large spatial and temporal scale.

Water conservation can be reasonably calculated by using a daily or even monthly time-step. However, in order to produce and analyze flood flows, a finer time step resolution was required. This necessitated that LSPC utilize an input and output time-step of an hour. LSPC generated outputs of the hydrology simulations in raw numbers and a significant post-processing analysis had to be conducted.

Section 2.2.1. describes the baseline hydrology modeling for the LA Basin Study.

Section 2.2.2. discusses the future hydrology modeling utilizing the climate change projections.

Section 2.2.3. defines the model inputs required to run LSPC.

Section 2.2.4. discusses the corresponding outputs for the target subwatersheds.

2.2.1. Historic Hydrology (Water Years 1987 through 2000)

Hydrology modeling using the observed meteorological record period (or Historic Hydrology) was simulated in order to obtain baseline conditions for the Basin Study Watersheds. Historic precipitation and evaporation records spanning water years 1987 through 2000 were used within LSPC to produce simulated hydrologic records for stormwater runoff and volume for that period. As discussed earlier in the report, the LSPC model starts out as "dry," and it is necessary to disregard an initial period of hydrologic simulation results in order to build antecedent conditions within the Basin Study Watersheds.

2.2.2. Projected Hydrology (Water Years 2012 through 2095)

Hydrology modeling for the future periods—or Projected Hydrology—was simulated to advance the current understanding of potential climate change impacts on the Basin Study Watersheds. Projected Hydrology was simulated in LSPC for the future meteorological projections corresponding to water years 2012 through 2095. Meteorological inputs were produced for the following three climate change projections:

- **CMIP3-BCSD**
  - Bias Correction and Spatial Disaggregation Coupled Model Intercomparision Project, Phase 3
  - 50 out of 112 climate models selected to represent Q1 to Q5 in five ensemble model runs
- **CMIP5-BCSD**
  - Bias Correction and Spatial Disaggregation Coupled Model Intercomparision Project, Phase 5
  - 50 out of 100 climate models selected to represent Q1 to Q5 in five ensemble model runs
- **CMIP5-BCCA**
  - Bias Correction Constructed Analogue Coupled Model Intercomparision Project, Phase 5
  - Partial ensemble of Representative Concentration Pathway [RCP]2.6 (low emissions scenario) represented in 16 model runs
  - Partial ensemble of RCP8.5 (high emissions scenario) represented in 21 model runs

The meteorological inputs associated with the three climate change projections were each simulated separately in LSPC. Hourly hydrologic projections for stormwater runoff and volume were produced in order to analyze the future periods. The Projected Hydrology was compared against the Historic Hydrology to understand the overall trends of varying stormwater runoff and supplies.

2.2.3. Input to LSPC

LSPC required the following three inputs (Tetra Tech 2009) to simulate the hydrology for the LA Basin Study:

- LSPC Model Input File
- Meteorological Input Files
- WMMS Database

The LA Basin Study performed 58 hydrology simulations as follows:

- 1 Historic Meteorological
- 5 CMIP3-BCSD (Q1 through Q5)
- 5 CMIP3-BCSD-LID (Q1 through Q5)
- 5 CMIP5-BCSD (Q1 through Q5)
- 5 CMIP5-BCSD-LID (Q1 through Q5)
- 37 CMIP5-BCCA (16 RCP2.6 and 21 RCP8.5)

2.2.4. Output from LSPC

For each of the 58 hydrologic simulations, LSPC generated one output file for each of the 210 target subwatersheds with continuous records of mean-hourly runoff (RO) and total volume (VOL). For the LA Basin Study, hourly data was essential in order to have a resolution fine enough to capture flood flows. Figure 17 shows a portion of a typical output file for a single subwatershed.

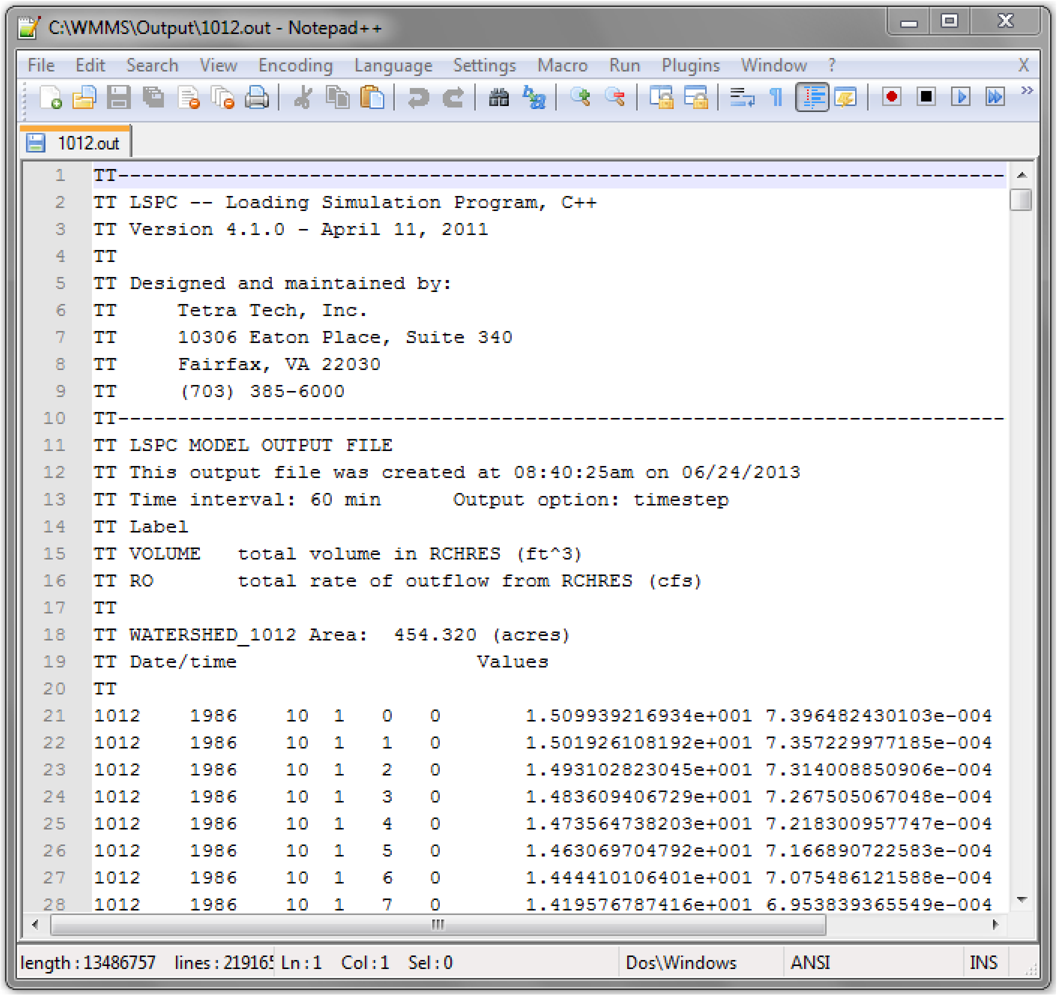


Figure 17. LSPC Output File

2.3. Hydrology Model Output Processing

The LA Basin Study produced an exceptionally large amount of hydrologic outputs which required significant post-processing. To develop a meaningful set of output values for the one (1) Historic Hydrology and fifty-seven (57) Projected Hydrology outputs simulated by LSPC, a set of macro-enabled excel workbooks was created. These binary excel files performed the vast majority of post-processing work on the raw data.

2.3.1. Output Compiler

The mass compiler and analysis workbook allowed for an efficient bulk file import and analysis for each of the climate scenarios.

Within WMMS, the highest resolution areas are subwatersheds, which are approximately 500 acres on average. Yet, these subwatersheds can be much smaller within urban areas and, conversely, these subwatersheds can be much larger for rural or undeveloped regions. Within the Study Area, there were 210 target subwatershed locations that were selected for analysis.

The targeted subwatershed locations consist of one of the following:

- Facility
    - Dam/Reservoir
    - Downstream Edge of Groundwater Basin
    - Rubber Dams
    - Spreading Grounds
    - Soft Bottom Channels
    - Stream Gaging Station
- Other
    - Subbasin

In total, the LA Basin Study selected 182 facility subwatersheds and 28 subbasins for output. Subbasins accounted for the amount of water recharged at each of the spreading facilities, rubber dams, or soft bottom channels. For all the subwatersheds, WMMS produced hourly projections for two output metrics:

- Rate Outflow (RO)
- Volume in the Subwatershed (VOL)

Most subwatersheds, other than dam/reservoirs, had only one appropriate metric. The applicability of an output was based on how WMMS manages these locations. Table 5 shows the required metric for each of the locations:

Table 5. LSPC Output Controls

Target Location	VOL	RO
Dam/Reservoirs	√	√
Edge of Groundwater Basin		√
Rubber Dams	√	
Spreading Grounds	√	
Soft Bottom Channels	√	
Stream Gaging Station		√
Subbasin	√	

For each of the climate change scenarios, the 210 target subwatershed output files were combined into a comprehensive import workbook as shown in Figure 18. This permitted for a uniform and consistent analysis for each of the hydrologic output files.

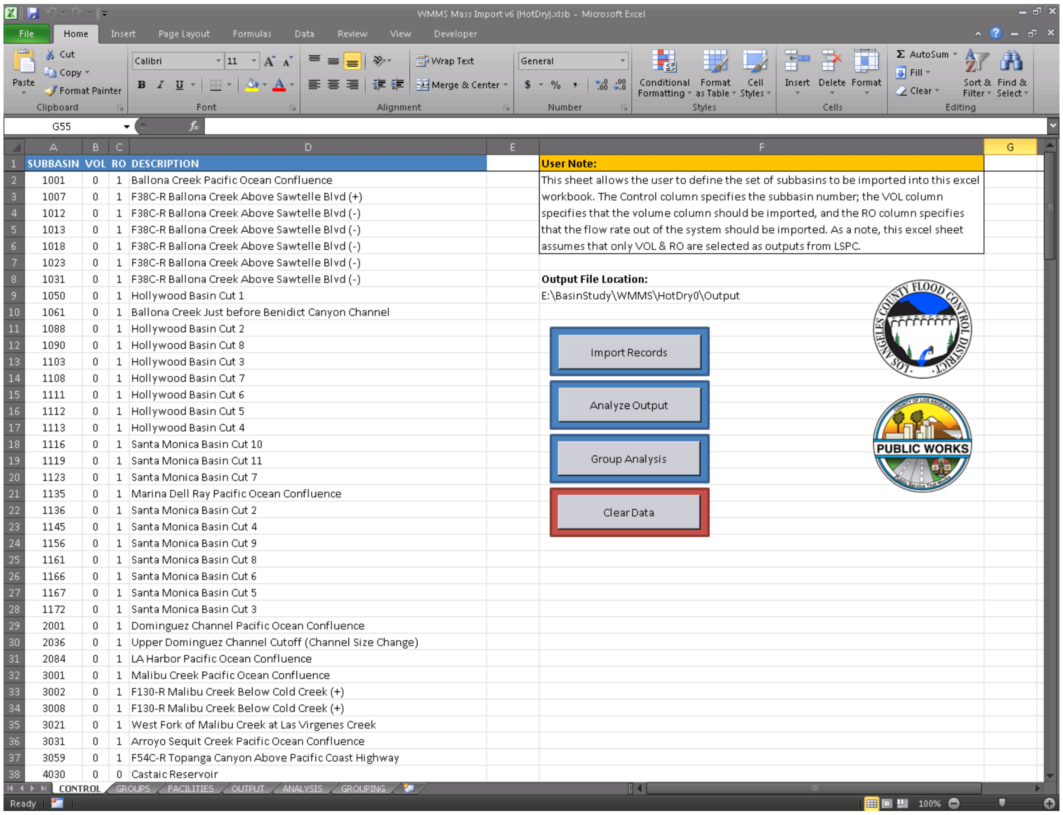


Figure 18. WMMS Mass Import Workbook (Control Sheet)

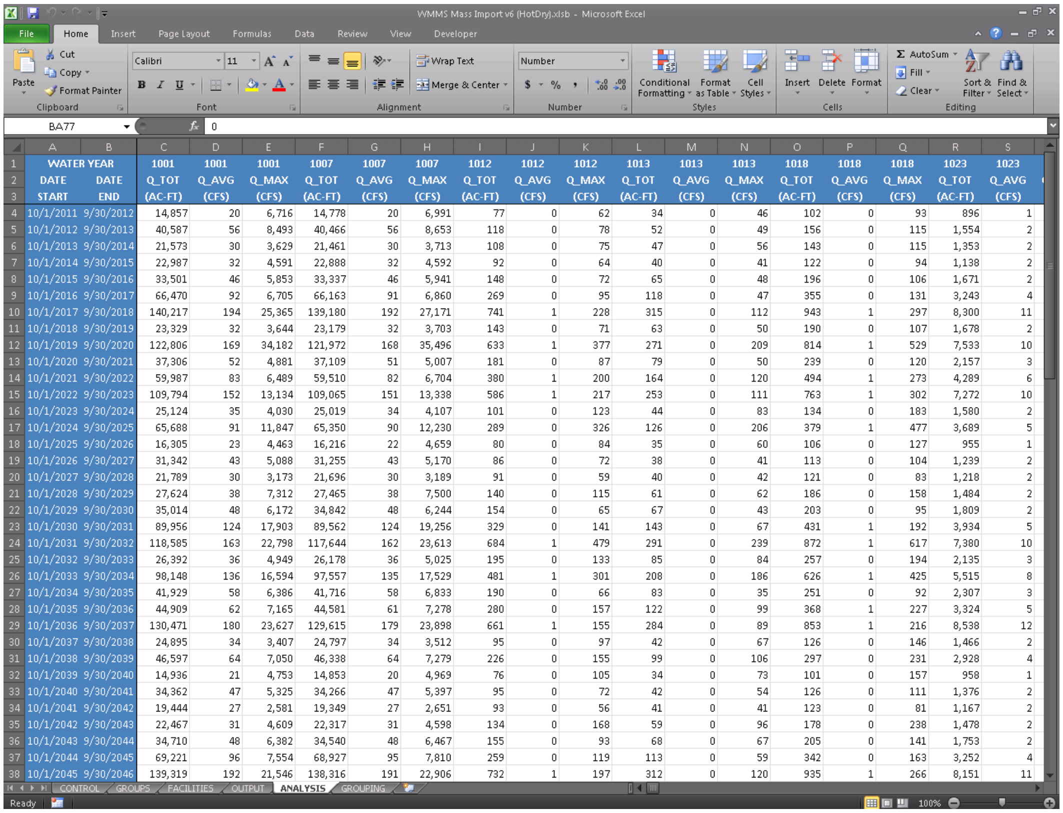
2.4. Hydrology Analysis

After the hydrologic output projections were imported and compiled into one workbook, the projections were then analyzed. The analysis combined all the hourly output projections into water years, which provided seasonal values that are typically used for stormwater conservation and flood flow.

The following guidelines show the metrics that were analyzed for the various target subwatersheds as previously noted in Figure 7.

- RO Output
  - Total Annual Stormwater Runoff (Q_{Total}, acre-feet [af])
  - Average Annual Flow Rate (Q_{Avg}, cubic feet per second [cfs])
  - Maximum Mean-Hourly Flow Rate ($Q_{Max\ Hour}$, cfs)
- VOL Output (Facility)
  - Average Annual Storage Volume (V_{Avg}, af)
  - Maximum Mean-Hourly Volume ($V_{Max\ Hour}$, af)
- VOL Output (Subbasin Only)
  - Total Annual Recharge Volume (Q_{Total}, af)

For each of the climate change scenarios, the 210 target subwatershed output files were combined into a comprehensive analysis workbook as shown in Figure 19. The different hydrologic metrics were calculated for the different types of target subwatersheds.



WATER YEAR DATE START	DATE END	1001 Q_TOT (AC-FT)	1001 Q_AVG (CFS)	1001 Q_MAX (CFS)	1007 Q_TOT (AC-FT)	1007 Q_AVG (CFS)	1007 Q_MAX (CFS)	1012 Q_TOT (AC-FT)	1012 Q_AVG (CFS)	1012 Q_MAX (CFS)	1013 Q_TOT (AC-FT)	1013 Q_AVG (CFS)	1013 Q_MAX (CFS)	1018 Q_TOT (AC-FT)	1018 Q_AVG (CFS)	1018 Q_MAX (CFS)	1023 Q_TOT (AC-FT)	1023 Q_AVG (CFS)
10/1/2011	9/30/2012	14,857	20	6,716	14,778	20	6,991	77	0	62	34	0	46	102	0	93	896	1
10/1/2012	9/30/2013	40,587	56	8,493	40,466	56	8,653	118	0	78	52	0	49	156	0	115	1,554	2
10/1/2013	9/30/2014	21,573	30	3,629	21,461	30	3,713	108	0	75	47	0	56	143	0	115	1,353	2
10/1/2014	9/30/2015	22,987	32	4,591	22,888	32	4,592	92	0	64	40	0	41	122	0	94	1,138	2
10/1/2015	9/30/2016	33,501	46	5,853	33,337	46	5,941	148	0	72	65	0	48	196	0	106	1,671	2
10/1/2016	9/30/2017	66,470	92	6,705	66,163	91	6,860	269	0	95	118	0	47	355	0	131	3,243	4
10/1/2017	9/30/2018	140,217	194	25,365	139,180	192	27,171	741	1	228	315	0	112	943	1	297	8,300	11
10/1/2018	9/30/2019	23,329	32	3,644	23,179	32	3,703	143	0	71	63	0	50	190	0	107	1,678	2
10/1/2019	9/30/2020	122,806	169	34,182	121,972	168	35,496	633	1	377	271	0	209	814	1	529	7,533	10
10/1/2020	9/30/2021	37,306	52	4,881	37,109	51	5,007	181	0	87	79	0	50	239	0	120	2,157	3
10/1/2021	9/30/2022	59,987	83	6,489	59,510	82	6,704	380	1	200	164	0	120	494	1	273	4,289	6
10/1/2022	9/30/2023	109,794	152	13,134	109,065	151	13,338	586	1	217	253	0	111	763	1	302	7,272	10
10/1/2023	9/30/2024	25,124	35	4,030	25,019	34	4,107	101	0	123	44	0	83	134	0	183	1,580	2
10/1/2024	9/30/2025	65,688	91	11,847	65,350	90	12,230	289	0	326	126	0	206	379	1	477	3,689	5
10/1/2025	9/30/2026	16,305	23	4,463	16,216	22	4,659	80	0	84	35	0	60	106	0	127	955	1
10/1/2026	9/30/2027	31,342	43	5,088	31,255	43	5,170	86	0	72	38	0	41	113	0	104	1,239	2
10/1/2027	9/30/2028	21,789	30	3,173	21,696	30	3,189	91	0	59	40	0	42	121	0	83	1,218	2
10/1/2028	9/30/2029	27,624	38	7,312	27,465	38	7,500	140	0	115	61	0	62	186	0	158	1,484	2
10/1/2029	9/30/2030	35,014	48	6,172	34,842	48	6,244	154	0	65	67	0	43	203	0	95	1,809	2
10/1/2030	9/30/2031	89,956	124	17,903	89,562	124	19,256	329	0	141	143	0	67	431	1	192	3,934	5
10/1/2031	9/30/2032	118,585	163	22,798	117,644	162	23,613	684	1	479	291	0	239	872	1	617	7,380	10
10/1/2032	9/30/2033	26,392	36	4,949	26,178	36	5,025	195	0	133	85	0	84	257	0	194	2,135	3
10/1/2033	9/30/2034	98,148	136	16,594	97,557	135	17,529	481	1	301	208	0	186	626	1	425	5,515	8
10/1/2034	9/30/2035	41,929	58	6,386	41,716	58	6,833	190	0	66	83	0	35	251	0	92	2,307	3
10/1/2035	9/30/2036	44,909	62	7,165	44,581	61	7,278	280	0	157	122	0	99	368	1	227	3,324	5
10/1/2036	9/30/2037	130,471	180	23,627	129,615	179	23,898	661	1	155	284	0	89	853	1	216	8,538	12
10/1/2037	9/30/2038	24,895	34	3,407	24,797	34	3,512	95	0	97	42	0	67	126	0	146	1,466	2
10/1/2038	9/30/2039	46,597	64	7,050	46,338	64	7,279	226	0	155	99	0	106	297	0	231	2,928	4
10/1/2039	9/30/2040	14,936	21	4,753	14,853	20	4,969	76	0	105	34	0	73	101	0	157	958	1
10/1/2040	9/30/2041	34,362	47	5,325	34,266	47	5,397	95	0	72	42	0	54	126	0	111	1,376	2
10/1/2041	9/30/2042	19,444	27	2,581	19,349	27	2,651	93	0	56	41	0	41	123	0	81	1,167	2
10/1/2042	9/30/2043	22,467	31	4,609	22,317	31	4,598	134	0	168	59	0	96	178	0	238	1,478	2
10/1/2043	9/30/2044	34,710	48	6,382	34,540	48	6,467	155	0	93	68	0	67	205	0	141	1,753	2
10/1/2044	9/30/2045	69,221	96	7,554	68,927	95	7,810	259	0	119	113	0	59	342	0	163	3,252	4
10/1/2045	9/30/2046	139,319	192	21,546	138,316	191	22,906	732	1	197	312	0	120	935	1	266	8,151	11

Figure 19. WMMS Mass Import Workbook (Analysis Sheet)

2.4.1. Stormwater Conservation

To effectively summarize potential climate change impacts on the major watersheds and subwatersheds, a set of indicator values based on standard LACFCD record keeping was used. The standard values used to assess stormwater conservation are:

- **Recharge:** The total amount of stormwater infiltrated within the subwatershed with contributions from all water conservation facilities (reported in af).

- **Available:** The amount of stormwater runoff that flows out of the subwatershed which can potentially be captured within itself at upstream locations (reported in af).

- **Total Stormwater:** The total amount of stormwater within the subwatershed system. It is the sum of Recharge and Available (reported in af).

- **% Capture**: The ratio of Recharge to Total Stormwater for the subwatershed.

The Historic and Projected Hydrology simulations produced output data VOL (af). Generally, an hourly resolution for VOL is too detailed for stormwater conservation. However, by summing and/or averaging the VOL data across larger time periods, it allowed for more meaningful results by reformatting them in a recognizable temporal resolution.

2.4.2. Flood Flow Analysis

Analyzing the flood control capacity of the existing infrastructure is another central aspect of the LA Basin Study. Since the water conservation system and flood control infrastructure are closely related, it is important to identify the potential climate change impacts to each and how each may affect one another.

To highlight potential climate change impacts on the major watersheds and subwatersheds, a standard set of flood analysis values were established. The standards used to assess the flood control infrastructure within the watersheds and subwatersheds are:

- **Stormwater Flow Volume:** The total volume of stormwater that discharges through a certain location (reported as an annual average in af). This value does not inherently aid in analyzing the flood control capacity of a channel, but it does help to show the amount of water discharging through a certain watershed or subwatershed system over the course of a water year. This value is useful to compare the Historic Hydrology to the Projected Hydrology to understand changes in the amount of stormwater due to climate change.

- **Peak Flow Rate:** The maximum flow rate attained at a specific discharge location (cfs).

The Historic and Projected Hydrology simulations produced output data RO (cfs). An hourly time-step was necessary in order to perform a flood flow analysis for the infrastructure.

3. Results and Discussion

Hydrologic simulations were conducted for the LA Basin Study with the purpose of analyzing the potential impacts that climate change may have on stormwater conservation and flood flows. WMMS used observed meteorological inputs to produce the simulated Historic Hydrology for water years 1987 through 2000. For the future period of water years 2012 through 2095, WMMS produced hydrologic outputs corresponding to the CMIP3-BCSD, CMIP5-BCSD, and CMIP5-BCCA climate projections.

It is important to recognize that the WMMS model is not a perfect representation of the actual natural system; however, it remains an extremely valuable tool in approximating large scale hydrologic effects across the County of Los Angeles. For that reason, the simulated Historic Hydrology results rather than the actual observed hydrology records are used for the baseline condition. This allows an analogous comparison to measure relative increases and decreases for the different hydrology metrics between the historic and future periods. The hydrologic results presented aid in understanding how the variability among the potential climate change projections may impact the watersheds that encompass the LACFCD system.

Furthermore, the LA Basin Study analyzed 210 target subwatershed locations. To illustrate the overall impact of the potential climate change to the Basin Study Watersheds, an aggregated set of figures was developed for the entire region. Nonetheless, a similar characteristic is displayed across the individual subwatersheds. Appendix A and Appendix B include figures for particular watershed and groundwater basin locations, respectively, for a more detailed understanding of the potential climate change impacts.

This section discusses the results for the Historic Hydrology and the Projected Hydrology model outputs for all climate-adjusted hydrologic projections.

> Section 3.1. provides a brief overview of the Historic Hydrology, which serves as the baseline conditions.
>
> Section 3.2. compares the Projected Hydrology to the baseline.

3.1. Historic Hydrology

3.1.1. Stormwater Conservation

Subwatersheds that are located in geologically favorable areas for groundwater recharge normally have a large number of water conservation facilities, allowing for an efficient stormwater recharge environment. Historically, the subwatersheds tributary to the Rio Hondo Channel and the San Gabriel River have very high stormwater captures rates. On average—inclusive of driest and wettest season on record—the Rio Hondo Channel stream gaging station at Stuart Avenue and the San Gabriel River stream gage at Firestone Avenue capture 72% and 97% of stormwater runoff, respectively (LACDPW 2011).

Conversely, subwatersheds that are not in geologically or even geographically favorable areas have fewer or smaller water conservation facilities. These areas are only able to capture a small percentage of the total stormwater runoff. As an example, on average only 22% of stormwater is captured tributary to the mouth of the Los Angeles River (LACDPW 2011). The lower stormwater capture rates here indicate the potential for improving the stormwater capture capacity; however, unfavorable soil properties in addition to densely populated and expensive land could make potential recharge improvements difficult.

3.1.2. Flood Flow Analysis

Analyzing the flood control capacity of the current infrastructure is another central aspect of the LA Basin Study. Because flood control infrastructure and the water conservation system are closely related, it is important to identify the potential impacts to each from a changing climate.

Figure 20 shows the selected points within the Basin Study Watersheds that were used to summarize the peak flow rate responses to climate change. Both the Historic Hydrology and Projected Hydrology use the outlets of the Los Angeles River, San Gabriel River, Ballona Creek, Dominguez Channel, and Malibu Creek as sites to assess the broad impact of climate change on hydrology. These locations were selected as each has a well-defined discharge point to the Pacific Ocean, vary in size, and have differing upstream control conditions.

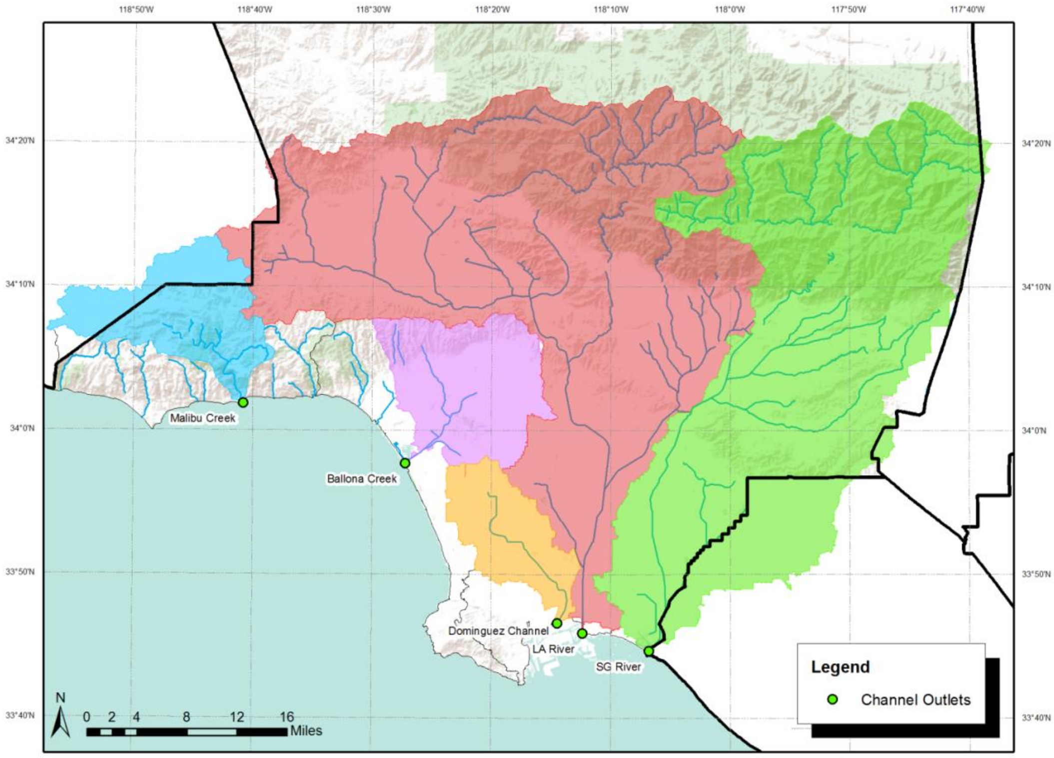


Figure 20. Peak Flow Rate Indicator Locations

3.2. Projected Hydrology

Results in this section are presented as an areal average across the Basin Study Watersheds and are shown as a range of possibilities for each of the projected future periods.

Box plots are used to demonstrate the variability among the Projected Hydrology with respect to the different emissions scenarios within each of the over-arching climate projections. For the array of hydrologic projections, the plot from Figure 21 indicates the 5th, 25th, 50th, 75th, and 95th percentile rankings as well as the ensemble mean or average across all scenarios. These values assess the overall spread of the projections and offer a measure of uncertainty within each climate projection.

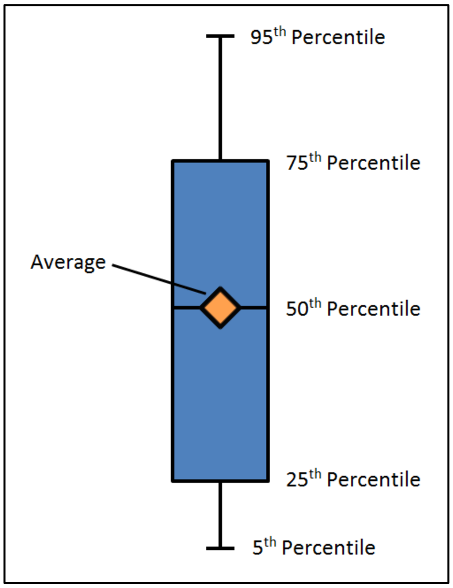


Figure 21. Box Plot Legend

Specific to the stormwater conservation results, the average runoff volume and the average recharge volume projection plots represent percent changes in the annual average stormwater volumes for each future period. These graphs do not represent the variation in the absolute maximum and minimum extreme years. Accordingly, the range presented in the box plots shows only the variation between the average annual stormwater volumes of different climate change scenarios. (For the baseline period 1987 through 2000, there is only one average annual data set for that period, the Historic Hydrology; thus the baseline is held to be the 0% opening comparison point and has no spread associated with it.)

For the flood flow analysis, the peak flow rate plots do display the potential variability among extreme maximum events for each climate change scenario during each future period.

This section discusses the results of the different climate change projections used to develop the Projected Hydrology.

> Sections 3.2.1. and 3.2.2. discuss the CMIP3-BCSD and the CMIP3-BCSD-LID results, respectively.
>
> Sections 3.2.3. and 3.2.4. discuss the CIMP5-BCSD and CMIP5-BCSD-LID results, respectively.
>
> Section 3.2.5. describes the CMIP5-BCCA-RCP2.6 results.
>
> Section 3.2.6. describes the CMIP5-BCCA-RCP8.5 results.

3.2.1. CMIP3-BCSD

3.2.1.1. Stormwater Conservation Results

Figure 22 and Figure 23 show runoff and recharge, respectively. For the CMIP3-BCSD climate scenario, the Projected Hydrology demonstrates a rather variable projection in stormwater runoff volume over the course of the future period (Figure 22). This characteristic pattern in the stormwater runoff volume remains similar across all target subwatersheds. Inspection of the hydrology results shows elevated runoff in the short-term and mid-century followed by a potential decrease towards the end of the century. Changes here are highly variable and show a large range in potential stormwater runoff volumes.

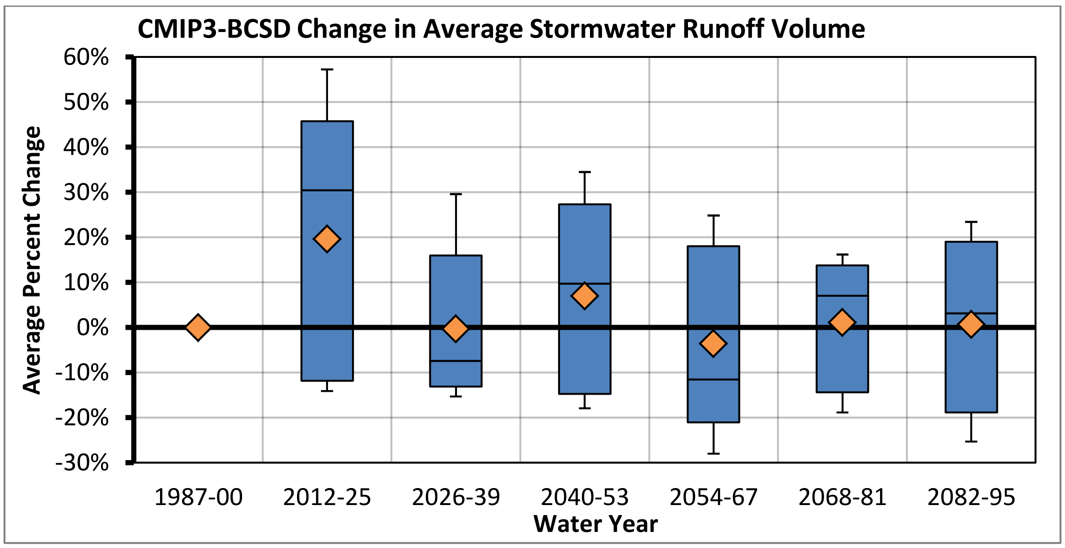


Figure 22. CMIP3-BCSD Stormwater Runoff Projections

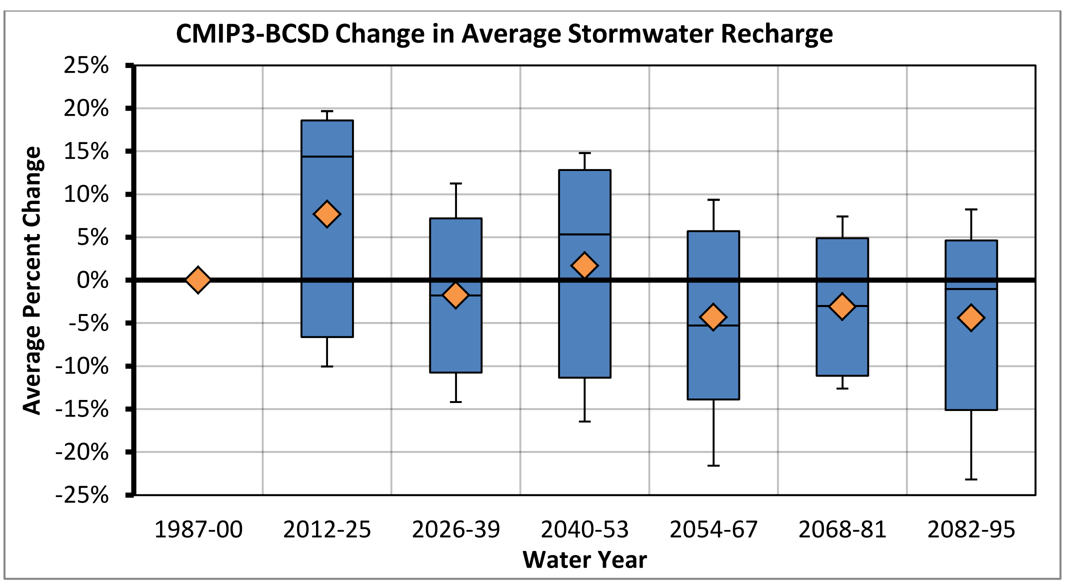


Figure 23. CMIP3-BCSD Stormwater Recharge Projections

The stormwater recharge volume exhibits a similar pattern to the stormwater runoff volume projections (Figure 23); however, the variability appears to be less sensitive to changes in climate. There is a slightly higher recharge during water years 2012 through 2025, with decreasing amounts towards the end of the century. Nevertheless, the projected change for the stormwater recharge is less intense than the variations for stormwater runoff. As explained earlier, the recharge characteristics and operational guidelines of spreading facilities were held constant within the model as they were established from the baseline Historic Hydrology. This assumption may be the cause of this lowered sensitivity; however, that remains unclear. A more advanced analysis of recharge will be conducted later during LA Basin Study Tasks 4 and 5.

3.2.1.2. Flood Flow Analysis Results

For the CMIP3-BCSD Projected Hydrology, the peak (maximum) flow rate has a much different pattern than the stormwater conservation projections. Overall, the peak flow rate appears to remain elevated for all projected future periods (Figure 24). The deviation in the projections is also much more variable than the average stormwater volume characteristics. Uniquely, the upper bound for the projected flow rates increases dramatically in the early part of the century, but then lessens through the rest of the future periods.

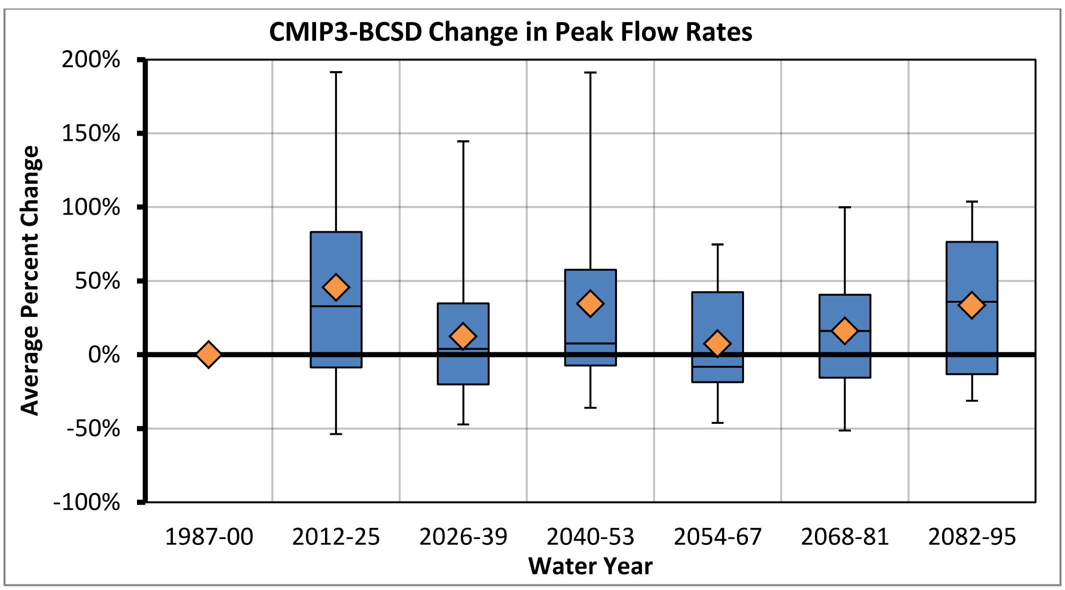


Figure 24. CMIP3-BCSD Peak Flow Rate Projections

3.2.2. CMIP3-BCSD with LID Implementation

3.2.2.1. Stormwater Conservation Results

Figure 25 and Figure 26 show runoff and recharge, respectively. For the CMIP3-BCSD climate scenario with LID Implementation, the Projected Hydrology demonstrates the same variable pattern in stormwater runoff over the course of the future period with slight changes towards the end of the century. Due to the methodology for applying LID effects, there is little initial deviation in the average percent change between the CMIP3-BCSD and CMIP3-BCSD-LID projections. Towards the end of the century, a decrease in total runoff volume is observed. Comparison of the ensemble means for the final period shows a decrease of 9% in the total stormwater runoff volume for the LID scenario.

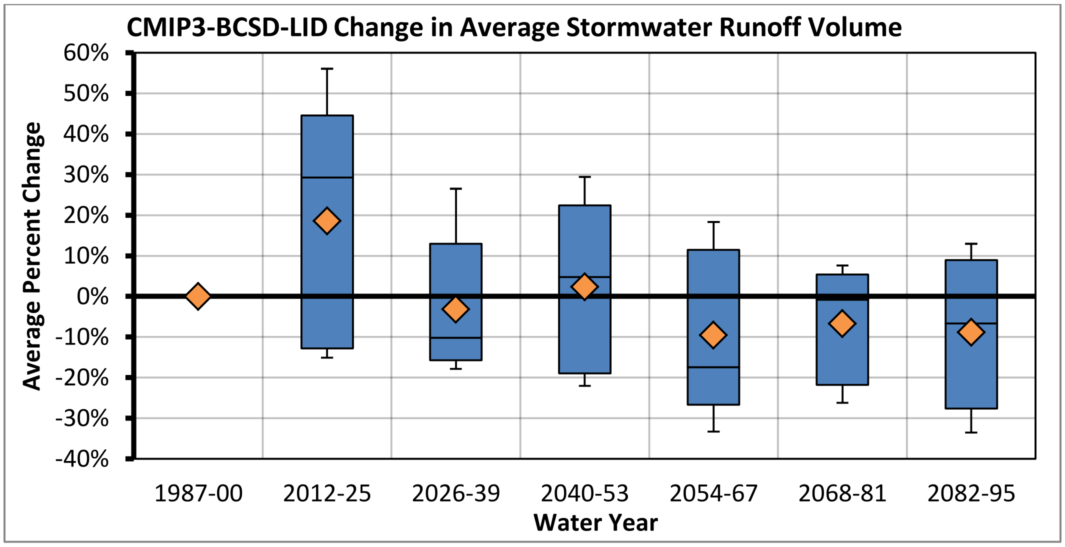


Figure 25. CMIP3-BCSD-LID Stormwater Runoff Projections

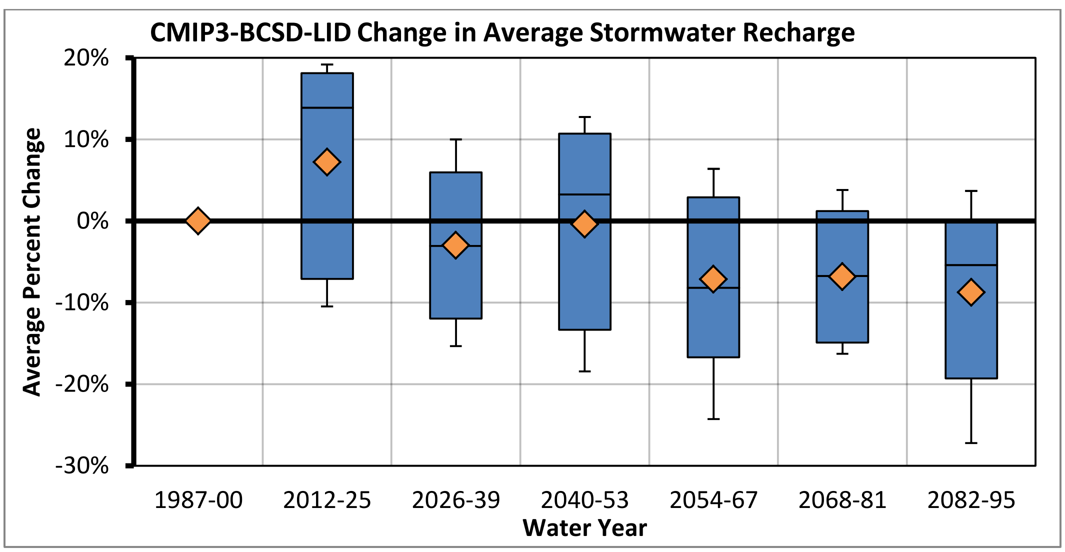


Figure 26. CMIP3-BCSD-LID Stormwater Recharge Projections

Similar to the CMIP3-BCSD case, the stormwater recharge volume variability is again less sensitive to changes in climate and effects of LID implementation are less noticeable in the early century periods (Figure 26). There is a reduction in the total stormwater recharged, but this is not as large of a reduction as is the drop in total stormwater runoff. Since many of the larger spreading facilities are located further upstream, these facilities are less influenced by the effects of widespread urban LID implementation.

Compared to CMIP3-BCSD, the stormwater recharge ensemble mean drops by an additional 5% and equates to 9% below baseline during water years 2082 through 2095. For the stormwater runoff volume ensemble mean, LID is projected to decrease volumes by 10% by water years 2082 through 2095, which equals a 9% decrease below the historic average. However, this does not imply that less water is conserved within Los Angeles County. With less stormwater runoff reaching the stream network, this implies that more water is being captured through other means, with less of that stormwater reaching LACFCD spreading facilities.

3.2.2.2. Flood Flow Analysis Results

From the Projected Hydrology for CMIP3-BCSD with LID implementation, the peak flow rate does not differ substantially from the CMIP3-BCSD projections. Similar to the non-LID scenario, the peak flow projections appear to remain elevated for the future periods and show a large range in the values (Figure 27). In comparing the two cases, only a 4% reduction in the ensemble mean peak flow rate is observed for the LID scenario for water years 2082 through 2095.

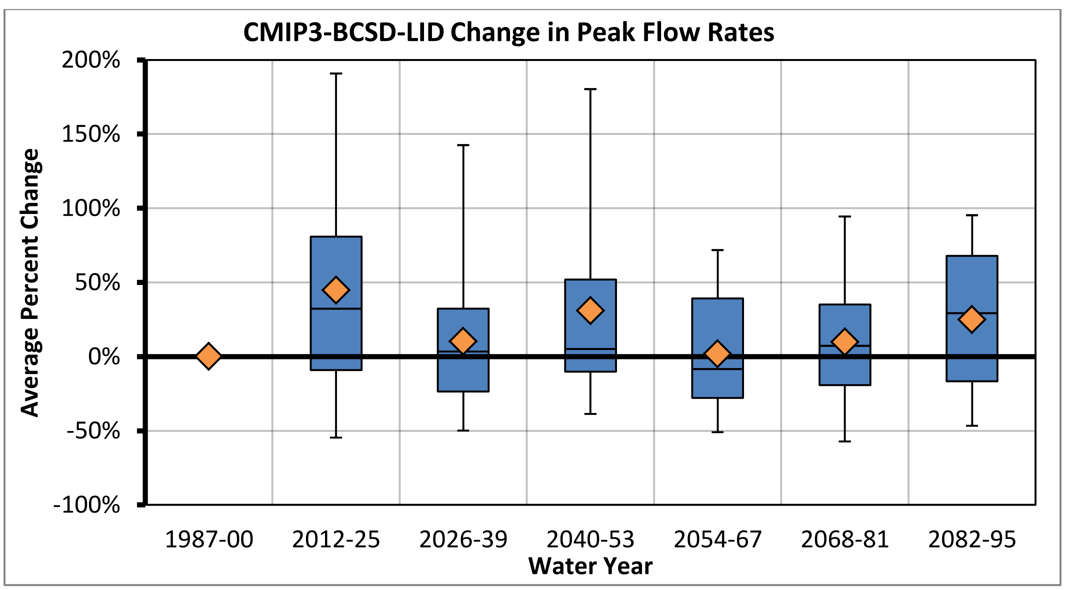


Figure 27. CMIP3-BCSD-LID Peak Flow Rate Projections

3.2.3. CMIP5-BCSD

3.2.3.1. Stormwater Conservation Results

Figure 28 and Figure 29 show runoff and recharge, respectively. For the CMIP5-BCSD climate scenario, the Projected Hydrology exhibits an elevated pattern in stormwater runoff over the course of the study period (Figure 28). This climate scenario suggests an overall and sustained increase in the average annual runoff for nearly all future periods. During water years 2040 through 2053, however, there appears to be a potential reduction or drier period. Changes here are highly variable; however, and exhibit a very large range of possibilities.

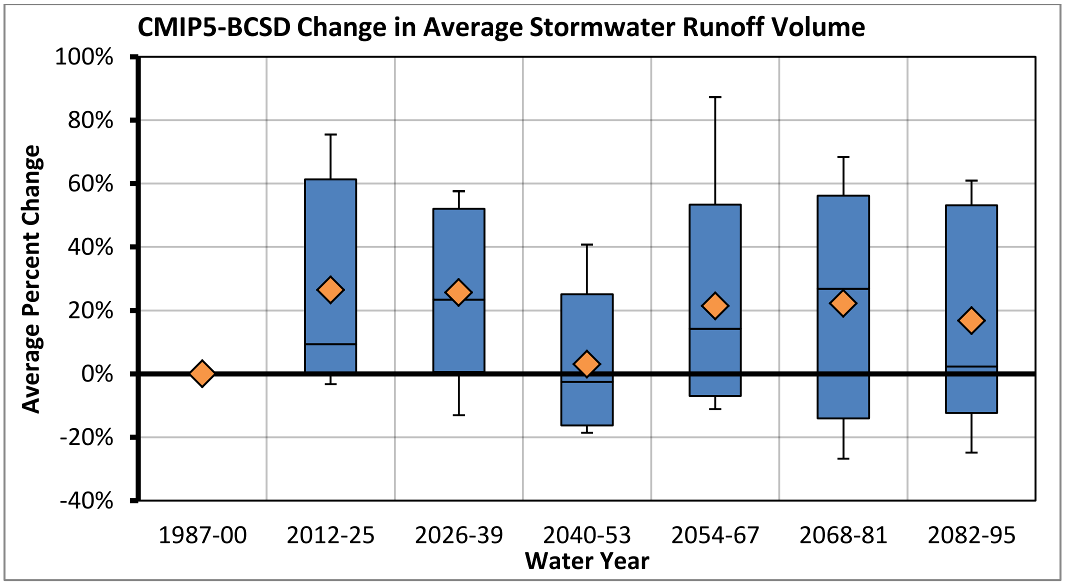


Figure 28. CMIP5-BCSD Stormwater Runoff Projections

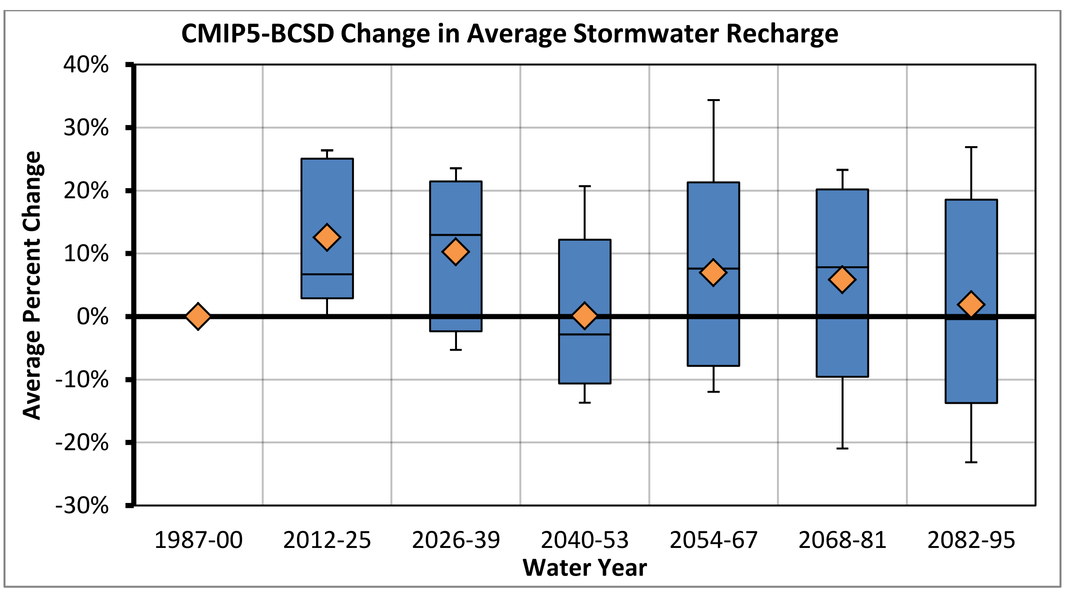


Figure 29. CMIP5-BCSD Stormwater Recharge Projections

The stormwater recharge volume exhibits a similar pattern to the stormwater runoff volume; with recharge variability being less sensitive to changes in climate. There is a higher sustained amount of potential average annual recharge observed with a slight reduction during water years 2040-2053 (Figure 29). Finally, the range becomes larger towards the end of future periods.

3.2.3.2. Flood Flow Analysis Results

From the Projected Hydrology for CMIP5-BCSD, the peak flow rate has a very similar pattern as the stormwater runoff and recharge volumes. Overall, the peak flow rate remains elevated during the future periods, with a slightly lesser projection for the water years 2040 through 2053 (Figure 30). The differences in the projections are highly variable for this climate scenario. The projected flow rates appear to increase dramatically in the early part of the century and generally remain at this elevated level throughout the future periods.

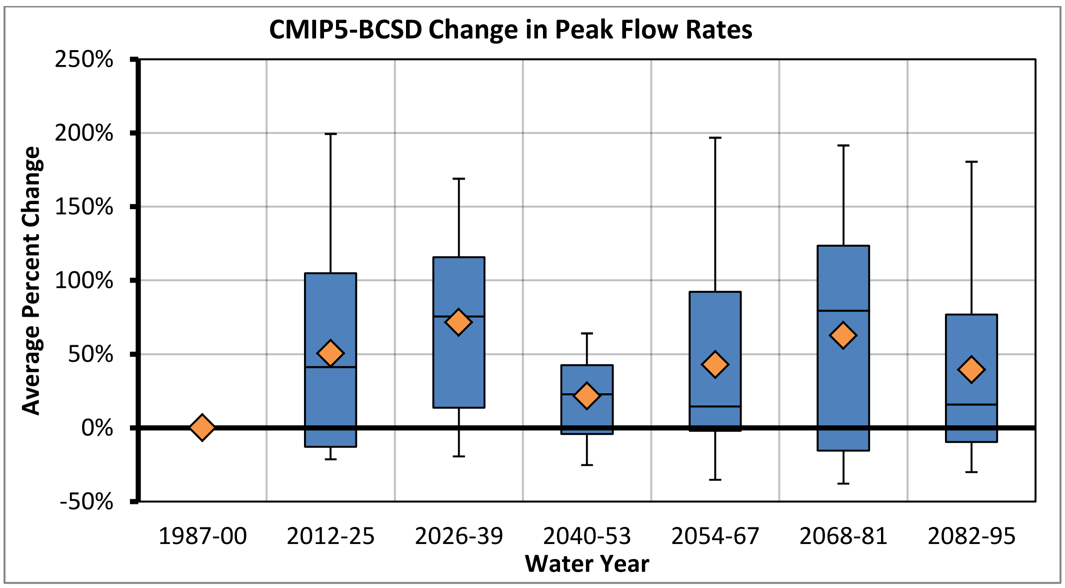


Figure 30. CMIP5-BCSD Peak Flow Rate Projections

3.2.4. CMIP5-BCSD with LID Implementation

3.2.4.1. Stormwater Conservation Results

Figure 31 and Figure 32 show runoff and recharge, respectively. For the CMIP5-BCSD climate scenario with LID Implementation, the Projected Hydrology demonstrates the same variable pattern in stormwater runoff over the course of the future period with minor changes towards the end of the century (Figure 31). Due to the methodology for applying LID, there is very little initial deviation in the average percent change between the CMIP5-BCSD and CMIP5-BCSD-LID hydrology projections. At the end of the century, a decrease in total runoff volume is observed. Comparison of the ensemble means for the final period shows a decrease of 10% in the projected stormwater runoff volume for the LID scenario.

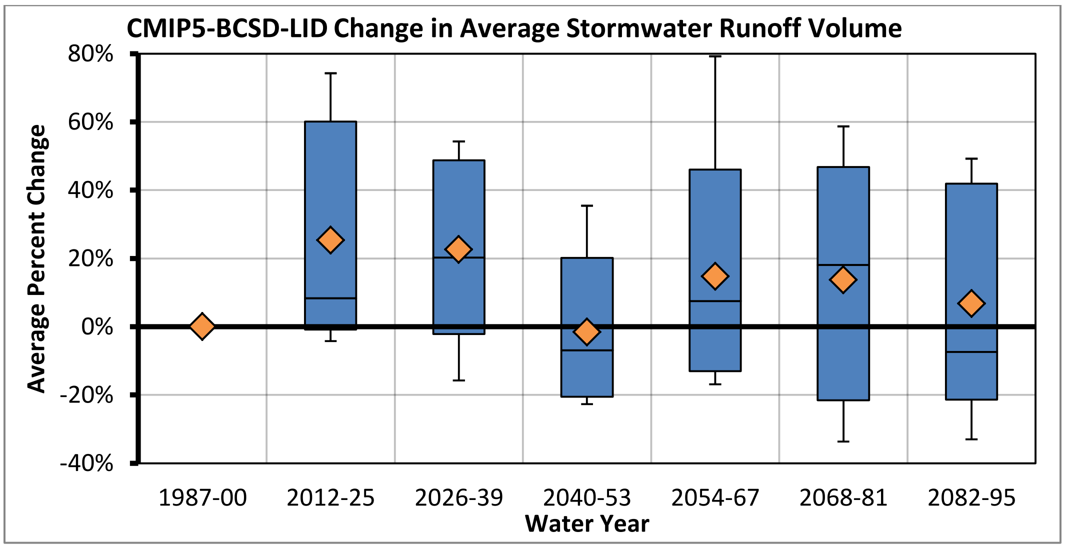


Figure 31. CMIP5-BCSD-LID Stormwater Runoff Projections

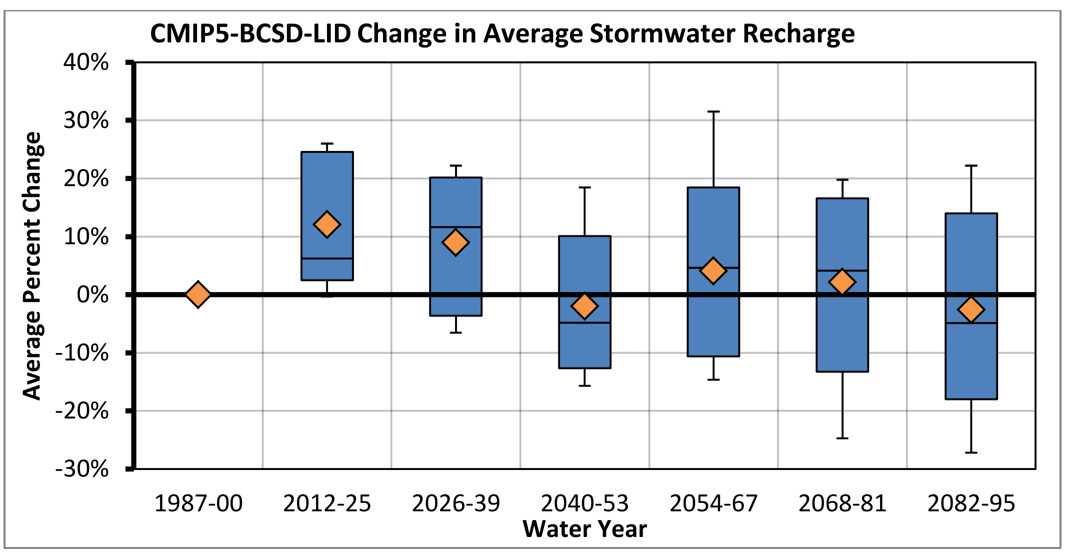


Figure 32. CMIP5-BCSD-LID Stormwater Recharge Projections

From Figure 32, the projected stormwater recharge volume variability is again observed to be less sensitive to changes in climate. Additionally, effects of LID implementation are less noticeable in the early century and the reduction in the projected stormwater recharged is not as large as the drop in total stormwater runoff.

Compared to CMIP5-BCSD, the stormwater recharge ensemble mean drops by an additional 5% and equates to 3% below baseline during water years 2082-2095. For the stormwater runoff volume ensemble mean, LID is projected to decrease volumes by 10% by water years 2082 through 2095 which equals to 7% above the historic mean. This implies that less water is recharged overall within LACFCD stormwater facilities.

3.2.4.2. Flood Flow Analysis Results

From the Projected Hydrology for CMIP5-BCSD with LID implementation, the peak flow rate does not deviate substantially from the CMIP5-BCSD projections. Similar to the non-LID case, the projected peak flow rates remain elevated for the future periods and show a large range in values (Figure 33). In comparing the two cases, a potential 10% reduction in peak flow rates is observed for the LID scenario during water years 2082 through 2095.

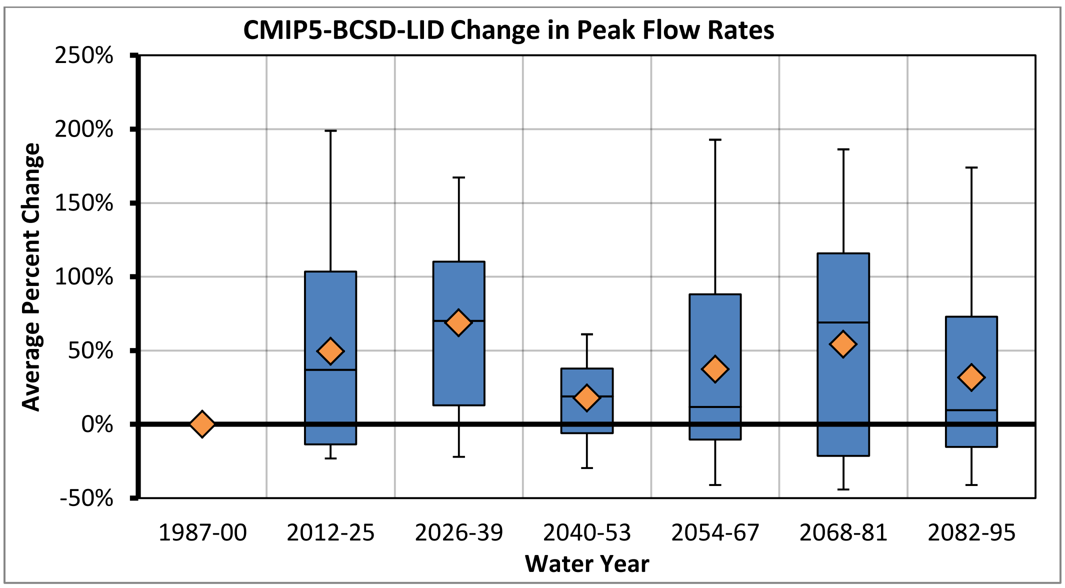


Figure 33. CMIP5-BCSD-LID Peak Flow Rate Projections

3.2.5. CMIP5-BCCA-RCP2.6

3.2.5.1. Stormwater Conservation Results

Figure 34 and Figure 35 show runoff and recharge, respectively. For the CMIP5-BCCA climate scenario with the RCP2.6 or “mitigation” pathway, the Projected Hydrology exhibits an elevated pattern in stormwater runoff over the course of the entire future period. This climate scenario suggests an overall and sustained increase in the average annual runoff for nearly all future periods (Figure 34). It is observed that the range between the 25th and 75th percentiles for each of the future periods generally widens over time until the end of the century.

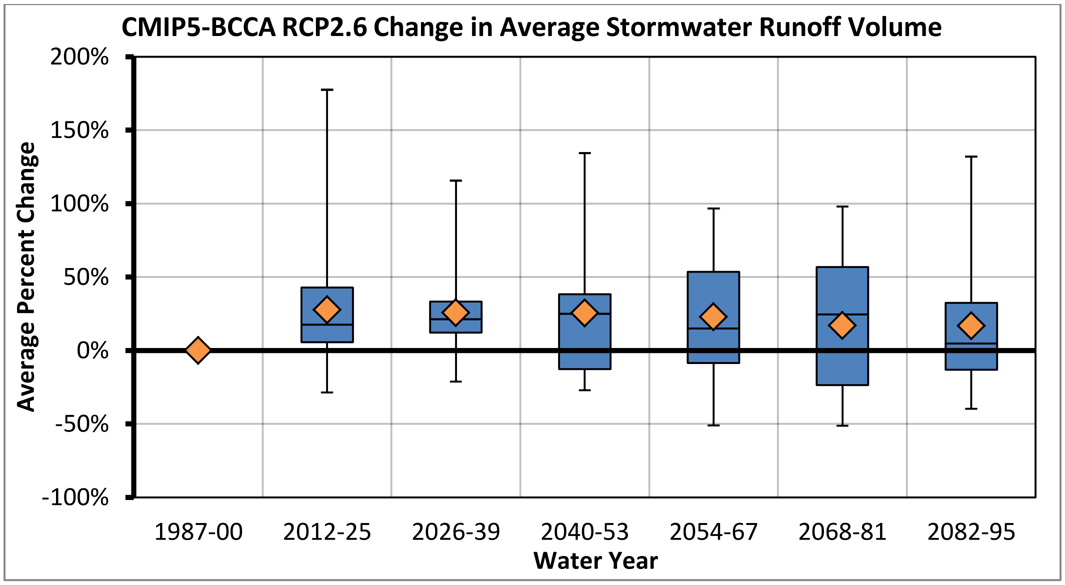


Figure 34. CMIP5-BCCA RCP2.6 Stormwater Runoff Projections

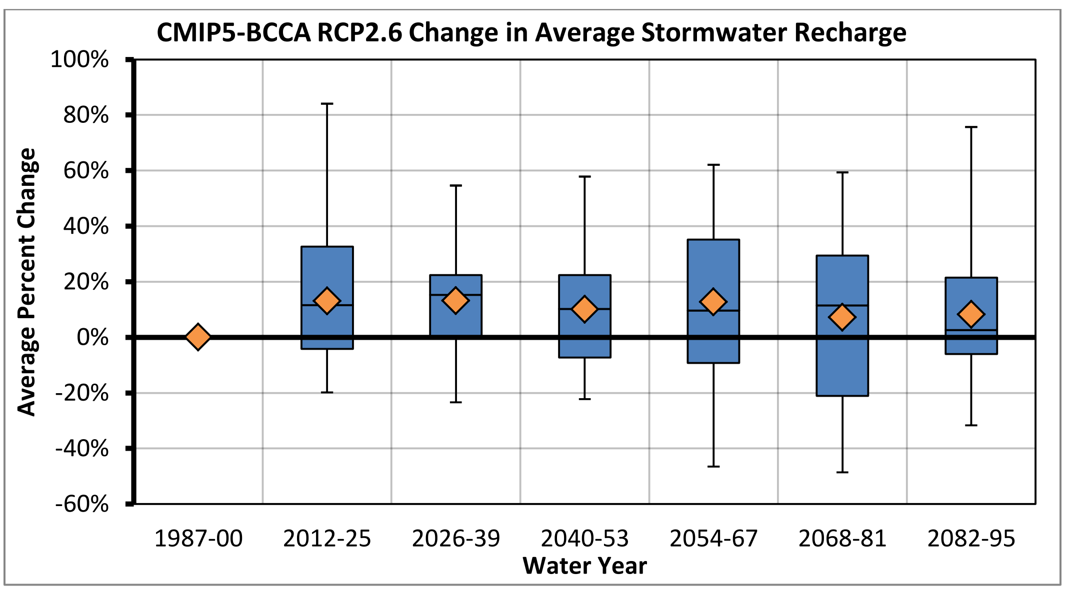


Figure 35. CMIP5-BCCA RCP2.6 Stormwater Recharge Projections

For the CMIP5-BCCA-RCP2.6 projections, projected stormwater recharge volume exhibits a similar pattern to the stormwater runoff volume projections. Recharge variability is again less sensitive to changes in climate, but it appears to have a higher uncertainty for each future period. Overall, there is potentially a sustained higher amount of average annual recharge (Figure 35).

3.2.5.2. Flood Flow Analysis Results

For the CMIP5-BCCA-RCP2.6 Projected Hydrology, the peak flow rate exhibits a different pattern than the stormwater conservation projections. The maximum flow rate for the this scenario generally exhibits a neutral pattern, remaining more or less constant at baseline values when observing the ensemble mean (Figure 36). The projections suggest that overall, the potential peak flows may remain centered on the historic average, but there is still a very wide range of uncertainty across all future periods.

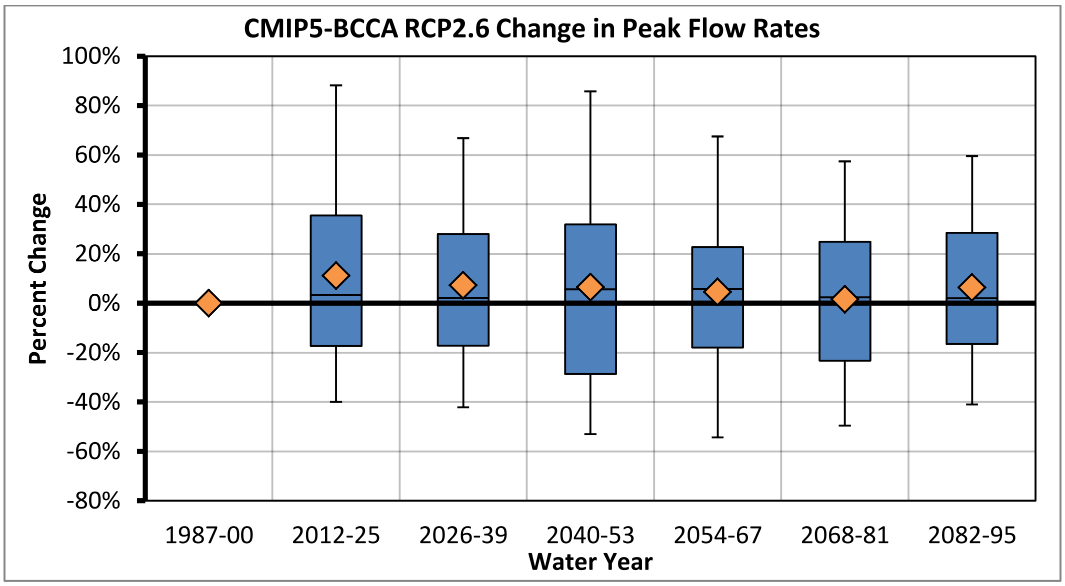


Figure 36. CMIP5-BCCA RCP2.6 Peak Flow Rate Projections

3.2.6. CMIP5-BCCA-RCP8.5

3.2.6.1. Stormwater Conservation Results

Figure 37 and Figure 38 show runoff and recharge, respectively. For the CMIP5-BCCA climate scenario with the RCP8.5 or "business as usual" pathway, the Projected Hydrology displays an elevated pattern in stormwater runoff over the course of the entire future period. This climate scenario suggests an overall and sustained increase in the average annual runoff projections for nearly all future periods. Similar to the CMIP5-BCCA-RCP2.6 projections, it is observed that the range for each of the future periods generally widens over time until the end of the century. Stormwater runoff volume projections appear to increase in both magnitude and spread from the baseline hydrology, suggesting that more stormwater may be available with this climate change scenario (Figure 37).

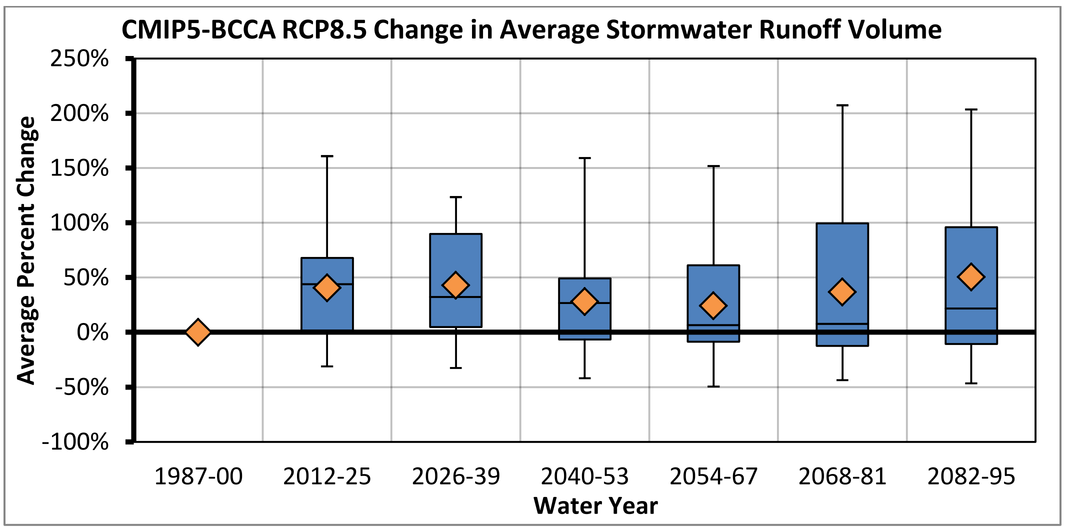


Figure 37. CMIP5-BCCA RCP8.5 Stormwater Runoff Projections

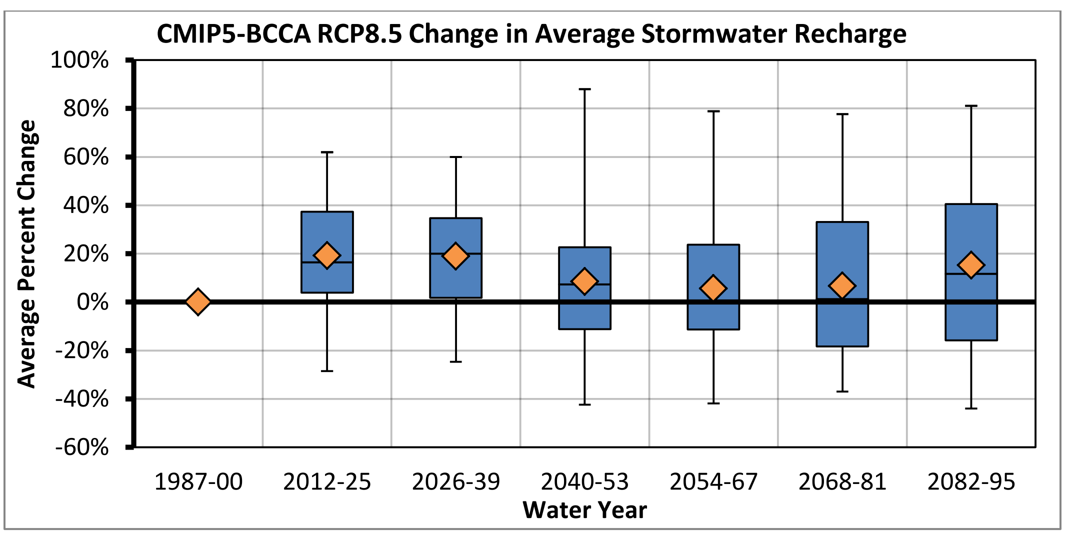


Figure 38. CMIP5-BCCA RCP8.5 Stormwater Recharge Projections

For the CMIP5-BCCA-RCP8.5 projections, stormwater recharge volume exhibits a similar pattern as the stormwater runoff volume projections. Recharge variability is again less sensitive to changes in climate, but it appears to have a higher uncertainty towards the end of the century. Generally, there is a sustained higher amount of average annual recharge (Figure 38).

3.2.6.2. Flood Flow Analysis Results

For the CMIP5-BCCA-RCP8.5 Projected Hydrology, the peak flow rates display a pattern similar to the stormwater conservation projections. The peak flow rate for this scenario generally exhibits a neutral to positive pattern, remaining elevated above baseline values when observing the ensemble mean (Figure 39). The scenario suggests that overall, peak flows may remain centered on present day hydrology values, but there is still a very wide range of uncertainty for all future periods.

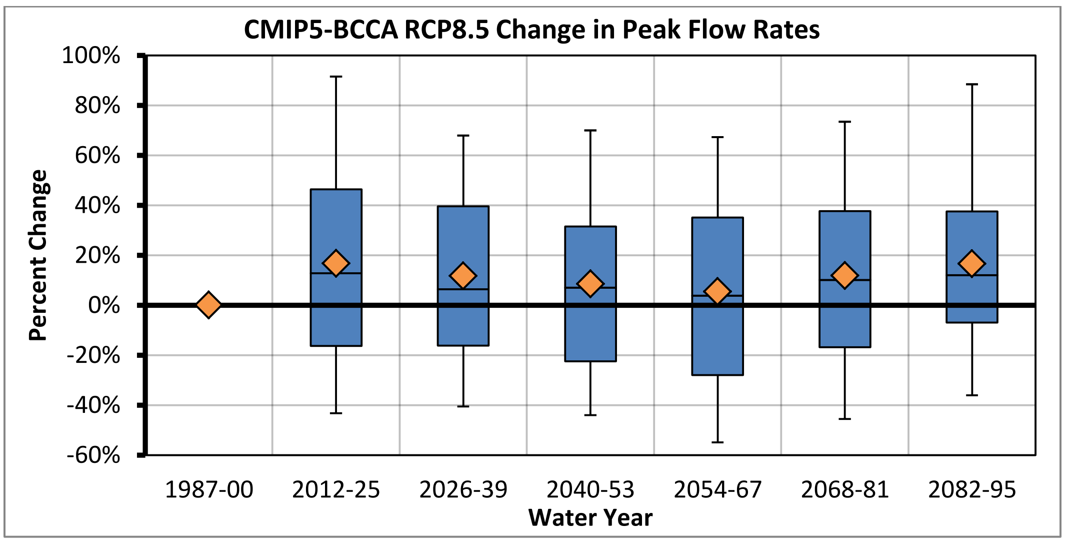


Figure 39. CMIP5-BCCA RCP8.5 Peak Flow Rate Projections

4. Conclusion

The key objective of Task 3.2 was to produce hourly outputs of stormwater runoff volumes and rates over the historic and future periods for the LA Basin Study. WMMS used existing meteorological data to simulate the Historic Hydrology. For the Projected Hydrology, the climate-adjusted hydrologic inputs developed by Reclamation were used to generate the future hydrology projections. Within the Basin Study Watersheds studied, 210 target subwatersheds had individual hydrology projections produced and analyzed to identify climate change impacts to the overall stormwater conservation and flood control system.

Section 4.1. discusses and compares the overall projection and ensemble mean comparisons of the hydrologic patterns and temporal changes between the different climate change projections.

Section 4.2. discusses selecting hydrologic projections for future analysis.

4.1. Overall Trends and Variations

The Projected Hydrology results produced from the CMIP3-BCSD, CMIP5-BCSD, and CMIP5-BCCA climate projections each exhibit a wide variability when compared to one another. This variability directly relates to the climate change models themselves, the downscaling techniques used, as well as their underlying emission scenarios. By combining the climate scenarios, each set of projections could be compared to the baseline Historic Hydrology.

The Projected Hydrology results are compared to one another by considering their overall areal response to climate change across the entire future period for water years 2012 through 2095 over the Basin Study Watersheds. Further, the results are rearranged to reflect the ensemble means of the different projections and how the means change over time with respect to the separate projections.

Section 4.1.1. summarizes the stormwater runoff volume results.

Section 4.1.2. summarizes the stormwater recharge results.

Section 4.1.3. summarizes peak flood flow results.

Section 4.1.4. summarizes the LID observations and results.

4.1.1. Stormwater Runoff Volumes

Projections for stormwater runoff volumes are projected to increase in magnitude over the next century. Moreover, there exists a wide range of variability between the overall projection and ensemble mean comparisons as shown in Figure 40 and Figure 41, respectively.

The overall Projected Hydrology comparison in Figure 40 shows that there is a potential for increased stormwater runoff when all of the climate change projections are considered over the entire future period. Four out of the six Projected Hydrology results show there is a positive projection that stormwater could increase during the century, while the remaining two appear to remain neutral. There exists variability within each scenario; however, through inspection of the overall ensemble means, stormwater runoff could potentially increase between 4% and 37%.

The individual ensemble mean comparison, Figure 41 shows CMIP5-BCCA-RCP8.5 or the “business as usual” scenario as projecting the greatest elevation in stormwater runoff levels with increases between 24% to 51%—depending on the future period. Conversely, the lowest stormwater runoff is exhibited by the CMIP3-BCSD scenario, which projects a maximum increase of 20% during water years 2012 through 2025, but then declines over the course of the century. Nevertheless, while there is significant variability between the ensemble means of all climate projections, there is an overall pattern of increasing stormwater supplies.

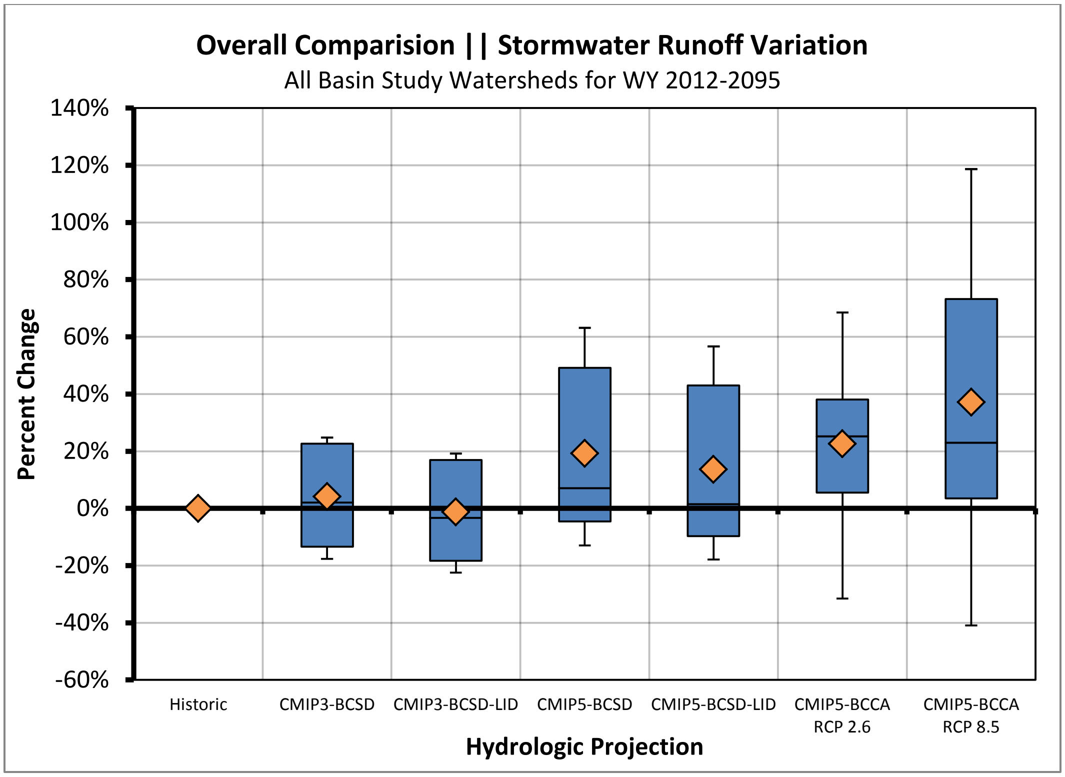


Figure 40. Projected Hydrology – Overall Comparison of Stormwater Runoff

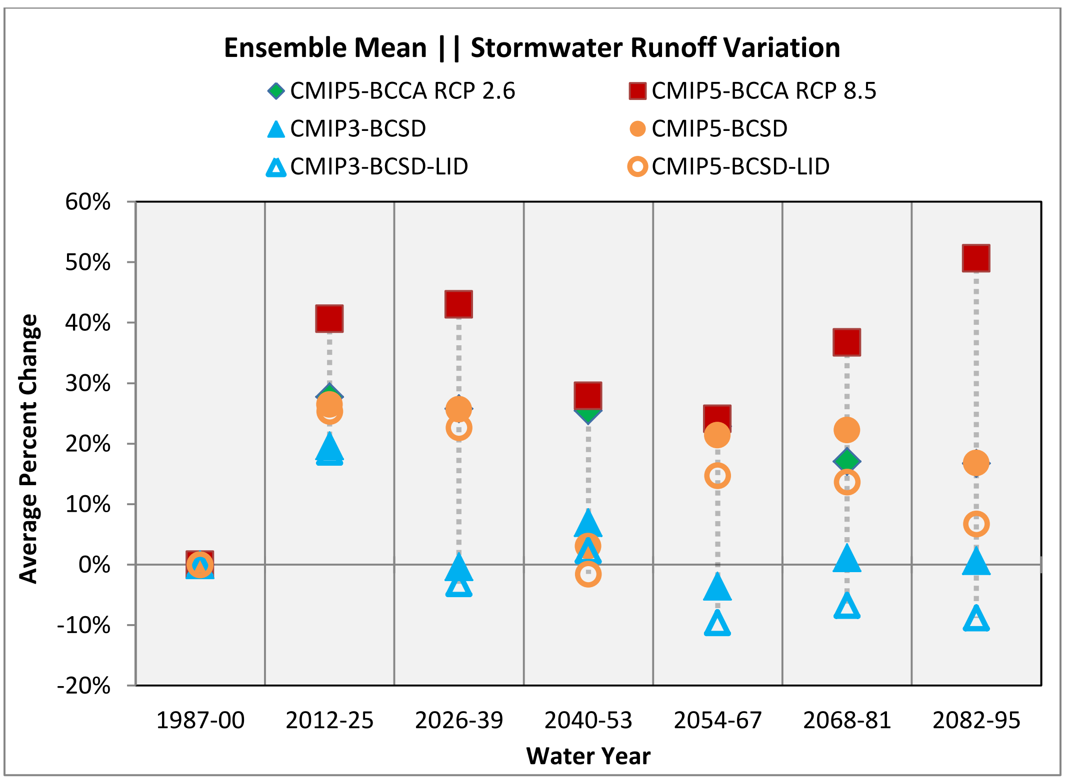


Figure 41. Projected Hydrology – Ensemble Mean Comparison of Stormwater Runoff

4.1.2. Stormwater Recharge Volumes

For stormwater recharge volume, the projections indicate that there may be potential for a minor increase when all of the climate change scenarios are considered. There happens to be wide variability between the overall projection and ensemble mean comparisons as shown in Figure 42 and Figure 43, respectively.

Four out of the six hydrology scenarios show there is an overall positive projection for stormwater recharge, with the other two projections exhibiting a neutral and slight decrease in behavior (Figure 42). The majority of the overall variability remains greater than neutral, possibly signaling that there could be increased recharge over the course of the future period. Furthermore, the ensemble mean for the four positive projections display a potential increase of between 6% and 12%.

For the individual ensemble mean comparison, Figure 43 shows CMIP5-BCCA-RCP8.5 or the “business as usual” scenario as projecting the greatest increase in stormwater recharge with increases between 4% to 19%—depending on the future period. Conversely, the lowest stormwater recharge is exhibited by the CMIP3-BCSD and CMIP3-BCSD-LID scenarios. Nevertheless, while there is significant variability between the ensemble means of all climate projections, there is a slight overall increase in stormwater recharge.

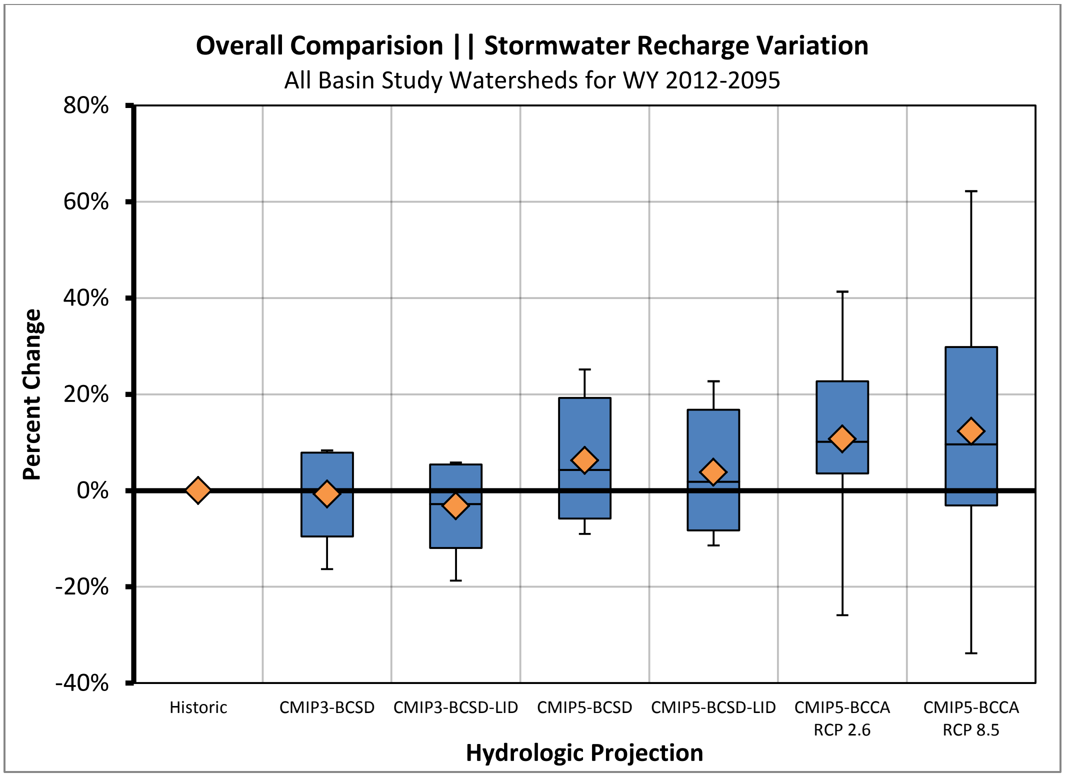


Figure 42. Projected Hydrology – Overall Comparison of Stormwater Recharge

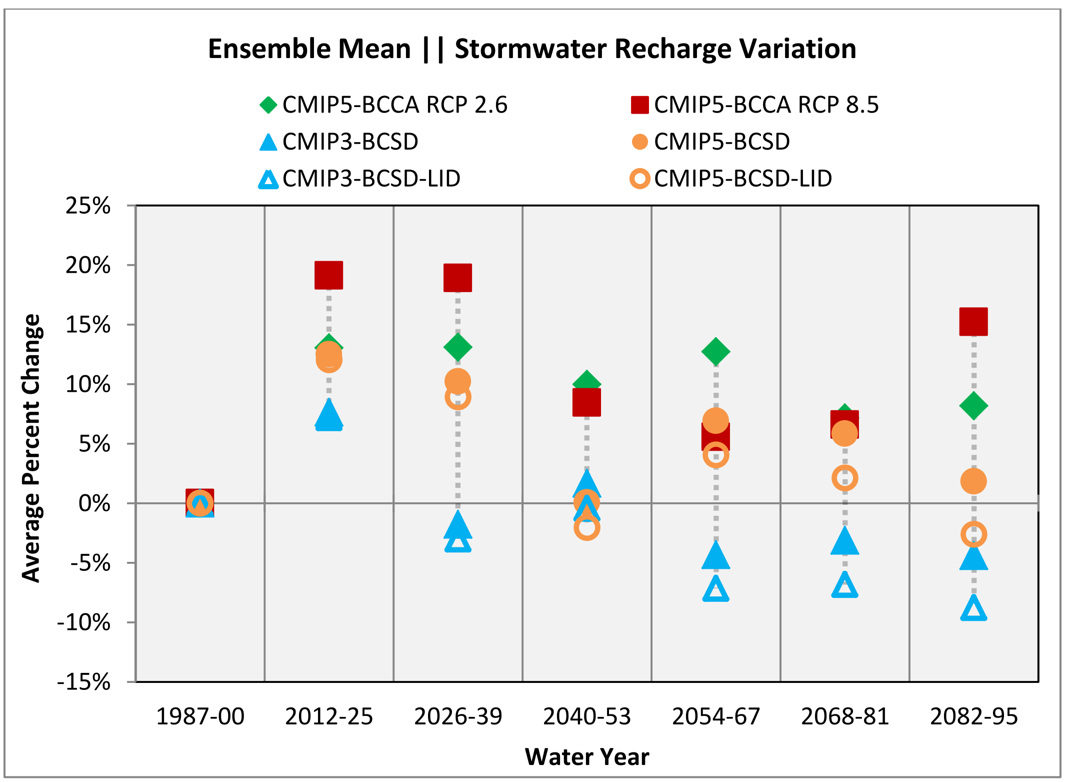


Figure 43. Projected Hydrology – Ensemble Mean Comparison of Stormwater Recharge

4.1.3. Peak Flood Flows

Similar to the projections for stormwater runoff volumes, the projected peak flows appear to increase in magnitude over the future periods. Furthermore, there exists a wide variability between the overall projections and ensemble means as shown in Figure 44 and Figure 45, respectively. However, it is important to note that beyond these Projected Hydrology ensemble mean results, there is still an even greater range of variability between the different climate change projections. Few projections show a reduction in peak flows. However, collectively, the projections indicate an increased magnitude of flood flow rates.

For the overall comparison of peak flood flow rates, Figure 44 shows that there is the potential for an increase of peak flows after all of the climate change scenarios are inspected. All six hydrology scenarios display an overall positive increase of peak flood flows. However, it is important to recognize the wide variability within the peak flood flow projections. The majority of the projections show that there is less potential for peak flows to decrease rather than increase. The ensemble mean for the peak flow rates could potentially increase anywhere between 6% and 48%.

When the peak flood flow rates are inspected temporally over each of the future periods for the individual projections, a distinct pattern between each of the Projected Hydrology results is revealed (Figure 45). The individual ensemble mean for CMIP5-BCSD is the projection that yields the highest results for a potential increase in peak flood flow rates of between 22% to 72%, while CMIP5-BCCA-RCP2.6 or the “mitigation” scenario projects the smallest increase in flow rates of 2% to 11%. Generally, CMIP3-BCSD results appear to be the central projection with respect to increasing peak flow rates.

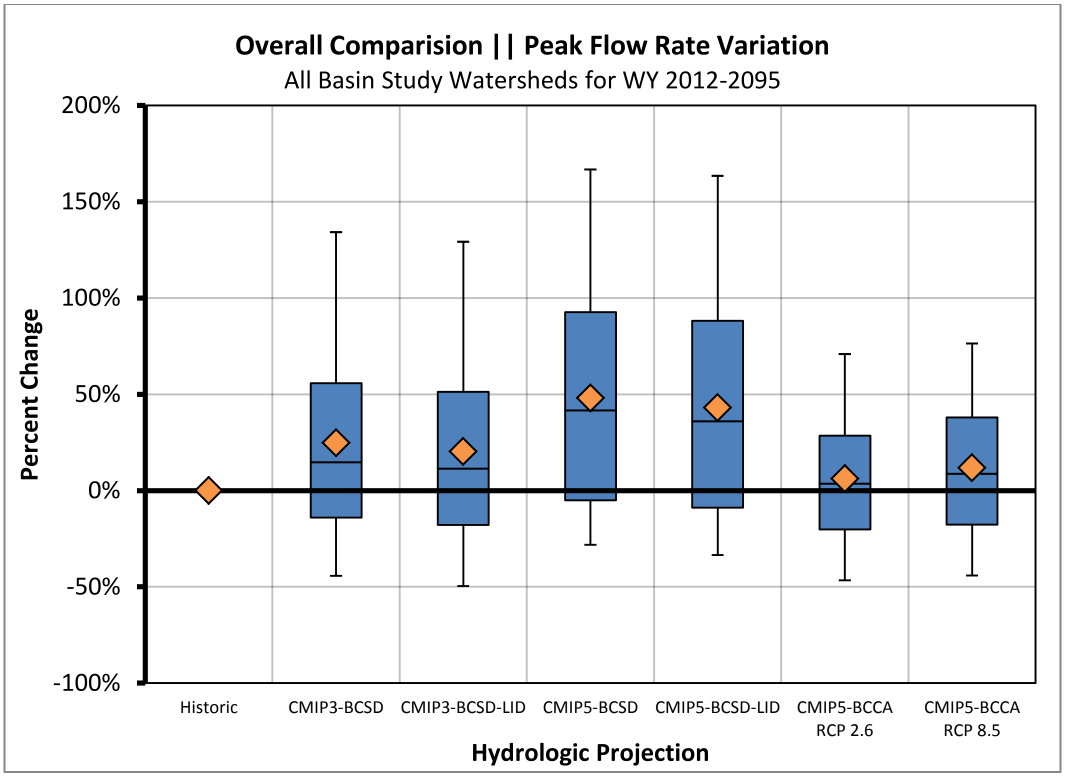


Figure 44. Projected Hydrology – Bulk Comparison of Peak Flow Rates

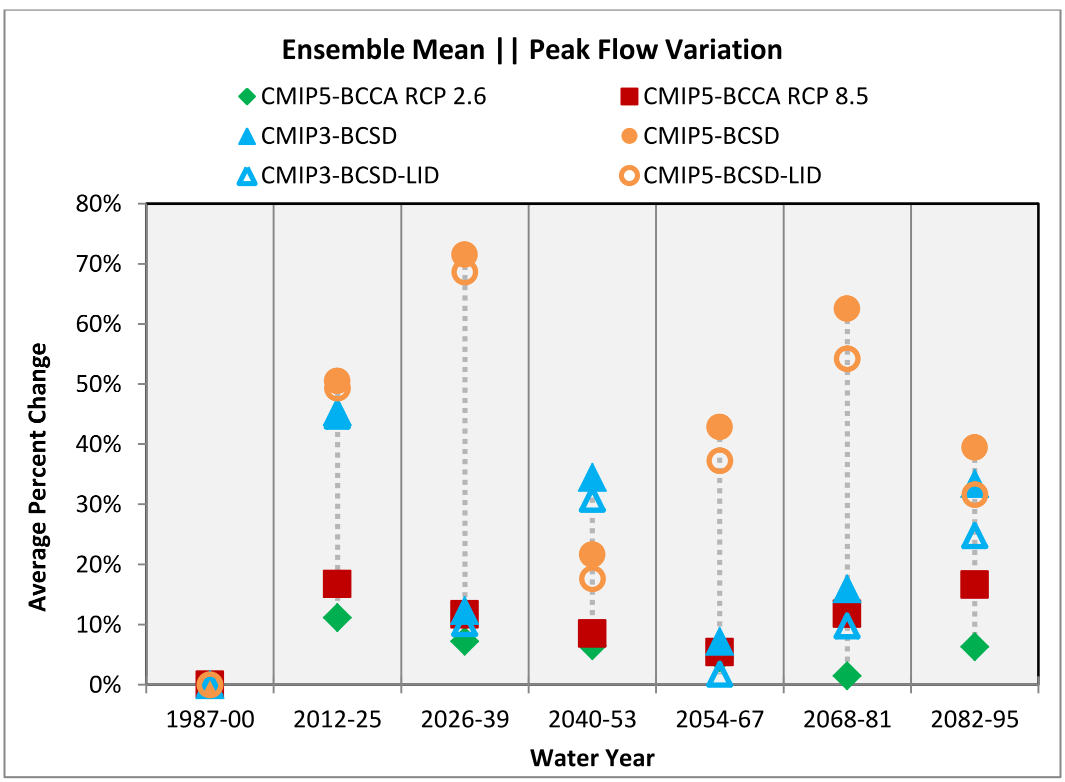


Figure 45. Projected Hydrology – Ensemble Mean Comparison of Peak Flow Rates

4.1.4. LID Impacts

Through the incorporation of LID as outlined in the methodology (see Section 2.1.4), the LA Basin Study was able to approximately simulate the potential effects of widespread LID implementation.

Depending on the actual extent and rate of LID implementation over the course of the century, there may be considerable variability among the projections. The major limitation with the hydrologic projections with LID implementation is that it only assumed one reasonable implementation case. The CMIP3-BCSD-LID and CMIP5-BCSD-LID projections do not provide a range of values—no lower or upper bound—with respect to varying LID implementation cases. The difference between CMIP3-BCSD-LID and CMIP5-BCSD-LID projections are a product of the climate change scenarios.

When assessing changes to overall stormwater conservation, LID appears to both reduce stormwater recharge at spreading facilities and decrease runoff to the ocean. Therefore, the direct influence of LID on the amount of capture has to be extrapolated and stormwater runoff and recharge needs to be considered in tandem. Due to this, it is not possible to assess the impacts of LID directly from the previous plots. Instead, since the amount of total precipitation does not change between the LID and non-LID projections, direct capture due to LID can be approximately determined from the reduced ocean stormwater runoff volume in combination with the amount of stormwater recharge at all LACFCD facilities.

Figure 46 shows that when introducing LID, there is a reduction in ocean stormwater runoff volumes (see Section 4.1.1) and a slight decrease in the amount of stormwater that reaches LACFCD facilities (see Section 4.1.2). Overall, however, there is the potential for additional stormwater water to be captured and less to be lost to the ocean. From the analysis, ocean runoff could potentially be reduced by 10% by 2095 with the assumed LID implementation rates.

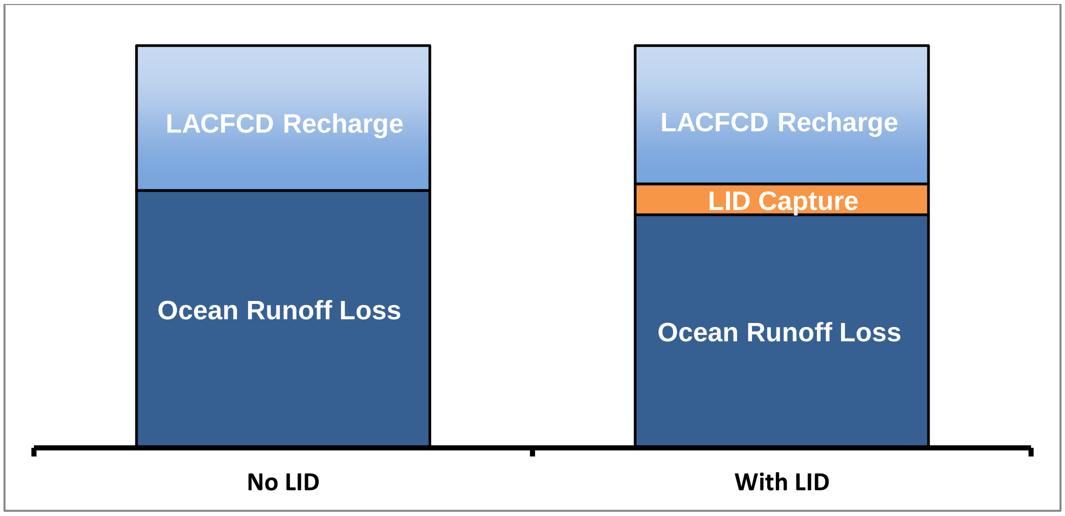


Figure 46. LID Capture Contribution

With widespread LID capturing and infiltrating stormwater on site, this could potentially free up LACFCD facilities to provide more capacity to recharge other sources of water. Considering this high-level analysis and the limitations set forth by the LID assumptions (see Section 2.1.4), there is a promising potential for LID to supplement stormwater recharge supplies.

In contrast, the overall impacts of LID implementation on peak flow rates appear to be nominal. At the end of the century during water year 2095 when LID implementation was assumed to be at its maximum implementation for the LA Basin Study timeline, peak flows are only reduced by a very small margin. The potential for peak flow reduction due to LID implementation was near 3%.

In general, LID does not appear to significantly aid in the reduction of peak flow rates. This finding is reinforced when the design standard that is used for the majority of LID is considered. Since LID intends to capture stormwater volumes or flows associated with the 85th percentile, 24-hour storm event, it can become quickly overwhelmed by larger storm events.

4.2. Preferred Hydrology for Continued Study Use

As the LA Basin Study progresses, certain tasks may require a re-run of the hydrology model due to modifications to operational guidelines or structural enhancements for the water conservation and flood control facilities. To move forward with the LA Basin Study, three hydrologic projections will be selected within Task 4. These projections will represent the extreme high, the extreme low and the central tendency for the overall stormwater runoff volumes and peak flow rates.

5. References

Department of Finance, 2013. State of California, Department of Finance, Report P-1 (County): State and County Total Population Projections, 2010-2060. Sacramento, California, January 2013. Online: <http://www.dof.ca.gov/research/demographic/reports/projections/P-1/>.

Los Angeles County, 2009. County of Los Angeles Low Impact Development Standards Manual. Prepared for the County of Los Angeles, by Los Angeles County Department of Public Works. Alhambra, California. January 2009. Online: <http://dpw.lacounty.gov/wmd/LA_County_LID_Manual.pdf>.

Los Angeles County Department of Public Works (LACDPW), 2004. Analysis of 85th Percentile 24-hour Rainfall Depth Analysis Within the County of Los Angeles. Los Angeles County Department of Public Works, Water Resources Division. Alhambra, California. February 2004. Online: <http://ladpw.org/wrd/publication/engineering/Final_Report-Probability_Analysis_of_85th_Percentile_24-hr_Rainfall1.pdf>.

LACDPW, 2006. Hydrology Manual. Los Angeles County Department of Public Works, Water Resources Division. Alhambra, California. January 2006. Online: <http://ladpw.org/wrd/publication/engineering/2006_Hydrology_Manual/2006%20Hydrology%20Manual-Divided.pdf>.

LACDPW, 2013. 2011-2012 Hydrologic Report. Los Angeles County Department of Public Works, Water Resources Division. Alhambra, California. July 2013. Online: <http://ladpw.org/wrd/report/acrobat/Hydrologic%20Report%202011-2012.pdf>.

LACDPW, 2011. 11-Year Water Conservation Totals and Averages. Los Angeles County Department of Public Works, Water Resources Division. Alhambra, California. September 2011.

MWD, 2012. Annual Report 2012. The Metropolitan Water District of Southern California, Los Angeles, California. 2012. Online: <http://www.mwdh2o.com/mwdh2o/pages/about/AR/AR12/2012AR-low-res.pdf>.

Reclamation, 2009. Basin Study Framework: WaterSMART Program. U.S. Department of the Interior, Bureau of Reclamation. Washington D.C. December 2009. Online: (http://www.usbr.gov/WaterSMART/bsp/docs/Revised%20Framework%202.26.13.pdf>.

Reclamation, 2013. Los Angeles Basin Stormwater Conservation Study: Task 3.1. Downscaled Climate Change Report. Technical Service Center, Denver Colorado.

Tetra Tech, 2009. Loading Simulation Program in C++ (LSPC) Version 3.1 User’s Manual. Tetra Tech, Inc. Fairfax, Virginia. December 11, 2009. Online: <http://dpw.lacounty.gov/wmd/wmms/docs/LSPC-UserManual.pdf>.

Tetra Tech, 2010. Los Angeles County Watershed Model Configuration and Calibration—Part I: Hydrology. Prepared for County of Los Angeles, Department of Public Works, by Tetra Tech, Inc. Pasadena, California. August 6, 2010. Online: <http://dpw.lacounty.gov/wmd/wmms/docs/Final_Phase_I_Modeling_Report_Part_I.pdf>.

Water Replenishment District of Southern California (WRD), 2012. Stormwater Recharge Feasibility and Pilot Project Development Study. Prepared for the Water Replenishment District of Southern California, by The Council for Watershed Health, Geosyntec Consultants, and Santa Monica Bay Restoration Commission, Los Angeles, California. August 20, 2012. Online: <http://www.wrd.org/1208020_SWRechargeFeasibility%20and%20PPDS_FinalReport.pdf>.

RECLAMATION

Managing Water in the West

Los Angeles Basin Stormwater Conservation Study

Task 3.2 Hydrologic Modeling Appendices

U.S. Department of the Interior
Bureau of Reclamation

County of Los Angeles
Department of Public Works

Los Angeles County
Flood Control District

This page intentionally left blank.

Appendix A: Hydrologic Projection Variation for Select Watershed Locations

Figures

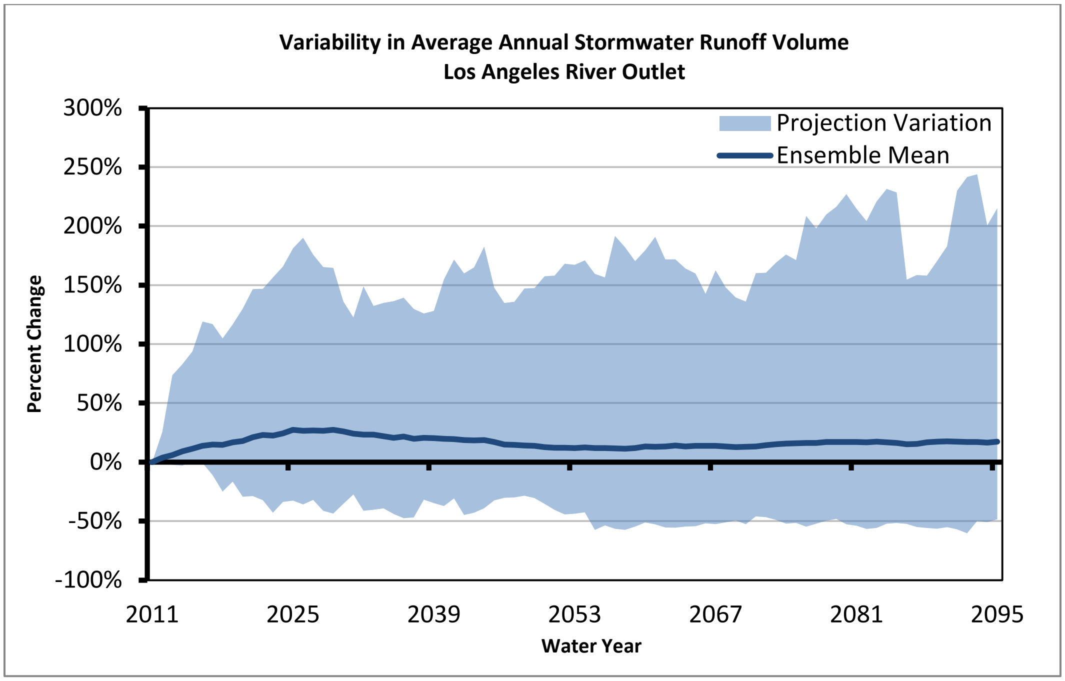


Figure A-1. Los Angeles River Outlet
Variability in Average Annual Stormwater Runoff Volume

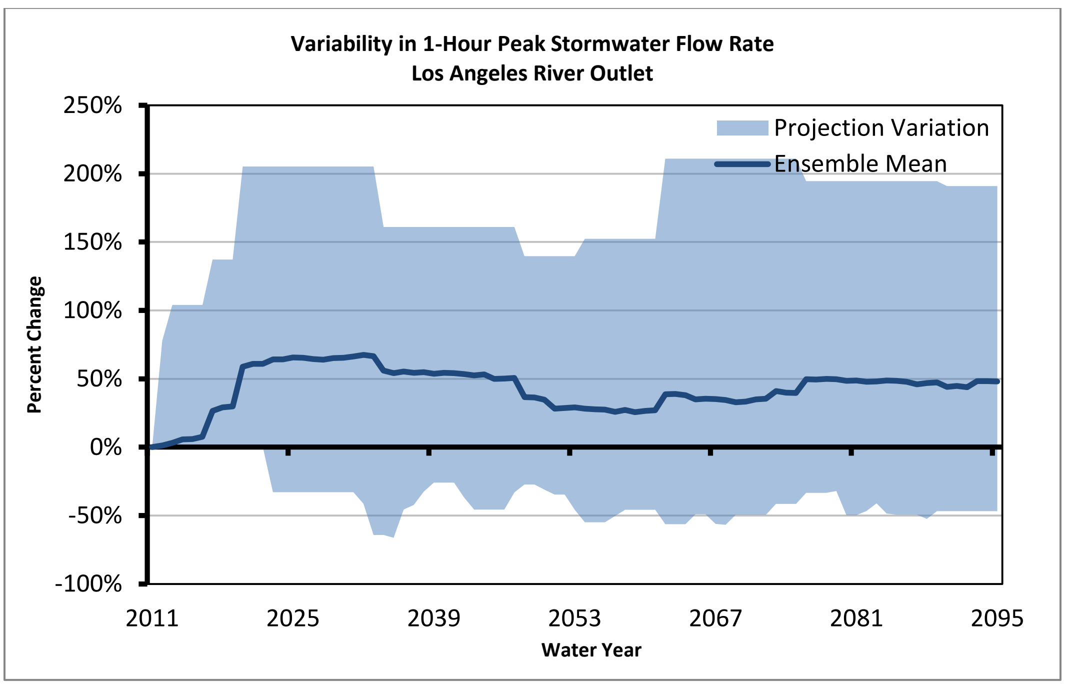


Figure A-2. Los Angeles River Outlet
Variability in 1-Hour Peak Stormwater Flow Rate

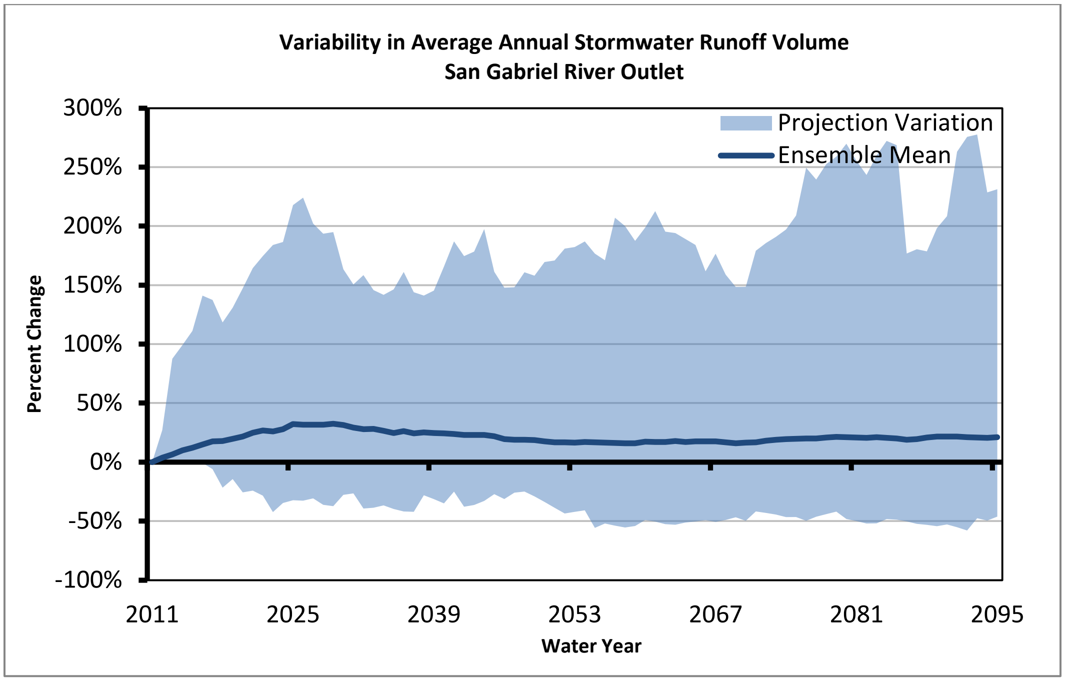


Figure A-3. San Gabriel River Outlet
Variability in Average Annual Stormwater Runoff Volume

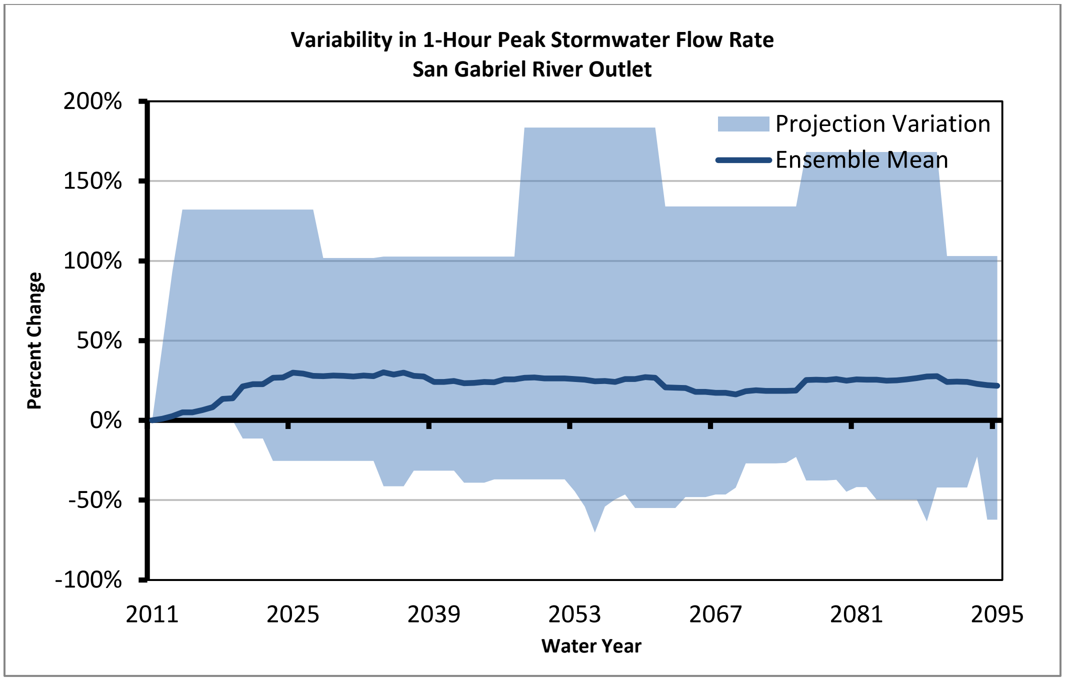


Figure A-4. San Gabriel River Outlet
Variability in 1-Hour Peak Stormwater Flow Rate

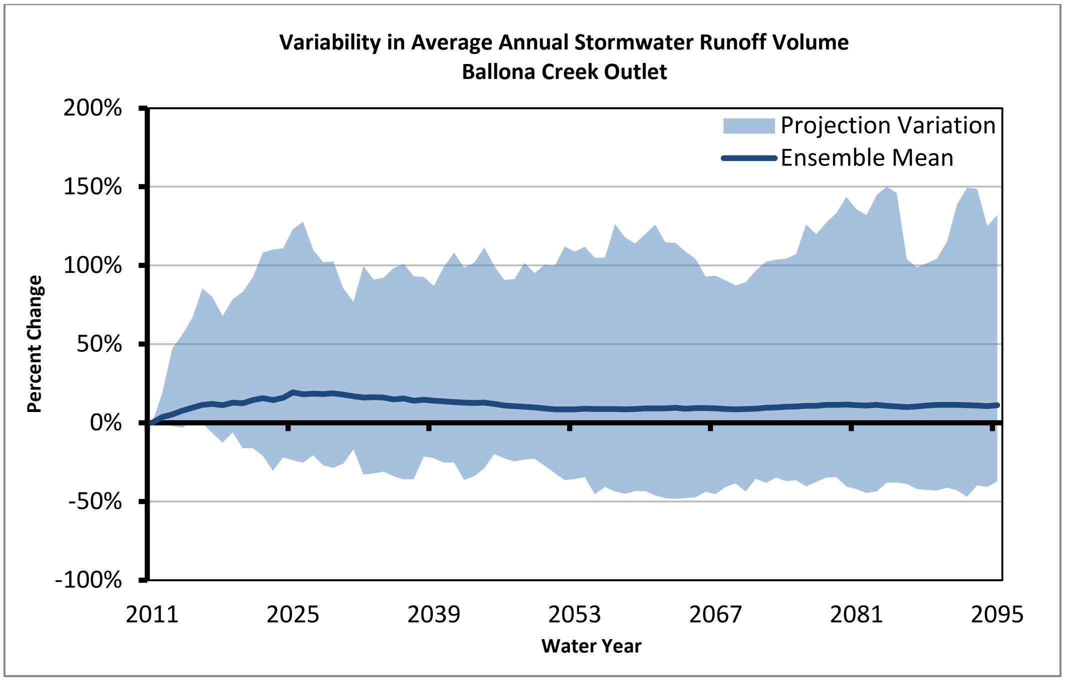


**Figure A-5. Ballona Creek Outlet
Variability in Average Annual Stormwater Runoff Volume**

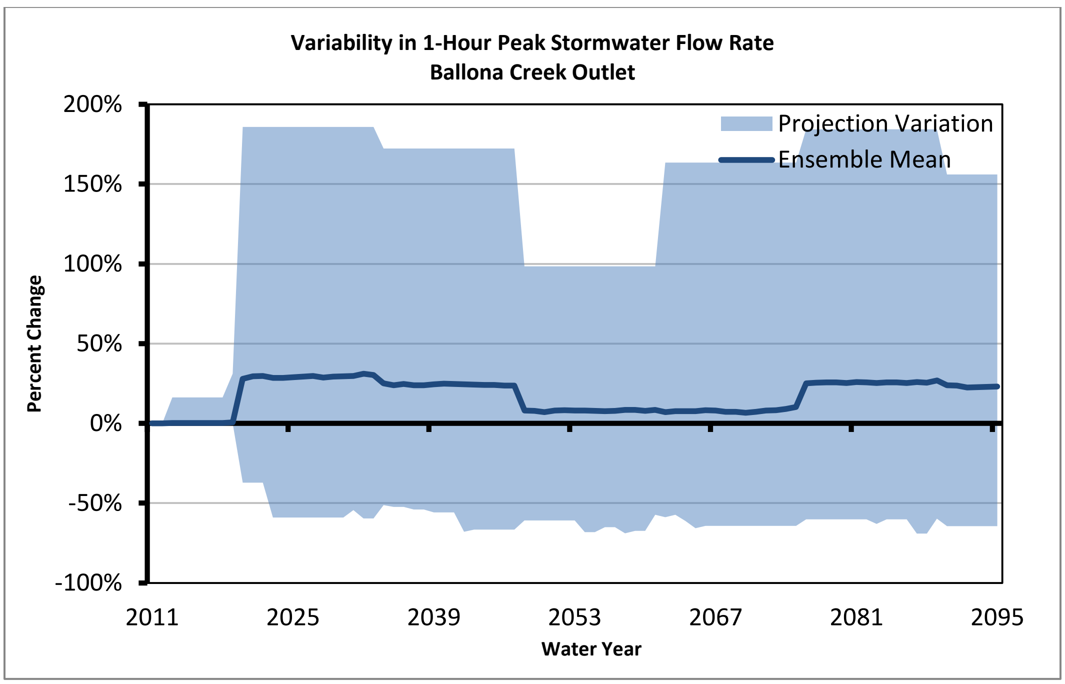


**Figure A-6. Ballona Creek Outlet
Variability in 1-Hour Peak Stormwater Flow Rate**

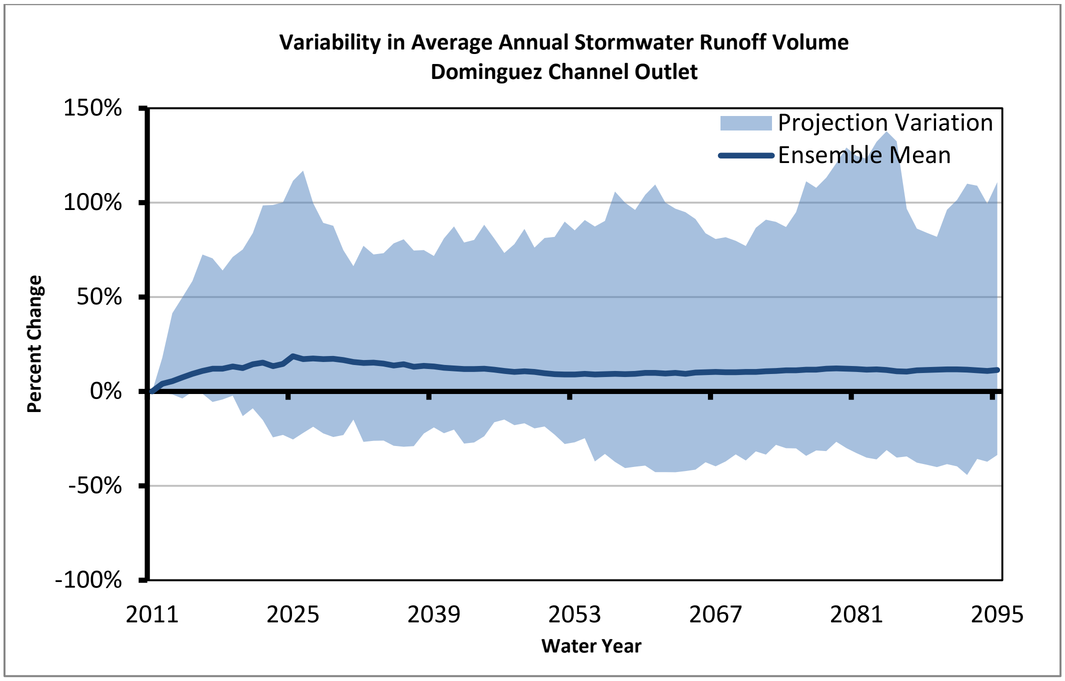


Figure A-7. Dominguez Channel Outlet
Variability in Average Annual Stormwater Runoff Volume

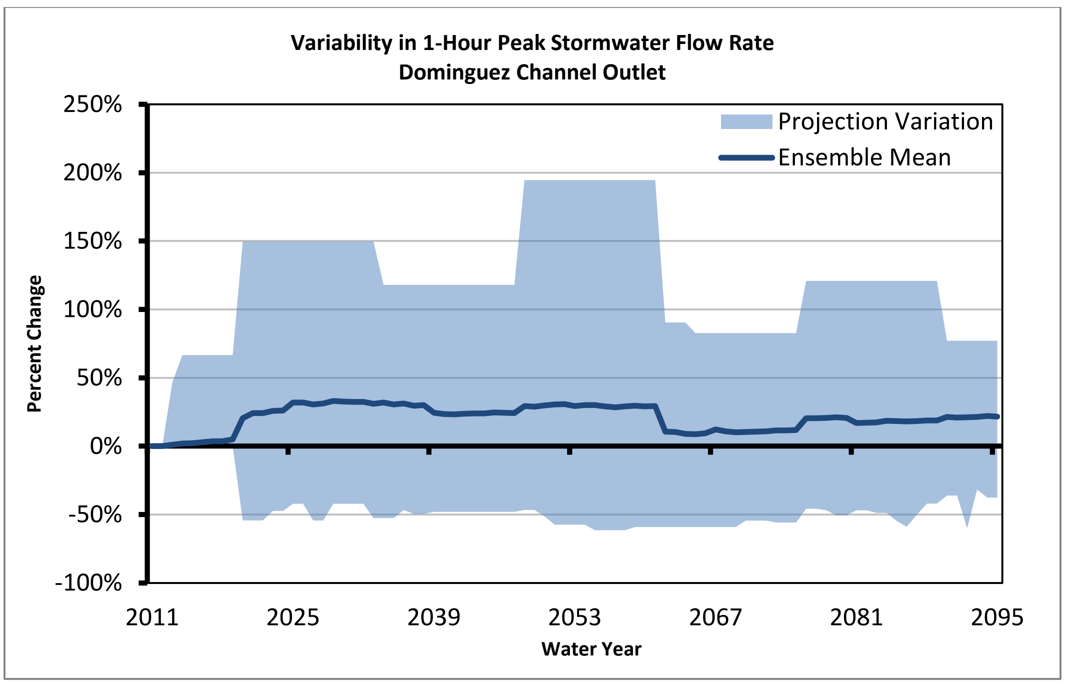


Figure A-8. Dominguez Channel Outlet
Variability in 1-Hour Peak Stormwater Flow Rate

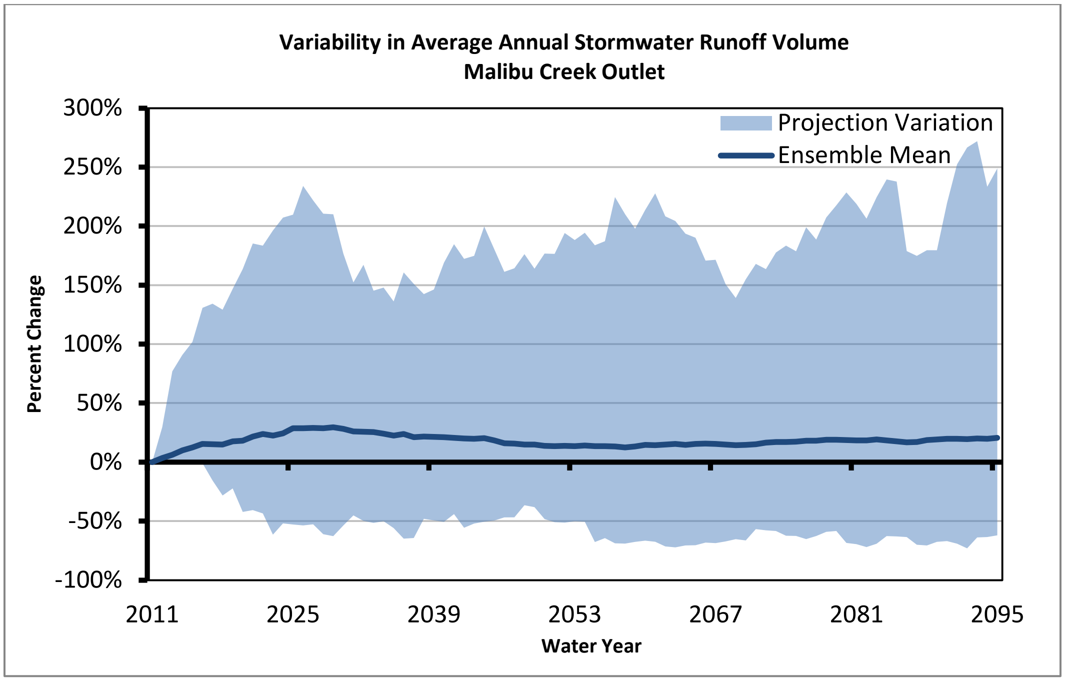


Figure A-9. Malibu Creek Outlet
Variability in Average Annual Stormwater Runoff Volume

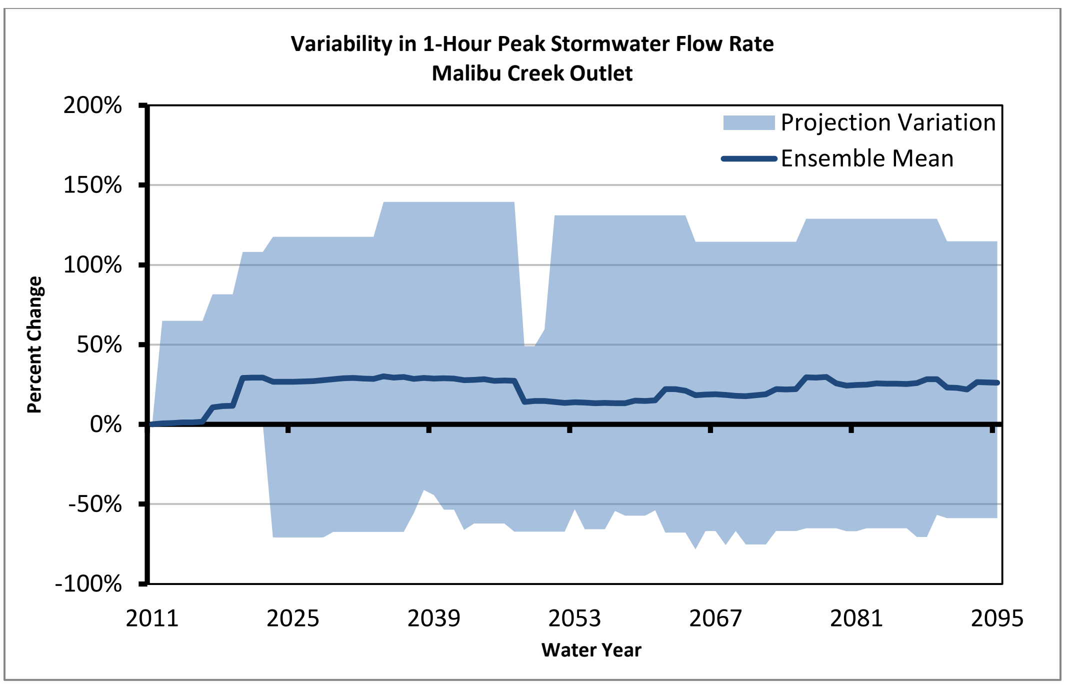


Figure A-10. Malibu Creek Outlet
Variability in 1-Hour Peak Stormwater Flow Rate

Appendix B: Hydrologic Projection Variation for Select Groundwater Basins

Figures

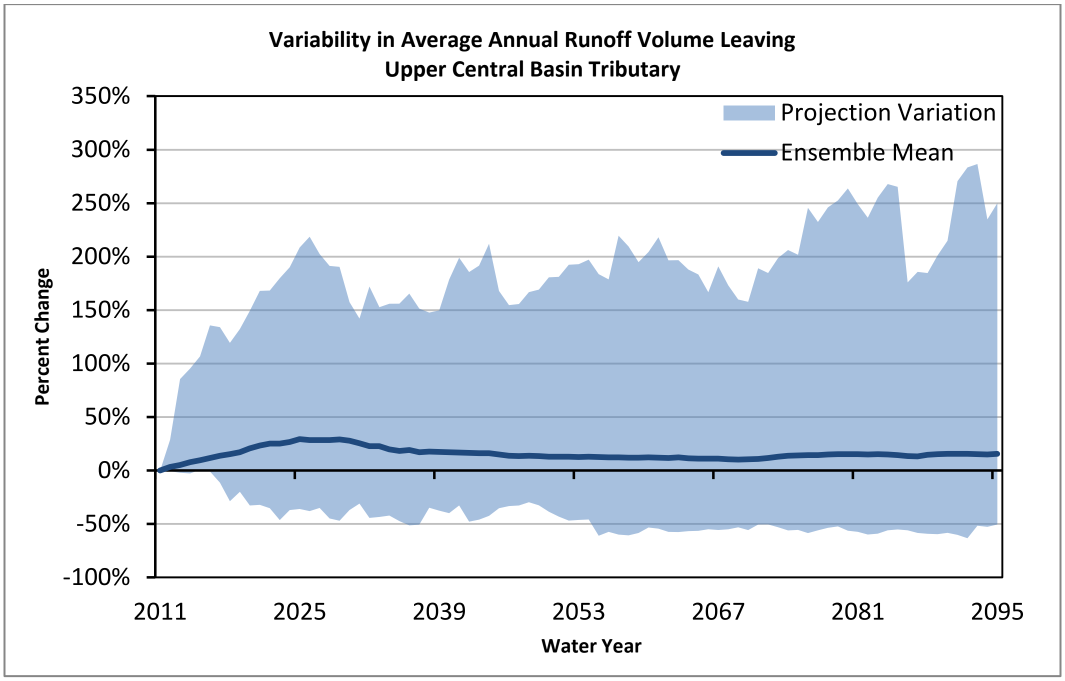


**Figure B-1. Central Basin (Upper)
Variability in Average Annual Runoff Volume Bypassing**

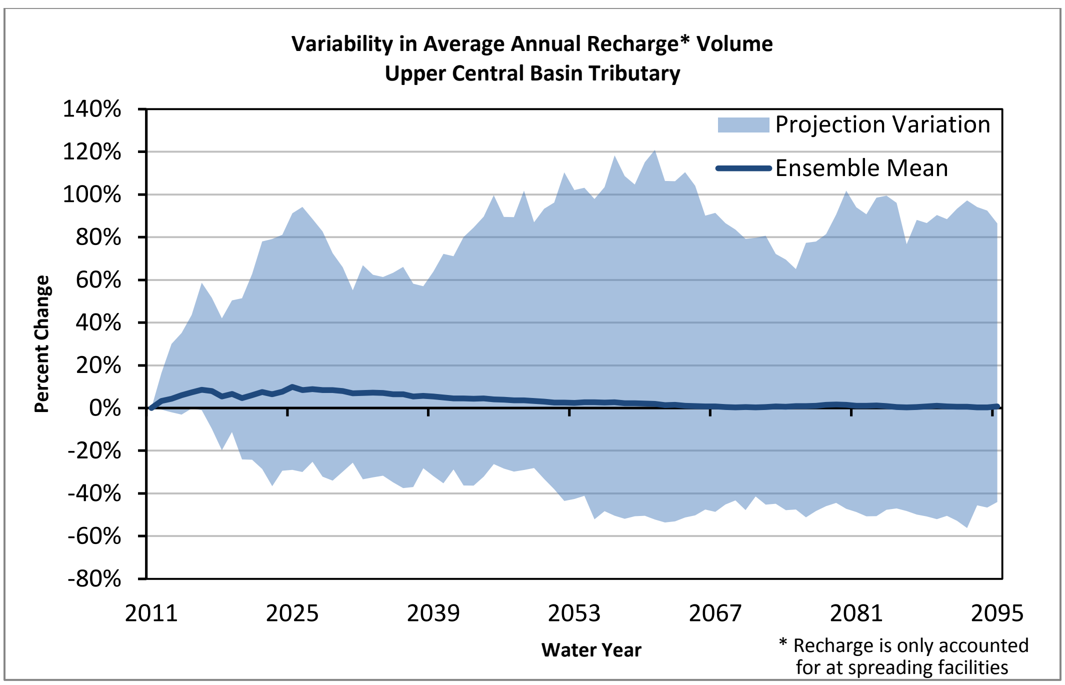


**Figure B-2. Central Basin (Upper)
Variability in Average Annual Recharge Volume**

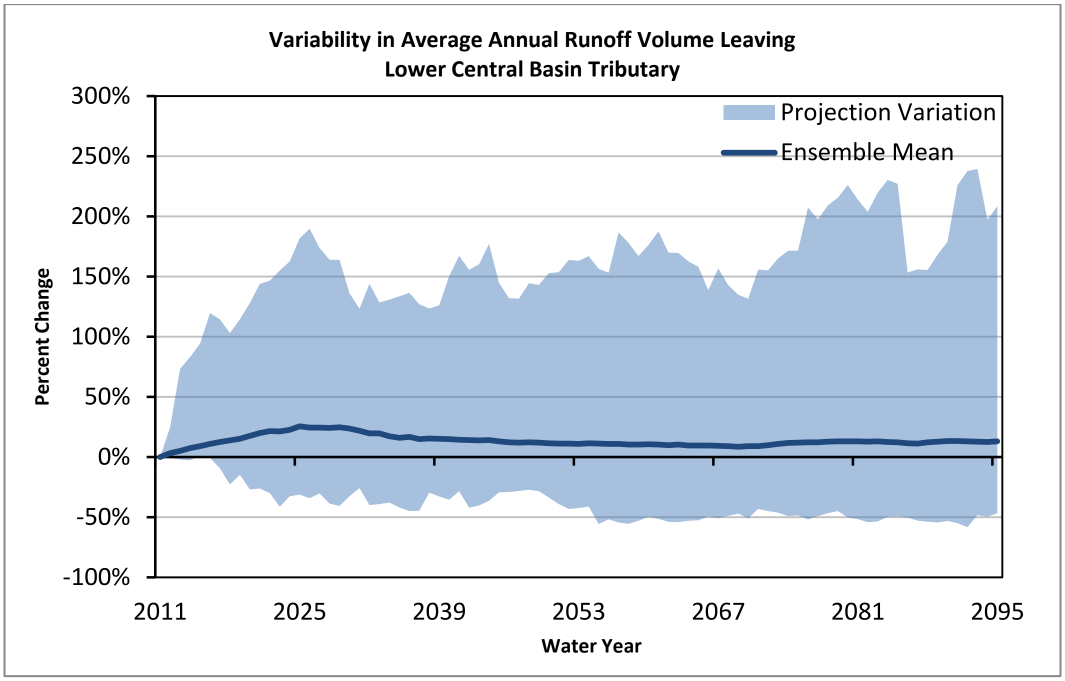


**Figure B-3. Central Basin (Lower)
Variability in Average Annual Runoff Volume Bypassing**

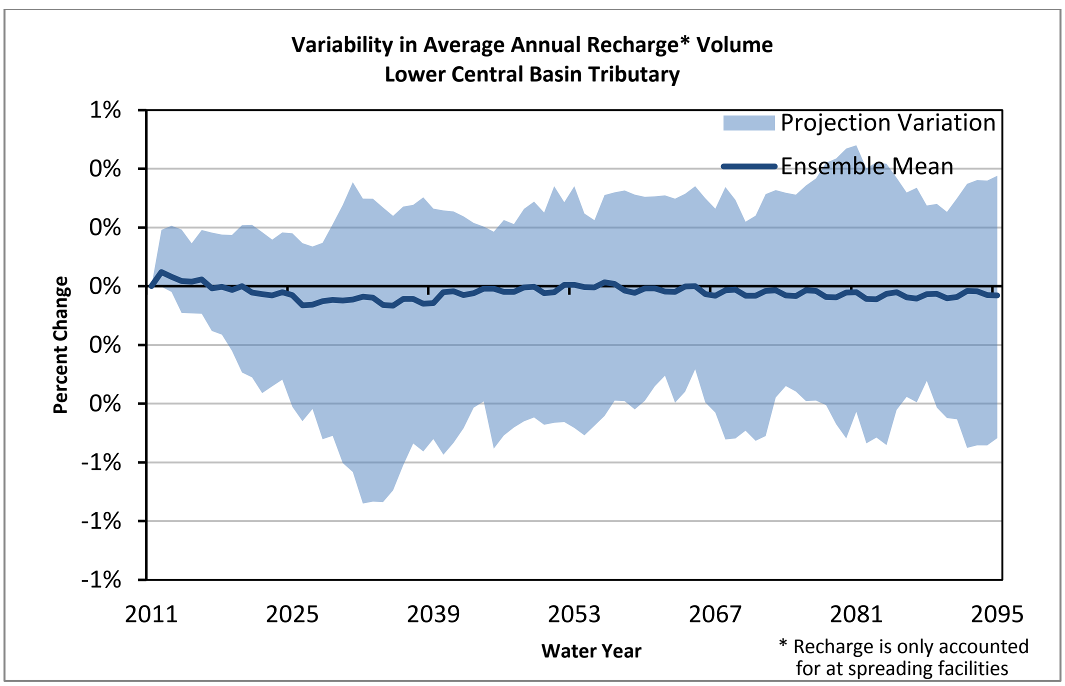


**Figure B-4. Central Basin (Lower)
Variability in Average Annual Recharge Volume**

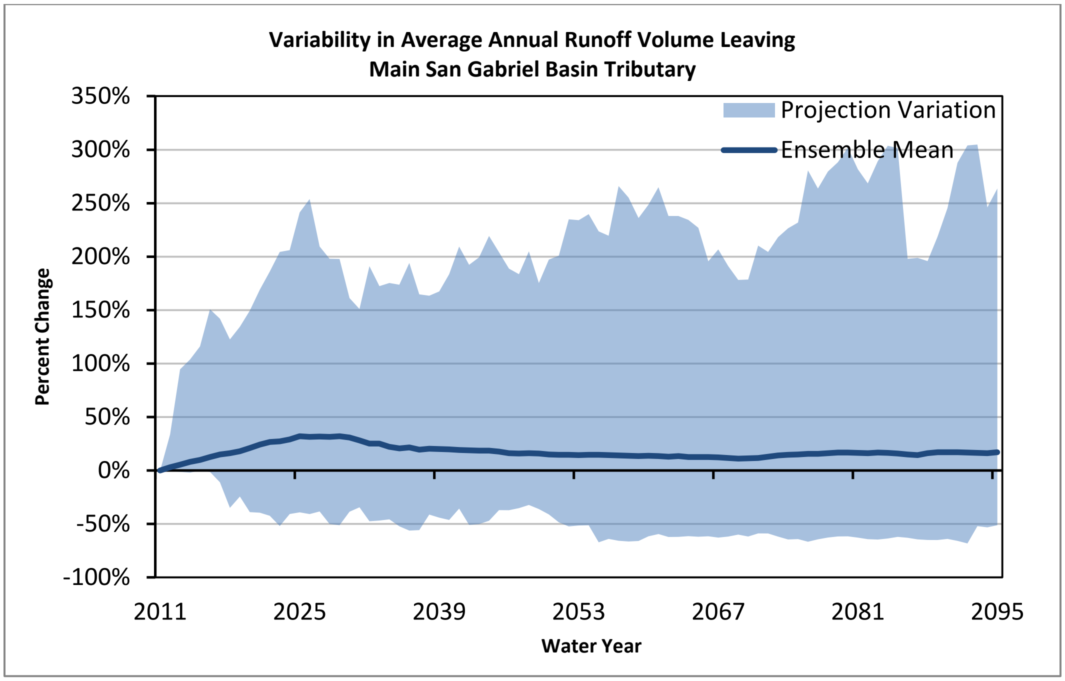


Figure B-5. Main San Gabriel Basin
Variability in Average Annual Runoff Volume Bypassing

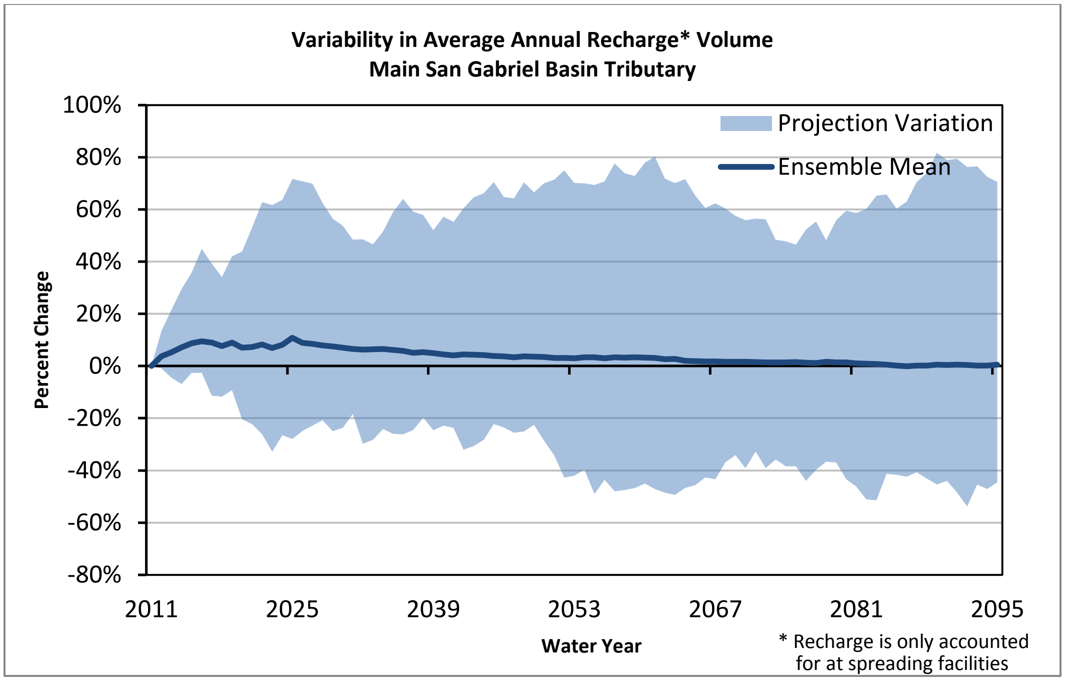


Figure B-6. Main San Gabriel Basin
Variability in Average Annual Recharge Volume

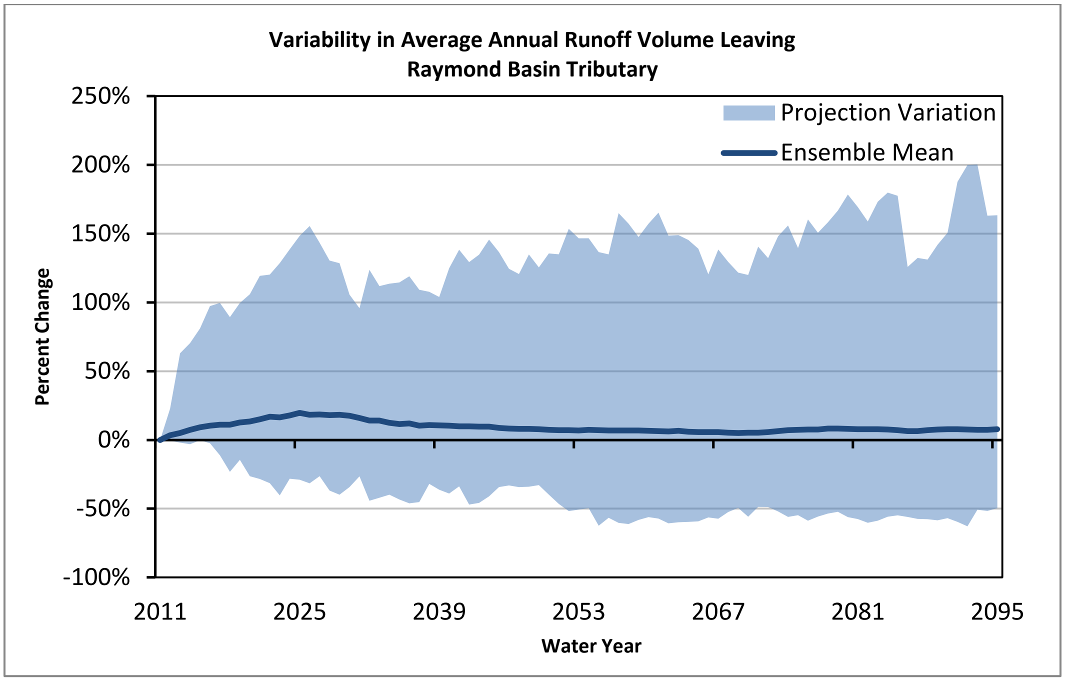


Figure B-7. Raymond Basin
Variability in Average Annual Runoff Volume Bypassing

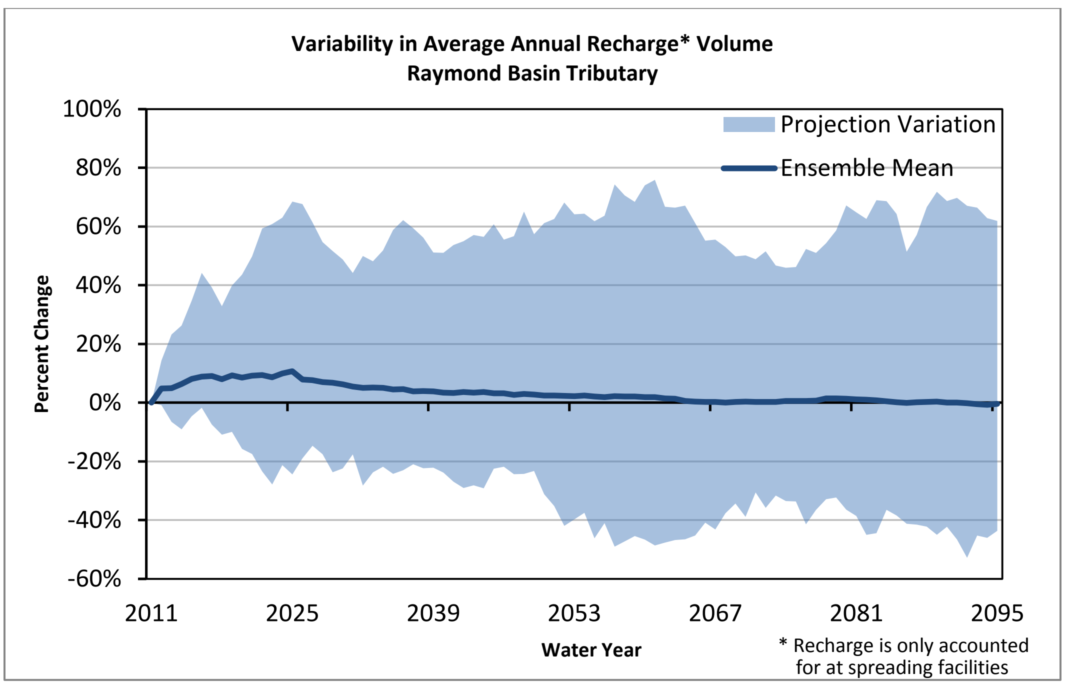


Figure B-8. Raymond Basin
Variability in Average Annual Recharge Volume

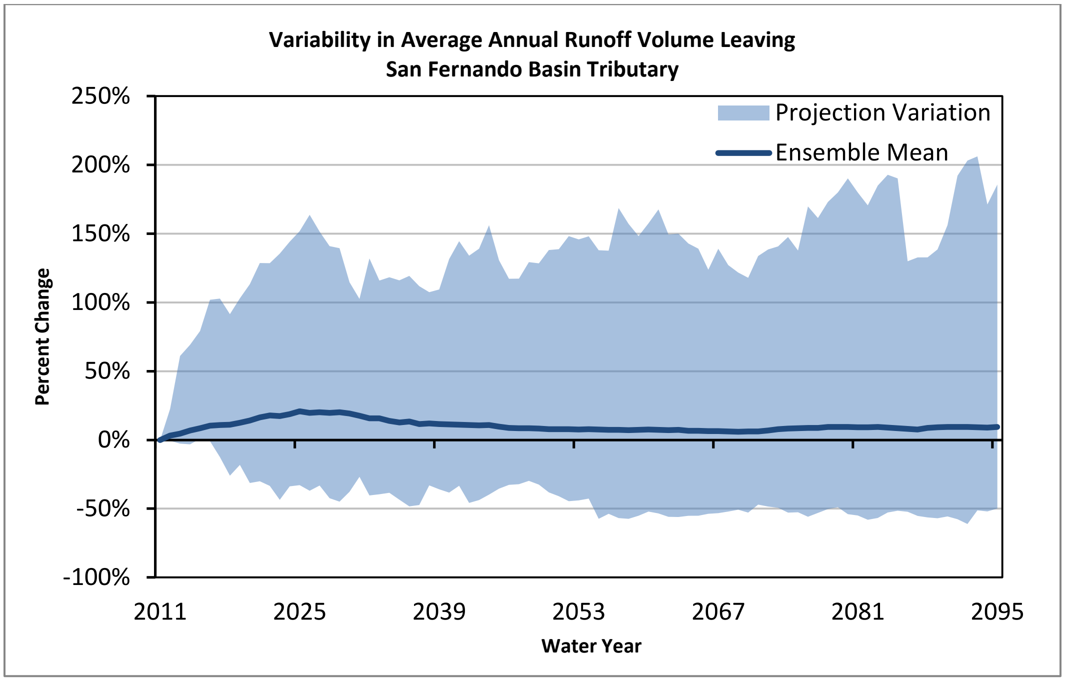


Figure B-9. San Fernando Basin
Variability in Average Annual Runoff Volume Bypassing

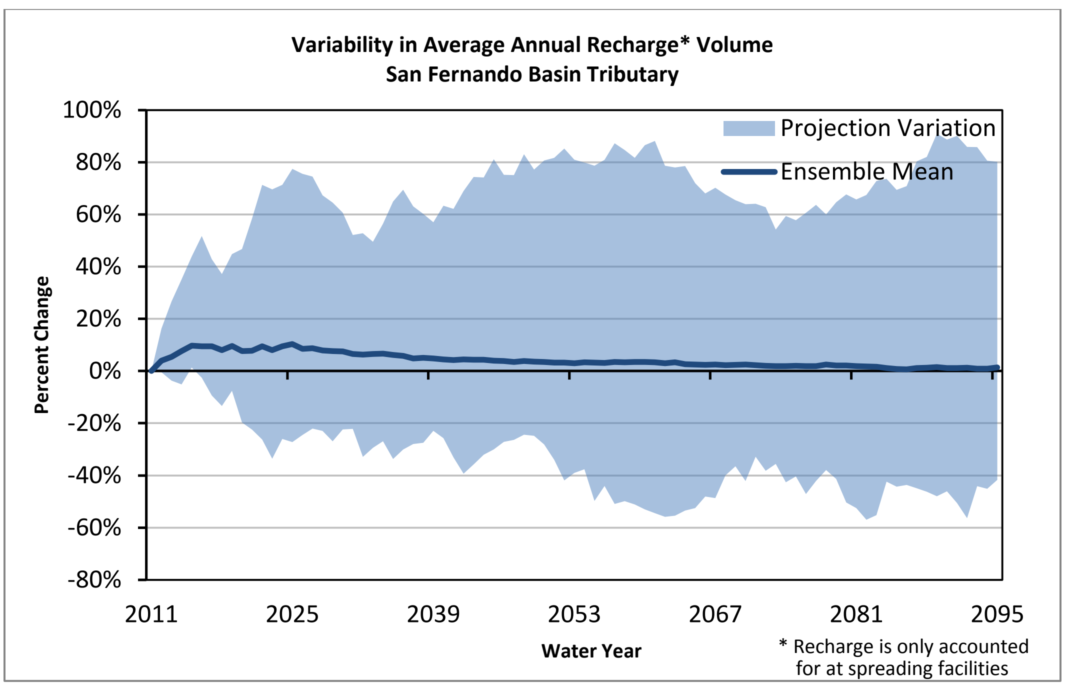


Figure B-10. San Fernando Basin
Variability in Average Annual Recharge Volume

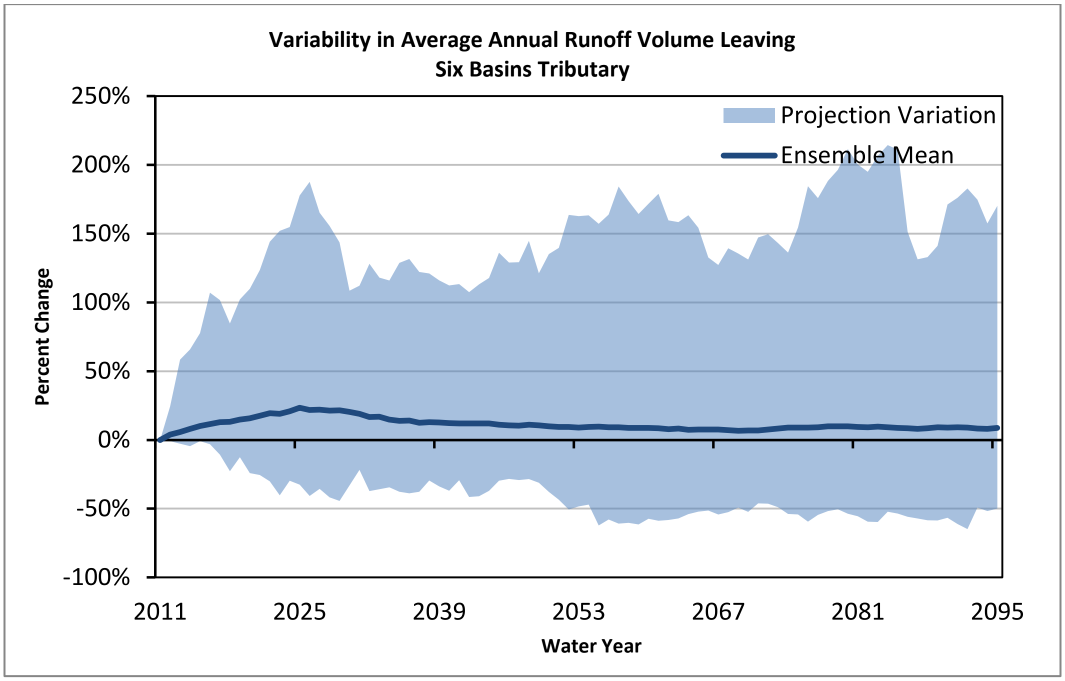


Figure B-11. Six Basins
Variability in Average Annual Runoff Volume Bypassing

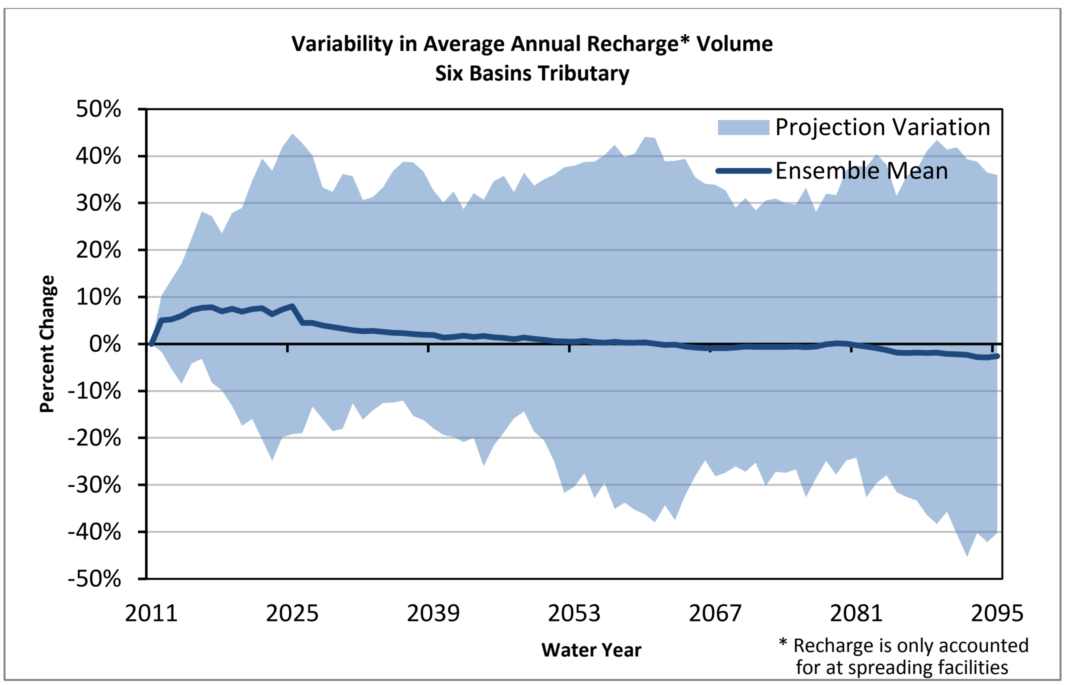


Figure B-12. Six Basins
Variability in Average Annual Recharge Volume

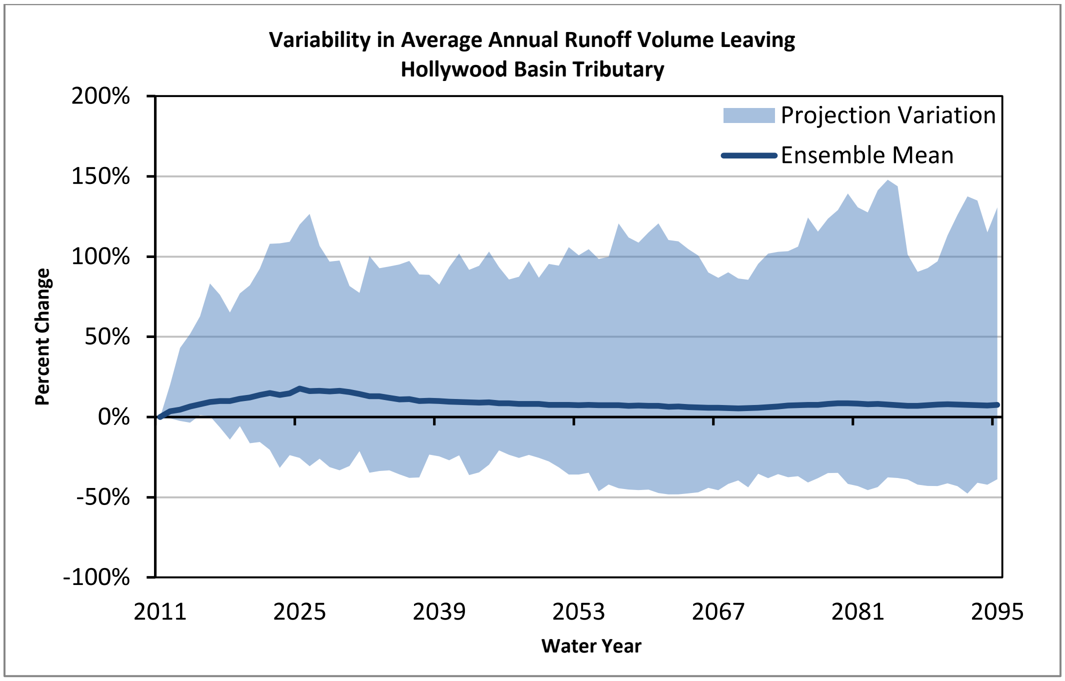


Figure B-13. Hollywood Basin
Variability in Average Annual Runoff Volume Bypassing

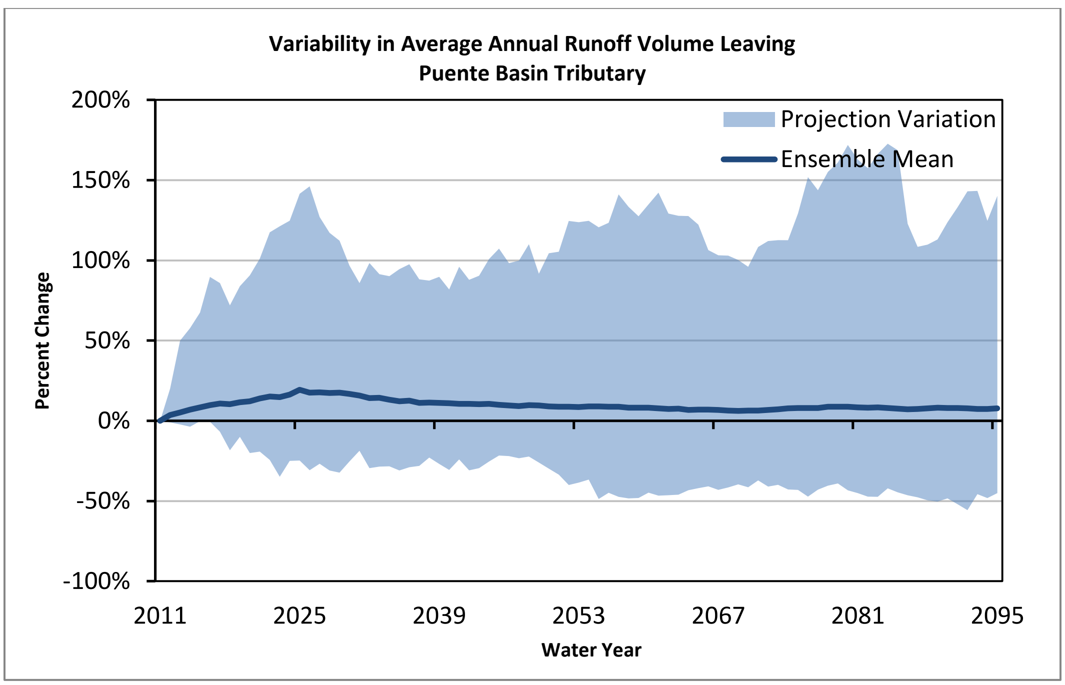


Figure B-14. Puente Basin
Variability in Average Annual Runoff Volume Bypassing

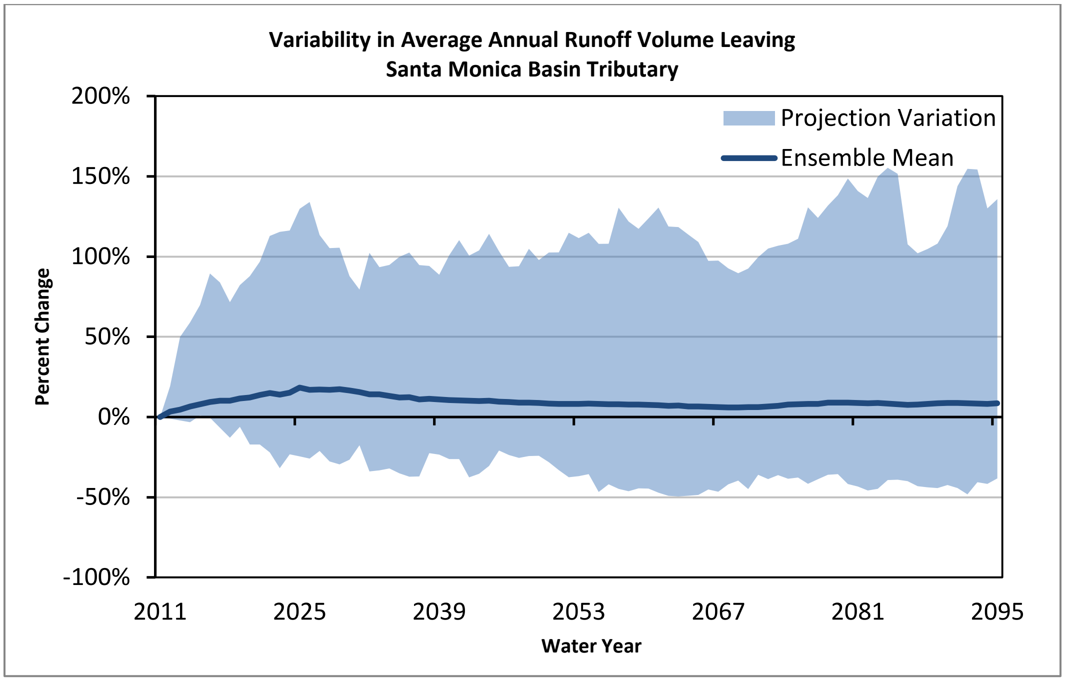


Figure B-15. Santa Monica Basin
Variability in Average Annual Runoff Volume Bypassing

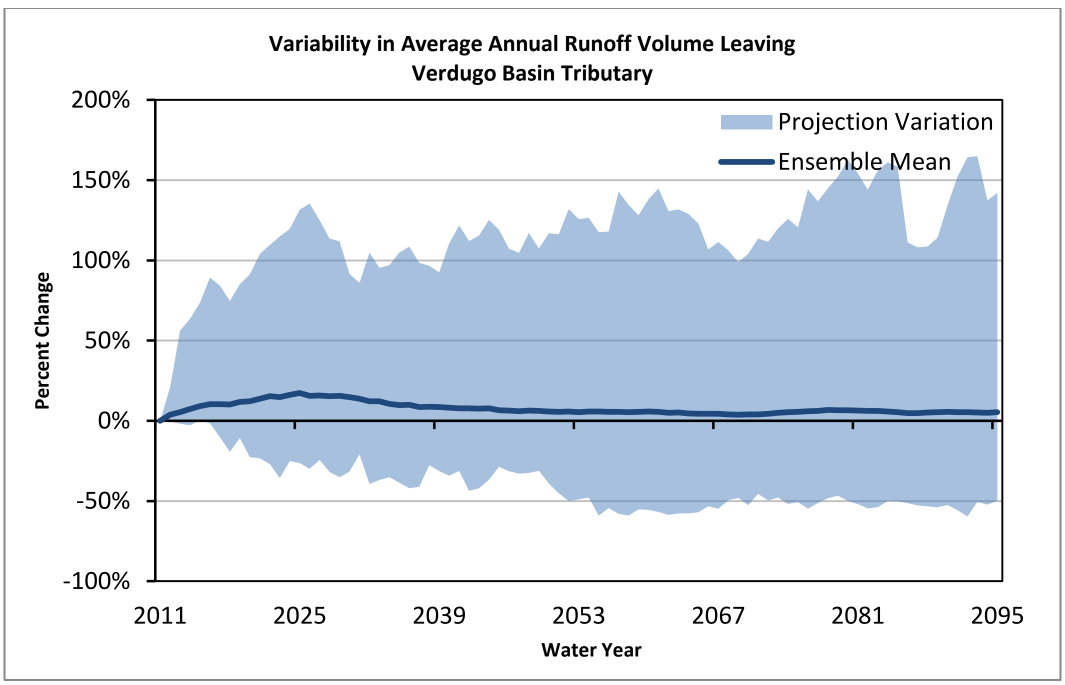


Figure B-16. Verdugo Basin
Variability in Average Annual Runoff Volume Bypassing

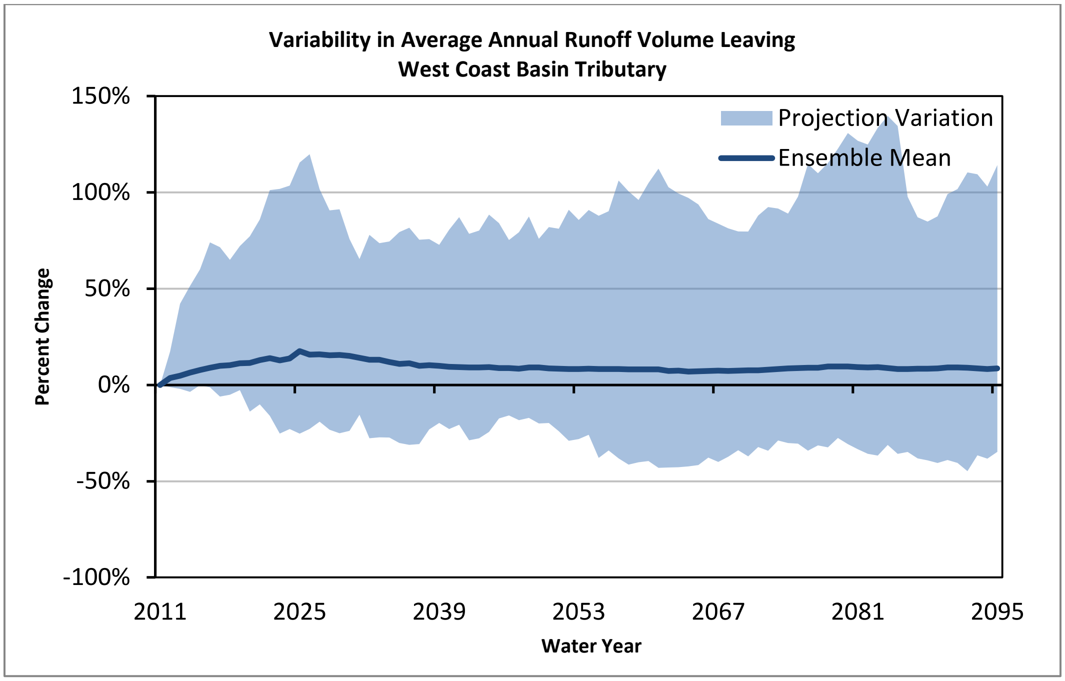


Figure B-17. West Coast Basin
Variability in Average Annual Runoff Volume Bypassing