THE METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA

Regional Recycled Water Program
Conceptual Planning Studies Report

Appendices

Report No. 1618

February 21, 2019

Appendices

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Appendix A:

Detailed Comparison of Phasing Alternatives

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Table A-1: Summary of First Phase Scenario Alternatives

Program Phase 1					
Evaluation Criteria	1 Phase	2 Phases		3 Phases	
	Alternative A	Alternative B	Alternative C	Alternative D	Alternative E
Starting Location	AWT	AWT	AWT	AWT	AWT
Terminus	Complete	Santa Fe SG	OC Spreading	Rio Hondo	Cerritos JS
Basins Served[1]	W/C/M/O	C/M	C/O	W/C	W/C
Annual Demands in Phase (MGD)	150	95	60	32	23
Annual Demands in Phase (TAFY)	168	106	67	36	26
Miles of Conveyance in Phase (miles)	62	38	29	36	21
Highest Elevation (ft.)	500	500	223	200	90
AWT Prod Capacity in Phase (MGD)	150	100	50	50	25
AWT Prod Capacity in Phase (TAFY)	168	112	56	56	28
Average Yield (MGD)	147	98	49	49	25
Average Annual Yield (TAF)	165	110	55	55	27
Capital Cost of Phase ($Million)	$3,080	$2,423	$1,519	$1,836	$1,177
JWPCP Modifications	$150	$150	$150	$150	$150
Advanced Water Treatment Plant	$570	$431	$208	$206	$127
Conveyance Facilities	$899	$726	$523	$569	$333
Well Facilities	$205	$128	$19	$163	$88
Engineering Costs (25%)	$456	$359	$225	$272	$174
Contingency (35%)	$798	$628	$394	$476	$305
Annual O&M Cost of Phase ($Million)	$134	$74	$42	$33	$15
Advanced Water Treatment	$108	$56	$36	$28	$14
Conveyance	$24	$17	$6	$4	$1
Well Field and Spreading Facilities	$1	$1	$0	$1	$1
Annual Financing Costs ($Million)[2]	**$155**	**$120**	**$79**	**$96**	**$62**
Total Average Annual Costs ($Million)	**$288**	**$194**	**$122**	**$129**	**$78**
Unit Cost of Yield by Phase ($/AF)	$1,752	$1,768	$2,216	$2,347	$2,831
MWD Cost Increase by Phase ($/AF)	$170	$114	$72	$76	$46
Construction Duration (Years)	11	10	8	8	7

[1]W=West Coast Basin, C=Central Basin, M=Main San Gabriel Basin, O=Orange County Basin — Revised: 01/19/18

[2]Assumes a 30 year term and 4.00% per annum interest rate.

Table A-2: Summary of Second Phase Scenario Alternatives

Evaluation Criteria		Program Phase 2: 2 Phases – Alternative B	2 Phases – Alternative C	3 Phases – Alternative D	3 Phases – Alternative E
Starting Location		Cerritos JS	Cerritos JS	Rio Hondo	Cerritos JS
Terminus		OC Spreading	Santa Fe SG	Santa Fe SG	Santa Fe SG
Basins Served[1]		W/C/M/O	W/C/M	W/C/M	W/C/M
Annual Demands in Phase (MGD)		55	90	72	81
Annual Demands in Phase (TAFY)		62	101	81	91
Miles of Conveyance in Phase (miles)		24	33	10	25
Highest Elevation (ft.)		223	500	500	500
AWT Prod Capacity in Phase (MGD)		50	100	50	75
AWT Prod Capacity in Phase (TAFY)		56	112	56	84
Average Yield (MGD)		49	98	49	74
Average Annual Yield (TAF)		55	110	55	82
Capital Cost of Phase ($Million)		**$782**	**$1,785**	**$847**	**$1,574**
JWPCP Modifications		$0	$0	$0	$0
Advanced Water Treatment Plant		$188	$440	$287	$375
Conveyance Facilities		$190	$414	$173	$433
Well Facilities		$85	$205	$42	$125
Engineering Costs (25%)		$116	$264	$126	$233
Contingency (35%)		$203	$463	$220	$408
Annual O&M Cost of Phase ($Million)		**$60**	**$91**	**$41**	**$43**
Advanced Water Treatment		$52	$72	$28	$26
Conveyance		$7	$18	$13	$17
Well Field and Spreading Facilities		$1	$1	$0	$0
Annual Financing Costs ($Million)[2]		**$42**	**$94**	**$45**	**$83**
Total Average Annual Costs ($Million)		**$101**	**$186**	**$86**	**$127**
Production Unit Cost of Phase ($/AF)		**$1,846**	**$1,692**	**$1,575**	**$1,540**
MWD Cost Increase by Phase ($/AF)		$60	$109	$51	$75
Construction Duration (Years)		5	6	5	6

[1]W=West Coast Basin, C=Central Basin, M=Main San Gabriel Basin, O=Orange County Basin

Revised: 01/19/18

[2]Assumes a 30 year term and 4.00% per annum interest rate.

Table A-3: Summary of Third-Phase Scenario Alternatives

Program Phase 3					
Evaluation Criteria				3 Phases	
				Alternative D	Alternative E
Starting Location				Cerritos JS	Cerritos JS
Terminus				OC Spreading	OC Spreading
Basins Served[1]				W/C/M	W/C/M
Annual Demands in Phase (MGD)				46	46
Annual Demands in Phase (TAFY)				52	52
Miles of Conveyance in Phase (miles)				16	16
Highest Elevation (ft.)				223	223
AWT Prod Capacity in Phase (MGD)				50	50
AWT Prod Capacity in Phase (TAFY)				56	56
Average Yield (MGD)				49	49
Average Annual Yield (TAF)				55	55
Capital Cost of Phase ($Million)				$661	$659
JWPCP Modifications				$0	$0
Advanced Water Treatment Plant				$188	$186
Conveyance Facilities				$199	$199
Well Facilities				$5	$5
Engineering Costs (25%)				$98	$98
Contingency (35%)				$171	$171
Annual O&M Cost of Phase ($Million)				$59	$75
Advanced Water Treatment				$52	$68
Conveyance				$7	$7
Well Field and Spreading Facilities				$0	$0
Annual Financing Costs ($Million)[2]				**$35**	**$35**
Total Average Annual Costs ($Million)				**$94**	**$110**
Production Unit Cost of Phase ($/AF)				$1,717	$2,000
MWD Cost Increase by Phase ($/AF)				$55	$65
Construction Duration (Years)				6	6

[1]W=West Coast Basin, C=Central Basin, M=Main San Gabriel Basin, O=Orange County Basin

Revised: 01/19/18

[2]Assumes a 30 year term and 4.00% per annum interest rate.

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Appendix B:

Technical Memorandum:

Considerations for the Potential Future Integration of Raw Water Augmentation into the Regional Recycled Water Program

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Potential Regional Recycled Water Program
Task Order 35 – Regulatory and Design Considerations for Direct Potable Reuse
Agreement No. 160244

Considerations for the Potential Future Integration of Raw Water Augmentation into the Regional Recycled Water Program

Technical Memorandum | January 18, 2019

Date: September 5, 2018 (Draft)
September 14, 2018 (Revised)
January 18, 2019 (Final)

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Subject: Considerations for the Potential Future Integration of Raw Water Augmentation into the Regional Recycled Water Program (Final)

1. Background and Introduction

The Metropolitan Water District of Southern California (Metropolitan) and Sanitation Districts of Los Angeles County (Sanitation Districts) are partnering to consider the implementation of a potential Regional Recycled Water Program (Program) to provide a drought-resistant new water source for Metropolitan's member agencies. The potential Program will comply with regulatory requirements for the groundwater recharge (GWR) form of indirect potable reuse (IPR), including an advanced water treatment facility (AWTF) with an anticipated maximum capacity of 150 MGD to purify secondary effluent from the Sanitation Districts' Joint Water Pollution Control Plant (JWPCP) located in Carson, California. Purified water would be recharged into one or more groundwater recharge basins either through well injection or surface spreading.

In a GWR setting, the regulatory requirements for the AWTF include, but are not limited to, satisfying pathogen requirements of 12-log removal of virus and 10-log removal of *Cryptosporidium* and *Giardia*, achieving 0.5-log removal of 1,4-dioxane, and satisfying Basin Plan limits for the receiving groundwater basins. To address these requirements, the AWTF is expected to include a treatment train with a membrane bioreactor (MBR), reverse osmosis (RO), and ultraviolet light with advanced oxidation process (UV/AOP). Depending on the results of the demonstration testing and source control assessments, additional treatment might be needed to remove constituents such as boron or nitrate.

An alternative concept being considered includes the potential future use of the AWTF product water for direct potable reuse (DPR) through raw water augmentation at either the Weymouth or Diemer

Water Treatment Plants (WTPs), which are two of Metropolitan's surface water treatment plants. Under this scenario, product water from the AWTF would be conveyed to Weymouth or Diemer for additional treatment before it is added to Metropolitan's drinking water distribution system. This concept would use the existing capacity of the Weymouth or Diemer WTPs to help satisfy the expected regulatory requirements for the implementation of raw water augmentation, including treatment and dilution.

The purpose of this technical memorandum (TM) is to discuss the regulatory and design considerations for modifying the currently proposed GWR advanced water treatment concept to integrate raw water augmentation DPR as a potential future opportunity for the Program. Current potable reuse regulations will be reviewed, and the anticipated modifications to the public health elements of these regulations that are likely to be required for raw water augmentation will be discussed. Important aspects of the regulations are expected to include components such as source control, treatment requirements, and blending requirements. The TM will conclude by discussing the next steps in evaluating raw water augmentation as a future Program opportunity, should Metropolitan choose to pursue it further.

2. Status and Shape of Future DPR Regulations

2.1. Types of Water Reuse

Six forms of potable reuse are either currently regulated or anticipated for regulations in California (Figure 1). The first three forms are categorized as IPR because the advanced treated waters must pass through an environmental buffer—either an aquifer or reservoir—prior to distribution. Groundwater recharge regulations and surface water augmentation regulations became effective in June 2014 and October 2018, respectively. In 2017, the State Water Resources Control Board (State Board) determined that it was *feasible* to develop uniform regulations for DPR (SWRCB 2016). As a result, California Assembly Bill 574 (AB 574) was passed, requiring the State Board to develop regulations for two forms of DPR: raw water augmentation (the introduction of advanced treated water upstream of a drinking water treatment plant) and treated drinking water augmentation (the introduction of advanced treated water directly into the distribution system). AB 574 mandates the development of raw water augmentation regulations by December 31, 2023.

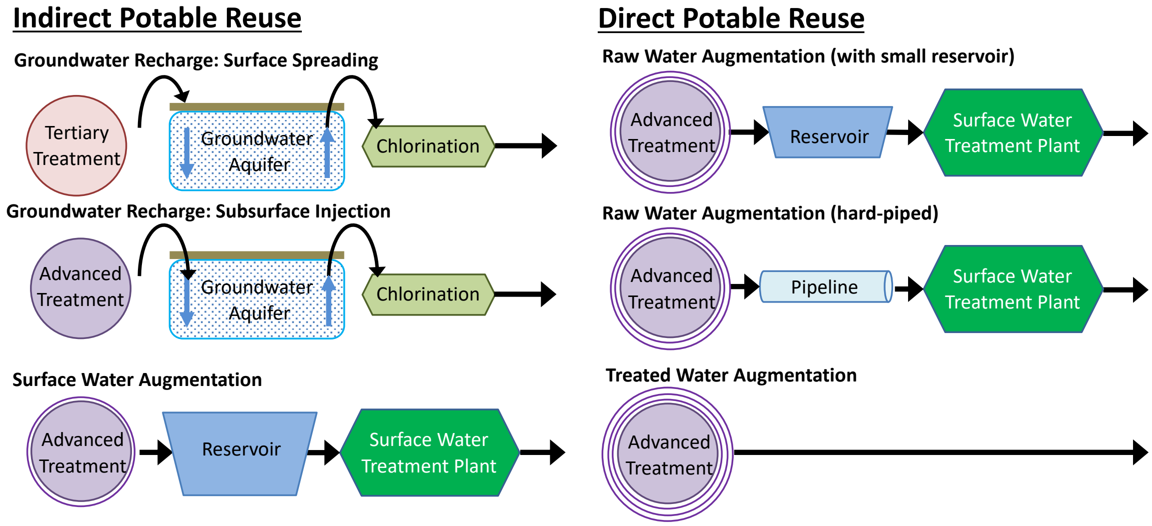


Figure 1. The six existing and anticipated forms of potable reuse in California.

Because of the industry's lack of experience with DPR, a number of research needs were identified in the State Board's DPR feasibility study (SWRCB 2016). The six priority research topics pertain to the control of contaminants—both microbial pathogens and toxic chemicals (Figure 2). The pathogen topics include developing additional information on the concentrations of pathogens present in raw wastewater (under both typical and outbreak conditions), as well as the use of quantitative microbial risk assessment (QMRA) to understand microbial risks and how treatment can be used to control those risks. For chemical risks, the State Board identified three topics of concern for DPR: (1) the need for enhanced source control, (2) an evaluation of strategies to control peaks of chemical contaminants, and (3) the use of non-targeted analysis to identify unknown contaminants or those more likely to pass through advanced treatment (low molecular weight compounds). The six DPR research topics are currently contracting with the Technical Work Groups overseeing these efforts, and results from these studies should be available for use by the State Board by the end of 2020 (Olivieri et al., 2018).

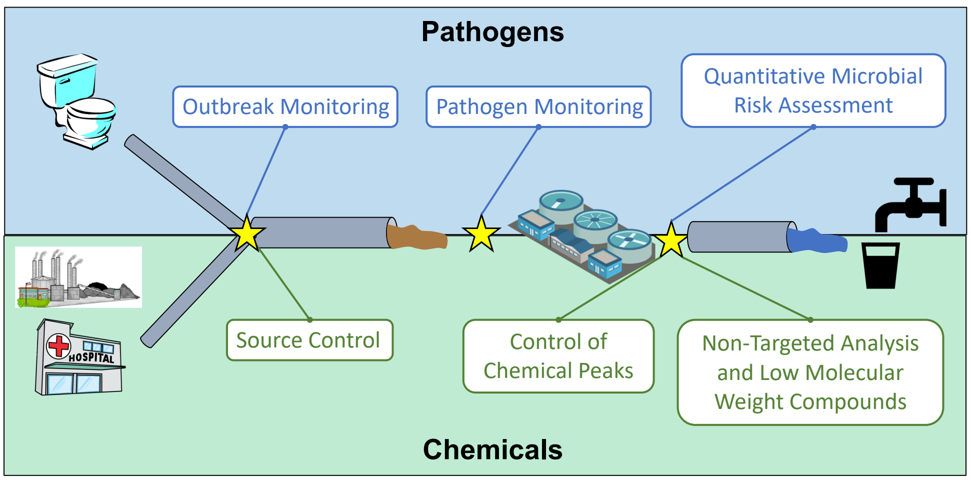


Figure 2. The State Board's six priority research topics for DPR in California.

Once these topics have been further researched, the State Board must develop regulations for both forms of DPR stipulated in AB 574. It is worth noting a potential divergence between the requirements of AB 574 and the State's own documentation on the future DPR Regulatory Framework (SWRCB 2018). While AB 574 identifies only a single form of raw water augmentation, the State Board has differentiated two forms for a total of three types of DPR:

> *It is important to recognize that there are at least three possible types of DPR projects that will have different risk profiles:*
>
> 1. *A project delivering recycled water to a surface water reservoir, with the reservoir providing some benefits, but lacking the full complement of benefits provided by IPR [indirect potable reuse] with SWA [surface water augmentation] and is therefore considered DPR by the Expert Panel*
> 2. *A project delivering recycled water directly to a surface water treatment plant or a surface water reservoir, with the reservoir providing no benefits*
> 3. *A project delivering finished water to a public water system's distribution system*
>
> *Each type of DPR will have its unique set of criteria.* (SWRCB 2016)

While it remains unclear how many forms of DPR will ultimately be regulated, the State Board has given indications that it prefers to first permit a raw water augmentation project through a small reservoir, and that it may offer incentives (e.g., less strict requirements for other project elements, more rapid permitting, etc.) for projects that utilize reservoirs. While the timeline for raw water augmentation regulations is currently set at December 31, 2023, there are stipulations in AB 574 that allow the State Board to ask for up to an 18-month extension. It is reasonable to assume that treated water augmentation regulations would not be promulgated until (1) raw water augmentation regulations have been promulgated, (2) DDW has gained sufficient experience with surface water and raw water augmentation, and (3) another state bill mandates the development of these regulations.

3. Source Control

Potable reuse regulations require multiple project elements for public health protection, the first of which is source control. The requirements for source control in the existing potable reuse regulations go beyond the scope of the National Pretreatment Program, which focuses on (1) preventing chemicals that interfere with wastewater treatment or operation (*interference*), and (2) preventing chemicals that pass through treatment and cause NPDES permit violations (*pass-through*). In potable reuse settings, source control focuses more on protecting the quality and reliability of wastewater intended for potable reuse, and therefore expands to include considerations for public health (Tchobanoglous et al., 2015). The goals of source control programs include:

- Minimize the discharge of potentially harmful or difficult-to-treat chemical constituents to the wastewater collection system.
- Improve wastewater effluent quality and advanced water treatment performance.
- Provide the public with confidence that the wastewater collection system is being managed with potable reuse in mind.

Key elements in the source control programs for groundwater replenishment projects include: (1) assessment of the fate of specified contaminants; (2) contaminant source investigations and monitoring; (3) contaminant inventories; and (4) outreach program to industrial, commercial, and residential communities. The State Board has stated that the requirements for DPR source control will be stricter than those for IPR to reduce the discharge of regulated and unregulated contaminants to the wastewater collection system (SWRCB 2018). Their argument is that eliminating the environmental buffer—which provides dilution, retention, and additional treatment—requires additional measures so that DPR systems provide equivalent protection (Figure 3). Source control will be one element.

One benefit of the groundwater basin is that it provides time to *respond* to any upstream issues, including treatment, monitoring, and operations. This also applies to source control. Given the long aquifer retention times, IPR source control programs have developed strategies that include extensive monitoring, sampling, and inspection to identify and address non-compliant discharges. This approach is, in part, a reactive one—vigilantly surveilling the collection system, identifying illegal dischargers, and enforcing corrective actions. Responding to source control events is feasible for groundwater recharge projects, but alone may not be adequate for more direct forms of reuse with shorter response times, such as a hard-piped raw water augmentation approach. In these cases, greater emphasis on the *prevention* of source control events may be required.

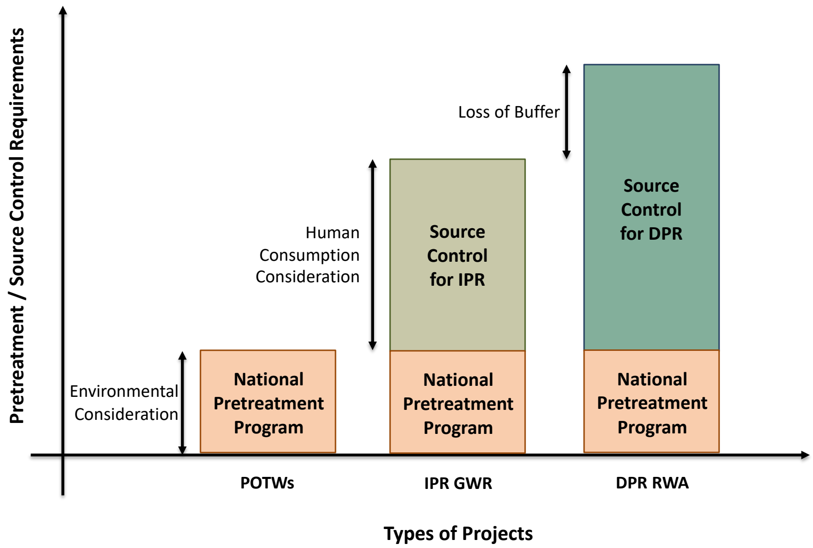


Figure 3. Growth of source control requirements with IPR and DPR

In multiple locations practicing potable reuse, one strategy that has been implemented is the separation of industrial wastewaters from the domestic sewage serving as the source water for potable reclamation. For example, at the DPR system in Windhoek, Namibia—the longest running DPR facility in the world—industrial wastewaters are routed to a separate plant (Lahnsteiner et al. 2018). One of the factors facilitating this approach was the localization of many industries in a separate area of the city; these waters are also reclaimed—for non-potable applications such as irrigation—or discharged into the environment (Oyango et al., 2014). Orange County Water District's (OCWD's) Groundwater Replenishment System (GWRS) utilizes a similar approach by limiting which of Orange County Sanitation District's (OCSD's) wastewater treatment plants can serve as feed waters. OCSD plants receiving high-strength wastewater from the Inland Empire Brine Line (including effluent from the Stringfellow Superfund Site Pretreatment Plant) are excluded in the GWRS's operating permit (OCWD 2016). The partnership between OCWD and OCSD—which administers the source control program—has been a key to the GWRS's success.

Source control serves as a non-treatment (management) barrier that can address many of the DPR concerns raised by the State Board. By separating industrial from domestic waste streams, there is improved control against chemical peaks, lower inputs of toxic or difficult to treat compounds, and improved protection against both known and unknown contaminants. Treatment could also provide similar outcomes, though the State Board's communications suggest that they will require multiple barriers (both treatment and non-treatment) for managing chemicals in DPR systems (SWRCB 2018).

4. Treatment Requirements

4.1. Pathogen Log Reduction Requirements for DPR

Both the State Board and the State Expert Panel have recommended the use of treatment redundancy to enhance the public health reliability of DPR systems. The State Panel stated that DPR treatment trains should use "multiple, independent barriers—i.e., redundancy—that meet performance criteria greater than the public health threshold $\log_{10}$ reduction value (LRV) goals established for microorganisms" (Olivieri et al. 2016). The State Board echoed this idea by stating that "to minimize the chance that LRVs necessary to meet the health objective are not consistently met, DPR projects must provide log reduction capacity in excess of the basic LRVs (redundant LRV treatment)" (SWRCB 2018). While the pathogen LRV requirements have not been established, understanding the relationship between treatment and risk is a key focus of the State Board's DPR Research Program. Nevertheless, insights into potential minimum LRVs for DPR can be developed by evaluating the existing potable reuse requirements.

The State Board has required increasingly higher degrees of pathogen control (i.e., log reduction requirements) as projects move from large, significant environmental barriers to smaller ones (Figure 4). If large environmental buffers such as groundwater basins or surface water reservoirs provide significant advantages (including dilution, additional treatment, and response time) eliminating these barriers should require compensation by other system components, including treatment. In the GWR regulations, potable reuse systems must provide 12/10/10-log reductions for virus, *Giardia*, and *Cryptosporidium*, respectively. In the surface water augmentation regulations, projects that reduce the reservoir benefits to the minimum allowable levels (i.e., 10-to-1 dilution with 2-month theoretical retention times) must provide additional protection with no less than 14/12/12-log reductions. Given this trend, it is likely that the next step forward—raw water augmentation with a small reservoir—will have requirements of at least 15/13/13.

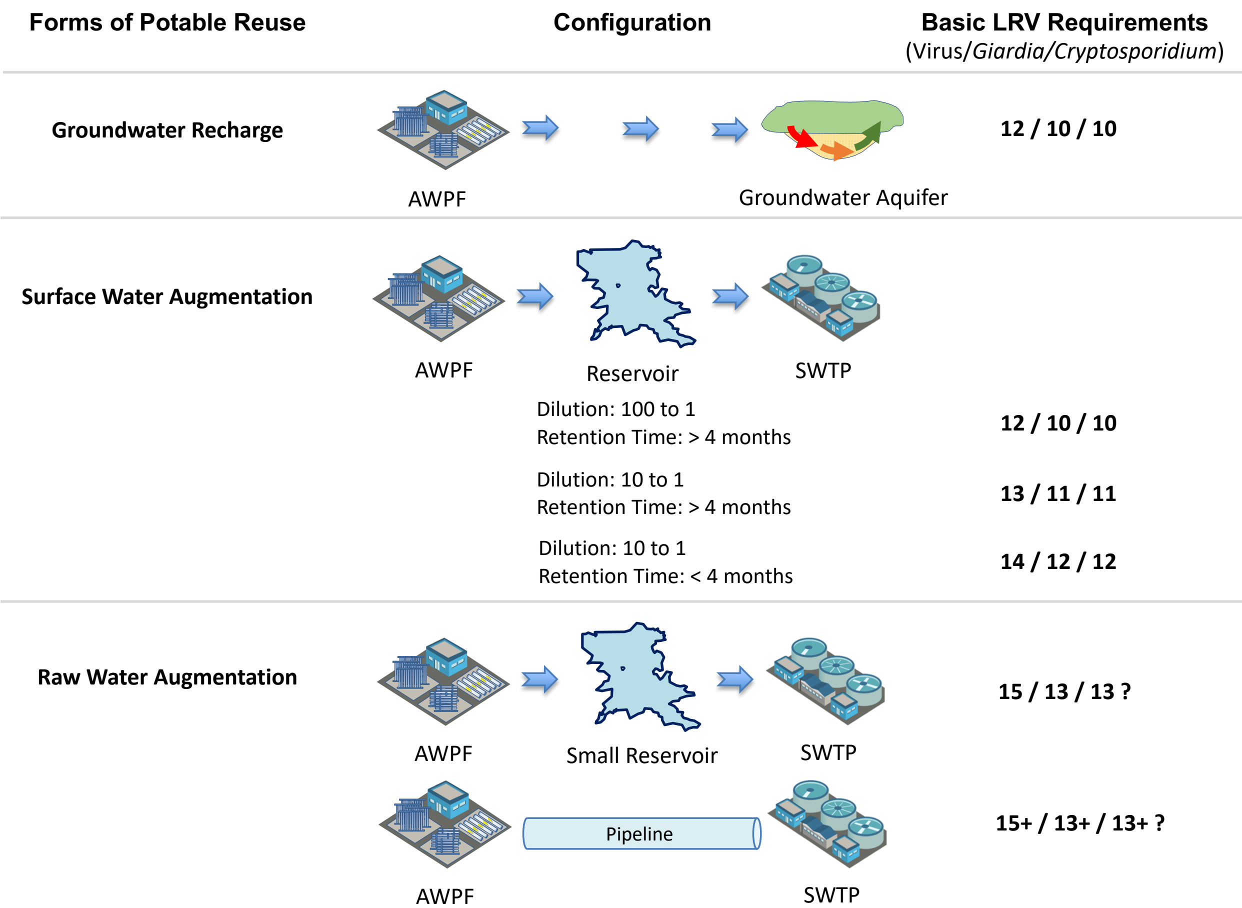


Figure 4. Pathogen removal requirements in IPR and predicted requirements for DPR

The State Board has differentiated between “basic” LRVs and “redundant” LRVs (SWRCB 2018):

> *The log reductions provided by a SWTP [surface water treatment plant] could be used to meet the extra log reduction capacity for a DPR project, but not the basic LRVs. This is for two reasons: (a) SWTP is designed to treat natural surface water, not RO permeate, and (b) the potable reuse LRV validation procedures are very different from those used for surface water treatment.*

Consequently, the State Board may require that all basic LRVs be obtained at the AWTF; any credits sought at downstream facilities such as a SWTP may only count toward the “redundant”—but not the “basic”—treatment requirements. For the purposes of this document, it is assumed that the basic LRV requirements for a DPR AWTF are no less than 15/13/13.

4.2. Wastewater Treatment Requirements

Like the evolution in source control, the industry is reassessing the role of wastewater treatment in the context of potable reuse. Historically, wastewater treatment has sought to produce waters suitable for environmental discharge; with potable reuse, it is increasingly viewed as a critical first barrier to prepare a consistent and high-quality feedwater for the AWTF (Olivieri et al. 2016, Tchobanoglous et al. 2015). One way to achieve this is to ensure a high degree of physical and biological treatment, both of which can provide significant protection against both pathogens and toxic chemicals.

Achieving this high-quality feedwater may require modifications at the wastewater treatment plant including: (a) flow equalization, (b) elimination or equalization of return flows, (c) upgrading secondary process to provide biological nutrient removal, (d) converting to suspended growth biological processes, (e) effluent filtration, and (f) more rigorous process performance monitoring. These modifications can improve water quality including lowering the concentration of organic compounds, providing greater degrees of pathogen removal and inactivation, and improving the performance of downstream processes such as membrane filtration. While not making explicit recommendations, the State Expert Panel included both biological nutrient removal and tertiary filtration in all of their potential future DPR treatment trains (Olivieri et al., 2016).

Currently, Metropolitan and the Sanitation Districts are evaluating the use of a tertiary MBR that would meet a number of the criteria listed above including biological nutrient removal with a suspended growth system, tertiary filtration, and higher degree of process performance monitoring. Other modifications that would need to be evaluated at the JWPCP upstream of the AWTF include the diversion of return flows (e.g., centrate and filtrate from solids handling steps) and the need for additional flow equalization.

While significant work has been undertaken to evaluate the role of wastewater treatment on the control of toxic chemicals, less is known about the relationship with pathogen reduction. The State Board is allocating significant research funds to further characterize the pathogens entering wastewater treatment plants (WWTPs); this project will likely expand to also quantify removal through different WWTP trains as well. The State Board has previously allocated pathogen reduction credits for WWTPs in potable reuse trains. Site-specific pathogen monitoring studies could therefore be used as a basis for future DPR LRV credits.

4.3. Advanced Water Treatment

As previously discussed, the State Board has not yet provided specific requirements for the advanced water treatment in DPR trains. Nevertheless, they have identified a number of characteristics that they will seek in these trains, including treatment redundancy for pathogens (section 4.1). Other concepts of interest include robustness, or the use of multiple types of barriers (e.g., physical, biological, chemical), which provides broader protection against the wide range of potential contaminants—both microbiological and chemical (Pecson et al. 2015). Based on the priority DPR research topics, the State Board is also interested in creating DPR trains that provide protection against slugs (or "peaks") of toxic chemicals. Source control is one strategy to *prevent* these occurrences; treatment can also be used to *respond* to such events.

One potential DPR advanced water treatment train that has been thoroughly evaluated by the State Board consists of ozone (O_3), biological activated carbon (BAC), membrane filtration (MF), reverse osmosis (RO), and ultraviolet light with advanced oxidation process (UV/AOP) (Figure 5). Through testing undertaken in WateReuse Research Foundation project 14-12, this train was deemed to provide a consistent and high degree of public health protection, incorporating the concepts of both treatment redundancy and robustness (Olivieri et al. 2016, Pecson et al. 2017, SWRCB 2016).

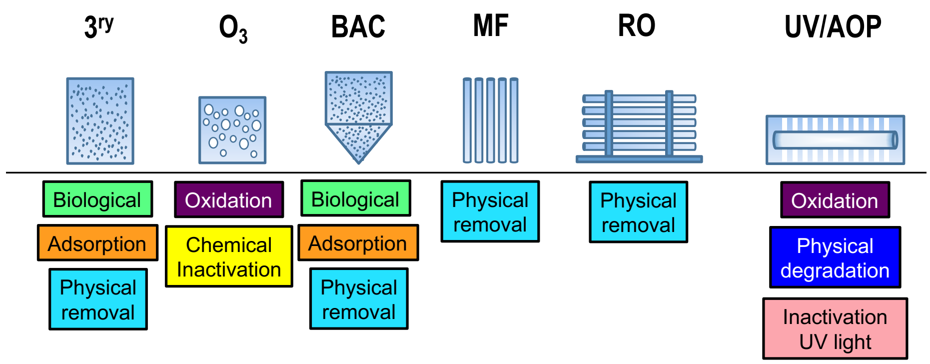
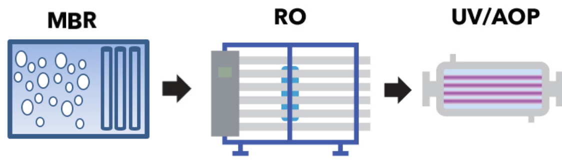


Figure 5. Multiple types of barriers provide a high degree of robustness in a DPR treatment train

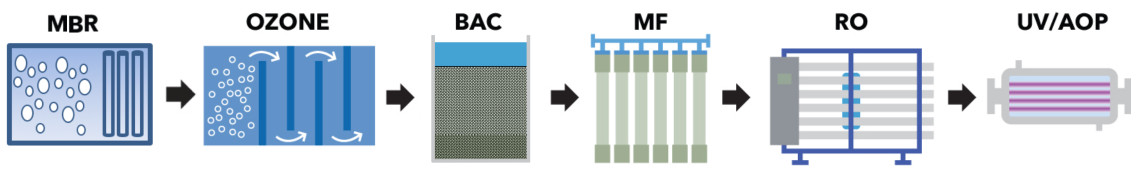
Adaptations that would provide additional redundancy and robustness to the advanced water treatment train proposed for Metropolitan's current GWR project (Figure 6A) include (1) the addition of O_3 and BAC prior to membrane filtration and (2) the use of a free chlorine residual (Figure 6B) in the pipeline conveying the water to the Weymouth or Diemer WTPs. With the MBR providing a consistently high-quality tertiary, filtered feedwater, the enhanced process train provides multiple removal mechanisms for broad control of pathogens and toxic chemicals. The inclusion of O_3/BAC/MF would likely satisfy the State Board's requirement for the control of chemical peaks and provide additional pathogen control to meet or exceed the 15/13/13 levels discussed in Section 4.1 (Figure 6B).

A.



Pathogen	WRF	MBR	RO	UV/AOP	Cl2	Total
Virus	—[a]	0[b]	1.5	6	5	12.5
Giardia	—[a]	2.5[b]	1.5	6	0	10
Crypto	—[a]	2.5[b]	1.5	6	0	10

B.



Pathogen	WRF	MBR	O3/BAC	MF	RO	UV/AOP	Cl2	Total
Virus	—[a]	0[b]	6	0	2[c]	6	6	20
Giardia	—[a]	2.5[b]	6	4	2[c]	6	0	20.5
Crypto	—[a]	2.5[b]	1	4	2[c]	6	0	15.5

[a] WRF pathogen credit possible, though may require site-specific testing (see Section 4.2)

[b] Based on current minimum MBR crediting being pursued for GWR project

[c] Assumes use of enhanced monitoring for higher RO crediting

Figure 6. Pathogen log removal values of (A) the current groundwater recharge train and (B) a potential raw water augmentation train

5. Raw Water Augmentation without an Environmental Buffer

As discussed in Section 2, the State Board has indicated that it would prefer to *first* permit raw water augmentation projects that utilize small reservoirs. The benefits of a reservoir—even a small one—include dilution (to attenuate off-spec events and chemical peaks), retention time (to respond to treatment failures), and decoupling of the AWTF and drinking water treatment plant (Pecson et al. 2018a, 2018b). Raw water augmentation systems that bypass the reservoir and utilize a hard-piped approach will likely need to provide additional protections to compensate. While small reservoirs would be granted an easier permitting approach, it should also be feasible to pursue the "hard-piped" raw water augmentation project that is currently being considered by Metropolitan.

This section describes the added protections that may be required moving from a GWR project to a raw water augmentation project. While future regulatory distinctions between a small reservoir and hard-piped raw water augmentation project are not yet clear, it is likely that both will have more stringent requirements than groundwater recharge.

5.1. Enhanced Monitoring

The time to respond to off-spec events decreases as potable reuse schemes become more direct. Consequently, the stringency of monitoring should be inversely related to the amount of response time provided by the system. Because a raw water augmentation project will have less response time if it does not incorporate a reservoir, the State Board will likely impose more stringent monitoring requirements for hard-piped systems. The goal of these requirements would be for the project sponsor to *rapidly* detect and correct or respond to any issues, since less time is available between advanced treatment and distribution to consumers.

It should be noted that the degree of monitoring and control may need to be significantly more rigorous than existing GWR systems. In GWR settings, water must spend at least two months (and typically six or more months) in the aquifer prior to extraction and distribution. Consequently, there has not been a regulatory driver to develop control systems that integrate and automatically respond to performance data in real-time. The need for such systems will increase as potable reuse gains in directness, particularly for hard-piped raw water augmentation and treated water augmentation. Understanding that this is a knowledge gap, the State Board is currently seeking researchers to evaluate and demonstrate that a control system is capable of integrating high-frequency performance data (Water Research Foundation RFP #4954).

5.2. Use of Conveyance Pipeline for Response Time and Additional Treatment

A hard-piped raw water augmentation project can still benefit from the retention time provided by the conveyance pipeline from the AWTF to the drinking water treatment plant. Assuming a conveyance pipeline of 30-40 miles and a conservatively high flow velocity of 5 feet per second, the retention time in Metropolitan's pipeline would be approximately 9-12 hours. This travel requirement provides additional response time as well as contact time for chlorine (or another form of) disinfection. The LRV table presented in Figure 6 assumes the pipeline would provide sufficient contact times to achieve significant degrees of virus (and potentially also *Giardia*) inactivation.

5.3. Diversions

The concept of redundancy has been discussed frequently with regard to treatment, though it can also provide advantages in other system elements as well. Redundancy in disposal options benefits the system so that any water that does not meet specifications (or potentially does not meet specifications) could be quickly rerouted away from distribution. Options include constructing pipelines to discharge AWTF effluents to existing outfalls or into systems with less stringent water quality requirements, such as non-potable systems. For Phase I of their Pure Water Program, the City of San Diego has included multiple diversion points—both within the AWTF and the conveyance infrastructure—to dispose of or reroute any effluents that have failed (or are presumed to have failed) water quality requirements.

5.4. Alternative Drinking Water Supplies

Access to redundant source waters also enhances system reliability. Currently, the Weymouth and Diemer WTPs have multiple options for source waters—including both Colorado River and State Water Project—which would allow them to rapidly shift to alternative feedwaters in the event of an off-spec event at the AWTF. This requirement for alternative source waters has been included in all of the potable reuse regulations in California and will likely be included in the future DPR regulations as well. One aspect that may change for DPR is the *speed* with which these switches must be made, i.e., a project with only twelve hours of response time may be required to demonstrate that it could switch to an alternative source in a period less than twelve hours.

5.5. Engineered Storage Buffer

One option to provide additional response time in a DPR system is an engineered storage buffer (ESB)—e.g., a reservoir tank—in which effluents can be detained and tested before continuing to the drinking water treatment plant or distribution (Tchobanoglous et al. 2015). The retention time in the ESB could also be used for disinfectant contact time. Challenges with ESBs include that they require substantial space and cost, particularly when providing significant retention time. For example, at a flow rate of 100 MGD an ESB would need a capacity of 25 million gallons to provide a *theoretical* retention time of 6 hours; depending on the configuration (e.g., baffling) of the tank, it is likely that a significant fraction of the water would be retained for less than 6 hours. More complex ESB arrangements envision the use of three equally-sized tanks continuously rotating between three modes: (1) filling tank 1, while (2) testing tank 2, and (3) draining tank 3. It remains an active debate whether the cost of developing this infrastructure would be better utilized for other elements that enhance system reliability, such as redundancy in treatment and monitoring, or enhanced operational control. New technologies to rapidly assess water quality would also need to be developed to rapidly test and verify that the advanced treated waters meet effluent requirements, both for pathogens and chemicals. Currently, there are no technologies sensitive enough to verify the microbial safety of treated drinking water.

6. Blending Requirements

Pulses of off-spec water can be mitigated if they are blended with a separate, high-quality water source. The requirement for blending—or dilution—is already present in both the surface water augmentation regulations (which require a minimum of either 100-to-1 or 10-to-1 dilution) and the groundwater recharge regulations (which require blending to reduce total organic carbon (TOC) levels below 0.5 mg/L). The State Board has recently indicated that they will also incorporate blending requirements into the future raw water augmentation regulations. In the DPR Regulatory Framework, the State Board states that it intends to define raw water augmentation projects as those where “recycled water is mixed with raw water in the conveyance to a drinking water treatment plant such that the blend provides a *meaningful public health benefit*.” It is unlikely that raw water augmentation projects, particularly those hard-piped to a drinking water treatment plant, would be able to provide the same degree of dilution as surface water augmentation projects (i.e., 10- to 100-fold dilution).

Given the lack of experience with surface water augmentation in California, the regulators have preferred to take a conservative approach when evaluating new topics like blending. For example, the San Diego Pure Water project will not begin immediately at the lowest dilution and blending ratios in Lake Miramar (i.e., 10-to-1), but will start at higher levels and gradually phase into lower dilution and blending ratios. This provides the regulators with experience understanding the challenges and gaining confidence that the downstream drinking water treatment plants can continue to operate reliably and meet compliance requirements. It is likely that this conservative, phased approach will also be pursued for the blending requirements of raw water augmentation.

Ultimately, it may be possible to maintain a three- to four-fold dilution in the feedwaters to either the Weymouth or Diemer WTPs. Because pathogen removal requirements are specified in terms of $\log_{10}$ reduction values, a 3- to 4-fold reduction in concentrations would not provide a significant pathogen barrier (0.5- to 0.6-log reduction). Chemicals, conversely, do not typically require multiple log reductions to reach acceptable levels. Minimum dilution requirements for surface water augmentation are set at 10-to-1, in part to ensure a significant degree of protection against chemical contaminants. The provision of 3- to 4-fold dilution would provide essentially half of that protection for chemicals. Additional protection against chemicals could occur at other locations — including the AWTF. One benefit of the O_3 and BAC in a raw water augmentation train is that they could be presented to the State Board as compensation for lower degrees of blending or dilution.

In other locations in their DPR Regulatory Framework, the State Board expressed concern about granting pathogen removal credits to a surface water treatment plant that was designed to treat natural surface waters and not RO permeate. The concern is that a low-turbidity water devoid of particulates (RO permeate) would not benefit from the removal mechanisms that are employed in surface water treatment plants (e.g., flocculation, sedimentation, and filtration). Consequently, the State Board may not assign pathogen log removal credits if the water entering the surface water plant is composed primarily of RO permeate. This scenario is deemed unlikely for the DPR concept that Metropolitan is considering; therefore, having a blend of RO permeates with significant fractions of surface water would decrease this risk. Setting minimum blending ratios of advanced treated effluents-to-surface water sources (e.g., 1:1) may be sufficient to continue obtaining credit at the surface water treatment plant. As stated previously, the State Board would likely require a phased approach beginning at higher levels of dilution, gaining confidence that the WTPs could maintain compliance, and gradually ramping down to lower dilution ratios. A 4-fold dilution (3-parts surface water to 1-part advanced treated water) would lead to a 25% reduction in the turbidity and TOC of the source water entering the plant; this reduction would likely be sufficiently small to continue assigning surface water treatment plant credits in a raw water augmentation project.

Beyond these two topics—dilution requirements and WTP pathogen removal performance—there are other operational and design issues to consider when introducing an advanced treated effluent directly into a WTP. The introduction of a stabilized RO product water will likely decrease certain chemical and disinfectant dosing requirements (e.g., coagulant, ozone, chlorine) given the reduction in both turbidity and total organic carbon. Post-treatment design criteria will also need to be developed to ensure that relevant water quality parameters—such as alkalinity—remain at appropriate levels for surface water treatment. A hard-piped raw water augmentation project may have different post-treatment needs than a GWR project where the water has an opportunity to equilibrate with the aquifer prior to extraction and distribution.

The manner in which the AWTF effluents are mixed with the other surface water sources will need to be considered, as will the impact of this blending on the temperature of the mixed source waters, which impacts multiple processes including disinfection, DBP formation, and corrosion control. Pilot- or demonstration-scale testing may be needed to evaluate these topics.

7. Expert Panel Engagement

Independent scientific advisory panels (ISAPs) are often convened to provide an assessment of and guidance for water recycling projects. Per the existing potable reuse regulations, ISAPs are required under the following conditions:

- Surface Water Augmentation: to verify the requirements pertaining to the hydraulic characterization of the reservoir, including tracer study verifications and hydraulic modeling. If the project sponsor seeks an alternative minimum theoretical retention time, the expert panel is also required to review the project and assess whether it provides an equivalent or better level of public health protection.

- Groundwater Recharge: to pursue an alternative to any of the recharge requirements. A review of the proposed alternative by the panel is required to verify that the project provides at least the same level of protection of public health.

Oftentimes, projects convene ISAPs voluntarily to help satisfy a number of other goals including public outreach, as well as to facilitate the regulatory and permitting process. Historically, they have been involved in all of the groundbreaking and innovative potable reuse projects to help assess compliance with regulatory requirements. Most recently, San Diego convened an ISAP to assist with the implementation of the first SWA project in California. Padre Dam has also convened an ISAP to help them in their pursuit of the second SWA project. Given the lack of DPR precedents in California, engagement from an ISAP will be beneficial to assist the initial raw water augmentation projects work through any public health, scientific, or technical issues. Metropolitan is currently engaging an ISAP to assist with their demonstration project, which includes the validation of an alternative advanced water treatment train for GWR. This ISAP could also serve to assist with a future raw water augmentation project, potentially supplemented with additional members to address DPR-specific topics.

8. Summary and Next Steps

With regulations scheduled for 2023, raw water augmentation should be considered as a potentially viable option worthy of further exploration by Metropolitan and the Sanitation Districts. The State Board has indicated that it would prefer to permit a project that incorporates a reservoir first, though it should also be possible to go directly to a hard-piped project. One option for future study would be to examine the use of existing reservoirs and whether the incorporation of this infrastructure would provide sufficient benefits in terms of cost, schedule, and permitting to warrant further evaluation.

Regardless of the specific form of raw water augmentation pursued, multiple system enhancements will be needed to integrate a raw water augmentation DPR approach into the currently proposed GWR system. The State Board will likely require these enhancements to compensate for the loss of the environmental buffer and all of its benefits. Significant modifications should be expected in the following system elements: (1) source control, (2) wastewater treatment, (3) advanced water treatment, and (4) monitoring and control. The degree to which the State Board will modify these elements remains uncertain, though there is a significant on-going research program to help build the knowledge needed for the future regulations. Furthermore, there will likely be requirements for (1) blending advanced treated waters, (2) alternative diversions for off-spec water, and (3) the use of alternative source waters. Each of these topics will need further study and evaluation for a raw water augmentation project to the Weymouth or Diemer WTPs. A comprehensive plan incorporating all of these elements will need to be developed, and the approach will need to be vetted by both the State Board and an independent advisory panel. Similar efforts have been undertaken in the past with innovative projects, including San Diego's Pure Water program, which has engaged in testing and dialogue with the regulators over the course of several years.

Although the details are currently unclear, it is expected that the State Board will be open to permitting raw water augmentation projects on a case-by-case basis prior to the promulgation of the regulations. The State Board understands the benefit of experience in the regulatory development process: their 2014 groundwater recharge regulations evolved as a result of five decades of project experience. San Diego's Pure Water Program also provided them important clarity in the development of the 2018 surface water augmentation regulations. It is likely that they will readily engage a potential project sponsor, such as Metropolitan and the Sanitation Districts, to help them flesh out the components that need to be detailed in their future raw water augmentation regulation. While a hard-piped raw water augmentation project is a more direct approach to reuse than they would prefer to initially permit, it is reasonable to assume that they would be open to permitting this type of project. It is unlikely that they will permit a treated water augmentation project without experience in raw water augmentation. As with any groundbreaking potable reuse project, the permitting process will be greatly facilitated by the inclusion of an ISAP.

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Appendix C:

Nitrogen Management Evaluation for Full-scale Advanced Water Treatment Facility

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SANITATION DISTRICTS OF LOS ANGELES COUNTY

THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

Potential Regional Recycled Water Supply Program

Nitrogen Management Evaluation for Full-scale Advanced Water Treatment Facility

Final Report

June 05, 2018

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Abbreviations

Abbreviation	Definition
ac	Acre
ac-ft	Acre foot
AOP	Advanced Oxidation Process
AWT	Advanced Water Treatment
BAF	Biologically Active Filter
BIM	Building Information Model
BOD	Biochemical Oxygen Demand
CA	California
cBOD	Carbonaceous Biochemical Oxygen Demand
DAF	Dissolved Air Flotation
DDW	Division of Drinking Water
Sanitation Districts	Sanitation Districts of Los Angeles County
EED	Electrical Energy Dose
FAT	Full Advanced Treatment
ft	Feet
gfd	Gallon per Square Foot per Day
gpd	Gallons per Day
gfd	Gallons per Square Foot per Day
gpm	Gallons per Minute
gpm/ft^2	Gallons per Minute per Square Foot
hp	Horsepower
hr	hour
HPOAS	High Purity Oxygen Activated Sludge
HRT	Hydraulic Retention Time
IPR	Indirect Potable Reuse
JWPCP	Joint Water Pollution Control Plant
kWh	Kilowatt Hours
lb	Pound
lb/d	Pound per Day
LSI	Langelier Saturation Index
MBR	Membrane Bioreactor
Metropolitan	Metropolitan Water District of Southern California
MG	Million Gallons
mg/L	Milligrams per liter
MGD	Million Gallons per Day

min	Minute
mJ/cm^2	Mill joules per Square Centimeter
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
N	Nitrogen
NDEA	N-Nitrosodiethylamine
NDMA	N-Nitrosodimethylamine
NdN	Nitrification-Denitrification
NDPA	N-Nitrosopropylamine
ng/L	Nanograms per Liter
NL	Notification Level
N-only	Nitrification only
NO_2	Nitrite
NO_3	Nitrate
NO_X	Oxides of Nitrogen
NPV	Net Present Value
O&M	Operation and Maintenance
OC	Orange County
OPCC	Opinion of Probable Construction Cost
RAS	Return Activated Sludge
RO	Reverse Osmosis
SNMP	Salt and Nutrient Management Plan
SRT	Solids Retention Time
TDS	Total Dissolved Solids
TIN	Total Inorganic Nitrogen
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
tpd	Tonnes per Day
TSS	Total Suspended Solids
UV	Ultraviolet
VSS	Volatile Suspended Solids
WAS	Waste Activated Sludge

Acknowledgements

The Nitrogen Management Committee consisted of the following members:

Sanitation Districts of Los Angeles County

- Ken Rademacher
- Nikos Melitas
- Bruce Mansell
- Michael Liu

Metropolitan Water District of Southern California

- Sun Liang
- Gloria Lai-Bluml
- Joyce Lehman
- Zakir Hirani (Stantec)

The committee members appreciate valuable input from John Bednarski (Metropolitan Water District of Southern California), Martha Tremblay (Sanitation Districts of Los Angeles County) and Paul Brown (Paul Redvers Brown Inc.). Technical review of the report by the following advisory panel members is highly appreciated:

- Dr. David Jenkins, Professor Emeritus, University of California, Berkeley
- Joseph Reichenberger, Professor, Loyola Marymount University
- Dr. Paul Westerhoff, Professor, Arizona State University
- Ed Means, Means Consulting

Comments from the advisory panel members on this report and response to those comments from the nitrogen management committee are attached in **Appendix D**.

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1.0 EXECUTIVE SUMMARY

The Metropolitan Water District of Southern California (Metropolitan) and Sanitation Districts of Los Angeles County (Sanitation Districts) are jointly exploring the potential of building a 150-MGD advanced water treatment (AWT) Facility that will treat non-nitrified secondary effluent from the Sanitation Districts' Joint Water Pollution Control Plant (JWPCP) in Carson, CA (**Figure 1.1**).

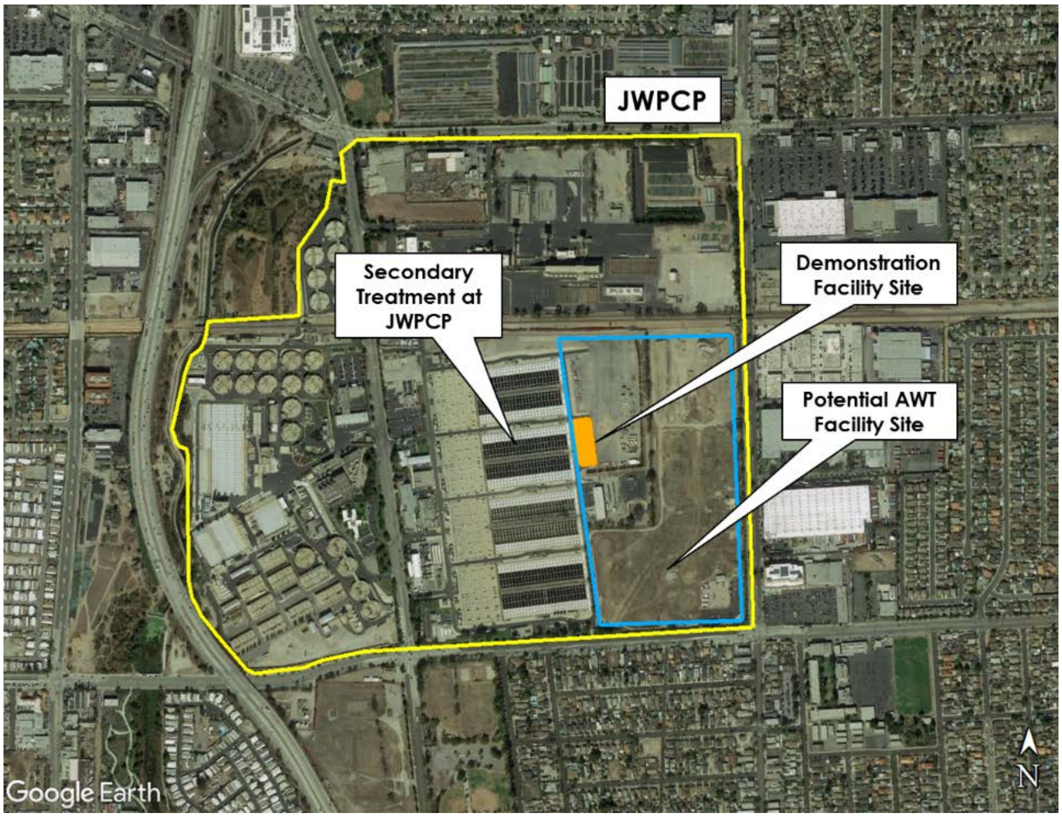

Figure 1.1 – Aerial View of JWPCP

JWPCP is a 400-MGD capacity high-purity oxygen activated sludge (HPOAS) facility that discharges its treated effluent (secondary effluent) to the ocean. The existing process was neither designed to oxidize ammonia to nitrate nor to remove nitrogen from the effluent. Previous pilot-scale studies have shown that with additional advanced treatment, JWPCP's effluent can be beneficially reused to supplement local potable supplies through groundwater recharge.

Nitrogen management in an advanced water treatment (AWT) facility at the JWPCP will be crucial for potable reuse to meet water quality objectives. The objective of this study was to identify and evaluate alternatives to manage nitrogen for the proposed AWT Facility. The approach used identified a holistic nitrogen management strategy, considering the potential treatment options at the JWPCP and/or AWT Facility. For the purpose of the evaluation, it was assumed that the AWT facility would be located on the former Fletcher Oil and Refinery Company (FORCO) property.

A demonstration facility is currently under construction to provide testing opportunities for potential AWT trains. Demonstration testing is anticipated to start in early 2019 to evaluate the operational and water quality performance of the potential train to obtain approval from the Division of Drinking Water (DDW). The performance of nitrogen removal will be assessed during the demonstration testing. In addition to supporting the regulatory approval process, the demonstration facility would also help to develop and optimize full-scale design, refine capital and operational costs for the full-scale AWT Facility, facilitate operational coordination between Metropolitan and the Sanitation Districts, and serve as a vehicle for public outreach and acceptance.

Treated water from the full-scale AWT Facility could be used to recharge four groundwater basins: Main San Gabriel, West Coast, Central and Orange County. One of the key requirements of the Groundwater Replenishment Regulations in Title 22 California Code of Regulations (CCR) Division 4, Chapter 3, is that the concentration of total nitrogen (TN) in recycled or recharge water must not exceed 10 mg/L (State Water Resources Control Board, 2015). In addition to Title 22 criteria, recycled water must also comply with water quality standards and objectives in applicable Water Quality Control Plans (Basin Plans), Salt and Nutrient Management Plans (SNMPs), and other applicable regulations and policies to protect water quality and the beneficial uses of surface water and groundwater.

Basin Plans for Main San Gabriel, West Coast, and Central Basins have nitrate and nitrate + nitrite limits of 10 mg/L-N, and as such, one water quality goal for the AWT Facility effluent was defined as TN ≤ 10 mg/L. A lower nitrate limit has been applied by the Santa Ana Regional Water Quality Control Board (RWQCB) in the Orange County Basin due to basin-specific nitrate issues. The Orange County Basin Plan limit for nitrate is 3.4 mg/L-N based on assimilative capacity findings, whereas the Orange County Water District's (OCWD's) permit (Order No. R8-2016-0051) requires meeting an even lower nitrate level of 3 mg/L-N. For the purpose of this evaluation, a nitrate goal corresponding to the Basin Plan objective of 3.4 mg/L-N was defined. Practically speaking, since any ammonia remaining in treated water would still have the potential to nitrify after leaving the AWT Facility, a nitrate limit would be adhered to by ensuring an equivalent total nitrogen limit at the AWT Facility effluent. Also, since some residual organic nitrogen (<0.1 mg/L-N) would be present in RO permeate, TN ≤ 3.5 mg/L was defined as a water quality goal for AWT Facility effluent if used for recharge in the Orange County Basin. It should be noted that the unit processes in the process trains can be optimized to achieve lower effluent TN (< 3 mg/L), if required in future. For example, the carbon dose for NdN tertiary membrane bioreactor (MBR) can be increased to lower the nitrate concentration in MBR filtrate and consequently lower TN concentration in RO permeate.

In summary, two levels of nitrogen removal goals for RO product water were established for the evaluation of alternative process trains:

- TN ≤ 10 mg/L for Main San Gabriel, West Coast, and Central Basins
- TN ≤ 3.5 mg/L (i.e. NO_3-N < 3.4 mg/L) for Orange County Basin

Figure 1.2 presents the approach for selection of recommended process trains for the full-scale AWT Facility.

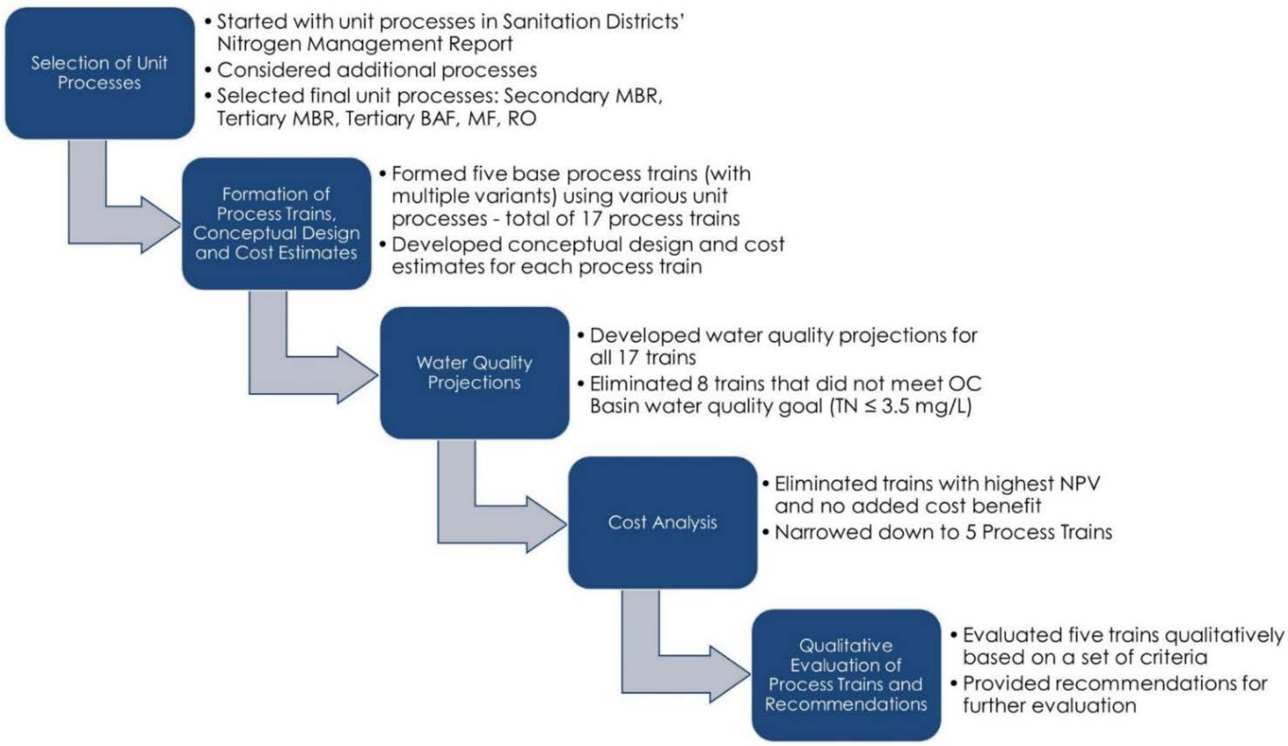

Figure 1.2 – Approach for Selection of Recommended Process Trains

Five base process trains were evaluated, mostly stemming from the Tier 1/Tier 2 unit processes identified in the Sanitation Districts' nitrogen management report (Sanitation Districts of Los Angeles County, October 2016). Multiple variants for each of these base trains were evaluated. In total, 17 different process trains were conceived and evaluated during this study. When treating primary effluent for organics and nitrogen removal, the MBR process is referred to as "Secondary MBR". On the contrary, Tertiary MBR treats secondary effluent primarily for nitrogen removal.

Biological processes within the process trains were evaluated with nitrification only (N-only) for complete nitrification and nitrification-denitrification (NdN) for complete nitrification and partial denitrification. The level of denitrification for NdN trains was chosen such that the biologically-treated effluent, when further treated with RO, would meet the water quality goal of TN ≤ 3.5 mg/L. RO is expected to further reduce the ammonia, nitrate and organic nitrogen remaining from the upstream treatment by 85%, 80% and 95%, respectively. Selected trains were also evaluated with upstream centrate treatment for ammonia removal at the JWPCP.

The five base process trains and their variants are outlined below:

- **Train 1 – Secondary MBR (Retrofit) + RO**

  Train 1 involves retrofitting four JWPCP HPOAS trains (200 MGD total) as secondary MBRs to treat primary effluent. Train 1 was evaluated in N-only and NdN configurations and, with and without centrate treatment for each configuration.

  - Train 1A – N-only Secondary MBR (Retrofit) + RO
  - Train 1B – NdN Secondary MBR (Retrofit) + RO
  - Train 1C – Centrate Treatment + N-only Secondary MBR (Retrofit) + RO
  - Train 1D – Centrate Treatment + NdN Secondary MBR (Retrofit) + RO

- **Train 2 – Tertiary MBR + RO**

  Train 2 involves building a new tertiary MBR at the AWT site. Train 2 was evaluated in N-only and NdN configurations and, with and without centrate treatment for each configuration. To avoid use of a supplemental carbon source for denitrification, an additional train that coupled the N-only tertiary MBR with a two pass RO was also evaluated.

  - Train 2A – N-only Tertiary MBR + RO
  - Train 2B – NdN Tertiary MBR + RO
  - Train 2C – Centrate Treatment + N-only Tertiary MBR+ RO
  - Train 2D – Centrate Treatment + NdN Tertiary MBR + RO
  - Train 2E – N-only Tertiary MBR + Two Pass RO

- **Train 3 – Tertiary BAF + MF + RO**

  Train 3 involves building a new tertiary biologically active filter (BAF) at the AWT site. Train 3 was evaluated in N-only and NdN configurations and, with and without centrate treatment for each configuration:

  - Train 3A – N-only Tertiary BAF + MF + RO
  - Train 3B – NdN Tertiary BAF + MF + RO
  - Train 3C – Centrate Treatment + N-only Tertiary BAF + MF + RO
  - Train 3D – Centrate Treatment + NdN Tertiary BAF + MF + RO

- **Train 4 – MF + RO**

  Train 4 uses as a basis, the DDW's approved processes that meet the required pathogen removal for indirect potable reuse (IPR). Train 4 was evaluated with centrate treatment and two pass RO.

  - Train 4A – MF + RO

  - Train 4B – Centrate Treatment + MF + RO
  - Train 4C – MF + Two Pass RO

- **Train 5 – NdN Secondary MBR + RO**

  Train 5 involves building a new secondary NdN MBR at the AWT site. Under this configuration, part of JWPCP's primary effluent flow (180 MGD of the current daily average flow of 260 MGD) will be diverted to the new NdN secondary MBR. It is expected that some of the existing HPOAS trains may no longer be used once the new NdN secondary MBR is in operation.

After the process trains were formed, conceptual designs of the unit processes were conducted by determining the design flows and using JWPCP's primary and secondary effluent and centrate characteristics. Design criteria were established for each unit process and cost estimates were developed accordingly. Cost estimates developed for each unit process provided modular cost information to create the cost estimates for all 17 process trains.

Table 1.1 summarizes the cost estimates for all 17 process trains evaluated during the study. Cost estimates were also developed for Trains 2B, 3B, 2D, 3D, 4C and 2E for the operating scenario where they would be operated to achieve TN ≤ 10 mg/L; these costs are also shown in **Table 1.1**. For such scenario, the capital costs for these trains were left unchanged but O&M costs were adopted using following assumptions:

- No carbon would be added to tertiary MBR and BAF processes for Trains 2B, 3B, 2D and 3D.
- The second pass of the two pass RO would not be operated for Trains 4C and 2E.

It should be noted that the cost estimates for tertiary MBR and RO processes were prepared with direct quantity take-offs (QTOs) from the Building Information Model (BIM) that was previously developed to support Metropolitan's Potential Regional Recycled Water Program Feasibility Study (Metropolitan Water District of Southern California, 2016). These estimates are considered to be at a Class 4 level (-15 to -30% on the low end and +20 to +50% on the high end). BIM models were not developed for the secondary MBR (retrofit and new), tertiary BAF, submerged MF, and second pass of the two pass RO processes. Therefore cost estimates for these processes are considered to be at a Class 5 level (-20 to -50% on the low end and +30 to +100% on the high end).

In addition, the costs presented in **Table 1.1** were prepared for the purpose of comparing process trains, and do not account for any treatment downstream of RO. An additional $90/ac-ft should be added to the net present value (NPV) to include costs for UV/AOP and product water stabilization. Other associated AWT costs, such as site development, utilities, and plant support facilities (e.g. operations building, electrical building, substation, etc.) were also not included. Since the ancillary facility requirements may vary amongst different process trains, these costs were not prepared.

Table 1.1 – Cost Estimates for 17 Process Trains Evaluated

	Process Train	RO Product Water TN Goal (mg/L)	Capital Cost ($M)	Capital Cost Range ($M)	O&M Cost ($M)	RO Product Water NPV - Total Cost ($M)	RO Product Water NPV - Total Cost Range ($M)	RO Product Water NPV - Unit Cost ($/ac-ft)	RO Product Water NPV - Unit Cost Range ($/ac-ft)
Train 1A	N-only Secondary MBR (Retrofit) + RO	10	$641	$386 - $1,119	$88	$1,837	$1,582 - $2,315	$547	$471 - $689
Train 2A	N-only Tertiary MBR + RO	10	$686	$480 - $1,030	$104	$2,099	$1,893 - $2,442	$625	$563 - $727
Train 3A	N-only Tertiary BAF + MF + RO	10	$821	$476 - $1,478	$110	$2,314	$1,969 - $2,972	$689	$586 - $884
Train 1C	Centrate Treatment + N-only Secondary MBR (Retrofit) + RO	10	$767	$449 - $1,369	$91	$2,008	$1,690 - $2,611	$598	$503 - $777
Train 2C	Centrate Treatment + N-only Tertiary MBR + RO	10	$767	$537 - $1,151	$107	$2,219	$1,989 - $2,602	$660	$592 - $774
Train 3C	Centrate Treatment + N-only Tertiary BAF + MF + RO	10	$869	$500 - $1,574	$111	$2,379	$2,010 - $3,084	$708	$598 - $918
Train 1B	NdN Secondary MBR (Retrofit) + RO	3.5	$673	$402 - $1,182	$86	$1,848	$1,577 - $2,357	$550	$469 - $701
Train 2B	NdN Tertiary MBR + RO	3.5	$731	$511 - $1,096	$125	$2,428	$2,209 - $2,793	$723	$657 - $831
Train 2B	NdN Tertiary MBR + RO	10	$731	$511 - $1,096	$104	$2,143	$1,924 - $2,509	$638	$573 - $747
Train 3B	NdN Tertiary BAF + MF + RO	3.5	$997	$564 - $1,830	$133	$2,809	$2,376 - $3,642	$836	$707 - $1084
Train 3B	NdN Tertiary BAF + MF + RO	10	$997	$564 - $1,830	$110	$2,490	$2,057 - $3,323	$741	$612 - $989
Train 1D	Centrate Treatment + NdN Secondary MBR (Retrofit) + RO	3.5	$794	$463 - $1,425	$90	$2,021	$1,689 - $2,651	$601	$503 - $789
Train 2D	Centrate Treatment + NdN Tertiary MBR + RO	3.5	$801	$560 - $1,201	$122	$2,459	$2,219 - $2,859	$732	$660 - $851
Train 2D	Centrate Treatment + NdN Tertiary MBR + RO	10	$801	$560 - $1,201	$107	$2,252	$2,012 - $2,652	$670	$599 - $789
Train 3D	Centrate Treatment + NdN Tertiary BAF + MF + RO	3.5	$991	$561 - $1,817	$128	$2,727	$2,298 - $3,554	$812	$684 - $1058
Train 3D	Centrate Treatment + NdN Tertiary BAF + MF + RO	10	$991	$561 - $1,817	$111	$2,501	$2,071 - $3,327	$744	$616 - $990
Train 4A	MF + RO	10	$556	$343 - $948	$95	$1,844	$1,632 - $2,236	$549	$486 - $665
Train 4B	Centrate Treatment + MF + RO	10	$632	$381 - $1,099	$97	$1,952	$1,702 - $2,420	$581	$506 - $720
Train 4C	MF + Two Pass RO	3.5	$700	$420 - $1,224	$115	$2,264	$1,985 - $2,789	$674	$591 - $830
Train 4C	MF + Two Pass RO	10	$700	$420 - $1,224	$95	$1,988	$1,708 - $2,513	$592	$508 - $748
Train 2E	N-only Tertiary MBR + Two Pass RO	3.5	$838	$565 - $1,311	$124	$2,519	$2,246 - $2,992	$750	$668 - $890
Train 2E	N-only Tertiary MBR + Two Pass RO	10	$838	$565 - $1,311	$104	$2,251	$1,978 - $2,723	$670	$589 - $810
Train 5	NdN Secondary MBR + RO	3.5	$837	$484 - $1,510	$84	$1,982	$1,629 - $2,655	$590	$485 - $790

[1]Cost estimates for tertiary MBR and RO processes are based on quantity take-offs (QTOs) from the BIM model and are considered to be at Class 4 level (-30% to +50%). The cost estimates for the secondary MBR (retrofit and new), submerged MF and two pass RO processes are considered to be at Class 5 level (-50% to +100%).

Water quality projections were developed for each process train (**Table 1.2**) and the process trains were divided into two groups based on RO product water quality goals for nitrogen removal. All 17 process trains can achieve the water quality goal of TN less than 10 mg/L. **Table 1.3** shows the cost estimates for the nine trains that could meet the more stringent TN goal of TN ≤ 3.5 mg/L. Among these nine trains, those with centrate treatment were excluded from further evaluation because they did not provide any added cost benefit compared to their counterparts (e.g. Train 1B vs 1D and Train 2B vs 2D). The BAF trains (Trains 3B and 3D) were among the most expensive and were subsequently excluded from further evaluation. As a result of this analysis, the following five trains were selected for further detailed evaluation:

- Train 1B – NdN Secondary MBR (Retrofit) + RO
- Train 2B – NdN Tertiary MBR + RO (Existing process train in Metropolitan's Demonstration Facility)
- Train 2E – N-only Tertiary MBR + Two Pass RO
- Train 4C – MF + Two Pass RO
- Train 5 – NdN Secondary MBR + RO

These trains were then further evaluated based on their ability to meet water quality goals for nitrogen, operational complexity, operational reliability/redundancy, technology maturity, cost, and environmental impact. Each of these five trains meet overall water quality goals for the project. The remaining evaluation criteria vary from one process train to another.

Table 1.4 summarizes the pros and cons for all five trains with respect to these criteria.

Table 1.2 – Water Quality Projections for Process Trains (TN/NH_3-N/NO_3-N)

	Process Train	Primary Effluent (mg/L)	Secondary Effluent (mg/L)	Tertiary MBR/BAF/MF Effluent (mg/L)	RO Permeate (mg/L)
Train 1A	N-only Secondary MBR (Retrofit) + RO	**60/45/0**	50/0/48	N/A	9.7/0/9.6
Train 2A	N-only Tertiary MBR + RO	60/45/0	**50/48/0**	48/0/46	9.3/0/9.2
Train 3A	N-only Tertiary BAF + MF + RO	60/45/0	**50/48/0**	48/0/46	9.3/0/9.2
Train 1C	Centrate Treatment + N-only Secondary MBR (Retrofit) + RO	**50/38/0**	40/0/38	N/A	7.7/0/7.6
Train 2C	Centrate Treatment + N-only Tertiary MBR + RO	50/38/0	**40/38/0**	39/0/37	7.5/0/7.4
Train 3C	Centrate Treatment + N-only Tertiary BAF + MF + RO	50/38/0	**40/38/0**	39/0/37	7.5/0/7.4
Train 1B	NdN Secondary MBR (Retrofit) + RO	**60/45/0**	16/0/14	N/A	2.9/0/2.8
Train 2B	NdN Tertiary MBR + RO	60/45/0	**50/48/0**	16/0/14	2.9/0/2.8
Train 3B	NdN Tertiary BAF + MF + RO	60/45/0	**50/48/0**	16/0/14	2.9/0/2.8
Train 1D	Centrate Treatment + NdN Secondary MBR (Retrofit) + RO	**50/38/0**	12/0/10	N/A	2.1/0/2.0
Train 2D	Centrate Treatment + NdN Tertiary MBR + RO	50/38/0	**40/38/0**	16/0/14	2.9/0/2.8
Train 3D	Centrate Treatment + NdN Tertiary BAF + MF + RO	50/38/0	**40/38/0**	16/0/14	2.9/0/2.8
Train 4A	MF + RO	60/45/0	**50/48/0**	50/48/0	7.3/7.2/0
Train 4B	Centrate Treatment + MF + RO	50/38/0	**40/38/0**	40/38/0	5.8/5.7/0
Train 4C	MF + Two Pass RO	60/45/0	**50/48/0**	50/48/0	3.1/3.0/0
Train 2E	N-only Tertiary MBR + Two Pass RO	60/45/0	**50/48/0**	48/0/46	3.3/0/3.2
Train 5	NdN Secondary MBR + RO	**60/45/0**	16/0/14	N/A	2.9/0/2.8

Table 1.3 – Cost Estimates for Trains that Meet TN ≤ 3.5 mg/L

	Process Train	Capital Cost ($M)	Capital Cost Range ($M)	O&M Cost ($M)	RO Product Water NPV - Total Cost ($M)	RO Product Water NPV - Total Cost Range ($M)	RO Product Water NPV - Unit Cost ($/ac-ft)	RO Product Water NPV - Unit Cost Range ($/ac-ft)
Train 1B	NdN Secondary MBR (Retrofit) + RO	$673	$402 - $1,182	$86	$1,848	$1,577 - $2,357	$550	$469 - $701
Train 2B	NdN Tertiary MBR + RO	$731	$511 - $1,096	$125	$2,428	$2,209 - $2,793	$723	$657 - $831
Train 3B	NdN Tertiary BAF + MF + RO	$997	$564 - $1,830	$133	$2,809	$2,376 - $3,642	$836	$707 - $1084
Train 1D	Centrate Treatment + NdN Secondary MBR (Retrofit) + RO	$794	$463 - $1,425	$90	$2,021	$1,689 - $2,651	$601	$503 - $789
Train 2D	Centrate Treatment + NdN Tertiary MBR + RO	$801	$560 - $1,201	$122	$2,459	$2,219 - $2,859	$732	$660 - $851
Train 3D	Centrate Treatment + NdN Tertiary BAF + MF + RO	$991	$561 - $1,817	$128	$2,727	$2,298 - $3,554	$812	$684 - $1058
Train 4C	MF + Two Pass RO	$700	$420 - $1,224	$115	$2,264	$1,985 - $2,789	$674	$591 - $830
Train 2E	N-only Tertiary MBR + Two Pass RO	$838	$565 - $1,311	$124	$2,519	$2,246 - $2,992	$750	$668 - $890
Train 5	NdN Secondary MBR + RO	$837	$484 - $1,510	$84	$1,982	$1,629 - $2,655	$590	$485 - $790

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Table 1.4 – Assessment of Nitrogen Management Trains against Evaluation Criteria

	Process Train	Ability to Meet Water Quality Goal[1] (TN≤3.5 mg/L)	Operational Complexity (Technology)	Operational Reliability and Redundancy	Technology Maturity	RO Product Water NPV[2] ($/ac-ft)	Environmental Impact	Constructability
1B	NdN Secondary MBR (Retrofit) + RO	Yes	• MBR more complex to operate • No need for additional biological process • Pressure decay testing may add complexity	• Higher risk during wet weather flows • Flow balancing between MBR and HPOAS reactors would be necessary • 10% derating for TN≤3.5 mg/L	• Secondary MBR full-scale facilities in operation. Retrofit of HPOAS to MBR has not been done. • Regulatory approval pending	• $550/ac-ft ($469-701/ac-ft) • Includes back-up and redundancy to ensure reliable operation	• High carbon emissions	• Potential challenges with retrofitting the existing facility • Integration into the existing facility requires detailed assessment. • Retrofit does not allow for optimal design • Less phasing flexibility due to constraint to 50-mgd increments
2B	NdN Tertiary MBR + RO	Yes	• MBR more complex to operate • Additional biological process required • Pressure decay testing may add complexity	• Does not impact JWPCP operation or capacity • Unaffected by diurnal or wet weather flow variation • Relies on continuous carbon addition	• No full-scale installations; proven at pilot-scale • Regulatory approval pending	• $723/ac-ft ($657-831/ac-ft)	• Highest carbon emissions • Carbon addition required - more chemical handling and trucks	• Greenfield • Phasing flexibility
2E	N-Only Tertiary MBR + Two Pass RO	Yes	• MBR more complex to operate • Additional biological process and 2nd pass RO required • Pressure decay testing may add complexity	• Does not impact JWPCP operation or capacity • Unaffected by diurnal or wet weather flow variation	• No full-scale installations; proven at pilot-scale • Regulatory approval pending	• $750/ac-ft ($668-890/ac-ft)	• Highest carbon emissions • Potential for enhanced removal of micropollutants due to combination of nitrification and second pass RO	• Greenfield • Phasing flexibility
4C	MF + Two Pass RO	Yes	• Simpler to operate • 2nd pass RO required	• Does not impact JWPCP operation or capacity • Unaffected by diurnal or wet weather flow variation • Potential increase in rate of membrane fouling	• Proven technology due to longevity in reuse • Approved by regulators	• $674/ac-ft ($591-674/ac-ft)	• Lowest carbon emissions • No potential for enhanced biodegradation of micropollutants – second pass RO may compensate • Ammonia toxicity in brine may be of concern	• Greenfield • Phasing flexibility
5	NdN Secondary MBR + RO	Yes	• MBR more complex to operate • Additional biological process required • Pressure decay testing may add complexity	• Flow balancing between MBR and HPOAS reactors would be necessary	• Secondary MBR full-scale facilities in operation • Regulatory approval pending	• $590/ac-ft ($485-790/ac-ft)	• High carbon emissions	• Greenfield - allows for optimal design • Phasing flexibility

ADF = average daily flow; gpd = gallons per day; HPOAS = high purity oxygen activated sludge; JWPCP = Joint Water Pollution Control Plan; MBR = membrane bioreactor; MF = membrane filtration; mgd = million gallons per day; N-Only = nitrification only; NdN = nitrification/denitrification; RAS = return activated sludge; RO = reverse osmosis

1. Based on RO Permeate.

2. Costs for all trains include O&M costs for organics and nitrogen removal. Cost estimates for Secondary MBR (retrofit and new), MF, and Two Pass RO are Class 5 Construction Cost Estimates with +100%/-50% error. Cost estimates for Tertiary MBR (N-only and NdN) and RO are Class 4 Construction Cost Estimates with slightly less margin of error (+50%/-30%). RO Product Water NPV range shown accounts for this cost variability.

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The results of this work effort identified five process trains that are potentially well suited to meet the nitrogen management objectives of the Regional Recycled Water Program. The current work identified potential issues with each of the five shortlisted process trains. In order to address these issues, additional literature searches, process modeling, detailed conceptual design, expert review, and field testing are required. Additionally, it is recommended that specific modifications/enhancements be made to Metropolitan's Demonstration Facility to facilitate testing of these trains.

The recommended next steps for each train are as follows:

- **Train 1B – NdN Secondary MBR (Retrofit) + RO**
    - Construct process line to convey JWPCP's primary effluent to the AWT Demonstration Facility for testing of secondary MBR process.
    - Further develop the NdN secondary MBR retrofit design concept, similar to that which was conducted previously for the tertiary MBR.
    - Refine the cost estimate to Class 4 level using the information obtained from a BIM model, to be created as part of the conceptual design.
    - Assess the operational and water quality performance of the NdN secondary MBR at the AWT Demonstration Facility.
    - Evaluate the impact of flow variation on the performance of secondary MBR and HPOAS reactors.
    - Identify operational requirements for obtaining pathogen removal credits.
- **Train 2B - NdN Tertiary MBR + RO** (Base case process train from feasibility report and basis of AWT Demonstration Facility)
    - Assess the operational and water quality performance of the NdN tertiary MBR at the AWT Demonstration Facility, especially with respect to membrane fouling and supplemental carbon consumption for denitrification. This information will be used to further refine cost.
    - Identify operational requirements for obtaining pathogen removal credits.
- **Train 2E - N-only Tertiary MBR + Two Pass RO**
    - Add second pass RO to AWT Demonstration Facility.
    - Investigate implications of two pass RO on the downstream UV/AOP process performance, treated water quality, and regulatory approval.
    - Identify operational requirements for obtaining pathogen removal credits.

- **Train 4C - MF + Two Pass RO**
  - Investigate membrane performance of the MF system treating non-nitrified secondary effluent on pilot-scale.
  - Develop a more detailed conceptual design, similar to that which was conducted previously for tertiary MBR, and create a BIM model for submerged MF.
  - Refine the cost estimate to Class 4 level.
  - Investigate implications of two pass RO on the downstream UV/AOP process performance, treated water quality, and regulatory approval.
- **Train 5 - NdN Secondary MBR + RO**
  - Construct process line to bring JWPCP's primary effluent to AWT Demonstration Facility for testing of secondary MBR process.
  - Further develop the NdN secondary MBR design concept, similar to that which was conducted previously for the tertiary MBR.
  - Refine the cost estimate to Class 4 level using the information obtained from a BIM model, to be created as part of the conceptual design.
  - Assess the operational and water quality performance of the NdN secondary MBR at the AWT Demonstration Facility.
  - Evaluate the impact of flow variation on the performance of secondary MBR and HPOAS reactors.
  - Identify operational requirements for obtaining pathogen removal credits.

Once these additional investigations and demonstration testing have been conducted, further discussions should take place to determine which process train would be employed in a full-scale AWT (up to 150 MGD) to achieve the overall goals of the Regional Recycled Water Program.

2.0 BACKGROUND AND OBJECTIVES

The Metropolitan Water District of Southern California (Metropolitan) and Sanitation Districts of Los Angeles County (Sanitation Districts) are jointly exploring the potential of building a 150-MGD advanced water treatment (AWT) Facility that will treat secondary effluent from the Joint Water Pollution Control Plant (JWPCP) in Carson, CA (**Figure 2.1**). This effort is part of Metropolitan's Regional Recycled Water Program (RRWP) to create a new water resource with regional benefit for Southern California, including a new conveyance system to deliver the water to four groundwater basins.

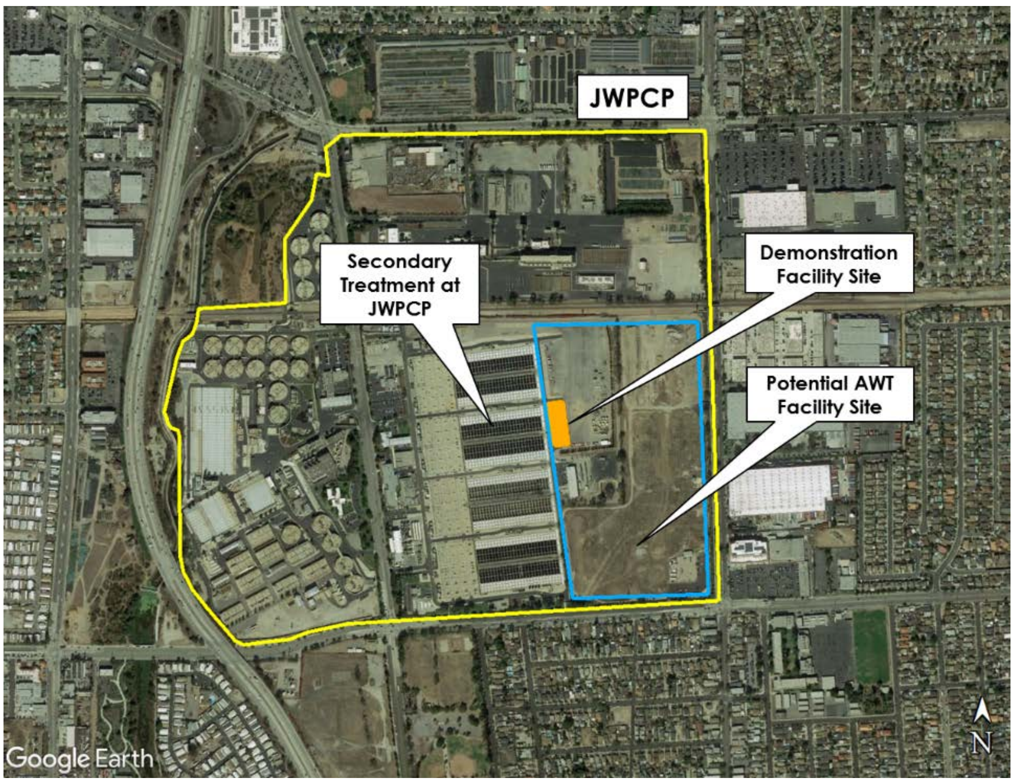

Figure 2.1 – Aerial View of JWPCP

JWPCP is a 400-MGD capacity high-purity oxygen activated sludge (HPOAS) facility that produces non-nitrified effluent, most of which is sent to the ocean through two existing tunnels and four outfalls. Currently, JWPCP receives and treats approximately 260 MGD of wastewater flow. The existing process was neither designed for ammonia nor nitrogen removal. Previous pilot studies have shown that with additional advanced treatment, a portion of JWPCP's secondary effluent could be beneficially reused to supplement local potable supplies through groundwater recharge. Treated water from the AWT Facility could be used to recharge four groundwater basins: Main San Gabriel, West Coast, Central and Orange County.

The potential AWT Facility would be located east of the existing secondary treatment basins on the Sanitation Districts' former Fletcher Oil and Refinery Company (FORCO) property that is currently being remediated for soil contamination. Constructing a full-scale project on the FORCO property would require a varying degree of contaminated soil management based on which process train was selected.

Nitrogen management in an AWT Facility at the JWPCP will be crucial for potable reuse to meet specific water quality goals. A Nitrogen Management Committee was formed on April 6, 2017 to explore cost-effective and reliable alternatives and identify a holistic nitrogen management strategy, considering the potential treatment options at both the JWPCP and AWT Facility.

A demonstration facility is currently under construction to provide testing opportunities for potential AWT trains. Demonstration testing is anticipated to start in early 2019 to evaluate the operational and water quality performance of the proposed trains in order to obtain approval from DDW for the overall pathogen log removal credit and ultimately to secure a water recycling permit. The performance of nitrogen removal will be assessed during demonstration testing. In addition to supporting the regulatory approval process, the demonstration facility would help to develop and optimize full-scale design, refine capital and operational costs for the full-scale AWT Facility, facilitate operational coordination between Metropolitan and the Sanitation Districts, and serve as a vehicle for public outreach and acceptance.

3.0 APPROACH

Figure 3.1 shows the approach for selection of recommended process trains. This selection was conducted in five major steps:

1) Selection of Unit Processes
2) Formation of Process Trains
3) Water Quality Projections
4) Cost Analysis
5) Qualitative Evaluation of Process Trains and Recommendation

The evaluation culminated in a recommended shortlist of process trains for consideration and final selection by Metropolitan and the Sanitation Districts. Specific recommendations for further evaluation of each train were also developed. Each of these steps is discussed in detail in the following sections.

3.1 SELECTION OF UNIT PROCESSES

The first major step was the selection of unit processes to form process trains. The approach for unit process selection first included a review of previous work conducted by the Sanitation Districts, which was summarized in an earlier report (Sanitation Districts of Los Angeles County, October 2016). Since 2009, the Sanitation Districts' Wastewater Research Section has been evaluating nitrogen treatment options at JWPCP for meeting potential regulatory requirements and for conditioning the secondary effluent for further treatment and reuse. Through literature surveys and pilot testing conducted between 2009 and 2016, 15 nitrogen treatment processes were identified. Three more processes (Secondary MBR – Replacement, Membrane Aerated Biofilm Reactor (MABR) and MF + RO) not considered by the Sanitation Districts during the initial evaluation, were added for evaluation (shown in bold in **Table 3.1**).

The processes were classified based on location within JWPCP treatment processes:

- Within secondary treatment involving replacement or retrofit of the existing HPOAS process,
- After secondary treatment as add-on or tertiary processes, and
- Treatment of the nitrogen-rich centrifuge centrate stream in the JWPCP (sidestream treatment).

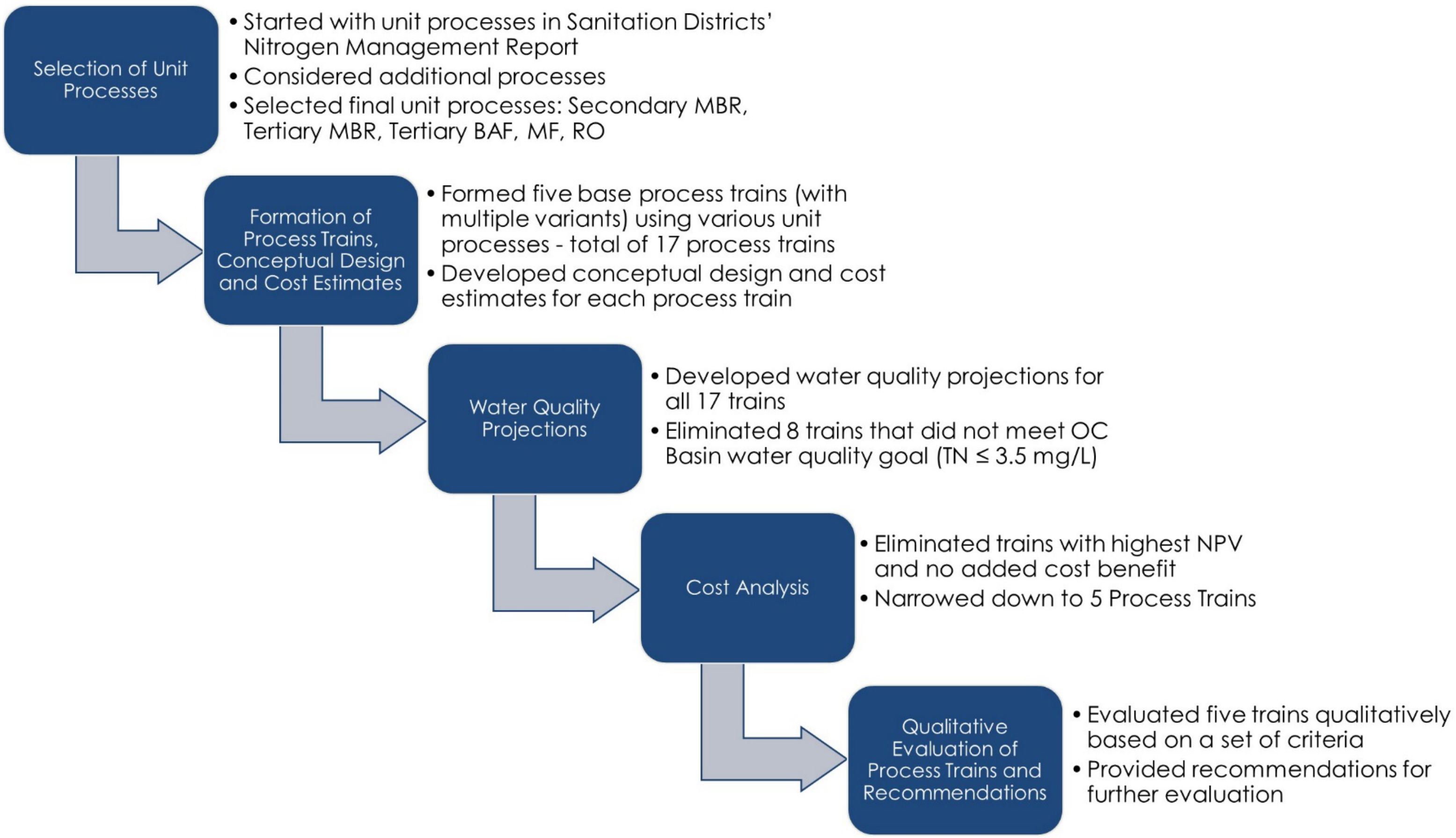

Figure 3.1 – Approach for Selection of Recommended Process Trains

Table 3.1 – Processes Evaluated for Nitrogen Management

Class	Process	Ranking
HPOAS Replacement/Retrofit	Air BNR-AS (Replacement)	Tier 3
	HPO BNR-AS (Retrofit)	Tier 3
	IFAS (Retrofit)	Tier 3
	MBR (Retrofit)	Tier 1
	MBR (New)	Tier 1
	BioMag (Retrofit)	Tier 3
	MABR (Retrofit)	Tier 3
Add-On (Tertiary) Treatment	Air BNR-AS	Tier 3
	MBBR	Tier 3
	MBR	Tier 1
	BAF	Tier 1
	Ammonia Stripping	Tier 3
	Ion Exchange	Tier 3
	Breakpoint Chlorination	Tier 3
	Deammonification	Tier 2
	MF + RO	Tier 1
Sidestream/Centrate Treatment	Bioaugmentation	Tier 2
	Deammonification	Tier 1

1. Processes in bold font are additional processes that were not considered in the original evaluation by the Sanitation Districts.
2. BNR: Biological Nutrient Removal; AS: Activated Sludge; HPO: High Purity Oxygen; IFAS: Integrated Fixed-film AS; MABR: Membrane Aerated Biofilm Reactor; MBBR; Moving Bed Biofilm Reactor.

These processes were then evaluated against the following criteria: ability to meet treatment objectives, technology maturity, ease of operation, ability to implement at the JWPCP, and impacts on existing operation. These unit processes were ranked from Tier 1 to 3 with Tier 1 being most suitable for implementation. The following Tier 1 unit processes were used by the Nitrogen Management Committee to form process trains:

1) Secondary MBR (Retrofit and New)
2) Tertiary MBR
3) Tertiary BAF
4) MF
5) RO
6) Deammonification (Centrate Treatment)

Detailed description of the Tier 1 unit processes is provided in **Section 4**.

3.2 FORMATION OF PROCESS TRAINS

After the selection of unit processes, the second major step was to form process trains for evaluation (**Table 3.2**). Five base trains, with 4 of the 5 trains having several variants, were developed. Including the variants, a total of 17 process trains were developed for evaluation. A detailed description of the selected process trains may be found in **Section 5**.

The process design included selection of design flows, feed water characteristics, product water quality goals, design criteria, and sizing of the unit processes. Information pertaining to unit process design may be found in **Section 6** and **Appendix A**. After unit process designs were completed, preliminary costs estimates were developed. The methodologies for developing cost estimates are discussed in **Section 7** and the summary of cost estimates for unit processes are shown in **Appendix B**. Further cost breakdown for unit processes for different capital and O&M cost categories is shown in **Appendix C**.

Table 3.2 – Process Trains Evaluated for Nitrogen Management

	Process Train Description
Train 1A	N-only Secondary MBR (Retrofit) + RO
Train 1B	NdN Secondary MBR (Retrofit) + RO
Train 1C	Centrate Treatment + N-only Secondary MBR (Retrofit) + RO
Train 1D	Centrate Treatment + NdN Secondary MBR (Retrofit) + RO
Train 2A	N-only Tertiary MBR + RO
Train 2B	NdN Tertiary MBR + RO (Process train at Metropolitan's Demonstration Plant)
Train 2C	Centrate Treatment + N-only Tertiary MBR + RO
Train 2D	Centrate Treatment + NdN Tertiary MBR + RO
Train 2E	N-only Tertiary MBR + Two Pass RO
Train 3A	N-only Tertiary BAF + MF + RO
Train 3B	NdN Tertiary BAF + MF + RO
Train 3C	Centrate Treatment + N-only Tertiary BAF + MF + RO
Train 3D	Centrate Treatment + NdN Tertiary BAF + MF + RO
Train 4A	MF + RO
Train 4B	Centrate Treatment + MF + RO
Train 4C	MF + Two Pass RO
Train 5	NdN Secondary MBR + RO

3.3 WATER QUALITY PROJECTIONS

Water quality projections were developed for each process train; further details are provided in **Section 6.5**. These water quality projections were used to divide the process trains into two groups based on the RO product water quality goals (TN ≤ 10 mg/L and TN ≤ 3.5 mg/L). From the 17 process trains, nine trains that met the more stringent water quality goal (TN ≤ 3.5 mg/L), were considered for further evaluation.

3.4 COST ANALYSIS

Cost estimates, developed during Step 2, were used to eliminate the process trains that were the most expensive among the nine trains shortlisted based on water quality projections. The process trains that did not provide any added cost benefit (e.g. Train 1B vs 1D and Train 2B vs 2D – refer to **Section 7.2** for cost comparison) were also eliminated, leaving five process trains for further evaluation.

3.5 QUALITATIVE EVALUATION OF PROCESS TRAINS AND RECOMMENDATIONS

The final step of the study was to assess the pros and cons of the five selected trains against the following, pre-defined set of criteria:

- Ability to meet water quality goal
- Operational complexity (technology)
- Operational reliability and redundancy
- Technology maturity
- RO product water NPV
- Environmental impact
- Constructability

Results of the qualitative evaluation of the five shortlisted trains are shown in **Section 8**. Also, in order to assess the economic viability of these trains with respect to capacity phasing, an economy of scale analysis was conducted. Capital and O&M costs were used to develop a cost curve that showed the RO product water cost against different plant flow-rates; results are shown in **Section 9**. Specific recommendations for further evaluation of each train are discussed in **Section 10**.

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4.0 DESCRIPTION OF UNIT PROCESSES

The following section provides a brief description of each unit treatment process included in the process trains. The design criteria for each process are presented in **Appendix A.**

4.1 CENTRATE TREATMENT WITH DEAMMONIFICATION

At JWPCP, solids from anaerobic digestion are dewatered in the centrifuges with the aid of a polymer. Centrate is the liquid stream separated from the dewatered solids. Polymer helps in floc formation and improve separations of liquid from solids. The dewatered solids are hauled offsite while the centrate is further treated in Dissolved Air Flotation (DAF) units before returning to the headworks. DAF-treated centrate currently contributes approximately 25% of the plant’s nitrogen loading. One way of reducing the nitrogen loading to the JWPCP is to treat the nitrogen-rich centrate. Solids processing and centrate treatment cannot be restricted to just the flow into the AWT Facility but must be applied to the entire 260 MGD JWPCP flow.

Centrate treatment with deammonification involves a nitritation step (conversion of ammonia to nitrite) followed by an anaerobic ammonia oxidation step, also known as anammox (conversion of ammonia and nitrite to nitrogen gas). Use of anammox-based treatment is economical because nitritation requires substantially lower process air (by 40 to 60%) than nitrification. Additionally, since the process converts ammonia and nitrite to nitrogen gas, no carbon addition is required for denitrification. The proper conditions required for anammox can be achieved in an engineered environment that sustains both ammonia oxidizing bacteria (AOBs) and anammox bacteria. The process is designed to achieve around 80-90% removal of ammonia and approximately 70-80% removal of TIN.

For the purpose of this evaluation, the ANITA™ Mox MBBR by Veolia (**Figure 4.1**) was selected for basis of design to treat the centrate stream. It is an attached-growth process, where a layered biofilm grows on the surface of proprietary fluidized plastic media. The process takes place in a reactor where the flow and continuous aeration keeps the media suspended.

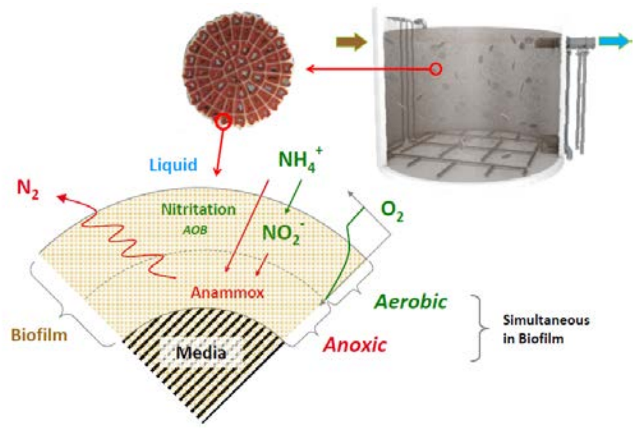

Figure 4.1 – Schematic of ANITA™ Mox Process (Courtesy of Veolia)

The media in the reactor are continuously fluidized and the process does not require backwashing. The outer layer of the biofilm on the media is exposed to dissolved oxygen and remains aerobic while the inner biofilm layer is anaerobic. Oxidation of ammonia to nitrite takes place in the outer aerobic layer, while the anammox reaction (ammonia and nitrite are oxidized to nitrogen gas) takes place in the anaerobic layer. The system is designed as a single reactor with air diffusers at the bottom of the tank and screens at the surface outlet to retain the media. The design criteria are provided in **Appendix A.2.**

4.2 SECONDARY MEMBRANE BIOREACTOR

The secondary MBR process involves treating primary effluent from JWPCP with either complete nitrification only (N-only) or complete nitrification and partial denitrification (NdN). Secondary MBR at JWPCP could be implemented by either (1) retrofitting the current activated sludge reactors and secondary clarifiers or (2) building a new MBR at the AWT site. For both of these options, the biological system for the secondary MBR was designed for a solids retention time (SRT) of at least 10 days to ensure complete nitrification. For the NdN configurations (retrofit and new), the anoxic basins were sized to target an MBR filtrate nitrate concentration of <14 mg/L-N without carbon addition. At this target level of MBR filtrate nitrate concentration and an 80% nitrate rejection by RO, the nitrate concentration in the treated water is expected to be less than 3.4 mg/L-N. Process modeling using BioWin was performed to calculate the anoxic and aerobic basin volumes for the secondary MBR.

When operating with the secondary MBR NdN configuration, primary effluent would be fed to the anoxic tank first. Mixed liquor would flow from the anoxic tank to the aerobic tank, then into the membrane modules for solids separation. The carbon present in JWPCP's primary effluent would be utilized for denitrification eliminating the need for supplemental carbon. Due to site constraints, a single recycle flow combining solids and nitrate recycle would be utilized. The design criteria for the secondary MBR process is provided in **Appendix A.3**. For the purpose of this evaluation, GE's ZeeWeed MBR system was used for the basis of design.

Figure 4.2 presents the schematic for retrofitting JWPCP's secondary treatment facilities to N-only secondary MBR and **Figure 4.3** presents the schematic for the NdN retrofit. For the N-only configuration, the existing reactors would stay in the current mode of operation (HPOAS) and the secondary clarifiers would be equipped with fine bubble diffused aeration to provide additional aerobic tank volume. For the NdN configuration, to achieve the target effluent nitrate concentration, the existing reactors and a small portion of the secondary clarifiers would be used as anoxic zones for denitrification. The majority of the secondary clarifiers would be converted to aeration tanks. For both N-only and NdN configurations, membrane separation modules would be housed towards the end of each secondary clarifier. Depending on the intended configuration (N-only or NdN), which affects how the reactors and secondary clarifiers would be modified, the plant capacity may be derated by as much as 10%.

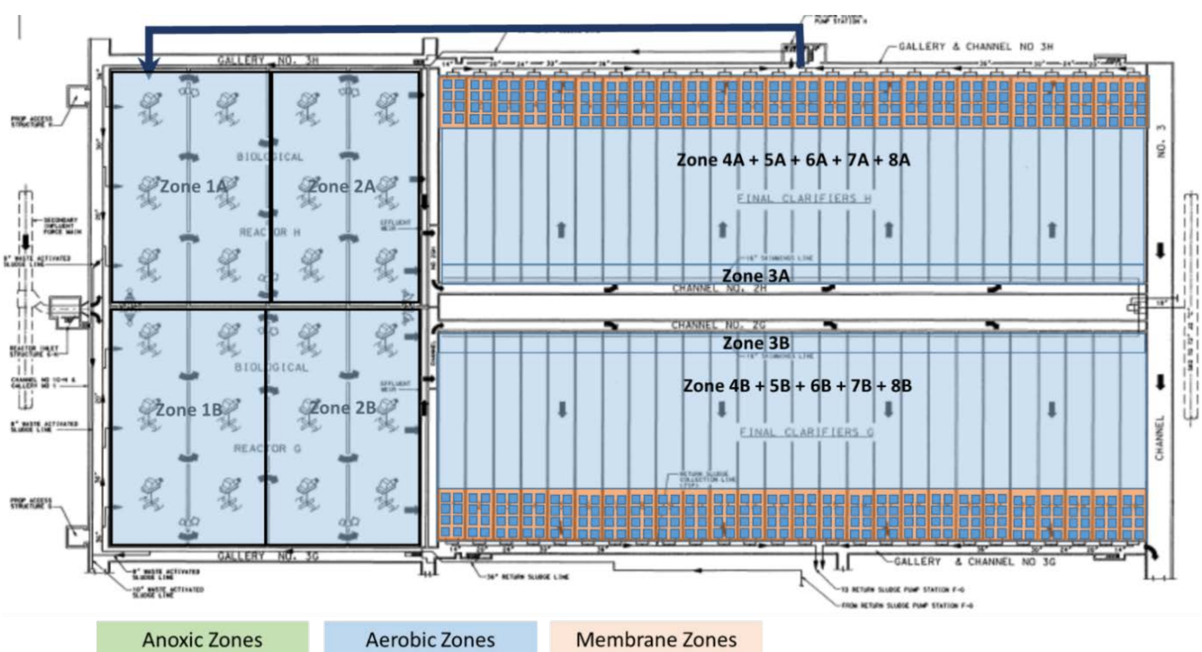

Figure 4.2 – Schematic of Secondary Facilities Retrofit to N-only Secondary MBR at JWPCP

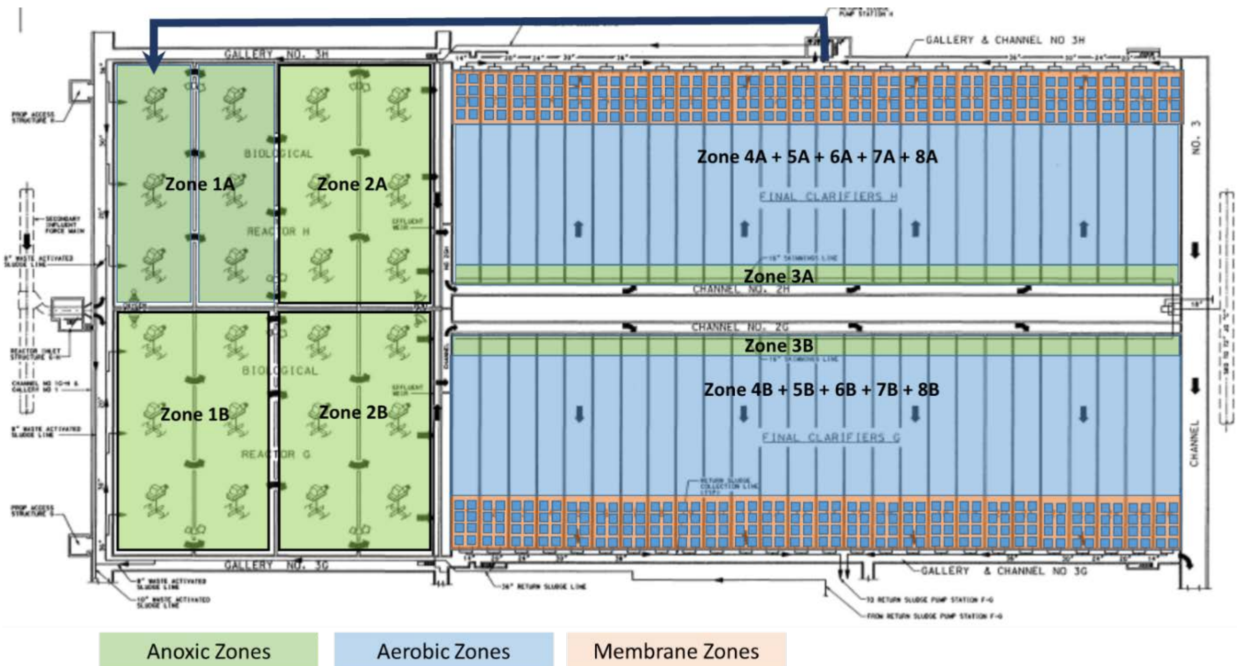

Figure 4.3 – Schematic of Secondary Facilities Retrofit to NdN Secondary MBR at JWPCP

4.3 TERTIARY MEMBRANE BIOREACTOR

The tertiary MBR process was designed to achieve either complete nitrification (N-only) or complete nitrification and partial denitrification (NdN) of non-nitrified secondary effluent from the JWPCP. For the NdN configuration, supplemental carbon (e.g. MicroC 2000) would need to be added to the anoxic zone to achieve partial denitrification because secondary effluent from the JWPCP does not have enough biodegradable COD to support denitrification.

The biological system for the tertiary MBR was designed for an SRT of 10 days to ensure complete nitrification. The anoxic tanks were sized to achieve an effluent nitrate concentration of <14 mg/L-N based on an influent TKN concentration of 50 mg/L-N (or 40 mg/L-N if centrate treatment is implemented). When combined with an 80% removal of nitrate by RO, the treated water is expected to meet the water quality goal for nitrate of less than 3.4 mg/L-N.

Screened non-nitrified secondary effluent would be fed to the aerobic zone for nitrification and flow by gravity to the anoxic tank for denitrification and then into the membrane tank for solids separation. A single recycle flow would be used to recycle solids and nitrate. The design criteria for the tertiary MBR process are provided in **Appendix A.4**. For the purpose of this evaluation, GE's ZeeWeed MBR system was used for the basis of design, as depicted in **Figure 4.4**.

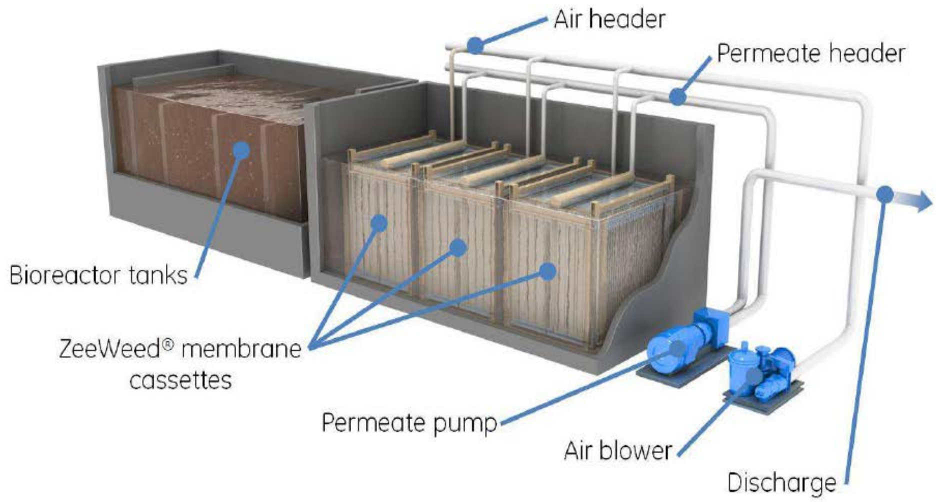

Figure 4.4 – Example Layout of GE's ZeeWeed MBR system (Courtesy of GE)

4.4 TERTIARY BIOLOGICALLY ACTIVE FILTER

The tertiary biologically active filter (BAF) uses reactors filled with tightly packed plastic attached-growth media. Wastewater flows either upward or downward and receives treatment to biologically remove nitrogenous compounds (NH_4-N, NO_3-N) and produce filtered water. The media serves two functions: (1) provide a surface for microbial growth, and (2) filtration. The attached-growth nature of the process enables retention of slow-growing organisms, such as nitrifiers, in the system. Filtration by the media with periodic backwash eliminates the need for clarification downstream. Air is added to the bottom of the reactor to facilitate the nitrification process. Additional anoxic reactors are added downstream to achieve denitrification. For tertiary BAF, supplemental carbon is added to the anoxic reactor for denitrification. The reactors are backwashed periodically with air and BAF effluent to maintain acceptable head loss through the reactors.

The BIOSTYR® unit by Veolia (**Figure 4.5**), an up-flow submerged fixed-film process, was selected for the basis of design to treat non-nitrified secondary effluent. Influent wastewater is pumped to a common inlet feed channel above the BIOSTYR® cells from which it flows by gravity down to the individual cells. Within each BIOSTYR® cell, the wastewater flow is evenly distributed across the bottom of the cell by a set of distribution troughs. As the wastewater flows upwards through the filter media, the biological growth on the surface of the media provides treatment. Ceiling plates with equally spaced nozzles are used to retain the filter media while allowing the treated water to enter a common water reservoir, which also provides the water for backwash. During backwashing, air is introduced for scouring the media while the downward counter-current of water removes accumulated solids into drain pipes located at the bottom of the cells. The design criteria are provided in **Appendix A.5**.

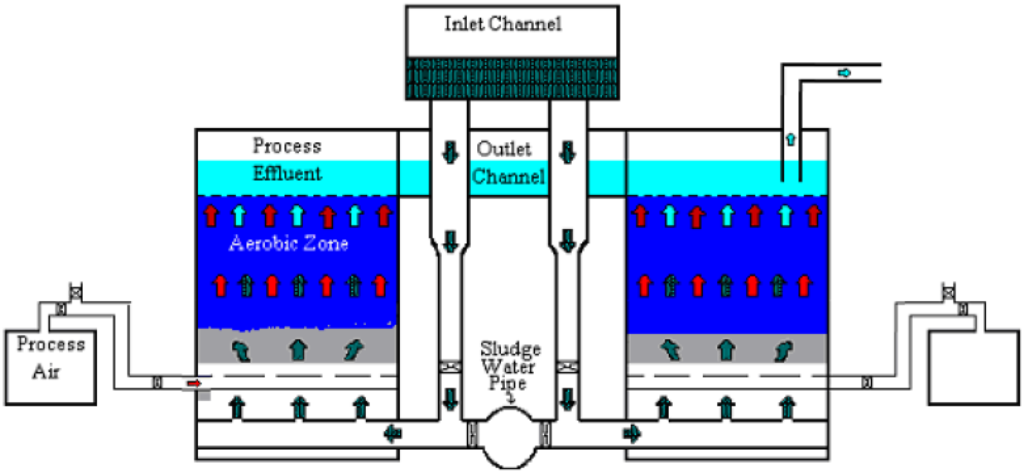

Figure 4.5 – Schematic of BIOSTYR® Process (Courtesy of Veolia)

4.5 MEMBRANE FILTRATION

The MF system uses microfiltration or ultrafiltration membranes to remove particulate matter from the feed water that would otherwise foul the downstream RO membranes. While various membrane technologies and module configurations exist, this design was based on a submerged hollow-fiber membrane system. For the purpose of this evaluation, equipment sizes, costs, power use, and cleaning frequencies were obtained from the membrane vendor (GE). **Figure 4.6** shows a cross section of a typical submerged MF system. Design criteria are provided in **Appendix A.6**.

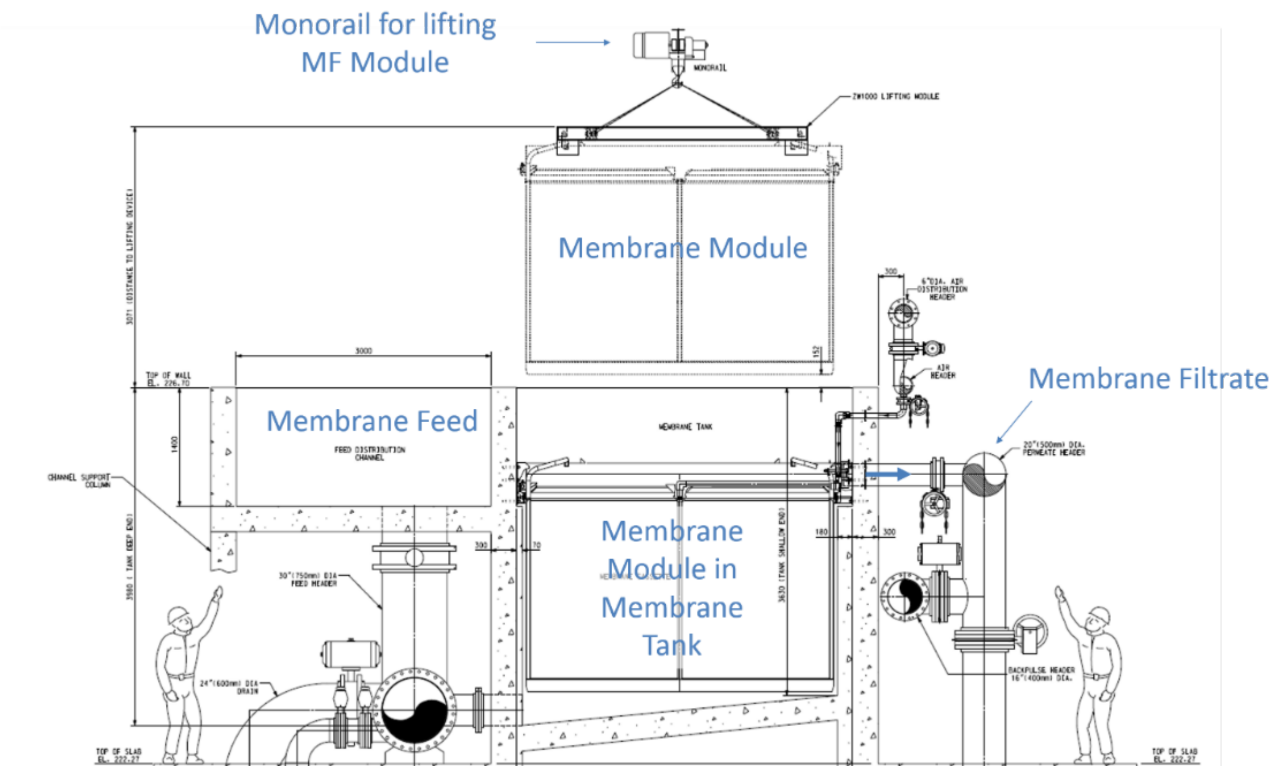

Figure 4.6 – Example Cross-section of Submerged MF System

4.6 REVERSE OSMOSIS

The RO system removes a significant portion of the dissolved solids, organics, and pathogens that remain after the preceding treatment steps. RO membranes reject ammonia, nitrate, and organic nitrogen to varying degrees. Both single pass and two pass configurations were considered for the various process trains. The two pass configuration was used for increased removal of nitrogen species by RO.

For the single pass configuration, a 3-stage with an overall recovery of 85% was assumed. For the two pass configuration, the first pass was the same as for single pass (3 stages). The second pass consisted of 2-stages with an overall recovery of 90%. **Figure 4.7** shows a schematic of a two pass RO system with a 3-stage first pass and a 2-stage second pass. To achieve the desired effluent water quality, 63% of the 1st pass RO permeate would be passed on to the 2nd pass RO for further treatment and the rest would be blended with the 2nd pass RO permeate. The design criteria are provided in **Appendix A.7**.

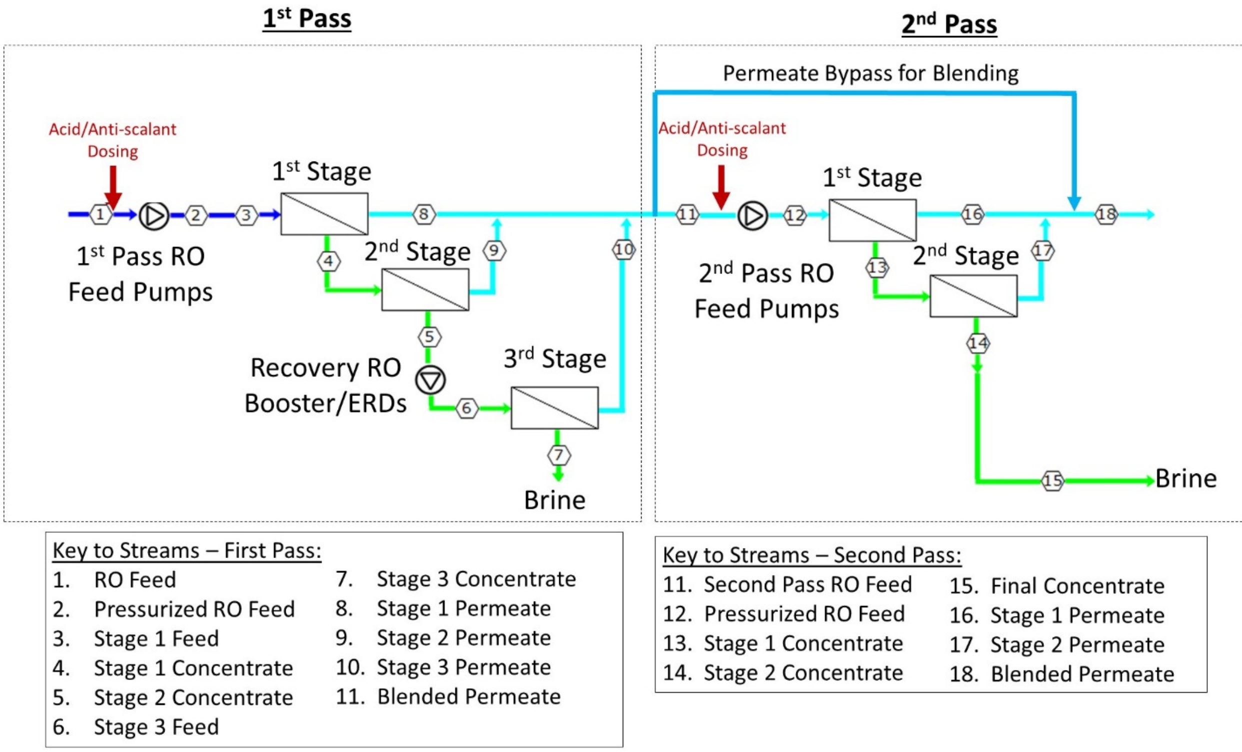

Figure 4.7 – Process Schematic of a Two Pass RO System

4.7 POST-RO TREATMENT

After RO, additional treatment applicable to all trains includes ultraviolet/advanced oxidation process (UV/AOP) and stabilization of the product water. The AOP generates hydroxyl radicals at ambient temperature and pressure to facilitate oxidation of organic compounds and inactivation/removal of viruses, *Cryptosporidium*, and *Giardia*. The primary water quality goals of the UV/AOP system are as follows:

- ≥ 0.5 log reduction of 1,4-dioxane;
- NDMA, NDEA, and NDPA removal below DDW's notification level (NL) of 10 ng/L;
- 6 log removal each of virus, *Cryptosporidium*, and *Giardia*.

Although many options are available for UV reactors and oxidants, this design was based on low-pressure high-output (LPHO) reactors with chlorine as an oxidant. An example of a LPHO reactor is shown in **Figure 4.8**. The design criteria are provided in **Appendix A.8**.

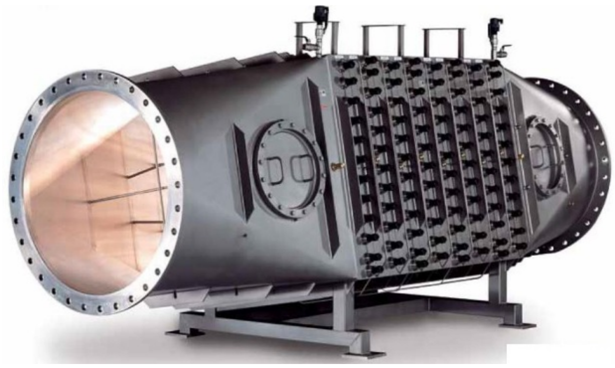

Figure 4.8 – Xylem Wedeco K-143 UV Reactor (Courtesy of Xylem)

After RO and UV/AOP treatment, the water has relatively low pH and TDS levels, and requires stabilization. To prevent corrosion of downstream piping, most facilities use pH and/or alkalinity adjustment to stabilize the water prior to reuse. The stabilization method for this design included lime and CO_2 addition; lime is added in order to increase hardness, alkalinity, and pH, while CO_2 is used to reduce and control the final pH, independently of mineral addition. A schematic of the lime feed system is shown **Figure 4.9**.

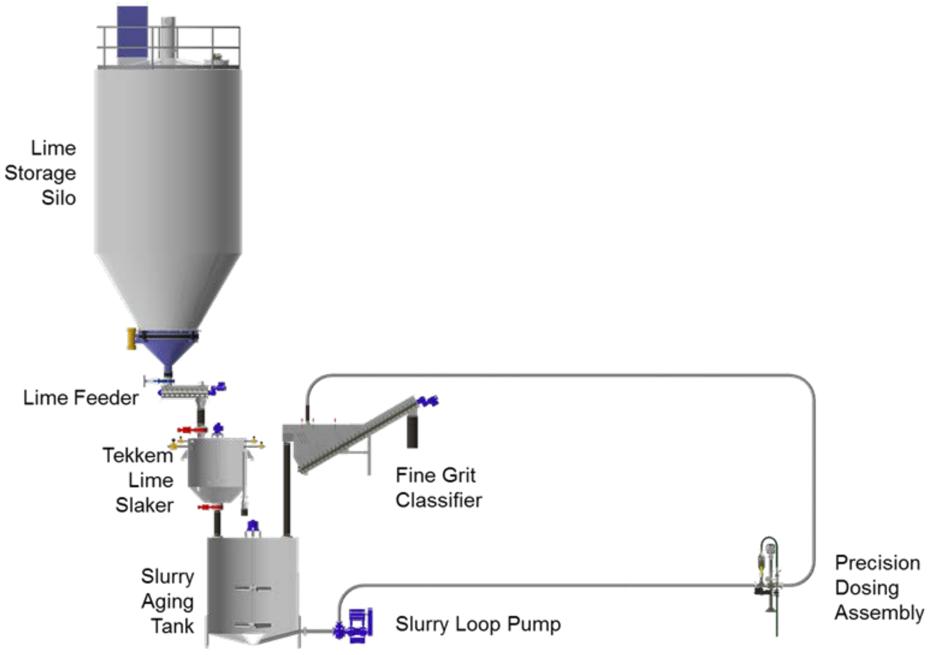

Figure 4.9 – Schematic of the Batch Lime Feeding System (Courtesy of RDP Tekkem)

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5.0 DESCRIPTION OF PROCESS TRAINS

This section describes the various process trains that were developed to meet the nitrogen management goals established for this study. Since UV/AOP and stabilization are common to all trains, the description of trains is limited up to RO process effluent – the last unit process in the trains for achieving nitrogen removal.

5.1 TRAIN 1 – SECONDARY MBR (RETROFIT) + RO

Train 1 involves retrofitting four HPOAS trains (200 MGD) at the JWPCP with secondary MBR. MBR filtrate is treated further using RO to meet the water quality goals. Four variants of Train 1 were evaluated. **Figure 5.1** presents the process schematics of Train 1 variants.

5.1.1 Train 1A – N-only Secondary MBR (Retrofit) + RO

Train 1A utilizes secondary MBR for full nitrification and relies on RO for removal of the majority of nitrate. When retrofitting JWPCP with N-only secondary MBR, the existing reactors at JWPCP would continue to be used as aerobic zones and, the majority of the oxygen demand (~75%) for organics and ammonia removal would be met using the existing cryogenic system. Secondary clarifiers would be repurposed to provide additional aerobic zone volume and to house the membranes.

5.1.2 Train 1B – NdN Secondary MBR (Retrofit) + RO

Train 1B utilizes secondary MBR for full nitrification and partial denitrification (NdN). Based on process modeling, the carbon available in the JWPCP primary effluent is sufficient to achieve an MBR filtrate nitrate concentration of <14 mg/L-N. RO is expected to remove 80% of the remaining nitrate. Without centrate treatment, Train 1B would require derating of JWPCP's secondary process by up to 10%.

With this retrofit, some of the existing reactors would be converted to anoxic zones for denitrification by replacing their surface aerators in the reactors with mixers. Secondary clarifiers would be repurposed to serve as anoxic and aerobic zones and to house the MBR membranes.

5.1.3 Train 1C – Centrate Treatment + N-only Secondary MBR (Retrofit) + RO

Train 1C is identical to Train 1A with centrate treatment upstream of the MBR process to lower the nitrogen loading to the JWPCP mainstream process.

5.1.4 Train 1D – Centrate Treatment + NdN Secondary MBR (Retrofit) + RO

Train 1D is identical to Train 1B with centrate treatment upstream of the MBR process to lower the nitrogen loading to the JWPCP mainstream process. With centrate treatment, derating of JWPCP's secondary process would not be necessary.

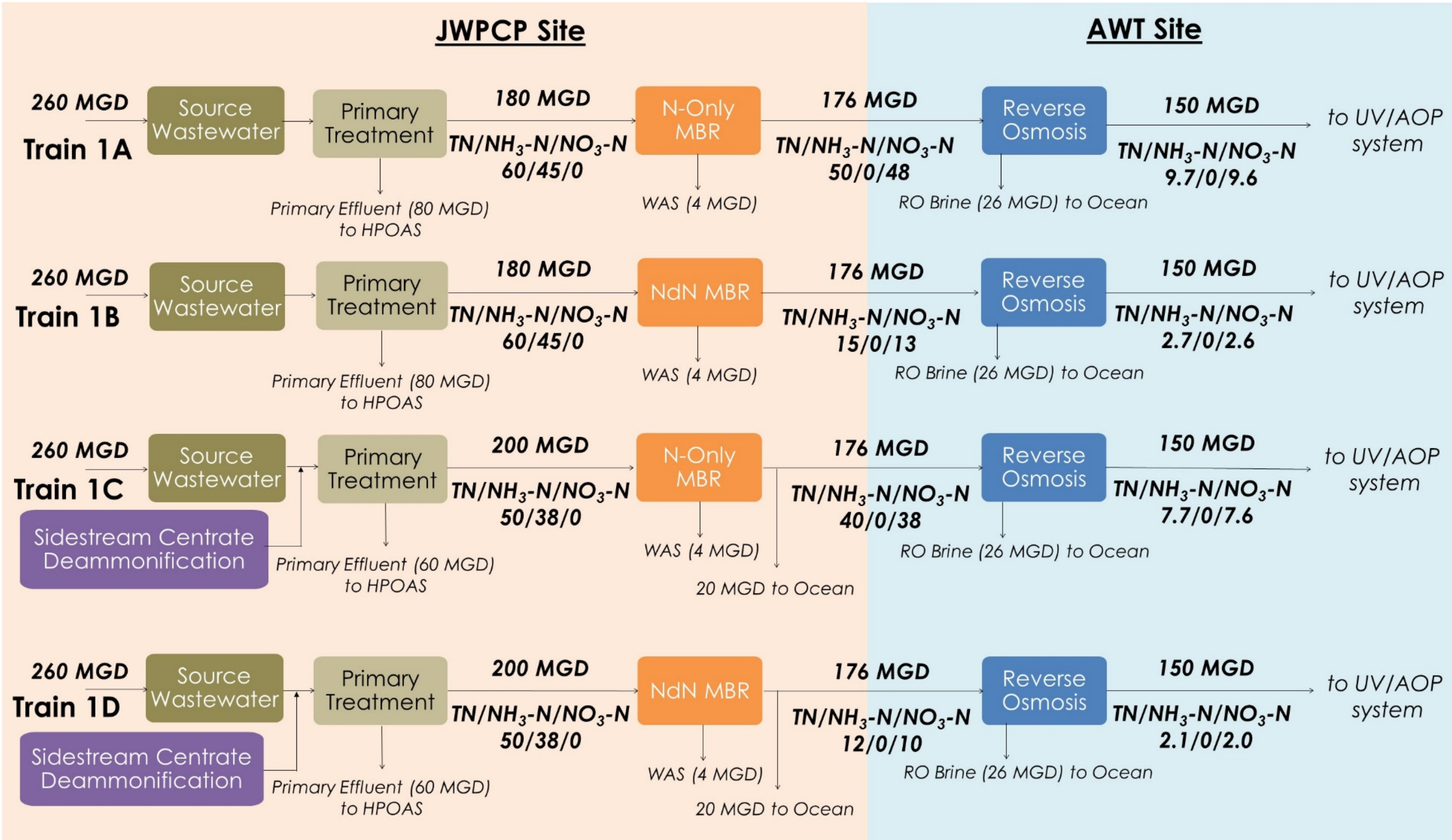

Figure 5.1 – Process Schematics for Train 1 Variants

5.2 TRAIN 2 - TERTIARY MBR + RO

Train 2 involves constructing a new tertiary MBR at the AWT site. MBR filtrate would be treated further with RO to meet water quality goals. Since the tertiary MBR would be a new facility sized based on nitrogen removal requirements, adding centrate treatment would lower the nitrogen loading and subsequently reduce the bioreactor basin volumes, the process aeration and the supplemental carbon addition. Five variants of Train 2 were evaluated. **Figure 5.2** presents the process schematics of Train 2 variants.

5.2.1 Train 2A – N-only Tertiary MBR + RO

Train 2A uses tertiary MBR for full nitrification and relies on RO for removal of the majority of nitrate produced by biological nitrification process. This nitrate would be captured in the RO brine and discharged to the ocean.

5.2.2 Train 2B – NdN Tertiary MBR + RO

Train 2B uses tertiary MBR for full nitrification and partial denitrification. Since JWPCP's secondary effluent contains little biodegradable carbon, supplemental carbon addition will be required for denitrification. Based on process modeling, approximately 32,100 gallons of supplemental carbon would be required daily to achieve sufficient nitrogen removal by MBR such that with additional removal by RO, the final product water TN concentration would be less than 3.5 mg/L.

5.2.3 Train 2C – Centrate Treatment + N-only Tertiary MBR + RO

Train 2C is identical to Train 2A with centrate treatment upstream to lower the nitrogen loading to JWPCP's mainstream process.

5.2.4 Train 2D – Centrate Treatment + NdN Tertiary MBR + RO

Train 2D is identical to Train 2B with centrate treatment upstream to lower the nitrogen loading to JWPCP's mainstream process.

5.2.5 Train 2E – N-only Tertiary MBR + Two Pass RO

Train 2E requires addition of a second pass RO to Train 2A to remove additional nitrogen from the first pass RO permeate. The second pass of the two pass RO would treat a portion (up to approximately 63%) of the permeate from the first pass; this treated water would be blended with the remaining permeate from the first pass to meet the TN goal of < 3.5 mg/L-N.

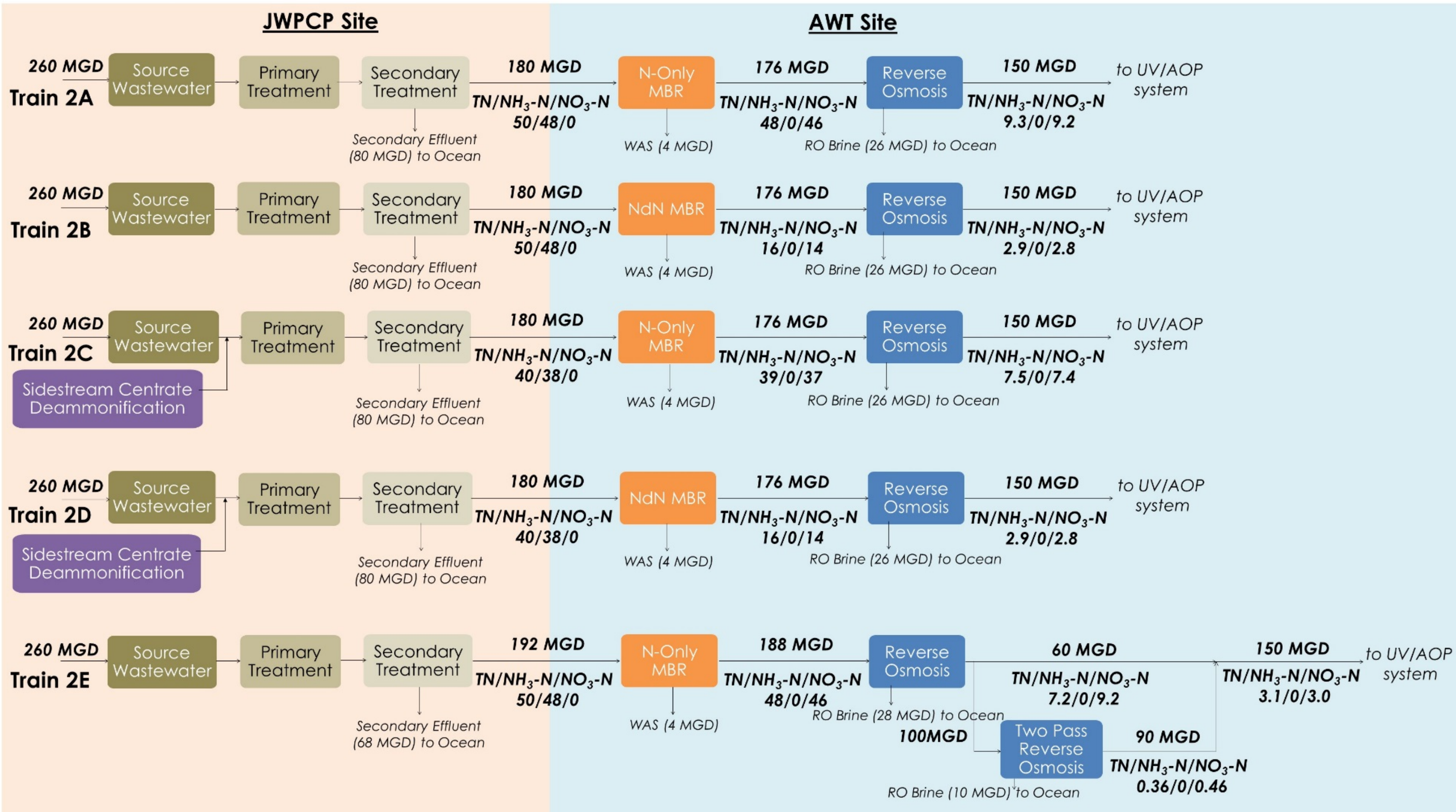

Figure 5.2 – Process Schematics of Train 2 Variants

5.3 TRAIN 3 - TERTIARY BAF + MF + RO

Train 3 involves constructing a new tertiary BAF at the AWT site. BAF filtrate would be treated using MF and RO to meet water quality goals. MF is required to reduce the suspended solids in the BAF effluent to protect the downstream RO process. Similar to Train 2, adding centrate treatment would lower the nitrogen loading and subsequently reduce the requirements of filter beds/cells volumes, process aeration requirements and supplemental carbon addition. Four variants of Train 3 were evaluated and are shown in **Figure 5.3**.

5.3.1 Train 3A – N-only Tertiary BAF + MF + RO

Train 3A utilizes tertiary BAF for full nitrification and relies on RO for removal of the majority of nitrate produced by nitrification is captured in the RO brine and discharged to the ocean.

5.3.2 Train 3B – NdN Tertiary BAF + MF + RO

Train 3B utilizes tertiary BAF for full nitrification and partial denitrification. Since the secondary effluent does not contain a substantial amount of biodegradable carbon, supplemental carbon addition is required for denitrification. Based on process modeling, approximately 33,800 gallons of supplemental carbon would be required daily for denitrification. With additional nitrate removal by RO, the final product water would meet the TN goal of ≤ 3.5 mg/L.

5.3.3 Train 3C – Centrate Treatment + N-only Tertiary BAF + MF + RO

Train 3C is identical to Train 3A with centrate treatment upstream to lower the nitrogen loading to JWPCP's mainstream process.

5.3.4 Train 3D – Centrate Treatment + NdN Tertiary BAF + MF + RO

Train 3D is identical to Train 3B with centrate treatment upstream to lower the nitrogen loading to JWPCP's mainstream process.

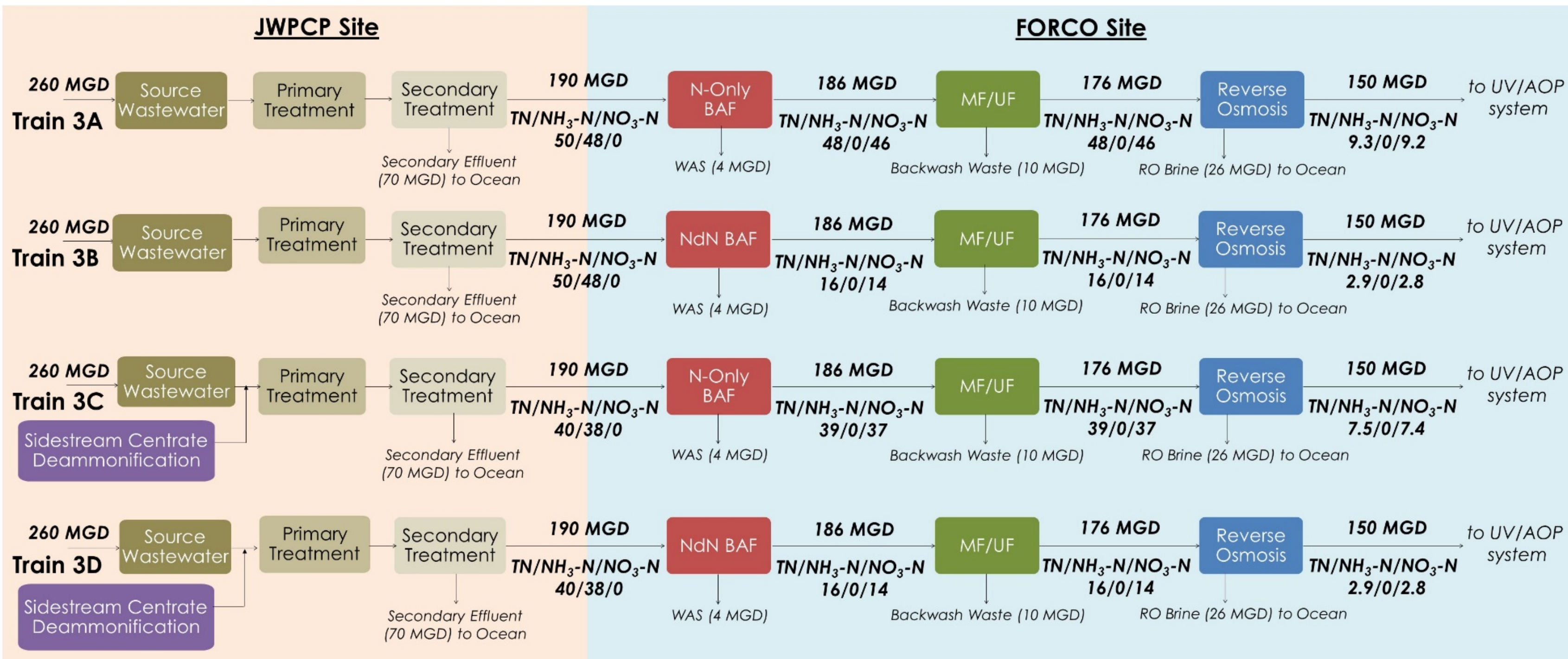

Figure 5.3 – Process Schematics for Train 3 Variants

5.4 TRAIN 4 – MF + RO

MF is included in Train 4 to provide pretreatment for the RO process, while all of the nitrogen removal is achieved using RO. Three different variants of this train were evaluated and are shown in **Figure 5.4**.

5.4.1 Train 4A – MF + RO

RO is relied upon for the removal of all nitrogen species. The majority of nitrogen is captured in the RO brine and discharged to the ocean. This process configuration has been approved by DDW for indirect potable reuse.

5.4.2 Train 4B – Centrate Treatment + MF + RO

Train 4B is identical to train 4A with centrate treatment upstream to lower the nitrogen loading to JWPCP's mainstream process.

5.4.3 Train 4C – MF + Two Pass RO

Train 4C adds a second pass RO to Train 4A to remove additional ammonia from the first pass RO permeate. A portion of first pass RO permeate (63%) would be retreated with second pass RO; treated water would be blended with the remaining first pass RO permeate to meet the TN goal of less than 3.5 mg/L.

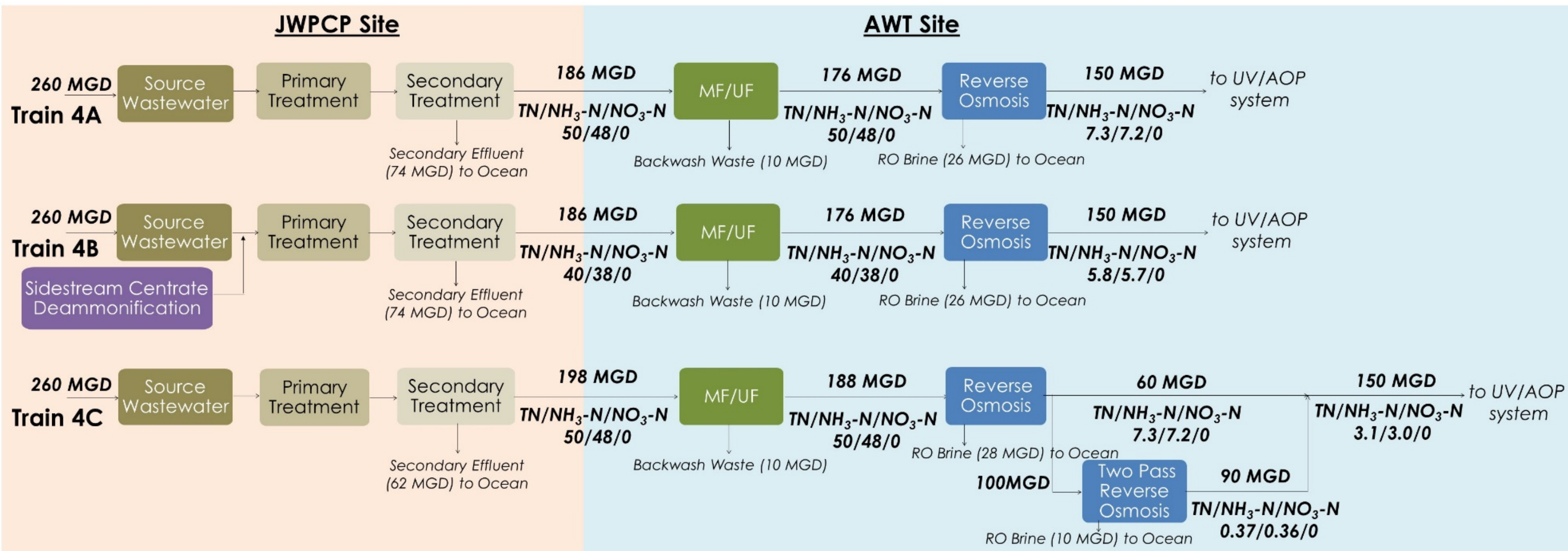

Figure 5.4 – Process Schematics for Train 4 Variants

5.5 TRAIN 5 – SECONDARY MBR + RO

Train 5 involves constructing a new secondary NdN MBR followed by RO treatment at the AWT site (**Figure 5.5**). In this configuration, part of JWPCP's primary effluent would be diverted to the new secondary NdN MBR. JWPCP would continue to treat the remaining flow using the existing HPOAS facility.

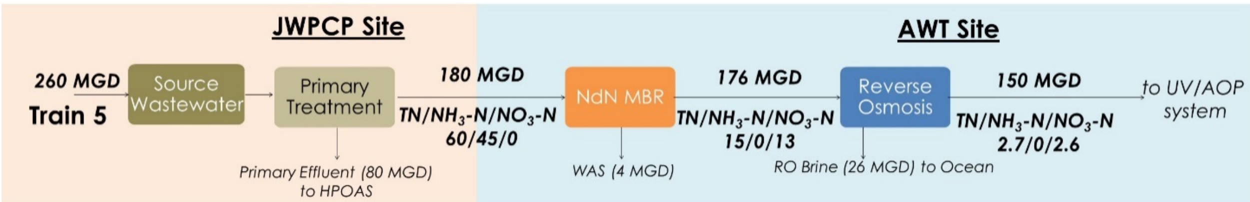

Figure 5.5 – Process Schematic for Train 5

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6.0 PROCESS DESIGN ASSUMPTIONS

Individual unit processes were sized based on the flows and feed water characteristics discussed in this section. The treatment processes at the JWPCP include screening, grit removal, primary clarification, high-purity oxygen activated sludge (HPOAS), and secondary clarification to produce non-nitrified secondary treated wastewater. JWPCP, being a HPOAS plant, is typically operated with a low SRT (<2.5 days). Key design criteria for secondary treatment at JWPCP, as applicable to this study, are provided in **Appendix A-1**.

6.1 DESIGN FLOWS

Recoveries and losses for unit processes are shown in **Table 6.1** and the design flows are shown in **Table 6.2**. Each unit process was sized to achieve a final AWT Facility product flow of 150 MGD. Detailed flow balances for each process train are shown in the process schematics presented in **Section 5.0**.

Reverse Osmosis: The single pass RO process was sized as a 3-stage system with 85% recovery. The second pass of the two pass RO system was sized as a 2-stage system with 90% recovery. Because there is an additional brine loss from the second pass of the two pass RO, it was sized with an influent flow of 188 MGD rather than the 176 MGD used to size the single pass RO. This allowed both RO systems to produce the same final product flow of 150 MGD.

Membrane Filtration: The MF system was sized as a submerged hollow-fiber system with 95% recovery. For the trains that include two pass RO instead of a single pass RO, the MF system was sized for a higher feed flow (198 vs 186 MGD) to account for brine losses from the second pass of the two pass RO.

Secondary Membrane Bioreactor: The secondary MBR trains (either retrofit or new) were sized based on a waste activated sludge (WAS) loss of 2%, corresponding to a design influent flow of 180 MGD. The NdN retrofit option may require derating the four 50-MGD secondary process trains by up to 10%. Secondary MBR (retrofit) trains with centrate treatment would not require derating. In order to maintain consistency in evaluation, all secondary trains without centrate treatment were evaluated for feed flow of 45 MGD per reactor or 180 MGD total.

Tertiary Membrane Bioreactor: The tertiary MBR trains were sized based on a WAS loss of 2%, corresponding to a design flow of 180 MGD. The benefit of centrate treatment, which results in lower secondary effluent nitrogen concentration for tertiary MBR trains, was realized by reducing the size of the bioreactor basins, process equipment and carbon addition, when applicable. For the tertiary N-only MBR train with two pass RO, the design flow was increased to 192 MGD to account for additional brine loss from the second pass of the two pass RO.

Tertiary Biologically Activated Filter: The tertiary BAF trains were sized based on a waste sludge loss of 2%, corresponding to a design flow of 180 MGD. The benefit of centrate treatment (lower secondary effluent nitrogen concentration) for tertiary BAF trains was realized by reducing the size for the filter beds/cells, process equipment and carbon addition.

Centrate Treatment: Centrate flow at JWPCP was assumed to be 6.1 MGD (before thickening). It was assumed that the entire centrate flow would be treated at JWPCP using sidestream deammonification based on Kruger's ANITA™ Mox process.

Table 6.1 – Recoveries/Losses for Unit Processes

Unit Processes	Recoveries/Losses
RO Recovery	85%
Recovery for the Second Pass of the Two Pass RO	90%
MF Recovery	95%
Secondary / Tertiary MBR WAS Losses	2%
Tertiary BAF Backwash Waste Losses	2%

Table 6.2 – Design Flows for Unit Processes

Unit Processes	Design Flows	
	Influent (MGD)	Effluent (MGD)
UV/AOP	150	150
Second Pass of the Two Pass RO		
MF + Two Pass RO Train	100	90
N-only Tertiary MBR + Two Pass RO Train	133	120
RO		
MBR + RO, MF + RO Trains	176	150
MF + Two Pass RO Train	188	160
N-only Tertiary MBR + Two Pass RO Train	192	163
MF		
FAT, FAT + Centrate, BAF + MF Trains	186	176
Two Pass RO Train	198	188
Secondary MBR		
N-only, NdN Trains	180	176
N-only + Centrate, NdN + Centrate Trains	200	196
Tertiary MBR		
N-only, NdN, N-only + Centrate, NdN + Centrate Trains	180	176
N-only Tertiary MBR + Two Pass RO Train	196	192
Tertiary BAF		
N-only, NdN, N-only + Centrate, NdN + Centrate Trains	190	186
Centrate Treatment	6.1	6.1

6.2 WASTEWATER CHARACTERISTICS

Table 6.3 and **Table 6.4** summarize the JWPCP primary and secondary effluent characteristics for the period of 2016-2017. The 90th percentile TN concentrations in the primary and chlorinated secondary effluent were 63 and 48.8 mg/L, respectively. The data presented in **Table 6.3** is based on a small dataset and the TN concentrations are thought to be overly conservative. Therefore, an alternative approach was employed to estimate the primary effluent TN concentration – by adding the expected TN removal via the HPOAS process (~ 10 mg/L) to the 90th percentile TN concentration of the chlorinated secondary effluent for which larger dataset was available. As a result, the TN concentrations for the primary and secondary effluent were assumed to be 60 and 50 mg/L, respectively. **Figure 6.1** shows the process schematic of JWPCP. The design criteria for secondary treatment at JWPCP are provided in **Appendix A.1**.

Table 6.3 – JWPCP Primary Effluent Characteristics (Jan 2016 – June 2017)

Parameter	COD	BOD	TKN[1]	NH_4[1]	TN[1]	TSS	Alkalinity[1]	pH
	mg/L	mg/L	mg/L-N	mg/L-N	mg/L	mg/L	mg/L as $CaCO_3$	
Median	385	234	56.0	46.2	58.4	150	383	6.9
Average	389	233	56.9	46.1	58.7	158	382	6.8
Min	217	79	52.8	42.5	54.2	42	365	4.2
Max	1,067	424	63.8	49.8	65.9	1,120	395	9.9
90%-tile	435	273	60.8	48.6	63.0	195	394	7.1

[1]Non-routine; reflects data from research projects/special sampling.

Table 6.4 – JWPCP Chlorinated Secondary Effluent Characteristics (Jan 2016- June 2017)

Parameter	COD	BOD	TKN[1]	NH_4[1]	NO_X[1]	TN[1]	TSS	Alkalinity[1]	TP
	mg/L	mg/L	mg/L-N	mg/L-N	mg/L-N	mg/L-N	mg/L	mg/L as CaCO3	mg/L
Median	54	2.6	47.3	45.1	0.13	47.4	9.5	393	0.6
Average	55	2.7	46.7	44.9	0.13	46.8	10.5	389	0.7
Min	36	1.8	43.3	37.8	<0.1	43.4	5.4	360	0.5
Max	170	5.5	48.8	58.5	0.18	49.0	130	405	0.9
90%-tile	62	3.1	48.7	48.3	0.16	48.8	13.0	401	0.9

[1]Non-routine; reflects data from research projects/special sampling.

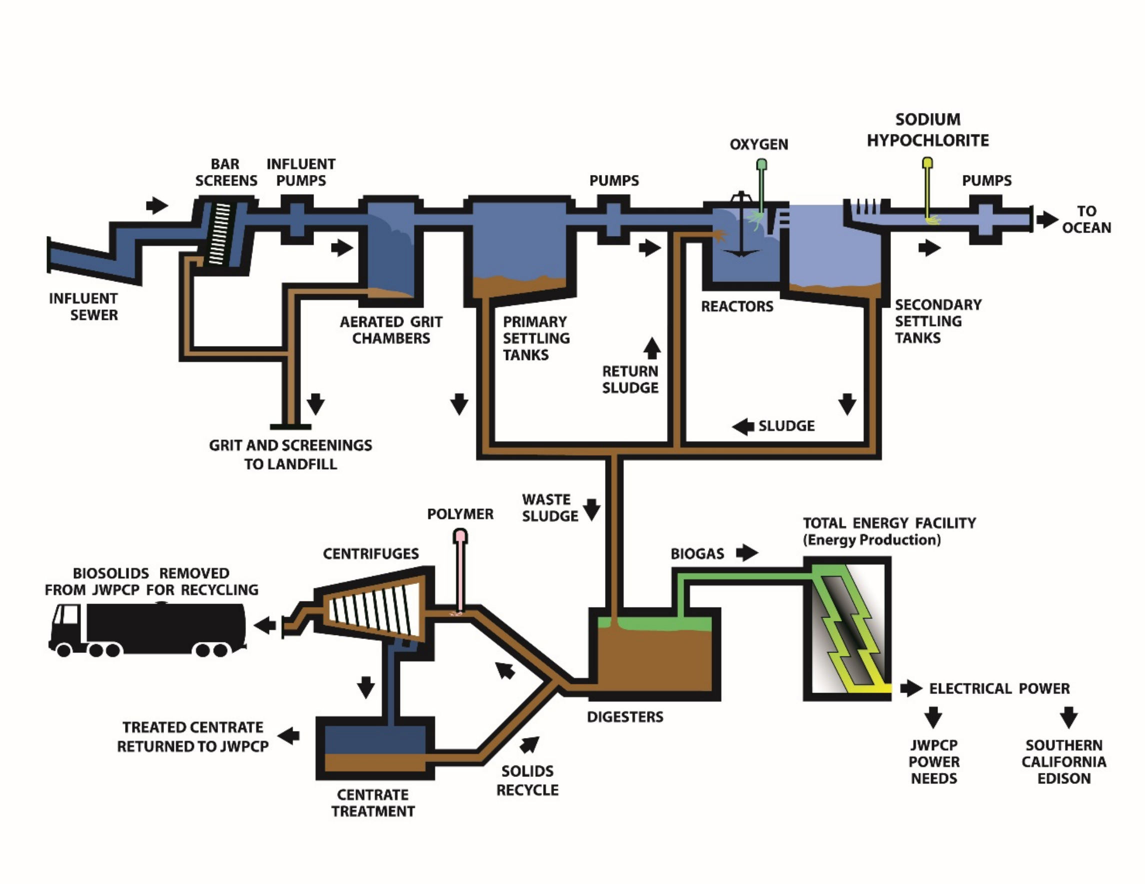


Figure 6.1 – Process Schematic of JWPCP

6.3 CENTRATE CHARACTERISTICS

Table 6.5 shows the characteristics of JWPCP's pre-DAF centrate based on the sampling conducted from July 17th to 27th, 2016. The pre-DAF centrate flow is approximately 6.1 MGD with an average TKN concentration of 602 mg/L.

Table 6.5 – Pre-DAF Centrate Characteristics at JWPCP

Parameter	Unit	Concentration (Average ± Standard Deviation)
TKN	mg/L-N	602 ± 45
NH_4	mg/L-N	592 ± 44
$NO_2 + NO_3$	mg/L-N	<0.2 ± 0.01
COD	mg/L	349 ± 52
cBOD	mg/L	45 ± 11
TSS	mg/L	269 ± 57
Alkalinity	mg/L as $CaCO_3$	2,044 ± 155

With a primary effluent total inorganic nitrogen (TIN) concentration of 60 mg/L and flow of 260 MGD, the TIN loading to the JWPCP is approximately 125,770 lb/d (**Table 6.6**). Based on a 2013/2014 Sanitation Districts pilot study using an ANITA™ Mox system (Liu et al., 2015) centrate treatment was estimated to remove 68% of its TIN loading. Since untreated centrate contributes approximately 25% of the JWPCP influent TIN loading to JWPCP, centrate treatment would reduce the TIN loading to the JWPCP by 17%. The primary effluent TN concentration would be decreased from 60 to 50 mg/L-N with this reduction in TIN loading. The TN uptake during the secondary biological process was assumed to be 10 mg/L-N so that with centrate treatment, the secondary effluent TN concentration would be 40 mg/L-N. Even though the centrate treatment lowers the primary and secondary effluent TN concentration of the entire 260 MGD of JWPCP flow, the benefit is only partially realized as only a portion of this flow (<190 MGD) will be used for the AWT Facility.

During the Sanitation Districts' pilot study on centrate treatment, the observed ammonia removal efficiency was 78%. The residual nitrate in the treated centrate stream (based on the difference between the TIN and ammonia removal efficiency) is expected to be removed at the JWPCP in the anoxic/anaerobic selector. However, such removal was ignored for the purpose of this study.

Table 6.6 – Impact of Centrate Treatment on Nitrogen Concentration at JWPCP

JWPCP	**Units**	**Value**
Flow-rate	MGD	260
Primary Effluent TIN, Concentration	mg/L	58
Primary Effluent TIN, Loading	lb/d	125,767
Primary Effluent, Recalcitrant Organic Nitrogen	mg/L	2
Primary Effluent TN, Concentration	mg/L	60
Biomass Uptake of TN in Secondary Treatment at JWPCP	mg/L	10
Secondary Effluent TN	mg/L	50
Centrate	**Units**	**Value**
Flow-rate	MGD	6.1
TIN Concentration	mg/L	620
TIN Loading	lb/d	31,542
% of JWPCP TIN Loading	%	25%
Impact of Centrate Treatment	**Units**	**Value**
TIN Removal Efficiency	%	68%
TIN Removed	lb/d	21,448
% of JWPCP TIN Loading Reduced	%	17%
Primary Effluent TIN after Centrate Treatment	lb/d	104,319
Primary Effluent TIN after Centrate Treatment	mg/L	48
Primary Effluent TN after Centrate Treatment	mg/L	50
Secondary Effluent TN after Centrate Treatment	mg/L	40

6.4 RO PRODUCT WATER QUALITY GOALS

RO is the final process in the process trains that achieves removal of nitrogen species. Therefore, RO permeate would have to meet the required nitrogen goals. For the purpose of this evaluation, regulatory compliance was based on the product water quality leaving the AWT Facility rather than at the groundwater basins.

Regulatory oversight of recycled water projects is carried out by the SWRCB through DDW and by the individual RWQCBs. The RWQCBs have the exclusive authority to enforce water reclamation requirements through permit enforcement. The RWQCBs rely on DDW's expertise to establish the permit conditions for protecting public health. DDW and the RWQCBs regulate groundwater recharge projects under 22 CCR Division 4, Chapter 3. Final regulations for groundwater replenishment reuse projects using surface application (i.e. spreading) and subsurface application (i.e. injection) went into effect in June 2014. These Groundwater Replenishment Regulations address the protection of public health with respect to chemicals, microorganisms, and constituents of emerging concern.

One of the key requirements of the Groundwater Replenishment Regulations is that the concentration of total nitrogen in recycled or recharge water must not exceed 10 mg/L. Compliance with the TN requirement is defined in the permits for the various Project Sponsors involved in a recycled water project; some require minimum weekly or twice weekly 24-hr composite or grab samples of final advanced treated water and establish compliance based on 4- or 20-week averages.

In addition to Title 22 criteria, recycled water must also comply with water quality standards and objectives in applicable Basin Plans, Salt and Nutrient Management Plans (SNMPs), and other applicable regulations and policies to protect water quality and the beneficial uses of surface water and groundwater.

Basin Plans for Main San Gabriel, West Coast, and Central Basins have either nitrate or nitrate + nitrite limits of 10 mg/L-N, and as such, one water quality goal for the AWT Facility effluent was defined as TN ≤ 10 mg/L.

A lower nitrate limit has been applied by the Santa Ana RWQCB in the Orange County Basin due to basin-specific nitrate issues. The Orange County Basin Plan limit for nitrate is 3.4 mg/L-N based on assimilative capacity findings, and OCWD's permit (Order No. R8-2016-0051) for GWRS requires meeting an even lower nitrate level of 3 mg/L-N. Compliance in OCWD's permit for the nitrate limit is based on a 12-month running average, with minimum monthly sampling. For the purpose of this evaluation, a nitrate goal corresponding to the Basin Plan objective of 3.4 mg/L-N was defined. Practically speaking, since any ammonia remaining in treated water would still have the potential to nitrify after leaving the AWT Facility, a nitrate limit would be adhered to by ensuring an equivalent total nitrogen limit at the AWT Facility effluent. Also, since some residual organic nitrogen will be present after RO (< 0.1 mg/L-N), a TN of ≤ 3.5 mg/L was selected as the water quality goal for AWT Facility effluent if used for recharge in the Orange County Basin. It should be noted that the operations of the unit processes in the process trains can be optimized to achieve lower effluent TN concentration (< 3 mg/L), if required in future. For example, carbon dose for

NdN tertiary MBR can be increased to achieve higher nitrate removal and subsequently lower effluent TN.

In summary, two levels of nitrogen removal goals for the RO product water were established for the evaluation of alternative process trains:

- TN ≤ 10 mg/L, for Main San Gabriel, West Coast, and Central Basins
- TN ≤ 3.5 mg/L (i.e. NO_3 < 3.4 mg/L-N), for Orange County Basin

6.5 WATER QUALITY PROJECTIONS FOR PROCESS TRAINS

Water quality projections for each train, summarized in **Table 6.7**, were developed to identify the trains that would meet the nitrogen goals. The assumptions used to determine the water quality for individual trains were as follows:

1) The TN values for primary and secondary effluent (with and without centrate treatment) were based on 90^{th} percentile water quality data obtained from the Sanitation Districts.
2) Centrate treatment was assumed to reduce the TIN loading to the JWPCP by 17%.
3) BioWin process modeling was used to predict the concentrations of nitrogen species for secondary and tertiary MBR effluents. The model predicted complete removal of nitrite during nitrification for all MBR configurations.
4) Effluent nitrogen species concentrations for the tertiary BAF were assumed to be the same as those for the tertiary MBR.
5) RO removes 80% of nitrate, 85% of ammonia and 95% of organic nitrogen.
6) Recalcitrant organic nitrogen concentration in secondary effluent is 2 mg/L.
7) A consumption of 10 mg/L of nitrogen biomass uptake occurs in JWPCP’s secondary process.

Table 6.7 – Water Quality Projections for Process Trains (TN/NH_3-N/NO_3-N)

	Process Train	Primary Effluent (mg/L)	Secondary Effluent (mg/L)	Tertiary MBR/BAF/MF Effluent (mg/L)	RO Permeate (mg/L)
Train 1A	N-only Secondary MBR (Retrofit) + RO	**60/45/0**	50/0/48	N/A	9.7/0/9.6
Train 2A	N-only Tertiary MBR + RO	60/45/0	**50/48/0**	48/0/46	9.3/0/9.2
Train 3A	N-only Tertiary BAF + MF + RO	60/45/0	**50/48/0**	48/0/46	9.3/0/9.2
Train 1C	Centrate Treatment + N-only Secondary MBR (Retrofit) + RO	**50/38/0**	40/0/38	N/A	7.7/0/7.6
Train 2C	Centrate Treatment + N-only Tertiary MBR + RO	50/38/0	**40/38/0**	39/0/37	7.5/0/7.4
Train 3C	Centrate Treatment + N-only Tertiary BAF + MF + RO	50/38/0	**40/38/0**	39/0/37	7.5/0/7.4
Train 1B	NdN Secondary MBR (Retrofit) + RO	**60/45/0**	16/0/14	N/A	2.9/0/2.8
Train 2B	NdN Tertiary MBR + RO	60/45/0	**50/48/0**	16/0/14	2.9/0/2.8
Train 3B	NdN Tertiary BAF + MF + RO	60/45/0	**50/48/0**	16/0/14	2.9/0/2.8
Train 1D	Centrate Treatment + NdN Secondary MBR (Retrofit) + RO	**50/38/0**	12/0/10	N/A	2.1/0/2.0
Train 2D	Centrate Treatment + NdN Tertiary MBR + RO	50/38/0	**40/38/0**	16/0/14	2.9/0/2.8
Train 3D	Centrate Treatment + NdN Tertiary BAF + MF + RO	50/38/0	**40/38/0**	16/0/14	2.9/0/2.8
Train 4A	MF + RO	60/45/0	**50/48/0**	50/48/0	7.3/7.2/0
Train 4B	Centrate Treatment + MF + RO	50/38/0	**40/38/0**	40/38/0	5.8/5.7/0
Train 4C	MF + Two Pass RO	60/45/0	**50/48/0**	50/48/0	3.1/3.0/0
Train 2E	N-only Tertiary MBR + Two Pass RO	60/45/0	**50/48/0**	48/0/46	3.3/0/3.2
Train 5	NdN Secondary MBR + RO	**60/45/0**	16/0/14	N/A	2.9/0/2.8

7.0 COST ESTIMATES

7.1 METHODOLOGY FOR COST ESTIMATE

The initial step for determining the cost estimates for the various treatment options was the compilation of cost information for each unit process. All costs included in this compilation are in 2017 dollars. The two principal cost components are capital and operations and maintenance (O&M) costs. The methodology for cost development and net present value (NPV) calculations are described in this section.

7.1.1 Capital Costs

Capital costs were calculated for each unit process based on major equipment costs, installation, civil work, and specialized work including electrical and instrumentation. Assumptions for these costs are further discussed below.

Equipment

Process equipment costs were based on vendor proposals and previous estimates developed for the Feasibility Study (Metropolitan Water District of Southern California, 2016). A full list of equipment and associated costs analyzed for each unit process are included in **Appendix C.1**.

Installation

Installation cost was assumed at 40% of the equipment cost.

Civil

Civil related costs were calculated based on Opinion of Probable Construction Cost (OPCC) estimates and were divided into the following four main categories:

- General Civil Costs - includes structure excavation, grade/compact foundation, aggregate base, concrete, reinforcing steel, epoxy coating, and backfill;
- Process Piping - includes piping and valves for process equipment connections;
- Yard Piping - includes any piping between processes;
- General Site Development - includes general demolition and earthworks costs.

The breakdown of civil costs for unit processes is provided in **Appendix C.2**.

Electrical and Instrumentation

The allocation for Electrical and Instrumentation was assumed at 45% of the equipment cost.

Contingencies and Fees

A contingency of 30% was applied to the construction cost. An additional 35% mark-up was applied to the construction costs plus contingency to account for engineering, legal and administrative fees.

Land and Remediation Costs

New processes constructed at the JWPCP site would be located east of the existing secondary clarifiers at the FORCO site. The total footprint was estimated for each process. A land cost of $2.5M/acre was applied based on prevailing real estate prices. The site is currently under remediation to address soil contamination associated with its previous refinery operation. The existing gas and oil pipes also need to be removed or abandoned in place. Remediation is required before new construction can begin.

A total remediation cost of $20M for the part of the site to be used for the 150-MGD AWT Facility was estimated by the Sanitation Districts and was divided among the unit processes based on land requirement. Since the centrate treatment facilities would be located near the centrifuges, no land or remediation costs were assigned for centrate treatment. The breakdown of land and remediation costs for unit processes are provided in **Appendix C.3**.

7.1.2 Operation and Maintenance Costs

The principal components for the operations and maintenance (O&M) costs included power for process equipment, chemicals associated with process operations (membrane cleaning and pre-treatment chemicals), labor to operate the facilities, and maintenance and replacement parts for process equipment. Additionally, disposal costs were calculated for sludge generated from the biological processes. Assumptions for each O&M component are described below.

Power

The estimated power costs account for the electricity consumption of major process equipment under average annual operating conditions. The cost of electricity was assumed at $0.15/kWh. The breakdown of equipment power consumption for unit processes is provided in **Appendix C.4**.

Chemicals

Chemical costs were calculated using the average doses for chemical feed under normal operating conditions over one year. A full list of chemicals and a breakdown of associated costs can be found in **Appendix C.5**.

Labor

Additional staff would be required to operate and maintain the unit processes at the new AWT Facility. Additions to existing JWPCP staff would also be needed to operate the secondary MBR (JWPCP retrofit) to account for membrane maintenance needs. Annual labor costs are based on the estimated number of full-time employees required to operate the facilities, their average hourly rate of $150/hr, and 2,080 work-hours per employee per year. The breakdown of labor costs for unit processes is provided in **Appendix C.6**.

Maintenance

Maintenance costs include supplies for the routine maintenance of process equipment such as pumps, valves and instrumentation. These costs were estimated to be 2% of the equipment cost estimate for each unit process, rounding to the nearest $1,000.

Replacements Parts

The following components of the unit processes have a well-defined useful life and require routine replacement:

- MBR membrane modules
- MF membrane modules
- RO cartridge filters
- RO membrane elements

Replacement intervals for these items were developed using a combination of project experience and vendor input. Replacement costs were calculated by prorating the amount of equipment that must be replaced in one year, and adding a 9% sales tax. Details on replacement parts for unit processes are provided in **Appendix C.7**.

Solids Disposal

The biological processes (MBR and BAF) require sludge disposal (WAS for MBR and backwash waste sludge for BAF) that would need to be treated at the JWPCP solids processing facilities. Disposal costs for these solids were calculated using the Sanitation Districts' industrial wastewater surcharge formula and 2017 rates: $863/MG + $152.50/1000-lb-COD + $431.40/1000-lb-TSS. Details on solids disposal cost for unit processes are provided in **Appendix C.8**.

Contingencies

A 15% contingency was applied to all O&M costs.

JWPCP Costs

For the purpose of this analysis, treatment costs include all unit processes from primary effluent onwards to RO, for removal of both organics and nitrogen. All secondary biological treatment trains would achieve both organics and nitrogen removal in one process, either at the JWPCP (secondary MBR retrofit) or at the new AWT Facility (secondary MBR). For the tertiary trains, organics removal is achieved at the JWPCP and nitrogen removal is achieved at the AWT Facility (either using tertiary MBR or BAF). Therefore, the costs to operate JWPCP's secondary treatment process were included when calculating the overall treatment costs for the tertiary processes. With this approach, all treatment train costs account for associated expenses from primary effluent through RO permeate.

The current O&M cost for the entirety of the JWPCP facility is approximately $1,040/MGD. Based on Sanitation Districts' staff input, it was assumed that 40% of this cost is for secondary treatment.

A portion of this cost was then used to account for the secondary effluent flow required for the tertiary unit processes because only 180 MGD out of an average 260-MGD secondary effluent produced from JWPCP will be utilized for AWT. An estimated breakdown of JWPCP's O&M costs is provided in **Appendix B.1**.

7.1.3 Net Present Value

A present worth analysis was conducted for each unit process. The net present value (NPV) is based on a 20-year analysis period and a 4% interest rate, as follows:

$$NPV = Capital\ Cost + \left(O\&M\ Cost \times \frac{(1+i)^n - 1}{i \times (1+i)^n}\right)$$

where,

n = number of years,

i = interest rate

7.2 COST ESTIMATES FOR PROCESS TRAINS

Conceptual designs including a 3D BIM for tertiary MBR, RO, UV/AOP and stabilization processes were developed as part of the supporting work for the Feasibility Study (Metropolitan Water District of Southern California, 2016). Quantity take-offs (QTOs) from the BIM model were used to develop the cost estimates for these processes and therefore, those estimates are considered to be at Class 4 level (-15 to -30% on the low end and +20 to +50% on the high end). BIM models were not developed for the secondary MBR (retrofit and new), submerged MF and second pass of the two pass RO and therefore cost estimates for those processes are considered to be at Class 5 level (-20 to -50% on the low end and +30 to +100% on the high end).

Based on the water quality projections shown in **Table 6.7**, the process trains were divided into two categories based on the water quality goals for TN. **Table 7.1** and **Table 7.2** present the preliminary cost estimates for the process trains that meet the total nitrogen goals of ≤ 10 mg/L and ≤ 3.5 mg/L, respectively. These costs are also presented in **Figure 7.1** through **Figure 7.7**. A detailed breakdown of these cost estimates are found in **Appendix B** and **Appendix C**.

Cost estimates were also developed for Trains 2B, 3B, 2D, 3D, 4C and 2E for the operating scenario where they would be operated to achieve TN ≤ 10 mg/L; these costs are also shown in **Table 7.1** and **Table 7.2**. For such scenario, the capital costs for these trains were left unchanged but O&M costs were adopted using following assumptions:

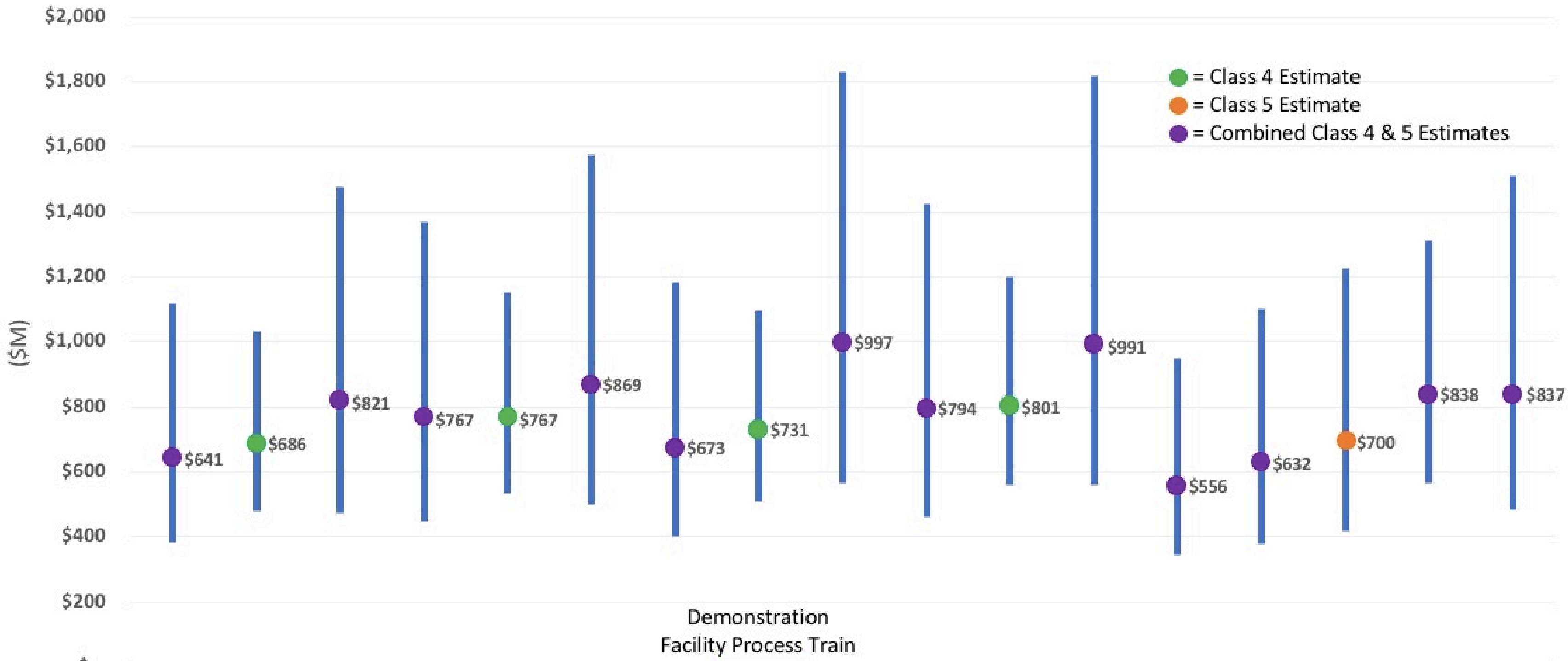
- No carbon would be added to tertiary MBR and BAF processes for Trains 2B, 3B, 2D and 3D.
- The second pass of the two pass RO would not be operated for Trains 4C and 2E.

Table 7.1 – Cost Estimates for 150-MGD Trains that Meet TN ≤ 10 mg/L

	Process Train	RO Product Water TN Goal (mg/L)	Capital Cost ($M)	Capital Cost Range ($M)	O&M Cost ($M)	RO Product Water NPV - Total Cost ($M)	RO Product Water NPV - Total Cost Range ($M)	RO Product Water NPV - Unit Cost ($/ac-ft)	RO Product Water NPV - Unit Cost Range ($/ac-ft)
Train 1A	N-only Secondary MBR (Retrofit) + RO	10	$641	$386 - $1,119	$88	$1,837	$1,582 - $2,315	$547	$471 - $689
Train 2A	N-only Tertiary MBR + RO	10	$686	$480 - $1,030	$104	$2,099	$1,893 - $2,442	$625	$563 - $727
Train 3A	N-only Tertiary BAF + MF + RO	10	$821	$476 - $1,478	$110	$2,314	$1,969 - $2,972	$689	$586 - $884
Train 1C	Centrate Treatment + N-only Secondary MBR (Retrofit) + RO	10	$767	$449 - $1,369	$91	$2,008	$1,690 - $2,611	$598	$503 - $777
Train 2C	Centrate Treatment + N-only Tertiary MBR + RO	10	$767	$537 - $1,151	$107	$2,219	$1,989 - $2,602	$660	$592 - $774
Train 3C	Centrate Treatment + N-only Tertiary BAF + MF + RO	10	$869	$500 - $1,574	$111	$2,379	$2,010 - $3,084	$708	$598 - $918
Train 1B	NdN Secondary MBR (Retrofit) + RO	3.5	$673	$402 - $1,182	$86	$1,848	$1,577 - $2,357	$550	$469 - $701
Train 2B	NdN Tertiary MBR + RO	3.5	$731	$511 - $1,096	$125	$2,428	$2,209 - $2,793	$723	$657 - $831
Train 2B	NdN Tertiary MBR + RO	10	$731	$511 - $1,096	$104	$2,143	$1,924 - $2,509	$638	$573 - $747
Train 3B	NdN Tertiary BAF + MF + RO	3.5	$997	$564 - $1,830	$133	$2,809	$2,376 - $3,642	$836	$707 - $1084
Train 3B	NdN Tertiary BAF + MF + RO	10	$997	$564 - $1,830	$110	$2,490	$2,057 - $3,323	$741	$612 - $989
Train 1D	Centrate Treatment + NdN Secondary MBR (Retrofit) + RO	3.5	$794	$463 - $1,425	$90	$2,021	$1,689 - $2,651	$601	$503 - $789
Train 2D	Centrate Treatment + NdN Tertiary MBR + RO	3.5	$801	$560 - $1,201	$122	$2,459	$2,219 - $2,859	$732	$660 - $851
Train 2D	Centrate Treatment + NdN Tertiary MBR + RO	10	$801	$560 - $1,201	$107	$2,252	$2,012 - $2,652	$670	$599 - $789
Train 3D	Centrate Treatment + NdN Tertiary BAF + MF + RO	3.5	$991	$561 - $1,817	$128	$2,727	$2,298 - $3,554	$812	$684 - $1058
Train 3D	Centrate Treatment + NdN Tertiary BAF + MF + RO	10	$991	$561 - $1,817	$111	$2,501	$2,071 - $3,327	$744	$616 - $990
Train 4A	MF + RO	10	$556	$343 - $948	$95	$1,844	$1,632 - $2,236	$549	$486 - $665
Train 4B	Centrate Treatment + MF + RO	10	$632	$381 - $1,099	$97	$1,952	$1,702 - $2,420	$581	$506 - $720
Train 4C	MF + Two Pass RO	3.5	$700	$420 - $1,224	$115	$2,264	$1,985 - $2,789	$674	$591 - $830
Train 4C	MF + Two Pass RO	10	$700	$420 - $1,224	$95	$1,988	$1,708 - $2,513	$592	$508 - $748
Train 2E	N-only Tertiary MBR + Two Pass RO	3.5	$838	$565 - $1,311	$124	$2,519	$2,246 - $2,992	$750	$668 - $890
Train 2E	N-only Tertiary MBR + Two Pass RO	10	$838	$565 - $1,311	$104	$2,251	$1,978 - $2,723	$670	$589 - $810
Train 5	NdN Secondary MBR + RO	3.5	$837	$484 - $1,510	$84	$1,982	$1,629 - $2,655	$590	$485 - $790

Table 7.2 – Cost Estimates for 150-MGD Trains that Meet TN ≤ 3.5 mg/L

	Process Train	Capital Cost ($M)	Capital Cost Range ($M)	O&M Cost ($M)	RO Product Water NPV - Total Cost ($M)	RO Product Water NPV - Total Cost Range ($M)	RO Product Water NPV - Unit Cost ($/ac-ft)	RO Product Water NPV - Unit Cost Range ($/ac-ft)
Train 1B	NdN Secondary MBR (Retrofit) + RO	$673	$402 - $1,182	$86	$1,848	$1,577 - $2,357	$550	$469 - $701
Train 2B	NdN Tertiary MBR + RO	$731	$511 - $1,096	$125	$2,428	$2,209 - $2,793	$723	$657 - $831
Train 3B	NdN Tertiary BAF + MF + RO	$997	$564 - $1,830	$133	$2,809	$2,376 - $3,642	$836	$707 - $1084
Train 1D	Centrate Treatment + NdN Secondary MBR (Retrofit) + RO	$794	$463 - $1,425	$90	$2,021	$1,689 - $2,651	$601	$503 - $789
Train 2D	Centrate Treatment + NdN Tertiary MBR + RO	$801	$560 - $1,201	$122	$2,459	$2,219 - $2,859	$732	$660 - $851
Train 3D	Centrate Treatment + NdN Tertiary BAF + MF + RO	$991	$561 - $1,817	$128	$2,727	$2,298 - $3,554	$812	$684 - $1058
Train 4C	MF + Two Pass RO	$700	$420 - $1,224	$115	$2,264	$1,985 - $2,789	$674	$591 - $830
Train 2E	N-only Tertiary MBR + Two Pass RO	$838	$565 - $1,311	$124	$2,519	$2,246 - $2,992	$750	$668 - $890
Train 5	NdN Secondary MBR + RO	$837	$484 - $1,510	$84	$1,982	$1,629 - $2,655	$590	$485 - $790



	1A	2A	3A	1C	2C	3C	1B*	2B*	3B*	1D*	2D*	3D*	4A	4B	4C*	2E*	5*
High	$1,119	$1,030	$1,478	$1,369	$1,151	$1,574	$1,182	$1,096	$1,830	$1,425	$1,201	$1,817	$948	$1,099	$1,224	$1,311	$1,510
Low	$386	$480	$476	$449	$537	$500	$402	$511	$564	$463	$560	$561	$343	$381	$420	$565	$484
● Estimate	$641	$686	$821	$767	$767	$869	$673	$731	$997	$794	$801	$991	$556	$632	$700	$838	$837

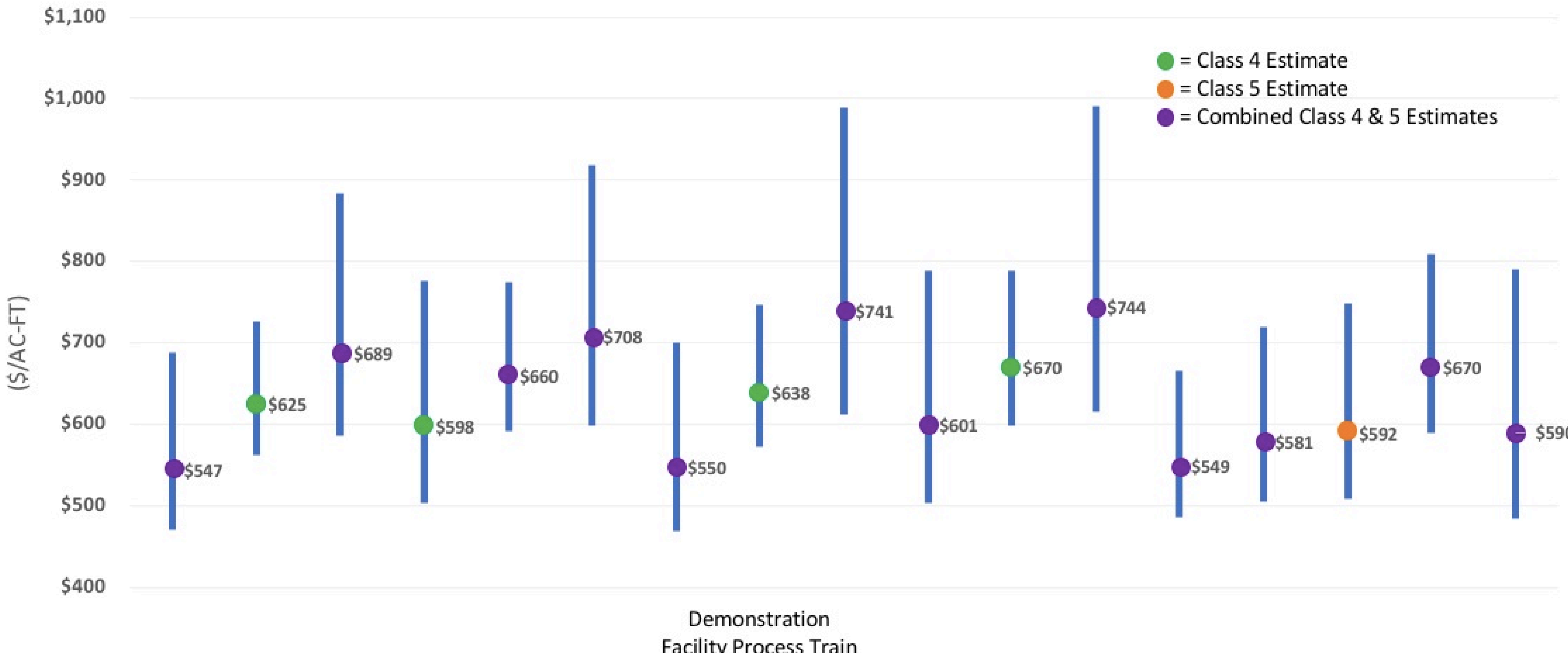
*Process trains that can be operated to achieve TN ≤ 3.5 mg/L

Process Trains

Figure 7.1 – Capital Cost Estimate for 150-MGD Trains that Meet TN ≤ 10 mg/L

	1A	2A	3A	1C	2C	3C	1B	2B	3B	1D	2D	3D	4A	4B	4C	2E	5
High	$2,315	$2,442	$2,972	$2,611	$2,602	$3,084	$2,357	$2,509	$3,323	$2,651	$2,652	$3,327	$2,236	$2,420	$2,513	$2,723	$2,655
Low	$1,582	$1,893	$1,969	$1,690	$1,989	$2,010	$1,577	$1,924	$2,057	$1,689	$2,012	$2,071	$1,632	$1,702	$1,708	$1,978	$1,629
● Estimate	$1,837	$2,099	$2,314	$2,008	$2,219	$2,379	$1,848	$2,143	$2,490	$2,021	$2,252	$2,501	$1,844	$1,952	$1,988	$2,251	$1,982

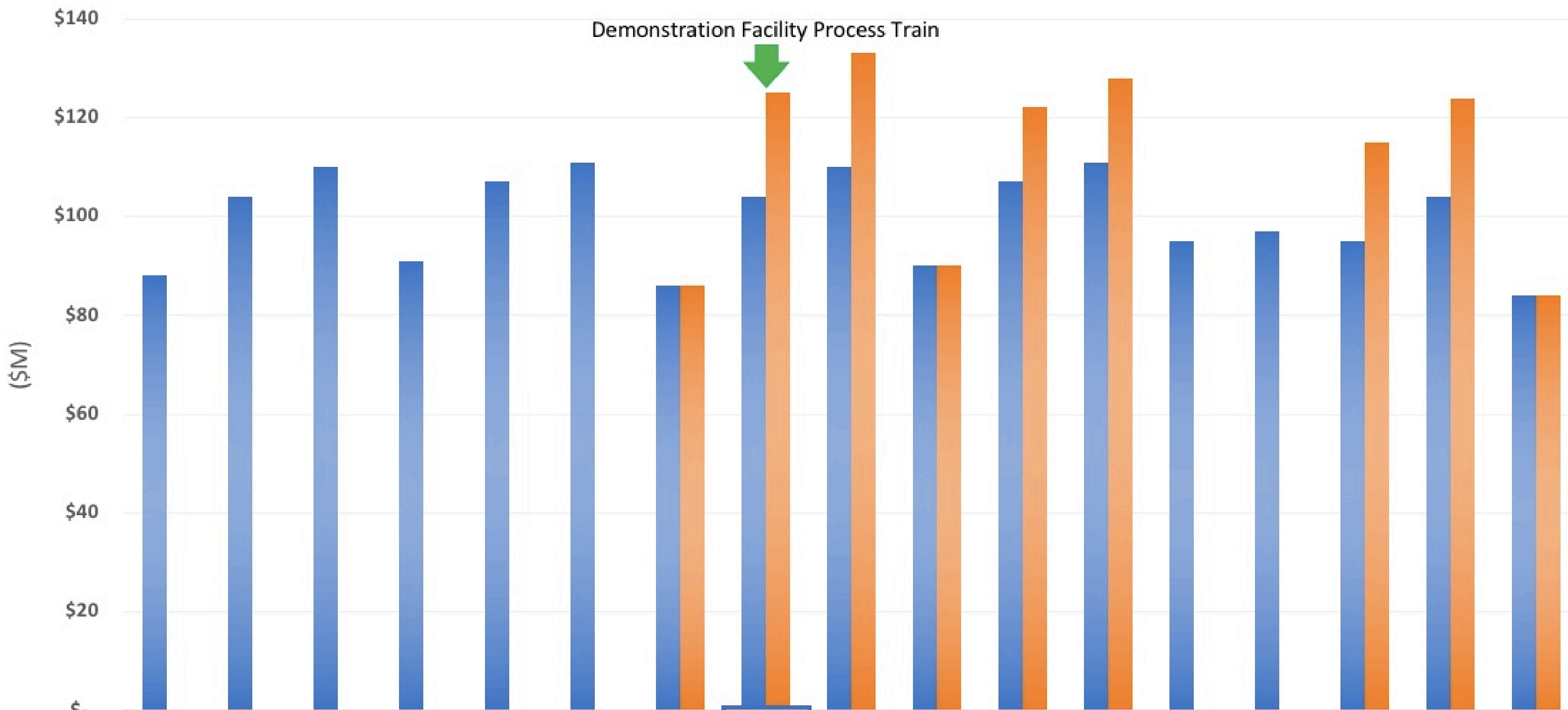
Figure 7.2 – NPV Total Cost RO Product Water for 150-MGD Trains that Meet TN ≤ 10 mg/L



	1A	2A	3A	1C	2C	3C	1B	2B	3B	1D	2D	3D	4A	4B	4C	2E	5
High	$689	$727	$884	$777	$774	$918	$701	$747	$989	$789	$789	$990	$665	$720	$748	$810	$790
Low	$471	$563	$586	$503	$592	$598	$469	$573	$612	$503	$599	$616	$486	$506	$508	$589	$485
● Estimate	$547	$625	$689	$598	$660	$708	$550	$638	$741	$601	$670	$744	$549	$581	$592	$670	$590

Process Trains

Figure 7.3 – NPV Unit Cost RO Product Water for 150-MGD Trains that Meet TN ≤ 10 mg/L



	1A	2A	3A	1C	2C	3C	1B	2B	3B	1D	2D	3D	4A	4B	4C	2E	5
< 10 mg/L	$88	$104	$110	$91	$107	$111	$86	$104	$110	$90	$107	$111	$95	$97	$95	$104	$84
< 3.5 mg/L							$86	$125	$133	$90	$122	$128			$115	$124	$84

Process Trains

Figure 7.4 – O&M Cost Estimate for 150-MGD Trains that Meet TN ≤ 10 and ≤ 3.5 mg/L

	1B	2B	3B	1D	2D	3D	4C	2E	5
High	$1,182	$1,096	$1,830	$1,425	$1,201	$1,817	$1,224	$1,311	$1,510
Low	$402	$511	$564	$463	$560	$561	$420	$565	$484
● Estimate	$673	$731	$997	$794	$801	$991	$700	$838	$837

Process Trains

Figure 7.5 – Capital Cost Estimate for 150-MGD Trains that Meet TN ≤ 3.5 mg/L

	1B	2B	3B	1D	2D	3D	4C	2E	5
High	$2,357	$2,793	$3,642	$2,651	$2,859	$3,554	$2,789	$2,992	$2,655
Low	$1,577	$2,209	$2,376	$1,689	$2,219	$2,298	$1,985	$2,246	$1,629
● Estimate	$1,848	$2,428	$2,809	$2,021	$2,459	$2,727	$2,264	$2,519	$1,982

Process Trains

Figure 7.6 – NPV Total Cost RO Product Water for 150-MGD Trains that Meet TN ≤ 3.5 mg/L

	1B	2B	3B	1D	2D	3D	4C	2E	5
High	$701	$831	$1,084	$789	$851	$1,058	$830	$890	$790
Low	$469	$657	$707	$503	$660	$684	$591	$668	$485
● Estimate	$550	$723	$836	$601	$732	$812	$674	$750	$590

Process Trains

Figure 7.7 – NPV Unit Cost RO Product Water for 150-MGD Trains that Meet TN ≤ 3.5 mg/L

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8.0 QUALITATIVE EVALUATION OF FIVE SELECTED PROCESS TRAINS

From the 17 process trains evaluated, only the nine that met the more stringent water quality goal (TN ≤ 3.5 mg/L) were considered for further evaluation. Of these nine trains, those that used a BAF process (Trains 3B and 3D) were eliminated due to high NPVs. The trains that used centrate treatment did not offer any cost benefit compared to their counterparts without centrate treatment (i.e. Trains 1B vs 1D and 2B vs 2D) and were not considered for further evaluation. The following five remaining trains were shortlisted for further consideration:

- Train 1B - NdN Secondary MBR (Retrofit) + RO
- Train 2B - NdN Tertiary MBR + RO
- Train 2E - N-only Tertiary MBR + Two Pass RO
- Train 4C - MF + Two Pass RO and,
- Train 5 - NdN Secondary MBR + RO

Further evaluation of these five trains using the selected criteria is presented below.

COST

Detailed discussion on cost estimation is provided in **Section 7**. Given the uncertainties associated with the cost for each train, cost alone cannot be used as the basis for train comparison and selection at this point. The relative difference in cost is expected to change after detailed process design, project phasing, and water quality goals, are further refined.

ABILITY TO MEET WATER QUALITY GOAL

All five shortlisted trains meet the more stringent water quality goal of TN ≤ 3.5 mg/L.

OPERATIONAL COMPLEXITY (TECHNOLOGY)

Operation and Maintenance Complexity

The combination of biological and membrane processes in MBR adds operational and maintenance complexity. Pressure decay testing (PDT) for MBR membranes may also add operational and maintenance complexity compared to MF + RO if PDT is required by the regulators to grant future pathogen log credits to MBR. Train 4C (MF + Two Pass RO) is expected to be relatively simple to operate compared to the MBR processes due to absence of biological treatment. However, addition of second pass RO adds complexity in the N-only Tertiary MBR and MF trains (2E and 4C) compared to the other three trains.

Operation of Additional Process

The NdN Secondary MBR (Retrofit) train eliminates the need for operation of an additional MBR process (either secondary or tertiary) at the AWT Facility. The N-only Tertiary MBR and MF trains (2E and 4C) require an additional RO pass than the other three trains.

OPERATIONAL RELIABILITY AND REDUNDANCY

Plant Operation

Biological reactors cannot be placed into or out of service quickly for responding to high or low flow conditions. In 2016, the diurnal flow at JWPCP ranged from 130 to 480 MGD and the daily flows ranged from 220 to 320 MGD. A peak flow of ~590 MGD was observed in January 2017. Demand for MBR effluent combined with incoming flow to JWPCP may result in low or high flows to the in-service HPOAS reactors. In extreme cases, no flow or very high flows may be possible. The impact of such flow variability on the biological treatment process at JWPCP needs to be investigated. In the same way, if HPOAS reactors must operate within a flow range, the MBR train would have to absorb the flows outside of that range. In this case, the impact of extreme flows on MBR performance needs to be examined. Therefore, a balance between the number of HPOAS reactors in service and flow distribution between the HPOAS and MBR trains needs to be established to optimize operation and performance of both trains. Potential need for flow equalization or additional membrane surface area to maintain the flux for the MBR membranes within a desired range also needs to be factored into this process.

The tertiary MBR and MF processes for the trains that treat secondary effluent from JWPCP (Trains 2B, 2E and 4C) would be designed to operate at a relatively constant flow and would not have to handle the diurnal or wet weather flow variability. Influent flow to the tertiary MBR and MF processes can be controlled to meet potable water demand with the remaining portion of the JWPCP effluent discharged to the ocean. As such, their operation would not be affected by JWPCP influent or effluent flow variation. Also, capacity or operation of JWPCP would likely not be significantly impacted.

Operational Risk

At an MBR facility, treated water has to leave the plant through membranes. With fouled membranes, plant throughput could be reduced substantially, affecting product water cost. For the secondary MBR trains (Trains 1B and 5), operating membranes instead of clarifiers for solids separation poses a risk for loss of capacity for MBR trains and/or flooding if the wastewater cannot be treated by HPOAS trains. In order to mitigate this risk, adequate back-up and redundancy for the membrane system equipment would be required to ensure reliable operation of the membranes.

For the N-only tertiary MBR and MF trains that include two pass RO (Trains 2E and 4C), lower combined RO permeate pH is expected compared to a single pass RO system. The impact of lower pH on downstream UV/Cl_2 AOP performance needs to be investigated.

Impact on JWPCP Capacity

Dry-weather capacity for the NdN Secondary MBR (Retrofit) train may be reduced by up to 10% to meet the water quality goal of TN ≤ 3.5 mg/L. The other alternatives do not impact the plant's capacity.

Reliance on Carbon Deliveries

In contrast to the other alternatives, the NdN Tertiary MBR (Train 2B) would rely on delivery of supplemental carbon for proper operation. Primary effluent would provide carbon for the secondary MBR trains (Trains 1B and 5). N-only Tertiary MBR and MF trains (Trains 2E and 4C) do not require carbon addition.

Membrane Fouling

The MF process in Train 4C would be treating non-nitrified secondary effluent resulting from a low SRT activated sludge process. Use of non-nitrified effluent has been associated with higher fouling rates compared to nitrified effluent (Orange County Sanitation District). Operating at an SRT high enough to achieve nitrification can enhance degradation of effluent organic matter, which is thought to be one of the main causes for membrane fouling. Increased fouling would have to be mitigated with pre-treatment such as coagulant addition and/or more frequent membrane replacement, which adds operational and maintenance complexity. Potential for fouling should be investigated. For this evaluation, cost for more frequent membrane replacement was included for Train 4C.

TECHNOLOGY MATURITY

Full Scale Operation

MF + RO is the most proven technology due to its longevity in reuse applications. Secondary MBR has been implemented in full-scale as a standalone treatment process. However, absence of any known retrofit of an existing HPOAS facility to MBR creates substantial uncertainty with respect to potential operational issues. Retrofitting existing infrastructure and integration into an existing facility can be challenging. One 50-MGD reactor at JWPCP would need to be operated as an MBR for an extended period to evaluate performance and O&M needs. Even though the tertiary MBR process is proven at pilot scale, there are no known full scale tertiary MBR installations, currently in operation.

Regulatory Approval

MF and RO processes are approved by the regulators for pathogen removal credits. Addition of two pass RO is assumed not to have any implications on regulatory approval of the process train. The MBR process is currently not granted any pathogen credits by regulators and therefore approval of secondary or tertiary MBR process in an IPR application in lieu of MF process is pending.

ENVIRONMENTAL IMPACT

Carbon Emissions

Power consumption for process equipment was used to calculate carbon emissions related to equipment for each unit process. A line loss factor of 1.057 was applied to the equipment power consumption. The line loss corrected power consumption was used to calculate equipment carbon dioxide emissions based on an equivalency factor of 0.23 MT CO_2e/MWh obtained from SoCal Edison (SoCal Edison, 2015). Process related emissions from biological processes were obtained from BioWin. The sum of equipment emissions and process emissions was used to calculate the total emissions. A vehicle equivalent of 4.67 MT CO_2e emission per vehicle per year was used to obtain a relative number of vehicle emission equivalent per year for each process train.

Table 8.1 shows the carbon emissions calculated for each process train. MF + RO has substantially lower carbon emission compared to the MBRs. Secondary and tertiary MBRs have similar carbon emissions, with secondary MBR having marginally lower carbon emission.

Chemical Deliveries

More chemical handling and more delivery trucks would be needed for the NdN Tertiary MBR (Train 2B) due to its reliance on supplemental source of carbon.

Ammonia and/or Nitrogen Discharge to Ocean

The trains employing NdN (Trains 1B, 2B and 5) would reduce the total nitrogen concentration and loading discharged to the ocean as RO brine. The N-only Tertiary MBR train (Train 2E) would not reduce the total nitrogen concentration and load in the brine discharge, but the nitrogen would be in the form of nitrate, which is typically less toxic to aquatic organisms. The non-nitrifying MF + Two Pass RO train (Train 4C) would transfer nitrogen (including ammonia) from the effluent to the brine; potential toxicity associated with ammonia should be investigated.

Other Considerations

All trains can meet existing water quality regulatory limits. The effectiveness of the MF train (Train 4C) in removing contaminants of emerging concern (CECs) compared to the MBR trains (Trains 1B, 2B, 2E and 5) may need to be investigated. The MF process in Train 4C would receive a low SRT effluent, which according to literature is associated with lesser removal of CECs. However, a previous study conducted by the Sanitation Districts and Metropolitan showed no significant difference in CEC removal performance between MF + RO and MBR + RO (Sanitation Districts of Los Angeles County and Metropolitan Water District of Southern California, 2012).

CONSTRUCTABILITY

The NdN Secondary MBR (Retrofit) train (Train 1B) would require retrofitting the existing HPOAS reactors and clarifiers. While this approach would require less excavation and concrete, it presents challenges including:

- Limited space for ancillary equipment, difficult RAS flow channel construction, logistical challenges associated with construction staging and maintaining continuous operation of the remainder of the plant during construction.
- Retrofit does not allow for optimal design, especially for process aeration; shallow water depth of clarifiers (12 ft) retrofitted to aeration basins would result in higher process aeration demand.
- Less phasing flexibility since a retrofit would need to proceed in increments of 50 MGD, corresponding to the capacity for each reactor at JWPCP.

All other trains would involve greenfield construction. As such, optimal design and greater phasing flexibility can be achieved.

A summary of the evaluation is provided in **Table 8.2.**

Table 8.1 – Carbon Emissions from Process Trains

	Process Trains	Metric Tonnes of CO_2 equivalent[1] Per Year			
		Equipment Emissions	Process Emissions	Total Emissions	Vehicle Equivalent Per Year
Train 1A	N-only Secondary MBR (Retrofit) + RO	60,000	146,000	206,000	44,200
Train 2A	N-only Tertiary MBR + RO	60,000	120,000	180,000	38,600
Train 3A	N-only Tertiary BAF + MF + RO	63,000	120,000	183,000	39,200
Train 1B	NdN Secondary MBR (Retrofit) + RO	58,000	122,000	180,000	38,600
Train 2B	NdN Tertiary MBR + RO	60,000	141,000	201,000	43,100
Train 3B	NdN Tertiary BAF + MF + RO	64,000	141,000	205,000	43,900
Train 1C	Centrate Treatment + N-only Secondary MBR (Retrofit) + RO	62,000	147,000	209,000	44,800
Train 2C	Centrate Treatment + N-only Tertiary MBR + RO	62,000	120,000	182,000	39,000
Train 3C	Centrate Treatment + N-only Tertiary BAF + MF + RO	63,000	102,000	165,000	35,400
Train 1D	Centrate Treatment + NdN Secondary MBR (Retrofit) + RO	61,000	124,000	185,000	39,700
Train 2D	Centrate Treatment + NdN Tertiary MBR + RO	60,000	117,000	177,000	38,000
Train 3D	Centrate Treatment + NdN Tertiary BAF + MF + RO	64,000	117,000	181,000	38,800
Train 4A	MF + RO	43,000	34,000	77,000	16,500
Train 4B	Centrate Treatment + MF + RO	45,000	34,000	79,000	17,000
Train 4C	MF + Two Pass RO	61,000	34,000	95,000	20,400
Train 5	NdN Secondary MBR + RO	55,000	120,000	175,000	37,500
Train 2E	N-only Tertiary MBR + Two Pass RO	77,000	120,000	197,000	42,200

1. Based on 0.24 MT CO_2e/MWh

Table 8.2 – Assessment of Nitrogen Management Trains against Evaluation Criteria

	Process Train	Ability to Meet Water Quality Goal[1] (TN≤3.5 mg/L)	Operational Complexity (Technology)	Operational Reliability and Redundancy	Technology Maturity	RO Product Water NPV[2] ($/ac-ft)	Environmental Impact	Constructability
1B	NdN Secondary MBR (Retrofit) + RO	Yes	• MBR more complex to operate • No need for additional biological process • Pressure decay testing may add complexity	• Higher risk during wet weather flows • Flow balancing between MBR and HPOAS reactors would be necessary • 10% derating for TN≤3.5 mg/L	• Secondary MBR full-scale facilities in operation. Retrofit of HPOAS to MBR has not been done. • Regulatory approval pending	• $550/ac-ft ($469-701/ac-ft) • Includes back-up and redundancy to ensure reliable operation	• High carbon emissions	• Potential challenges with retrofitting the existing facility • Integration into the existing facility requires detailed assessment. • Retrofit does not allow for optimal design • Less phasing flexibility due to constraint to 50-mgd increments
2B	NdN Tertiary MBR + RO	Yes	• MBR more complex to operate • Additional biological process required • Pressure decay testing may add complexity	• Does not impact JWPCP operation or capacity • Unaffected by diurnal or wet weather flow variation • Relies on continuous carbon addition	• No full-scale installations; proven at pilot-scale • Regulatory approval pending	• $723/ac-ft ($657-831/ac-ft)	• Highest carbon emissions • Carbon addition required - more chemical handling and trucks	• Greenfield • Phasing flexibility
2E	N-Only Tertiary MBR + Two Pass RO	Yes	• MBR more complex to operate • Additional biological process and 2nd pass RO required • Pressure decay testing may add complexity	• Does not impact JWPCP operation or capacity • Unaffected by diurnal or wet weather flow variation	• No full-scale installations; proven at pilot-scale • Regulatory approval pending	• $750/ac-ft ($668-890/ac-ft)	• Highest carbon emissions • Potential for enhanced removal of micropollutants due to combination of nitrification and second pass RO	• Greenfield • Phasing flexibility
4C	MF + Two Pass RO	Yes	• Simpler to operate • 2nd pass RO required	• Does not impact JWPCP operation or capacity • Unaffected by diurnal or wet weather flow variation • Potential increase in rate of membrane fouling	• Proven technology due to longevity in reuse • Approved by regulators	• $674/ac-ft ($591-830/ac-ft)	• Lowest carbon emissions • No potential for enhanced biodegradation of micropollutants – second pass RO may compensate • Ammonia toxicity in brine may be of concern	• Greenfield • Phasing flexibility
5	NdN Secondary MBR + RO	Yes	• MBR more complex to operate • Additional biological process required • Pressure decay testing may add complexity	• Flow balancing between MBR and HPOAS reactors would be necessary	• Secondary MBR full-scale facilities in operation • Regulatory approval pending	• $590/ac-ft ($485-790/ac-ft)	• High carbon emissions	• Greenfield - allows for optimal design • Phasing flexibility

ADF = average daily flow; gpd = gallons per day; HPOAS = high purity oxygen activated sludge; JWPCP = Joint Water Pollution Control Plan; MBR = membrane bioreactor; MF = membrane filtration; mgd = million gallons per day; N-Only = nitrification only; NdN = nitrification/denitrification; RAS = return activated sludge; RO = reverse osmosis

1. Based on RO Permeate.

2. Costs for all trains include O&M costs for organics and nitrogen removal. Cost estimates for Secondary MBR (retrofit and new), MF, and Two Pass RO are Class 5 Construction Cost Estimates with +100%/-50% error. Cost estimates for Tertiary MBR (N-only and NdN) and RO are Class 4 Construction Cost Estimates with slightly less margin of error (+50%/-30%). RO Product Water NPV range shown accounts for this cost variability.

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9.0 ECONOMY OF SCALE

Cost curves were developed for five selected trains that met the most stringent water quality goal (TN ≤ 3.5 mg/L), as shown in **Figure 9.1**. The objectives of developing the capacity vs cost curve were to identify the projected treatment cost for potential phasing of the project and to identify an optimum capacity for the first phase. The capital and O&M costs for selected treatment trains were adjusted by scaling down from 150 MGD of product water in 5 MGD increments. The secondary MBR (Retrofit) can only be scaled down in 50 MGD increments based on the treatment capacity of the existing single train at JWPCP.

The scale down cost adjustments to the capital cost were conducted using the six-tenth rule:

$$C_B = C_A \left(\frac{S_B}{S_A} \right)^{0.6}$$

Where,

C_B = approximate cost ($) of equipment with size SB

C_A = known cost ($) of equipment with size SA

S_B/S_A = size factor (dimensionless)

The scale down cost adjustments to the O&M cost were conducted using the following formula:

$$O\&M = \left[(Power + Chemicals + Labor + Replacement\ Parts + Solids\ Disposal) \left(\frac{S_B}{S_A} \right) + (Capital\ Cost\ of\ Equipment) \left(\frac{S_B}{S_A} \right)^{0.6} \right] (1 + \%\ Contingency)$$

Where,

S_B/S_A = size factor (dimensionless),

Maintenance cost scale down was calculated based on capital cost of equipment as shown in the formula above.

Once the capital and O&M costs were scaled down, the NPVs were calculated for each increment. As shown in **Figure 9.1**, at product water flows above approximately 35 MGD, there is minimal cost difference between each phasing alternative.

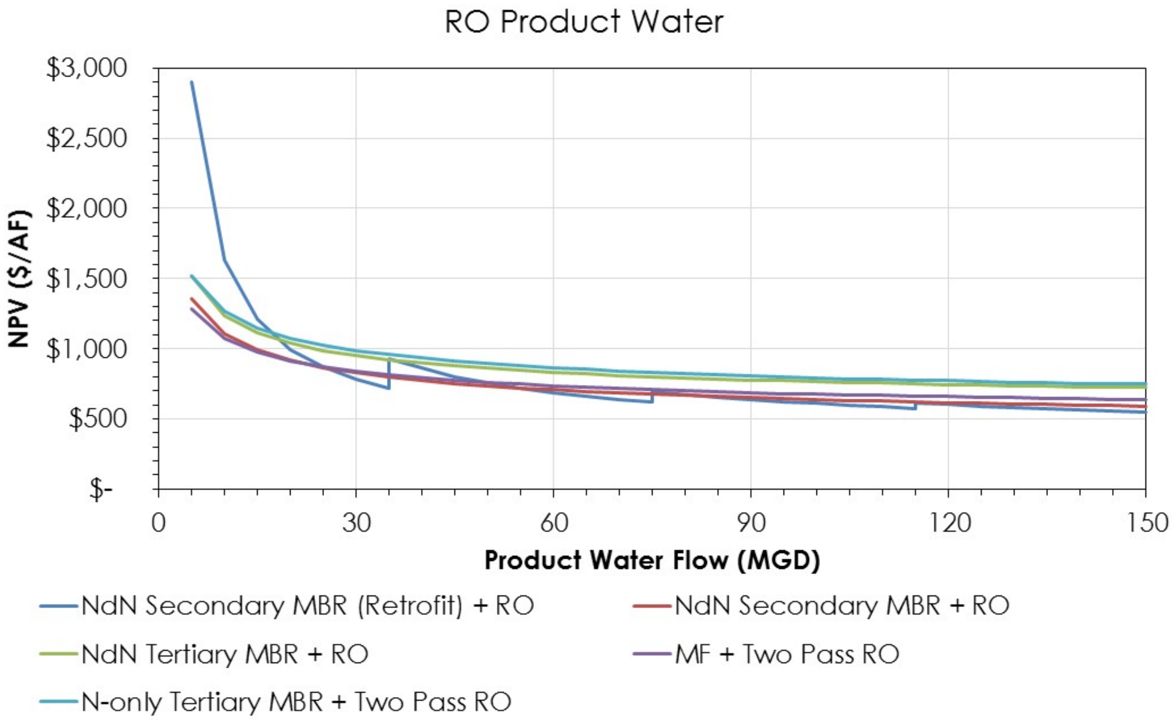

Figure 9.1 – Capacity vs Cost Curve for RO Product Water from Selected Trains

10.0 CONCLUSIONS AND RECOMMENDATIONS

Of the 17 process trains evaluated, the following five cost-effective trains were selected for further evaluation:

- Train 1B - NdN Secondary MBR (Retrofit) + RO
- Train 2B - NdN Tertiary MBR + RO
- Train 2E - N-only Tertiary MBR + Two Pass RO
- Train 4C - MF + Two Pass RO and,
- Train 5 - NdN Secondary MBR + RO

These trains were evaluated against criteria including: ability to meet water quality goals; operational complexity (technology); operational reliability and redundancy; technology maturity; RO product water NPV (cost); environmental impact; constructability.

RECOMMENDED NEXT STEPS

This report identified potential issues with each of the five shortlisted process trains. In order to address these issues, additional literature review, process modeling, detailed conceptual design, expert review, and field testing are recommended.

The recommended next steps for each train are as follows:

- **Train 1B – NdN Secondary MBR (Retrofit) + RO**
  - Construct a process line to convey JWPCP primary effluent to the AWT Demonstration Facility for testing of the secondary MBR process.
  - Further develop the NdN secondary MBR retrofit design concept, similarly to that which was conducted previously for the tertiary MBR.
  - Refine the cost estimate to Class 4 level using the information obtained from a BIM model, to be created as part of the conceptual design.
  - Assess operational and water quality performance of the NdN secondary MBR at the AWT Demonstration Facility.
  - Evaluate the impact of flow variation on the performance of secondary MBR and HPOAS reactors.
  - Identify operational requirements for obtaining regulatory pathogen removal credits.

- **Train 2B - NdN Tertiary MBR + RO** (Base case process train from feasibility report and design basis of the AWT Demonstration Facility)
    - Assess the operational and water quality performance of the NdN tertiary MBR at the AWT Demonstration Facility, especially with respect to its supplemental carbon consumption for denitrification.
    - Identify operational requirements for obtaining pathogen removal credits.
- **Train 2E - N-only Tertiary MBR + Two Pass RO**
    - Add a second pass RO to the AWT Demonstration Facility.
    - Assess the operational and water quality performance of N-only tertiary MBR and Two Pass RO at the AWT Demonstration Facility.
    - Investigate the implications of Two Pass RO on the downstream UV/AOP process performance, treated water quality, and regulatory approval.
    - Identify operational requirements for obtaining pathogen removal credits.
- **Train 4C - MF + Two Pass RO**
    - Investigate the membrane performance of the MF system treating non-nitrified secondary effluent.
    - Develop a more detailed conceptual design, similar to that which was conducted previously for tertiary MBR, and create a BIM model for a submerged MF.
    - Refine the cost estimate to Class 4 level.
    - Investigate implications of two pass RO on the downstream UV/AOP process performance, treated water quality, and regulatory approval.
- **Train 5 - NdN Secondary MBR + RO**
    - Construct a process line to convey JWPCP's primary effluent to the AWT Demonstration Facility for testing of secondary MBR process.
    - Further develop the NdN secondary MBR design concept, similar to that which was conducted previously for the tertiary MBR.
    - Refine the cost estimate to Class 4 level using the information obtained from a BIM model, to be created as part of the conceptual design.
    - Assess the operational and water quality performance of the NdN secondary MBR at the AWT Demonstration Facility.

- Evaluate the impact of flow variation on the performance of secondary MBR and HPOAS reactors.
- Identify operational requirements for obtaining pathogen removal credits.

Once these additional investigations and demonstration testing have been conducted, further discussions should take place to determine which process train should be employed in a full-scale AWT (up to 150 MGD) to achieve the overall goals of the Regional Recycled Water Program.

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11.0 REFERENCES

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APPENDICES

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Appendix A DESIGN CRITERIA FOR UNIT PROCESSES

Design criteria used for developing cost estimates for each unit process are discussed in this section. These design criteria were used to calculate the capital and O&M costs for each unit process, provided in Appendices B and C.

A.1 JOINT WATER POLLUTION CONTROL PLANT

Design criteria for secondary treatment at JWPCP are presented in **Table A.1**. JWPCP has four process trains, each rated at 100 MGD dry weather flow and 175 MGD wet weather flow. Each train is further divided into 50-MGD modules with a dedicated set of bioreactor basins and secondary clarifiers.

Table A.1 – Design Criteria for Secondary Treatment at JWPCP

Parameter	Units	Value
Bioreactor Basins		
Number of Trains	-	4
Design Daily Flow per Train	MGD	100
Storm Flow Capacity per Train	MGD	175
Number of Bioreactors Basins per Train	-	2
Volume of Bioreactor, Each	MG	5.26
Number of Stages in Bioreactor, Each	-	4
Cell Residence Time (Total System Solids)	days	3.5
Hydraulic Retention Time	hours	2.5
F/M Ratio	lb BOD_5-day/lb MLVSS	0.81
Oxygen Required per Train	tpd of oxygen	90
Oxygen Required, Total	tpd of oxygen	360
Total Oxygenation Capacity Available	tpd of oxygen	625
Secondary Clarifiers		
Number of Trains	-	4
Design Daily Flow per Train	MGD	100
Number of Clarifiers per Train	-	52
Volume per Clarifier	MG	0.37
Total Clarifier Volume per Train	MG	19.1
Overflow Rate	gpd/ft^2	548
Hydraulic Retention Time	hours	4.6
Total Surface Area per Train	ft^2	182,364
Waste Activated Sludge System		
Number of Pumps	-	3
Capacity per Pump	MGD	2.52
Return Activated Sludge System		
Number of Pumps	-	6
Capacity per Pump	MGD	75
Total Return Sludge Flow Capacity	% of Q	60

A.2 CENTRATE TREATMENT

The centrate treatment design was based on treating centrate prior to thickening (pre-DAF). Centrate flow and characteristics from JWPCP were provided to the vendor (Veolia) and design information obtained from the vendor was used to develop the cost estimates. The percent removal efficiency for ammonia and TIN shown in **Table A.2** were similar to those observed by Sanitation Districts during a pilot study at JWPCP using ANITA™Mox system.

Table A.2 – Design Criteria for ANITA™ Mox MBBR for Centrate Treatment.

Parameter	Unit	Value
Influent		
Flow	MGD	6.1
COD	mg/L	365
TSS	mg/L	195
NH_4-N	mg-N/L	620
Minimum Alkalinity	mg-$CaCO_3$/L	2,300
Minimum Temperature	^oC	30.0
Reactor Configuration		
Number of Reactors	--	7
Total Reactor Volume	ft^3	529,200
Media Type	--	Anox-Kaldnes K5
Media Specific Surface Area	m^2/m^3	800
Media Fill	%	46
Total Media Volume	ft^3	240,744
Total Process Air Blower Capacity	scfm	16,520
Aeration System Type	--	Medium Bubble
Residual Do, Max Month	mg/L	1.5
Effluent		
NH_4 Removal	%	80-85
TIN Removal	%	70-75

A.3 SECONDARY MEMBRANE BIOREACTOR

Table A.3 shows the design criteria for N-only Secondary MBR (Retrofit) – with and without centrate treatment. Each concept includes converting four HPOAS trains into MBR.

Table A.4 presents the design criteria for the NdN Secondary MBR (Retrofit) – with and without centrate treatment as well as new NdN Secondary MBR. The new NdN Secondary MBR was conceptualized with three trains of 60 MGD each to maintain design consistency with the new Tertiary MBR. The membrane system equipment was sized to handle peak flows of up to 50% higher than the design flow (peaking factor of 1.5). When converted to secondary MBR, the four MBR trains at JWPCP will handle up to 300 MGD of wet weather flow and the remaining four HPOAS trains will handle another 400 MGD of wet weather flow.

Table A.3 – Design Criteria for N-only Secondary MBR (Retrofit)

Parameter	Units	N-only Secondary MBR (Retrofit)	N-only Secondary MBR (Retrofit) with Centrate
Influent			
Flow	MGD	180	200
Number of Trains		4	4
Flow per Train	MGD	45	50
TN	mg/L	60	50
COD	mg/L	395	395
TP	mg/L	7.7	7.7
Alkalinity	mg/L as $CaCO_3$	380	380
Bioreactor Configuration			
SRT, Total	days	10	10
Total Volume (Bioreactor + Membrane)	MG	58.2	58.2
HRT, Total	hours	7.8	7.0
Aerobic HRT	% of total HRT	82%	82%
RAS Flow (entering membrane tanks)	times Q	4	4
Mixed Liquor Characteristics			
Aerobic MLSS	mg/L	3,950	4,360
Membrane MLSS	mg/L	5,210	5,760
Aerobic VSS/TSS	%	77%	77%
Process Aeration	scfm	253,932	250,272
Fine Bubble Diffused Aeration	% of Total	25%	25%
Waste Activated Sludge			
Flow	MGD	4.6	4.6
COD	lb/d	233,596	257,232
TSS	lb/d	201,608	222,344
Membrane System Design			
Membrane Instantaneous Flux	gfd	14.1	14.1
Membrane Surface Area Per Cassette	ft^2	17,760	17,760
Number of Membrane Cassettes	-	748	832
Scour Air Flow Per Cassette	scfm	250	250

Table A.4 – Design Criteria for NdN Secondary MBR

Parameter	Units	NdN Secondary MBR (Retrofit)	NdN Secondary MBR (Retrofit) with Centrate	NdN Secondary MBR
Influent				
Flow	MGD	180	200	60
Number of Trains		4	4	3
Flow per Train	MGD	45	50	60
TN	mg/L	60	50	60
COD	mg/L	395	395	395
TP	mg/L	7.7	7.7	7.7
Alkalinity	mg/L as $CaCO_3$	370	370	370
Bioreactor Configuration				
SRT, Total	days	12	12	12
Total Volume (Bioreactor + Membrane)	MG	58.2	58.2	51.3
HRT, Total	hours	7.8	7.0	6.8
Anoxic HRT	% of total HRT	44%	36%	41%
Aerobic HRT	% of total HRT	38%	45%	38%
RAS Flow (entering membrane tanks)	times Q	4	4	4
Mixed Liquor Characteristics				
Aerobic MLSS	mg/L	4,540	4,990	5,140
Membrane MLSS	mg/L	6,000	6,600	6,810
Aerobic VSS/TSS	%	76%	77%	77%
Process Aeration	scfm	184,688	190,880	129,498
Fine Bubble Diffused Aeration	% of Total	100%	100%	100%
Waste Activated Sludge				
Flow	MGD	3.8	3.8	3.4
COD	lb/d	222,692	244,360	223,581
TSS	lb/d	193,344	212,684	194,088
Membrane System Design				
Membrane Instantaneous Flux	gfd	14.1	14.1	14.1
Membrane Surface Area Per Cassette	ft^2	17,760	17,760	17,760
Number of Membrane Cassettes	-	748	832	750
Scour Air Flow Per Cassette	scfm	250	250	250

A.4 TERTIARY MEMBRANE BIOREACTOR

Table A.5 shows the design criteria for N-only Tertiary MBR – with and without centrate treatment.

Table A.6 presents the design criteria for the NdN Tertiary MBR – with and without centrate treatment. Each concept includes three new MBR trains each with a capacity of 60 MGD. The tertiary MBR trains are designed are scalping facilities with an assumption that they will always operate at constant flow.

Table A.5 – Design Criteria for N-only Tertiary MBR

Parameter	Units	N-only Tertiary MBR	N-only Tertiary MBR with Centrate
Influent			
Flow	MGD	180	180
Number of Trains		3	3
Flow per Train	MGD	60	60
TN	mg/L	50	40
COD	mg/L	49	49
TP	mg/L	2.0	2.0
Alkalinity	mg/L as $CaCO_3$	370	370
Bioreactor Configuration			
SRT, Total	days	10	10
Total Volume (Bioreactor + Membrane)	MG	20.6	17.0
HRT, Total	hours	2.7	2.3
Aerobic HRT	% of total HRT	69%	63%
RAS Flow (entering membrane tanks)	times Q	4	4
Mixed Liquor Characteristics			
Aerobic MLSS	mg/L	3,360	3,884
Membrane MLSS	mg/L	4,460	5,170
Aerobic VSS/TSS	%	37%	36%
Process Aeration	scfm	89,724	70,389
Waste Activated Sludge			
Flow	MGD	1.7	1.4
COD	lb/d	33,612	31,398
TSS	lb/d	62,301	60,621
Membrane System Design			
Membrane Instantaneous Flux	gfd	16.8	16.8
Membrane Surface Area Per Cassette	ft^2	17,760	17,760
Number of Membrane Cassettes	-	630	630
Scour Air Flow Per Cassette	scfm	150	150

Table A.6 – Design Criteria for NdN Tertiary MBR

Parameter	Units	NdN Tertiary MBR	NdN Tertiary MBR with Centrate
Influent			
Flow	MGD	180	180
Number of Trains		3	3
Flow per Train	MGD	60	60
TN	mg/L	50	40
COD	mg/L	49	49
TP	mg/L	2.0	2.0
Alkalinity	mg/L as $CaCO_3$	370	370
Bioreactor Configuration			
SRT, Total	days	10	10
Total Volume (Bioreactor + Membrane)	MG	30.5	24.4
HRT, Total	hours	4.1	3.3
Anoxic HRT	% of total HRT	33%	30%
Aerobic HRT	% of total HRT	47%	44%
Membrane Tank HRT	% of total HRT	21%	26%
RAS Flow (entering membrane tanks)	times Q	4	4
Mixed Liquor Characteristics			
Aerobic MLSS	mg/L	5,050	5,260
Membrane MLSS	mg/L	6,730	7,010
Aerobic VSS/TSS	%	55%	52%
Carbon (MicroC 2000) Addition	gpd	32,100	23,400
Process Aeration	scfm	99,150	73,872
Waste Activated Sludge			
Flow	MGD	2.4	2.0
COD	lb/d	107,514	86,250
TSS	lb/d	135,666	114,849
Membrane System Design			
Membrane Instantaneous Flux	gfd	16.8	16.8
Membrane Surface Area Per Cassette	ft^2	17,760	17,760
Number of Membrane Cassettes	-	630	630
Scour Air Flow Per Cassette	scfm	150	150

A.5 TERTIARY BIOLOGICALLY ACTIVE FILTER

Table A.7 shows the design criteria for both N-only and NdN Tertiary BAF. These design parameters were based on vendor (Veolia's) input. Capital and O&M costs for BAF trains with centrate treatment were corrected proportionately based on reduction in nitrogen loading.

Table A.7 – Design Criteria for N-only and NdN Tertiary BAF

Parameter	Units	N-Only Tertiary BAF	NdN Tertiary BAF
Influent			
Flow	MGD	190	190
TN	mg/L	50	50
COD	mg/L	49	49
TP	mg/L	2.0	2.0
Alkalinity	mg/L as $CaCO_3$	370	370
Bioreactor Configuration			
Number of Batteries	--	2	14
Number of Cells/Battery	--	18	2
Total Number of Cells	--	36	28
Biostyrene Media Size	mm	3.6	4.5
Biostyrene Media Depth	ft	11.48	9.80
Total Biostyrene Media Volume	ft^3	1,066,676	708,226
Total Filter Area	ft^2	92,916	72,268
Hydraulic, Max Month Loading (All Cells)	gpm/ft^2	1.55	1.51
Hydraulic, Peak Loading w/2 Cells in Backwash/Battery	gpm/ft^2	1.68	1.80
Loading (All Cells)			
cBOD	$lb/1{,}000\ ft^3/d$	8.1	--
TSS	$lb/1{,}000\ ft^3/d$	18.1	--
NH_3-N	$lb/1{,}000\ ft^3/d$	79.3	--
NO_3-N	$lb/1{,}000\ ft^3/d$	--	88.0
Backwash Design			
Sludge Production	lb/day	8,224	862,894
Total Process Air/Cell (Average)	scfm	2,034	--
Backwash Air/Cell (Average)	scfm	1,694	1,694
Assumed Backwash Interval	hr	96	24

A.6 MEMBRANE FILTRATION

The MF system is based on a submerged, hollow-fiber system from GE (Suez) with a nominal average flux of apprimxately18 gfd (**Table A.8**) in N-1 configuration assuming one train of each subsystem will be offline at any time. The design criteria for the MF system for all trains without two pass RO is summarized in the table below. For the cost estimating purposes of this report, the MF system upstream of the two pass RO process is assumed to increase by approximately 6.5% to account for the increase in flow from 186 mgd to 198 mgd.

Table A.8 – Design Criteria for MF

Parameter	Units	Value
Influent Flow	MGD	186
Effluent Flow	MGD	176
Recovery	%	95%
Number of Sub-systems	-	4
Number of Trains Per Sub-system	-	7
Number of Cassettes Per Train	-	8
Number of Installed Modules Per Cassette	-	96
Total Number of Cassettes		224
Membrane Surface Area Per Module	ft^2	550
Membrane Surface Area Per Train (N)	ft^2	422,400
Total Membrane Surface Area	ft^2	11,827,200
Influent Flow Per Train	MGD	7.7
Membrane Instantaneous Flux in N-1 Configuration	gfd	18

A.7 REVERSE OSMOSIS

The RO system design criteria is summarized in **Table A.9** for single pass and two pass configurations.

Table A.9 – Design Criteria for RO

Parameter	Units	Single Pass	Two Pass	
			First Pass	Second Pass
Total Influent Flow	MGD	176	188	100
Total Permeate Flow	MGD	150	160	90
Total Concentrate Flow	MGD	26	28	10
Overall System Recovery	%	85%	85%	90%
No. of Skids (Duty + Standby)	--	45 + 3	45 + 3	28 + 2
Influent Flow Per Skid	MGD	3.9	4.2	3.6
Number of Elements Per Vessel	--	7	7	7
Membrane Area per Module	ft^2	400	400	400
RO Feed Pumps, (Duty + Standby)		5 + 1	5 + 1	3 + 1
RO Feed Pump Flow, Each, mgd		36	38	33
Number of Stages		3	3	2
Pressure Vessel Array, Each Skid	--	64:32:21	68:34:22	45:15
Average Flux	gfd	11	11	19

A.8 POST-RO TREATMENT

A.8.1 UV/AOP

The UV-AOP system design criteria is summarized in **Table A.10**, which is based on water quality goals of ≥ 0.5 log reduction of 1,4-dioxane; NDMA, NDEA, and NDPA removal below the DDW's notification level (NL) of 10 ng/L; and 6-log removal each of virus, *Cryptosporidium*, and *Giardia*.

Table A.10 – Design Criteria for UV/AOP

Parameter	Units	Value
Type of UV System	-	Low Pressure - High Output
Oxidant	-	NaOCl
Maximum Oxidant Dose	mg/L	1 to 5
Minimum EED	kWh/kgal	0.36
Minimum UV Dose	mJ/cm^2	1600
Minimum UV Transmittance	%	96
Capacity per UV Reactor	MGD	10
Number of UV Reactors (Duty + Standby)	-	15+3

A.8.2 Stabilization

The stabilization process design criteria, using lime and CO_2 addition, is summarized in **Table A.11**.

Table A.11 – Design Criteria for Stabilization

Parameter	Units	Value
Target Finished Water LSI	-	-0.25 to 0
Stabilization Process	-	Lime Addition + CO_2
Lime Dose	mg/L as $Ca(OH)_2$	30 to 50
Lime Clarifiers	-	3
Lime System Solution Water Pumps	-	3
Lime System Solution Water Pumps, Power, Each	hp	7.5
Total Storage Volume	ton	210
Carbon Dioxide Storage, Total	ton	90
Carbon Dioxide Storage Tank, Each	ton	6

Appendix B SUMMARY OF COST ESTIMATES FOR UNIT PROCESSES

B.1 JWPCP SECONDARY TREATMENT O&M COSTS

The overall O&M cost of $1,040/MGD for JWPCP was obtained from the Sanitation Districts. After consulting with Sanitation Districts' staff, it was assumed that 40% of this cost is associated with secondary treatment at the JWPCP. The O&M cost (added to tertiary processes at AWT Facility) was further adjusted to account for only 180 MGD of water that will be used for the AWT Facility from the daily average of 260 MGD produced from JWPCP.

The breakdown of O&M cost among different O&M categories (labor, power, etc.) was not available and therefore these breakdowns (percentages) were obtained from O&M cost estimates developed for N-only Secondary MBR (Retrofit). **Table B.1** shows the breakdown of JWPCP secondary treatment O&M costs after these percentages were applied to the JWPCP O&M cost for 180 MGD of secondary treatment. JWPCP's secondary treatment does not require any chemical so there is no chemical cost. These costs were added to the tertiary MBR, tertiary BAF and MF trains in the Appendix B cost breakdowns to account for the total O&M cost from primary effluent to RO product water. For example, the power costs presented in **Table B.2** for tertiary MBR includes the power costs for JWPCP shown in **Table B.1**.

Table B.1 – Breakdown of JWPCP Secondary Treatment O&M Costs

	JWPCP Secondary O&M Costs	% of Total O&M Cost
Power, $/yr	$12,551,000	54%
Chemicals, $/yr	$0	0%
Labor, $/yr	$7,205,000	31%
Maintenance, $/yr	$930,000	4%
Replacement Parts, $/yr	$1,395,000	6%
Solids Disposal, $/yr	$1,163,000	5%
Contingency	$0	0%
JWPCP O&M Cost for 180 MGD of Secondary Treatment	$23,244,000	100%

B.2 N-ONLY BIOLOGICAL UNIT PROCESSES

Table B.2 presents the summary of cost estimates for N-only biological unit processes. In order to evaluate these processes with respect to similar effluent water quality, costs for the MF process were added to tertiary BAF process to make it comparable to membrane filtered water produced by secondary and tertiary MBRs. The tertiary MBR and BAF processes also include the O&M cost of JWPCP secondary treatment to account for the total O&M cost from primary effluent through RO.

Table B.2 – Summary of Cost Estimates for N-Only Biological Unit Processes

	Secondary MBR (Retrofit)	Tertiary MBR	Tertiary MBR for Two Pass RO	Tertiary BAF + MF
Construction Costs				
Equipment	$87,694,000	$81,585,000	$86,812,000	$115,668,000
Installation	$35,078,000	$32,634,000	$34,725,000	$46,268,000
Civil	$16,519,000	$43,462,000	$46,362,000	$57,629,000
Electrical & Instrumentation	$39,462,000	$36,713,000	$39,066,000	$52,051,000
Total	**$178,753,000**	**$194,394,000**	**$206,966,000**	**$271,616,000**
Capital Costs				
Contingencies	$53,626,000	$58,318,000	$62,090,000	$81,485,000
Engineering/Legal/Admin	$81,333,000	$88,449,000	$94,169,000	$123,586,000
Land Cost	N/A	$12,500,000	$13,325,000	$11,900,000
Remediation Cost	N/A	$5,000,000	$5,330,000	$4,760,000
Total Capital Cost	**$313,712,000**	**$358,661,000**	**$381,880,000**	**$493,347,000**
Annual O&M Costs				
Power, $/yr	$18,501,000	$24,643,000	$25,565,000	$19,238,000
Chemicals, $/yr	$642,000	$642,000	$685,000	$5,749,000
Labor, $/yr	$8,736,000	$14,693,000	$15,005,000	$19,997,000
Maintenance, $/yr	$1,754,000	$2,562,000	$3,490,000	$3,243,000
Replacement Parts, $/yr	$3,600,000	$4,427,000	$4,630,000	$3,869,000
Solids Disposal, $/yr	$1,584,000	$1,724,000	$1,762,000	$1,754,000
Contingency	$5,229,000	$7,304,000	$7,671,000	$8,077,000
Total O&M Cost, $/yr	**$40,040,000**	**$55,950,000**	**$58,808,000**	**$61,927,000**
Net Present Value				
Net Present Value, $	**$857,869,000**	**$1,119,652,000**	**$1,181,100,000**	**$1,334,956,000**

B.3 N-ONLY BIOLOGICAL UNIT PROCESSES WITH CENTRATE TREATMENT

Table B.3 includes the line item cost of each unit process plus the line item cost of centrate treatment. The differences between the mainstream unit processes with and without centrate along with a detailed breakdown of centrate costs can be found in **Appendix C**.

Table B.3 – Summary of Cost Estimates for N-Only Biological Unit Processes with Centrate Treatment

	Secondary MBR	Tertiary MBR	Tertiary BAF + MF
Construction Costs			
Equipment	$110,645,000	$94,842,000	$117,096,000
Installation	$49,998,000	$43,677,000	$52,579,000
Civil	$33,149,000	$52,582,000	$70,035,000
Electrical & Instrumentation	$56,248,000	$49,137,000	$59,152,000
Total	**$250,040,000**	**$240,238,000**	**$298,862,000**
Capital Costs			
Contingencies	$75,012,000	$72,071,000	$89,659,000
Engineering/Legal/Admin	$113,768,000	$109,308,000	$135,982,000
Land Cost	N/A	$12,800,000	$11,875,000
Remediation Cost	N/A	$5,120,000	$4,750,000
Total Capital Cost	**$438,820,000**	**$439,537,000**	**$541,128,000**
Annual O&M Costs			
Power, $/yr	$19,982,000	$24,644,000	$19,470,000
Chemicals, $/yr	$714,000	$642,000	$5,749,000
Labor, $/yr	$9,360,000	$15,317,000	$20,621,000
Maintenance, $/yr	$2,500,000	$3,114,000	$3,559,000
Replacement Parts, $/yr	$3,600,000	$5,822,000	$3,869,000
Solids Disposal, $/yr	$1,597,000	$1,638,000	$1,663,000
Contingency	$5,663,000	$7,677,000	$8,239,000
Total O&M Cost, $/yr	**$43,416,000**	**$58,854,000**	**$63,170,000**
Net Present Value			
Net Present Value, $	**$1,028,858,000**	**$1,239,383,000**	**$1,399,630,000**

B.4 NDN BIOLOGICAL UNIT PROCESSES

Table B.4 presents the summary of cost estimates for the NdN biological unit processes. BAF process achieves both biological treatment and filtration in a single reactor and therefore, adding a denitrification step requires another set of basins with filtration media. This is unlike a tertiary MBR where water is filtered only once using membranes. The impact of this key difference is prominent in the capital cost of N-only vs NdN configurations for tertiary MBR vs BAF (**Table B.3** vs **Table B.4**).

Table B.4 – Summary of Cost Estimates for NdN Biological Unit Processes

	Secondary MBR (Retrofit)	Secondary MBR	Tertiary MBR	Tertiary BAF + MF
Construction Costs				
Equipment	$94,704,000	$93,123,000	$83,948,000	$156,471,000
Installation	$36,682,000	$37,249,000	$33,579,000	$62,589,000
Civil	$17,689,000	$94,330,000	$60,297,000	$76,833,000
Electrical & Instrumentation	$43,517,000	$41,905,000	$37,777,000	$70,412,000
Total	**$196,592,000**	**$262,441,000**	**$215,601,000**	**$366,305,000**
Capital Costs				
Contingencies	$58,978,000	$79,982,000	$64,680,000	$109,892,000
Engineering/Legal/Admin	$89,450,000	$121,306,000	$98,098,000	$166,669,000
Land Cost	N/A	$29,525,000	$17,550,000	$18,875,000
Remediation Cost	N/A	$11,810,000	$7,020,000	$7,550,000
Total Capital Cost	**$345,020,000**	**$501,919,000**	**$402,949,000**	**$699,291,000**
Annual O&M Costs				
Power, $/yr	$17,260,000	$15,536,000	$24,923,000	$20,037,000
Chemicals, $/yr	$642,000	$642,000	$18,217,000	$24,249,000
Labor, $/yr	$8,736,000	$8,736,000	$14,693,000	$19,997,000
Maintenance, $/yr	$1,934,000	$1,862,000	$2,609,000	$4,059,000
Replacement Parts, $/yr	$3,600,000	$3,600,000	$4,427,000	$3,869,000
Solids Disposal, $/yr	$1,327,000	$1,195,000	$2,045,000	$2,048,000
Contingency	$5,025,000	$4,736,000	$10,037,000	$11,000,000
Total O&M Cost, $/yr	**$38,524,000**	**$36,307,000**	**$76,951,000**	**$85,397,000**
Net Present Value				
Net Present Value, $	**$868,574,000**	**$1,002,654,000**	**$1,448,739,000**	**$1,829,865,000**

B.5 NDN BIOLOGICAL UNIT PROCESSES WITH CENTRATE TREATMENT

Table B.5 presents the summary of cost estimates for the NdN biological unit processes with centrate treatment.

Table B.5 – Summary of Cost Estimates for NdN Biological Unit Processes with Centrate Treatment

	Secondary MBR (Retrofit)	Tertiary MBR	Tertiary BAF + MF
Construction Costs			
Equipment	$118,523,000	$96,617,000	$145,129,000
Installation	$53,149,000	$44,387,000	$63,792,000
Civil	$34,319,000	$64,988,000	$83,099,000
Electrical & Instrumentation	$59,793,000	$49,936,000	$71,767,000
Total	**$265,784,000**	**$255,928,000**	**$363,787,000**
Capital Costs			
Contingencies	$79,735,000	$76,778,000	$109,136,000
Engineering/Legal/Admin	$120,932,000	$116,447,000	$165,523,000
Land Cost	N/A	$16,850,000	$17,450,000
Remediation Cost	N/A	$6,740,000	$6,980,000
Total Capital Cost	**$466,451,000**	**$472,743,000**	**$662,876,000**
Annual O&M Costs			
Power, $/yr	$19,136,000	$24,831,000	$19,711,000
Chemicals, $/yr	$714,000	$13,454,000	$19,235,000
Labor, $/yr	$9,360,000	$15,317,000	$20,621,000
Maintenance, $/yr	$2,657,000	$3,149,000	$4,120,000
Replacement Parts, $/yr	$3,600,000	$5,822,000	$3,869,000
Solids Disposal, $/yr	$1,339,000	$1,840,000	$1,876,000
Contingency	$5,521,000	$9,662,000	$10,313,000
Total O&M Cost, $/yr	**$42,327,000**	**$74,075,000**	**$79,846,000**
Net Present Value			
Net Present Value, $	**$1,041,689,000**	**$1,479,447,000**	**$1,748,010,000**

B.6 MEMBRANE FILTRATION

Table B.6 presents the summary of cost estimates for MF process for different train variants. The centrate cost is included in the MF + RO Train w/centrate train resulting in the cost difference between the MF + RO and MF + RO w/centrate trains. The cost difference between the MF + RO and MF + Two Pass RO train accounts for additional influent flow to the MF to make up for additional brine losses associated with the second pass of the two pass RO system.

Table B.6 – Summary of Cost Estimates for MF

	MF + RO Train	MF + RO Train w/Centrate	MF + Two Pass RO Train
Construction Costs			
Equipment	$55,699,000	$70,049,000	$59,413,000
Installation	$22,280,000	$28,020,000	$23,765,000
Civil	$24,486,000	$41,116,000	$26,120,000
Electrical & Instrumentation	$25,065,000	$31,522,000	$26,736,000
Total	**$127,530,000**	**$170,707,000**	**$136,034,000**
Capital Costs			
Contingencies	$38,259,000	$51,212,000	$40,810,000
Engineering/Legal/Admin	$58,026,000	$77,672,000	$61,895,000
Land Cost	$2,975,000	$2,975,000	$3,150,000
Remediation Cost	$1,190,000	$1,190,000	$1,260,000
Total Capital Cost	**$227,980,000**	**$303,756,000**	**$243,149,000**
Annual O&M Costs			
Power, $/yr	$14,722,000	$15,840,000	$15,704,000
Chemicals, $/yr	$5,749,000	$5,749,000	$6,133,000
Labor, $/yr	$12,509,000	$20,338,000	$5,616,000
Maintenance, $/yr	$2,044,000	$2,331,000	$1,188,000
Replacement Parts, $/yr	$4,576,000	$5,971,000	$4,882,000
Solids Disposal, $/yr	$1,163,000	$1,163,000	$1,241,000
Contingency	$6,114,000	$7,709,000	$5,215,000
Total O&M Cost, $/yr	**$46,877,000**	**$59,101,000**	**$39,979,000**
Net Present Value			
Net Present Value, $	**$865,054,000**	**$1,106,958,000**	**$786,477,000**

B.7 REVERSE OSMOSIS

Table B.7 presents the associated line costs for single pass RO and two pass RO. Two pass RO is only utilized in Trains 4C and 2E.

Table B.7 – Summary of Cost Estimates for RO

	RO (Single Pass)	Two Pass RO
Construction Costs		
Equipment	$73,937,000	$102,898,000
Installation	$29,575,000	$41,159,000
Civil	$44,787,000	$62,470,000
Electrical & Instrumentation	$33,272,000	$46,304,000
Total	**$181,571,000**	**$252,831,000**
Capital Costs		
Contingencies	$54,471,000	$75,850,000
Engineering/Legal/Admin	$82,615,000	$115,038,000
Land Cost	$6,500,000	$9,075,000
Remediation Cost	$2,600,000	$3,630,000
Total Capital Cost	**$327,757,000**	**$456,424,000**
Annual O&M Costs		
Power, $/yr	$16,525,000	$26,991,000
Chemicals, $/yr	$13,006,000	$14,286,000
Labor, $/yr	$5,616,000	$7,488,000
Maintenance, $/yr	$1,479,000	$2,058,000
Replacement Parts, $/yr	$5,066,000	$6,403,000
Solids Disposal, $/yr	$-	$-
Contingency	$6,254,000	$8,584,000
Total O&M Cost, $/yr	**$47,946,000**	**$65,810,000**
Net Present Value		
Net Present Value, $	**$979,359,000**	**$1,350,804,000**

B.8 POST-RO TREATMENT

Table B.8 presents cost summary for post-RO treatment processes including UV/AOP and post-stabilization.

Table B.8 – Summary of Cost Estimates for Post-RO Treatment

	UV/AOP	Post-Stabilization
Construction Costs		
Equipment	$15,196,000	$5,051,000
Installation	$6,078,000	$2,021,000
Civil	$8,780,000	$2,092,000
Electrical & Instrumentation	$6,838,000	$2,273,000
Total	**$36,892,000**	**$11,437,000**
Capital Costs		
Contingencies	$11,068,000	$3,432,000
Engineering/Legal/Admin	$16,786,000	$5,205,000
Land Cost	$2,075,000	$1,925,000
Remediation Cost	$830,000	$770,000
Total Capital Cost	**$67,651,000**	**$22,769,000**
Annual O&M Costs		
Power, $/yr	$2,460,000	$168,000
Chemicals, $/yr	$701,000	$6,226,000
Labor, $/yr	$1,872,000	$624,000
Maintenance, $/yr	$304,000	$101,000
Replacement Parts, $/yr	$1,067,000	$-
Solids Disposal, $/yr	$-	$-
Contingency	$961,000	$1,068,000
Total O&M Cost, $/yr	**$7,365,000**	**$8,187,000**
Net Present Value		
Net Present Value, $	**$167,744,000**	**$134,034,000**

B.9 CENTRATE TREATMENT

Table B.9 presents cost summary for centrate treatment processes. Each line item shown in **Table B.9** was added to the unit processes line items in **Table B.3** and **Table B.5** to obtain the unit process cost estimates for processes with centrate treatment.

Table B.9 – Summary of Cost Estimates for Centrate Treatment

Construction Costs	
Equipment	$14,350,000
Installation	$5,740,000
Civil	$16,630,000
Electrical & Instrumentation	$6,458,000
Total	**$43,178,000**
Capital Costs	
Contingencies	$12,954,000
Engineering/Legal/Admin	$19,647,000
Land Cost	N/A
Remediation Cost	N/A
Total Capital Cost	**$75,779,000**
Annual O&M Costs	
Power, $/yr	$1,118,000
Chemicals, $/yr	N/A
Labor, $/yr	$624,000
Maintenance, $/yr	$287,000
Replacement Parts, $/yr	N/A
Solids Disposal, $/yr	N/A
Contingency	$305,000
Total O&M Cost, $/yr	**$2,334,000**
Net Present Value	
Net Present Value, $	**$107,499,000**

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Appendix C COST BREAKDOWN FOR UNIT PROCESSES

C.1 EQUIPMENT

The cost shown as total w/centrate in **Table C.1, Table C.2** and **Table C.3** include only the cost for mainstream equipment; this cost is added to the centrate cost in the cost breakdowns in **Appendix B**. The MF equipment cost is not impacted with centrate treatment since it only lowers the nitrogen loading and not the hydraulic loading.

Table C.1 – Equipment Cost Breakdown for N-Only Secondary and Tertiary MBR Processes

Process Area	Equipment	Capacity (each)	Cost per Unit	N-only Secondary MBR (Retrofit)		N-only Tertiary MBR		N-only Tertiary MBR for Two Pass RO	
				No. of Units	Total Cost	No. of Units	Total Cost	No. of Units	Total Cost
Drum Screen & Influent Pump Station	Influent Pumps	20 mgd	$110,000	N/A	N/A	11	$1,210,000	12	$1,320,000
	Drum Screen	60 mgd	$1,200,000	4	$4,800,000	3	$3,600,000	3	$3,600,000
Aeration	Process Aeration Blowers	8,570 cfm	$225,000	12	$2,700,000	15	$3,375,000	16	$3,600,000
Membrane System	Membranes & Cassettes, Membrane Filtrate Pumps, RAS Pumps, Air Compressors, Instrumentation, Backwash Pumps, Membrane Blowers	N/A	N/A	N/A	$78,480,000	N/A	$70,680,000	N/A	$75,392,000
Additional Items	Diffusers	N/A	$40	42,840	$1,714,000	41,868	$1,675,000	44,659	$1,787,000
	Superstructure Specialties	N/A	N/A	N/A	N/A	N/A	$515,000	N/A	$565,000
	Sluice Gates	N/A	$53,000	N/A	N/A	10	$530,000	N/A	N/A
			TOTAL		**$87,694,000**		**$81,585,000**		**$86,813,000**
			TOTAL w/CENTRATE		**$96,295,000**		**$80,492,000**		**--**

Table C.2 – Equipment Cost Breakdown for NdN Secondary and Tertiary MBR Processes

Process Area	Equipment	Capacity (each)	Cost per Unit	NdN Secondary MBR (Retrofit)		NdN Secondary MBR		NdN Tertiary MBR	
				No. of Units	Total Cost	No. of Units	Total Cost	No. of Units	Total Cost
Drum Screen & Influent Pump Station	Influent Pumps	20 mgd	$110,000	N/A	N/A	11	$1,210,000	11	$1,210,000
	Drum Screen	60 mgd	$1,200,000	4	$4,800,000	3	$3,600,000	3	$3,600,000
Anoxic Basins	Mixers	25 hp	$62,000	36	$2,232,000	24	$1,488,000	12	$744,000
	Mixers	1.6 hp	$15,000	104	$1,560,000	0	N/A	0	N/A
Aeration	Process Aeration Blowers	8,570 cfm	$225,000	28	$6,300,000	21	$4,725,,000	15	$3,375,000
Membrane System	Membranes & Cassettes, Membrane Filtrate Pumps, RAS Pumps, Air Compressors, Instrumentation, Backwash Pumps, Membrane Blowers	N/A	N/A	N/A	$78,480,000	N/A	$78,480,000	N/A	$70,680,000
Additional Items	Diffusers	N/A	$40	83,300	$3,332,000	64,368	$2,575,000	47,850	$1,914,000
	Superstructure Specialties	N/A	N/A	N/A	N/A	N/A	$515,000	N/A	$597,000
	Sluice Gates	N/A	$53,000	N/A	N/A	10	$530,000	10	$530,000
	MicroC 2000 Storage & Dosing	N/A	N/A	N/A	N/A	N/A	N/A	N/A	$1,298,000
			TOTAL		**$96,704,000**		**$93,123,000**		**$83,948,000**
			TOTAL w/CENTRATE		**$104,173,000**		**--**		**$82,267,000**

Table C.3 – Equipment Cost Breakdown for N-only and NdN BAF Processes

Process Area	Equipment	Capacity (each)	Cost per Unit	N-only Tertiary BAF		NdN Tertiary BAF	
				No. of Units	Total Cost	No. of Units	Total Cost
Aeration	Blowers	Included in BAF System					
Backwash	Sludge Pumps	Included in BAF System					
BAF System	Biostyr System	N/A	N/A	N/A	$63,872,000	N/A	$106,326,000
Additional Items	Sluice Gates	N/A	$53,000	10	$530,000	10	$530,000
	Superstructure Specialties	N/A	N/A	N/A	$205,000	N/A	$269,000
	MicroC 2000 Storage & Dosing	N/A	N/A	N/A	N/A	N/A	$1,366,000
			TOTAL		**$59,969,000**		**$100,771,000**
			TOTAL w/CENTRATE		**$47,047,000**		**$75,080,000**

Table C.4 – Equipment Cost Breakdown for MF Processes

Process Area	Equipment	Capacity (each)	Cost per Unit	MF for BAF + MF + RO, MF + RO and, MF + RO with Centrate		MF for MF + Two Pass RO	
				No. of Units	Total Cost	No. of Units	Total Cost
Influent Pump Station	Influent Pumps	20 mgd	$110,000	11	$1,210,000	11	$1,210,000
MF System Equipment	Membrane Blowers	1,052 cfm	N/A	8	$44,550,000	9	$47,520,000
	Permeate Pumps	5,239 gpm	N/A	28		30	
	Backpulse Pumps	6,911 gpm	N/A	8		9	
	Drain/Recirculation Pumps	2,544 gpm	N/A	8		9	
	CIP Tank Heater	183 kW	N/A	4		5	
	Compressor	162 cfm	N/A	8		9	
	CIP Tanks	11,000 gal	$60,000	4	$240,000	5	$256,000
Additional Items	Superstructure Specialties	N/A		N/A	$9,699,000	N/A	$10,346,000
			TOTAL		**$55,699,000**		**$59,332,000**

Table C.5 – Equipment Cost Breakdown for RO Processes

Process Area	Equipment	RO		Two Pass RO - 1st Pass		Two Pass RO - 2nd Pass	
		No. of Units	Total Cost	No. of Units	Total Cost	No. of Units	Total Cost
RO System	RO Feed Pumps	6	$2,220,000	6	$2,368,000	4	$1,258,000
	Cartridge Filters	64	$2,300,000	64	$2,453,000	N/A	N/A
	RO Skids + Booster Pumps	48	$58,080,000	48	$61,952,000	30	$19,054,000
	RO CIP Tanks	7	$700,000	7	$747,000	4	$230,000
	RO Flush Tank Superstructure	N/A	$80,000	N/A	$85,000	N/A	$26,000
Additional Items	Superstructure Specialties	N/A	$10,557,000	N/A	$11,261,000	N/A	$3,463,000
		TOTAL	**$73,937,000**		**$78,866,000**		**$24,031,000**

Table C.6 – Equipment Cost Breakdown for UV/AOP

Process Area	Equipment	Capacity (each)	Cost per Unit	UV/AOP	
				No. of Units	Total Cost
UV/AOP System	UV Reactors + Controls	10 mgd	N/A	18	$11,300,000
Additional Items	Superstructure Specialties	N/A	N/A	N/A	$3,896,000
			TOTAL		**$15,196,000**

Table C.7 – Equipment Cost Breakdown for Stabilization

Process Area	Equipment	Capacity (each)	Cost per Unit	Stabilization	
				No. of Units	Total Cost
Lime System	Lime Silos, Slaking System	N/A	N/A	3	$2,746,000
Lime System Clarifiers	Lime Clarifiers	N/A	N/A	3	$1,050,000
	Solution Water Pumps	N/A	N/A	7	$114,000
CO2 System	CO_2 Feed System	N/A	N/A		$700,000
Additional Items	Superstructure Specialties	N/A	N/A	N/A	$441,000
			TOTAL		**$5,051,000**

Table C.8 – Equipment Cost Breakdown for Centrate Treatment

Process Area	Equipment	Capacity (each)	Cost per Unit	Stabilization	
				No. of Units	Total Cost
Influent Pump Station	Influent Pumps	N/A	$225,000	2	$450,000
Centrate Equipment	Centrate Equipment	N/A	N/A	N/A	$13,900,000
			TOTAL		**$14,350,000**

C.2 CIVIL

Table C.9 – Civil Cost Breakdown for Unit Processes

Unit Process		Civil Costs	Process Piping	Yard Piping	Site Development	Total Cost
N-Only	Secondary MBR (Retrofit)	$12,779,000	$3,320,000	N/A	$420,000	**$16,519,000**
	Tertiary MBR	$20,103,000	$17,476,000	$1,416,000	$4,467,000	**$43,462,000**
	Tertiary MBR + Two Pass RO	$21,444,000	$18,642,000	$1,511,000	$4,765,000	**$46,362,000**
	Tertiary BAF	$22,354,000	$8,700,000	$793,000	$1,296,000	**$33,143,000**
N-Only with Centrate	Secondary MBR (Retrofit)	$12,779,000	$3,320,000	N/A	$420,000	**$16,519,000**
	Tertiary MBR	$16,629,000	$14,456,000	$1,172,000	$3,695,000	**$35,952,000**
	Tertiary BAF	$18,491,000	$8,700,000	$656,000	$1,072,000	**$28,919,000**
NdN	Secondary MBR (Retrofit)	$13,949,000	$3,320,000	N/A	$420,000	**$17,689,000**
	Secondary MBR	$44,980,000	$42,603,000	$2,280,000	$4,467,000	**$94,330,000**
	Tertiary MBR	$28,516,000	$25,898,000	$1,416,000	$4,467,000	**$60,297,000**
	Tertiary BAF	$39,917,000	$8,700,000	$1,416,000	$2,314,000	**$52,347,000**
NdN with Centrate	Secondary MBR (Retrofit)	$13,949,000	$3,320,000	N/A	$420,000	**$17,689,000**
	Tertiary MBR	$22,869,000	$20,770,000	$1,136,000	$3,583,000	**$48,358,000**
	Tertiary BAF	$32,013,000	$6,978,000	$1,136,000	$1,856,000	**$41,983,000**
Submerged MF	MF (for BAF train)	$8,688,000	$11,390,000	$1,710,000	$2,698,000	**$24,486,000**
	MF + RO	$8,688,000	$11,390,000	$1,710,000	$2,698,000	**$24,486,000**
	MF + RO with Centrate	$8,688,000	$11,390,000	$1,710,000	$2,698,000	**$24,486,000**
	MF + Two Pass RO	$9,268,000	$12,150,000	$1,824,000	$2,878,000	**$26,120,000**
RO	Single Pass RO	$12,108,000	$29,029,000	$1,416,000	$2,234,000	**$44,787,000**
	Two Pass RO	$16,889,000	$40,489,000	$1,976,000	$3,116,000	**$62,470,000**
UV/AOP		$2,660,000	$3,587,000	$1,416,000	$1,117,000	**$8,780,000**
Stabilization		$875,000	$100,000	N/A	$1,117,000	**$2,092,000**
Centrate		$13,156,000	$604,000	$1,435,000	$1,435,000	**$16,630,000**

C.3 LAND AND REMEDIATION

Table C.10 – Land and Remediation Costs for Unit Processes

Unit Process		Total Estimated Footprint (acre)	Land Cost	Remediation Cost
N-Only	Secondary MBR (Retrofit)	--	N/A	N/A
	Tertiary MBR	5.00	$12,500,000	$5,000,000
	Tertiary MBR for Two Pass RO	5.33	$13,325,000	$5,330,000
	Tertiary BAF	3.57	$8,925,000	$3,570,000
N-Only with Centrate	Secondary MBR (Retrofit)	--	N/A	N/A
	Tertiary MBR	5.12	$12,800,000	$5,120,000
	Tertiary BAF	3.56	$8,900,000	$3,560,000
NdN	Secondary MBR (Retrofit)	--	N/A	N/A
	Secondary MBR	11.81	$29,525,000	$11,810,000
	Tertiary MBR	7.02	$17,550,000	$7,020,000
	Tertiary BAF	6.36	$15,900,000	$6,360,000
NdN with Centrate	Secondary MBR (Retrofit)	--	N/A	N/A
	Tertiary MBR	6.74	$16,850,000	$6,740,000
	Tertiary BAF	5.79	$14,475,000	$5,790,000
Submerged MF	MF (for BAF train)	1.19	$2,975,000	$1,190,000
	MF + RO	1.19	$2,975,000	$1,190,000
	MF + RO with Centrate	1.19	$2,975,000	$1,190,000
	MF + Two Pass RO	1.26	$3,150,000	$1,260,000
RO	Single Pass RO	2.6	$6,500,000	$2,600,000
	Two Pass RO	3.63	$9,075,000	$3,630,000
UV/AOP		0.83	$2,075,000	$830,000
Stabilization		0.77	$1,925,000	$770,000

C.4 POWER

Equipment online factor of 95% was applied to all process equipment when calculating the total power consumption. **Table C.11** presents the equipment power consumption for N-only MBR processes. The N-only Secondary MBR includes the power consumption for the current oxygenation system at the JWPCP HPOAS reactors, as that system would still be used for the process. The power cost for JWPCP for tertiary MBR processes (not shown in the table) is added in the power costs shown in Appendix B.

Table C.11 – Equipment Power Consumption for N-Only MBR Processes

Process Area	Equipment	Power per Unit (hp)	N-Only Secondary MBR (Retrofit)			N-Only Tertiary MBR			N-Only Tertiary MBR for Two Pass RO		
			No. of Units On-line	Total Power (hp)	Energy (kWh)	No. of Units On-line	Total Power (hp)	Energy (kWh)	No. of Units On-line	Total Power (hp)	Energy (kWh)
Drum Screen & Influent Pump Station	Influent Pumps	100	--	--	--	9	900	5,585,000	10	1,000	6,206,000
	Drum Screen	5	4	20	124,000	3	15	93,000	3	15	93,000
Aeration	Process Aeration Blowers	400	8	3,200	19,858,000	12	4,800	29,787,000	13	5,200	32,270,000
	Oxygenation System*	400	22	8,800	54,610,000	--	--	--	--	--	--
Membrane System	Membrane Blowers	120	34	4,080	25,319,000	30	3,600	22,341,000	32	3,840	23,830,000
Additional Items	Membrane Filtrate Pumps	25	52	1,300	8,067,000	24	1,200	7,447,000	26	1,300	8,067,000
	Return Activated Sludge Pumps	75	32	2,400	14,894,000	32	2,400	14,894,000	34	2,550	15,825,000
	Air Compressors	75	1	75	465,000	1	75	465,000	1	75	465,000
TOTAL					**123,337,000**			**80,612,000**			**86,756,000**
TOTAL w/CENTRATE					**125,756,000**			**73,166,000**			**--**

Table C.12 – Equipment Power Consumption for NdN MBR Processes

Process Area	Equipment	Power per Unit (hp)	NdN Secondary MBR (Retrofit)			NdN Secondary MBR			NdN Tertiary MBR		
			No. of Units On-line	Total Power (hp)	Energy (kWh)	No. of Units On-line	Total Power (hp)	Energy (kWh)	No. of Units On-line	Total Power (hp)	Energy (kWh)
Drum Screen & Influent Pump Station	Influent Pumps	100	--	--	--	9	900	5,585,000	9	900	5,585,000
	Drum Screen	5	4	20	124,000	3	15	93,000	3	15	93,000
Anoxic Basins	Mixers	25	36	900	5,585,000	23	575	3,723,000	11	275	1,862,000
	Mixers	1.6	104	166	1,033,000	--	--	--	--	--	--
Aeration	Process Aeration Blowers	400	24	9,600	59,575,000	18	7,200	44,681,000	12	4,800	29,787,000
Membrane System	Membrane Blowers	120	34	4,080	25,319,000	35	4,200	26,064,000	30	3,600	22,341,000
	Membrane Filtrate Pumps	25	52	1,300	8,067,000	52	1,300	8,067,000	24	1,200	7,447,000
	Return Activated Sludge Pumps	75	36	2,700	14,894,000	32	2,400	14,894,000	32	2,400	14,894,000
	Air Compressors	75	1	75	465,000	1	75	465,000	1	75	465,000
TOTAL					**115,062,000**			**103,572,000**			**82,474,000**
TOTAL w/CENTRATE					**120,120,000**			**--**			**74,407,000**

Table C.13 – Equipment Power Consumption for Tertiary BAF Processes

Process Area	Equipment	Power per Unit (hp)	N-Only Tertiary BAF			NdN Tertiary BAF		
			No. of Units On-line	Total Power (hp)	Energy (kWh)	No. of Units On-line	Total Power (hp)	Energy (kWh)
Aeration	Blowers	700	7	4,900	29,625,000	7	4900	29,625,000
Backwash	Sludge Pumps	80	6	480	2,902,000	12	960	5,804,000
		TOTAL			**32,527,000**			**35,429,000**
		TOTAL w/CENTRATE			**26,143,000**			**27,876,000**

Table C.14 – Equipment Power Consumption for MF Processes

Process Area	Equipment	Power per Unit (hp)	MF for BAF + MF +RO, MF + RO and, MF + RO with Centrate			MF for Two Pass RO		
			No. of Units On-line	Total Power (hp)	Energy (kWh)	No. of Units On-line	Total Power (hp)	Energy (kWh)
Influent Pump Station	Influent Pumps	100	9	900	5,879,000	9	900	5,879,000
MF System	Membrane Equipment (Membrane & Cassettes, Instrumentation and Control)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Membrane Blowers	50	4	200	224,000	4	210	239,000
	Permeate Pumps	100	28	2,800	6,975,000	28	2990	7,440,000
	Backpulse Pumps	125	4	500	77,000	4	530	82,000
	Drain/Recirculation Pumps	25	4	100	182,000	4	110	194,000
	CIP Tank Heater	245	4	980	599,000	4	1050	639,000
	Compressor	92	4	369	534,000	4	390	570,000
	CIP Tanks	N/A	4	N/A	N/A	4	N/A	N/A
		TOTAL			**14,470,000**			**15,043,000**

Table C.15 – Equipment Power Consumption for RO Processes

Process Area	Equipment	RO			Two Pass RO - First Pass			Two Pass RO - Second Pass		
		No. of Units On-line	Max Total Power (hp)	Energy (kWh)	No. of Units On-line	Max Total Power (hp)	Energy (kWh)	No. of Units On-line	Max Total Power (hp)	Energy (kWh)
RO System	RO Feed Pumps	5	2,178	110,161,000	5	2,324	117,505,000	3	1,234	62,425,000
	RO First Stage Booster Pumps	45	14,853		45	8,599		28	17,938	
	RO Third Stage Booster Pumps	45	491		45	593		N/A	N/A	
	RO CIP Tanks / Pumps	5	1,400		N/A	1,493		N/A	2,359	
TOTAL				**110,161,000**			**117,505,000**			**62,425,000**

Table C.16 – Equipment Power Consumption for UV/AOP

Process Area	Equipment	Power per Unit (hp)	UV/AOP		
			No. of Units On-line	Total Power (hp)	Energy (kWh)
UV/AOP System	UV Reactors + Controls	174	15	2,615	16,399,000
TOTAL					**16,399,000**

Table C.17 – Equipment Power Consumption for Stabilization

Process Area	Equipment	Stabilization Energy (kWh)
Lime System	Lime Silos, Slaking System	1,114,000
Lime System Clarifiers	Lime Clarifiers	
	Solution Water Pumps	
CO2 System	CO_2 Feed System	
	TOTAL	**1,114,000**

Table C.18 – Equipment Power Consumption for Centrate Treatment

Process Area	Equipment	Power per Unit (hp)	Centrate*		
			No. of Units On-line	Total Power (hp)	Energy (kWh)
Influent Pump Station	Influent Pumps	45	2	90	588,000
Aeration	Blowers	150	7	1050	6,859,000
	TOTAL				**7,447,000**

*Mixers are used intermittently under startup and maintenance conditions, therefore, power per unit value is not accounted for due to minimal annual impact

C.5 CHEMICALS

Chemical costs are calculated using the average doses for major chemical feed systems during the course of normal operation over one year. **Table C.19** summarizes the chemicals included in this analysis, the estimated chemical costs, the sources of those costs and the uses for each chemical.

Table C.20 summarizes the chemical costs for each unit process, including assumptions, annual usage and cost.

Table C.19 – Unit Costs, Concentrations and Applications for Chemicals

Chemical	Concentration	Unit Cost	Uses
Ammonium sulfate	40%	$3.54/gal[1]	Chloramine formation
Antiscalant	100%	$8.63/gal[2]	RO scaling control
Carbon dioxide	N/A	$0.08/lb[3]	Product water stabilization
MicroC 2000	100%	$1.50/gal[4]	Carbon source for denitrification
Caustic Soda	25%,	$1.39/gal[5]	RO cleaning
Citric acid	50%	$5.05/gal[5]	MBR/MF/RO cleaning
Hydrated lime	N/A	$0.25/lb[5]	Product water stabilization
Hydrochloric acid	33%	$1.8/gal[6]	MF cleaning
Sodium bisulfite	25%	$1.10/gal[7]	Neutralizing MBR/MF/RO cleaning solutions
Sodium Hypochlorite	12.50%	$0.62/gal[8]	Chloramine formation, MBR/MF cleaning, oxidant for AOP, and disinfection
Sulfuric acid	93%	$1.84/gal[5]	RO scaling control

Notes:
[1] Price from Brenntag Pacific (Santa Fe Springs, CA)
[2] Price for Vitec 1400 from Avista Technologies (San Marcos, CA)
[3] Price from Burnett, Inc. (Campobello, SC) for carbon dioxide from Airgas (Long Beach, CA)
[4] Price for MicroC 2000 from Environmental Operating Solutions, Inc. (Bourne, MA)
[5] Price from Brenntag Pacific (Santa Fe Springs, CA)
[6] Price from Univar USA (Santa Fe Springs, CA)
[7] Price from Olin Chlor Alkali Products (Santa Fe Springs, CA)

Table C.20 – Annual Consumption and Costs for Chemicals

System	Chemical	Purpose	Assumptions	Quoted Annual Usage (US gal/yr)	Rounded Annual Cost	Rounded Annual Cost by System
N-only Secondary MBR, NdN Secondary MBR, N-only Tertiary MBR	Sodium Hypochlorite	Membrane cleaning	Maintenance Clean: daily @ 200 mg/L Recovery clean: 2 per year @ 1,000 mg/L	139,160	$86,000	$642,000
	Citric Acid	Membrane cleaning	Maintenance clean: 1 per week @ 2,000 mg/L Recovery clean: 2 per year @ 2,000 mg/L	106,740	$539,000	
	Sodium Bisulfite	Neutralizes sodium hypochlorite	Sufficient to neutralize remaining 30% sodium hypochlorite	15,188	$17,000	
NdN Tertiary MBR	Sodium Hypochlorite	Membrane cleaning	Maintenance Clean: daily @ 200 mg/L Recovery clean: 2 per year @ 1,000 mg/L	139,160	$86,000	$18,217,000
	Citric Acid	Membrane cleaning	Maintenance clean: 1 per week @ 2,000 mg/L Recovery clean: 2 per year @ 2,000 mg/L	106,740	$539,000	
	Sodium Bisulfite	Neutralizes sodium hypochlorite	Sufficient to neutralize remaining 30% sodium hypochlorite	15,188	$17,000	
	MicroC 2000	Carbon source	32,100 gpd	11,716,500	$17,575,000	
NdN Tertiary MBR with Centrate	MicroC 2000	Carbon source	23,400 gpd	8,541,000	$12,812,000	$13,454,000
NdN Tertiary BAF	MicroC 2000	Carbon source	33,790 gpd	12,333,158	$18,500,000	$18,500,000
NdN Tertiary BAF with Centrate	MicroC 2000	Carbon source	24,630 gpd	8,990,526	$13,486,000	$13,486,000
MF (MF + RO and MF + RO with Centrate)	Sodium Hypochlorite	Membrane cleaning	Maintenance Clean: daily @ 250 mg/L Recovery clean: 12 per year @ 500 mg/L	196,488	$122,000	$5,749,000
	Citric Acid	Membrane cleaning	Recovery clean: 12 per year @ 2,000 mg/L	22,662	$114,000	

System	Chemical	Purpose	Assumptions	Quoted Annual Usage (US gal/yr)	Rounded Annual Cost	Rounded Annual Cost by System
	Hydrochloric Acid	Membrane cleaning	Recovery cleans: 12 per year per membrane train @ 250 mg/L HCl to reduce pH to 2.2	2,217	$4,000	
	Sodium Bisulfite	Neutralize sodium hypochlorite	Sufficient to neutralize remaining NaOCl	47,190	$52,000	
	Sodium Hypochlorite	Chloramine formation	Target dose of 8 mg/L upstream of MF	1,859,423	$1,153,000	
	Ammonium Sulfate	Chloramine formation	Assumes mass ratio for chlorine to ammonia is 4.3:1	1,214,906	$4,304,000	
Submerged MF (Two Pass RO Train)	Sodium Hypochlorite	Membrane cleaning	Maintenance Clean: daily @ 250 mg/L Recovery clean: 12 per year @ 500 mg/L	209,587	$130,000	$6,132,000
	Citric Acid	Membrane cleaning	Recovery clean: 12 per year @ 2,000 mg/L	24,173	$122,000	
	Hydrochloric Acid	Membrane cleaning	Recovery cleans: 12 per year per membrane train @ 250 mg/L HCl to reduce pH to 2.2	2,365	$4,000	
	Sodium Bisulfite	Neutralize sodium hypochlorite	Sufficient to neutralize remaining NaOCl	50,336	$55,000	
	Sodium Hypochlorite	Chloramine formation	Target dose of 8 mg/L upstream of MF	1,983,384	$1,230,000	
	Ammonium Sulfate	Chloramine formation	Assumes mass ratio chlorine to ammonia is 4.3:1	1,295,899	$4,591,000	
RO	Sulfuric Acid	Scaling prevention and CIP neutralization	Target dose of 50 mg/L; neutralization of 75% of sodium hydroxide CIP	2,082,558	$3,832,000	$13,006,000
	Antiscalant	Scaling prevention	Target dose of 3 mg/L	167,583	$1,447,000	

System	Chemical	Purpose	Assumptions	Quoted Annual Usage (US gal/yr)	Rounded Annual Cost	Rounded Annual Cost by System
	Citric Acid	Membrane cleaning	CIP: 12 per year stage 3 cleans @ 2%, 2 per year stage 1 and 2 cleans @ 2%	156,000	$788,000	
	Sodium Hydroxide	Membrane cleaning and CIP neutralization	CIP: 12 per year stage 3 cleans @ 2%, 4 per year for stage 1 and 2 cleans @ 2%; Neutralization of 75% of citric acid CIP	487,863	$678,000	
	Sodium Hypochlorite	Chloramine formation	Target dose of 4 mg/L upstream of RO for MBR-RO trains	1,833,290	$2,017,000	
	Ammonium Sulfate	Chloramine formation	Assumes mass ratio chlorine to ammonia is 4.3:1	1,197,831	$4,244,000	
Two Pass RO - First Pass	Sulfuric Acid	Scaling prevention	Target dose of 50 mg/L; neutralization of 75% of sodium hydroxide CIP	2,221,396	$4,087,000	$13,871,000
	Anitscalant	Scaling prevention	Target dose of 3 mg/L	178,755	$1,543,000	
	Citric Acid	Membrane cleaning	CIP: 12 per year stage 3 cleans @ 2%, 2 per year stage 1 and 2 cleans @ 2%	166,400	$840,000	
	Sodium Hydroxide	Membrane cleaning and CIP neutralization	CIP: 12 per year stage 3 cleans @ 2%, 4 per year for stage 1 and 2 cleans @ 2%; Neutralization of 75% of citric acid CIP	520,387	$723,000	
	Sodium Hypochlorite	Chloramine formation	Target dose of 8 mg/L upstream of MF for MF-RO-AOP trains; Target dose of 4 mg/L upstream of RO for MBR-RO-AOP trains	1,955,510	$2,151,000	
	Ammonium Sulfate	Chloramine formation	Assumes mass ratio chlorine to ammonia is 4.3:1	1,277,687	$4,527,000	
Two Pass RO - Second Pass	Sulfuric Acid	Scaling prevention	No pH adjustment required since treating RO permeate	1,180,116	$-	$415,000

System	Chemical	Purpose	Assumptions	Quoted Annual Usage (US gal/yr)	Rounded Annual Cost	Rounded Annual Cost by System
	Anitscalant	Scaling prevention	No antiscalant required since treating RO permeate	94,963	$-	
	Citric Acid	Membrane cleaning	Cleaning frequency assumed half as much as first pass RO	44,200	$223,000	
	Sodium Hydroxide	Membrane cleaning	Cleaning frequency assumed half as much as first pass RO	138,228	$192,000	
	Sodium Hypochlorite	Chloramine formation	No additional chloramine required since treating RO permeate	1,038,864	$-	
	Ammonium Sulfate	Chloramine formation	No additional chloramine required since treating RO permeate	678,771	$-	
UV/AOP	Sodium Hypochlorite	Oxidant	Target dose of 3 mg/L	1,130,730	$701,000	$701,000
Stabilization	Lime		Target dose of 30-60 mg/L	21,900,000	$5,475,000	$6,226,000
	Carbon Dioxide		Average consumption of 1,070 lb/hr	9,386,000	$751,000	

C.6 LABOR

Table C.21 – Labor Costs for Unit Processes

Unit Process		Estimated Number of Staff	Total Cost
N-Only	Secondary MBR (Retrofit)	28	$8,736,000
	Tertiary MBR	24	$7,488,000
	Tertiary MBR + Two Pass RO	25	$7,800,000
	Tertiary BAF	24	$7,488,000
N-Only with Centrate	Secondary MBR (Retrofit)	28	$8,736,000
	Tertiary MBR	24	$7,488,000
	Tertiary BAF	24	$7,488,000
NdN	Secondary MBR (Retrofit)	28	$8,736,000
	Secondary MBR	28	$8,736,000
	Tertiary MBR	24	$7,488,000
	Tertiary BAF	24	$7,488,000
NdN with Centrate	Secondary MBR (Retrofit)	28	$8,736,000
	Tertiary MBR	24	$7,488,000
	Tertiary BAF	24	$7,488,000
Submerged MF	BAF + MF + RO	17	$5,304,000
	MF + RO	17	$5,304,000
	MF + RO with Centrate	17	$5,304,000
	MF + Two Pass RO	18	$5,616,000
RO	Single Pass RO	18	$5,616,000
	Two Pass RO	24	$7,488,000
UV/AOP		6	$1,872,000
Post-Stabilization		2	$624,000
Centrate		2	$624,000

C.7 REPLACEMENT PARTS

There are major process components that will require regular replacement. For the processes considered in this report, this includes MBR and MF membrane modules, RO membrane elements, cartridge filters, and UV lamps and ballasts. Other minor maintenance items associated with mechanical equipment are included within the Maintenance section. The tables below summarize the replacement costs for the relevant processes.

C.7.1 MBR Replacement Parts

The following assumptions are used in the replacement parts cost calculations for MBR modules:

- Each ZW500D cassette has 48 membrane modules
- Membrane module replacement cost = $920 / module (based on GE/Suez's ZW500 membrane module)
- Membrane module life = 10 years
- Sales tax = 9%

Table C.22 – MBR Module Replacement Cost Summary

Unit Process	Total Number of Cassettes	Total modules	Cost of complete replacement plus 9% sales tax	Prorated annual replacement cost
N-only and NdN Secondary MBR (Retrofit)	748	35,904	$36,004,531	$3,600,000
N-only and NdN Tertiary MBR	630	30,240	$30,324,672	$3,032,000
N-only Tertiary MBR for Two Pass RO	672	32,256	$32,346,317	$3,235,000
NdN Secondary MBR	750	35,904	$36,004,531	$3,600,000

C.7.2 MF Replacement Parts

The following assumptions are used in the replacement parts cost calculations for MF modules:

- Each ZW1000 cassette has 96 membrane modules
- Membrane module replacement cost = $950 / module (based on Suez's ZW1000 membrane module)
- Membrane module life = 9 years for MF trains with BAF upstream and 7 years for MF trains without BAF upstream
- Sales tax = 9%

Table C.23 – Submerged MF Module Replacement Cost Summary

Unit Process	Number of Subsystems	Modules per Subsystem	Total modules	Membrane module life (years)	Cost of complete replacement plus 9% sales tax	Prorated annual replacement cost
MF for BAF + MF + RO	4	5,376	21,504	9	$22,267,392	$2,474,000
MF for MF + RO with and without centrate	4	5,376	21,504	7	$22,267,392	$3,181,000
MF for MF + Two Pass RO	4	5,735	22,940	7	$23,754,370	$3,393,000

C.7.3 RO Replacement Parts

The following assumptions are used in the replacement parts cost calculations for RO system:

- Elements per pressure vessel = 7
- Membrane element replacement cost = $365 / element (based on quote for highest cost element from San Diego Pure Water Demonstration Plant)
- Sales tax = 9%

Table C.24 – Single Pass RO Replacement Costs Summary

Single Pass RO						
Stages 1 and 2						
No. of Skids (Duty)	Stage 1 pressure vessels per skid	Stage 2 pressure vessels per skid	Total Stage 1/2 elements	Membrane Element Life (years)	Cost of complete replacement plus 9% sales tax	Prorated annual replacement cost
45	64	32	30,240	5	$12,030,984	$2,406,000
Stage 3						
No. of Skids (Duty)	Stage 3 pressure vessels per skid		Total Stage 3 elements	Membrane Element Life (years)	Cost of complete replacement plus 9% sales tax	Prorated annual replacement cost
45	21		6,615	1	$2,631,778	$2,632,000
Cartridge Filters						
Vessels	Filters per Vessel		Total filters	Filter Life (years)	Cost of complete replacement plus 9% sales tax	Prorated annual replacement cost
64	12		768	0.5	$14,030	$28,000
RO Replacement Cost					Total	$5,066,000

Table C.25 – Two pass RO Replacement Costs Summary

Two Pass RO						
First Pass - Stages 1 and 2						
No. of Skids (Duty)	Stage 1 pressure vessels per skid	Stage 2 pressure vessels per skid	Total Stage 1/2 elements	Membrane Element Life (years)	Cost of complete replacement plus 9% sales tax	Prorated annual replacement cost
45	68	34	32,130	5	$12,782,921	$2,557,000
First Pass - Stage 3						
No. of Skids (Duty)	Stage 3 pressure vessels per skid		Total Stage 3 elements	Membrane Element Life (years)	Cost of complete replacement plus 9% sales tax	Prorated annual replacement cost
45	22		6930	1	$2,757,101	$2,757,000
Second Pass - Stages 1 and 2						
No. of Skids (Duty)	Stage 1 pressure vessels per skid	Stage 2 pressure vessels per skid	Total Stage 1/2 elements	Membrane Element Life (years)	Cost of complete replacement plus 9% sales tax	Prorated annual replacement cost
45	46	22	13,328	5	$5,302,545	$1,061,000
RO system - Cartridge Filters						
Vessels	Filters per Vessel		Total filters	Filter Life (years)	Cost of complete replacement plus 9% sales tax	Prorated annual replacement cost
64	12		768	0.5	$14,030	$28,000
RO Replacement Cost					Total	$6,403,000

C.7.4 UV/AOP Replacement Parts

The following assumptions are used in the replacement parts cost calculations for the UV/AOP system:

- UV lamp replacement cost = $325 / lamp (based on vendor quote)
- UV lamp life = 14,000 hours (based on vendor quote)
- UV ballast replacement cost = $325 / ballast (based on vendor quote)
- UV ballast life = 10 years (based on vendor quote)
- Sales tax = 9%

Table C.26 – UV/AOP Replacement Cost Summary

UV/AOP				
UV/AOP Lamps				
Reactors (duty + standby)	Lamps per reactor	Total number of lamps	Total annual lamp replacement	Annual lamp replacement cost plus sales tax
5	828	4,140	2,590	$918,000
UV/AOP Ballasts				
Total number of lamps	Lamps per ballast	Total number of ballasts	Annual ballast replacement	Annual prorated ballast replacement cost plus sales tax
4140	2	2,070	207	$148,900
UV/AOP replacement cost				$1,067,000

C.8 SOLIDS DISPOSAL

Table C.27 – Solids Disposal Costs for Unit Processes

Unit Process		Annual Flow (mgd)	Annual COD Loading (lbs)	Annual TSS Loading (lbs)	Total Cost
N-Only	Secondary MBR (Retrofit)	1,694	234	202	$1,584,000
	Tertiary MBR	613	34	62	$561,000
	Tertiary MBR + Two Pass RO	654	36	66	$599,000
	Tertiary BAF	644	35	65	$589,000
N-Only with Centrate	Secondary MBR (Retrofit)	1,694	257	222	$1,597,000
	Tertiary MBR	515	31	61	$475,000
	Tertiary BAF	534	33	63	$493,000
NdN	Secondary MBR (Retrofit)	1,402	223	194	$1,327,000
	Secondary MBR	1,248	224	194	$1,195,000
	Tertiary MBR	887	108	136	$882,000
	Tertiary BAF	921	112	141	$872,000
NdN with Centrate	Secondary MBR (Retrofit)	1,402	244	212	$1,338,000
	Tertiary MBR	712	86	115	$677,000
	Tertiary BAF	739	90	119	$703,000

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Appendix D RESPONSE TO COMMENTS FROM THE ADVISORY PANEL

1. **Has the LACSD/MWD nitrogen work group identified all the feasible alternatives for achieving the nitrification goals and nitrate limits established in the study?**

   Advisory Panel (AP) Comments: The Subcommittee believes the presented alternatives represent all of the potentially feasible alternatives.

   Nitrogen Workgroup (NW) Response: Acknowledged.

2. **Are criteria used in the evaluation appropriate?**

   AP Comments: The Subcommittee believes the evaluation criteria are appropriate. The Subcommittee observes that the project consistently be viewed from the perspective of providing a future potable water supply. All process improvements are implemented with an eye toward producing stable, high quality, source water for advanced water treatment. We recognize that the focus of the report is on nitrogen management but would like to reiterate that an important measure of project success will be the ability to consistently produce a source of high quality drinking water that meets/surpasses all regulated contaminants and engenders confidence in the community its safety (i.e. perception issues). This begins with a high-quality source water. We understand demonstration testing will include a focus on drinking water constituents of emerging concern (CECs), boron, and disinfection by-products (nitrosamines) precursors, and process measurements such as dissolved organic carbon (related to membrane fouling and performance). For example, the use of thickening polymers at the JWPCP that may be potent NDMA precursors. Chemicals added during biological pre-treatment prior to the AWT (e.g. a recognized carbon source instead of primary sewage) should be similar to those used at potable water treatment plants. Therefore, an additional evaluation criteria could be “suitability to serve as a drinking water supply”.

   The evaluation criteria do not contain weightings even though there are clear quantitative differences in the importance of the criteria. We encourage Metropolitan and LACSD to develop those weightings, and to test their sensitivity as part of the criteria used to select a process train from the various alternatives.

   NW Response: Acknowledged. Additional sampling for drinking water CECs, boron, disinfection by-products (nitrosamines) precursors and DOC will be conducted during the demonstration testing. Treatment process trains that including unit processes operating at higher SRT are expected to provide better removal of CECs; this advantage is discussed in Table 1.4 of the report in the “Environmental Impact” column.

   The objective of this study was to shortlist the most promising process trains that can achieve nitrogen goals in a cost-effective manner. At this point, the nitrogen workgroup does not have all the necessary information to provide weightings for the shortlisted trains. Data obtained from the demonstration facility will provide more information on some of the pros and cons stated in Table 1.4 of the report for the five shortlisted trains. Additionally, design concepts for some of the shortlisted process trains will have to be developed further to obtain necessary information for sensitivity analysis.

3. Are there other considerations that should be evaluated?

AP Comments: The influent concentration of contaminants (loading) will be critical. The selection of 90th percentile source water concentrations is reasonable but the resiliency of the selected process trains to excursions beyond those levels must also be considered (e.g. hourly variations, diurnal variations, shock loads, etc.). Seasonal trends should be examined so as to ensure the demonstration testing program can target typical longer-term variations in contaminant concentration. Similarly, the process flow diagrams would also benefit from the inclusion of all flow streams (including flows from the AWT to upstream of the JWPCP or to the ocean outfall). The differences between “secondary” and “tertiary” MBR should be clearly defined.

The Report should consider how sunk costs are accounted for if the HPO tanks are not fully utilized.

Staff should verify that recycle stream costs based on industrial waste surcharges are not being double counted. The Subcommittee believes the costing approach is reasonable but some current secondary treatment costs at JWPCP appear to be included in the surcharges. If this is indeed the case, then the current secondary treatment should be removed from the surcharges.

Staff should consider the use of cost ranges for the cost information at this stage. Since some of the costs are Level 4 and some are Level 5 accuracy, showing a range of costs would better identify these differences in accuracy.

Page 1.2, Basin plan discussion – At several places in the report both Total N and nitrate-N product water limits are presented with values of 3.4 mg/L-N on a 12-month moving average basis. A Total N value is always higher than the corresponding Nitrate-N value because Nitrate-N is only one of the components of Total N. This issue needs to be rectified. Further since the 3.4 mg/L-N limit is a 12-month moving average there could be periods of time when the Total N exceeds 3.4 mg/L-N. Because even the 12-month moving average TN value exceeds the OCWD TN limit of 3.0 mg/L-N staff should ask OCWD whether their 3.0 mg/L TN permit limit could be amended to 3.4 mg/L. If this is not possible it will be necessary either to establish and meet a lower product water TN limit or to consider further TN removal at the OCWD site for the product water provided to them.

It is proposed that a relatively constant flow rate of ~160 mgd will be skimmed from the JWPCP to feed the AWT plant. The JWPCP influent dry weather flow currently varies through a typical day from about 150 mgd to nearly 350 mgd. Wet weather flows further add to the variation. Accordingly, the JWPCP will be subjected to significantly higher primary effluent flow variations than currently exist. The Report should describe how the HPOAS process will handle these increased primary effluent flow variations.

NW Response: Additional data on primary and secondary effluent nitrogen species concentration will be collected during the demonstration testing. Additional process modeling will be conducted in the future to determine the resiliency of the selected process trains to diurnal variability in nitrogen loading as well as shock loads. LACSD currently does not collect water quality data on primary effluent because there are no permit requirements to do so and therefore, sufficient data is not available to develop long-term trends. Additionally, the workgroup acknowledges that factors such as drought and water conservation measures have a significant impact on these trends, therefore making it harder to extrapolate the data for long-term trend.

The demonstration facility is configured to allow collection of RO brine samples. LACSD intends to conduct brine toxicity testing once the demonstration facility is in operation and brine samples are available.

Process schematics for trains in Figures 5.1, 5.2, 5.3, 5.4 and 5.5 have been updated to include JWPCP influent and WAS flows to complete the flow balance. When treating primary effluent, the MBR process is referred to as "Secondary MBR". Secondary MBR typically achieves both organics and nitrogen removal. Tertiary MBR treats secondary effluent, mostly for nitrogen removal. This explanation has been added in the report on Page 1-3.

For Train 5, the HPO tanks that would not be utilized for biological treatment can be repurposed as primary effluent equalization tank to maintain fairly constant flow through the new secondary MBR trains. Therefore, the sunk costs for the HPO tanks have not been accounted for in the report.

The workgroup acknowledges that the waste activated sludge from tertiary MBR and BAF would be sent directly to the solids processing facility and therefore should not incur the full industrial waste surcharge for solids disposal cost; these costs will be refined further in future analysis. Solids disposal cost is less than 5% of the annual operations and maintenance cost so this correction won't have any substantial impact.

Based on AP's recommendation, costs have been presented as a range for the five shortlisted trains to account for differences between Class 4 and 5 level accuracies.

The workgroup agrees with the comment on TN goal for the Orange County basin. Considering that there will be some residual organic nitrogen in the RO permeate (< 0.1 mg/L-N), the goal should be TN ≤ 3.5 mg/L. The text in the report has been revised accordingly. The recommended trains are expected to achieve TN of less than 3 mg/L and can be optimized further to achieve lower TN goal, if desired. For example, carbon addition to NdN tertiary MBR can be increased to achieve lower nitrate in MBR filtrate and consequently lower TN in RO permeate. Also, for Trains 2E and 4C, additional water can be treated with the second pass RO to achieve lower goal. Since the evaluation was meant to provide a relative comparison of process trains, changing the product water quality goal will have similar effect on each train.

Application of tertiary MBR/BAF processes would not affect JWPCP's operation. For secondary MBR train, the MBR trains will be sized to handle peak flows (diurnal and wet weather). Current assumptions are that MBR trains will handle 300 MGD of wet weather flow whereas remaining HPOAS trains will handle remaining 400 MGD to maintain the existing wet weather design capacity of JWPCP. With such configuration, the peaking factor for HPOAS trains will increase from 1.75 to 2.0. LACSD's operations confirmed that they can handle such peaking factor with the HPOAS trains.

For secondary MBR, there may not be sufficient organic loading during the low flow periods at the JWPCP to sustain the biomass in all operational HPOAS trains if a minimum amount of flow is always fed to the MBR trains. Therefore, the impact of low flow periods on the JWPCP operations needs to be assessed. An optimum number of HPOAS trains that can be kept in operation along with the MBR trains without affecting the operational and water quality performances of the JWPCP and the downstream AWT Facility needs to be determined. Approaches for primary effluent flow equalization need to be investigated.

4. **If secondary MBR is operated in parallel with the existing LACSD HPO process (with the secondary MBR product water feeding the AWT RO system), are there operational issues resulting from this type of parallel operation that should be considered?**

   AP Comments: The LACSD and MWDSC are working collaboratively on the development of a sustainable design, operations, and management plan for the recycled water plant that will continue to allow both Agencies to accomplish their respective missions. The selected treatment train must ultimately be robust enough to ensure compliance with applicable regulations/statutes. This will require clearly defining critical control points and the roles of different agencies/partners in meeting the nitrogen levels (concentration, speciation, and frequency of analysis – continuous, hourly, daily, weekly, etc.) in the raw water for the AWT plant.

   The project would benefit from the development of a long-term vision for the entire JWPCP. This vision would establish the idealized future treatment regime for the entire plant deemphasizing treatment strategies that employ side-stream or hybrid treatment trains. The vision should also consider possible future nitrogen discharge limits for ocean discharge as well as ultimately consider converting the JWPCP to air feed. The vision should incorporate scaling the AWT to 150 mgd. Any solution that bifurcates the process train at the JWPCP should be disfavored so as to remove potential future limitations, avoid operational complexity, and minimize the risk of future non-compliance. Whatever is proposed now to provide the source water to the AWT should be compatible with the long-range vision for the JWPCP.

   Tertiary MBR/RO provides the advantage/flexibility of a clear separation between source water treatment at the JWPCP and reclaimed water production at the AWT process. The Subcommittee believes this will simplify operations and allow each District to better accomplish their respective missions as well as the overall project mission. The Subcommittee is looking forward to the results of the demonstration testing.

   NW Response: Acknowledged. Demonstration testing would provide necessary information on establishing critical control points for each unit process and the roles of different agencies/partners in meeting regulatory requirements.

   The NW acknowledges that a long-term vision for the entire JWPCP should be developed that would consider treatment regime for the entire plant.

   The NW acknowledges AP's comments on tertiary MBR/RO process train.

5. **Is the evaluation of the alternatives according to the criteria reasonable?**

   AP Comment: Notwithstanding previous comments, the Subcommittee believes the evaluation of alternatives according to the criteria is reasonable.

   NW Response: Acknowledged.

Appendix D:

Boron Source Investigation Report

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Boron Source Investigation Report

SANITATION DISTRICTS OF LOS ANGELES COUNTY

January 12, 2018

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LIST OF ACRONYMS

AOP	Advanced Oxidation Process
AWTF	Advanced Water Treatment Facility
B	Boron
COC	Chemical of Concern
COD	Chemical Oxygen Demand
deg.	degree
F	Fahrenheit
gpd	gallons per day
IPR	Indirect Potable Reuse
IU	Industrial User
IW	Industrial Waste
JOS	Joint Outfall System
JO-A	Joint Outfall A
JO-B	Joint Outfall B
JO-C	Joint Outfall C
JO-D	Joint Outfall D
JWPCP	Joint Water Pollution Control Plant
kg/d	kilogram per day
LACSD	Los Angeles County Sanitation Districts
MBR	Membrane Bioreactor
mg/L	milligram per liter
MGD	Million gallons per Day
MSG	Main San Gabriel
MWD	Metropolitan Water District of Southern California
NPDES	National Pollutant Discharge Elimination System
POTW	Publicly Owned Treatment Works
RO	Reverse Osmosis
RWQCB	Regional Water Quality Control Boards
SWRO	Seawater Reverse Osmosis
TDS	Total Dissolved Solid
TSS	Total Suspended Solid
US	United States
UV	Ultraviolet
WHO	World Health Organization
WRP	Water Reclamation Plant

1.0 BACKGROUND

1.1 SANITATION DISTRICTS' SOURCE CONTROL PROGRAM

The County Sanitation Districts of Los Angeles County (Sanitation Districts) are a public agency created under state law to manage wastewater and solid waste on a regional scale and consist of 24 independent special districts serving about 5.6 million people in Los Angeles County, California. The service area covers approximately 850 square miles and encompasses 78 cities and unincorporated territory within the County.

The industrial waste pretreatment program was established to comply with Sanitation Districts' treatment plant's effluent discharge requirements and to protect the public, the environment, Sanitation Districts' personnel and the Sanitation Districts' facilities from potentially harmful industrial wastes. The program was approved on March 27, 1985, and oversight is provided by the United States Environmental Protection Agency (EPA) and the State of California. The Sanitation Districts' pretreatment program is among the largest in the country and has through the years proven to be exceptional in ensuring compliance with wastewater regulations.

Due to increasing recycled water use, the Sanitation Districts have established a source control program that encompasses not only the pretreatment program but also includes various elements aimed at providing a barrier that protects recycled water intended for potable reuse. The Sanitation Districts' source control program incorporates aspects such as legal authority, multiple jurisdictional coordination, enhanced pretreatment program, source investigation, and pollution prevention. A flow chart summarizing the Sanitation Districts' industrial waste source investigation process is shown in Figure 1.

1.2 POTENTIAL REGIONAL RECYCLED WATER PROGRAM AND STATUS

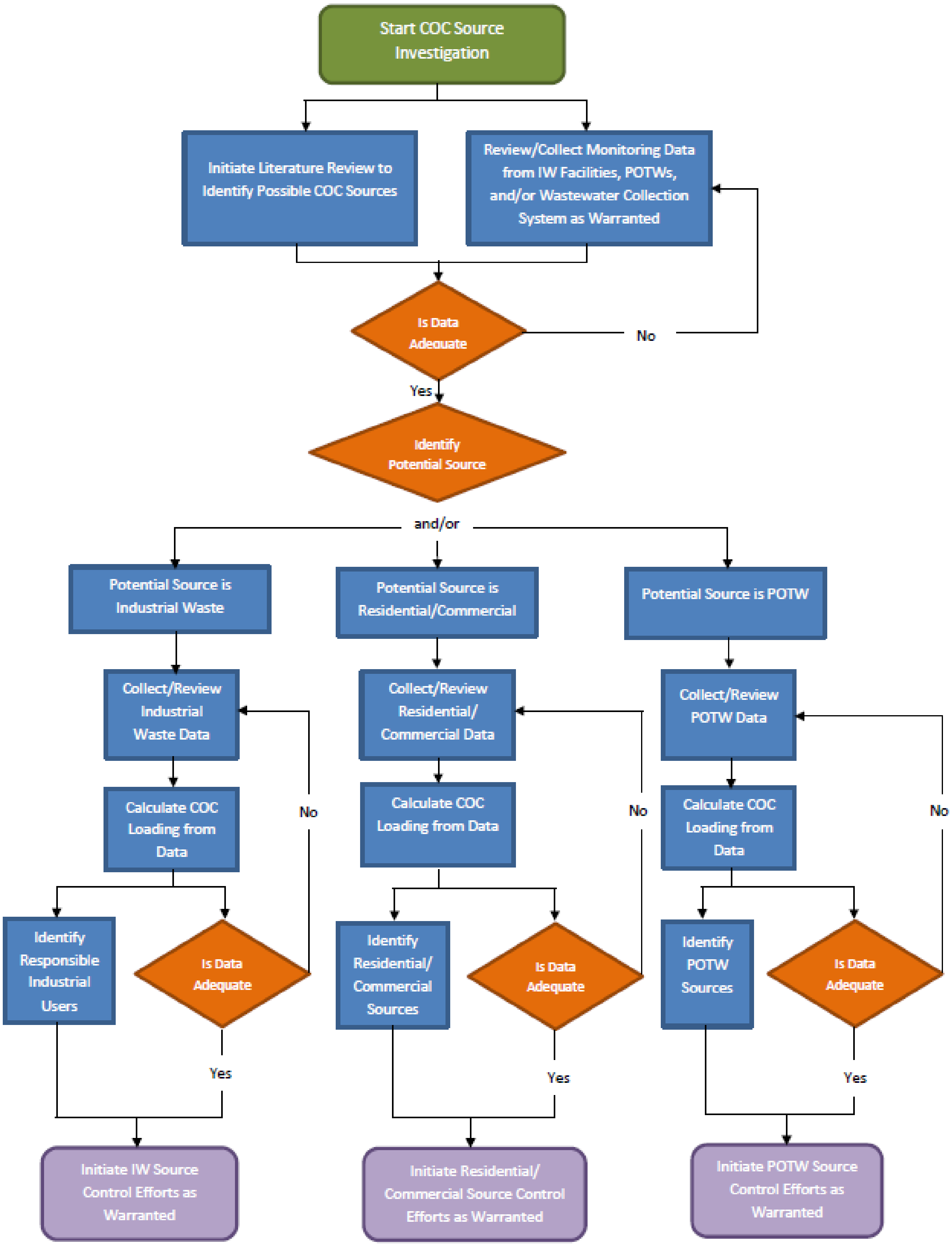
The Metropolitan Water District of Southern California (MWD) is considering a potential regional recycled water program in partnership with the Sanitation Districts. The program would consist of constructing a new Advanced Water Treatment Facility (AWTF) adjacent to the Sanitation Districts' Joint Water Pollution Control Plant (JWPCP), a wastewater treatment plant in Carson, California. The AWTF would purify unchlorinated secondary-treated effluent from JWPCP to produce up to 150 million gallons per day (MGD) of recycled water for groundwater recharge in Los Angeles and Orange Counties.

As an initial step in developing the full-scale AWTF, MWD and the Sanitation Districts jointly conducted pilot testing at JWPCP between 2010 and 2012. The testing demonstrated that a treatment train consisting of a membrane bioreactor (MBR), reverse osmosis (RO), and advanced oxidation processes (AOP) can purify JWPCP secondary effluent to high-quality recycled water that meets the water quality criteria for groundwater recharge. Construction on a 0.5 MGD demonstration facility with an MBR-RO-AOP process train began in Fall 2017; the facility will be used to obtain regulatory approval and to establish the basis of design for the full-scale AWTF, as well as serve as an educational and public outreach tool to promote recycled water use.

1.3 MOTIVATION FOR BORON SOURCE INVESTIGATION

Water purified by the AWTF will be used to recharge several groundwater basins within Los Angeles County and Orange County to help diversify the region's water supply sources. The groundwater basins being considered for potential recharge by this project include the Central, Main San Gabriel, Orange County, and West Coast Basins. These four basins were chosen due to their proximity to the JWPCP and available recharge capacity. A conveyance system would consist of approximately 60 miles of

Figure 1. Sanitation Districts' Industrial Waste Source Investigation Process



distribution pipeline to transport product water from the AWTF to the groundwater basins [1]. The Regional Water Quality Control Boards have established water quality objectives for each groundwater basin. Of the four basins, the Main San Gabriel Basin (MSG Basin) has the lowest concentration limit for boron at 0.5 mg/L, while the California State drinking water notification level for boron is 1 mg/L. Consequently, the target boron concentration in the AWTF product water is 0.5 mg/L.

JWPCP effluent boron concentration is currently about 0.9 mg/L; even with partial removal via RO, the AWTF may have trouble meeting the MSG basin boron objective of 0.5 mg/L [1, 2]. Three approaches are being considered for meeting the boron requirement: (1) source control; (2) additional AWTF treatment (i.e., second stage RO); and (3) regulatory relief. This investigation focuses on source control, which would reduce the amount of boron entering the JWPCP and subsequently the AWTF by regulating boron discharges. The results of this investigation can help inform decision-makers on the potential feasibility of this approach.

2.0 GENERAL INFORMATION AND PROPERTIES OF BORON

2.1 BORON IN THE ENVIRONMENT

Boron is a naturally occurring element that is widely distributed throughout the environment in rock, soil, and water. Boron compounds are often present in surface and groundwater as well as wastewater at concentration levels ranging from 5-100 mg/L [3]. Seawater contains approximately 0.5 to 9.6 mg/L of boron depending on the region [4].

Boron is released from rocks and soils through weathering, and subsequently ends up in the aqueous environment as boric acid ($H_3\,BO_3$) or borate ion species ($H_2BO_3^-$, HBO_3^{2-}, and BO_3^{3-}). Boron is also released into the environment from anthropogenic sources such as industrial air emissions, fertilizer applications, and industrial and municipal wastes [7]. The majority of the Earth's boron is found in the oceans, with an average concentration of 4.5 mg/L [8].

2.2 BORON AQUEOUS CHEMISTRY

Boric acid is a very weak acid which dissociates according to:

$$H_3BO_3 \leftrightarrow H^+ + H_2BO_3^- \qquad \text{p}K_a\ 9.14$$

$$H_2BO_3^- \leftrightarrow H^+ + HBO_3^{2-} \qquad \text{p}K_a\ 12.74$$

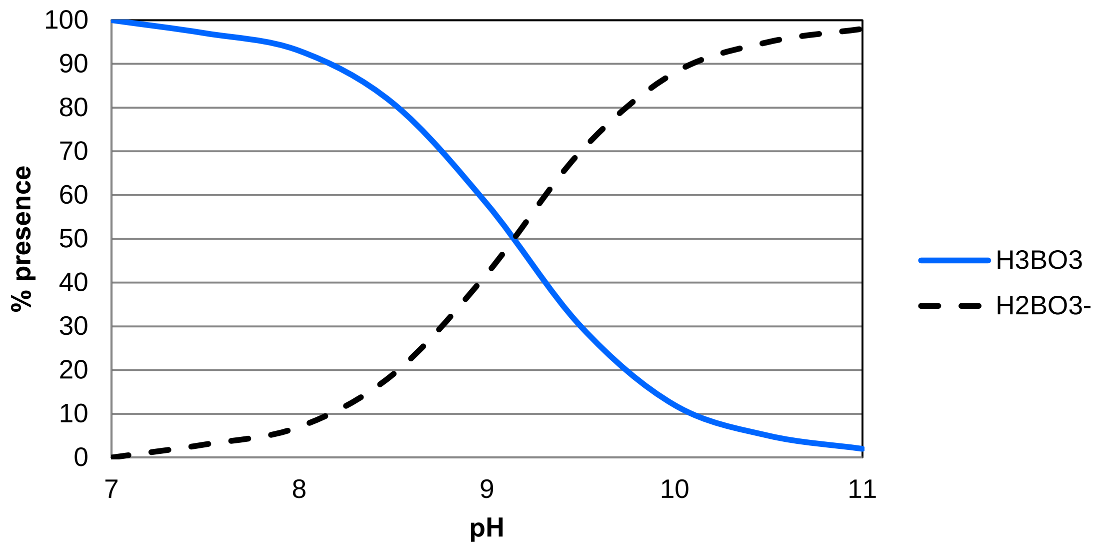
$$HBO_3^{2-} \leftrightarrow H^+ + BO_3^{3-} \qquad \text{p}K_a\ 13.8$$

Boron concentration is usually expressed as total boron, which includes all aqueous species and is expressed in terms of the molecular weight of the boron atom.

$$\text{Total Boron} = [H_3BO_3] + [H_2BO_3^-] + [HBO_3^{2-}] + [BO_3^{3-}] \qquad \text{(as mg/L of boron)}$$

When pH is 7 or less, boron is present as boric acid (non-dissociated form) and at a pH greater than 10.5, it is present as boric ions (dissociated borate form). The exact percentage distribution of the boron species in aqueous phase depends on pH and the relative distribution of the two most common species is shown in Figure 2.

Figure 2. Distribution of Boric Acid/Borate Ions as a Function of pH



2.3 BORON FATE AND TRANSPORT IN AN AQUIFER

Boron fate and transport in an aquifer refers to the physical, chemical, and biological processes that impact the movement of boron in the groundwater. Adsorption to soils is one process that potentially removes some boron from groundwater; however, boron adsorption to soils depends on the pH of the groundwater and the chemical composition of the soil. Soils rich in aluminum and iron oxides can result in significant borate adsorption [7]. Some boron may also be removed from the groundwater through precipitation reactions. Boron compounds can precipitate as hydroxyborate compounds with aluminum, iron, or silicon [7]. Additionally, boron is a necessary micronutrient for microbial growth but does not undergo biological transformation.

2.4 BORON DRINKING WATER STANDARDS

While boron is an essential element for plant growth, it can be damaging to certain plants when the irrigation water contains concentrations in excess of 2.0 mg/L of boron [5]. Similar pattern applies in human health. According to the World Health Organization (WHO), the tolerable daily intake of boron for an adult is 0.16 milligram per kilogram of body weight per day. Overconsumption of boron may cause acute boron toxicity with nausea, headache, diarrhea, kidney damage, and death from circulatory system collapse [6].

In 1993, the WHO included boron in the drinking water standards and established the permissible boron level at 0.3 mg/L. This guideline value was increased to 0.5 mg/L in 1998 due to a lack of financially viable technologies for removing boron in water. Subsequent data reported from the United Kingdom and the United States (US) on dietary boron intake led to further increase of the WHO guidelines to 2.4 mg/L. This revised drinking water standard for boron was incorporated into the WHO's *Guidelines for Drinking-Water Quality, 4th Edition* in 2011.

The US has no federal regulations for boron; establishment of the permissible level is delegated to the states. The California State Notification Level for boron in drinking water is 1.0 mg/L. Since the recycled water produced by the AWTF will be used for groundwater recharge, the product water must also comply with the water quality objectives set by the Regional Water Quality Control Board for the specific groundwater basin. The lowest water quality objective for boron in the four groundwater basins being considered for groundwater recharge is 0.5 mg/L.

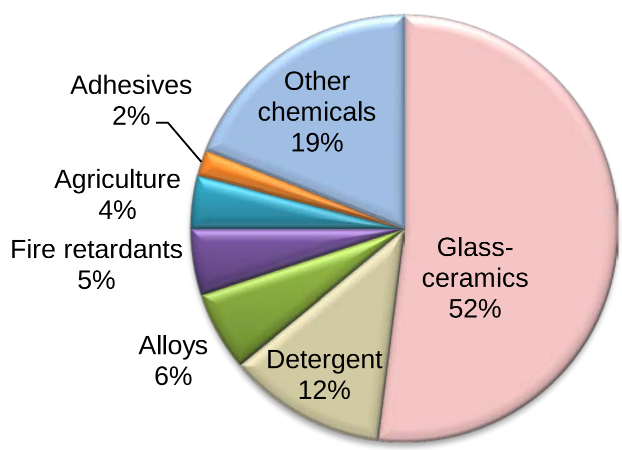
2.5 Residential Sources of Boron

Boron is one of the main ingredients in household surfactant products such as soaps, detergents, and bleaches to boost cleaning performance. Researchers in Europe have reported a correlation between boron loadings at wastewater treatment plants and detergent consumption [9]. Boron is also found in personal care products such as skin lotions, hair shampoos, denture cleaners, and cosmetic creams. Additionally, boron is naturally-occurring in potable water supplies. According to the 2016 Drinking Water Quality Report published by MWD, the average boron effluent concentrations from five of their Southern California water treatment plants are 0.19 mg/L (with a range of 0.14 mg/L to 0.27 mg/L) [13].

2.6 Industrial Use of Boron

At present, boron compounds are widely used in various industrial manufacturing processes such as additives for borosilicate glass, detergents, alloys, fire retardants, agricultural fertilizers, adhesives, and other chemicals (See Figure 3) [10]. Any future change in boron usage may depend on the growth in production of the aforementioned industries.

Figure 3. Boron Consumption in the US by Industry



3.0 BORON AT JWPCP

3.1 JWPCP Background

The AWTF will receive and purify non-nitrified secondary effluent from the JWPCP, the largest of the Sanitation Districts' wastewater treatment plants. The facility provides both primary and secondary treatment, and has a total permitted capacity of 400 MGD. JWPCP serves a population of approximately

3.5 million people throughout Los Angeles County and in 2016 it received an average daily flow of 253 MGD.

3.2 Boron Concentrations and Loading at JWPCP

The Sanitation Districts have been monitoring boron in the JWPCP influent and effluent on a quarterly basis since 2013. Figure 4 illustrates the sampling locations: Incoming Sewers (red); Headworks (also referred to as influent)(yellow); and Effluent (blue). Note that routine samples were collected at the Headworks (yellow) and Effluent (blue) locations; Incoming Sewers (red) was only used for special sampling events. In 2016, the average flowrate at the headworks was 275 MGD and the average incoming flowrate was 253 MGD. For analysis purposes, 275 MGD was used for headworks calculations and 253 MGD was used for incoming sewer calculations.

Figure 4. JWPCP Sampling Locations for Boron

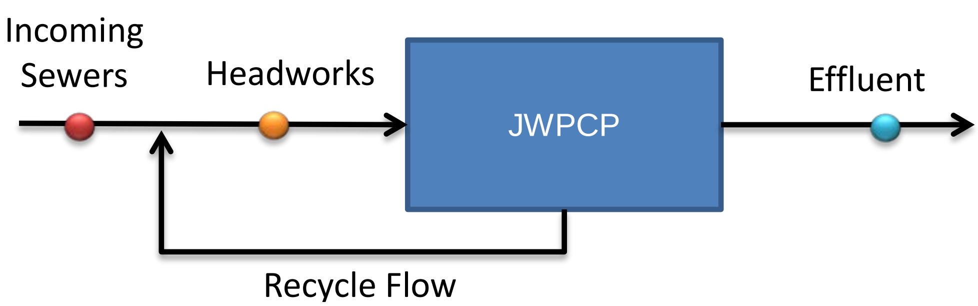


Figure 5 shows the historical boron concentration in the JWPCP headworks (influent) and effluent. The average influent and effluent concentrations and mass loading of boron from March 2013 to June 2017 are summarized in Table 1.

Figure 5. Boron Concentrations Observed at JWPCP

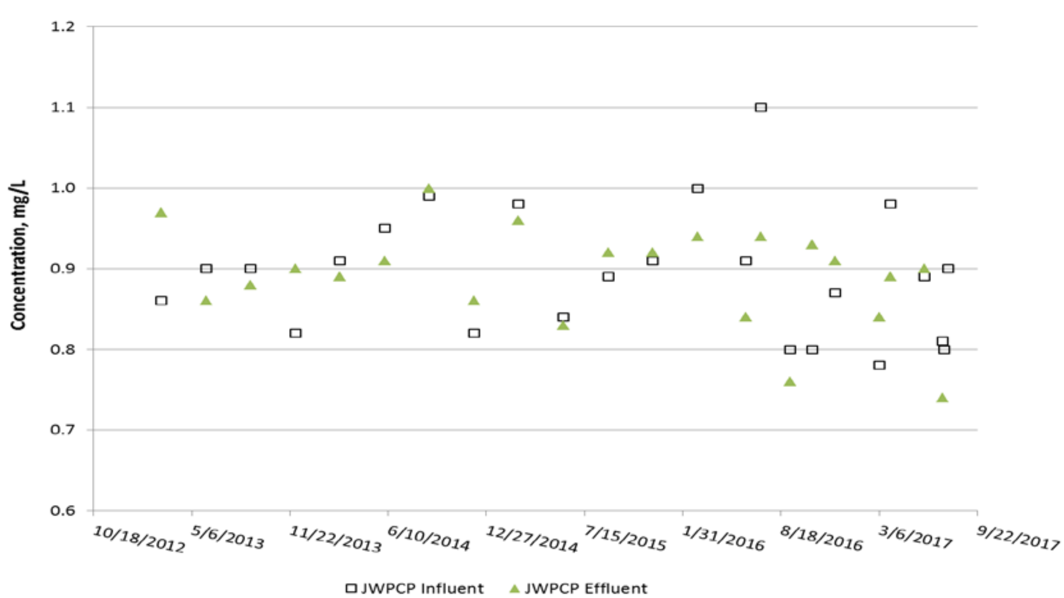


Table 1. JWPCP Influent and Effluent Boron Data Summary from March 2013 through June 2017

	JWPCP Headworks Boron		JWPCP Effluent Boron	
	Concentration (mg/L)	Mass Loading (kg/d)	Concentration (mg/L)	Mass Loading (kg/d)
Average	0.90	937	0.90	878
Minimum	0.78	812	0.76	736
Maximum	1.10	1145	1.00	1021
Median	0.90	937	0.90	872

3.3 Boron Removal at JWPCP and AWTF

Since the headworks concentration of boron is about equal to the effluent concentration, it appears that boron is neither added nor removed by the unit processes within the JWPCP treating the liquid stream. The JWPCP does not have a discharge limit or performance goal for boron in its NPDES discharge permit. JWPCP discharges to the Pacific Ocean.

However, some boron will be removed by the RO process in the AWTF. RO is better at removing charged ions such as borate ($H_2BO_3^-$) rather than boric acid ($H_3\,BO_3$); therefore, boron removal by RO is pH dependent (Figure 2) among other factors. Between 2010 and 2012, MWD and the Sanitation Districts conducted pilot testing of the AWTF processes at JWPCP [11]. As part of this pilot testing, boron concentrations, in addition to other water quality parameters, were monitored. The median concentration for boron in the secondary effluent during the testing period was 0.88 mg/L. The pilot testing achieved 30% boron removal, resulting in final boron concentrations of 0.5 to 0.8 mg/L [11].

Boron removal by RO depends on the pH of the feed water, the type of membrane used, and the number of stages in the RO process among other factors. RO can achieve 20% - 85% boron removal [12]. At this time, a final design for the AWTF has not been determined; therefore, exact boron removal amounts are not established.

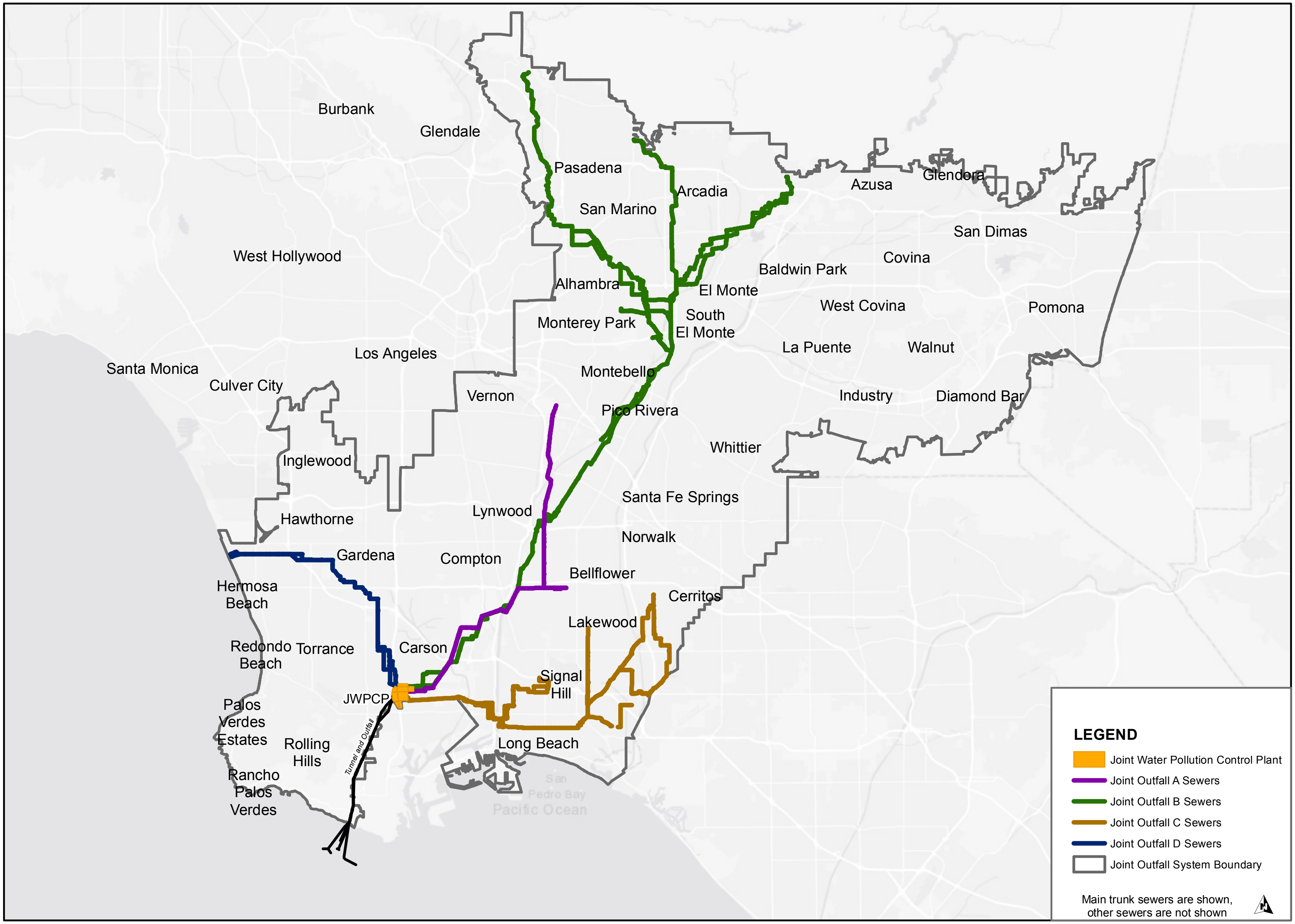
4.0 UPSTREAM SOURCES OF BORON AT JWPCP

4.1 By Trunk Sewers

Seventeen of the 24 independent districts in the Sanitation Districts' partnership have joined together to share a regional, interconnected sewerage system called the Joint Outfall System (JOS). The JOS covers approximately 660 square miles in Los Angeles County. The complex sewer network feeds into four main truck sewers, Joint Outfalls A, B, C, and D, which convey wastewater to the JWPCP for treatment, as show in Figure 6.

The four main trunk sewers, Joint Outfalls A, B, C, and D, were sampled upstream of the JWPCP in a special sampling event to help identify sources of boron. Samples (24-hour composite) were obtained on three different dates and the results are shown in Table 2. The 2016 average flow and the corresponding boron mass loading (calculated by Average [boron concentration] * Average [flow]) carried by each trunk sewer are also included.

Figure 6. Joint Outfall System Service Area and Trunk Sewers



The boron concentration and mass loading were highest in Joint Outfall C (JO-C), at 1.67 mg/L and 291 kg/d, respectively. This sewer receives flow from Long Beach and Signal Hill.

Based on the sample results from the trunk sewers in Table 2, the mass of boron entering the JWPCP is approximately 806 kg/d. Based on the historic average influent boron concentration of 0.90 mg/L, the influent mass of boron is approximately 937 kg/d (see Table 1). The influent mass shown in Table 2 is 14% lower than the mass based on the historic influent data. One possible explanation for the lower mass loading calculated from the truck sewer sampling in comparison to the historic data is that the sewer sampling corresponded with below-average boron headworks concentrations. Additionally, the trunk sewer sampling loading calculation is based on influent flow of 253 MGD and the historical average loading calculation is based on headworks flow of 275 MGD, which includes recycle flows. The mass loading calculated from the historic average influent concentration is based on a larger number of samples taken over a longer time period and therefore it is probably more representative of the actual influent boron loading.

Table 2. Results of Boron Sampling Program on the Four Main Trunk Sewers at the JWPCP

SAMPLE DATE	TRUNK SEWER				
	JO-A	JO-B	JO-C	JO-D	Total
9/28/2016	0.52 mg/L	0.64 mg/L	1.68 mg/L	0.80 mg/L	
4/4/2017	0.61 mg/L	0.62 mg/L	1.70 mg/L	0.79 mg/L	
4/5/2017	0.60 mg/L	0.64 mg/L	1.63 mg/L	0.76 mg/L	
Average Boron Concentration	**0.58 mg/L**	**0.63 mg/L**	**1.67 mg/L**	**0.78 mg/L**	
Average Flow[1]	**40 MGD (16 %)**	**116 MGD (46 %)**	**46 MGD (18 %)**	**51 MGD (20 %)**	**253 MGD**
Estimated Mass Loading	**88 kg/d (11%)**	**277 kg/d (34%)**	**291 kg/d (36%)**	**151 kg/d (19%)**	**806 kg/d**

1. Average JWPCP influent flow for 2016 (Figure 4).

4.2 RESIDENTIAL/COMMERCIAL SOURCES OF BORON

To estimate the contribution of residential and commercial sources to the JWPCP influent boron loading, the corresponding flow and boron concentration would be needed. Currently residential and commercial wastewaters account for 80% of the influent flow received at the JWPCP. Based on 2016 JWPCP influent flow rate of 253 MGD, residential and commercial flows are estimated to be 202 MGD.

However, the boron concentration in the residential/commercial flows cannot be readily measured. Instead, an alternate approach was employed to estimate this concentration with the following assumptions:

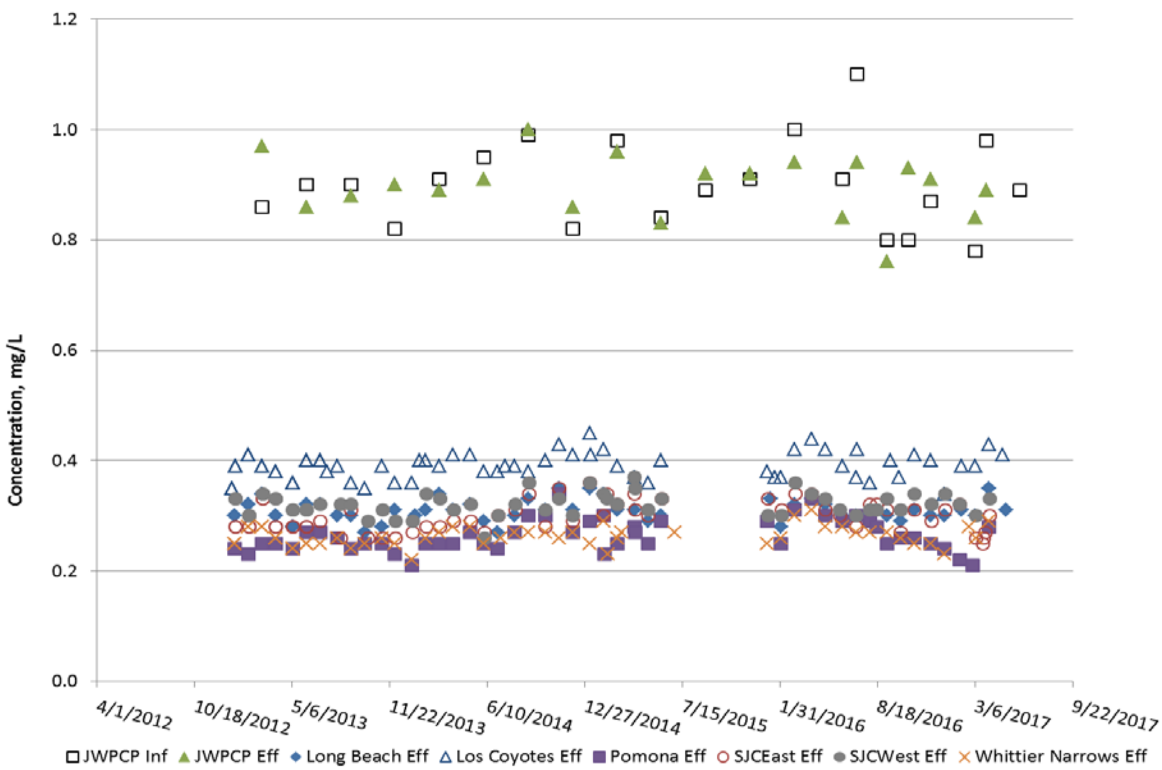
(1) Boron concentration in JWPCP's residential/commercial flows can be approximated by the average influent boron concentration at the six water reclamation plants (WRPs) upstream of the JWPCP. This assumption was considered reasonable as the WRPs receive primarily residential/commercial wastewater.

(2) The average influent boron concentration of the WRPs can be approximated by their average effluent boron concentration. This assumption was considered reasonable as there is no known boron source or sink within the plants, and that JWPCP which employs similar processes that showed no boron removal through the plant.

With the above assumptions, boron concentration in JWPCP's residential/commercial flow was estimated to be 0.31 mg/L. Figure 7 shows the historical effluent boron concentrations of the six WRPs and the JWPCP. Using the aforementioned flows and boron concentrations, the residential/commercial contribution to JWPCP's influent boron loading was estimated to be (202 MGD * 0.31 mg/L=) 237 kg/d. This loading is equivalent to 0.25 mg/L at an influent flow rate of 253 MGD.

As evident in Figure 7, there is a significant difference between the boron concentrations at JWPCP and the upstream WRPs. This is a strong indication that the source of boron at JWPCP is from other sources such as industrial discharges to the JWPCP.

Figure 7. Boron Concentrations Observed at the Sanitation Districts' JOS facilities



4.3 INDUSTRIAL SOURCES OF BORON AT JWPCP

The industrial contribution to JWPCP's influent boron loading was estimated by subtracting the residential/commercial loading from the headworks loading. The former was previously estimated to be 237 kg/d (Section 4.2), while the latter was estimated to be 937 kg/d (Table 1). As such, the boron loading from industrial sources was estimated to be approximately 700 kg/d (equivalent to 0.67 mg/L at the JWPCP headworks).

All four trunk sewers (Table 2) had boron concentrations that were higher than the residential/commercial background concentration of 0.31 mg/L (Section 4.2) and the water quality objective of 0.5 mg/L for the MSG Basin (Section1.2). Sewer sampling will continue in order to collect additional data.

4.4 SOURCE INVESTIGATION FOR INDUSTRIAL SOURCES OF BORON

To further identify the major industrial sources of boron to the JWPCP, boron data for industrial wastewater samples collected between April 2010 and June 2016 were reviewed[1]. Out of approximately 6,700 samples collected and analyzed for metals, approximately 1,000 samples showed boron levels above the detection limit. These samples reflected discharges from approximately 300 IUs spanning 35 different industrial categories. A headworks analysis, which involves estimating the mass loading and equivalent concentration of a pollutant of interest arriving at the JWPCP headworks, was subsequently conducted based on these results. Mass loading and equivalent headworks concentrations were calculated for all 300+ IUs and 35 industrial categories then ranked. The top ten industries with the highest boron loading contribution are presented in Table 3; the full list can be found in Appendix A. The combined boron loading from the top ten industries accounts for approximately 97% of the total industrial boron contribution to the JWPCP. The oil field industry accounted for 60% of the industrial contribution and was the largest boron discharging industry.

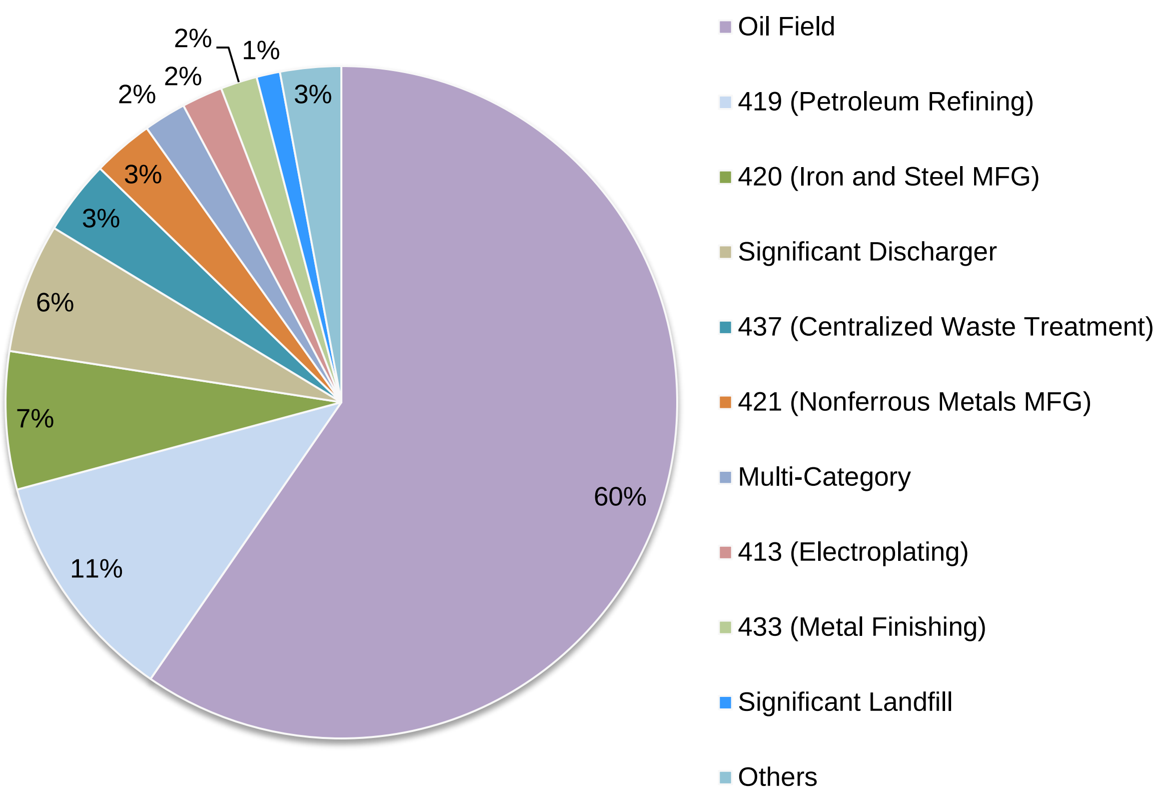
Table 3. Headworks Analysis of Top Ten Industries[5] by Boron Concentration Contribution

Industry Type	Locations with Boron Detected	No. of Samples with Boron Detected[1]	Average Concentration (mg/L)	Total Daily Average Flow Rate (MGD)	Mass Loading (kg/d)[4]	Theoretical Headworks Concentration (mg/L)[2]
Oil Field	39	40	49.6	2.36	379	0.36
40 CFR 419 (Petroleum Refining)	9	43	1.03	17.9	71.2	0.07
40 CFR 420 (Iron and Steel MFG)	4	7	105	0.85	42.1	0.04
Significant Discharger[3]	34	107	2.6	5.90	39.6	0.04
40 CFR 437 (Centralized Waste Treatment)	8	114	12.9	0.37	22.7	0.02
40 CFR 421 (Nonferrous Metals MFG)	5	16	4.58	0.53	18.6	0.02
Multi-Category	30	104	5.44	0.79	13.0	0.01
40 CFR 413 (Electroplating)	11	29	89.5	0.04	12.5	0.01
40 CFR 433 (Metal Finishing)	113	373	3.23	1.22	11.2	0.01
Significant Landfill	4	11	3.25	0.30	7.19	0.007
Sub-Total	**257**	**858**	**NA**	**30**	**617**	**0.58**

[1] The boron data was mined from previous metal analyses; the values were quantified but were not subject to typical QA/QC verifications.

NOTE:
1. Samples with boron detected were collected from April 7, 2010 through June 30, 2016.
2. Theoretical headworks concentrations were calculated by using 275 MGD as the daily average flow rate (includes recycle) at the JWPCP (Figure 4).
3. Significant discharger is defined as in IU that has the potential to significantly impact the POTW due to high flow rate and/or strength of discharge. For the purpose of this table, significant dischargers are those that are not included in the other industry types in this table.
4. The mass loading was calculated from the sum of each individual industry, not industry type as a whole.
5. The total industrial source mass loading (calculated from industrial sampling) was 636 kg/d (some data not shown), which is equivalent to an influent concentration of 0.61 mg/L at 275 MGD (headworks flow). See Appendix A for whole data set.

Figure 8. Boron Mass Loading Distribution for Various Industry Types



4.5 OIL FIELD INDUSTRY CONTRIBUTION

The headworks analysis (Table 3) showed that the oil fields contribute approximately 379 kg/d of the boron loading observed at the JWPCP, the largest contribution of any industry type. Oil fields discharge more boron than the next nine highest industry types combined (Table 3).The Sanitation Districts currently have approximately 65 oil field IUs with active Industrial Wastewater Discharge Permits. Permitted discharge rates from these facilities range from 192 gallons per day (gpd) to 546,000 gpd and the boron concentrations detected in the wastewater from oil fields ranged from 19.5 mg/L to 91.2 mg/L, with an average value of 49.6 mg/L. The top ten oil fields (by boron mass loading) are listed in Table 4. A map of the JOS Service Area and Oil Field Dischargers is shown in Figure 9. The boron loading from the top ten oil field dischargers is 337 kg/d (equivalent to 0.32 mg/L at the JWPCP headworks), which accounts for 89% of the oil field industry boron load (379 kg/d) and 48% of the total industrial boron load (700 kg/d). The total permitted quantity (not actual discharge amount) of oil field wastewater discharge is approximately 3 MGD.

Table 4. Top Ten Oil Field Dischargers with the Highest Boron Headworks Concentration

Facility	Number of Boron Samples[1]	Average Discharge Rate (gpd)	Average Boron Concentration (mg/L)	Mass Loading (kg/d)	Theoretical Headworks Concentration (mg/L)[2]
Oil Field No. 1	1	515,000	54.7	107	0.103
Oil Field No. 2	1	330,000	48.0	60.1	0.0577
Oil Field No. 3	2	370,000	35.0	49.1	0.0471
Oil Field No. 4	1	212,000	38.6	31.0	0.0297
Oil Field No. 5	1	343,000	19.5	25.3	0.0243
Oil Field No. 6	1	102,000	62.1	24.1	0.0231
Oil Field No. 7	1	85,000	49.8	16.1	0.0154
Oil Field No. 8	1	74,000	37.9	10.6	0.0102
Oil Field No. 9	1	40,000	56.4	8.47	0.0081
Oil Field No. 10	1	32,000	52.6	5.72	0.0055
Total (Top 10 – 89% of Boron Contribution from Oil Fields)				**337**	**0.32**

Note:
1. Samples were collected from April 7, 2010 through June 30, 2016.
2. Theoretical headworks concentrations were calculated based on the influent plus recycle flowrate of 275 MGD (Figure 4).

Five of the top ten oil fields (Oil fields no. 1, 2, 3, 7, and 9) discharge to trunk sewer JO-C. The combined contribution of these four oil fields (241 kg/d) is equivalent to (241/291=) 83% of the boron discharged to JO-C. A map of the JO-C Trunk Sewer and Oil Field Dischargers is shown in Figure 10.

The oil field operations bring water from deep subsurface formations into the sewer system. When oil is brought to the surface through an extraction well either by pump or natural reservoir pressure, it is a mixture of liquid petroleum, natural gas, and formation water. This mixture, called an emulsion, is then processed through an oil/water separator. The typical oil content of the emulsion can range from 2 to 10% at the oil fields in Los Angeles County. Most of the oil fields reinject some of the produced water (wastewater), which helps to mobilize some of the remaining oil in the formation, and discharge the excess amount (that cannot be reinjected) to the sewer. Some of the oil fields reinject all of their produced water back into the formation, and only discharge to the Sanitation Districts during emergency circumstances or maintenance activities.

Sometimes heat and chemicals are applied to the emulsion to facilitate the separation process. The separated oil is then transported to an oil storage tank for sale and the water is reinjected back into the

Figure 9. Joint Outfall System Service Area, Trunk Sewers, and Oil Field Dischargers

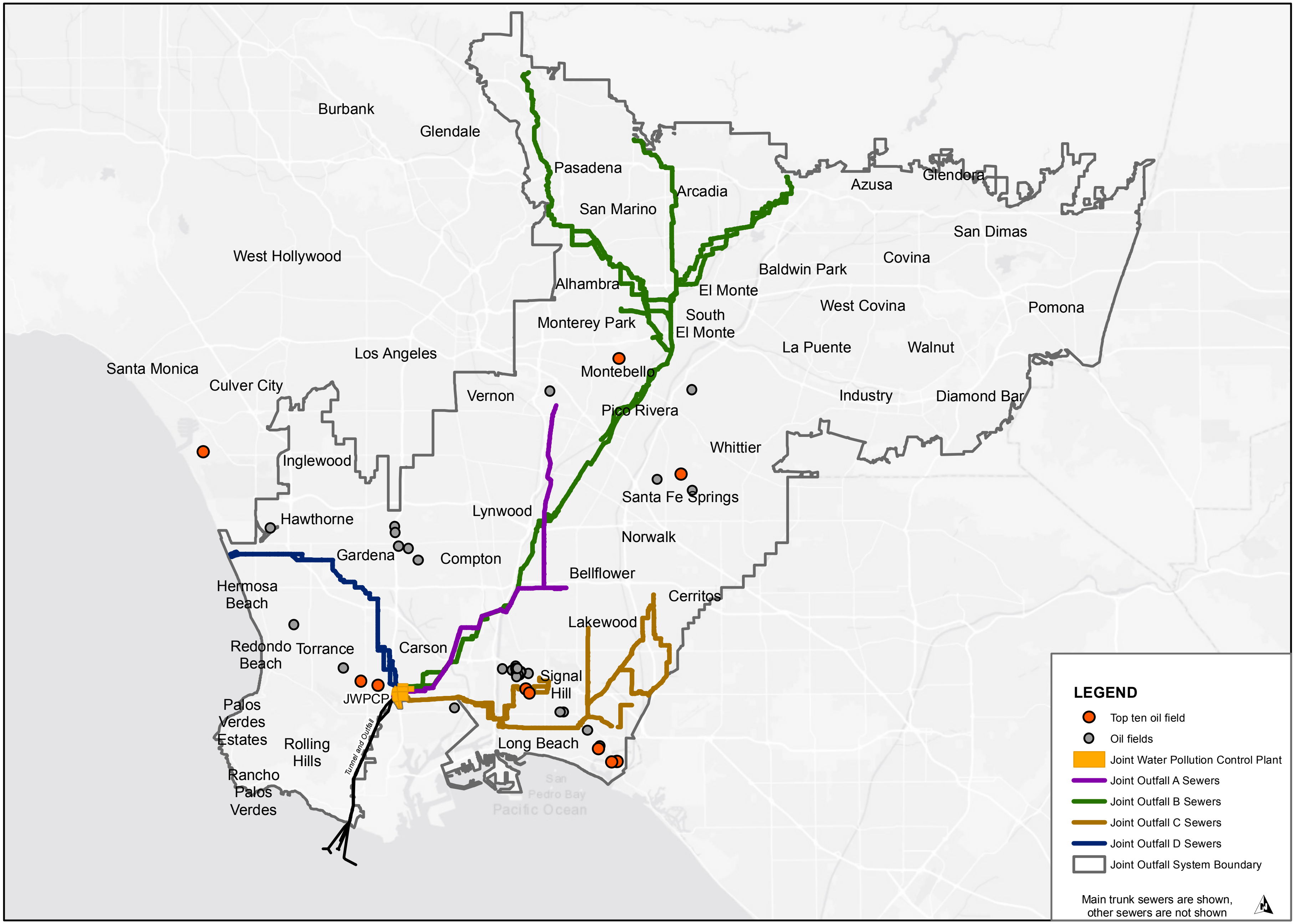
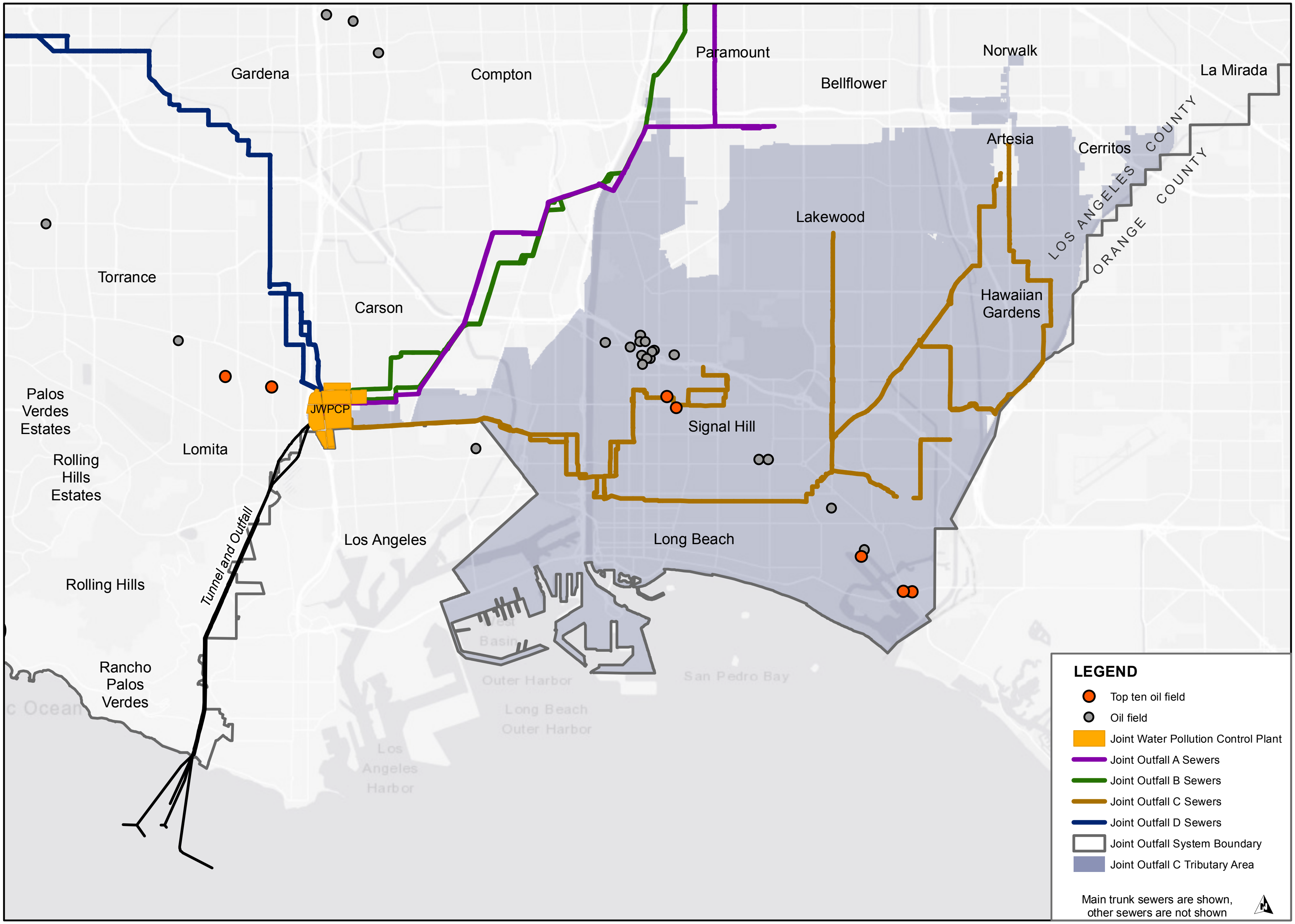


Figure 10. JO-C Trunk Sewer and Tributary Area and Oil Field Dischargers



ground or discharged to the sewer. The Sanitation Districts have collected samples and analyzed the boron content of the emulsion treatment chemical additives used by an oil field IU to see if they were contributing significant quantities of boron to the wastewater. These treatment chemicals include: scale inhibitors, emulsion breakers, and polymers. Based on the analytical results, these chemical additives are not a significant source of boron. Boron that exists in oil field wastewaters is likely present in the incoming water as a result of the decay of the same plants and animals that were the source of petroleum [14]. The characteristics for wastewater discharged from oil fields are presented in Table 5.

Table 5. Oil field Wastewater Characteristics

Water Quality Parameters	Number of Samples	Average	Standard Deviation	High	Low
Temperature (deg. F)	432	89	19	138	49
pH	536	7.3	0.44	10.1	6.1
COD (mg/L)	147	1,900	1,500	7,080	15.6
TSS (mg/L)	139	48	103	972	6
TDS (mg/L)	62	27,800	6,900	36,400	1,270
Oil & Grease (mg/L)	103	33	36	238	5
Chloride (mg/L)	62	14,700	4,000	19,700	461
Total Alkalinity (mg/L)	4	1,100	140	1,250	905

Note: Water quality data were collected during 2016.

4.6 POTENTIAL SOURCE CONTROL APPROACH AND ANTICIPATED EFFICACY

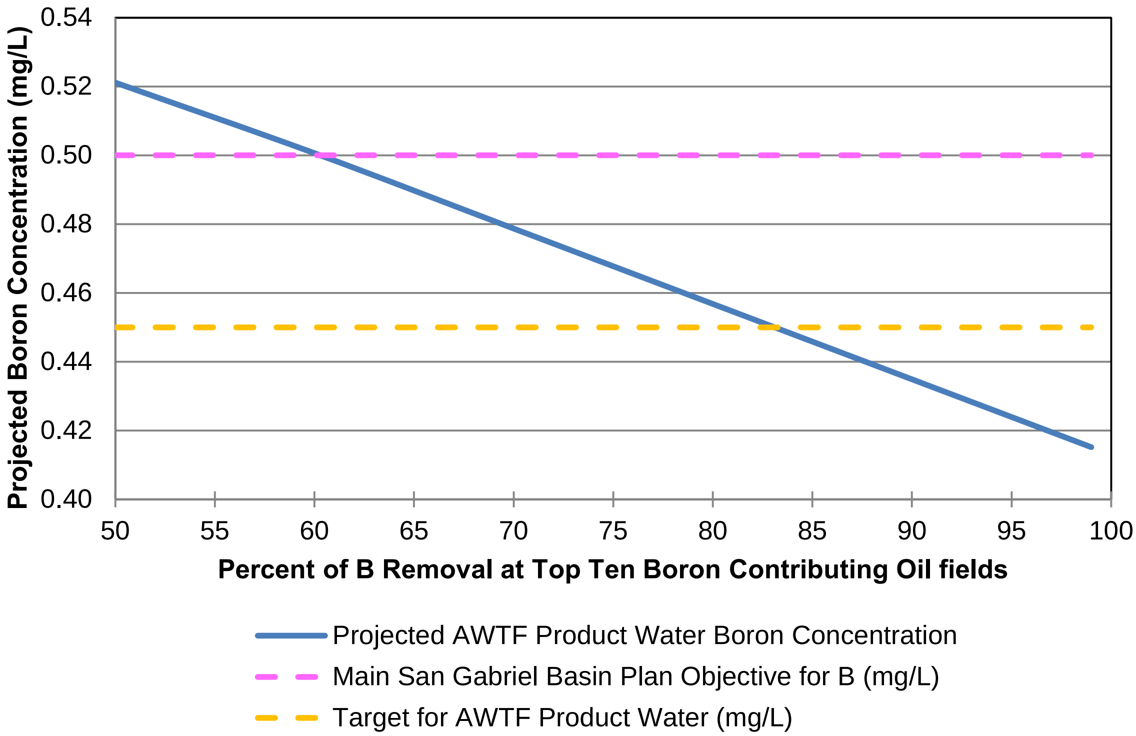
An analysis was conducted to estimate the boron load reduction needed to meet the AWTF's product water requirements with respect to boron. The following assumptions were employed:

(a) JWPCP influent boron concentrations of 0.90 mg/L;
(b) No boron addition or removal through the JWPCP;
(c) Target AWTF product water boron concentration of 0.45 mg/L;
(d) AWTF boron removal efficiency of 30%

Based on these assumptions, the maximum allowable boron concentration in the JWPCP influent would be (0.45 / (1-0.3) =) 0.64 mg/L. Compared to the current influent boron level (0.90 mg/L), the required reduction would be (0.90 – 0.64=) 0.26 mg/L.

One potential approach to deliver the required boron reduction via source control is by regulating boron discharges from the oil fields. As shown previously (Table 3), this industry contributes approximately 0.36 mg/L of the JWPCP's influent boron concentration. Therefore, a reduction of (0.26/0.36=) 72% of the industry's boron discharge would be sufficient to meet the target concentration. For the scenario where only the top ten oil fields are regulated, Figure 11 illustrates the relationship between reduction in boron discharge and the boron concentration in the AWTF product water.

Figure 11. Projected Boron Concentration in the AWTF Product Water versus Boron Removal in the Top Ten Oil Fields



Based on Figure 11, to meet the target boron concentration for the AWTF product water (0.45 mg/L), one would need to reduce the boron discharge from the top ten oil fields by more than 80%. Alternatively, if other sources of boron can be identified and controlled, a more modest reduction in the oil field contribution would be sufficient.

5.0 SUMMARY

The historical average influent concentration of boron is 0.90 mg/L and the influent mass loading of boron to the JWPCP is approximately 937 kg/day (Table 1). The residential/commercial background boron loading is approximately 237 kg/d, which is equivalent to an influent concentration of 0.25 mg/L (Section 4.2) and the boron loading from industrial sources is approximately 700 kg/d, which is equivalent to an influent concentration of 0.73 mg/L. The boron loading from the top ten oil field dischargers is 337 kg/d (equivalent to 0.32 mg/L), which is approximately 48% of the industrial load (Section 4.5). Therefore, the oil field industry has the largest boron contribution among all industry types.

The trunk sewer samples showed that the boron concentration and mass flow were highest in JO-C. This sewer receives flow from Long Beach and Signal Hill. Five of the top ten oil field facilities discharge to JO-C and contribute approximately 83% of the mass flow of boron in JO-C (Section 4.5).

Source control may potentially achieve the required reduction in boron entering the JWPCP to meet the MSG Basin objective of 0.5 mg/L. If a 72% reduction in the boron loading from the oil fields could be achieved, the target boron concentration of 0.5 mg/L in the AWTF product water could be met (Section 4.6). Alternatively, if additional controllable sources of boron can be identified, a more modest reduction in the oil field contribution would be sufficient.

6.0 FUTURE WORK

This report summarizes source identification efforts for the potentially largest contributions of boron to the JWPCP, which at this time appear to be from oil well fields that discharge wastewater to the JO-C trunk sewer system. Additional investigations will be initiated in the next few months to identify other potentially significant boron sources originating from other trunk sewer systems and boron data will continue to be collected quarterly to further characterize boron trends. A report of these efforts will be prepared if other significant sources are identified or if data trends change.

A report presenting a literature review of potential treatment options for removal of boron in oil well field wastewater discharges, feasibility of treatment and costs for boron removal from this wastewater stream is currently in development. Bench scale treatment data will be collected and used to determine treatment feasibility and costs. A recommendation regarding source control approach for boron from oil well field discharges will be included in the report.

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8.0 Appendix A

EPA Category	Locations with Boron Detected	No. of Samples with Boron Detected	Average Concentration (mg/l)	Total Daily Average Flow Rate (gpd)	Theoretical Headworks Concentration (µg/L)	Theoretical Headworks Concentration (mg/L)	Mass Loading (kg/day)
Oil Field	39	40	50	2,360,000	363	0.36	379
419 (Petroleum Refining)	9	43	1.0	17,900,000	68	0.07	71
420 (Iron and Steel MFG)	4	7	105	848,000	40	0.04	42
SN	34	107	2.6	5,900,000	38	0.04	40
437 (Centralized Waste Treatment)	8	114	13	366,000	22	0.02	23
421 (Nonferrous Metals MFG)	5	16	4.6	530,000	18	0.02	19
Multi-Category	30	104	5.4	790,000	13	0.01	13
413 (Electroplating)	11	29	90	41,000	12	0.01	13
433 (Metal Finishing)	113	373	3.2	1,220,000	11	0.01	11
SNLNDF	4	11	3.3	303,000	6.9	0.01	7.2
SNCHMF	5	11	1.2	554,000	5.5	0.01	5.7
SNPOCC	6	19	12	60,000	4.4	0.004	4.6
SNTEX	21	57	0.30	3,290,000	4.3	0.004	4.5
SNLDFH	3	7	5.8	46,000	0.82	0.001	0.86
439 (Pharmaceutical MFG)	1	3	0.63	300,000	0.68	0.001	0.71
SNGW	2	7	3.3	160,000	0.60	0.001	0.63
SNGAS	2	5	0.85	280,000	0.57	0.001	0.59
NONSIG	11	20	0.94	58,000	0.16	0.0002	0.16
467 (Aluminum Forming)	11	33	0.83	112,000	0.14	0.0001	0.14
442 (Transportation Equipment Cleaning)	4	16	0.50	63,000	0.12	0.0001	0.13
423 (Steam Electric Power Generating)	1	5	0.81	40,000	0.12	0.0001	0.12
SNGLSS	1	4	0.31	104,000	0.12	0.0001	0.12
464 (Metal Molding and Casting)	5	16	1.5	25,000	9.0E-02	0.0001	9.4E-02
INRAD	3	3	0.54	2,100	8.9E-02	0.000090	9.2E-02
SN13	1	2	96	160	5.6E-02	0.0001	5.8E-02
414 (OCPSF)	3	9	0.38	32,000	4.0E-02	0.00004	4.2E-02
SNPTFD	1	3	0.60	8,600	1.9E-02	0.00002	1.9E-02
469 (Electrical and Electronic Components)	2	3	0.18	28,000	1.8E-02	0.00002	1.9E-02
SNDRUM	2	5	0.60	4,600	1.5E-02	0.00001	1.5E-02
465 (Coil Coating)	3	5	0.38	30,000	1.3E-02	0.00001	1.3E-02
471 (Nonferrous Metals Forming)	2	4	2.2	830	7.1E-03	0.00001	7.4E-03
SNPRIN	1	3	1.5	630	3.4E-03	0.000003	3.6E-03
430 (Pulp Paper and Paperboard)	1	3	0.16	1,500	8.5E-04	0.000001	8.9E-04
SNRAD	1	2	0.73	164	4.4E-04	0.0000004	4.6E-04
SN55	1	2	0.28	230	2.3E-04	0.0000002	2.4E-04

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Appendix E:

Ion Exchange Study for Boron Removal

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Potential Regional Recycled Water Supply Program

Advanced Water Treatment Facility - Boron Removal

Task Order No. 33

July 10, 2018

Prepared for:

Metropolitan Water District of Southern California

Prepared by:

Stantec

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1.0 BACKGROUND AND OBJECTIVE

Metropolitan Water District of Southern California (Metropolitan) and the Los Angeles County Sanitation Districts (Districts) are investigating the feasibility of building a 150-MGD Advanced Water Treatment Facility (AWT) Facility at the Joint Water Pollution Control Plant (JWPCP) in Carson, CA. JWPCP is a 400-MGD high-purity oxygen activated sludge (HPOAS) facility that produces non-nitrified effluent, most of which is sent to the ocean through two existing tunnels and four outfalls. Currently, JWPCP receives and treats approximately 260 MGD of wastewater flow. The existing process was neither designed for ammonia nor nitrogen removal. Previous pilot studies have shown that with additional advanced treatment, a portion of JWPCP's secondary effluent could be beneficially reused to supplement local potable supplies through groundwater recharge. Four groundwater basins are currently under consideration: Main San Gabriel, West Coast, Central and Orange County. The Total Nitrogen requirement for the Orange County basin is ≤ 3.5 mg/L whereas that for the other three basins is ≤ 10 mg/L. The base-case process train for the full-scale AWT Facility consists of a nitrifying-denitrifying (NdN) tertiary MBR, reverse osmosis (RO), ultraviolet/advanced oxidation process (UV/AOP) and stabilization. While nitrogen management at the AWT Facility has been studied extensively, another crucial factor is boron removal to meet specific water quality goals for the groundwater basins.

The JWPCP effluent exhibits relatively high concentrations of boron, with median and maximum concentrations at 0.88 and 1.1 mg/L[1], respectively. The largest contribution of boron to the JWPCP has been attributed to industrial discharges in the collection system, and oil field dischargers are the largest contribution of the industries[2]. The presence of boron in the secondary effluent from the JWPCP at levels exceeding groundwater basin plan boron limits of 0.5 mg/L would require either source control or treatment for boron removal at the AWT Facility.

An ion-exchange process for boron removal can be added to the base-case AWT Facility process train. The objective of this study was to evaluate IX treatment for boron removal as an additional process within the AWT Facility's process train.

2.0 ION EXCHANGE PROCESS ALTERNATIVES

IX for boron removal could be accomplished with one of two resins; boron-selective resin or strong base anion (SBA) resin. These resins contain different properties that can be affected by certain constituents in the water (i.e. competing ions, pH, Total Dissolved Solids, etc.) and therefore, they would be placed at different locations in the process train with different pre- and post-treatment requirements.

Multiple process trains have been evaluated for the 150 MGD AWT Facility. However, for this study, two trains were evaluated to incorporate IX treatment for boron removal and are described in subsequent sections below. Both trains consist of tertiary membrane bioreactor followed by RO,

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[1] Source: Joint Water Purification Pilot Program: Pilot Study of Advanced Treatment Processes to Recycle JWPCP Secondary Effluent – Final Report", Districts and Metropolitan, 2012.

[2] Source: Boron Source Investigation Report, Sanitation Districts of Los Angeles, January 12, 2018.

ultraviolet advanced oxidation process (UV/AOP), stabilization and residual chlorination before storage in an effluent clearwell prior to pumping and conveyance.

2.1 Alternative 1 - Boron-selective IX Process

Alternative 1 utilizes boron-selective IX resin in conjunction with nitrifying-denitrifying (NdN) tertiary MBR + RO + UV/AOP + Stabilization train (**Figure 1**), referred to as Train 2B in nitrogen management analysis. The IX process was designed as a split-stream treatment after stabilization and was sized to produce a final blended effluent boron concentration of less than 0.4 mg/L. The IX process will need to treat 100 MGD of the 150 MGD of the product water flow with this alternative. Since the boron-selective resin primarily removes boron only, a biological denitrification step is required in tertiary MBR for nitrate removal.

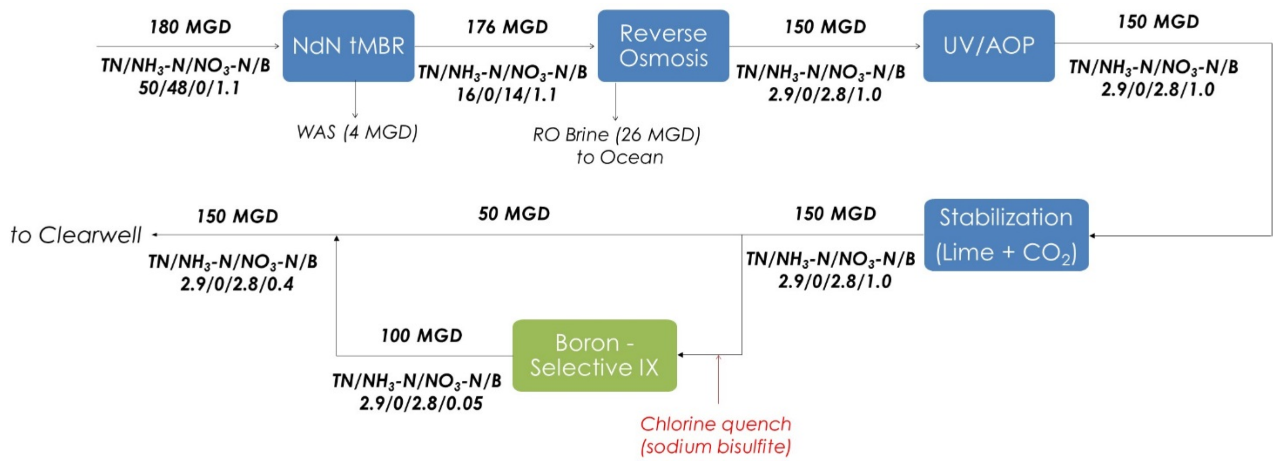

Figure 1 – Boron-selective IX Process Train

Boron-selective IX resins utilize a specialized structure with functional groups that selectively remove boron. This allows the process to achieve effective removal of boron over a wide range of feed water pH (5-10) with little interference from other ions. The process would be located downstream of RO to minimize the process size/flow-rate, but could be located either upstream or downstream of stabilization. For the purposes of this investigation, it was assumed that the IX process would be located downstream of stabilization to protect facilities from aggressive water conditions.

The only pretreatment requirement for this process is quenching of chlorine prior to the IX filters. Exposure to chlorine would reduce the useful life of the resin. There are no post-treatment requirements.

Resin regeneration for boron-selective resin is conducted in two steps; displacement using acid treatment (3 to 5% HCl or H_2SO_4) followed by complete conversion with 2 to 6% NaOH. It is assumed that regeneration waste will be neutralized and discharged to the ocean via the JWPCP outfall. The resin life is typically between 5 to 8 years, with 5% reduction in capacity per year. Three different resins such as Amberlite PWA10, ResinTech SIR 150 and Purolite S108 were considered for this application. Resin properties and system designs proposed by vendors of all three types considered have been included in Appendix B.

A concrete filter configuration is generally advantageous at this scale, although there are material compatibility and operational challenges associated with resin regeneration using low and high pH chemical solutions. The concrete filter boxes would have to be lined and maintained to prevent concrete corrosion and damage. It would be challenging to provide a liner that will not crack due to shrinkage of the concrete. Any cracks that develop allow for the acid solution to attack the concrete and bonding and lead to failure of the coating. Therefore, lined pressure vessels are recommended for this process and have been utilized successfully by IX vendors.

2.1.1 Design Criteria

Table 1 presents conceptual level design criteria and operating conditions for the boron-selective IX process that forms the basis for conceptual site layout and cost estimate. Detailed design criteria are included in **Appendix A**. Based on RO process modeling, the upstream RO process is expected to lower the influent boron concentration for the IX process from 1.1 to 0.99 mg/L and therefore, influent boron concentration of 1 mg/L was used for sizing the IX process.

Table 1 – Design Criteria for the Boron-selective IX Process

Parameter	Unit	Value
Product Water Flowrate	MGD	150
IX Feed Flowrate	MGD	100
Boron Removal Efficiency	%	95%
Influent Boron Concentration, Maximum	mg/L	1.0
Effluent Boron Concentration	mg/L	< 0.4
Resin Type		Boron-selective
Superficial Linear Velocity	gpm/ft^2	10[1]
Service flow rate	BV/hr	17[1]
Number of Filters, Duty + Standby	--	90[1] + 18
Time between Regeneration	days	5.25[1]
Regeneration Chemicals	--	5% HCl, 2% NaOH[1]

1. Based on information from Evoqua for equipment and using DOW Amberlite PWA10 resin.

2.1.2 Design Considerations

The following items should be considered when evaluating this alternative further for implementation:

- Appropriate materials and lining needs should be considered for the equipment, piping, and appurtenances that will be in contact with high and low pH regeneration solutions.
- Free chlorine and/or chloramine in the feed should be limited to less than 0.3 mg/L in order to avoid long-term damage to the resin. Quenching of chloramines/chlorine used in the upstream RO and possibly UV/AOP process is therefore required.

- Combining acid and base solutions to neutralize regeneration waste is typical practice, but needs to be handled with care to ensure safety. Additionally, the combined solution remains slightly acidic and requires additional sodium hydroxide to reach neutral pH.
- It is recommended to evaluate the process at bench and pilot-scale to provide performance data for design and operational optimization.
- Release of nitrosamines and its precursors from some ion-exchange resins have been published[3] and the issue needs to be investigated for selected resin since it will impact the placement of the IX process within the process train as well as economics of treatment.

2.1.3 Conceptual Site Layout

Figure 2 depicts a conceptual site layout for the boron-selective IX process. This site layout is a high level representation, and if a train is selected for further consideration, the layout of the complete process train should be optimized for maintenance and access of equipment, pipelines and chemicals, and with respect to its relationship to the other site facilities.

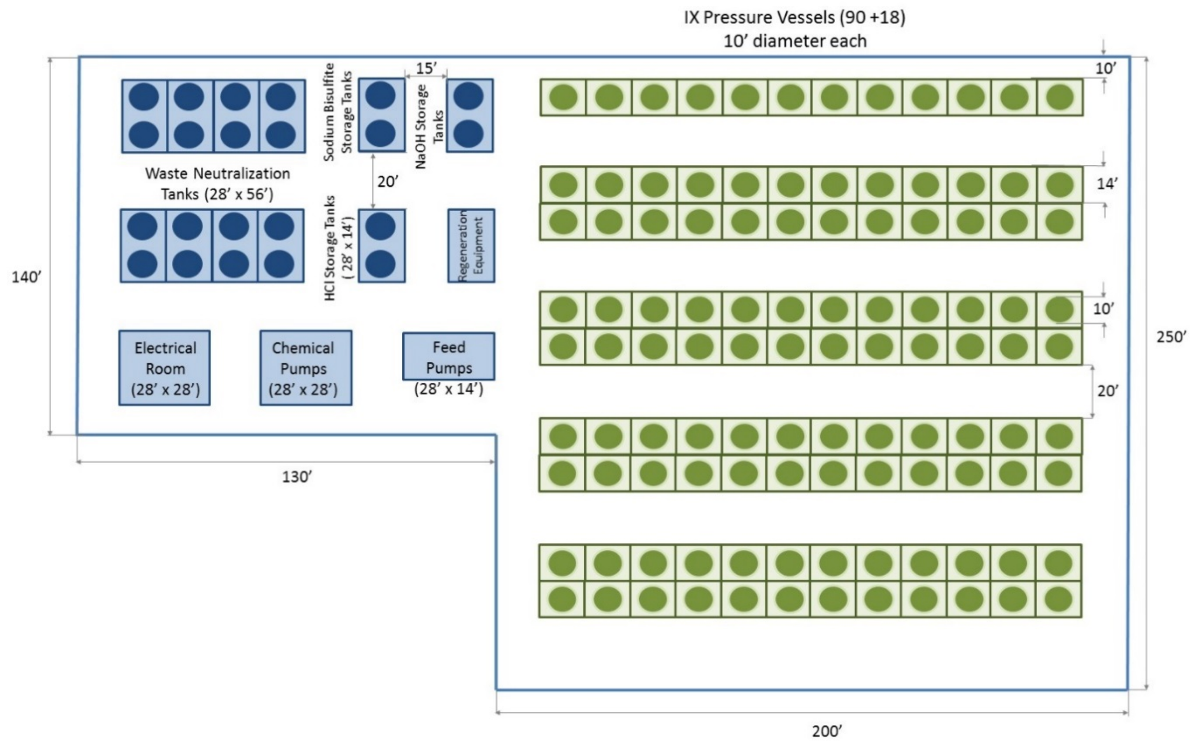

Figure 2 – Conceptual Site Layout for the Boron-selective IX Process

[3] Source: Flowers, R.C., Singer, P.C. (2013) Anion Exchange Resins as a Source of Nitrosamines and Nitrosamine Precursors, *Environmental Science & Technology*, 47, 7365-7372.

2.2 Alternative 2 – Strong Base Anion IX Process

Alternative 2 utilizes strong base anion (SBA) IX resin in conjunction with a nitrifying-only (N-only) tertiary MBR + RO + UV/AOP + Stabilization train (**Figure 3**), referred to as Train 2A in nitrogen management analysis. This train relies on nitrifying-only tertiary MBR for complete conversion of ammonia to nitrate and RO for partial removal (80%) of nitrate. An SBA IX process is added following lime stabilization to lower both nitrate and boron concentrations sufficient enough to meet the water quality goals for those parameters for four groundwater basins i.e. NO_3-N < 2.4 mg/L and Boron < 0.5 mg/L. Since IX is applied after the RO in this alternative, it needs to remove much smaller fraction of nitrate compared to biological treatment in Train 2B (7 vs 34 mg/L-N) to meet the effluent water quality goal of TN ≤ 2.5 mg/L.

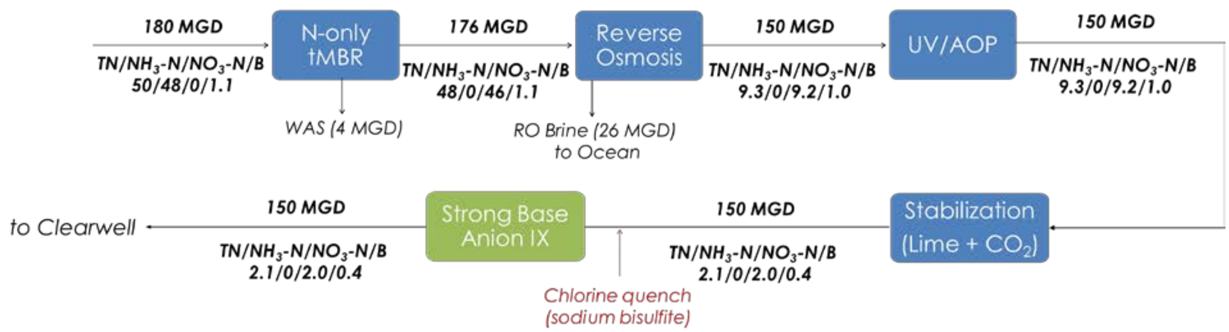

Figure 3 - Strong Base Anion IX Process Train

SBA resins are not selective for specific ions but have a high uptake capacity for negatively-charged ions. Removal of boron is highly dependent upon pH in order to have boron in the negatively-charged ionic form of borate (which occurs at pH > 9). Nitrate and borate are lower on the order of preference for uptake by the resin and are more loosely held than other anions with stronger negative charge, especially divalent ions. Therefore, competing ions and pH significantly affect performance for nitrate and borate removal. The process is located downstream of RO to minimize ion interference, and downstream of lime addition to take advantage of the high ph.

Downstream of RO where minimal competing ions are present, IX vendors report that SBA resins are able to achieve greater than 80% removal of nitrate and 60 % removal of boron at pH above 10. Based on this information, the IX process is required to treat the entire flow to lower the boron concentration from 1.0 to <0.5 mg/L. The performance of SBA resin for simultaneous removal of nitrate and boron should be investigated further with bench and pilot-scale testing due to the high dependence on feed water quality and the unique application of using this type of resin for boron removal.

Pretreatment requirements include pH adjustment and also quenching of chlorine to prevent damage to the resin and consequently, reduction of its useful life. Additional pH adjustment and stabilization is required downstream to meet final effluent targets for storage and conveyance of treated water. Carbon dioxide and sodium hydroxide are recommended for this final step to add alkalinity.

Regeneration for SBA resin is performed with 2 to 6% sodium chloride. The resin life for SBA resin is similar to boron-selective resin, typically between 5 and 8 years, with 5% reduction in capacity per year. There are many commercially available SBA resins; Resintech's SGB-2 was considered for this study and properties of this resin are presented in **Appendix B**.

SBA resins are regenerated using sodium chloride solution and therefore, conceptual design of this IX process was based on concrete filters although piping materials will need to be compatible with high chloride solutions. A concrete filter configuration provides many benefits including reduced costs and equipment to maintain, longer useful life of the infrastructure, and small footprint requirements. It was assumed that the regeneration waste would be discharged to the ocean through LACSD's outfall.

2.2.1 Design Criteria

Table 2 presents the design criteria and operating conditions for the SBA IX process that was used as a basis for conceptual design and cost estimate. Further detailed design criteria are included in **Appendix A**.

Table 2 – Design Criteria for the Strong Base Anion IX Process

Parameter	Unit	Value
Product Water Flowrate	MGD	150
IX Feed Flowrate	MGD	150
Boron Removal Efficiency	%	> 60%
Nitrate Removal Efficiency	%	> 80%
Influent Boron Concentration, Maximum	mg/L	1.0
Effluent Boron Concentration	mg/L	< 0.4
Influent Nitrate Concentration, Maximum	mg/L	10
Effluent Nitrate Concentration	mg/L	< 2.0
Resin Type		Strong Base Anion
Superficial Linear Velocity	gpm/ft^2	10
Service flow rate	BV/hr	13.4
Number of Filters, Duty + Standby	--	12 + 4
Time between Regeneration	days	1.7
Regeneration Chemicals	--	2% NaCl

2.2.2 Design Considerations

The following items should be considered when evaluating this alternative further for implementation:

- Appropriate materials and lining needs to be considered for the equipment, piping, and appurtenances that will be in contact with high chloride solutions.

- Free chlorine and/or chloramine in the feed should be limited to less than 0.3 mg/L in order to avoid long-term damage to the resin. Quenching is therefore required.
- Additional operational and process control complexity with pH adjustment, quenching of chlorine, and frequent regeneration should be considered. Stabilization processes have to achieve multiple goals (alkalinity, pH, mineral hardness), and are affected by SBA IX removal of carbonates and hydroxides.
- Performance of the SBA resin for boron removal is highly dependent upon pH, presenting a risk if pH adjustment is not performed correctly.
- Frequent regeneration and large size of facility mean that salt usage and required storage is very large (salt usage of ~ 170 tons/day, all filters will need to undergo regeneration every ~ 1.5 days).
- Even distribution of flow (feed, backwash, and regeneration) is important in concrete filters to achieve efficient use of resin capacity.
- Regeneration could be based on nitrate or boron breakthrough. If based on nitrate breakthrough then online nitrate analyzer could be utilized for process control.
- It is strongly recommended to evaluate the process at bench and pilot scale to provide performance data for design and operational optimization.
- Release of nitrosamines and its precursors from some ion-exchange resins have been published[4] and the issue needs to be investigated for selected resin since it will impact the placement of the IX process within the process train as well as economics of treatment.

2.2.3 Conceptual Site Layout

Figure 4 depicts a conceptual site layout for the boron-selective IX process. This site layout is a conceptual-level representation, and if a train is selected for further consideration, the layout of the complete process train should be optimized for maintenance and access of equipment, pipelines and chemicals, and with respect to its relationship with other site facilities.

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[4] Source: Flowers, R.C., Singer, P.C. (2013) Anion Exchange Resins as a Source of Nitrosamines and Nitrosamine Precursors, *Environmental Science & Technology*, 47, 7365-7372.

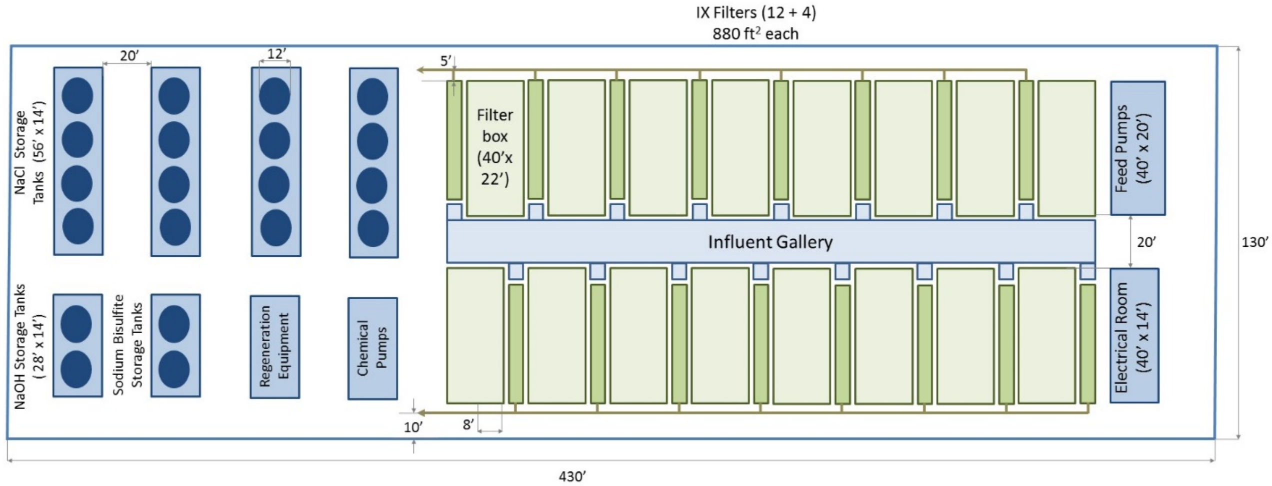

Figure 4 – Conceptual Site Layout for the Strong Base Anion IX Process

3.0 COST ESTIMATES

Cost estimates were developed in accordance with the criteria established by the Association for the Advancement of Cost Engineering (AACE) for a Class 5 cost estimate. The estimate has an accuracy level ranging between -50% to +100%. Capital costs developed for each IX process alternative include the following items:

- Equipment – Included costs for process equipment, pumps and the initial resin fill
- Electrical and Instrumentation and Control (I&C) – Assumed at 45% of equipment costs
- Mechanical Installation – Assumed at 40% of equipment costs
- Civil – Included site work, concrete and piping
- Contingencies – A 30% allowance for contingencies was added to the construction subtotal
- Engineering/Legal/Admin Fees – Assumed at 35% of the construction subtotal plus contingency
- Land Cost - The IX processes would be co-located with the other AWT processes east of the existing secondary clarifiers at the FORCO site. The total footprint was estimated for the IX processes and a land cost of $2.5M/acre was applied based on prevailing real estate prices

The principal components for the Operation and Maintenance (O&M) costs were:

- Resin Replacement – Life expectancy of the resin was assumed to be 6 years with 5% resin makeup required each year to account for reduction in resin capacity

- Maintenance – Assumed at 2% of the equipment cost
- Labor Cost – Assumed that 10 full-time employees would be required to operate the IX facility at an hourly rate of $150/hr and 2,080 work-hours per employee per year
- Chemicals including:
  - Hydrochloric acid (HCl) for regeneration of boron-selective resin
  - Sodium hydroxide (NaOH) for regeneration of boron-selective resin, neutralization of regeneration waste from Train A and pH adjustment for Train B
  - Sodium chloride for regeneration of SBA resin
  - Sodium bisulfite to quench chlorine
- Power – Additional power consumption due to influent pumping to IX system
- Contingency – 15% contingency added to O&M costs

A present worth analysis was conducted for both Alternatives. The net present value (NPV) is based on a 20-year analysis period and a 4% interest rate, as follows:

$$NPV = Capital\ Cost + \left(O\&M\ Cost \times \frac{(1+i)^n - 1}{i \times (1+i)^n}\right)$$

where,

n = number of years,

i = interest rate

A summary of the capital costs, O&M costs and NPV for the Alternatives is presented in **Table 3**. More detailed cost breakdowns can be found in **Appendix C** and **Appendix D**.

Table 3 - Cost Estimate Summary

	Boron-selective IX Process	Strong Base Anion IX Process
Construction Cost	$178M	$234M
Annual O&M Cost	$17.5M	$18M
NPV	$415M ($124/ac-ft)	$484M ($144/ac-ft)

4.0 COST COMPARISON OF IX PROCESS ALTERNATIVES

The primary objective of this analysis was to assess the costs of IX for boron removal. However, Alternative 2 provides added benefit of nitrate removal and therefore, it is important to compare the overall train costs for these trains. Cost estimates for the Alternatives 1 and 2 without the IX process for RO product water (i.e. excluding AOP and Stabilization processes) were developed earlier as part of nitrogen management analysis and these trains were referred to as Trains 2B and 2A, respectively in that study. Updated costs for these trains with IX process added to them are shown in **Table 4**. As shown, if both nitrate and boron removal were to be achieved at the AWT Facility site, then Alternative 2 (i.e. Train 2A + IX) provides a substantial cost benefit. If this option was to be pursued, then it is recommended to develop a more detailed design and associated Class 4 estimates for the complete train.

Table 4 - Cost Comparison of IX Process Alternatives

	Alternative 1	Alternative 2	Difference
NPV for IX ($/ac-ft)	$124	$144	($20)
NPV of Associated Train* ($/ac-ft)	$723	$625	$98
NPV of Associated Train* + IX ($/ac-ft)	$847	$769	$78

* Train cost does not include costs for UV/AOP and Stabilization processes

5.0 KEY FINDINGS

Two different IX process alternatives were evaluated to achieve boron removal at the AWT Facility. A boron-selective resin (Alternative 1) was evaluated in conjunction with an NdN Tertiary MBR + RO + UV/AOP train (Train 2B in nitrogen management analysis) and a SBA resin (Alternative 2) was evaluated in conjunction with an N-only Tertiary MBR + RO train (Train 2A in nitrogen management analysis).

The NPV for the IX process using boron-selective resin and SBA resin were found to be $124/ac-ft and $144/ac-ft, respectively. Since SBA resin can achieve both nitrate and boron removal, biological denitrification is not required when using this train. Therefore, the upstream treatment requirements for these resins differ if both nitrate and boron removal were to be achieved at the AWT Facility. When comparing the overall treatment train cost (excluding the AOP and Stabilization processes), Alternative 2 is more economical providing a cost benefit of $78/ac-ft. If boron removal has to be achieved at the AWT Facility, then Alternative 2 should be explored further by developing a more detailed design and Class 4 cost estimates.

APPENDICES

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Appendix A IX PROCESS DESIGN CRITERIA

Parameters	Units	Boron-selective IX	Strong Base Anion IX	Notes
Process Flowrate Design Basis				
Product Water Flow Capacity	MGD	150	150	
Percentage Flow Split	%	0.65	1.00	
Boron Removal Efficiency	%	0.95	0.60	
Nitrate Removal Efficiency	%	-	0.80	
Influent Capacity through IX	MGD	97.5	150	
Influent Boron Concentration	mg/L	1.0	1.0	From RO Permeate
Effluent Boron concentration	mg/L	0.383	0.400	Target < 0.4 mg/L (Basin limit < 0.5 mg/L)
Influent Nitrate Concentration	mg/L	-	10.0	From RO Permeate
Effluent Nitrate concentration	mg/L	-	2.000	Target < 2.5 mg/L (Basin limit < 3.4 mg/L)
IX Resin Bed Sizing				
Superficial Linear Velocity	gpm/ft^2	9.8	10.0	
Bed Depth	ft	4.7	6.0	Recommended by vendor
Filter Area, Required	ft^2	6,890	10,420	
Service Flowrate	gpm/ft^3	2.1	1.7	
	BV/hr	16.9	13.4	
Empty Bed Contact Time (EBCT)	min	3.6	4.5	
Equipment Arrangement				
Filter Arrangement/Equipment Type	-	Pressure Vessel Filters	Concrete Gravity Filters	

Appendix A IX Process Design Criteria

Parameters	Units	Boron-selective IX	Strong Base Anion IX	Notes
Number of Filters, Duty + Standby	--	90 + 18	12 + 4	Number of pressure vessels for selective resin from Evoqua quote; assume 12 hour day operation and 4 hours per regeneration
Vessel Diameter	ft	10.0	-	Size of vessels based on Evoqua quote
Filter Area, per Filter	ft^2	78.5	868.3	
Filter Area, Total	ft^2	8,480	13,890	
Resin Volume, Total	ft^3	39,573	83,340	
Headloss through the Resin	psi	7.4	6	From vendor
Headloss through the Resin	ft	17.1	13.8	
Headloss, Total	psi	10.0	10.0	Adding 3-4 psi to include pressure drop across the process. (5+1) configuration for feed pumps
	ft	23.1	23.1	
Chlorine Quenching				
Sodium Bisulfite Dose	mg/L	4.5	4.5	Based on 3 mg/L chlorine to quench
Sodium Bisulfite Consumption	lb/day	2,670	5,070	
Number of Storage Tanks		2	2	Based on 7 days storage, 25% solution
Size of Storage Tanks, Each	gal	4,200	4,200	Based on 7 days storage, 25% solution
pH Adjustment				
NaOH Dose	mg/L	-	20.0	Downstream of IX to meet effluent water quality goals
NaOH Consumption	lb/day	-	18,265	As 100% NaOH
Number of Storage Tanks		-	2	Based on 7 days storage, 50% solution
Size of Storage Tanks, each	gal	-	10,150	Based on 7 days storage, , 50% solution
Regeneration Process				
Loading Rate, L_{boron}	kg/hr	14.6	14.2	Calculated
Time between Regeneration	days	5.25	1.67	From vendor

Parameters	Units	Boron-selective IX	Strong Base Anion IX	Notes
Chemicals for Regeneration Process				
Chemical Consumption per Regeneration per Filter				
HCl	lb	597	-	From vendor
NaOH	lb	398	-	From vendor
NaCl	lb	-	46,890	Calculated
Chemical Consumption per Day				
HCl	lb/day	10,735	-	From vendor
NaOH	lb/day	7,001	-	From vendor
NaCl	lb/day	-	337,608	Calculated
Chemical Storage Tanks				
HCl, @ 35%	--	2 @ 12,000 gal each	-	Based on 7 days storage
NaOH, @ 50%	--	2 @ 6,000 gal each	-	Based on 7 days storage
NaCl, @ 100%	--	-	11 @ 75 tons each	Based on 7 days storage
Backwash/Rinse Pump Sizing				
Backwash Rate	gpm/ft^2	TBD by vendor	2	From vendor
Backwash Flowrate per Filter	gpm	TBD by vendor	1737	Calculated
Number of Backwash Systems	--	TBD by vendor	3	Allows three filters to backwash at the same time
Number of Pumps per Backwash System, Duty	--	TBD by vendor	2	
Number of Pumps, Total	--	TBD by vendor	6 + 1	Shared standby
Pump Efficiency	%	TBD by vendor	75%	
Headloss through the Resin	ft	TBD by vendor	6	From vendor
Headloss through the Underdrain	ft	TBD by vendor	0.5	Assumed
Static Lift Required	ft	TBD by vendor	20	Assumed

Parameters	Units	Boron-selective IX	Strong Base Anion IX	Notes
Headloss through Piping	ft	TBD by vendor	10	Assumed
Headloss Total	ft	TBD by vendor	36.5	
Pump Power, Each	hp	TBD by vendor	10.7	Calculated
Motor Power, Each	hp	TBD by vendor	15.0	
Regeneration Pump Sizing				
Regeneration Rate	gpm/ft^3	TBD by vendor	1.00	
Regeneration Flowrate per Filter	gpm	TBD by vendor	868	
Number of Regeneration Systems	--	TBD by vendor	3	Allows three filters to regenerate at the same time
Number of Pumps, Duty	--	TBD by vendor	1	
Number of Pumps, Total	--	TBD by vendor	3 + 1	Shared standby
Pump Efficiency	%	TBD by vendor	75%	
Headloss through the Resin	ft	TBD by vendor	6	From vendor
Headloss through the Underdrain	ft	TBD by vendor	0.5	Assumed
Static Lift Required	ft	TBD by vendor	20	Assumed
Headloss through Piping	ft	TBD by vendor	10	Assumed
Headloss Total	ft	TBD by vendor	36.5	
Pump Power, Each	hp	TBD by vendor	10.7	Calculated
Motor Power, Each	hp	TBD by vendor	15.0	

Appendix B INFORMATION ON VARIOUS IX RESINS AND CORRESPONDING BASIS OF SYSTEM DESIGN

Parameters	Boron-selective Resin				SBA Resin	Notes
	Purolite S108	Resintech SIR150	Amberlite PWA10	Amberlite PWA10	SBG-2	
Performance Design Criteria						
Optimum pH range	Varies	4 to 10	5 to 11	5 to 11	>10.5	For Boron removal
Service Flow Rate, gpm/ft^3	2	2	0.6 - 4.5	0.6 - 4.5	2 - 4	
Total Capacity, eq/L	>0.6	>0.6	>0.7	>0.7	> 1.4	
Design Conditions						
Resin Cost, $/ft^3	550	750	929	929	200	From vendors
Capacity, ft^3/filter	540	700	364	364	5,208	From vendor projections & correspondence for boron-selective resin; based on concrete filter design for SBA resin
Cost of Resin, $/filter	$ 297,000	$ 525,000	$ 338,000	$ 338,000	$ 1,041,667	
Diameter, ft	12	12	10	10	-	From vendors
Maximum Depth, ft	4.8	6	4.7	4.7	6.0	Purolite - from Projections, Resintech-refer email, Amberlite -cut sheets
Filter Area per filter, ft^2	113	113	79	79	868	Calculated
Flow per filter, gpm	1077	1400	771.3	1361.3	8681	From vendors
No. of Filters	63	48	88	50	12	Calculated
Total Filter Area, ft^2	7,111	5,470	6,894	3,906	104,167	Calculated
Resin Volume, ft^3	540	679	367	367	5,208	Calculated
Vessel EBCT, min	3.8	3.6	3.6	2.0	4.5	Calculated
Specific Flowrate, BV/hr	16.0	16.5	16.9	29.8	13.4	Calculated

Appendix B Information on various IX Resins and corresponding basis of System Design

Parameters	Boron-selective Resin				SBA Resin	Notes
	Purolite S108	Resintech SIR150	Amberlite PWA10	Amberlite PWA10	SBG-2	
Linear Velocity, gpm/ft^2	9.5	12.4	9.8	17.3	10.0	
Regeneration						
Throughout Capacity, gal/ft^3	12,575	30,000	15,910	11,143	4,000	From vendors
Cycle Time per Column, days	4	10	5.3	2.1	1.7	From vendors
Backwash Rate, gpm/ft^2	2.0	2.0	1.8	1.8	2.0	From product data sheets
Regeneration Rate, gpm/ft^3	0.25	0.25	1.30	1.30	1.00	
Regeneration Time, hours	3.7	3.67	3 - 4	3 - 4	-	Purolite- from projection, Resintech refer to cutsheet provided for regeneration
HCl used for Regeneration, %	4%	3-5%	5%	5%	-	
Acid Consumption per Regeneration, lb	1740	2800	818	818	-	
NaOH used for Regeneration, %	2%	4-6%	2%	2%	-	
Caustic Consumption per Regeneration, lb	1033	4200	545	545	-	
NaCl used for Regeneration, %	-	-	-	-	5%	
NaCl Consumption per Regeneration, lb	-	-	-	-	52,083	10 lb/ft^3 per vendor
Wastewater Produced per Regeneration, gal	46,854	105,000	18,242	18,242	598,958	

Appendix C DETAILED COST BREAKDOWN FOR BORON-SELECTIVE RESIN (ALTERNATIVE 1)

CONSTRUCTION COSTS			
Item	**Unit Cost**	**Qty**	**Cost**
Civil			
Sitework	$\$40/ft^2$	69,000	$2,760,000
Equipment Pads	$\$500/yd^3$	5,200	$2,600,000
Civil Subtotal			**$5,360,000**
Equipment			
Feed Pumps	$150,000/pump	5 + 1	$900,000
IX Pressure Vessels	$184,000/vessel	108	$19,870,000
Regeneration Equipment	LS	--	$6,700,000
Equipment Subtotal			**$27,470,000**
Piping and Valves Allocation	20% of equipment subtotal		$5,500,000
Electrical/I&C	45% of equipment subtotal		$12,370,000
Mechanical Installation	40% of equipment subtotal		$10,990,000
IX Media Initial Fill	$338,000/vessel	108	$36,510,000
Construction Subtotal			**$98,200,000**
Contingencies	30% of construction subtotal		$29,460,000
Engineering/Legal/Admin	35% of construction subtotal + contingencies		$44,690,000
Land Cost	$2.5M/acre	1.58	$3,960,000
Site Remediation	$1.0M/acre	1.58	$1,590,000
Total Construction Cost			**$177,900,000**
Low Range (-50%)			**$88,950,000**
High Range (+100%)			**$355,800,000**

Appendix C Detailed Cost Breakdown for Boron-Selective Resin (Alternative 1)

ANNUAL O&M COSTS			
Item	**Unit Cost**	**Qty**	**Cost**
Media Replacement			$7,910,000
Maintenance	2% of equipment subtotal		$550,000
Labor	$150/hr		$3,120,000
Chemicals			$2,921,000
HCl (for regeneration)	*$1.8/gal*	*1,156,523*	*$2,080,000*
NaOH (for regeneration)	*$1.4/gal*	*400,288*	*$560,000*
NaOH (for neutralization of regeneration waste)	*$1.4/gal*	*200,144*	*$280,000*
Sodium Bisulfite (for chlorine quenching)	*$1.1/gal*	*1,123*	*$1,000*
Power			$695,000
Feed Pump	*$0.15/kWh*	4,468,000	*$670,000*
Backwash Pump	*$0.15/kWh*	96,913	*$10,000*
Regeneration Pump	*$0.15/kWh*	39,444	*$10,000*
Chemical Pump	*$0.15/kWh*	31,333	*$5,000*
Contingency	15% of O&M Costs		$2,280,000
Annual O&M Cost			**$17,476,000**

Appendix D DETAILED COST BREAKDOWN FOR SBA RESIN (ALTERNATIVE 2)

CONSTRUCTION COSTS			
Item	**Unit Cost**	**Qty**	**Cost**
Civil			
Sitework	$40/ft^2$	56,000	$2,240,000
Equipment Pads	$500/yd^3$	2,300	$1,150,000
Civil Subtotal			**$3,390,000**
Equipment			
Feed Pumps	$150,000/pump	8 + 2	$1,500,000
Concrete Filter Boxes	$3,500/ft^2$	13,890	$48,620,000
Regeneration Equipment	LS	--	$6,700,000
Equipment Subtotal			**$56,820,000**
Piping and Valves Allocation	20% of equipment subtotal		$11,370,000
Electrical/I&C	45% of equipment subtotal		$25,570,000
Mechanical Installation	40% of equipment subtotal		$22,730,000
IX Media Initial Fill	$1,042,000/filter box	12	$12,510,000
Construction Subtotal			**$132,390,000**
Contingencies	30% of construction subtotal		$39,720,000
Engineering/Legal/Admin	35% of construction subtotal + contingencies		$60,240,000
Land Cost	$2.5M/acre	1.29	$3,210,000
Site Remediation	$1.0M/acre	1.29	$1,290,000
Total Construction Cost			**$236,850,000**
Low Range (-50%)			**$118,425,000**
High Range (+100%)			**$473,700,000**

Appendix D Detailed Cost Breakdown for SBA Resin (Alternative 2)

ANNUAL O&M COSTS			
Item	**Unit Cost**	**Qty**	**Train B**
Media Replacement			$2,710,000
Maintenance	2% of equipment subtotal		$1,140,000
Labor	$150/hr		$3,120,000
Chemicals			$7,620,000
NaOH (for pH adjustment)	*$1.4/gal*	*1,044,338*	*$1,450,000*
NaCl (for regeneration)	*$0.05/lb*	*123,226,920*	*$6,160,000*
Sodium Bisulfite (for chlorine quenching)	*$1.1/gal*	*2,132*	*$10,000*
Power			$1,227,000
Feed Pump	*$0.15/kWh*	7,447,000	*$1,120,000*
Backwash Pump	*$0.15/kWh*	457,000	*$70,000*
Regeneration Pump	*$0.15/kWh*	186,000	*$30,000*
Chemical Pump	*$0.15/kWh*	47,000	*$7,000*
Contingency	15% of O&M costs		$2,370,000
Annual O&M Cost			**$18,187,000**

Appendix F:

Results of Groundwater Modeling

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Appendix F-1:

Groundwater Modeling Evaluation of MWD Recycled Water Recharge in Orange County

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TECHNICAL MEMORANDUM

DATE: October 3, 2017

TO: Metropolitan Water District

FROM: Orange County Water District

SUBJECT: Groundwater Modeling Evaluation of MWD Recycled Water Recharge in Orange County

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The purpose of this Technical Memorandum is to present the groundwater model results of an evaluation of the potential effects of Metropolitan Water District (MWD) recycled water recharge in Orange County in the forebay area on groundwater elevations, groundwater flow direction and travel time.

Recharge is assumed to occur within City of Anaheim, northeastern portion of Orange County, California, into a new proposed basin and/or several existing groundwater recharge basins, such as Kraemer, Miller and Anaheim Lake etc. operated by OCWD, as shown in Figure 1. Land use in the vicinity is industrial and commercial.

Model Description

Orange County Groundwater Basin Model was used for this evaluation. The Basin Model was developed, calibrated, and utilized by OCWD to effectively manage the basin. The model has been proven to be a good representation of actual basin groundwater levels over the years.

The Basin Model is a transient numerical flow model using the widely-accepted MODFLOW code. The Basin Model accounts for variations in aquifer properties, monthly variations in the volume of applied recharge, and monthly variations in boundary conditions along the edges of the model domain.

Two scenarios were simulated for this evaluation. One scenario assumed a proposed new basin which recharges 45 million gallon per day (MGD) recycled water, while the second scenario assumed all recycled water from MWD was recharged using existing recharge basins.

Model Assumptions

1. Both simulations are balanced, i.e. total water into the groundwater basin equals to total water out, basin storage was kept relatively constant;

2. The sources of water during the entire simulation were SAR base flow, SAR storm flow, incidental recharge, GWRS including final expansion, MWD recycled water, and Alamitos Barrier injection.
3. Accumulated overdraft (volume of empty storage below a full basin condition) was maintained at approximately 200,000 acre feet (AF) over the simulation duration;
4. Average hydrology condition was assumed: 52,000 acre feet per year (AFY) Santa Ana River (SAR) base flow; 51,600 AFY SAR storm flow;
5. 65,000 AFY Metropolitan Water District (MWD) recycled/imported water for recharge;
6. A 9-year simulation period was performed, which was equivalent to the length of the original transient model calibration period and considered to be sufficiently long for the recharge-induced water level changes to stabilize.
7. Both simulations used actual 2014-15 groundwater production as a starting point. Minor adjustments were made to include new production wells installed after 2015 and eliminate wells that were permanently removed from service after 2015. The production data was then repeated for each of the nine years of the simulation.
8. The annual production amount from large system wells (excluding the water quality improvement wells) was adjusted in each simulation in order to maintain a balanced (negligible basin storage change) condition. Demand from each producer was not exceeded.
9. In Scenario 1, 50,400 AFY or 45 MGD was distributed to a proposed new basin, and the rest was distributed to Kraemer Basin and/or Miller Basin. Based on existing data of percolation performance in the vicinity of this location (Miller Basin, Kraemer Basin, Miraloma Basin and La Jolla Basin), to reach desired 45 MGD percolation rate, four 500 feet by 500 feet model grid cells were used to simulate the new basin area; therefore, the total modeled new basin recharge area was 1000,000 sq. feet, or 22.9 acres; The same percolation rate of 45 MGD was assumed to remain constant for all nine-year duration.
10. In Scenario 2, no new basin was proposed. All recycled water was recharged to Kraemer, Miller, and Anaheim Basins.
11. Burris basin, Santiago basin and Santiago Creek were assumed to be permitted to recharge GWRS water.
12. MWD recycled water was evenly distributed monthly, i.e. approximately 5,400 acre feet per month recharge.

<u>Model Results</u>

To balance the model, overall groundwater pumping was adjusted to 375,300 AF, represents an 84.5% basin pumping percentage (BPP) (excluding water quality projects) based on projected demand of 435,000 AF.

The main purpose of this evaluation is to estimate travel time for recycled water under different scenarios. Particle tracking analyses were conducted by running the computer code MODPATH along with flow results from both scenarios. The particles were placed in the Basin Model grid cells corresponding to the edges of the proposed new basin, other existing basins and Santa Ana River below Carbon Creek diversion or Five Cove rubber dam. The vertical placement of each particle was determined by the depth of each basin. The particles were released 6 months or 12 months before the end of the model simulation.

Figures 1 through 4 show the simulated 6-month and 12-month particle traces in the forebay area and Santa Ana River for both scenarios. Different color particle trace was used to illustrate the recycled water movements between aquifers or model layers.

Particle traces show that most of recycled water remained in shallow groundwater unit (model Layer 1) around shallow basins; but particles originated from Santiago Basin, Santiago Creek, Anaheim Lake, and small reach of Santa River (close to Five and Lincoln basins) travelled to principle aquifer (model layer 2) within 6 and 12 months period.

Under an average hydrology year, existing basins are capable to recharge MWD recycled water equally every month, with total 65,000 AFY, although in winter months, all basins reached their respective maximum capacities, and Burris Basin along with Santiago Basin, Santiago Creek were needed to recharge GWRS water. Therefore, during wet years (above average rainfall), there will be limitations on the amount of recycled water forebay facilities can take in addition to storm water.

All results should be considered preliminary.

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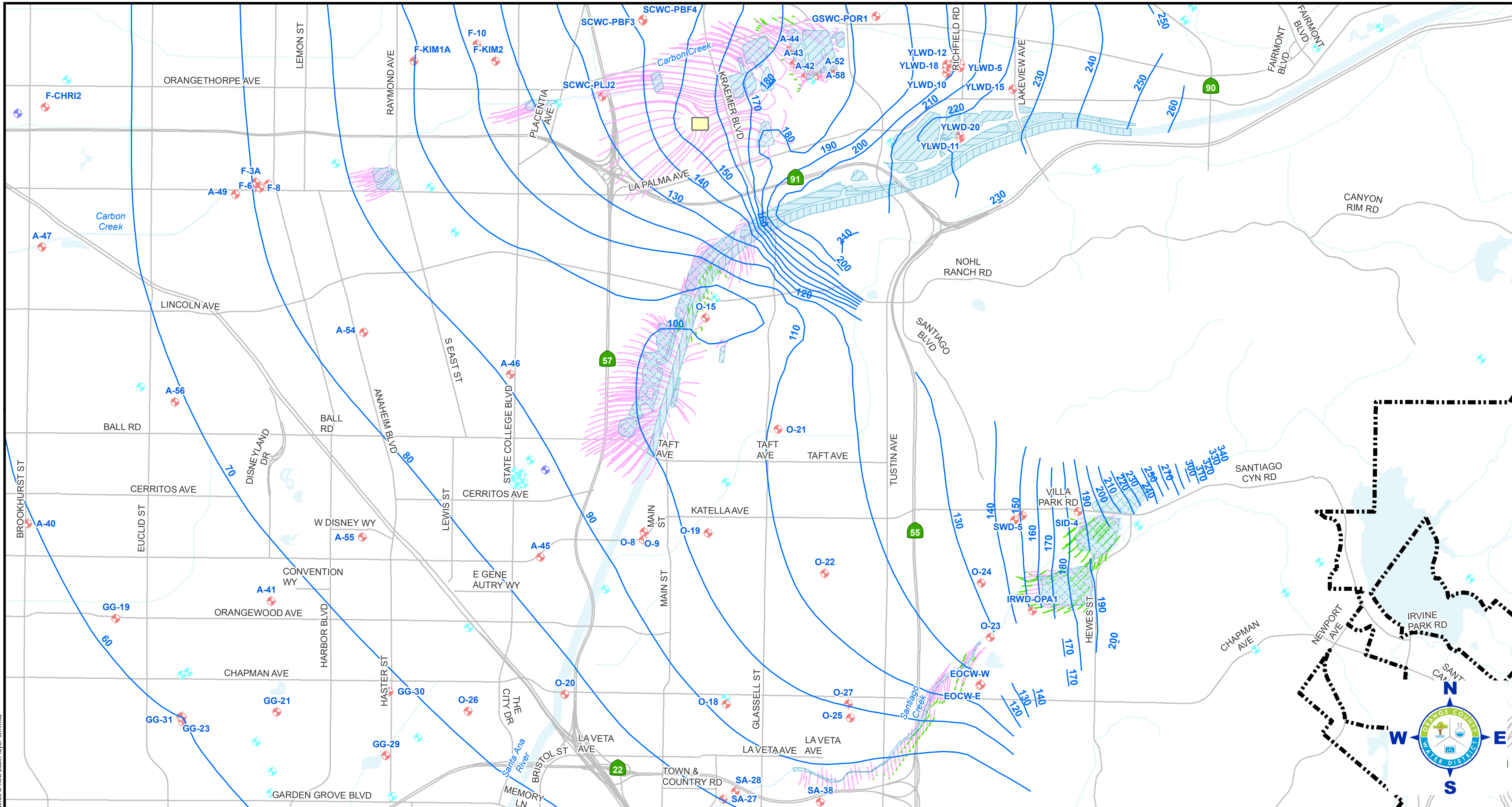

Simulated Groundwater contous

Particle Trace in Layer 2

Particle Trace in Layer 1

Proposed New Basin

OCWD Service Boundary

Active Large-System Production Well

Active Small-System Production Well

Other Active Production Well

0 3,100 6,200 Feet

Figure 1
MWD Recycled Water Recharge Evaluation
Six-Month Particle Trace
With Proposed New Basin

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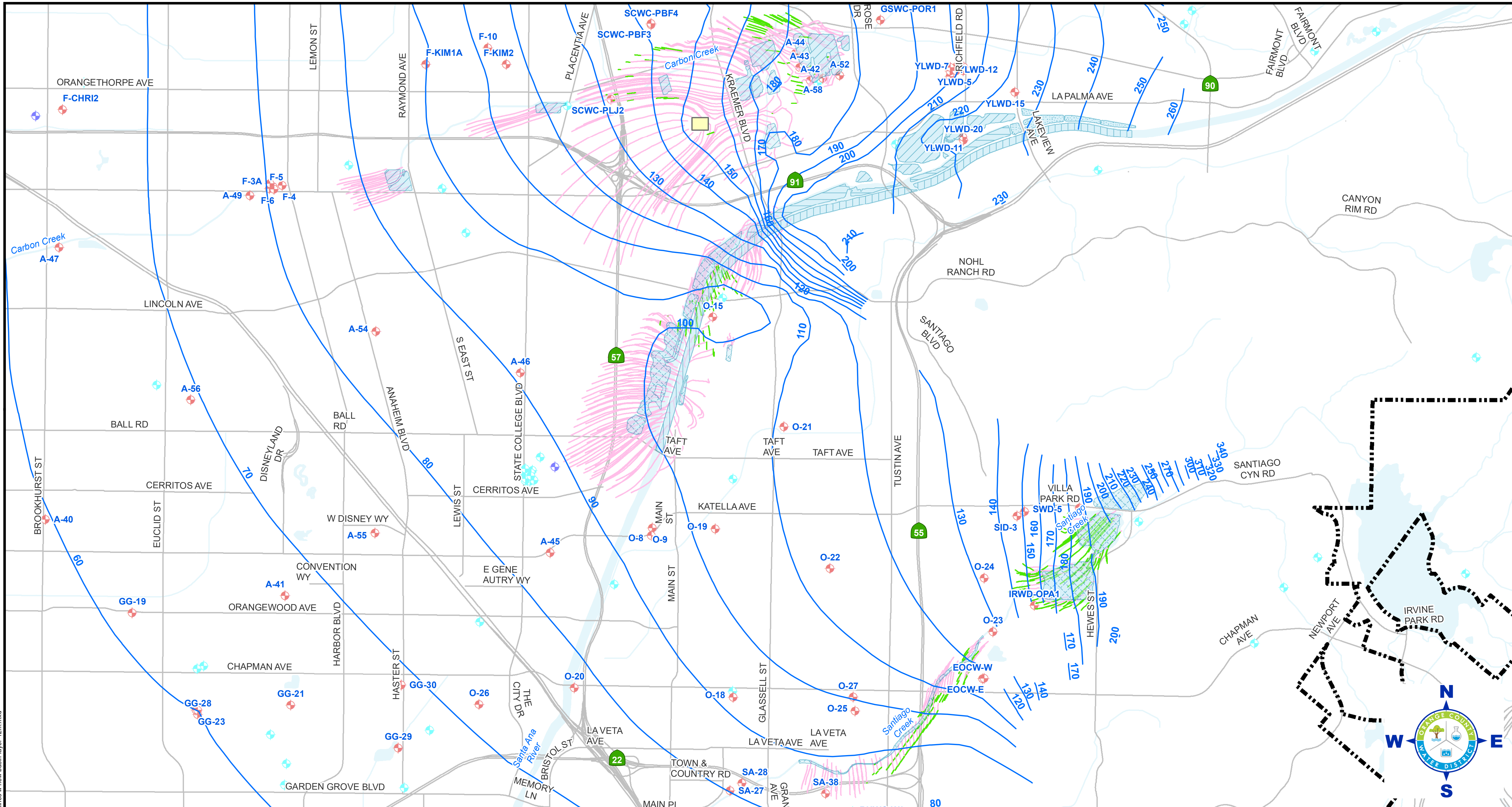

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Simulated Groundwater Contous
Particle Trace in Layer 2
Particle Trace in Layer 1
Proposed New Basin
OCWD Service Boundary
Active Large-System Production Well
Active Small-System Production Well
Other Active Production Well

0 3,100 6,200 Feet

Figure 2
MWD Recycled Water Recharge Evaluation
Twelve-Month Particle Trace
With Proposed New Basin

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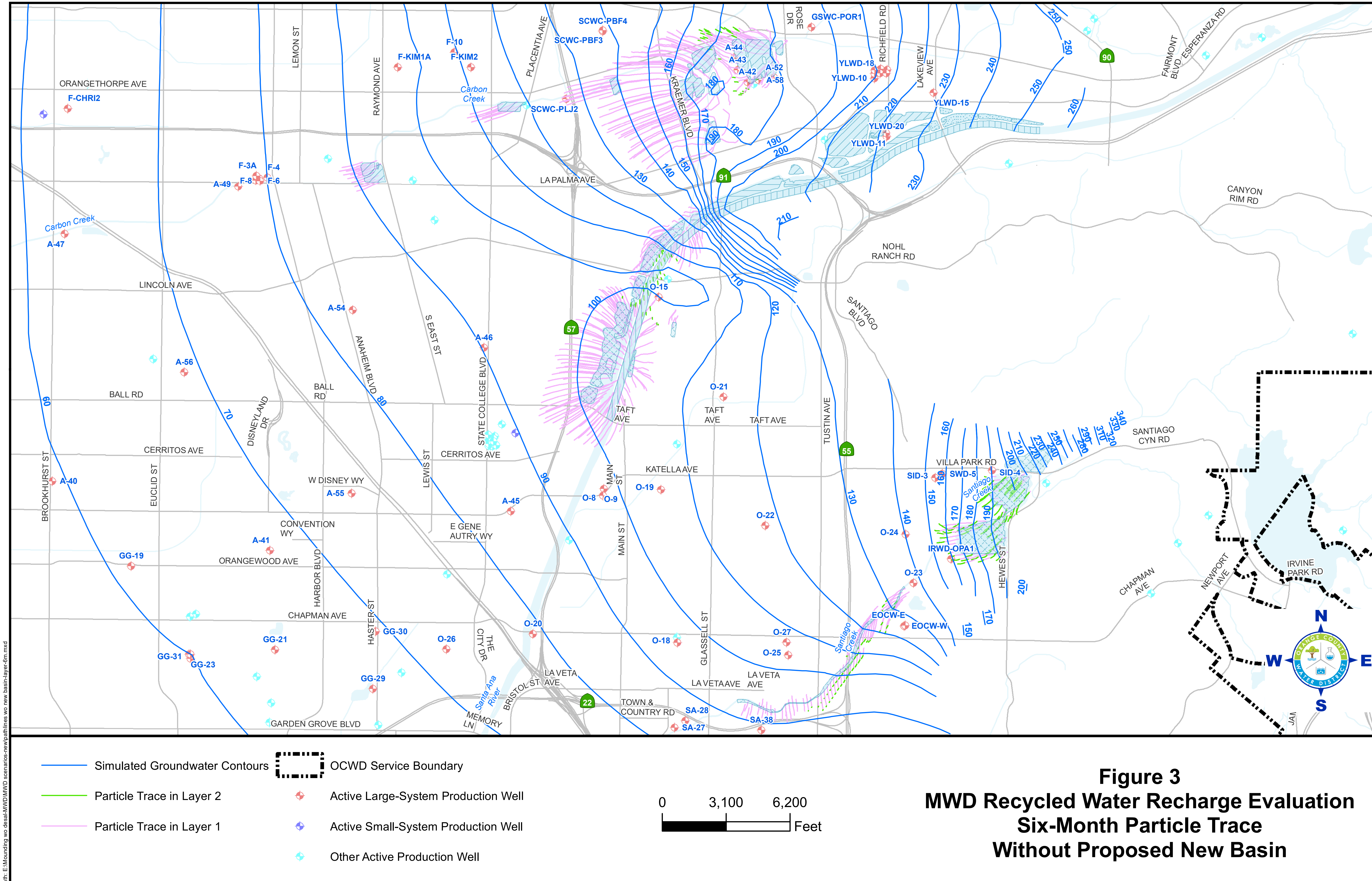

Figure 3
MWD Recycled Water Recharge Evaluation
Six-Month Particle Trace
Without Proposed New Basin

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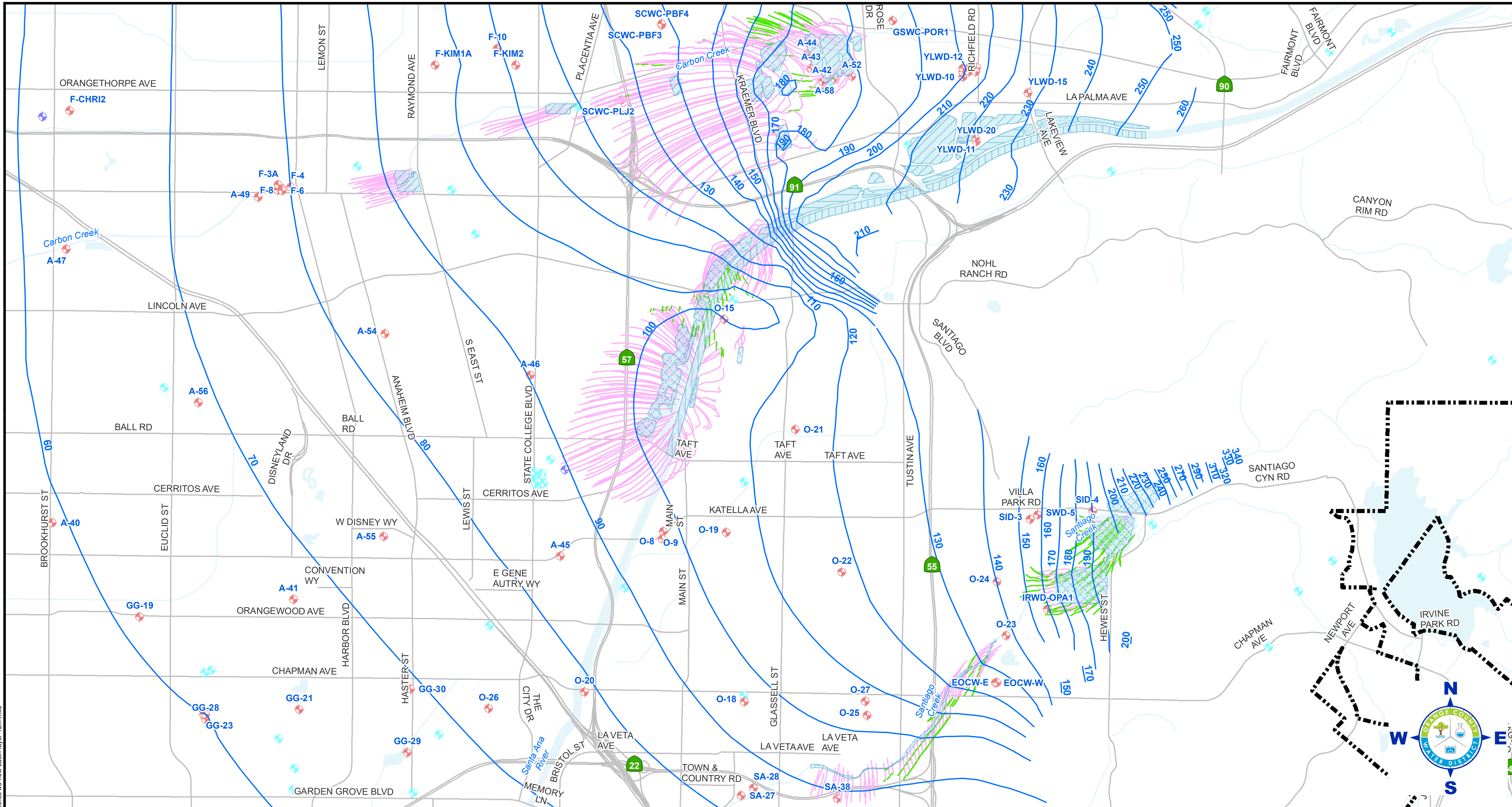

Simulated Groundwater contours		OCWD Service Boundary	
Particle Trace in Layer 2		Active Large-System Production Well	
Particle Trace in Layer 1		Active Small-System Production Well	
		Other Active Production Well	

0 3,100 6,200 Feet

Figure 4
MWD Recycled Water Recharge Evaluation Twelve-Month Particle Trace Without Proposed New Basin

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Appendix F-2:

Central and West Coast Basins Modeling for Metropolitan Regional Recycled Water Supply Program, Task Order 2

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Central and West Coast Basins Modeling for Metropolitan Regional Recycled Water Supply Program, Task Order 2

PREPARED FOR:	Ted Johnson/Water Replenishment District of Southern California (WRD)	Tom Hibner/Metropolitan Water District of Southern California (Metropolitan)
COPY TO:	Everett Ferguson/WRD	Matt Hacker/Metropolitan
PREPARED BY:	CH2M HILL Engineers, Inc. (CH2M)	
DATE:	May 26, 2018	

The Water Replenishment District (WRD) and its sub-consultant, CH2M, were contracted by Metropolitan Water District of Southern California (Metropolitan) to run WRD's groundwater model of the Central and West Coast Groundwater Basins, and evaluate the effects of additional recharge to these basins in support of a feasibility-level study of Metropolitan's Regional Recycled Water Supply Program (Reuse Program). Under this program, Metropolitan and the Los Angeles County Sanitation Districts (LACSD) have partnered to produce up to 150 million gallons per day of advanced-treated effluent from LACSD's Joint Water Pollution Control Plant and deliver the purified water to groundwater basins in the Los Angeles region, including the Central and West Coast Basins. Groundwater modeling was conducted to understand the effects of recharge from the Reuse Program on groundwater levels and basin storage in the Central and West Coast Groundwater Basins. CH2M used the model to evaluate scenarios developed by Metropolitan to evaluate the sustainable quantities of purified water that could be delivered to the Central and West Coast Basins for groundwater recharge and extraction.

CH2M simulated two alternatives in 2016 (CH2M, 2016a), under Task Order 1 between Metropolitan and WRD. This technical memorandum (TM) summarizes results of five additional alternatives performed under Task Order 2. This TM is organized as follows:

- Section 1 – Background
- Section 2 – Modeling Approach
- Section 3 – Modeling Results
- Section 4 – Summary and Conclusions
- Section 5 – References

1.0 Background

The original WRD/U.S. Geological Survey (USGS) groundwater flow model (USGS, 2003) was developed based on historical data from water years 1971 through 2000, and used annual stress periods. The model was extended through water year 2010 for the preparation of WRD's Groundwater Basins Master Plan (GBMP) in 2012 (CH2M, 2016b). The groundwater model was further updated under Task Order 1 to include WRD's Groundwater Replenishment Improvement Project (GRIP) and to run with monthly stress periods to assess the impact of two replenishment scenarios for Metropolitan's recycled water project. The two basin replenishment scenarios evaluated under Task Order 1 were: 1) Base Case, where injection was focused in Montebello Forebay, and 2) Alternative 1, in which injection was focused at LA Forebay. That work was completed in 2016 and a final TM was prepared and submitted (CH2M, 2016a).

Under this task order 2, potential impacts of five new injection replenishment and extraction alternatives were evaluated to further support Metropolitan's Reuse Program feasibility study. Potential impacts were evaluated assuming current spreading operations, existing production wells, and existing seawater barrier injection.

2.0 Modeling Approach

This section presents a brief description of the model used to simulate the alternatives developed by Metropolitan for this analysis. The model used is the same model that was used for the previous work conducted under Task Order 1, and is summarized in a TM (CH2M, 2016a). Note that the “Baseline” condition is identical to the Baseline in the Task Order 1 TM (CH2M, 2016a). The Baseline model simulates monthly stress periods using historical hydrology and groundwater pumping for water years 1971 through 2000 (480 stress periods), modified by replacing a portion of historical imported water use with 21,000 acre-feet per year (AFY) from GRIP to represent current operations in the basins. Simulation results of alternatives were analyzed by comparing results of alternatives against the Baseline condition.

The simulation results were used to assess the following:

- Changes in groundwater levels
- Changes in overall water budgets (including the effects on boundary flows)
- Cumulative change in basin-wide storage
- Travel time using particle tracking

Model grid and boundary conditions are presented in Figure 1. A more complete description of the groundwater model is presented in the Task Order 1 TM (CH2M, 2016a).

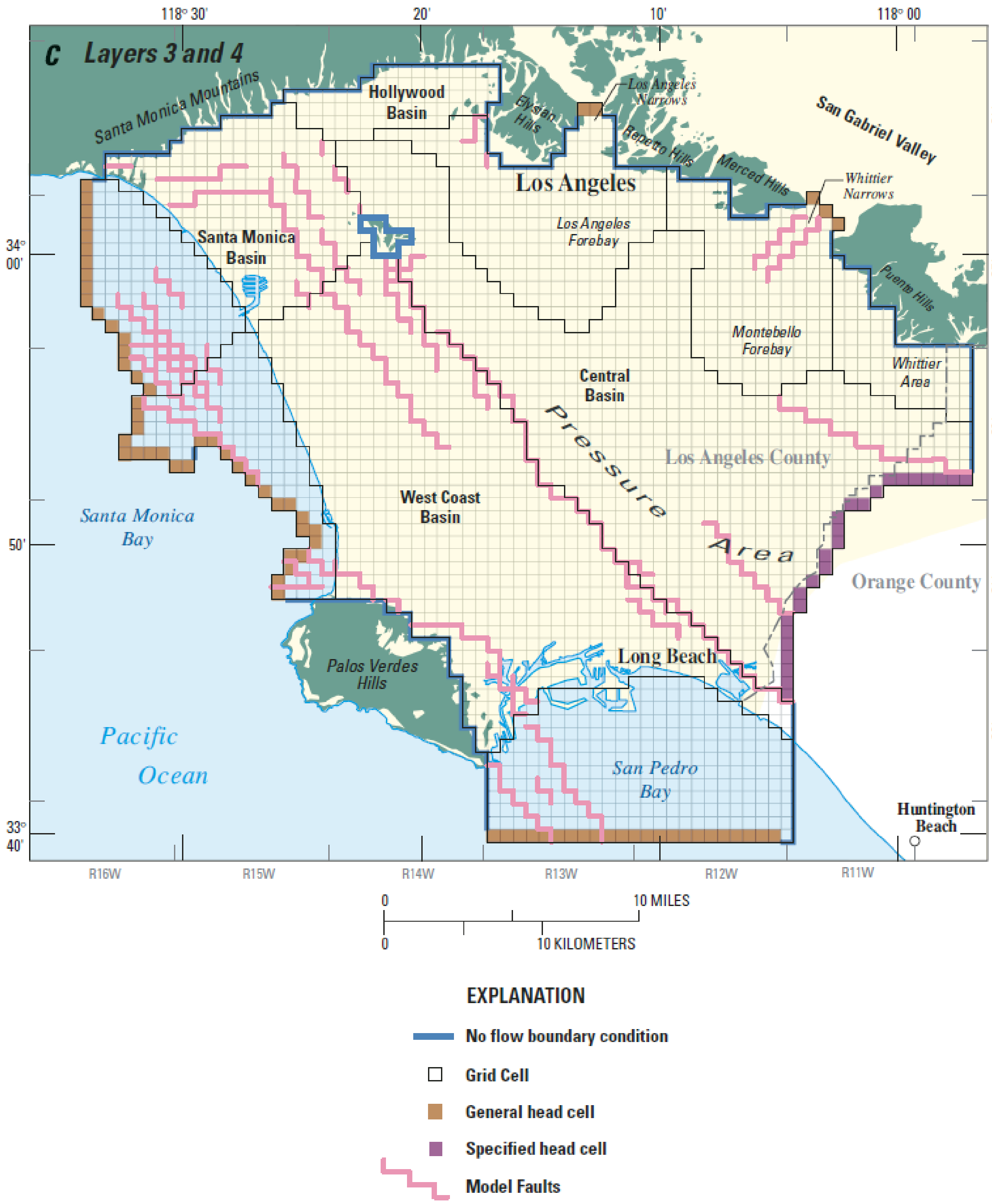

Figure 1. WRD/USGS Groundwater Flow Model – Grid and Boundary Conditions for Model Layers 3 and 4 (USGS, 2003)

2.1 Alternative Inputs

Five alternatives were developed by MWD and are intended to evaluate the impact of shifting pumping by refineries to other water pumpers in the West Coast Basin, along with phased implementation of additional extraction coupled with sustainable recharge of purified water in either the Montebello or LA Forebays. Location of wells and recharge for the alternatives are presented in Figure 2. A summary of the alternatives is presented in Table 1, and details consist of the following extraction and replenishment components:

- Alternative 1 (Note that this alternative is not the same as the "Alternative 1" in the work conducted under Task Order 1 (CH2M, 2016a):
    - Shift 11,733 AFY of pumping by refineries, Tesoro and Phillips, to other pumpers inland in the West Coast Basin. This would mean these refineries, located in Carson and Wilmington, will stop pumping from the basins and rely on recycled water. 11,733 AFY represents the historical average combined pumping from Tesoro and Philips, 1971 through 2010 (Figure 3). Distribution of pumping in the West Coast Basin is based on water rights and historical pumping and is presented in Table 1. The ratios of distribution of WCB pumping for these alternatives were consistent with those in the GBMP (CH2M, 2016a).
    - Add additional injection of 4,000 AFY of recycled water produced by the Reuse Program in Long Beach. Add additional pumping for 4,000 AFY in Long Beach to match the new injection water.
- Alternative 2a: Alternative 1 plus apply 10,000 AFY of injection in the Montebello Forebay and 10,000 AFY of pumping from the City of Los Angeles' Manhattan well field.
- Alternative 2b: Alternative 1 plus apply 10,000 AFY of injection in the LA Forebay and 10,000 AFY of pumping from the City of Los Angeles' Manhattan well field
    - Injection well locations in the Montebello Forebay Spreading Grounds (MFSG) and LA Forebay for Alternative 2a and 2b, respectively, were identical to the locations used for modeling the alternatives in under Task Order 1 (CH2M, 2016a).
- Alternative 3a: Alternative 2a plus apply 15,000 AFY of injection in the West Coast Basin and pumping in the West Coast Basin to balance the new injection. Distribution of the additional 15,000 AFY of pumping generally follows that of Alternative 1, except there was no additional pumping from Golden State Water Company, City of Inglewood, or California Water Services Hermosa-Redondo wells or well fields. That additional pumping instead was assigned to California Water Services Dominguez District wells. Distribution of pumping in the West Coast Basin for Alternative-3 is presented in Table 1[1,2].
- Alternative 3b: Alternative 2b plus apply 15,000 AFY of injection in the West Coast Basin and new pumping in the West Coast Basin to balance the new injections. Distribution of the additional 15,000 AFY of pumping is the same as in Alternative 3a.

Note that the pumping distributions are assumed for planning purposes to assess the potential impacts that could develop in the future based on the alternatives evaluated herein. Actual distributions will be determined (outside this study) by pumper needs, lease market, and economics.

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[1] Water rights by purveyor were evaluated. Total pumping in the West Coast Basin Alternatives 3a and 3b (55,838 AFY, based on 29,105 AFY recent pumping plus additional 26,733 AFY in Alternatives 3a and 3b) exceeds purveyors' water rights of 34,562 AFY. It is assumed that the gap of 21,276 AFY (55,838 AFY pumping minus 34,562 AFY water rights) would be filled by a combination of: 1) transfer or lease of water rights from refineries to purveyors (14,911 AFY), and 2) additional 6,365 AFY from unused leased rights.

[2] Pumping by purveyor was compared to projected demands presented in the 2015 Urban Water Management Plans. Pumping in Alternative 3 does not exceed purveyors' projected total water demands (supplied by groundwater and imported water).

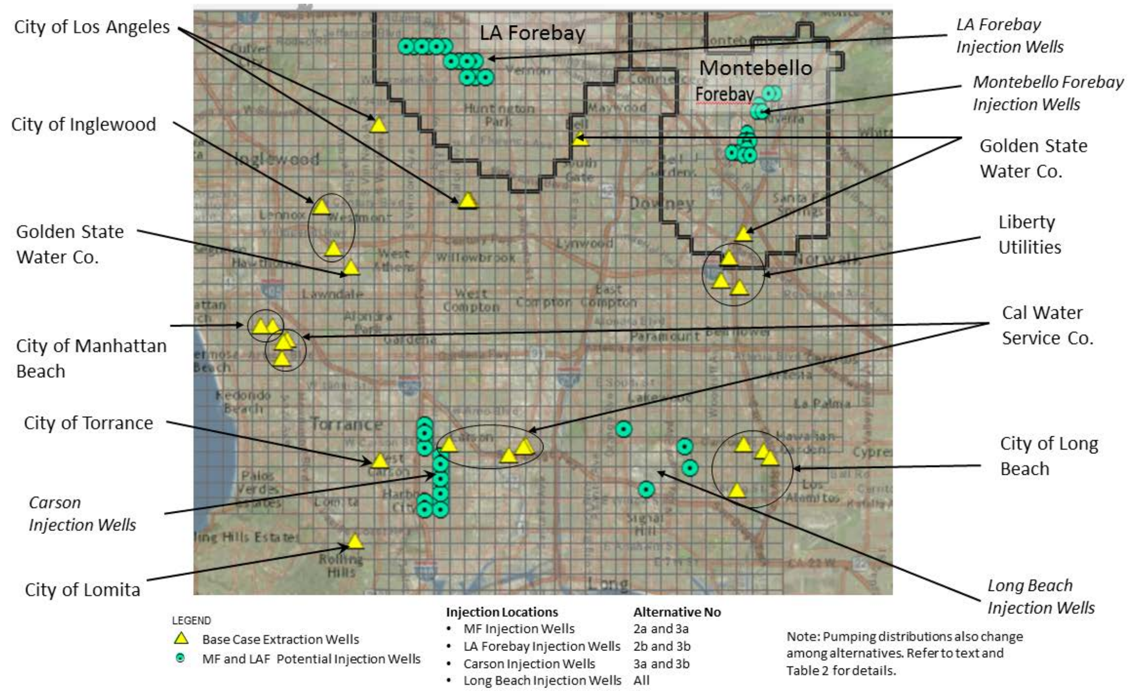

Figure 2. Well and Recharge Locations

Table 1: Summary of Alternatives

"Inflow"	*Reduce Refinery Pumping*	*Long Beach Injection*	*Forebay Recharge*	*Carson Injection*	*Total Injection / Extraction (AFY)*		
"Outflow"	*Increased West Coast Basin Pumping*	*Long Beach Extraction*	*City of Los Angeles Pumping*	*Increased West Coast Basin Pumping*	*West Coast Basin*	*Central Basin*	*Total*
Inflow / Outflow Rate	*11,733 AFY*	*4,000 AFY*	*10,000 AFY*	*15,000 AFY*			
Alternative 1	✓	✓			11,733	4,000	15,733
Alternative 2a	✓	✓	Montebello Forebay		11,733	14,000	25,733
Alternative 2b	✓	✓	LA Forebay		11,733	14,000	25,733
Alternative 3a	✓	✓	Montebello Forebay	✓	26,733	14,000	40,733
Alternative 3b	✓	✓	LA Forebay	✓	26,733	14,000	40,733

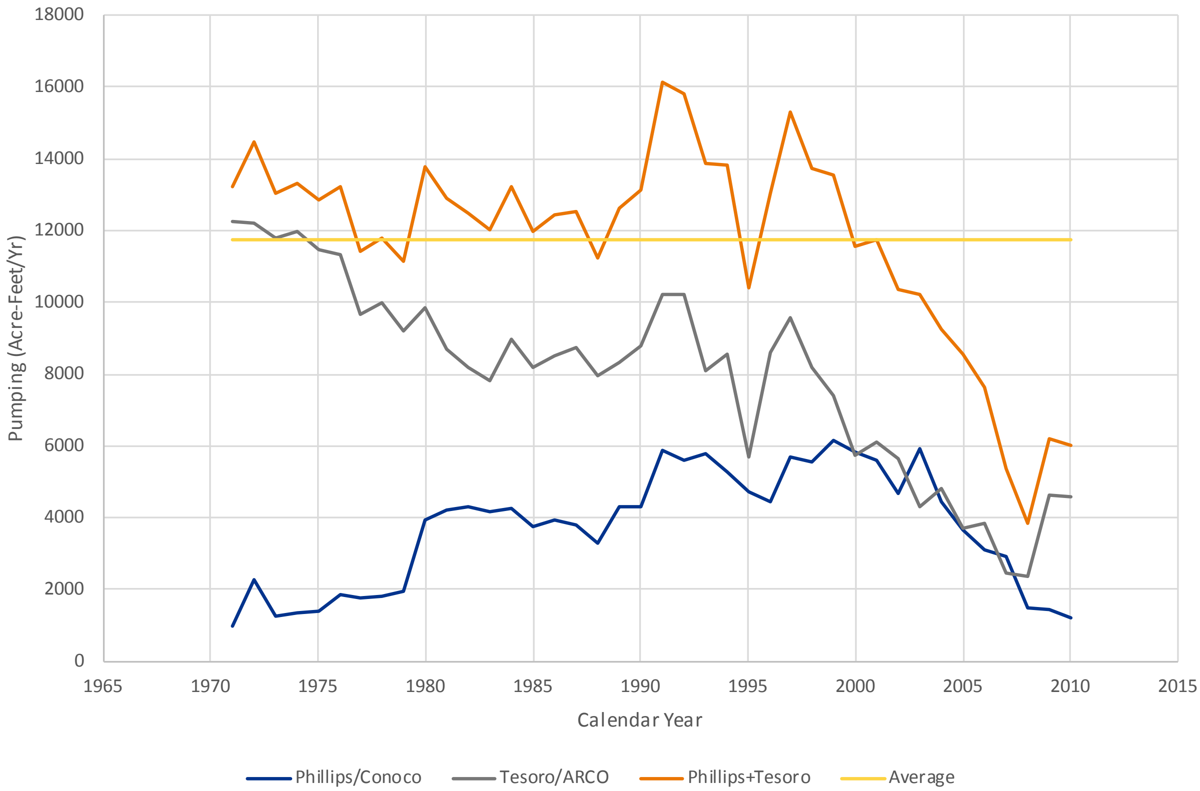

Figure 3. Historical Refinery Pumping

Table 2: West Coast Basin Pumping Distribution (AFY) for Alternatives 1, 3a, and 3b

Purveyor	Alternative 1	Additional, Alternatives 3a and 3b	Total, Alternatives 3a and 3b
California Water Services: Dominguez Hills	5,319	13,400	18,719
California Water Services: Hermosa Redondo	2,347	0	2,347
Golden State Water	235	0	235
City of Inglewood	2,581	0	2,581
City of Lomita	156	200	356
City of Manhattan Beach	782	1000	1,782
City of Torrance	313	400	713
Total	**11,733**	**15,000**	**26,733**

Note: Pumping for Alternatives 2a and 2b was identical to that for Alternative 1 and additional pumping of 10,000 AFY was added to City of Los Angeles' Manhattan well field

3.0 Modeling Results

This section summarizes the results of model simulations of alternatives. For each alternative, the following results are discussed:

- change in groundwater water levels (relative to the Baseline)
- change in overall water budget, with an emphasis on effects on boundary flows
- cumulative change in basin-wide storage
- particle tracking and potential for (new) injected water to reach production wells

3.1 Alternative 1 Modeling Results

This section summarizes results of the Alternative 1 simulation. Results are presented below in conjunction with the Baseline modeling results to facilitate evaluation of the changes due specifically to Alternative 1.

3.1.1 Change in Simulated Groundwater Levels

This section summarizes the projected change in water levels in response to Alternative 1 injection and extraction. Results are summarized both spatially and temporally. Model results suggest that the combined effect of reduced pumping from the refineries and injection in Long Beach results in a maximum 6-foot rise of both water levels at the groundwater table and hydraulic head in the injection zone.

Figure 4 shows the changes in water levels in the injection zone after 30 years of simulations across the basins. This change in water levels is for Alternative 1 relative to Baseline. Blue and green colors represent water levels that are higher in Alternative 1 than in the Baseline, and are centered around the injection locations. Similarly, yellow and orange colors represent levels that are lower in Alternative 1 than in the Baseline scenario, and are centered around the extraction locations. Selected hydrographs are presented in Figure 5A. Areas of water level rise are discussed below, followed by discussion of areas of water level declines.

Figure 5B shows a simulated hydrograph from the vicinity of the Long Beach injection area. As shown in this figure, the water level rise due to the injection and reduced pumping by refineries varies between approximately five and six feet (with some variation, and with the usual non-linear increase during the first years due to the new injection stress). Given the 60-foot, and greater, difference between the water level potentiometric surface and the ground surface in the vicinity, this simulated water level rise can be accommodated. However, the water level rises in the Carson and Long Beach areas could conceivably cause a change in inflow from San Pedro Bay (see Section 3.1.2 for further discussion), and may require minor operational changes to the Dominguez Gap seawater intrusion barrier.

Simulated water level declines shown in Figure 5 are centered around the City of Inglewood and Golden State Water Company's well fields, in response to the combined additional pumping of about 2,800 AFY in Alternative 1. Water level declines are estimated to be up to 34 feet.

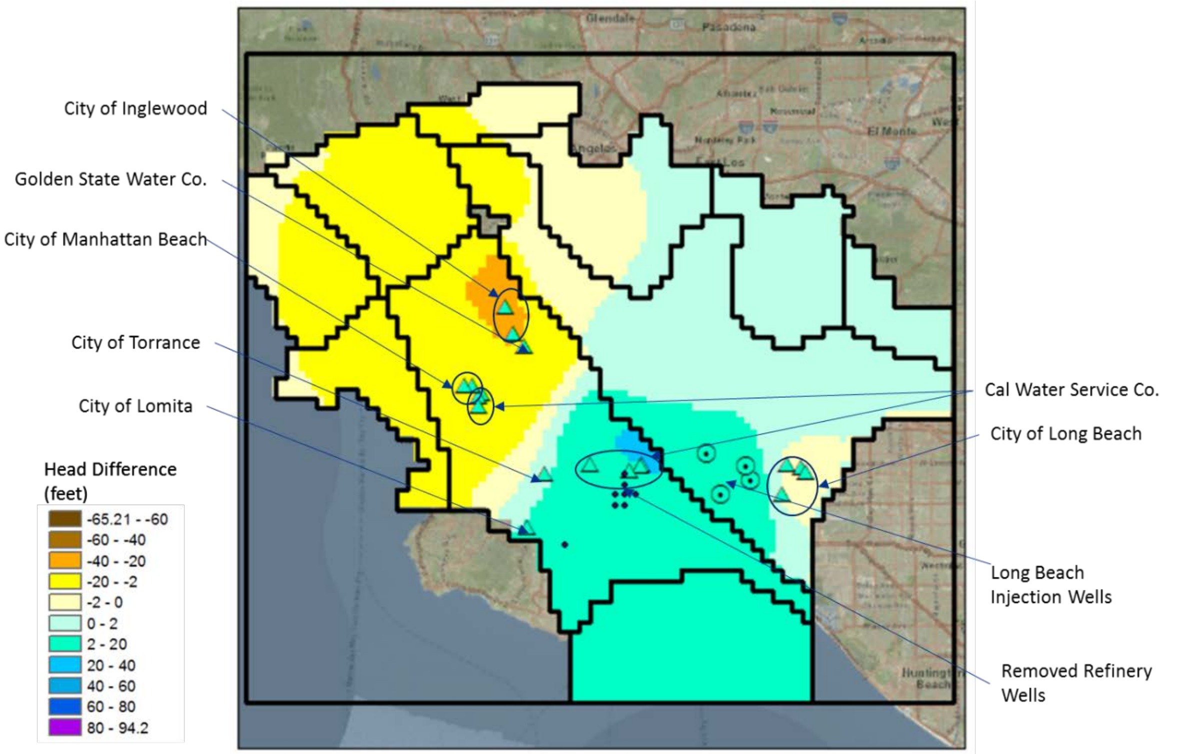

Figure 4. Simulated Head Differences in the Injection Zone Between the Baseline and Alternative 1 at 30 Years[3]

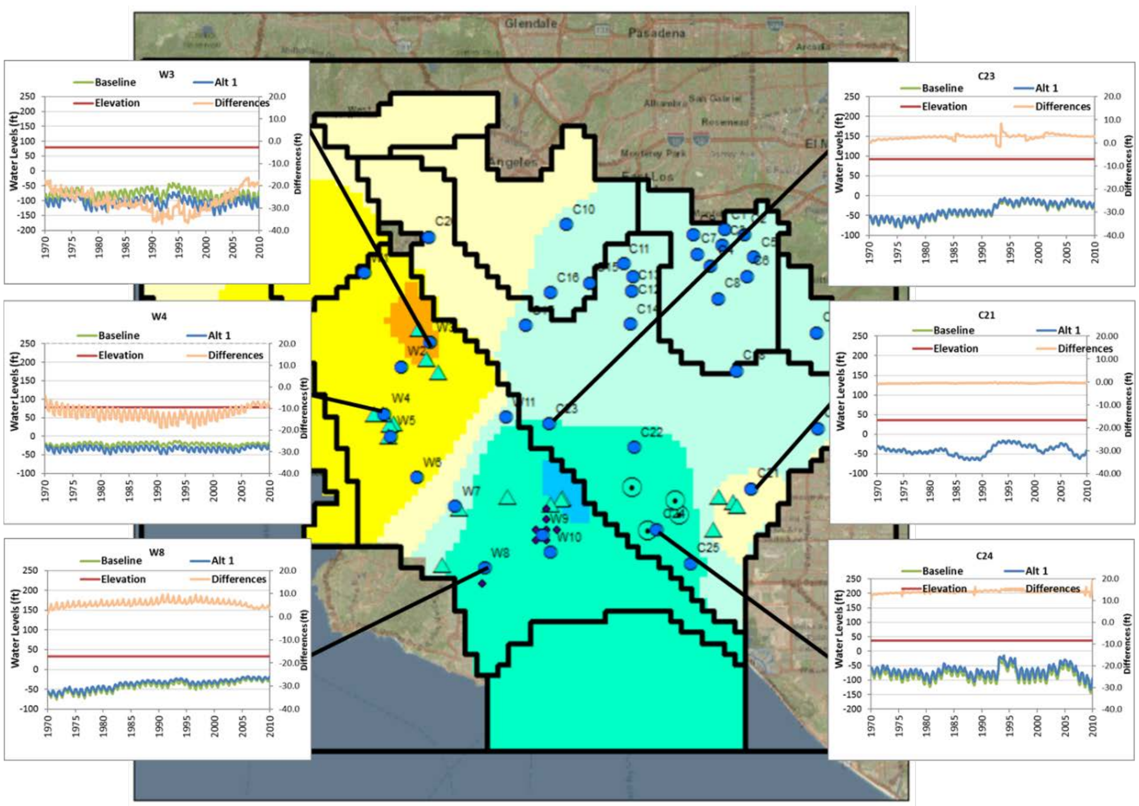

Figure 5A. Changes in Groundwater Levels: Alternative 1 vs. Baseline
Selected Hydrographs

[3] Note that 30 years was selected due to the transient nature of historical pumping from the refineries, which is turned off in Alternative 1.

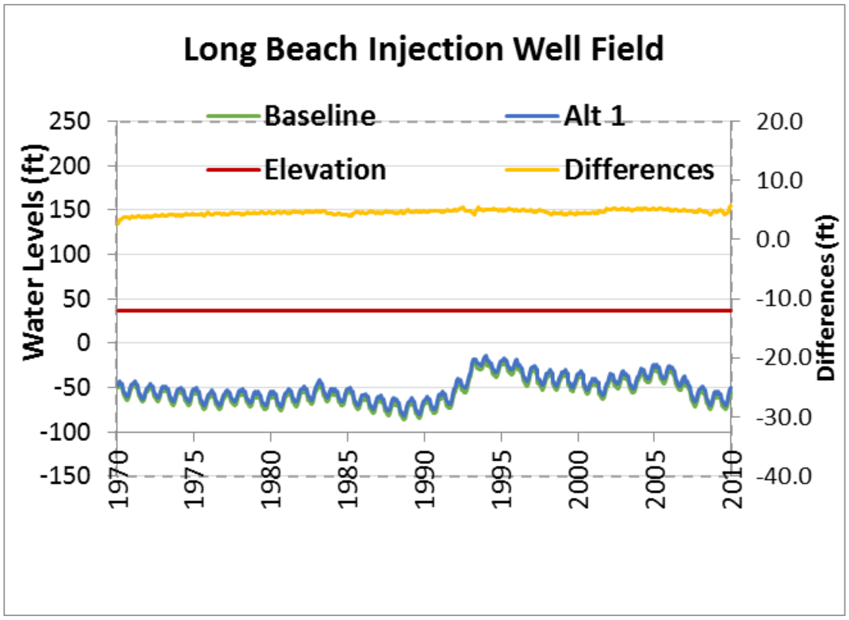

Figure 5B. Changes in Groundwater Levels: Alternative 1 vs. Baseline
Differences in Water Table Elevations Near the Long Beach Injection Well Field

3.1.2 Changes in Simulated Water Budget (Effects on Boundary Flows)

Changes in the simulated water budget and storage are shown in Figures 6A-6C. The water budget of the Baseline (Figure 6A) is followed by the change in water budget due to Alternative 1 (Figure 6B) and the cumulative change in storage due to Alternative 1 (Figure 6C). As can be seen on Figure 6B, there is 4,000 AFY of additional injection in all years, and 4,000 AFY of additional pumping in most years. There is an additional 11,766 AFY, on average, of transferred pumping (reduced pumping by refineries and increased pumping in the West Coast Basin), although there is a significant change through time.

In addition to the change in pumping and injection, there is a net change in boundary flows that causes a net change in storage. A minor basin-wide cumulative deficit of about 1,200 AF is simulated at the end of the simulation period for Alternative 1 (Figure 6C), or an average of about 1050 AFY.

As shown in Figure 7, the cumulative change in storage is caused, in part, by changes in boundary flows, which in turn are caused by changes in groundwater levels. Injection in Long Beach and reduced pumping by the refineries in Carson, and Wilmington causes an average reduction of inflow from San Pedro Bay of about 1,670 AFY. Pumping in the West Coast Basin induces about 1,290 AFY of inflow (and reduced outflow) from the Santa Monica Bay. Minor changes to the seawater intrusion barrier operations may be required to mitigate the changes in flows to/from offshore.

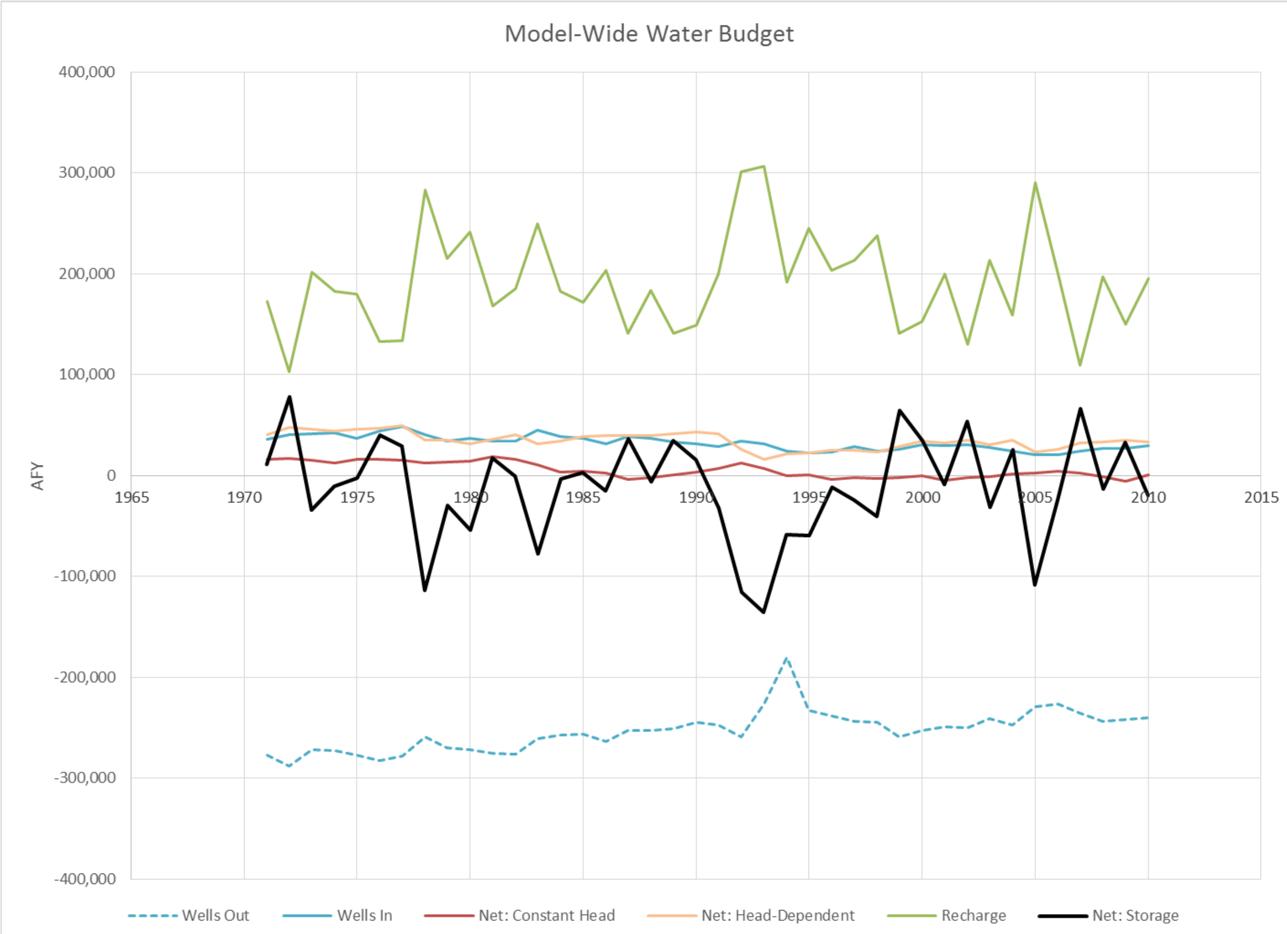

Figure 6A. Comparison of Water Budget: Alternative 1 vs. Baseline - *Baseline Model Water Budget*

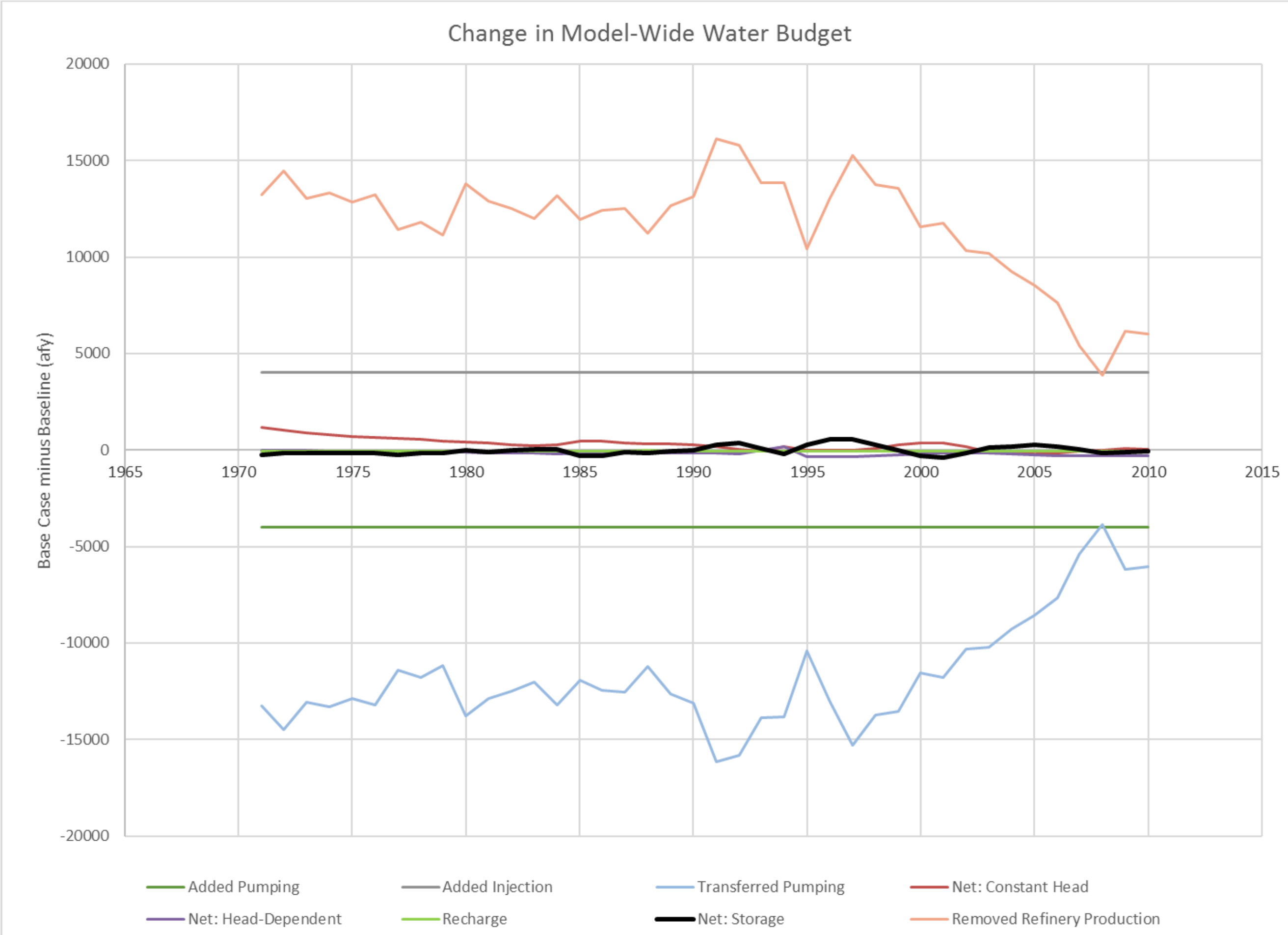

Figure 6B. Comparison of Water Budget: Alternative 1 vs. Baseline - *Change in Water Budget due to Alternative 1*

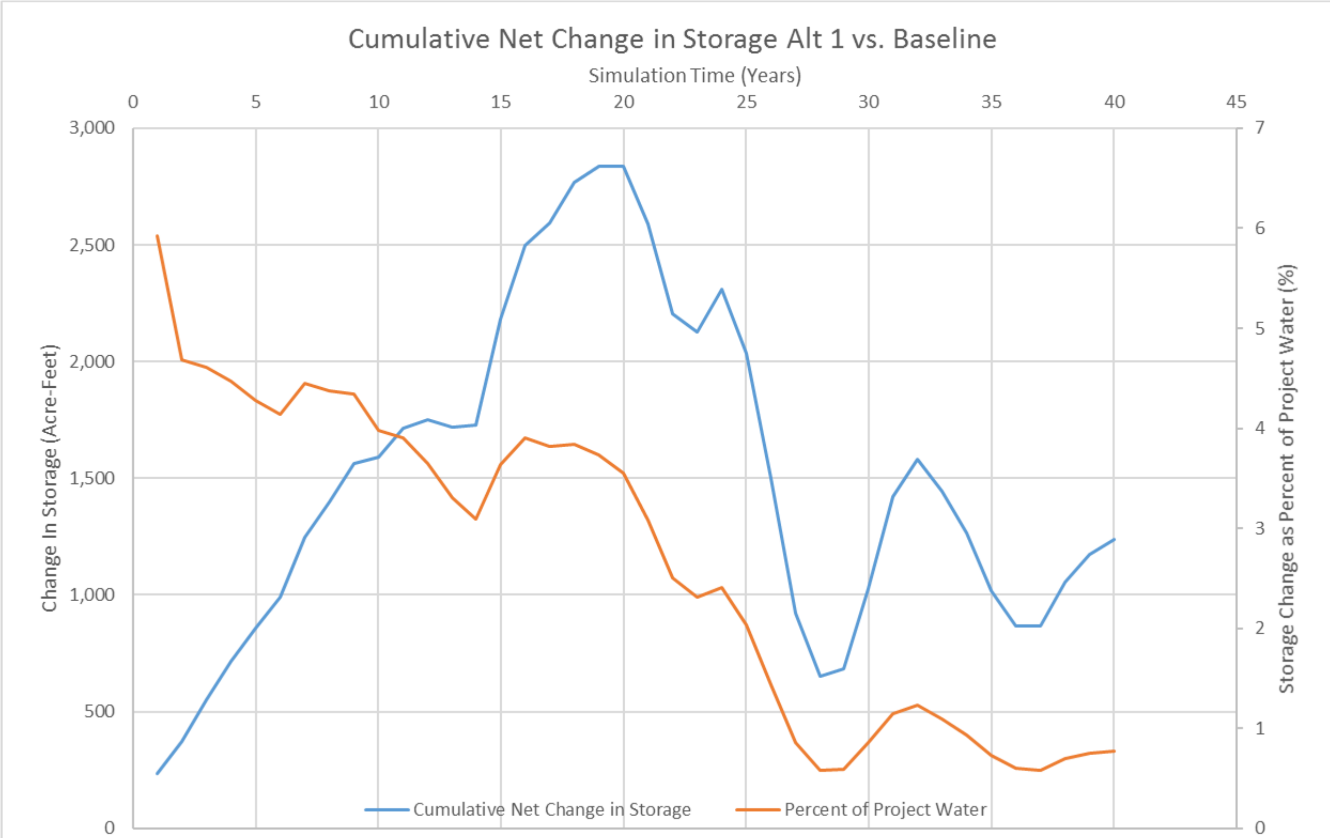

Figure 6C. Comparison of Water Budget: Alternative 1 vs. Baseline - *Cumulative Change in Storage due to Alternative 1 (Alternative 1 minus Baseline)*[4]

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[4] The storage changes in this figure, and in similar figures for the subsequent alternatives, incorporate a discrepancy between simulated project injection and project production that does not appear in the model input. Typically this discrepancy ranges from 3 to 12 AFY for most stress periods but exceeds 100 AFY in some cases, and it usually results in more project production than injection. It is assumed that this discrepancy is at least partly due to the dewatering and rewetting simulation problems inherent in MODFLOW-88/96, and that it could be addressed by upgrading the model to newer modeling software such as MODFLOW-NWT or MODFLOW-USG. The discrepant missing injection was added to the cumulative storage changes (e.g., shown on Figure 6c for Alternative 1) to make them more consistent with changes in interbasin flow due to the projects (e.g., shown on Figure 7 for Alternative 1) . This effectively credits the LA basin for the storage increase it should have received due to the missing injection, and debits the basin for missing production, but does not factor in changes in interbasin flow that might have resulted from increased water levels due to the added storage.

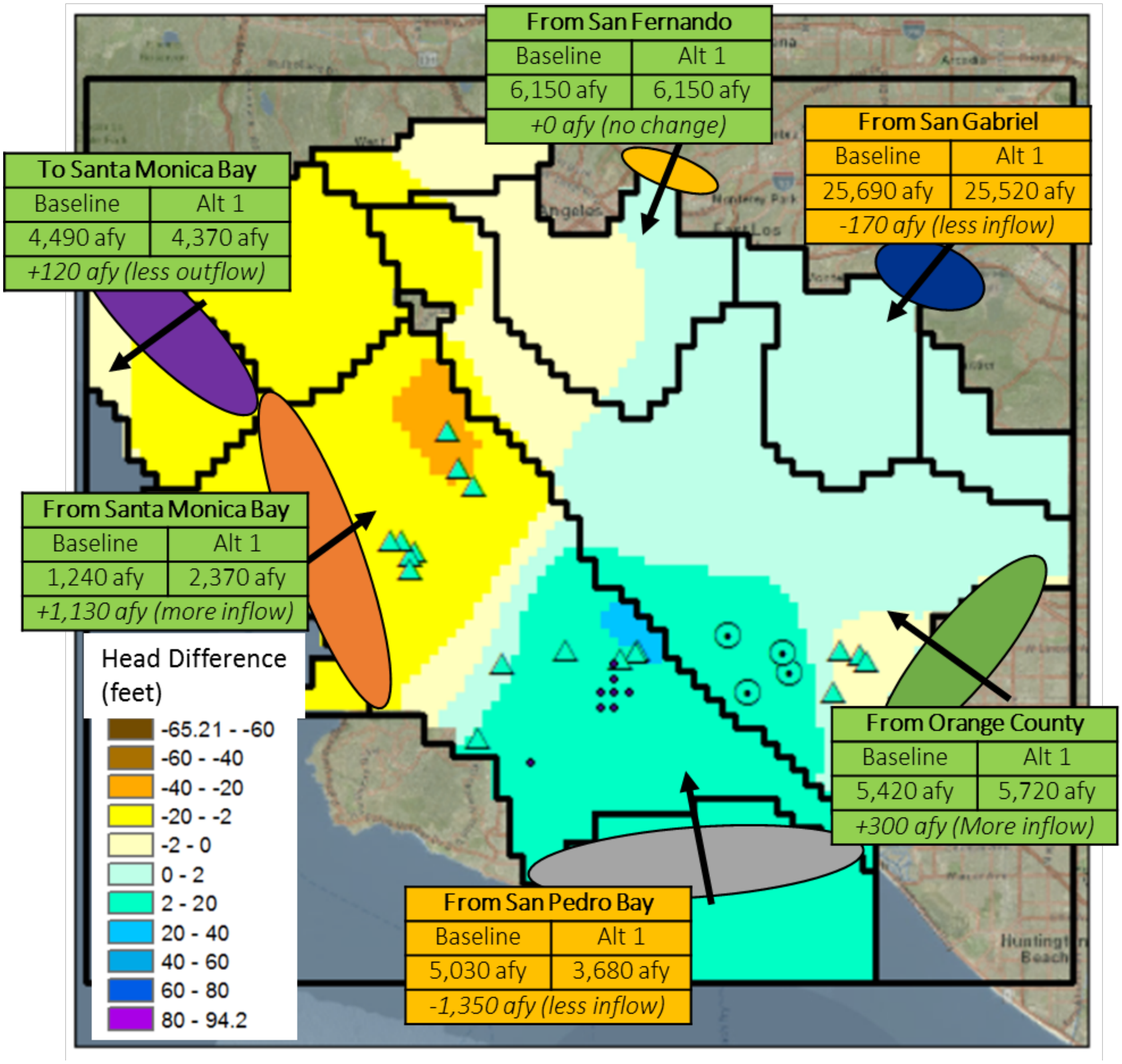

Figure 7. Alternative 1 Water Budget Change at Boundary Conditions

3.1.3 Travel Time Using Particle Tracking

Particle tracking was used to estimate travel distances from the injection wells after 3 months, 6 months, and 12 months of injection. The last year of the flow simulation timeframe was used for these particle tracking simulations. Particles were started at each of the proposed injection wells, in model layer 3, which has a model porosity value of 5 percent throughout. While this might appear to be a low porosity for the coarse sands and gravels that comprise much of the aquifer materials in the basin, it was established based on tracer analysis conducted during the development of the USGS/WRD model.[5]

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[5] USGS found that age dating with tritium and its daughter product, tritogenic helium indicated a much shorter travel time than that predicted by the model. Since the model uses an average hydraulic conductivity within each layer to compute advective velocities, the USGS reduced their initial assumed porosity of 25 percent to 5 percent to represent the reduction in model layer thickness through which most of the particle transport actually takes place. (USGS, 2003, page 127).

The results of the Alternative 1 particle tracking are shown below in Figure 8, for the Long Beach injection wells. These particles resulted in relatively short traces, partly due to the relatively low hydraulic conductivity in the vicinity. However, in this case, at least one high-flow production well (the southernmost one in Figure 8) is known to be close to an injection well, and therefore, there appears to be some risk for potential impact to produced water due to this project. The Long Beach injection well particle tracking was not repeated for subsequent Alternatives 2a, 2b, 3a, or 3b, because the pumping and injection in the vicinity are the same in all of these simulations. Therefore, it is reasonable to assume that results of particle tracking from the Long Beach injection wells for these alternatives would be nearly identical to those in Figure 8.

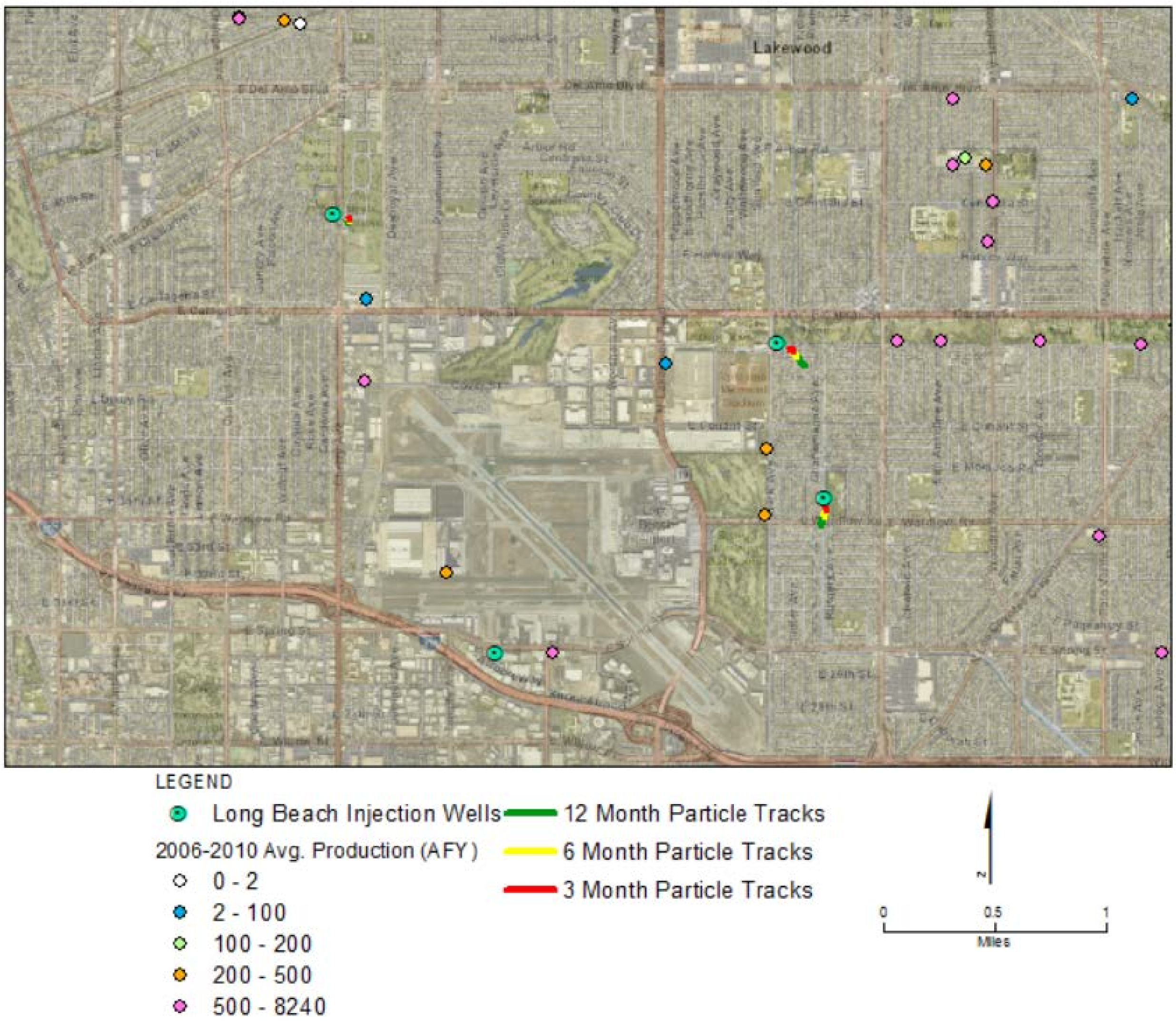

Figure 8. Alternative 1 Particle Tracking Results –Long Beach Area

3.2 Alternative 2a Modeling Results

This section summarizes results of the Alternative 2a simulation[6]. Results are presented below in conjunction with the Baseline modeling results to facilitate the evaluation of the changes specifically due to Alternative 2a. Alternative 2a builds off of Alternative 1 by adding 10,000 AFY of injection in the Montebello Forebay, with an equivalent 10,000 AFY of extraction from the City of Los Angeles' Manhattan well field.

3.2.1 Change in Simulated Groundwater Levels

This section summarizes the projected change in water levels in response to Alternative 2a injection and extraction. Results are summarized both spatially and temporally in Figures 9 and 10. Model results suggest that, in the Montebello Forebay area, the groundwater table would rise by approximately 7 feet in response to Alternative 2a injection, while hydraulic head in the injection zone (i.e., model layers 3 and 4) would rise by approximately 9 feet.

As discussed in the TM prepared under Task Order 1 (CH2M, 2016a), simulated historical water levels in the Montebello Forebay have fluctuated over a range of about 70 feet, and have risen very close to land surface. Accordingly, a 7-foot water table rise might limit the ability of the aquifer to accept additional recharge from the spreading grounds, on an occasional basis. Based on the historical simulated hydrographs, spreading might be affected in about 5 years out of 40. In addition, the rise in water levels in the Montebello Forebay may cause reduced inflow to the Central Basin from the San Gabriel Basin, as discussed in Section 3.2.2 below.

Simulated water level declines shown in Figure 9 are centered around the City of Los Angeles', City of Inglewood's, and Golden State Water Company's well fields, in response to the 10,000 AFY of pumping by the City of Los Angeles and combined 2,800 AFY of pumping by City of Inglewood and Golden State Water Company in Alternative 2a. Water level declines are estimated to be up to 67 feet.

There is limited to no change in the Long Beach (injection location) and Carson/Wilmington (refineries' location) areas from Alternative 1. Accordingly, the conclusion from Alternative 1 also applies to Alternative 2a: the aquifer could likely accommodate reduced pumping from the refineries and injection at Long Beach.

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[6] Note that the Alternative 2a model did not achieve convergence in 10 of the 14,400 model time steps (480 stress periods that approximately represent months, with 30 time steps in each one that represent days). The non-convergent time steps are confined to stress period 224. The non-cumulative (single time step) water budget errors were still 0.00% for these non-convergent time steps. It is assumed that these convergence errors do not affect the feasibility-level conclusions reported here, because they represent negligible volumes of water compared to the annual water budget of the basin; however, it is recommended that convergence errors be addressed in future more detailed evaluations.

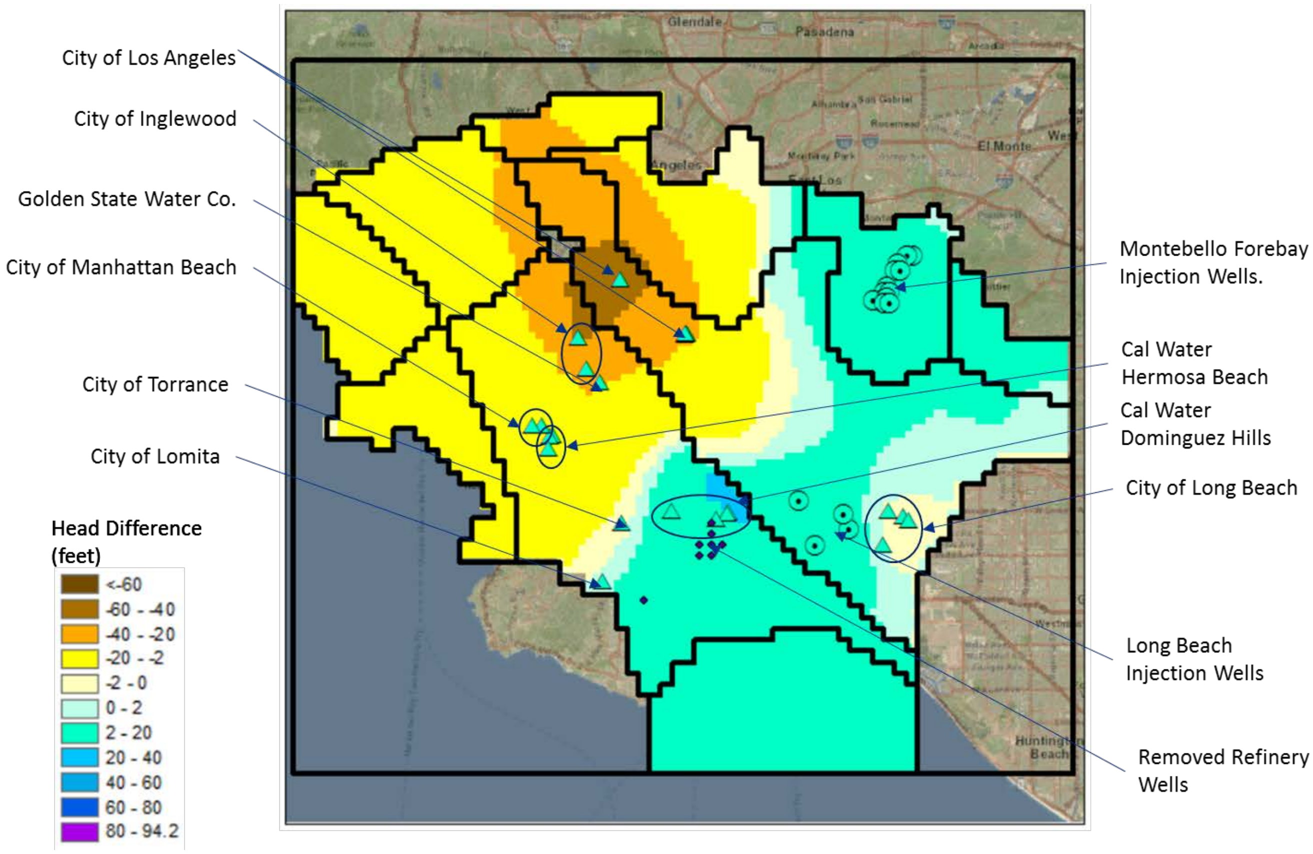


Figure 9. Simulated Head Differences in the Injection Zone Between the Baseline and Alternative 2a at 30 Years

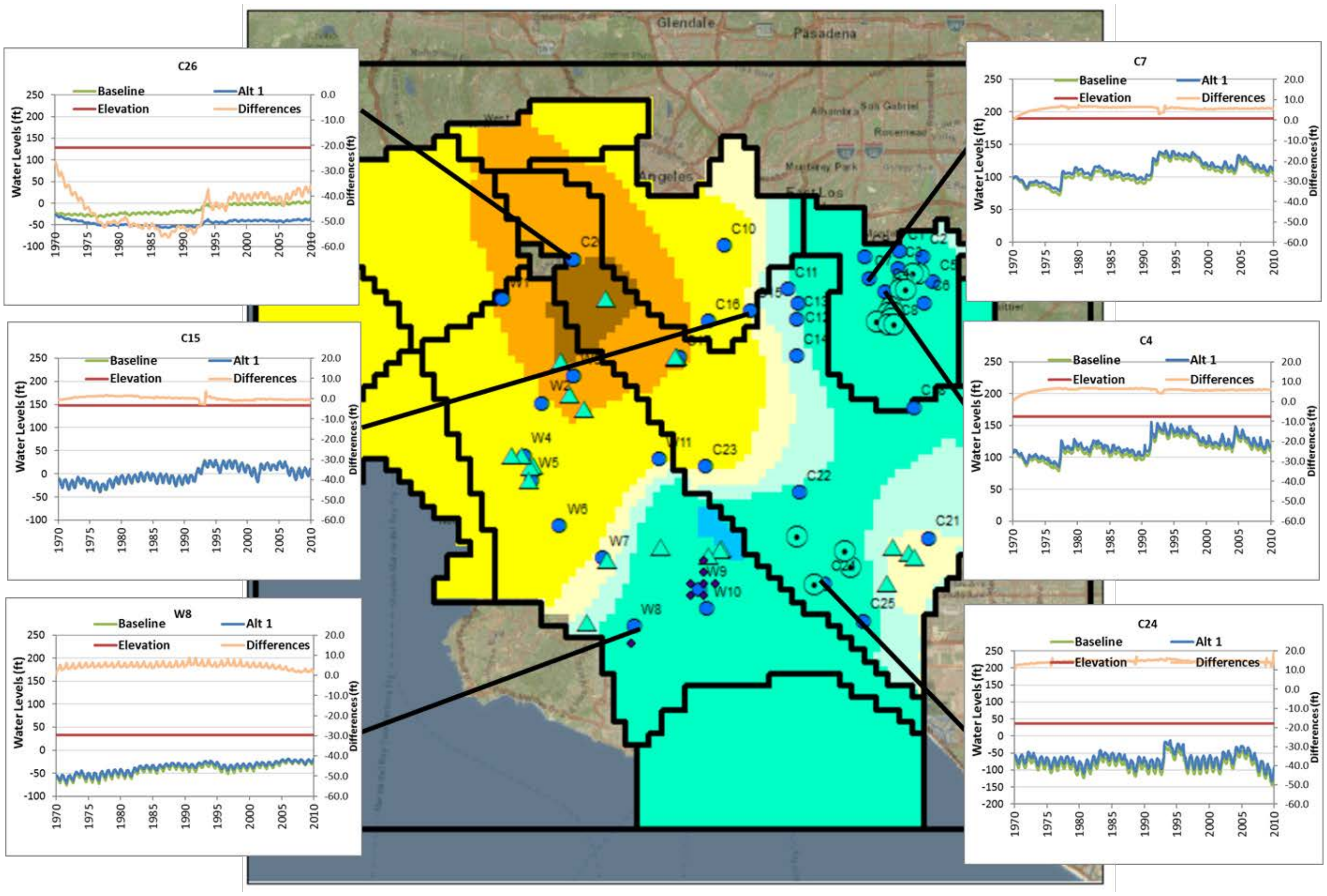
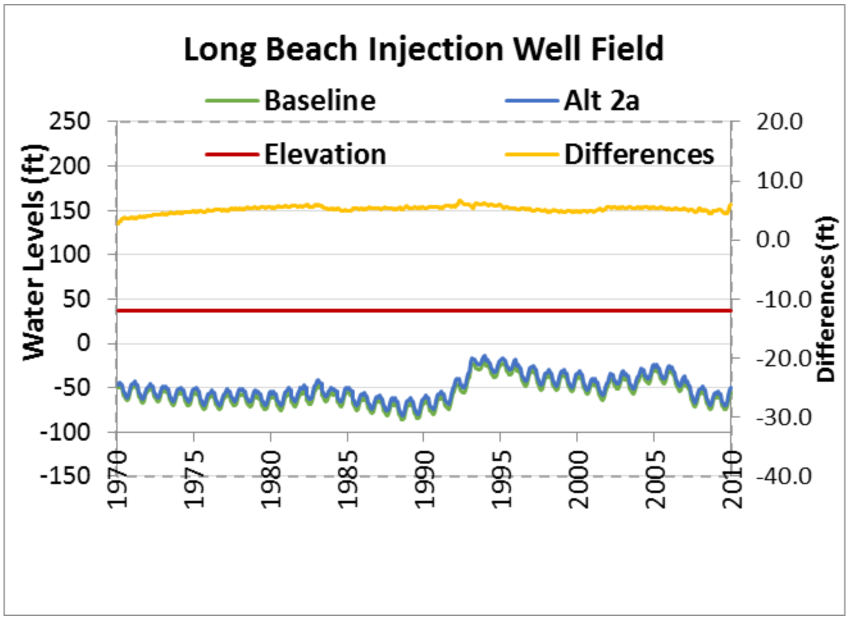


Figure 10A. Changes in Groundwater Levels: Alternative 2a vs. Baseline



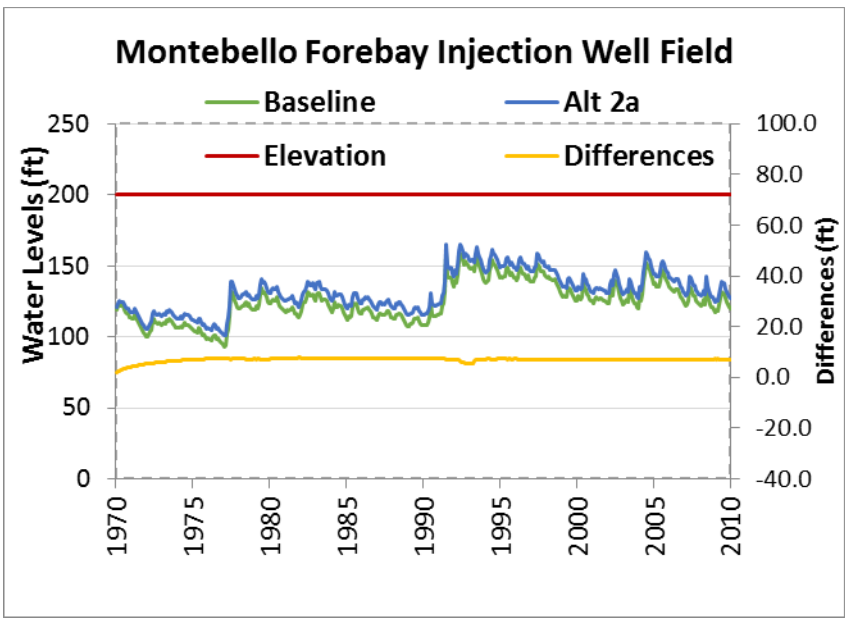


Figure 10B. Changes in Groundwater Levels: Alternative 2a vs. Baseline

3.2.2 Change in Simulated Water Budget

Changes in the simulated water budget and storage are shown in Figures 11A-11C. The water budget of the Baseline model (Figure 11A) is followed by the change in water budget due to Alternative 2a (Figure 11B) and the cumulative change in storage due to Alternative 2a (Figure 11C). As can be seen on Figure 11B, there is 14,000 AFY of additional injection in all years, and 14,000 AFY of additional pumping in most years. 4,000 AFY of the injection/pumping is from Long Beach, and is the same as Alternative 1. The additional 10,000 AFY is from injection at Montebello Forebay and extraction at Los Angeles' Manhattan well field. There is an additional 11,766 AFY, on average, of transferred pumping (reduced pumping at refineries, increased pumping in West Coast Basin), also consistent with Alternative 1.

In addition to the change in pumping and injection, there is a net change in boundary flows that causes a net change in storage. A basin-wide cumulative deficit of nearly 120,000 AF is simulated at the end of the simulation period for Alternative 2a (Figure 11C), or an average of about 3,000 AFY.

As shown in Figure 12, the cumulative change in storage is caused, in part, by changes in boundary flows, which in turn are caused by changes in groundwater levels. Injection at Montebello Forebay causes average reduction of inflow from the San Gabriel Basin of about 2,500 AFY. Pumping in the West Coast Basin induces about 1,700 AFY of inflow (and reduced outflow) from the Santa Monica Bay, while injection in the Long Beach area causes reduced inflow of about 1,600 AFY from the San Pedro Bay. Minor changes to the seawater intrusion barrier operations may be required to mitigate the changes in flows to/from offshore.

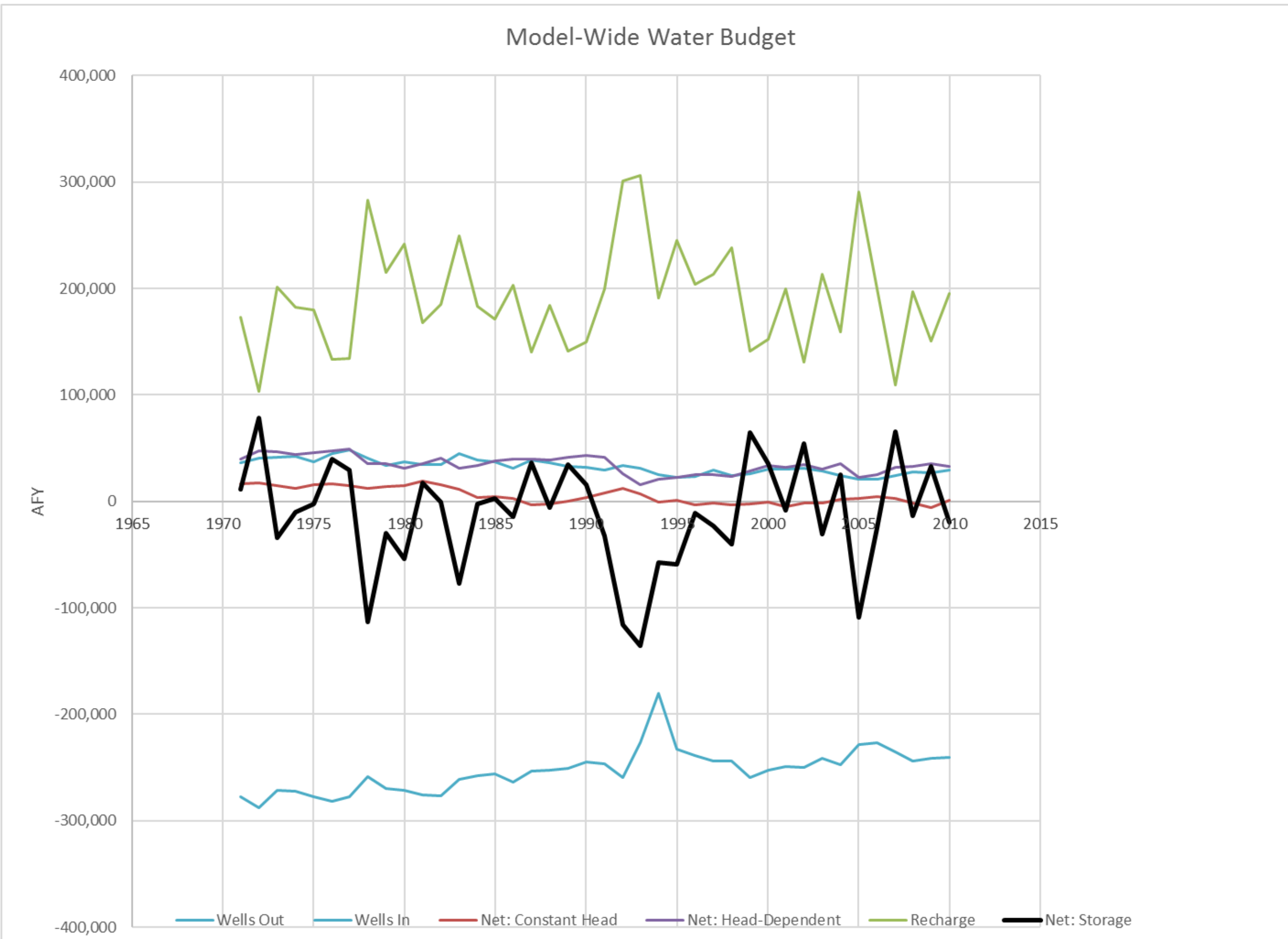


Figure 11A. Comparison of Water Budget: Alternative 2a vs. Baseline - *Baseline Model Water Budget*

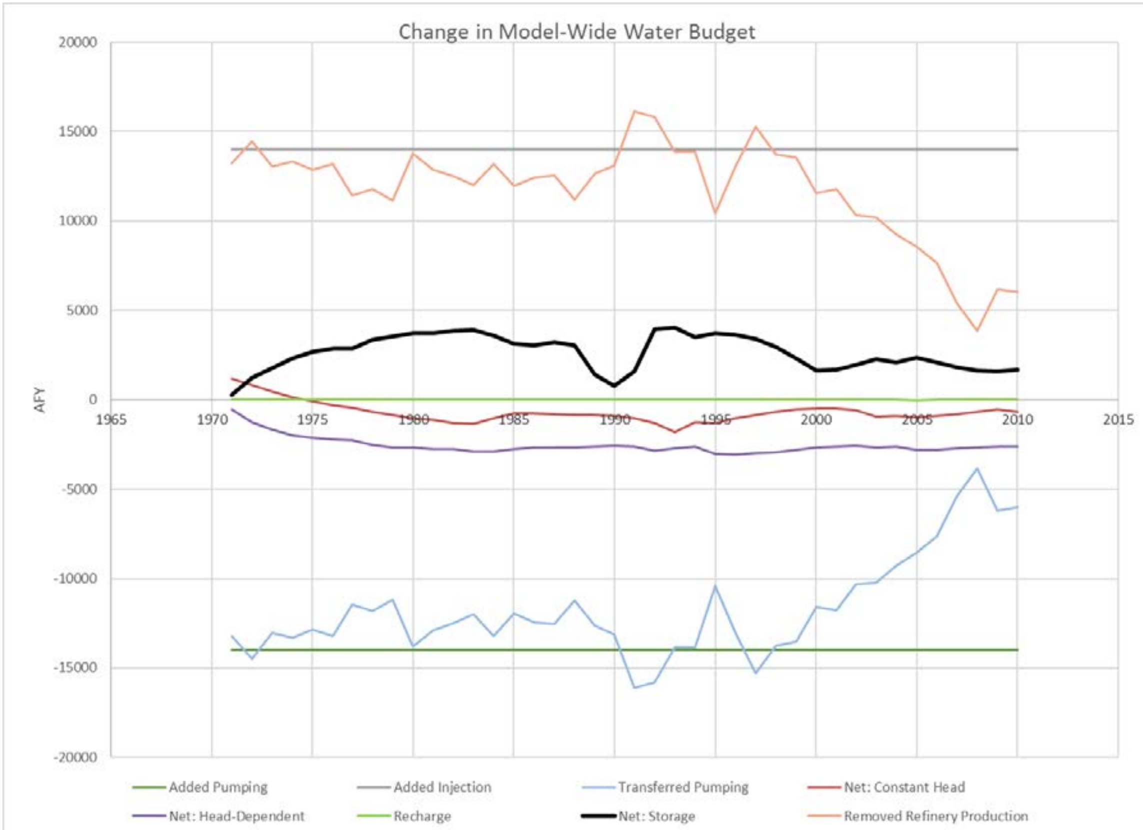


Figure 11B. Comparison of Water Budget: Alternative 2a vs. Baseline - *Change in Water Budget due to Alternative 2a*

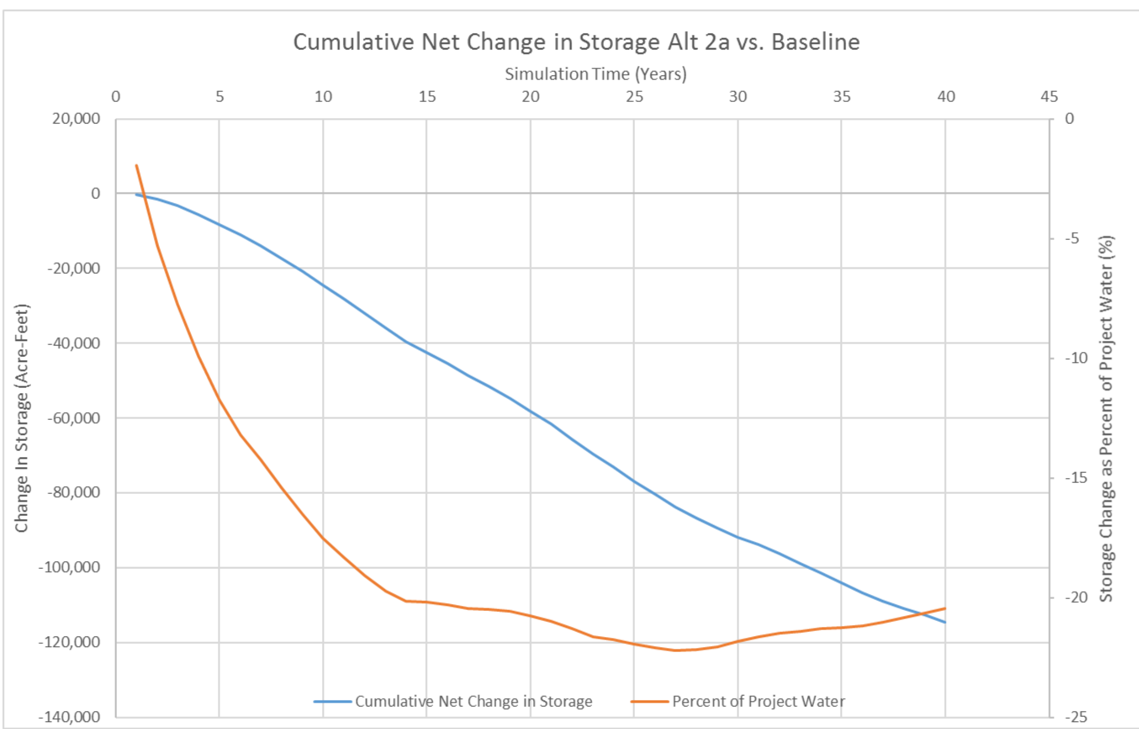


Figure 11C. Comparison of Water Budget: Alternative 2a vs. Baseline - *Cumulative Change in Storage due to Alternative 2a (Alternative 2a minus Baseline)*[7]

[7] See footnote to Figure 6c.

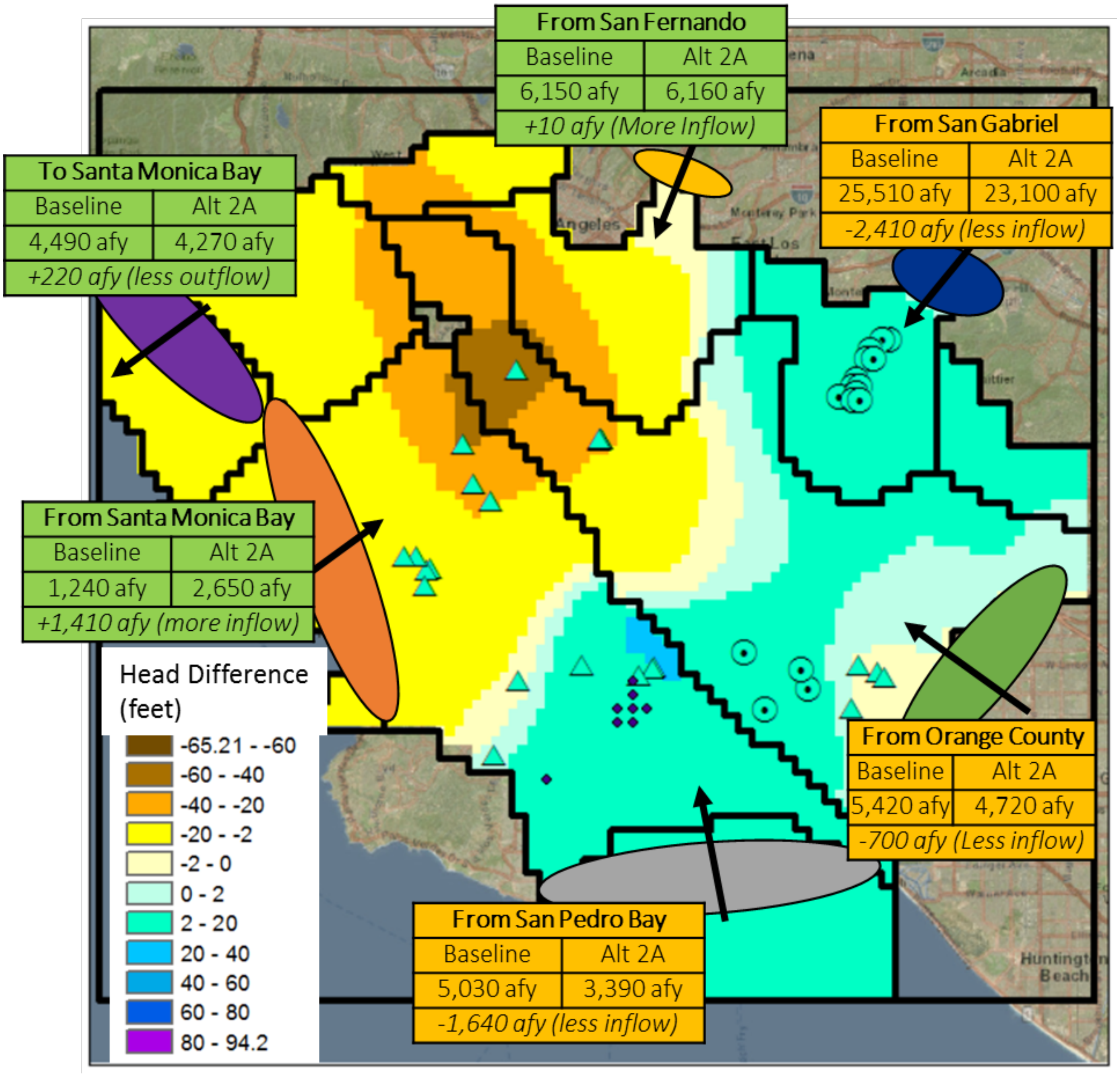


Figure 12. Alternative 2a Water Budget Change at Boundary Conditions.

3.2.3 Travel Time Using Particle Tracking

Particles were run for Alternative 2a starting from the Montebello Forebay injection wells (refer to Section 3.1.3 for details regarding timing and vertical placement, which were identical in all particle simulations.)

The travel distances of the Montebello Forebay particle tracks after one year range from approximately 0.3 to 0.5 mile (average 0.39 mile). As can be seen from Figure 13, some production wells with low to moderately high flow rates appear to be within that range. While none of the particle tracks actually intersect the production wells in this simulation, relatively small variations in either particle starting locations, ambient flow conditions, future pumping rates, or a combination thereof, could (if simulated) cause the simulated particles to be intercepted by the production wells within one year. Two of the nearby production wells are within range of 6 months travel time from injection locations. The model forecasts that no production wells are in range to receive the injected water within 3 months. However, in practice, the injection well locations for Montebello Forebay injection wells could also be relocated to reduce the risk to production wells.

Particles were not run from the Long Beach injection wells for Alternative 2a, because both pumping and injection in that area are the same as in Alternative 1. Therefore, the results of such particle tracking for Alternative 2a would be nearly identical to those shown in Figure 8.

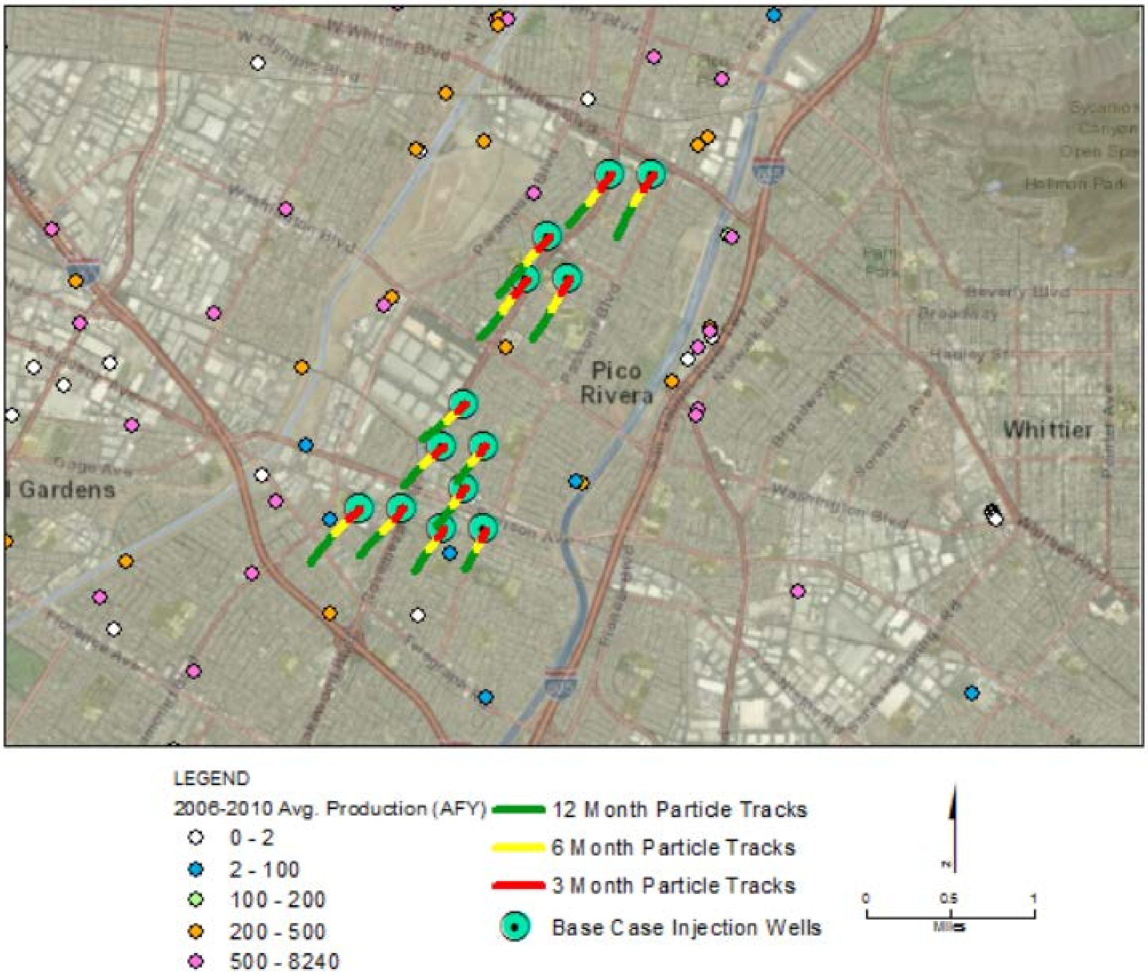


Figure 13. Alternative 2a Particle Tracking Results—Montebello Forebay Area

3.3 Alternative 2b Modeling Results

This section summarizes the results of the Alternative 2b simulation. Results are presented below in conjunction with the baseline modeling results to facilitate evaluation of the changes due specifically to Alternative 2b. Alternative 2b builds off of Alternative 1 by adding 10,000 AFY of injection in the LA Forebay, with an equivalent 10,000 AFY of extraction from the City of Los Angeles' Manhattan well field. Alternative 2b differs from Alternative 2a only in the location of 10,000 AFY of injection.

3.3.1 Change in Simulated Groundwater Levels

This section summarizes the projected change in water levels in response to Alternative 2b injection and extraction. Results are summarized both spatially and temporally in Figures 14 and 15. Model results suggest that, in the LA Forebay area, the groundwater table would rise by a maximum of approximately 40 feet, while hydraulic head in the injection zone (i.e., model layers 3 and 4) would rise by approximately 60 feet. The water level rise is non-linear, with the bulk of the water level rise occurring in the first 10 years (Figure 15B).

As simulated historical water levels in the LA Forebay have fluctuated over a range of about 40 feet, the simulated change due to Alternative 2b is substantial relative to historical change. However, simulated water levels in the injection area are about 200 feet below land surface in the Baseline, suggesting that a 60-foot water level rise could be readily accommodated. However, transmissivity in this area is uncertain; additional testing and evaluation of local transmissivity would be recommended to better estimate mounding and number of wells required for injection.

Simulated water level declines shown on Figure 14 are centered around the City of Los Angeles', City of Inglewood's, and Golden State Water Company's well fields, in response to the 10,000 AFY of pumping by City of Los Angeles and combined 2,800 AFY of pumping by City of Inglewood and Golden State Water Company in Alternative 2b. Water level declines are estimated to be up to 35 feet.

There is limited to no change in the Long Beach (injection location) and Carson/Wilmington (refineries' location) areas from Alternative 1 or Alternative 2a. Accordingly, the conclusion from Alternative 1 also applies to Alternative 2b: the aquifer could likely accommodate reduced pumping from the refineries and injection at Long Beach.

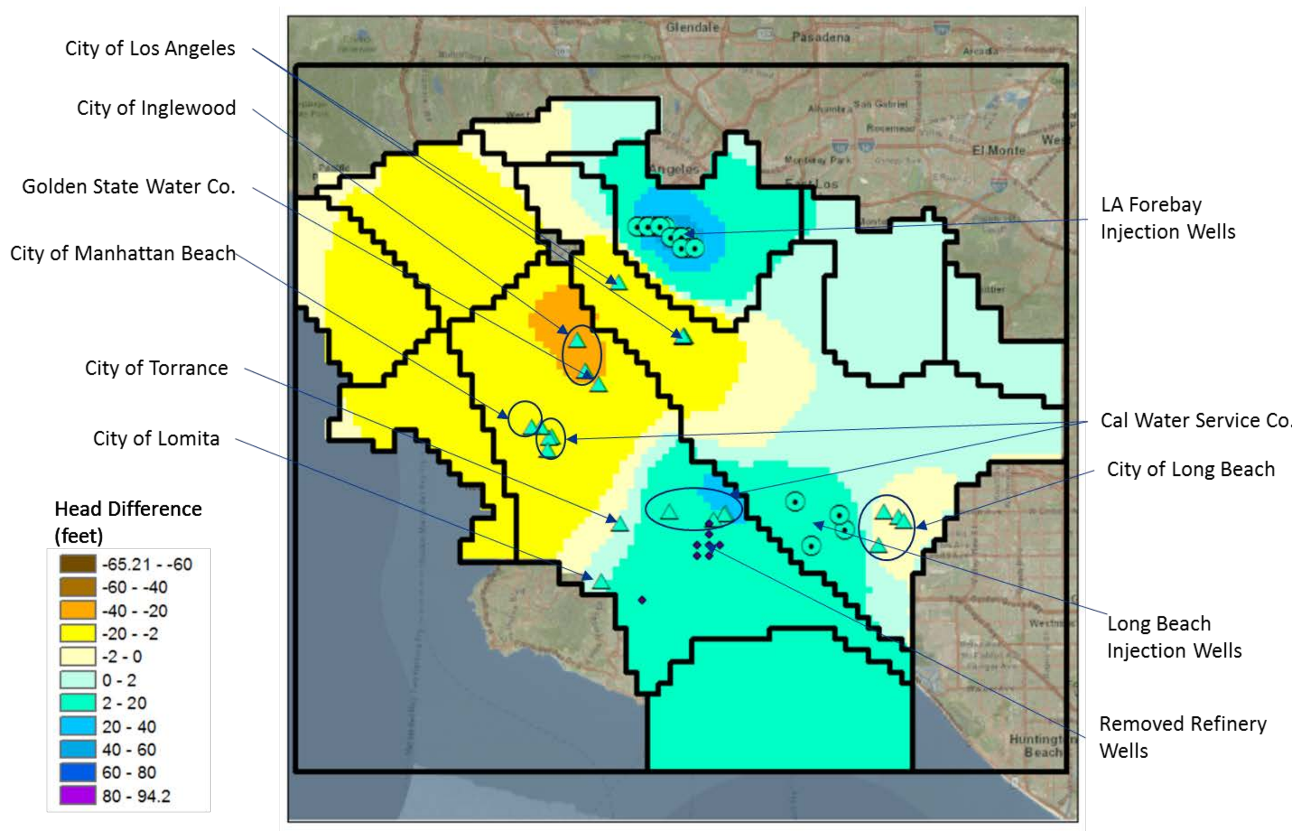


Figure 14. Simulated Head Differences in the Injection Zone Between Alternative 2b and Baseline at 30 Years

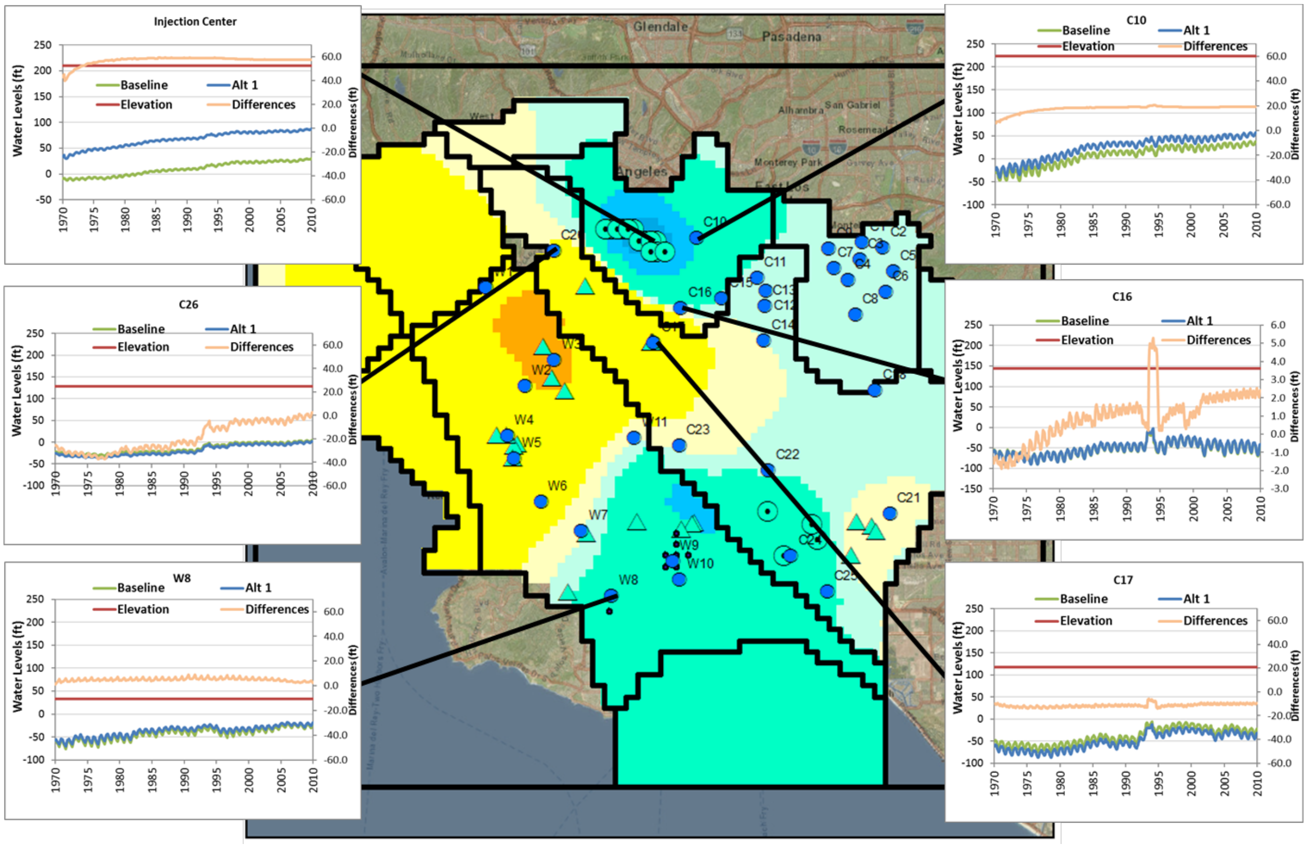
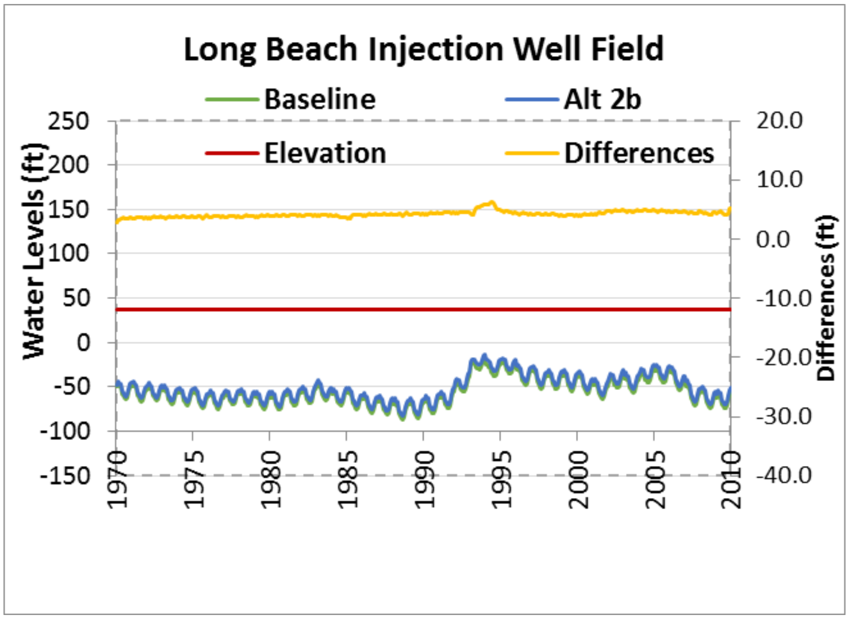


Figure 15A. Changes in Groundwater Levels: Alternative 2b versus Baseline



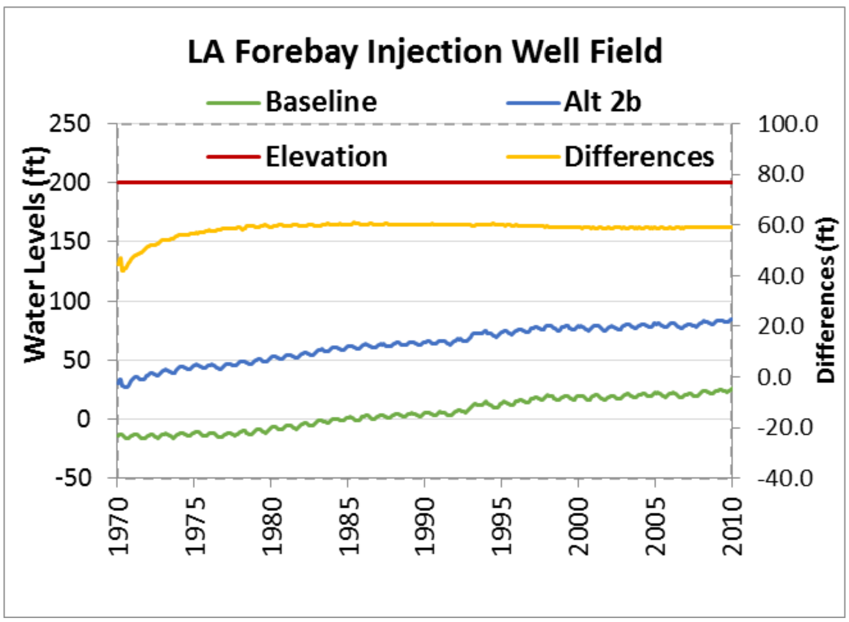


Figure 15B. Changes in Groundwater Levels: Alternative 2b vs. Baseline

3.3.2 Change in Simulated Water Budget

Changes in the simulated water budget and storage are shown on Figures 16A-16C. The water budget of the baseline model (Figure 16A) is followed by the change in water budget due to Alternative 2b (Figure 16B) and the cumulative change in storage due to Alternative 2b (Figure 16C). As can be seen on Figure 16B, there is 14,000 AFY of additional injection in all years, and 14,000 AFY of additional pumping in all years. 4,000 AFY of the injection/pumping is from Long Beach, and is the same as in Alternative 1 and Alternative 2a. The additional 10,000 AFY of injection at LA Forebay and extraction at Los Angeles' Manhattan well field is applied in this alternative. There is an additional 11,766 AFY, on average, of transferred pumping (reduced pumping by refineries and increased pumping in West Coast Basin), also consistent with Alternative 1 and Alternative 2a.

In addition to the change in pumping and injection, there is a net change in boundary flows that causes a net change in storage. A basin-wide cumulative surplus of about 20,000 AF is simulated at the end of the simulation period for Alternative 2b (Figure 16C), or an average of about 500 AFY.

As shown on Figure 17, the cumulative change in storage is caused, in part, by changes in boundary flows, which in turn are caused by changes in groundwater levels. Pumping in the Central Basin may induce a small amount of inflow from Orange County, while injection in the Central Basin may limit boundary inflows by a small amount (significantly less than Alternative 2a). Pumping in the West Coast Basin induces about 1,400 AFY of inflow (and reduced outflow) from the Santa Monica Bay, while injection in the Long Beach area causes reduced inflow of about 1,600 AFY from the San Pedro Bay. Minor changes to the seawater intrusion barrier operations may be required to mitigate the changes in flows to/from offshore.

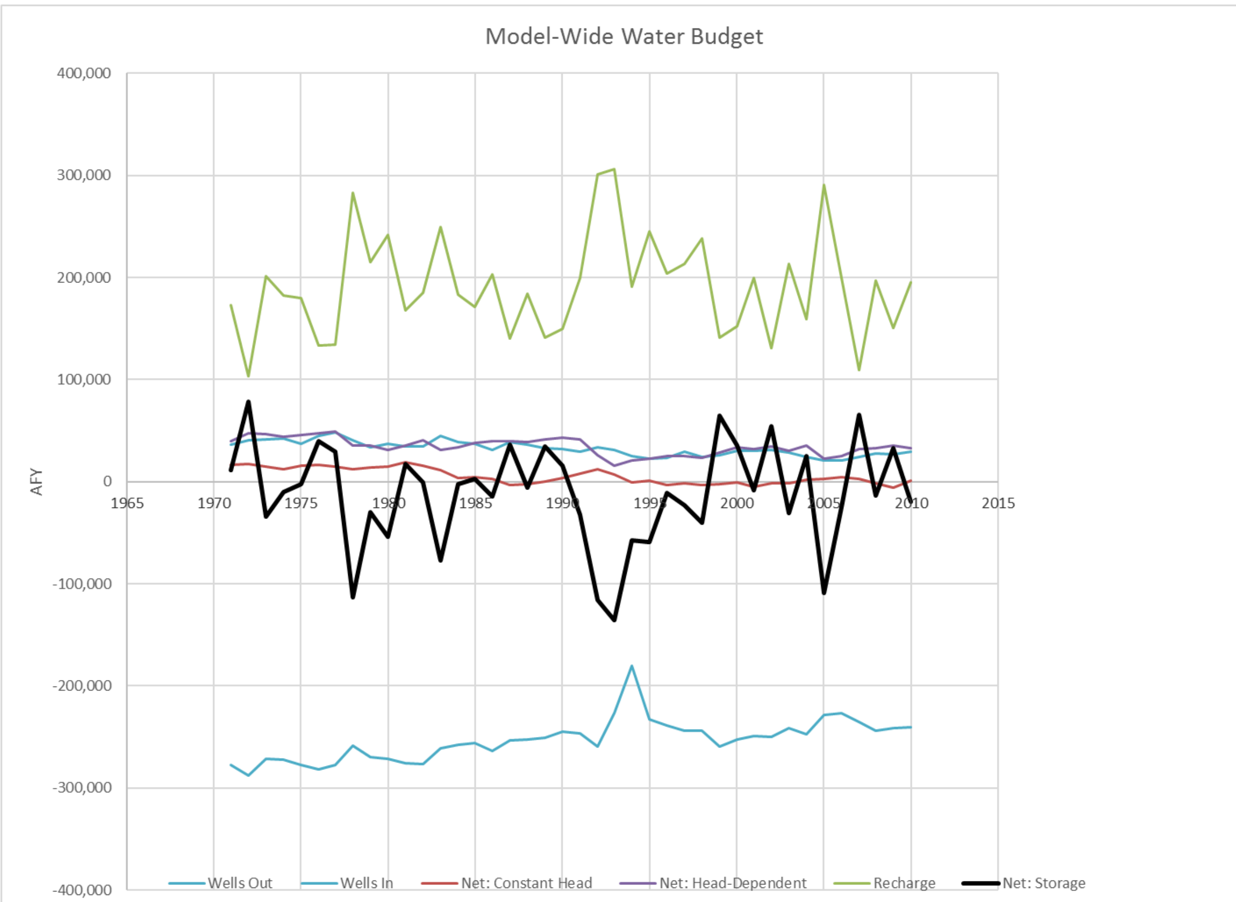


Figure 16A. Comparison of Water Budget: Alternative 2b vs. Baseline Scenario - *Baseline Model Water Budget*

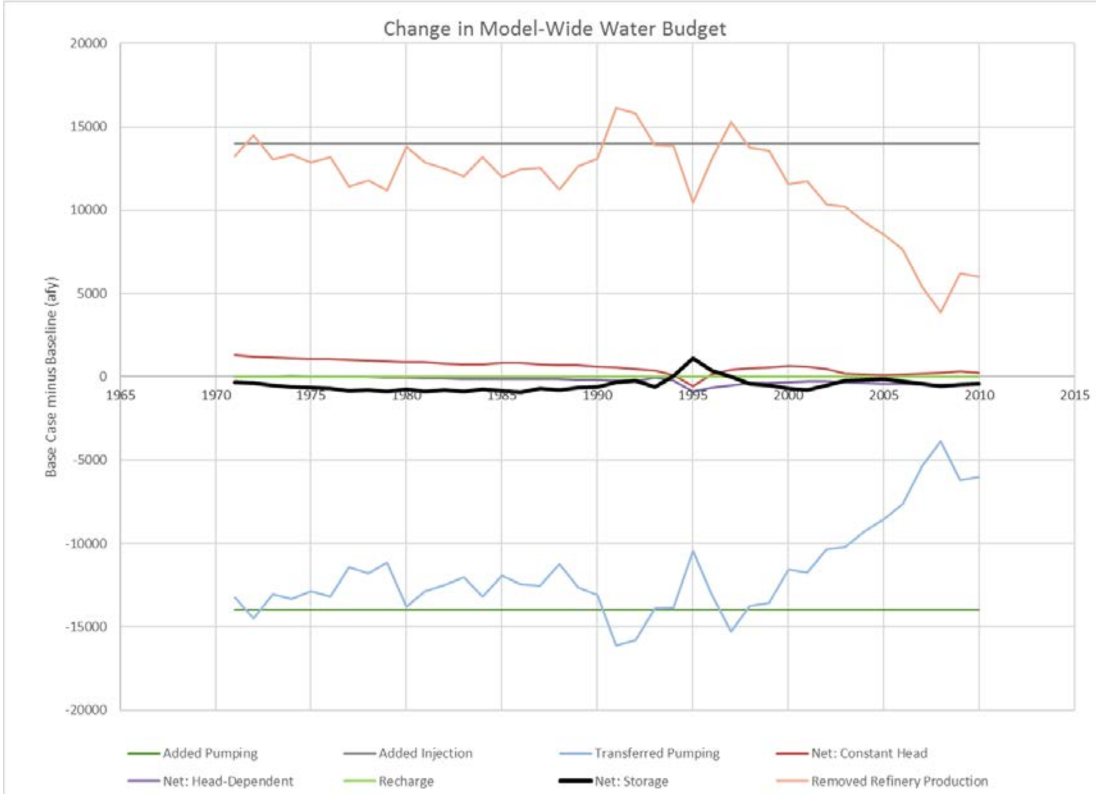


Figure 16B. Comparison of Water Budget: Alternative 2b vs. Baseline - *Change in Water Budget due to Alternative 2b*

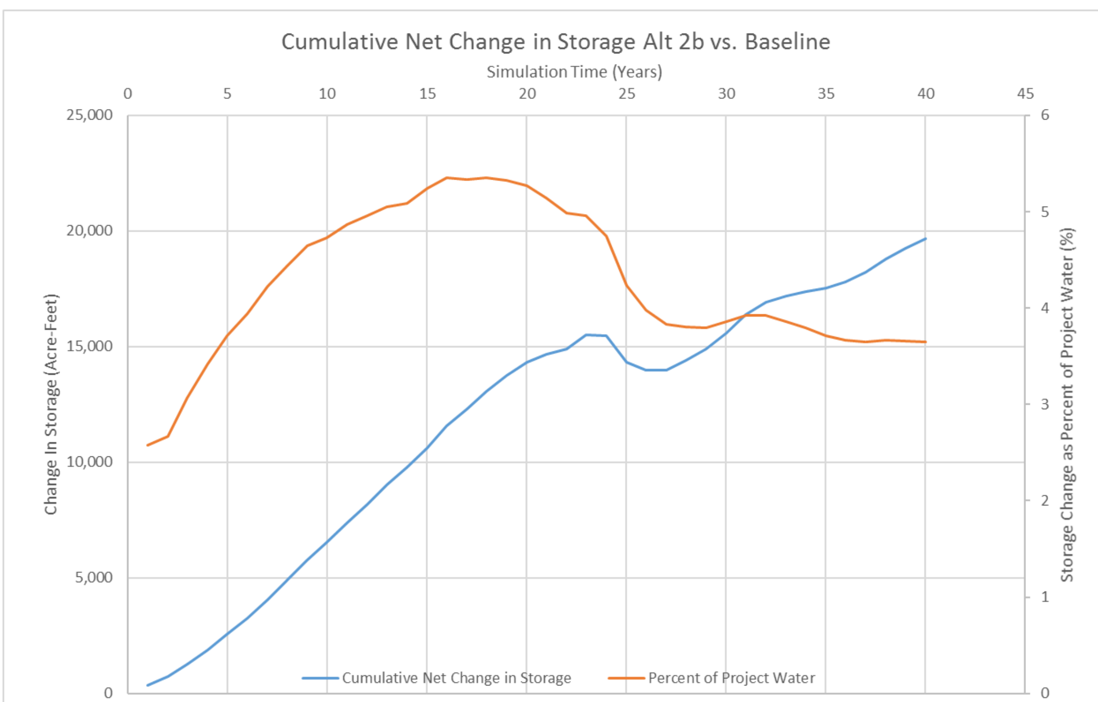


Figure 16C. Comparison of Water Budget: Alternative 2b vs. Baseline - *Cumulative Change in Storage due to Alternative 2b (Alternative 2b minus Baseline)*[8]

8 See footnote to Figure 6c.

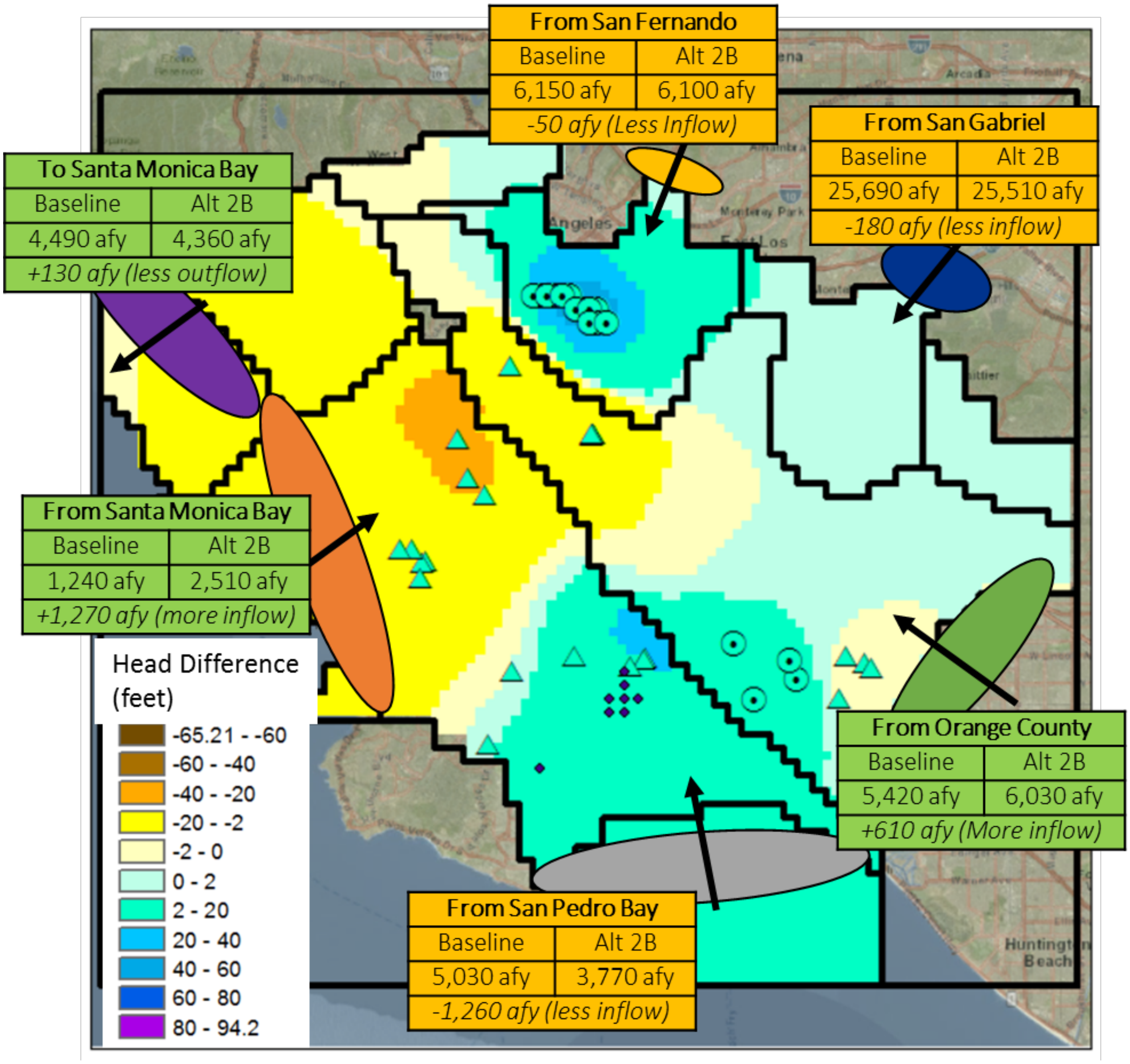


Figure 17. Alternative 2b Water Budget Change at Boundary Conditions

3.3.3 Travel Time Using Particle Tracking

The results of the Alternative 2b particle tracking from the LA Forebay injection wells are shown in Figure 18. The travel distances after 1 year are almost uniformly less than 0.1 mile (average 0.05 mile). These shorter travel distances, relative to those from the Montebello Forebay injection wells of Alternative 2a, are due to lower model hydraulic conductivity in the LA Forebay. As can be seen on Figure 18, no known production wells are nearby. For this reason, the risk of injected water reaching a production well within 12 months in this alternative is considered very low.

Particles were not run from the Long Beach injection wells for Alternative 2b, because both pumping and injection in that area are the same as in Alternative 1. Therefore, the results of such particle tracking for Alternative 2b would be nearly identical to those shown on Figure 8.

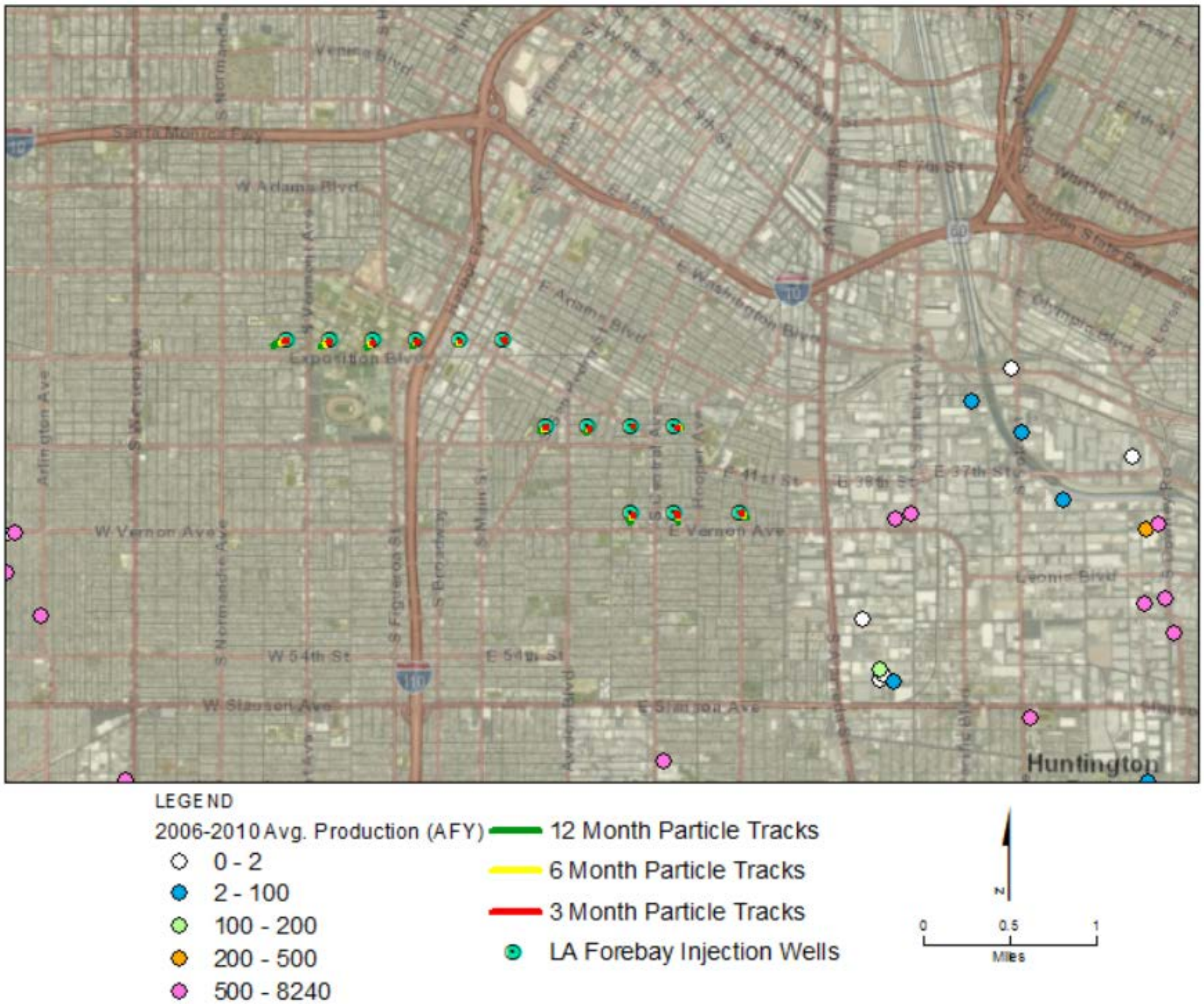


Figure 18. Alternative 2b Particle Tracking Results--Los Angeles Forebay Area

3.4 Alternative 3a Modeling Results

This section summarizes results of the Alternative 3a simulation[9]. Results are presented below in conjunction with both the baseline and Alternative 2a modeling results, to facilitate evaluation of the changes due specifically to Alternative 3a. Alternative 3a builds off of Alternative 2a by adding 15,000 AFY of injection in Carson, with an equivalent 15,000 AFY of extraction from the West Coast Basin. The additional West Coast Basin pumping is primarily located near the Carson injection; 14,000 AFY of the additional West Coast Basin pumping is from wells within 2.5 miles of Carson injection wells.

3.4.1 Change in Simulated Groundwater Levels

This section summarizes the projected change in water levels in response to Alternative 3a injection and extraction. Results are summarized both spatially and temporally in Figures 19 and 20. Model results suggest that, in the Carson area, the groundwater table would rise by a maximum of approximately 24 feet while hydraulic head in the injection zone (i.e., model layers 3 and 4) would rise by approximately 33 feet. The water level rise is non-linear, with the bulk of the water level rise occurring in the first 10 years (Figure 20b). Simulated historical water levels in the Carson area have fluctuated over a range of about 50 feet, with a minimum simulated depth to water in the Baseline of about 80 feet. Accordingly, a 24-foot water level rise could likely be accommodated in this area.

Regionally, model results suggest that there is very little change in water levels from Alternative 2a (Figure 19b). The biggest change is at the injection well field, with a maximum water level rise of about 24 feet due specifically to Alternative 3a.

Because there is very little change in water levels elsewhere in Alternative 3a, relative to Alternative 2a, the same conclusions from Alternative 2a apply: 1) injection in the Montebello Forebay may limit the ability of the aquifer to accept additional recharge from the spreading grounds, on an occasional basis (based on historical simulated hydrographs, spreading might be affected in about 5 years out of 40), 2) Long Beach injection could likely be accommodated, and 3) drawdown near City of Los Angeles' well field is estimated to be up to about 67 feet.

[9] Note that the Alternative 3a model did not achieve convergence in 20 of the 14,400 model time steps (480 stress periods that approximately represent months, with 30 time steps in each one that represent days). The non-convergent time steps are confined to stress periods 224, 272, and 294. While the non-cumulative (single time step) water budget errors are generally still 0.00% for these non-convergent time steps, there are three with more significant water budget errors: 0.04%, 1.86%, and 3.54%. None of these single-day water budget errors result in a cumulative water budget error for the model of more than 0.01%. It is assumed that these convergence errors do not affect the feasibility-level conclusions reported here, because they represent negligible volumes of water compared to the annual water budget of the basin; however, it is recommended that convergence errors be addressed in future more detailed evaluations.

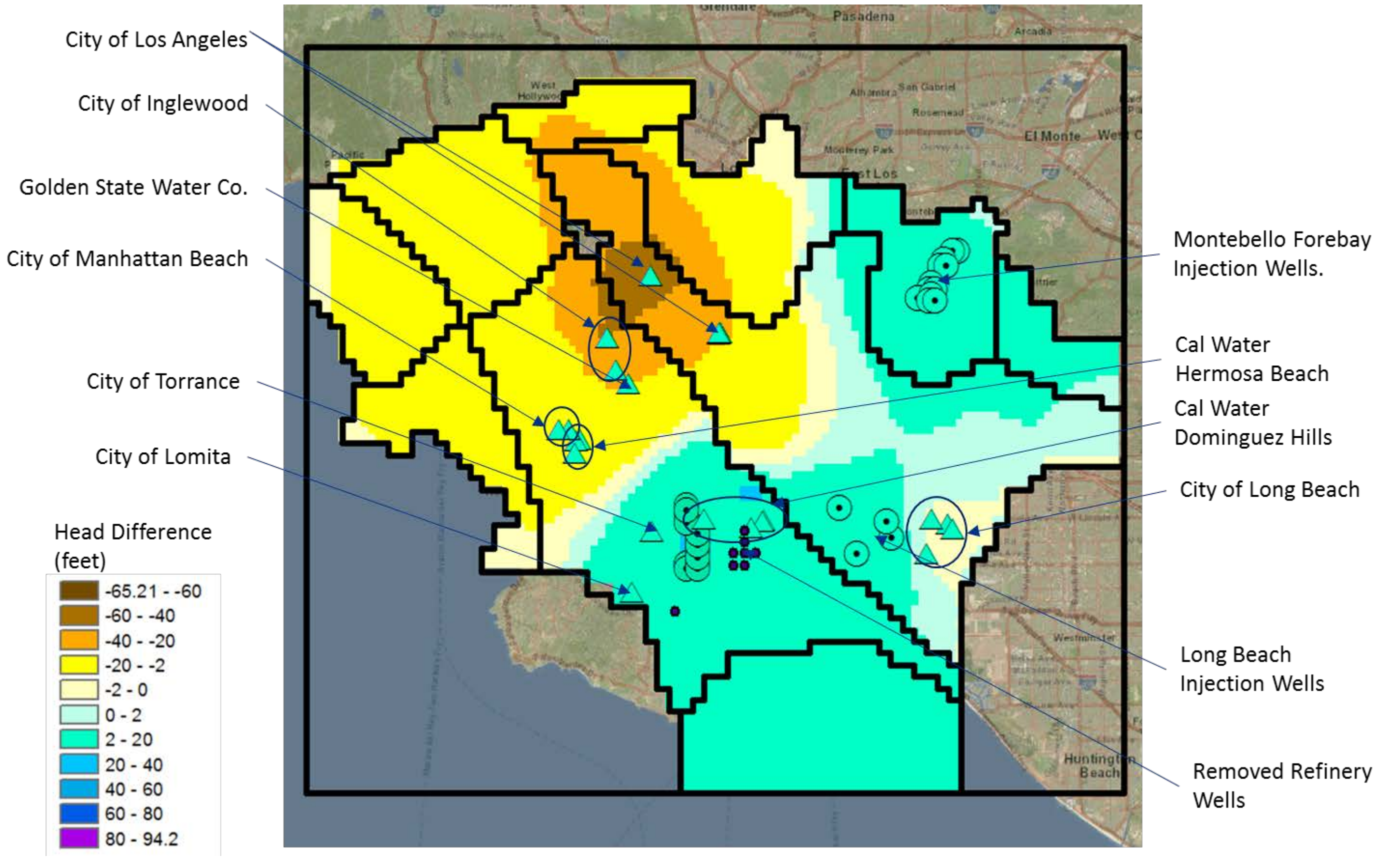


Figure 19a. Simulated Head Differences in the Injection Zone Between Alternative 3a and the Baseline at 30 Years

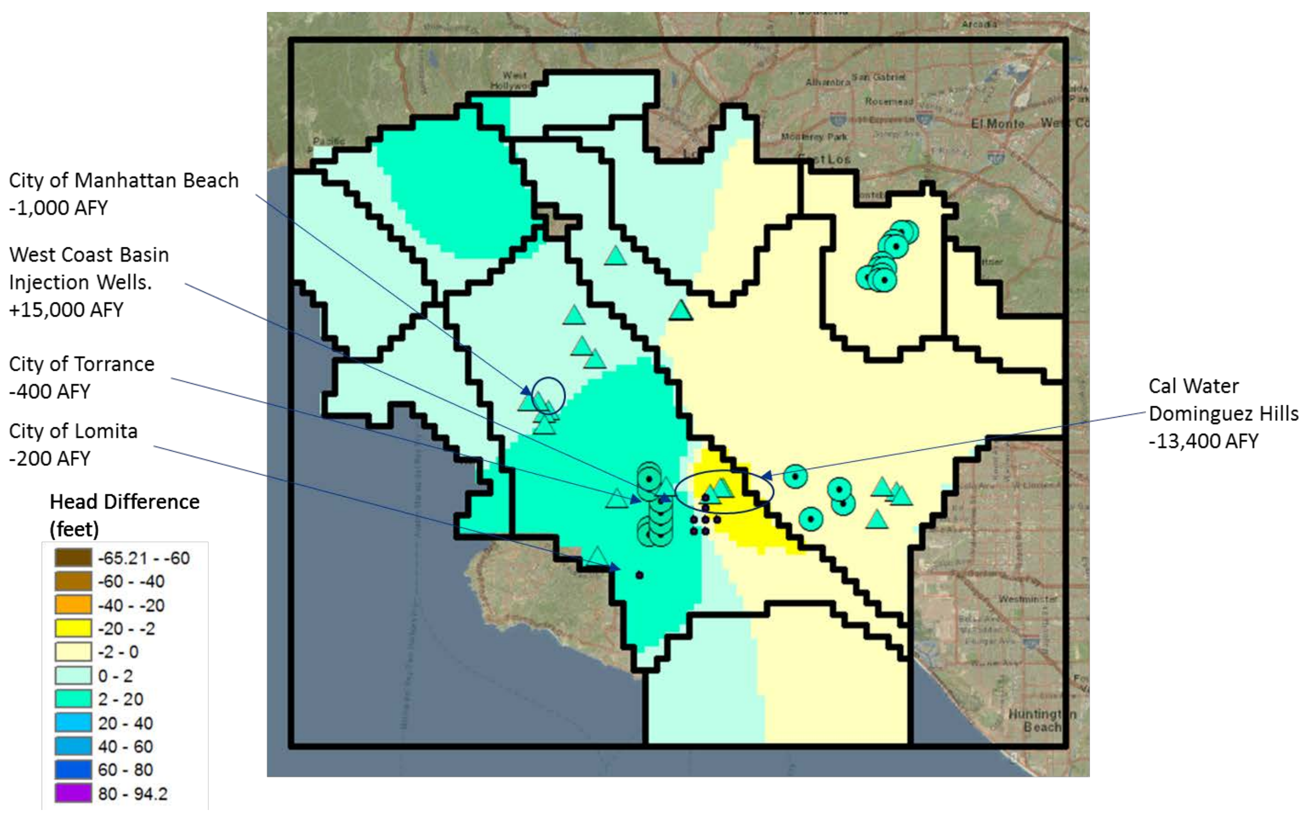


Figure 19b. Simulated Head Differences in the Injection Zone Between Alternative 3a and Alternative 2a at 30 Years

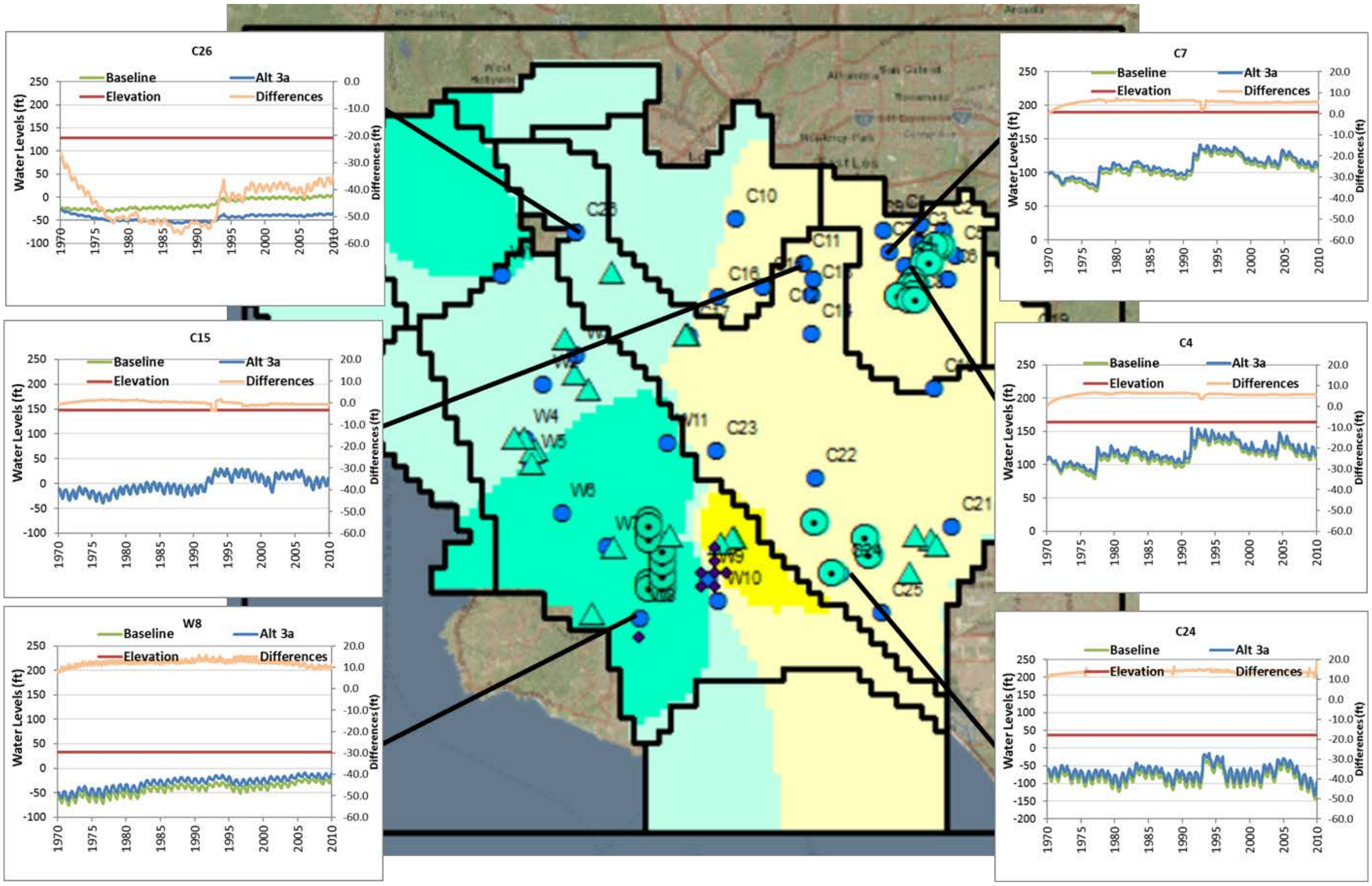


Figure 20a. Changes in Groundwater Levels: Differences Between Alternative 3a vs. Alternative 2a (Base Map), and Between Alternative 3a and Baseline (Time Series Plots)

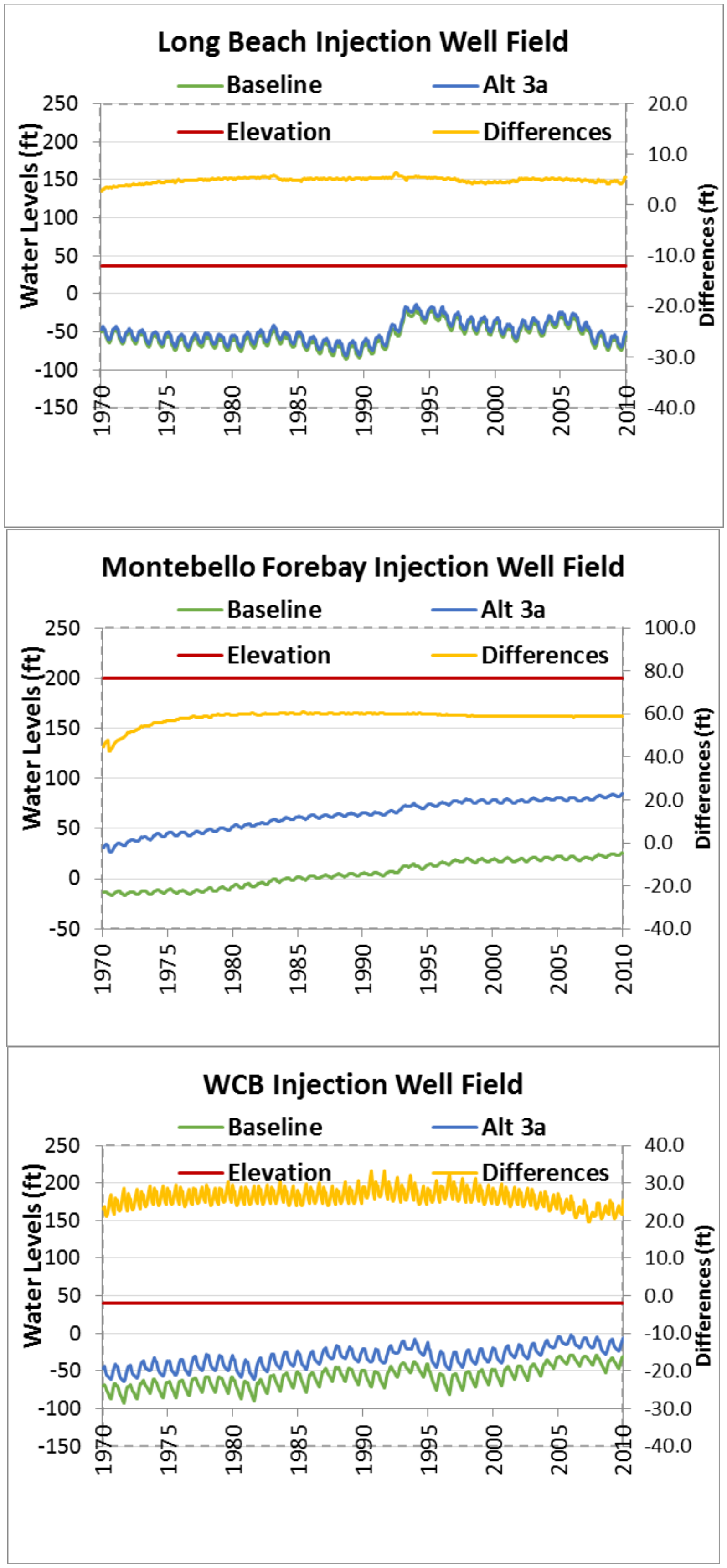


Figure 20b. Changes in Groundwater Levels: Alternative 3a vs. Baseline

3.4.2 Change in Simulated Water Budget

Changes in the simulated water budget and storage are shown in Figures 21A-21C. The water budget of the Baseline model (Figure 21A) is followed by the change in water budget due to Alternative 3a (Figure 21B) and the cumulative change in storage due to Alternative 3a (Figure 21C). As can be seen on Figure 21B, there is 29,000 AFY of additional injection and additional pumping in all years. The additional 15,000 AFY of injection and pumping, as compared with Alternative 2a, is from the addition of Carson injection and an equivalent rate of increased pumping from the West Coast Basin. There is an additional 11,766 AFY, on average, of transferred pumping (reduced pumping at refineries, increased pumping in West Coast Basin), also consistent with Alternatives 1, 2a, and 2b.

In addition to the change in pumping and injection, there is a net change in boundary flows that causes a net change in storage. A basin-wide cumulative deficit of nearly 120,000 AF is simulated at the end of the simulation period for Alternative 3a (Figure 21C), or an average of about 3,000 AFY. There is no significant change in water budget as compared with Alternative 2a, both through time (compare Figure 21C with Figure 11C) or space (compare Figure 22 to Figure 12). As with Alternative 2a, minor changes to the seawater intrusion barrier operations may be required to mitigate the changes in flows to/from offshore.

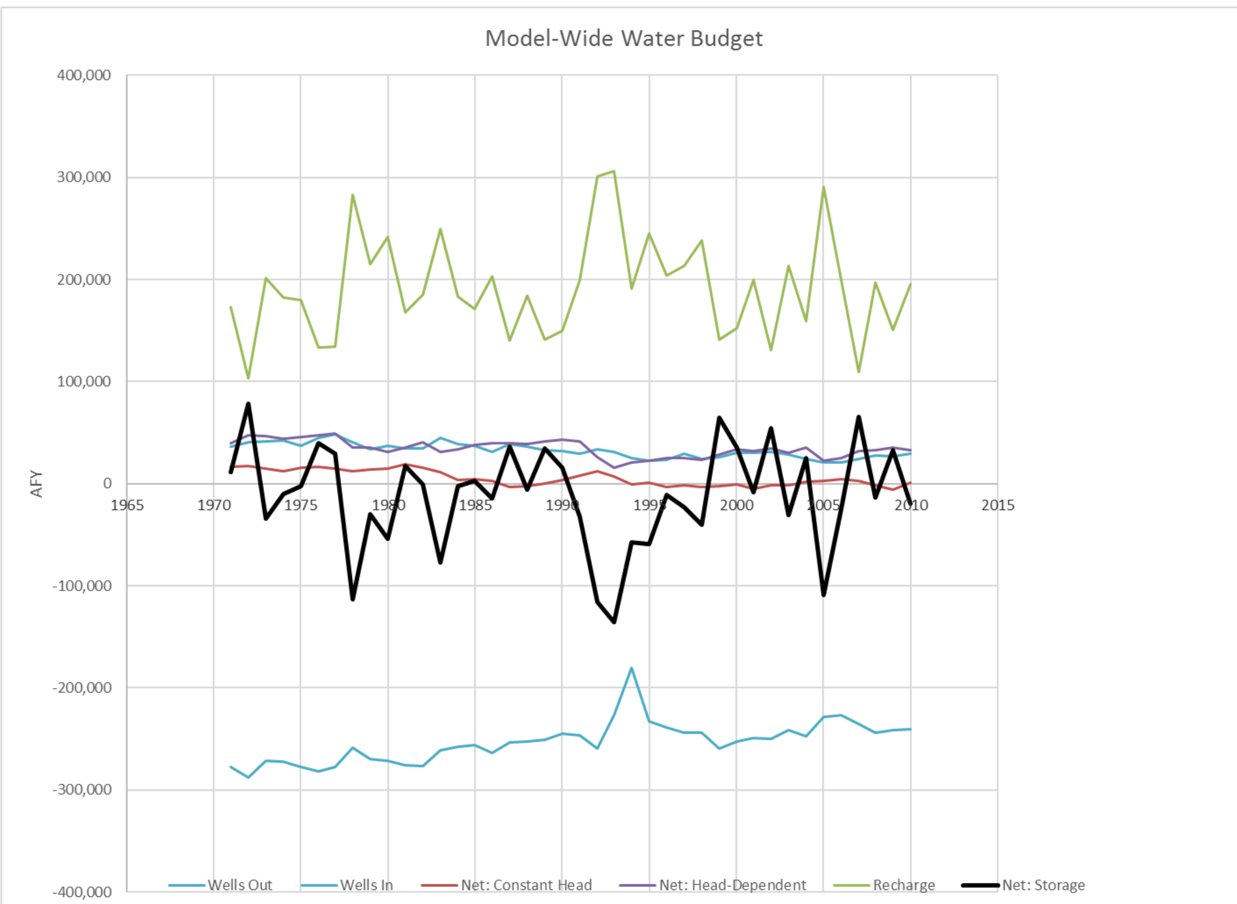


Figure 21A. Comparison of Water Budget: Alternative 3a vs. Baseline Scenario - *Baseline Model Water Budget*

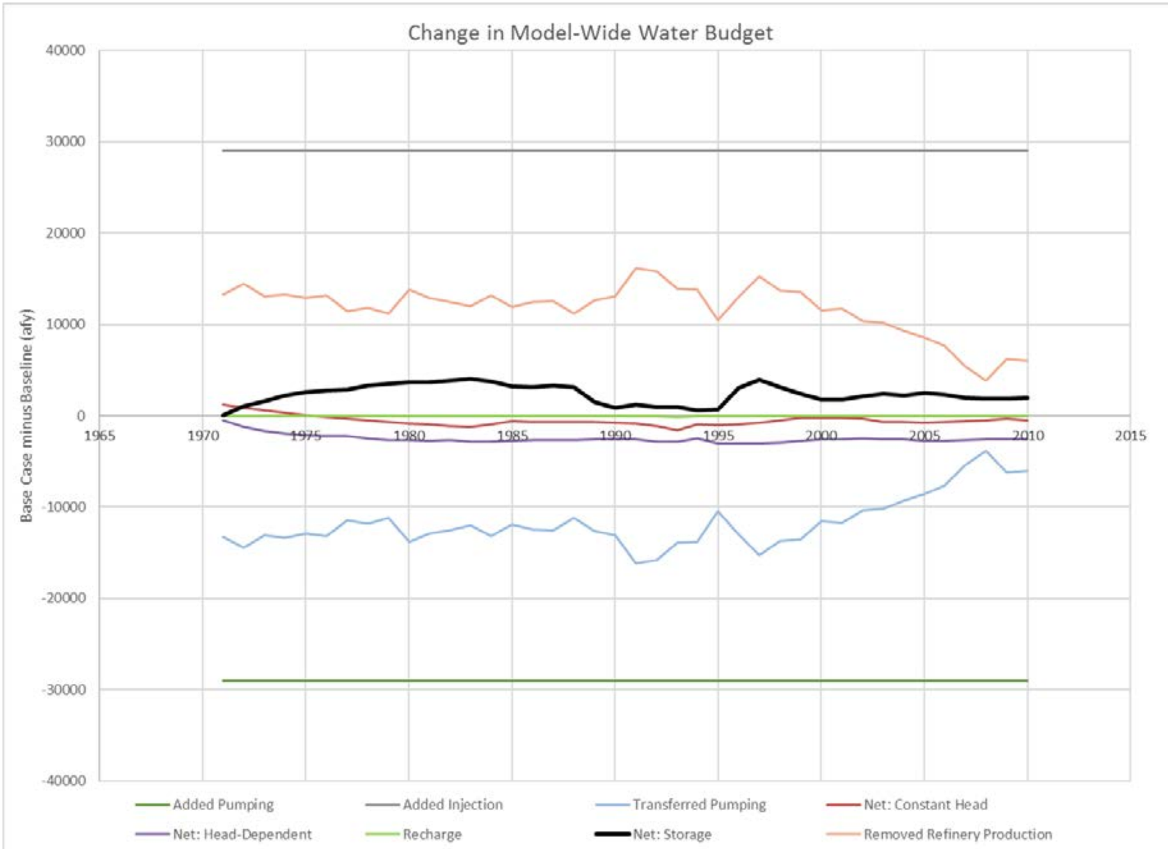


Figure 21B. Comparison of Water Budget: Alternative 3a vs. Baseline - *Change in Water Budget due to Alternative 3a*

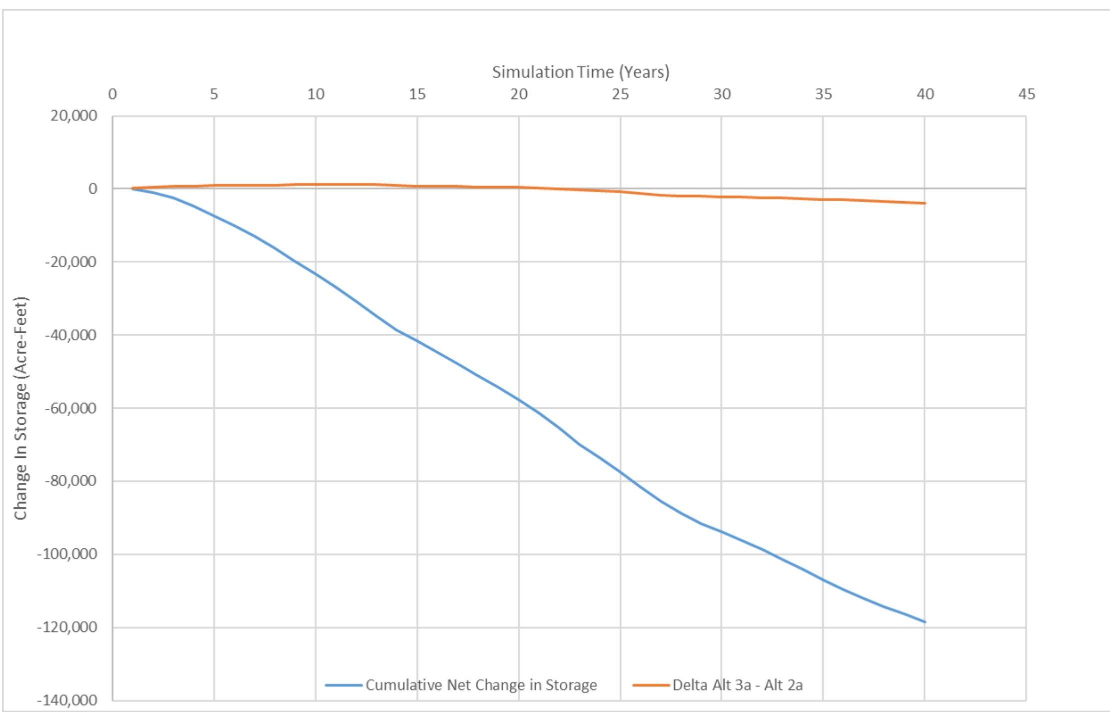


Figure 21C. Comparison of Water Budget: Alternative 3a vs. Baseline - *Cumulative Change in Storage due to Alternative 3a (Alternative 3a minus Baseline)*[10]

[10] See footnote to Figure 6c.

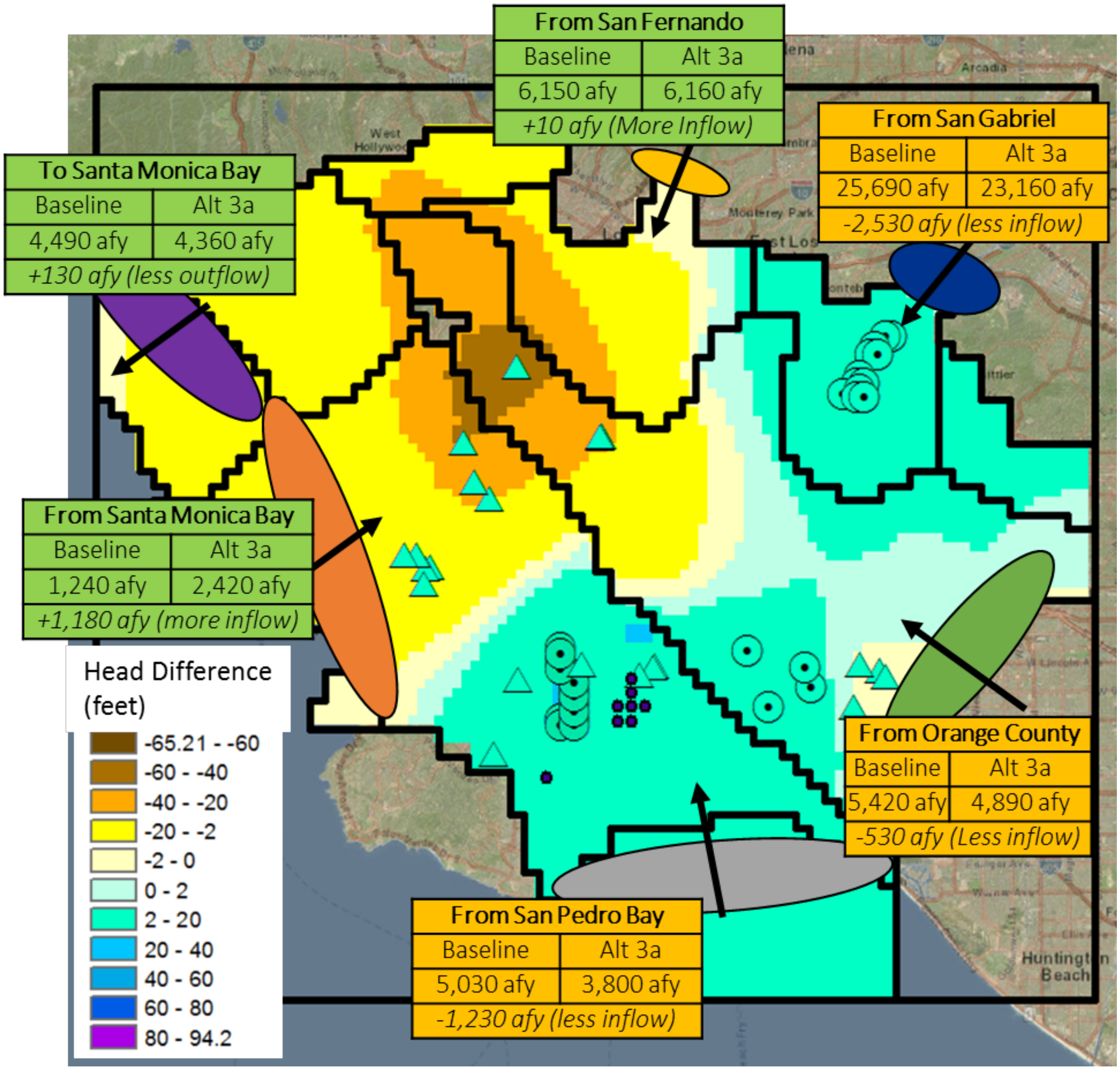


Figure 22. Alternative 3a Water Budget Change at Boundary Conditions

3.4.3 Travel Time Using Particle Tracking

Figure 23 shows the particle tracks that were initiated at the Carson area injection wells for Alternative 3a. Particles here travel relatively short distances, again due to relatively low simulated hydraulic conductivity in the area. The modeling suggests that one high capacity well may be impacted, but the injection well that causes the impact in the simulation could be readily relocated to a safer distance. Particles were not run from the Long Beach or Montebello Forebay injection wells for Alternative 3a, because both pumping and injection in those areas are the same as in Alternative 1 (in which the Long Beach pumping/injection is the same), and in Alternative 2a (in which both the Long Beach and Montebello Forebay pumping/injection are the same). Therefore, the results of such particle tracking for Alternative 2a would be nearly identical to those shown on Figures 8 and 13.

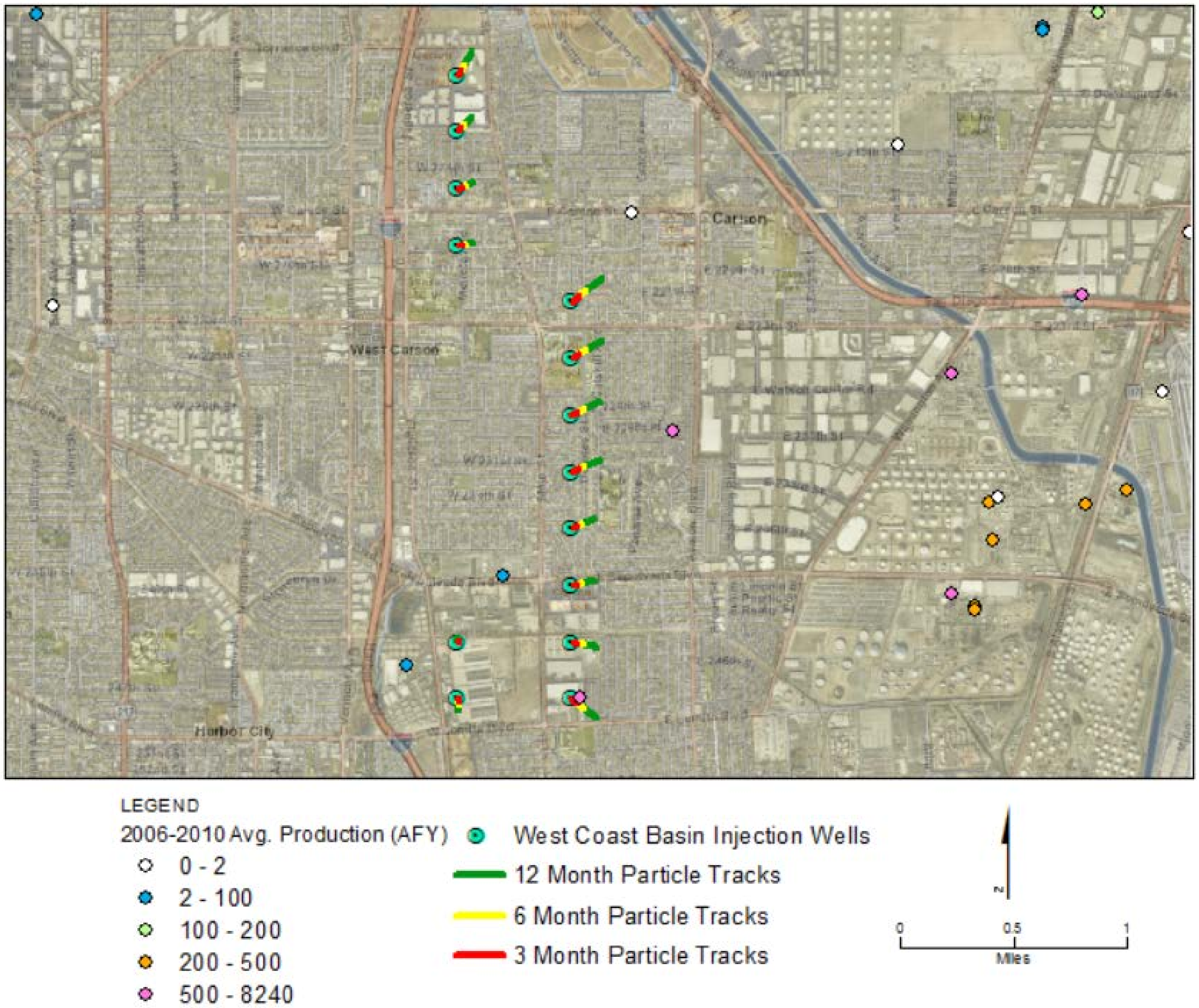


Figure 23. Alternative 3a Particle Tracking Results--Los Angeles Forebay Area

3.5 Alternative 3b Modeling Results

This section summarizes results of the Alternative 3b simulation. Results are presented below in conjunction with both the Baseline and Alternative 3a modeling results, to facilitate evaluation of the changes due specifically to Alternative 3b. Alternative 3b builds off of Alternative 2b by adding 15,000 afy of injection in Carson, with an equivalent 15,000 afy of extraction from West Coast Basin wells. The additional West Coast Basin pumping is primarily located near the Carson injection; 14,000 afy of the additional West Coast Basin pumping is from wells within 2.5 miles of Carson injection wells.

3.5.1 Change in Simulated Groundwater Levels

This section summarizes the projected change in water levels in response to Alternative 3b injection and extraction. Results are summarized both spatially and temporally in Figures 24 through 25. Similar to Alternative 3a, model results suggest that, in the Carson area, the groundwater table would rise by 24 feet after 40 years, while hydraulic head in the injection zone (i.e., model layers 3 and 4) would rise by approximately 34 feet. The water level rise is non-linear, with the bulk of the water level rise occurring in the first 10 years (Figure 25b). Simulated historical water levels in the Carson area have fluctuated over a range of about 50 feet, with a minimum simulated depth to water in the Baseline of about 80 feet. Accordingly, a 34-foot water level rise could likely be accommodated in this area.

Regionally, model results suggest that there is very little change in water levels from Alternative 2b. The biggest change is at the injection well field, with a maximum water level rise of about 24 feet due specifically to Alternative 3b.

Because there is very little change in water levels elsewhere in Alternative 3b, relative to Alternative 2b, the same conclusions from Alternative 2b apply: 1) Long Beach injection could likely be accommodated, and 2) drawdown near City of Inglewood's and Golden State Water Company's well fields is estimated to be up to about 35 feet.

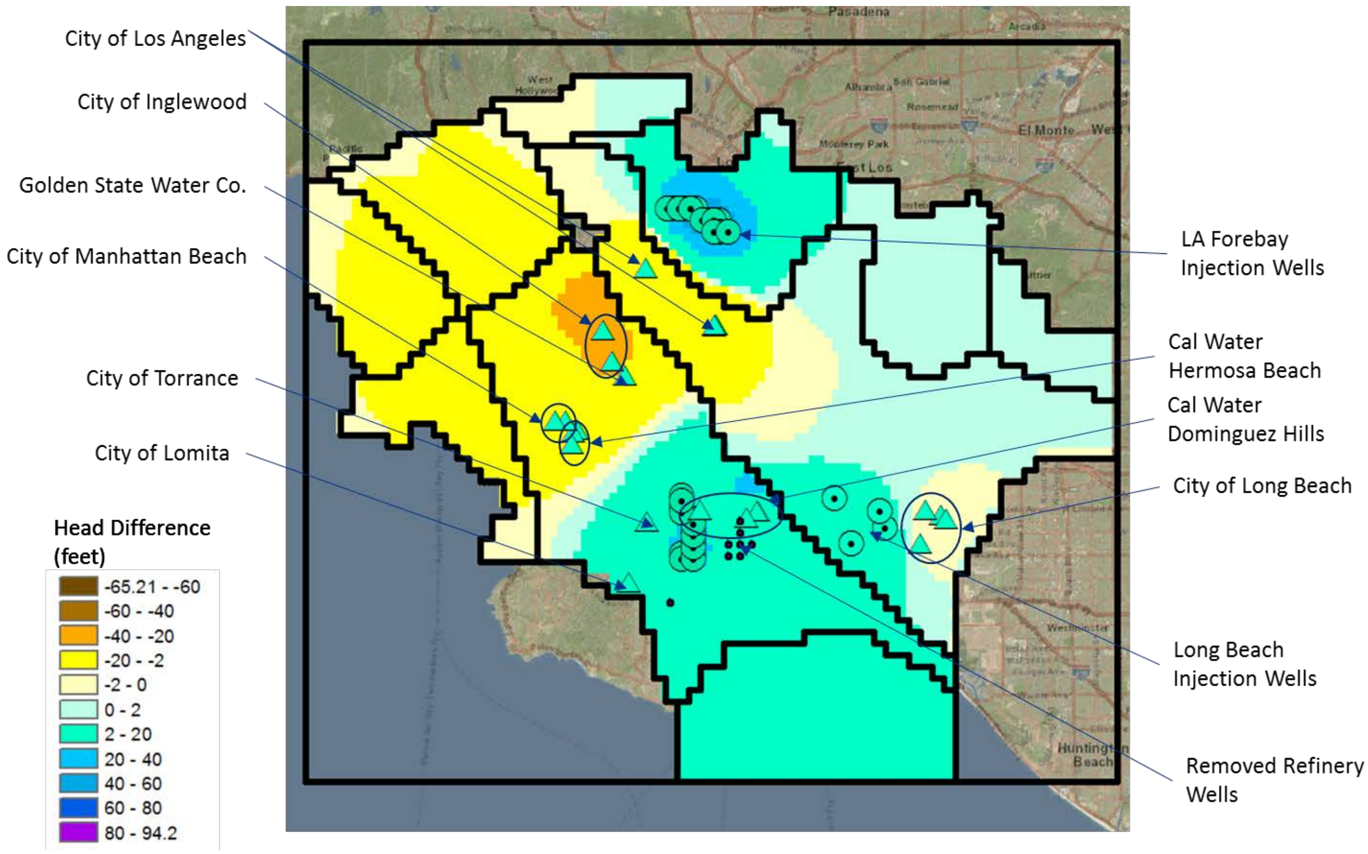


Figure 24a. Simulated Head Differences in the Injection Zone Between the Baseline and Alternative 3b at 30 Years

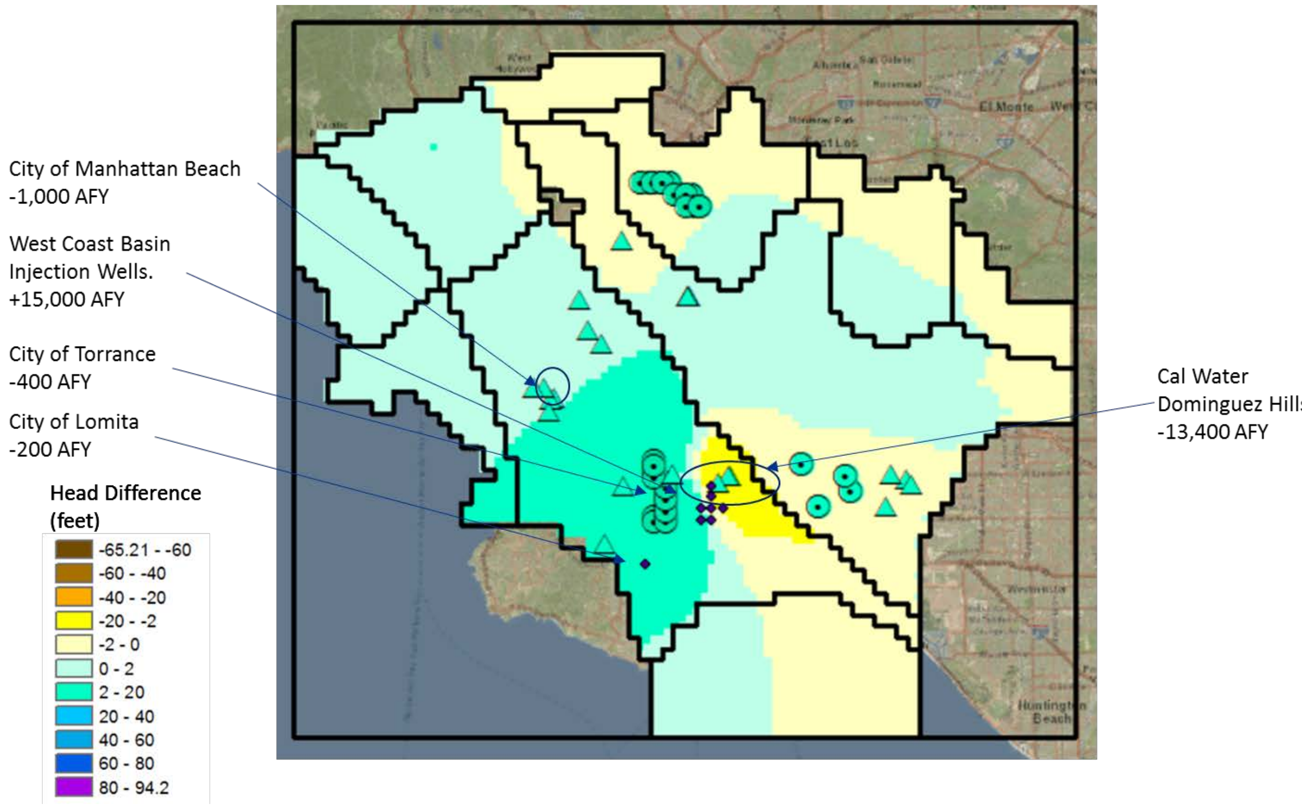


Figure 24b. Simulated Head Differences in the Injection Zone Between Alternative 3b and Alternative 2b at 30 Years

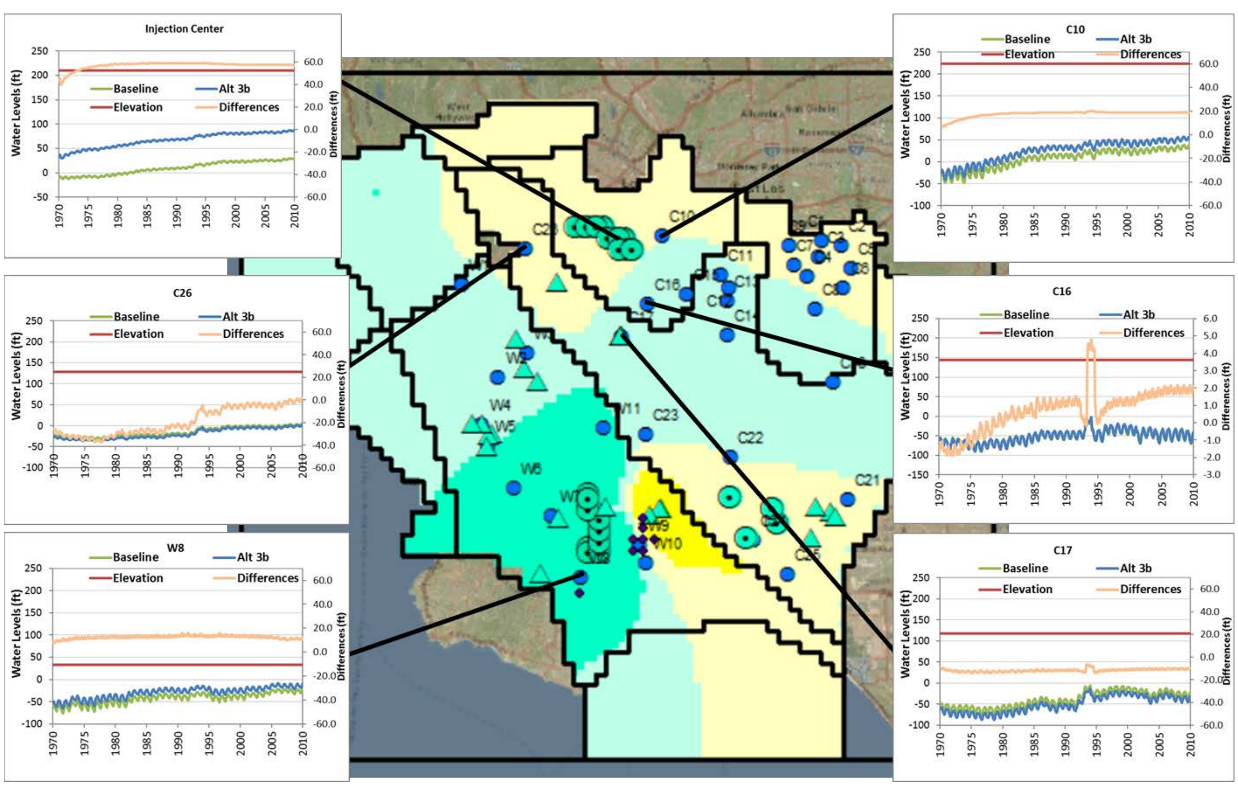


Figure 25a. Changes in Groundwater Levels: Differences Between Alternative 3b vs. Alternative 2b (Base Map), and Between Alternative 3b and Baseline (Time Series Plots)

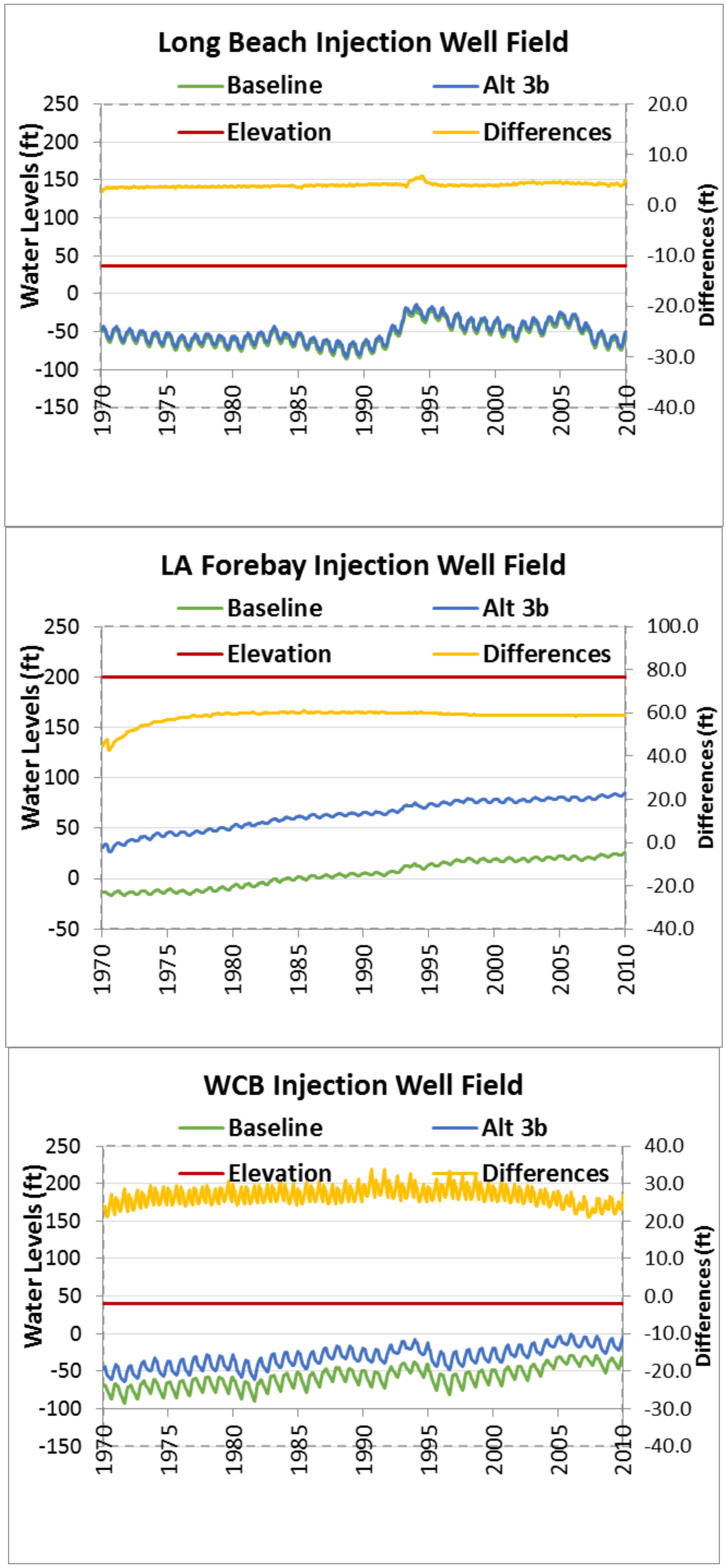


Figure 25b. Changes in Groundwater Levels: Baseline Modeling vs. Alternative 3b Scenario

3.5.2 Change in Simulated Water Budget

Changes in the simulated water budget and storage are shown on Figures 26A-26C. The water budget of the Baseline model (Figure 26A) is followed by the change in water budget due to Alternative 3b (Figure 26B) and the cumulative change in storage due to Alternative 3b (Figure 21C). As can be seen on Figure 21B, there is 29,000 AFY of additional injection and additional pumping in all years. The additional 15,000 AFY of injection and pumping, as compared with Alternative 2b, is from the addition of Carson injection and an equivalent rate of increased pumping from the West Coast Basin. There is an additional 11,766 afy, on average, of transferred pumping (reduced pumping at refineries, increased pumping in West Coast Basin), also consistent with Alternatives 1, 2a, and 2b.

In addition to the change in pumping and injection, there is a net change in boundary flows that causes a net change in storage. A basin-wide cumulative surplus of about 20,000 AF is simulated at the end of the simulation period for Alternative 3b (Figure 26C), or an average of about 500 AFY. There is no significant change in water budget as compared with Alternative 2b, both through time (compare Figure 26C with Figure 16C) or space (compare Figure 27 to Figure 17). As with Alternative 2b, minor changes to the seawater intrusion barrier operations may be required to mitigate the changes in flows to/from offshore.

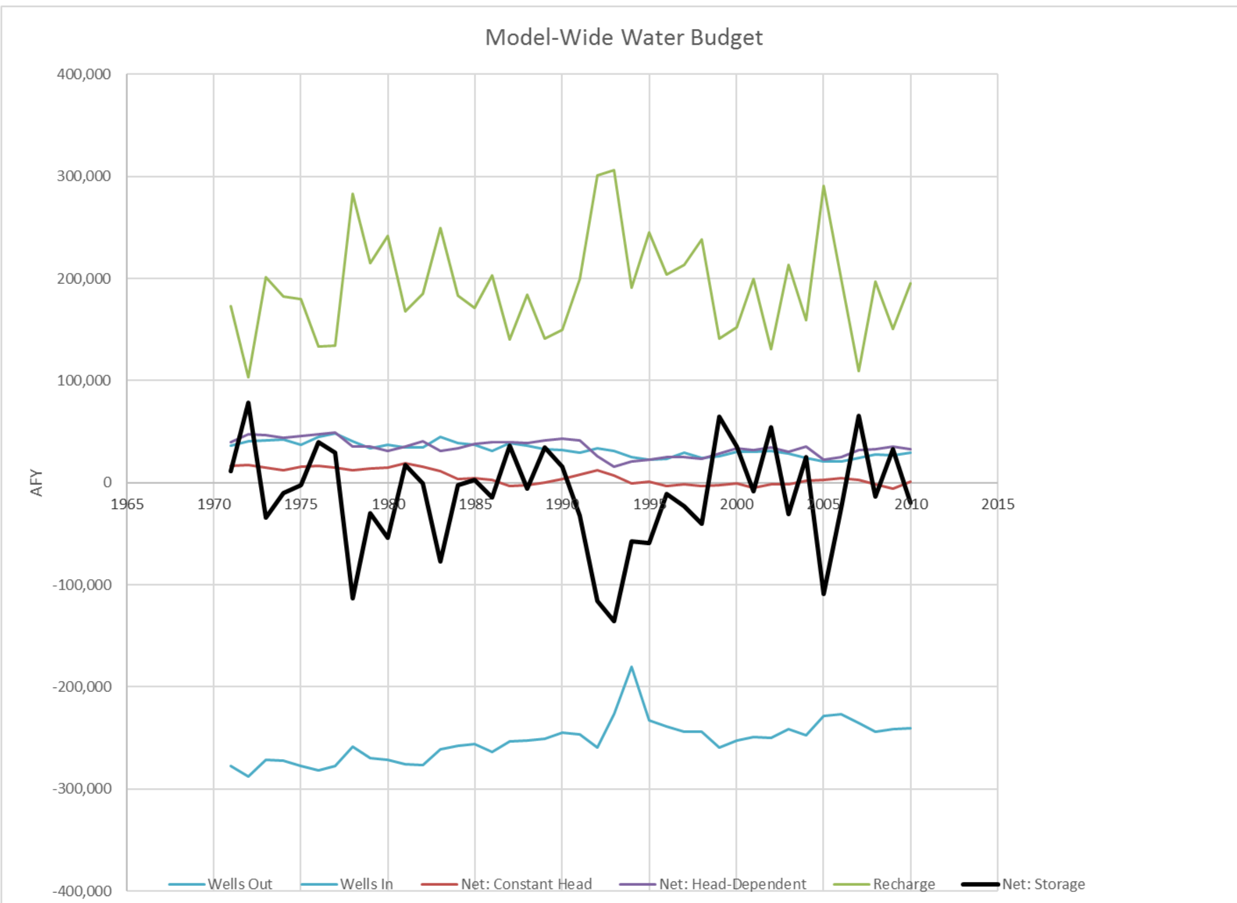


Figure 26A. Comparison of Water Budget: Alternative 3b vs. Baseline Scenario - *Baseline Model Water Budget*

Figure 26B. Comparison of Water Budget: Alternative 3b vs. Baseline - *Change in Water Budget due to Alternative 3b*

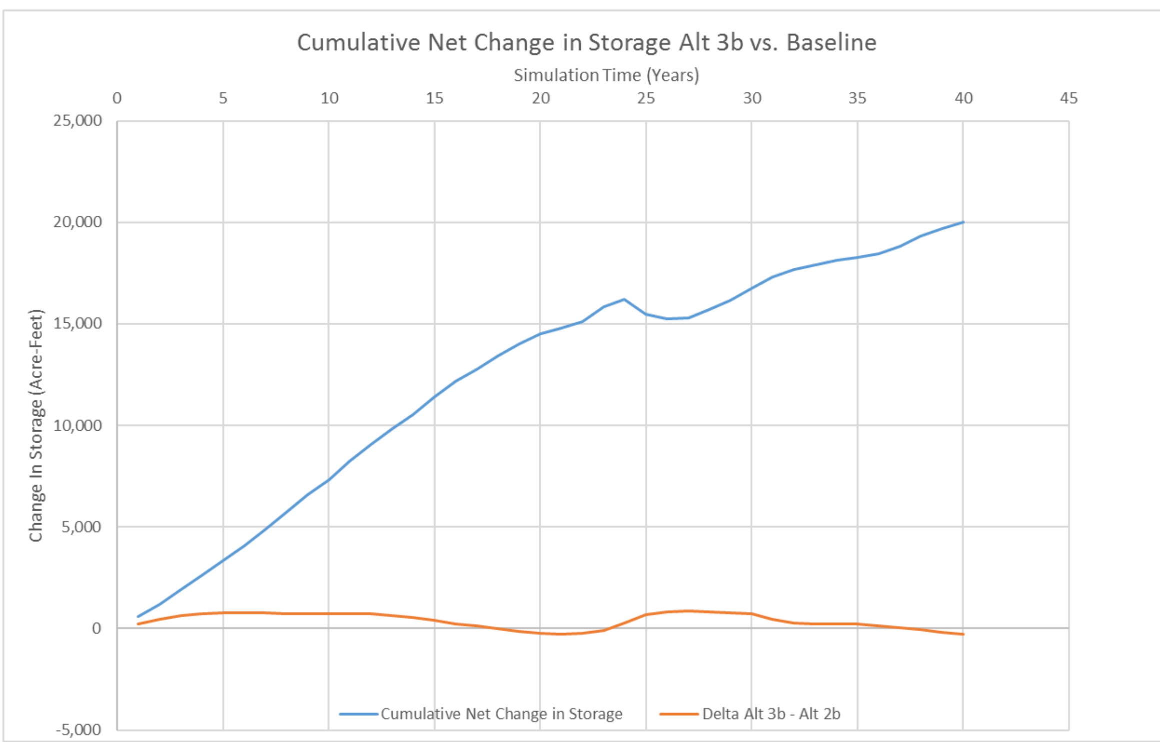


Figure 26C. Comparison of Water Budget: Alternative 3b vs. Baseline - *Cumulative Change in Storage due to Alternative 3b (Alternative 3b minus Baseline)*[11]

[11] Refer to footnote to Figure 6c.

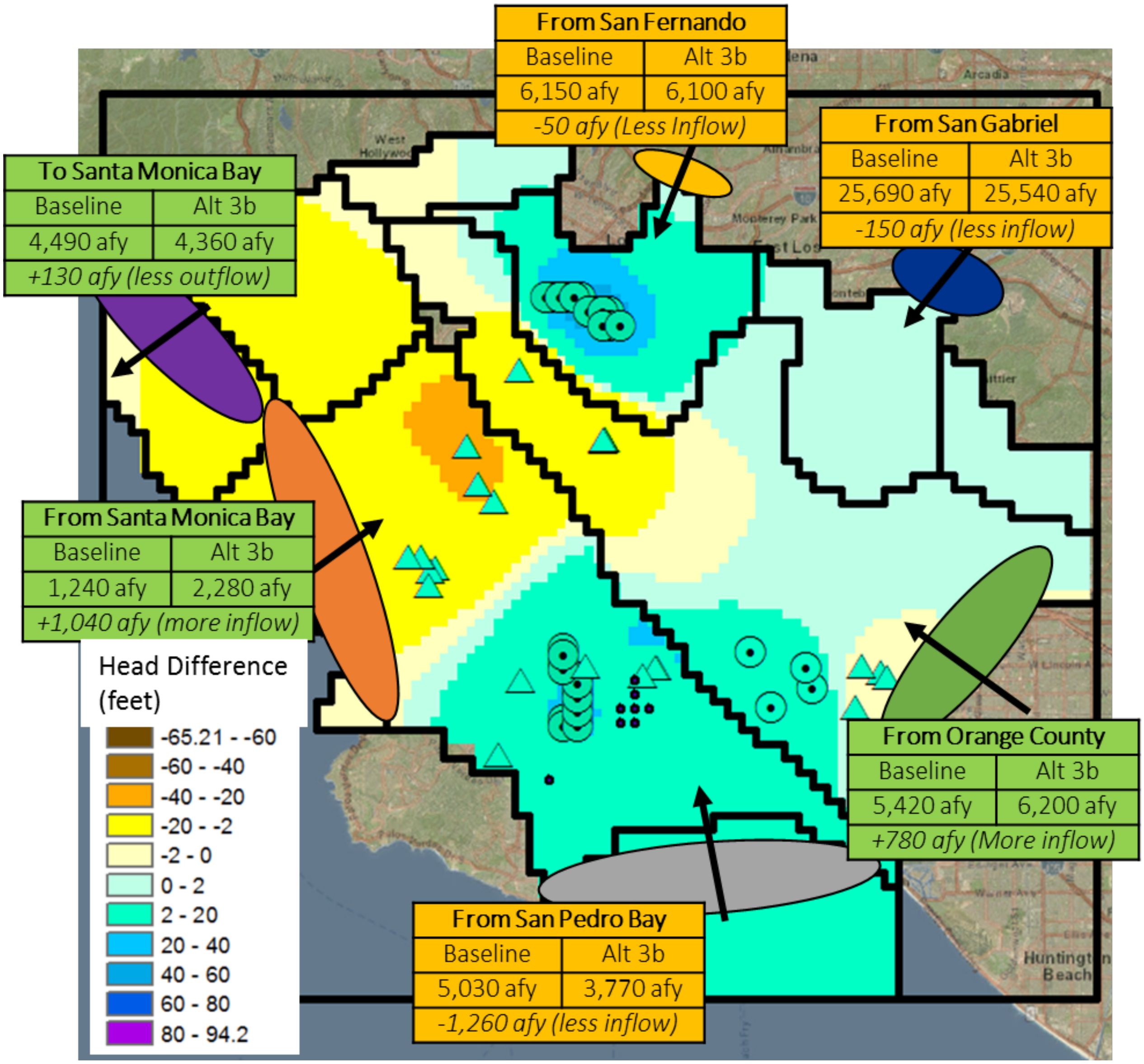


Figure 27. Alternative 3b Water Budget Change at Boundary Conditions

3.5.3 Travel Time Using Particle Tracking

Particles were not run from the Long Beach or LA Forebay injection wells for Alternative 3b, because both pumping and injection in those areas are the same as in Alternative 1 (in which the Long Beach pumping/injection is the same), and in Alternative 2b (in which both the Long Beach and Montebello Forebay pumping/injection are the same). Therefore, the results of such particle tracking for Alternative 2a would be nearly identical to those shown on Figures 8 and 18.

However, particles were run for the Carson (West Coast Basin) injection wells for Alternative 3b despite pumping/injection being identical to that in the same area in Alternative 3a. Figure 28 shows the particle tracks that were initiated at the Carson area injection wells for Alternative 3b. The results are nearly identical to those from Alternative 3a (Figure 23). Particles here travel relatively short distances, again of relatively low hydraulic conductivity in the area. The modeling suggests that one high capacity well may be impacted, but the injection well that causes the impact in the simulation could be readily relocated to a safer distance.

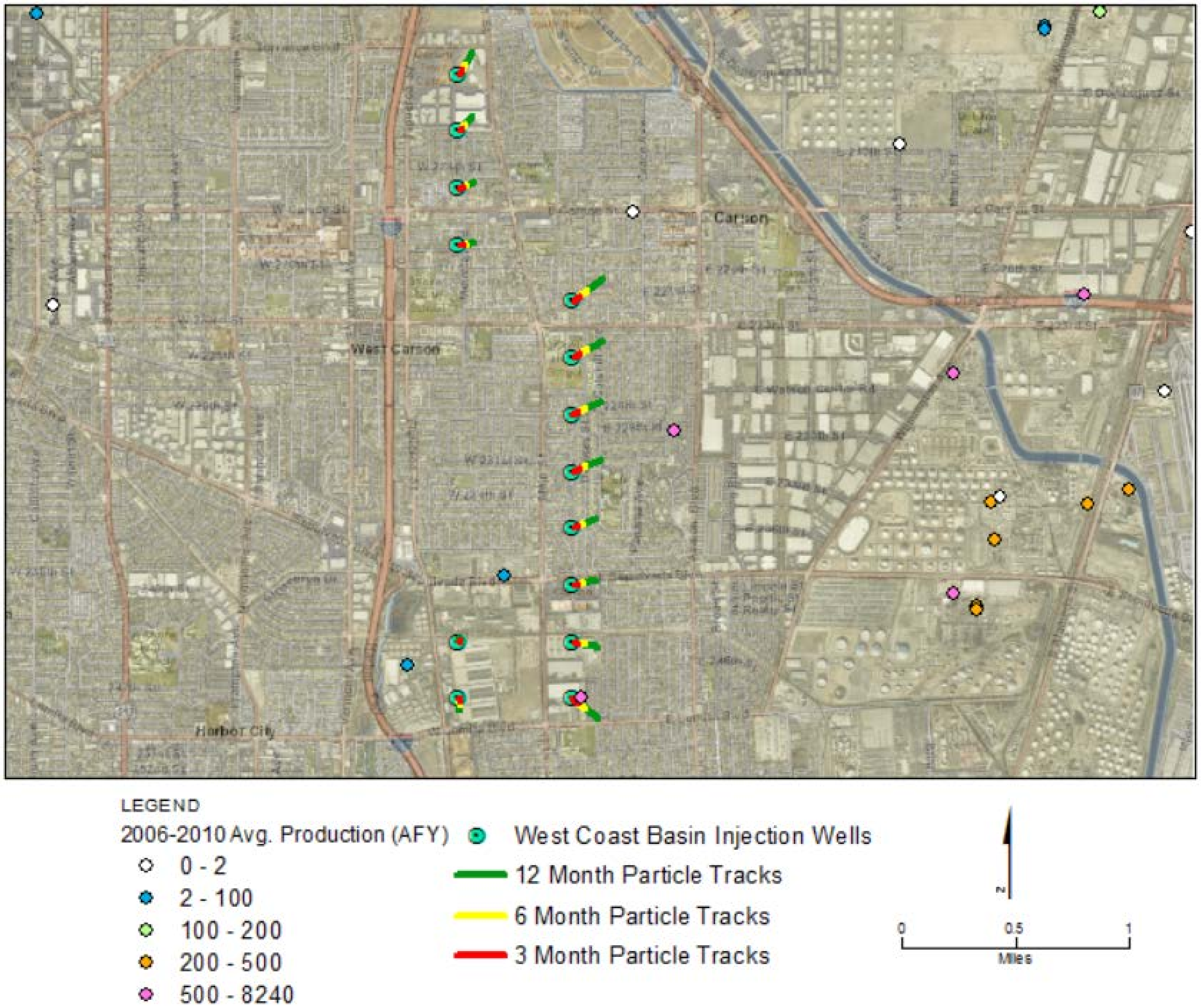


Figure 28. Alternative 3b Particle Tracking Results--Los Angeles Forebay Area.

4.0 Summary and Conclusions

Major results from the modeling of recharge from Metropolitan's Reuse Program are summarized in Table 2. Key conclusions are as follows:

- Water level rise due to injection
    - Long Beach area: Predicted water level rise in the Long Beach injection area could likely be accommodated, in all alternatives.
    - Carson area: Predicted water level rise in the Carson injection area could likely be accommodated in Alternatives 3a and 3b, the only alternatives evaluated with Carson injection
    - MFSG (Alternatives 2a and 3a): Alternatives 2a and 3a predicts a water table rise that could limit the recharge capacity of the MFSG in the Central Basin during periods of high water levels.

  - LA Forebay (Alternatives 2b and 3b): Predicted water level rise in the LA Forebay area could likely be accommodated in Alternatives 2b and 3b.
- Water level decline in response to pumping
  - Without Metropolitan's project, a 10-foot decline in water level in the vicinity of the City of Los Angeles' and City of Inglewood's well fields is predicted.
  - Additional water level declines near the City of Los Angeles' and City of Inglewood's well fields resulting from Alternatives 2a and 3a (with Montebello Forebay injection) are projected to be about 67 feet. In Alternatives 2b and 3b, with injection closer to the drawdown areas, drawdown is limited to about 35 feet. Additionally, the extent of drawdown is much smaller in Alternatives 2b and 3b where drawdown to the north and northeast is mitigated by the injection in the LA Forebay.
- Effect on Boundary Flows
  - In Alternatives 2a and 2b, a cumulative storage deficit of over 100,000 acre-feet was simulated, mostly caused by reduced inflow from the San Gabriel Basin in response to injection in the Montebello Forebay.
  - In all alternatives, there is some change in groundwater flow to/from the Pacific Ocean. Minor changes to the seawater intrusion barrier operations may be required to mitigate the changes in flow to/from offshore.
- Travel times to production wells
  - Travel times to production wells in the vicinity of the injection wells are generally longer than 3 months. Where simulated travel times are less, it is likely that injection wells could be relocated to maintain travel times to production wells in excess of 3 months.
  - There are no production wells within reach after 12 months of particle tracking from the Long Beach injection wells. However, there is a production well known to be within ¼-mile of one of the proposed injection locations, and the model with its ½-mile grid may lack sufficient resolution to properly simulate transport at such close quarters.
  - There are three production wells within reach of the 12-month particle tracking from the Montebello Forebay injection wells.
  - There are no production wells within reach of the 12-month particle tracking from the LA Forebay injection wells
  - There is one production within reach of the 3-month particle tracking from the Carson injection wells. At this location, the injection well could be relocated farther away.

Table 3. Summary of Key Modeling Results for the Five Alternatives

		Alternative 1	Alternative 2A	Alternative 2B	Alternative 3A	Alternative 3B	Notes
Maximum drawup (ft), injection zone, Layer 3	Long Beach	6	6	6	6	6	
	Montebello Forebay		9		8		where drawup noted, could limit spreading basin capacity
	LA Forebay			60		60	
	Carson				33	34	
Maximum drawup (feet), water table, Layer 1	Long Beach	6	6	6	6	6	
	Montebello Forebay		7		8		where drawup noted, could require pressurized wellheads to account for pressure above land surface
	LA Forebay			40		40	
	Carson				24	24	
Estimated zone of influence (feet), after 3-months (based on modeled 5 percent porosity)	Long Beach	140	a	a	a	a	
	Montebello Forebay		690		a		
	LA Forebay			120		a	
	Carson				190	190	
Number of production wells possibly reached within 12 months	Long Beach	0	a	a	a	a	
	Montebello Forebay		3		a		
	LA Forebay			0		a	
	Carson				1	1	
Water Level Decline	Los Angeles and Inglewood area	34	67	24	67	24	
Boundary effects	Reduced inflow from San Gabriel (afy)	n/a	3,000	n/a	3,000	n/a	
	Change in offshore boundary flows, potentially affecting seawater intrusion barrier operations (positive is increased inflow)	-380	+110	-140	-200	-360	

[a]Particle tracks were not run for this injection well field in this simulation, but it is assumed that the results would be similar to other alternatives with identical local pumping and injection.

*Note that these results are based on the assumed model porosity of 5 percent. Effective porosity could be higher, which would result in shorter travel distances.

If additional and more refined analyses are needed, CH2M recommends consideration of the following refinements to the modeling process:

- Adjust the pumping locations in the groundwater model to more accurately reflect their physical locations.

- Refine the model grid in the vicinity of the injection projects to enhance the mounding that is directly calculated in the model and the particle trace simulations.
- Consider real-world factors in the refinement of injection well locations, including proximity to production wells, depth to water, transmissivity, contamination, land use and access.
- Extend the historical model hydrology to include data beyond 2010.
- Focus on the more recent 20 years of historical basin conditions with higher water levels.
- For the LA Forebay area, evaluate accuracy of simulated transmissivity, and modify the transmissivity assumptions in the model as necessary.
- Convert the model from MODFLOW-'88 to MODFLOW-NWT, in order to take advantage of the newer model code's capability to better handle wetting and drying of model cells, multi-layer wells that automatically reroute pumping to lower layers as upper ones go dry, and a much more robust solver that should prevent the convergence problems.
- Add seasonally variable natural recharge (mountain-front recharge and deep percolation of precipitation).
- Reassess the seasonal variability of groundwater elevations once the simulated recharge has been refined, and identify and analyze real (measured) hydrographs of monitoring wells near the LA Forebay, Long Beach area, and Carson area injection projects.
- Better understand effective porosity values to enhance travel time estimates.

5.0 References

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Appendix F-3:

Phase II Computer Model Flow and Transport Simulations to Evaluate Impacts of Indirect Potable Reuse Water Replenishment from the MWD Carson Project Delivery to the Main San Gabriel Basin

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MEMORANDUM

TO: Mr. Tony Zampiello
Main San Gabriel Basin Watermaster

FROM: Stetson Engineers Inc.

SUBJECT: Phase II Computer Model Flow and Transport Simulations to Evaluate Impacts of Indirect Potable Reuse Water Replenishment from the MWD Carson Project Delivery to the Main San Gabriel Basin

DATE: May 25, 2018

JOB NO: 1205-1718:098-05.2.6

INTRODUCTION

The Main San Gabriel Basin (Main Basin), located in eastern Los Angeles County, California is an unconfined groundwater system with a total area of approximately 167 square miles as shown on Figure 1. The total groundwater storage capacity of the Main Basin is estimated to be about 10,740,000 acre-feet (AF) (DWR 1975). Despite the large storage capacity, groundwater storage has been continuously decreasing due to the semi-arid climate and groundwater overdraft in the Main Basin. The Main San Gabriel Basin Watermaster (Watermaster) is the court-appointed agency that administers water rights and manages groundwater resources within the Main Basin. Long-term supplemental water supply reliability in the Main Basin, such as untreated imported water or recycled water for indirect groundwater replenishment is essential to management of the Main Basin. .

The Metropolitan Water District of Southern California (MWD) is partnering with the County Sanitation Districts of Los Angeles County (CSD) to investigate the viability of providing Full Advanced Treatment for up to 150 million gallons per day (MGD) [approximately 168,000 acre-feet per year (AFY)] from CSD's Joint Water Pollution Control Plant in Carson, California (Carson Plant). The recycled water from the Carson Plant would then be placed into transmission pipelines for Indirect Potable Reuse (IPR) by replenishing the IPR water into various groundwater basins within MWD's service area, including the Main Basin. The benefits of groundwater replenishment with IRP water would not only provide long-term water supply reliability, but also improve the existing groundwater quality and reduce reliance on the less reliable untreated imported water from the State Water Project (SWP) and/or the Colorado River.

The IPR Water Replenishment Study (Study) is a numerical investigation to evaluate the feasibility of using IPR water to replenish the Main Basin. Three-dimensional (3D) numerical modeling was performed to assess the feasibility of the Main Basin receiving IPR water for up to 77.5 million gallons per day (MGD) [approximately 86,800 acre-feet per year (AFY)] from CSD's Carson Plant. This Technical Memorandum (TM) presents and discusses the modeling tasks performed in this Phase II Study. Results of the modeling study improve the understanding of the capacities of the recharge facilities and the Main Basin to receive the IPR water as well as the potential impacts of the IPR water to groundwater quality within the Main Basin and the existing United States Environmental Protection Agency (USEPA) Superfund Cleanup Programs, and particularly the Baldwin Park Operable Unit (BPOU). It should be noted the production, delivery, and use of recycled water for drinking water supplies are subject to various regulatory requirements by the State Water Resources Control Board (SWRCB), Division of Drinking Water (DDW) and the Regional Water Quality Control Board (RWQCB); however, the regulatory requirements are outside the scope of the project and will not be discussed.

BACKGROUND

MWD initiated the Study to evaluate the feasibility of replenishing IPR water at the Santa Fe Spring Grounds (SFSG) and nearby spreading grounds. On May 26, 2016, MWD issued Task Order No. 1 of Agreement No. 1600069 with Watermaster to conduct the Phase I Study. The main objective of the Phase I Study was to evaluate sustainable quantities of IPR water that could be delivered to the Main Basin for groundwater recharge and extraction. Watermaster directed its consulting engineer to perform the study using Watermaster's existing two-dimensional San Gabriel Basin Flow Model (2D Basin Model) to evaluate sustainable quantities of IPR water that can be delivered to the Main Basin under different operating scenarios. Results of the study indicated the Main Basin storage capacity and groundwater water levels were within the basin manageable limits under a long-term constant delivery of 65 million gallons per day (MGD) of IPR water which is approximately 72,800 AFY. Details of the modeling results were documented in the TM entitled, "***Evaluation of Replenishment of Sustainable Quantities of MWD Indirect Potable Reuse Water Delivered to the Main San Gabriel Basin from the Joint Water Pollution Control Plant at Carson, California***", dated September 29, 2016.

Following the completion of Task Order No. 1 (Phase I Study), MWD staff met with Watermaster staff on September 5, 2017, to coordinate a Scope of Work (SOW) for the Phase II Study to further evaluate the replenishment of the IPR water in the Main Basin. Agreement No. 160069, Task Order No. 2, was reached between MWD and Watermaster on October 19, 2017, regarding the additional studies, and a copy of Agreement 160069, Task Order No. 2, is included as Attachment A. The Phase II Study used Watermaster's 3D groundwater model and a 32-year model simulation period into the future starting from Fiscal Year (FY) 2015-16 to evaluate the impacts of IPR water on groundwater storage and water quality. The overall goals of the modeling tasks performed under Task Order No. 2 are to improve the understanding of the Main Basin to receive the IPR water and to evaluate the potential impacts to groundwater quality and the existing USEPA Superfund Cleanup Programs within the Main Basin.

Because of the increasing technical complexities involved in Phase II modeling work, it was agreed the Watermaster's newly developed 3D MODFLOW-based San Gabriel Basin Model (3D Basin Model), the United States Geological Survey (USGS) 3D Transport Multi-Species (MT3D) model (MT3D-USGS, Bedekar et al., 2016), and the USGS MODPATH (Pollock, 2016) post-processing program were used for the feasibility study, which included groundwater flow simulations, solute transport simulations, and particle tracking analysis. The work under Task Order No. 2 consists of seven (7) Sub-Tasks. Details of previous work (Sub-Task from No. 2.1 through No. 2.5) were documented in the following draft technical memoranda and will be briefly discussed and cited later.

1. Sub-Task No. 2.1 "***Main Basin Groundwater Production Projection***", dated November 1, 2017;
2. Sub-Task No. 2.2 "***Watermaster Three-Dimensional San Gabriel Basin Flow Model Recalibration***", dated November 16, 2017;
3. Sub-Task No. 2.3 "***Watermaster Three-Dimensional San Gabriel Basin Flow Model Sub-Task No. 2.3: Model Run I – Baseline Delivery of 39 MGD***", dated February 20, 2018; and
4. Sub-Tasks No. 2.4 and No. 2.5 "***Watermaster Three-Dimensional San Gabriel Basin Flow Model Sub-Task No. 2.4 Model Run II – Baseline Sustainability and Sub-Task No. 2.5 Model Run III – Augmented Basin Sustainability***", dated April 9, 2018.

STUDY OBJECTIVES

Groundwater, surface water, and imported water are generally the main sources of water supply in the Main Basin. Watermaster has managed the Main Basin on the basis there will be long-term supplemental water supply reliability to the Main Basin. An understanding of the amount of IPR water replenishment that can be applied, the potential impacts to Main Basin water quality, and the possible impacts to the existing Superfund Site Cleanup Programs within the Main Basin need to be evaluated. The main objective of the Phase II Study was to provide a quantitative assessment of the impacts from the long-term delivery of IPR water to the Main Basin. The assessment included evaluations of the ability of the Main Basin to receive the IPR water, potential migration of the replenished IPR water, , and potential impacts to USEPA's Superfund

Cleanup Programs within the Main Basin under long-term constant IPR water delivery. The Phase II Study included the following tasks:

1. **Quantify Projected Groundwater Demand in Main Basin** (Sub-Task No. 2.1). Groundwater production from each well within the Main Basin for the projected 32-year simulation will be quantified and applied to the 3D Basin Model.
2. **Fine-Tune 3D Basin Model** (Sub-Task No. 2.2). Recalibration of the 3D Basin Model will be performed mostly in the areas significantly impacted by the IPR water replenishment.
3. **Model Run I – Baseline Delivery of 39 MGD** (Sub-Task No. 2.3). The Main Basin receives a long-term average replenishment demand of about 39 MGD (approximately 43,250 AFY). Model Run I evaluates the impacts from the long-term replenishment demand (39 MGD) into the future in the Main Basin.
4. **Model Run II – Basin Sustainability 62.5 MGD** (Sub-Task No. 2.4). A further evaluation of the capacity of the spreading facilities and groundwater basin to receive the IPR water at a quantity greater than the long-term imported replenishment demand.
5. **Model Run III – Augmented Basin Sustainability 77.5 MGD** (Sub-Task No. 2.5). A continuous evaluation of the capacity of the spreading facilities and groundwater basin to receive the IPR water at a higher quantity than the replenishment rate used in Model Run II. However, the 15 MGD of additional IPR water can be offset with 15 MGD pumping from the Main Basin to the Raymond Basin, Six Basins and Puente Basin.
6. **Preparation of Technical Memorandum** (Sub-Task No. 2.6). A Technical Memorandum will be prepared which summarizes all tasks covered under Agreement Task Order No. 2.

STUDY AREA AND GENERAL HYDROGEOLOGY

The 3D Basin Model study area mainly consists of the Main Basin with a total area of 167 square miles. The 3D Basin Model study area is shown on Figure 1. The physical boundaries of the 3-D Basin Model are shown on Figure 2, including the Raymond fault to the northwest, the San Gabriel Mountains to the north, the exposed consolidated rocks of the Repetto, Merced, and Puente Hills to the south and west, and the Chino fault and San Jose fault to the east.

The Main Basin is generally an unconfined, water-bearing groundwater basin which is underlain and surrounded by relatively impermeable rock. Depth to the water table varies significantly in the Main Basin. Because of the shallow depth to water in the Whittier Narrows area, rising water (groundwater seepage to land surface) may occur during wet hydrologic conditions. Hydraulic conductivity and specific yield are two key properties which describe groundwater movement. The overall hydraulic conductivity in the Main Basin may range from less than 1 ft/day to over 1,000 ft/day, and the specific yield may range from 10 to 25 percent depending on the subsurface materials.

The primary groundwater discharge in the Main Basin is groundwater pumping. Other groundwater discharges may include subsurface outflow in the Whittier Narrows, seepages to surface water bodies (rising water), and evapotranspiration (ET); however, the quantities of these discharge mainly depend on groundwater conditions. The sources of recharge include precipitation, spreading activities, irrigation return flow, and seepage from surface water bodies. Similarly, the quantities of these recharge components depend on hydrologic conditions, the amount of replenishment water each year, and groundwater conditions.

The SFSG located within the Santa Fe Dam reservoir and spillway areas is operated by the Los Angeles County Department of Public Works (LACDPW). It is situated in a high-permeability aquifer area and has the highest recharge capacity (approximately 16,500 acre-feet per month) among the spreading basins within the Main Basin to receive local stormwater runoff, streamflows from Morris Reservoir, and untreated imported water. The Santa Fe Dam spillway area (Spillway) is located adjacent to the southwest edge of the SFSG. The recharge capacity of the Spillway is expected to be similar to the SFSG due to its similar size and hydrogeological features to SFSG. Locations of the SFSG, Spillway, and the nearby spreading grounds are show on Figure 3.

GROUNDWATER MODEL DESCRIPTIONS

The MODFLOW-based (Harbaugh 2005) 3D Basin Model and the UGSG MT3DUSGS transport model were the main numerical tools used for flow and solute transport simulations, respectively, to evaluate groundwater responses under various groundwater replenishment scenarios. The USGS MODPATH model was used for particle tracking analysis to identify the potential impacted wells. A modeled 32-year period (between FY 2015-16 and FY 2046-47) was performed with quarterly stress periods to evaluate the regional flow conditions in the Main Basin and chemical constituent migration from the SFSG to the vicinity and downgradient of the SFSG areas. Groundwater flow simulations were performed based on the projected groundwater demand (performed in Sub-Task No. 2.1) and three (3) constant IPR water replenishment scenarios (39 MGD, 62.5 MGD, and 77.5 MGD) at the SFSG, Spillway, and/or nearby spreading facilities; solute transport simulations were conducted to simulate the chemical constituents in the IPR water. Particle tracking analysis was performed to calculate IPR water travel time and to identify the potential impacted wells.

MODFLOW-2005: Groundwater Flow Simulation

The 3D Basin Model was developed using the USGS MODFLOW-2005 to perform the regional transient groundwater flow simulations. Conceptualization, development and calibration of the 3D Basin Model was discussed and summarized in the TM entitled, "***Sub-Task No. 2.2: Watermaster Three-Dimensional San Gabriel Basin Flow Model Recalibration***", dated November 17, 2017 (Stetson, 2017b). The 3D Basin Model divides the Main Basin into seven (7) model layers to represent the shallow, upper and lower intermediate, and lower aquifers, as well as three (3) semi-confined units to separate the overlying and underling aquifers. The extent and approximated elevations of each layer are shown on Figure 4. The 3D Basin Model was originally calibrated from FY 1973-74 to FY 2014-15. For Phase II Study purposes, the calibrated 3D Basin Model was fine-tuned (recalibrated) for better presentation of the local groundwater in the areas impacted by the Carson IPR water prior to modeling replenishment of the IPR water in the Main Basin. The calibrated horizontal and vertical hydraulic conductivity are shown on Figures 5 and 6, respectively. In addition, spatial distributions of the calibrated specific yield of each model layer are shown on Figure 7.

The fine-tuned 3D Basin Model was applied to simulate the future 32-year groundwater conditions (FY 2015-16 through FY 2046-47) based on the projected groundwater demand and the constant replenishment (39 MGD, 62.5 MGD, and 77.5 MGD) at the SFSG and/or Spillway, and the nearby spreading grounds if the SFSG capacity is exceeded. The 32-year simulation period was separated into 128 quarterly stress periods to accommodate the change of groundwater inflow and outflow components within each stress period. The starting heads and model required parameters were imported from the fine-tuned 3D Basin Model. Results of the flow simulations were used as the basis for the transport simulations and particle tracking analysis.

MT3D-USGS: Solute Transport Simulation

The solute transport simulation was performed using the USGS MT3D-USGS model (Bedekar et al., 2016), which is an updated release of the MT3DMS (Zheng, 2010), for the simulation of advection and dispersion of potential dissolved constituents in groundwater. It should be noted that the IPR water is highly purified water that has undergone multiple treatment processes including Reverse Osmosis (RO) to improve water quality for potable purposes. A groundwater basin receiving this highly purified IPR water will generally improve its current water quality. However, for the project purpose, investigations of the long-term IPR water plume migration in the Main Basin were performed under the assumption that the IPR water for groundwater replenishment may contain chemical constituents (e.g., boron). Plume migration in groundwater is chemical dependent, and the migration pathways are highly dependent on the characteristics of the constituents. Despite many other factors that may affect plume migration, two (2) major factors, groundwater flow (advection) and mixing process (a result of the change of concentration gradient), were considered to simulate constituent movement in groundwater. In addition, the solute transport simulations performed herein were considered as the worst-case scenario under the assumption that the simulated constituent with the maximum concentration was constantly applied to the top layer of the 3D Basin Model at the SFSG for the entire simulation period (FY 2015-16 to FY 2046-47). The maximum concentration of one (1) is a normalized concentration on a scale of zero (clean water) to one (maximum concentration) to represent the general constituent contained in the IPR water.

MODPATH: Particle Tracking Simulation

The particle tracking simulation was performed using the USGS MODPATH code (Pollock, 2016). Generally, MODPATH is a particle tracking postprocessing program to calculate groundwater flow path based on the simulated groundwater flow gradient from MODFLOW; therefore, travel time of the IPR water and plume can be estimated. A local groundwater mound will form during periods of high IPR water recharge at the SFSG spreading area. The increasing hydraulic pressure due to the rise of groundwater mounding causes the IPR water to migrate in a radial pattern away from the SFSG spreading area. Dilution of the IPR water with the existing groundwater is a function of travel time and distance. As time progresses, dilution of the IPR water continues as the IPR water migrates downgradient. The flow path and travel distance of the IPR water was generated by MODPATH for graphic presentation. Results of particle tracking simulation were used to identify the potential impacted wells and to determine the percent recycled water in each well.

GROUNDWATER MODEL SIMULATION ASSUMPTIONS

Groundwater modeling requires various simplified assumptions to describe groundwater movement; therefore, results from model simulations are subject to uncertainties due to the assumptions made. Despite the uncertainties involved in the numerical model, the 3D Basin Model was conceptualized to describe the major hydrogeologic features; to specify appropriate initial conditions and boundary conditions; and to identify known inflow and outflow components for a reasonable representation of the Main Basin's groundwater system. In addition, calibration of the 3D Basin Model was properly performed to ensure the simulated results agree with measured conditions. In other words, the model simulated results reasonably match the conditions observed in the field or estimated by other approaches.

The assumptions associated with the numerical codes used in the modeling work are described in the USGS reports including MODFLOW (Harbaugh 2005), MT3D-USGS (Bedekar et al., 2016), and MODPATH code (Pollock, 2016). Other non-model related assumptions include the following:

- The projected groundwater demands for the predictive simulations were based on an agreed upon approach described in Sub-Task No. 2.1. Because projected production is assumed to be less than historical production, groundwater levels will not decrease as they have in the past and, consequently, should be viewed as conservative. However, the projected groundwater demands may not represent the actual groundwater production in the future. The projected groundwater demands were based on urban water management plan data, may underestimate the actual future production, and are considered as a conservative approach.
- The hydrologic cycle from FY 1983-84 through FY 2014-15 (a total of 32 years), used in the fine-tuned 3D Basin Model, was applied to represent the future hydrologic conditions from FY 2015-16 through FY 2046-47.
- Imported water supplied from the Upper San Gabriel Valley Municipal Water District's (Upper District) USG-3 outlet during the predictive simulation period (from FY 2015-16 through FY 2046-47) was removed from the predictive simulations as required and described in the SOW.
- All Replacement Water deliveries to the Main Basin (including those historically made by San Gabriel Valley Municipal Water District and Three Valley's Municipal Water District) are made with IPR water.
- The simulated groundwater elevations at the end of the fine-tuned 3D Basin

Model were used as the initial groundwater conditions for the predictive simulations.

- Transient simulation was performed to evaluate the potential impacts to the Main Basin's groundwater storage and water quality under three (3) different constant replenishment scenarios, the Baseline Delivery (39 MGD, approximately 43,250 AFY), the Basin Sustainability Delivery (62.5 MGD, approximately 70,000 AFY), and the Augmented Basin Sustainability Delivery (77.5 MGD, approximately 86,800 AFY).
- For the Augmented Basin Sustainability Delivery (77.5 MGD), the withdrawal of 15 MGD of groundwater from the Main Basin to the Raymond Basin and Six Basins/Puente Basin was hypothetically accomplished by pumping a total of 5 MGD of groundwater from the existing production wells for the Raymond Basin and a total of 10 MGD of groundwater was pumped from the existing production wells for the Puente Basin.
- SFSG has a maximum capacity of approximately 16,500 acre-feet (AF) per month, and it is the main spreading ground to receive IPR water and local runoff. If the SFSG capacity is exceeded in any month, the excess water will be delivered and replenished to the Santa Fe Dam spillway area (). However, if the excess water still exceeds Spillway capacity in any month, then Buena Vista Spreading Grounds (BVSGs), Peck Road Spreading Grounds (PRSGs), and/or Hanson Pit are considered to receive the excess water. Locations of the spreading grounds and Spillway are show on Figure 3.
- The size of the Spillway is similar to SFSG, and it is located adjacent to the southwest edge of SFSG. The Spillway capacity is assumed to be limited to 16,500 AF per month.
- Constituents in the transport simulations are treated as solutes. Groundwater flow (advection) and mixing process (a result of the change of concentration gradient) were the only factors considered in the transport simulations. Decay or degradation is not considered.
- The longitudinal dispersivity of 300 feet and the transverse dispersivity of 30 feet were used for solute transport simulations.
- The constituent with constant concentration was continuously applied to the top

layer of the 3D Basin Model at the SFSG for the entire simulation period (FY 2015-16 to FY 2046-47).

PREDICTIVE MODEL SIMULATION SCENARIOS

The predictive simulations were performed using Watermaster's fine-tuned 3D Basin Model to quantitatively and qualitatively evaluate the Main Basin groundwater conditions over the period between FY 2015-16 and FY 2046-47. Responses of the Main Basin due to different IPR water replenishment rates and pumping scenarios were simulated and analyzed under the following eight (8) simulation scenarios.

39 MGD IPR Water "Baseline Delivery"

Scenario 1: Repeat historical production and historical replenishment. Implementation of the IPR water replenishment is not considered. Solute transport simulation was not performed.

Scenario 2: Repeat historical production and implementation of 39 MGD IPR water replenishment (imported water replenishment is excluded). Solute transport simulation was not performed.

Scenario 3: Projected groundwater production (based on Task 2.1, Approach 1 urban water management plan) and repeat historical replenishment. Solute transport simulation was not performed.

Scenario 4: Projected groundwater production (based on Task 2.1, Approach 1 urban water management plan) and implementation of 39 MGD IPR water replenishment (imported water replenishment is excluded). The simulated flow velocity field was used for solute transport simulation.

62.5 MGD IPR Water "Basin Sustainability"

Scenario 5: Projected production (based on Task 2.1, Approach 1 urban water management plan) and implementation of 62.5 MGD IPR water replenishment. The simulated flow velocity field was used for solute transport simulation.

77.5 MGD IPR Water Basin "Augmented Sustainability"

Scenario 6: Projected production (based on Task 2.1, Approach 1 urban water management plan) and implementation of 77.5 MGD IPR water replenishment. Solute transport simulation was not performed.

Scenario 7: Projected production (based on Task 2.1, Approach 1 urban water management plan) and implementation of 77.5 MGD IPR water replenishment. A total of 15 MGD (16,800 AFY) groundwater was pumped to offset the additional 15 MGD of IPR water replenishment. The simulated flow velocity field was used for solute transport simulation.

Scenario 8: Same as Scenario 7 except groundwater production was replaced with the projected production based on regression analysis. Solute transport simulation was not performed.

MAIN BASIN GROUNDWATER DEMAND PROJECTION

Prior to the predictive model simulations, the 32-year groundwater demand for groundwater simulations from FY 2015-16 through FY 2046-47 was estimated. The following two (2) approaches were used to project future groundwater demand:

Approach A

A conservative groundwater demand projection based primarily on projected groundwater production data developed by Upper San Gabriel Valley Municipal Water District, the San Gabriel Valley Municipal Water District, and Three Valleys Municipal Water District as part of their respective Urban Water Management plans. The projected groundwater demand based on this approach is significantly less than the historical production mainly due to water conservation efforts, drought planning, and customer awareness of the need to conserve water.

Approach B

A regression analysis based on the projected population from FY 2015-16 through FY 2030-31 and historical hydrologic condition data from FY 1999-00 through FY 2014-15 in the Main Basin for the projection of future groundwater demand.

The projected annual groundwater demands based on these two (2) approaches are shown in Table 1. For **Approach A**, the minimum, maximum and average groundwater demands over the projected 32-year period are 187,300 AFY, 196,800 AFY, and 192,00 AFY, respectively. The minimum, maximum and average groundwater demands for **Approach B** over the projected 32-year period are 234,200 AFY, 256,000 AFY, and 246,00 AFY, respectively. On average, **Approach B** projected groundwater demand is approximately 55,000 AFY higher than **Approach A**. The annual groundwater demands are apportioned quarterly and applied to each individual well based on the general seasonal pattern to accommodate the quarterly stress simulation for the entire 32-year model simulation period. Details of groundwater projection are presented in the Sub-Task No. 2.1 Technical Memorandum "***Main Basin Groundwater Production Projection***", dated November 1, 2017 (Stetson, 2017a).

STREAM FLOW FROM MORRIS DAM TO SANTA FE DAM

The Phase II Study notes there will be no USG-3 imported water during the predictive simulation period. Stream flow in the San Gabriel River is regulated by a series of dams; the removal of USG-3 imported water mainly affects the river reach between Morris Dam and Santa Fe Dam. The Upper District USG-3 outlet is located immediately downstream of Morris Dam. As required for the Phase II Study, monthly USG-3 imported water data was removed from the model predictive simulation by subtracting USG-3 imported water from the flow measurements at the LACDPW stream gaging station U8-R, located approximately 1.1 miles downstream of Morris Dam. The difference between the USG-3 imported water and the flow data at the U8-R gaging station was assumed to be the flow released from Morris Dam. Flow data at the further downstream LACDPW F190-R gaging station, located at Foothill Boulevard Bridge, was also adjusted by subtracting the USG-3 imported water and the water loss through infiltration (Stetson, 1995). The estimated monthly stream flow data released from Morris Dam and stream gaging station F-190R are tabulated in Table 2. The monthly stream flows were aggregated into quarterly flows and then applied to the predictive simulations.

WATERMASTER 3D BASIN FLOW MODEL FINE-TUNE

Prior to the predictive groundwater simulation, the 3D Basin Model was recalibrated based on the available data from FY 1973-74 to FY 2014-15. A total of 138 stress periods was discretized. Annual stress periods were applied to the first 10 years, and the remaining simulation period was discretized into quarterly stress periods. Model recalibration was performed by a trial and error approach. Values of model parameters were adjusted for each transient simulation to minimize the residuals between the simulated results and the field observations. The goal of model calibration is to ensure the calibrated model parameters stay within a reasonable range of field observations and the model responds to the overall hydrogeologic framework in the Main Basin.

Results of the groundwater contours maps from the calibrated 3D Basin Model in the shallow, upper intermediate, lower intermediate, and deep aquifers at the end of FY 2014-15 are presented on Figure 8. The simulated water levels at the end of FY 2014-15 was assigned as the initial conditions used in the prediction simulation. Results of model recalibration were evaluated by examining the individual well responses between the simulated heads and field observations (head residuals). Depending on the water level measurements available, a total of 24 wells located around the SFSG were selected to demonstrate the transient responses of the 3D Basin Model to pumping stresses. Locations of these 24 wells are shown on Figure 9, and the time series plot of the simulated and observed water levels of these 24 wells are provided on Figure 10. In addition, a scatter diagram of observed versus simulated water levels along with a histogram of residuals for these 24 wells are shown on Figures 11 and 12, respectively. Time series plots of simulated and observed heads shown on Figure 10 indicate model simulated heads closely follow the same pattern to the observed heads despite large discrepancies (over 30 feet difference between the simulated and observed heads). Although not a perfect match, the closely clustered data around the diagonal line shown in the scatter plot (Figure 11) illustrates a good fit of the simulated head to observations with no trend or bias to the error.

Simulated water levels were statistically evaluated by examining model residuals by means of Root Mean Square Error (***RMSE***), Residual Mean (***RM***), and Residual Standard Deviation (σ_R). ***RMSE***, ***RM*** and σ_R are used to measure how close the correlation is between the simulated (modeled), and field observed water levels. ***RMSE***, ***RM,*** and σ_R for the original 3D Basin Model (Stetson, 2017) were 11.36 feet, -3.16 feet and 11.36 feet, respectively. The calculated ***RMSE***, ***RM*** and σ_R for the recalibrated model are 8.04 feet, -1.37 feet and 8.04 feet, respectively. Figure 12 shows approximately 85 percent of model simulated water levels are within a ten-foot difference from the observed data (more than 2,500 water level measurements), and about 55 percent of model simulated water levels are within a five-foot difference. The closely clustered plot (Figure 11) and the small residuals indicate the 3D Basin Model is well calibrated.

MODEL FLOW SIMULATIONS

The fine-tuned 3D Basin Flow Model was applied to the Main Basin for transient simulations from FY 2015-16 through FY 2046-47. The predictive hydrologic cycle from FY 2015-16 through FY 2046-47 is the same as the historical hydrologic conditions from FY 1983-84 through FY 2014-15 used in the fine-tuned 3D Basin Model. Results from the flow simulations quantified the potential impacts to the Main Basin's groundwater storage under different replenishment scenarios. Following each of the three model flow simulations noted below, there is a brief summary and findings. In addition, the summary and findings are reiterated at the end of this Technical Memorandum.

Baseline Delivery of 39 MGD Flow Simulations

Under this scenario, the Main Basin receives a long-term average replenishment of about 39 MGD (approximately 43,250 AFY). Model Run I evaluates the impacts from the long-term replenishment demand (39 MGD) into the future in the Main Basin.

Scenario 4 is the predictive 32-year (FY 2015-16 through FY 2046-47) **Baseline Delivery** simulation with quarterly stress periods based on the projected groundwater demand (**Approach A,** urban water management plan, Table 1) and the constant IPR water replenishment (39 MGD) at the SFSG. The annual groundwater demands were quarterly apportioned and applied to each individual well based on the general seasonal pattern to accommodate the quarterly stress simulation for the entire 32-year simulation period. The IPR water replenishment was applied to the Main Basin through spreading at the SFSG. The quarterly groundwater replenishment for the entire model simulation period is tabulated in Table 3. Results of the simulated groundwater contours in the shallow, upper intermediate, lower intermediate, and deep aquifers at the end of FY 2015-16, FY 2020-21, FY 2025-26, FY 2030-31, FY 2035-36, FY 2040-41, and FY 2046-47 are presented on Figures 13a through 13g. The time series plots of the groundwater elevation levels of the selected 24 wells (locations shown on Figure 9) are provided on Figure 14a. The maximum and minimum water levels for these 24 wells, and their corresponding surface elevations, are tabulated in Table 4. The maximum simulated groundwater elevations of these 24 wells generally occurred in the first half of year 2037 (2037/Q1 or 2037/Q2), and the minimum simulated groundwater elevations generally occurred at the beginning of the model simulations.

Historically, the groundwater elevation at the Key Well between FY 1983-84 and FY 2014-15 fluctuated between about 170 feet above mean sea level (amsl) and 300 feet amsl. Although the groundwater elevation at the Key Well of 200 to 250 feet amsl is the operating range for the Main Basin, the Main Basin's groundwater resources can be properly managed as long as the Key Well elevation does not consistently stay above 250 feet amsl or below 200 feet amsl. Results from model simulations indicate the delivery of a constant IPR water supply of 39 MGD to the SFSGs with the reduced groundwater demand is feasible. As shown on Figure 10, the Key Well elevation may briefly reach above 270 feet amsl (272.2 feet amsl in 2037/Q2) due to the combination of the IPR water replenishment and the assumed wet conditions in 2037 (an extremely wet condition with an annual precipitation over 45 inches). However, the Key Well elevation recedes quickly and mostly stays within the operating range. The Key Well elevation at the end of simulation period is 216.9 feet amsl (2047/Q2).

Model **Scenario 1** through **Scenario 3** were performed to demonstrate and characterize the responses of groundwater conditions (Key Well elevations) under different pumping and replenishment schemes. Under the historical 32-year period, the Key Well elevation fluctuated and decreased by about 100 feet. The projected groundwater elevations at the Key Well under these four (4) simulation scenarios (**Scenario 1** through **Scenario 4**) all followed a similar pattern to the historical Key Well elevations as shown on Figure 14b. The volumetric rates of the fine-tuned 3D Basin Model water budgets for each stress period from FY 2025-16 through FY 2046-47 for these four (4) simulation scenarios are summarized and provided in Attachment B. Under **Scenario 1**, the simulated Key Well elevation denoted as red circles reached a new low and decreased by about 70 feet. The limit on the magnitude of the groundwater level decrease may be the result of the model adjusting for less subsurface outflow as the groundwater levels continued to decrease. **Scenario 2** is similar to **Scenario 1** but the historical SFSG replenishment from the imported water (**Scenario 1**) was replaced with the recycled water (39 MGD IPR water). **Scenario 3** is also similar to **Scenario 1** but the historical groundwater production (**Scenario 1**) was replaced with the projected groundwater demand (Approach A, urban water management plan). The similar responses of Key Well elevations under **Scenario 2** and **Scenario 3** simulations are demonstrated in Figure 14b. The simulated Key Well elevation at the end of of **Scenario 2** [denoted as green diamonds, 174 feet above mean sea level (amsl), 2047/Q2] is about 7 feet higher than **Scenario 3** (denoted as blue squares, 167 feet amsl). **Scenario 4** is the simulation of the combined constant recycled water replenishment and projected groundwater demand.

<u>Findings and conclusions</u>

Model simulation results of Sub-Task No. 2.3 to support the MWD Carson IPR water feasibility study under the scenario of a constant IPR water supply of 39 MGD (approximately 43,250 AFY) in the Main Basin for the evaluation of groundwater storage and water quality are summarized as follows:

- The long-term application of IPR water specifically to the SFSGs appears to significantly increase the groundwater elevation particularly during the period between FY 2015-16 and FY 2030-31. Historically a significant portion of USG-3 deliveries, and essentially all of San Gabriel Valley Municipal Water District's imported water (collectively about 915,000 acre-feet over the 32-year modeling period), infiltrated in the San Gabriel Canyon Basin or other portions of the Main Basin, and did not have a direct impact on the groundwater level at the Key Well. For this Sub-Task 2.3, all IPR water is replenished at the SFSGs and it directly impacts groundwater levels at the Key Well.

- The long-term IPR water Baseline Delivery at the SFSGs results in local groundwater mounding beneath the SFSGs and develops a radial flow of water toward the surrounding downgradient areas. The simulated constituents initially migrate radially away from the SFSGs. The IPR water plume migration pathways gradually follow the regional groundwater flow in a southwesterly direction from the SFSGs toward the Whittier Narrows.

It appears delivery of a constant IPR water supply of 39 MGD (approximately 43,250 AFY) to the SFSGs, instead of an equal amount of untreated imported water throughout the Main Basin, is viable. The combination of a projected decrease in groundwater production along with focusing all projected replenishment of IPR water at the SFSGs is projected to result in a net increase of about 37 feet at the Key Well, whereas if the historical period was repeated, the Key Well was projected to decrease by about 70 feet. The use of the 3D Model appears to provide greater sensitivity to the impacts of replenishment and groundwater production, compared to the results of the 2D Model. It appears the Main Basin may be able to accept additional amounts of IPR water on a sustained basis.

Basin Sustainability 62.5 MGD Flow Simulations

The **Basin Sustainability** simulation (**Scenario 5**) is to further evaluate the capacities of the spreading facilities and groundwater basin to receive the IPR water at a constant rate of 62.5 MGD which is greater than the long-term replenishment demand of 39 MGD. Under this scenario, the IPR water plus local runoff exceeded the SFSG capacity in certain months; however, the excess water did not exceed the Spillway capacity. The monthly replenishment was aggregated into quarterly replenishment and then applied to the predictive simulations. Groundwater recharge through spreading at the SFSG, Spillway, and/or other spreading grounds for **Scenario 5** is provided in Table 5. Results of the simulated groundwater contours for **Scenarios 5** (**62.5 MGD IPR Water Basin sustainability**) in the shallow, upper intermediate, lower intermediate, and deep aquifers at the end of FY 2015-16, FY 2020-21, FY 2025-26, FY 2030-31, FY 2035-36, FY 2040-41, and FY 2046-47 are illustrated on Figures 15a through 15g. The hydrograph of 24 wells located around the SFSG (locations shown on Figure 9) are provided in Figure 16. The maximum and minimum groundwater elevations for these 24 wells and their corresponding surface elevations are shown in Table 6. The maximum simulated groundwater elevations of these 24 wells generally occurred in year 2037, and the minimum simulated groundwater elevations generally occurred at the beginning of the model simulations (2015/Q3) except City of Arcadia Well Peck 1 (2016/Q1). The volumetric rates of water budgets for each stress period from FY 2015-16 through FY 2046-47 for **Scenario 5** are provided in Attachment B.

The water budget provides an insight of the change of groundwater storage which results in the change of groundwater elevation. The change of cumulative departure from mean change of storage plot over the entire simulation period (FY 1973-74 through FY 2046-47) for **Scenario 5** and the Baseline Delivery (**Scenario 4**) is demonstrated in Figure 17. The downtrend storage cumulative mean departure plot shown on Figure 17 indicates aquifer storage recovery for the Main Basin and vice versa. Groundwater storage of **Scenario 5 (Basin Sustainability, 62.5 MGD)** recovers more significantly than **Scenario 4 (Baseline Delivery, 39 MGD)**, leading to a faster recovery of the Key Well elevations. Results of **Scenario 5** show the Key Well elevation reaches the upper operating range of 250 feet amsl in 2027. The Key Well elevation remains above 250 feet amsl between 2027, and 2046 and the highest Key Well elevation of 301.5 feet amsl occurred in 2037/Q2. The Key Well elevation gradually decreases after 2037/Q2 and stays within the operating range by the end of simulation period (247.7 feet amsl, 2047/Q2). Although, the Key Well elevations under **Scenario 5** are mostly above the Key Well operating range of 250 feet amsl, the Key Well elevation can be managed to stay within the operating range.

Findings and Conclusions

Model simulation results of Sub-Task No. 2.4 to support the MWD Carson IPR water feasibility study under the scenarios of a constant IPR water supply of 62.5 MGD (70,000 AFY) in the Main Basin for the evaluation of groundwater storage and water quality are summarized as follows:

- Consistent with the modeling results from Sub-Task No. 2.3, the long-term application of high IPR water specifically to the SFSGs and Spillway has a direct impact on the groundwater level at the Key Well. The rise of Key Well elevations increase the chance of groundwater losses through rising water and subsurface outflow in the Whittier Narrows area.

- The long-term IPR water under Basin Sustainability (62.5 MGD) at the SFSGs and Spillway results in local groundwater mounding beneath the SFSGs and develops a radial flow of water toward the surrounding downgradient areas. The simulated constituents initially migrate radially away from the SFSGs. As time progresses, the easterly and southerly plume migrations gradually follow the regional groundwater flow in a southwesterly direction from the SFSGs toward the Whittier Narrows; however, the westerly plume migration appears to continue its westerly direction toward the Alhambra pumping hole area.

The Main Basin is an excellent groundwater basin for artificial recharge project due to its unconfined and highly permeable nature. A constant delivery of IPR water supply is a great alternative to maintain sustainable groundwater storage in the Main Basin; however, the benefits of IPR water replenishment may be eliminated particularly during the periods when the overall groundwater conditions in the Main Basin is high. Model simulations indicate when groundwater elevations particularly the Key Well elevation is approaching and/or over 280 feet amsl, any addition of the IPR water replenishment may be lost through the combination of rising water or subsurface outflow. However, a constant high volume of the IPR water replenishment (greater than 62.5 MGD) is feasible as long as the Key Well elevations can be controlled.

Augmented Basin Sustainability 77.5 MGD Flow Simulations

Three (3) scenarios were simulated under the **Augmented Basin Sustainability (PREDICTIVE MODEL SIMULATION SCENARIOS)**. **Scenario 6** is similar to **Scenario 5** except the SFSG replenishment rate (62.5 MGD, **Scenario 5**) was replaced with a higher replenishment rate of 77.5 MGD (additional 15 MGD of IPR water) which results in a net annual average of 16,800 AFY (15 MGD) more of recycled water applied to the Main Basin. **Scenario 7** is similar to **Scenario 6** except an additional 15 MGD groundwater was pumped from the Main Basin with an intention to deliver the pumped groundwater to the Raymond Basin, Six Basins, and Puente Basin. The withdrawal of 15 MGD groundwater was hypothetically accomplished by pumping a total of 5 MGD groundwater from eight (8) existing production wells for the Raymond Basin. These wells include Monrovia Wells 2, 3, 4, 5 and 6; Arcadia Wells Longden 1 and 2; and GSWC Well Jefferies 4. Each well pumps an additional 0.625 MGD disregarding their current capacities. In addition, a total of 10 MGD groundwater was pumped from twelve (12) existing production wells for the Puente Basin. These wells include CDWC Wells 2, 3, 5A, 6 and 8; SGVWC Wells B5B, B5D, B5E, 11A, 11B and 11C; and City of Industry (COI) Well 5. Each well pumps an additional 0.833 MGD disregarding their current capacities. These wells were selected due to their proximity to the existing well infrastructure. In practice, new wells may be installed in these same areas. It should be noted the overall water budget balance of **Scenario 7** is the same as **Scenario 5 (62.5 MGD IPR Water Basin Sustainability)** because the additional 15 MGD of IPR water replenishment considered in **Scenario 7** is offset by the additional 15 MGD groundwater withdrawal. **Scenario 8** is similar to **Scenario 7** except the projected groundwater demand based on urban water management plan (Approach A) was replaced with the higher projected groundwater demand (Approach B, regression analysis) which results in an annual average increase of about 55,000 AFY of groundwater production as shown in Table 1. Groundwater replenishment recharge at the SFSG is mainly from the IPR water and local runoff. Again, with the high IPR water replenishment, the IPR water and local runoff exceeded SFSG capacity in certain months; however, the excess water did not exceed Spillway capacity. The monthly replenishment was aggregated into quarterly replenishment and then applied to the predictive simulations. Groundwater recharge through spreading at the SFSG, Spillway, and/or other spreading grounds for **Scenarios 6, 7, and 8** are the same and is provided Table 7.

Results of the simulated groundwater contours for **Scenario 7** with additional 15 MGD groundwater pumping in the shallow, upper intermediate, lower intermediate, and deep aquifers at the end of FY 2015-16, FY 2020-21, FY 2025-26, FY 2030-31, FY 2035-36, FY 2040-41, and FY 2046-47 are illustrated on Figures 18a through 18g. The hydrograph of 24 wells located around the SFSG (locations shown on Figure 9) for **Scenario 7** are similar to **Scenario 5** and are not presented because **Scenario 5** and **Scenario 7** are comparable; however, the hydrograph of 24 wells for **Scenario 6** are presented on Figure 19. The maximum and minimum groundwater elevations for these 24 wells for **Scenarios 6** and **7** and their corresponding surface elevations, are tabulated in Tables 8a and 8b, respectively. Similarly, the maximum simulated groundwater elevations of these 24 wells generally occurred in year 2037, and the minimum simulated groundwater elevations generally occurred at the beginning of the model simulations (2015/Q3) except City of Arcadia Well Peck 1 (2016/Q1).

The volumetric rates of the simulated water budget components for **Scenarios 6**, and **7** from FY 2015-16 through FY 2046-47 are provided in Attachment B. The change of cumulative departure from mean change of storage plot over the entire simulation period for **Scenarios 6** and **7** as well as **Baseline Delivery** (**Scenario 4**) and **Basin Sustainability** (**Scenario 5**) are shown on Figure 17. As can be seen, plots of **Scenario 5** and **7** are almost identical due to their similar storage change. Figure 20 shows a comparison of the simulated Key Well elevations of **Scenarios 4, 5**, **6**, **7** and **8**. The highest Key Well elevation of 315.5 feet amsl occurred in the second quarter of year 2037 for **Scenario 6,** and simulated Key Well elevations of **Scenario 5** and **Scenario 7** are almost the same (301.5 feet and 303.4 feet, respectively). In addition, the simulated Key Well elevations from **Scenario 8** are close to but slightly higher than the simulated Key Well elevations from the Baseline Delivery (**Scenario 4**). Compared to **Scenario 4**, **Scenario 8** increases both the annual average of IPR water replenishment and groundwater production by approximately 43,600 AFY (86,800 AFY – 43,250 AFY) and 72,000 AFY (the total of an additional 15 MGD groundwater production for nearby Basins delivery and the difference of projected annual production between **Approach A** and **Approach B**, Table 1), respectively. On average, **Scenario 8** removes more groundwater (approximately 28,400 AFY) than **Scenario 4**. The slightly higher Key Well elevations from **Scenario 8** are mainly due to the fact that groundwater production is distributed throughout the entire Main Basin and the impact to Key Well is less significant. In addition, results of **Scenario 6** show the Key Well elevation reaches and stays above the upper operating range of 250 feet starting in 2025. However, the implementation of the 77.5 MGD IPR water replenishment is still feasible with more aggressive but not unrealistic groundwater withdrawal rates as demonstrated in **Scenario 8**.

Overall, the 32-year long-term IPR water replenishment results in higher water conditions in the Main Basin. The rise of groundwater elevation will slow down, particularly when the Key Well elevation reaches about 280 feet amsl. The rise in the groundwater table increases the chance of water losses, mainly through rising water and subsurface outflow in the area around the Whittier Narrows. The increase of subsurface outflow due to the rise of groundwater table is demonstrated in the simulated subsurface outflow at Whittier Narrows. The simulated subsurface outflows of **Scenarios 4, 5**, **6**, and **7** over the entire simulation period is shown on Figure 21. In addition, the relationship between the historical Key Well elevations and measured rising water at Whittier Narrows along with the 95 percent confidence interval is illustrated on Figure 22. The simulated rising water along the unlined San Gabriel River and Rio Hondo were quantified and compared to the historical measurements (Figure 22). The simulated rising water at the highest Key Well elevations (which occurred in the second quarter of year 2037) of **Scenarios 4, 5**, **6**, and **7** are provided in Table 9. The 3D Basin Model simulated rising water falls between the 95 percent upper and lower confidence levels. Results of model simulated rising water indicate increasing the IPR water replenishment can maintain sustainable groundwater storage in the Main Basin; however, the benefits of IPR water replenishment will be impacted by potential rising water when the Key Well elevation approaches 280 feet amsl or beyond. This would likely be a management task for the Watermaster.

Findings and Conclusions

Model simulation results of Sub-Task No. 2.5 to support the MWD Carson IPR water feasibility study under the scenarios of a constant IPR water supply of 77.5 MGD (86,800 AFY) in the Main Basin for the evaluation of groundwater storage and water quality are summarized as follows:

- Consistent with the modeling results from Sub-Task No. 2.3, the long-term application of high IPR water specifically to the SFSGs and Spillway has a direct impact on the groundwater level at the Key Well. The rise of Key Well elevations increase the chance of groundwater losses through rising water and subsurface outflow in the Whittier Narrows area.

- The long-term IPR water under Augmented Basin Sustainability (77.5 MGD) at the SFSGs and Spillway results in local groundwater mounding beneath the SFSGs and develops a radial flow of water toward the surrounding downgradient areas. The simulated constituents initially migrate radially away from the SFSGs. As time progresses, the easterly and southerly plume migrations gradually follow the regional groundwater flow in a southwesterly direction from the SFSGs toward the Whittier Narrows; however, the westerly plume migration appears to continue its westerly direction toward the Alhambra pumping hole area.

The Main Basin is an excellent groundwater basin for artificial recharge project due to its unconfined and highly permeable nature. A constant delivery of IPR water supply is a great alternative to maintain sustainable groundwater storage in the Main Basin; however, the benefits of IPR water replenishment may be eliminated particularly during the periods when the overall groundwater conditions in the Main Basin is high. Model simulations indicate when groundwater elevations particularly the Key Well elevation is approaching and/or over 280 feet amsl, any addition of the IPR water replenishment may be lost through the combination of rising water or subsurface outflow. However, a constant high volume of the IPR water replenishment (greater than 62.5 MGD) is feasible as long as the Key Well elevations can be controlled.

SOLUTE TRANSPORT SIMULATIONS AND PARTICLE TRACKING ANALYSIS

The solute transport simulations were performed using the MT3D-USGS code (Bedekar et al., 2016), and the particle tracking analysis was performed using the USGS MODPATH code (Pollock, 2016). Plume migration in groundwater is chemical dependent, and the migration pathways are highly dependent on the characteristics of the chemicals that may be contained in the IPR water. Advection and dispersion were the only two factors considered for the mass transport. The longitudinal dispersivity of 300 feet and the ratio of 0.1 was selected for the horizontal to longitudinal and vertical to longitudinal dispersivity. The solute transport simulation was performed under the assumption the simulated chemical with the maximum concentration of one (1) was constantly applied to the top layer of the 3D Basin Model at the SFSG for the entire simulation period. Model simulated concentrations were presented in terms of percentage relative to the maximum concentration. The transient transport simulation started from the beginning of the third quarter of year 2015 (2015/Q3) when the simulated chemical started to be applied to the SFSG. Both the solute transport simulation and particle tracking analysis were performed to evaluate the plume migration and to identify the potential impacted wells and the percent recycled water in each well under different pumping and replenishment rates in the Main Basin. In addition, impacts to wells from the IPR water are aquifer and depth dependent. The shallow aquifer generally has an immediate impact due to the surface spreading of the IPR water; however, the impacts to the deeper aquifer from the IPR water are less significant due to slow vertical groundwater flow. In addition, the applied IPR water in the shallow aquifer is constantly diluted by either the local stormwater runoff and/or stream leakage, especially during wet years. The weighted arithmetic average was used to present the generalized percent IPR water for the impacted wells due to the fact that most production wells in the Main Bain are perforated in more than one aquifer.

Baseline Delivery of 39 MGD Simulations

The migration of IPR water and its chemicals generally follow the flow paths (horizontal and vertical) towards the downgradient areas. In the event the IPR water contains certain chemicals and under the worst-case scenario, the simulated plume distribution (hypothetical) under the 39 MGD constant IPR water application (**Scenario 4**) in the shallow, upper intermediate, lower intermediate, and deep aquifers at the end of FY 2015-16, FY 2020-21, FY 2025-26, FY 2030-31, FY 2035-36, FY 2040-41, and FY 2046-47 are presented on Figures 23a to 23g. The movement of the replenished IPR water is similar to the plume migration. The spatial distribution of the replenished IPR water in the shallow, upper intermediate, lower intermediate, and deep aquifers; the BPOU composite contamination plume; groundwater flow paths; and the impacted wells at the end of FY 2015-16, FY 2030-31, and FY 2046-47 are presented on Figures 24a to 24c. The constant IPR water applied at the SFSG results in local groundwater mounding beneath the SFSG and develops a radial flow towards the surrounding downgradient areas. As time progresses, the easterly and southerly flow (IPR water) will gradually merge with the regional groundwater flow in a southwesterly direction towards the Whittier Narrows area. However, the westerly flow appears to continue its westerly direction toward the major groundwater depression area in the Alhambra pumping hole area. Results of plume migration indicate the USEPA BPOU cleanup may be partially affected, particularly the west portion of the BPOU remediation area, by the IPR water. However, it appears the impacts from the IPR water are minor and the additional chemicals can be contained by the BPOU existing remedial systems. These include the Valley County Water District (VCWD) Lante Subproject located in the upper BPOU area (Subarea 1) and the La Puente Valley County Water District (LPVCWD) Subproject; the San Gabriel Valley Water Company (SGVWC) B5 and B6 Subprojects; and the California Domestic Water Company (CDWC) Treatment Plant located in the lower BPOU area (Subarea 3).

Results of the travel time and the corresponding percent IPR water of the impacted wells at the end of FY 2015-16 (one-year travel time), FY 2020-21 (six-year travel time), FY 2025-26 (eleven-year travel time), FY 2030-31(sixteen-year travel time), FY 2035-36 (twenty-one-year travel time), FY 2040-41(twenty-six-year travel time), and FY 2046-47 (thirty-two-year travel time) based on the weighted arithmetic average calculation are presented on Figures 25a to 25g. The subsurface underflow beneath the spreading grounds will be gradually replaced by the IPR water. The groundwater mound formed by the applied IPR water creates a high hydraulic pressure to prevent and minimize the upgradient subsurface flow entering the areas beneath the spreading grounds. As time progresses, the lateral and vertical migration of the applied IPR water will mix with the diluent water (subsurface underflow, local stormwater runoff, and/or stream leakage) resulting in a dilution of the IPR water. It should be noted the results of the IPR water percentage to the groundwater are preliminary, and additional investigations may be required to refine and validate the current modeling results.

Basin Sustainability of 62.5 MGD

The spatial plume distribution under the constant 62.5 MGD IPR water application (**Scenario 5**) in the shallow, upper intermediate, lower intermediate, and deep aquifers at the end of FY 2015-16, FY 2020-21, FY 2025-26, FY 2030-31, FY 2035-36, FY 2040-41, and FY 2046-47 are presented on Figures 26a to 26g. The spatial distribution of the replenished IPR water in the shallow, upper intermediate, lower intermediate, and deep aquifers; the BPOU composite contamination plume; groundwater flow paths; and the impacted wells at the end of FY 2015-16, FY 2030-31, and FY 2046-47 are presented on Figures 27a to 27c. In addition, the percent IPR water of the impacted wells at the end of FY 2015-16, FY 2020-21, FY 2025-26, FY 2030-31, FY 2035-36, FY 2040-41, and FY 2046-47 are presented on Figures 28a to 28g. The migration of the IPR water is similar to the results from **Scenario 4** (39 MGD IPR water replenishment) except the extension of impacted area is larger.

Augmented Basin Sustainability of 77.5 MGD

The migration of the 77.5 MGD IPR water is similar to **Scenario 4** (**Baseline Delivery of 62.5 MGD**) and **Scenario 5** (**Basin Sustainability of 62.5 MGD**). The spatial plume distribution under the constant 77.5 MGD IPR water application with additional 15 MGD groundwater withdrawal (**Scenario 7**) in the shallow, upper intermediate, lower intermediate, and deep aquifers at the end of FY 2015-16, FY 2020-21, FY 2025-26, FY 2030-31, FY 2035-36, FY 2040-41, and FY 2046-47 are presented on Figures 29a to 29g. The spatial distribution of the replenished IPR water in the shallow, upper intermediate, lower intermediate, and deep aquifers; the BPOU composite contamination plume; groundwater flow paths; and the impacted wells at the end of FY 2015-16, FY 2030-31, and FY 2046-47 are presented on Figures 30a to 30c. In addition, the percent IPR water of the impacted wells at the end of FY 2015-16, FY 2020-21, FY 2025-26, FY 2030-31, FY 2035-36, FY 2040-41, and FY 2046-47 are presented on Figures 31a to 31g.

Results of the solute transport simulations and the particle tracking analysis suggest the application of the highly purified recycled water is likely to improve the existing groundwater quality in the main Basin. The improvement of groundwater quality is the results of groundwater dilution through the mixing of the highly purified IPR water with the existing groundwater. However, the IPR water travel time and retention time in the groundwater will require additional investigations to validate it, and these are subject to regulatory requirements and will need the support from the project sponsors.

SUMMARY AND FINDINGS

A feasibility study of the groundwater replenishment of IPR water from CSD's Carson Plant to the Main Basin was numerically performed to quantify the volume of IPR water replenishment that can be applied to the Main Basin, the potential impacts of water quality from the IPR water, and the possible influences to the existing Superfund Site Cleanup Programs. The feasibility study was performed using the Watermaster's regional scale 3D Basin Flow Model, USGS MT3D-USGS transport model, and USGS MODPATH post-processing program. Watermaster's 3D Basin Model was recalibrated between FY 1973-74 and FY 2014-15 to improve the 3D Basin Model's responses under different IPR water replenishment and pumping schemes. Eight (8) simulation scenarios were performed to quantitatively and qualitatively evaluate the Main Basin groundwater conditions over the period between FY 2015-16 and FY 2046-47. Results of the feasibility study are summarized as follows:

- The main objective of Phase II Study was to numerically evaluate impacts from the long-term delivery of IPR water to the Main Basin. Although the spreading areas (SFSG, Spillway, and/or other nearby spreading grounds) considered in this study are located within the jurisdiction of SWRCB, DDW, and RWQCB regulatory agencies, constraints from the regulatory requirements for the implementation of the IPR water project were not considered as part of this Study.

- The long-term application of IPR water specifically to the SFSG appears to significantly increase the groundwater elevation. Historically a significant portion of USG-3 deliveries, and essentially all of San Gabriel Valley Municipal Water District's imported water (collectively about 915,000 acre-feet over the 32-year modeling period), infiltrated in the San Gabriel Canyon Basin or other portions of the Main Basin and did not have a direct impact on the groundwater level at the Key Well. For this Sub-Task 2.3, all IPR water is replenished at the SFSG and directly impacts groundwater levels at the Key Well.

- The long-term IPR water Baseline Delivery at the SFSG results in a local groundwater mound beneath the SFSG and develops a radial flow toward the downgradient areas. As time progresses, migration or the IPR water in an easterly and southerly direction appear to merge with the southwesterly regional groundwater flow and towards the Whittier Narrows; however, the westerly IPR water flow appears to continue its westerly direction toward the Alhambra pumping hole area.

- The implementation of the highly purified recycled water is likely to improve the existing groundwater quality in the Main Basin due to the mixing of the highly purified IPR (drinking water standards) water with the existing groundwater. The improvement of groundwater quality in the Main Basin helps the existing USEPA Superfund Cleanup Programs. In the event the IPR water contains chemicals, the impacts from the contaminated IPR water does not appear to be crucial as the contaminated IPR water can be contained by the USEPA BPOU existing remedial systems.

- The long-term application of high volume of IPR water specifically to the SFSG and/or the Spillway has a direct impact on the groundwater level at the Key Well. The rise of Key Well elevations increases the potential for rising water and subsurface outflow in the Whittier Narrows area. Model simulations indicate the benefits of IPR water replenishment will be impacted by potential rising water when the Key Well elevation approaches 280 feet amsl or beyond. However, the loss of the IPR water replenishment through rising water and subsurface outflow can be addressed through groundwater basin management.

- Results of this numerical study are preliminary; specifically, the IPR water travel time in groundwater will require additional investigation for validation. These are subject to regulatory requirements and will need the support from the project sponsors.

- The production, delivery, and use of recycled water for drinking water supplies are subject to various regulatory requirements by SWRCB, DDW, and RWQCB. The regulatory requirements are outside the scope of the project and are not discussed.

CONCLUSIONS

The Main Basin is an excellent groundwater basin for an artificial recharge project, such as the IPR water, due to its unconfined and highly permeable nature. A constant delivery of IPR water supply is an effective alternative to maintain sustainable groundwater replenishment in the Main Basin; however, the benefits of significant IPR water replenishment may need to be locally managed during the periods when the overall groundwater conditions in the Main Basin are high. Model simulations indicate when groundwater elevations are high, particularly when the Key Well elevation is approaching and/or over 280 feet amsl, additional IPR water replenishment may increase rising water and subsurface outflow. However, it appears a constant high volume of the IPR water replenishment (greater than 62.5 MGD) is feasible as long as the Key Well elevations can be managed through proper groundwater pumping schemes.

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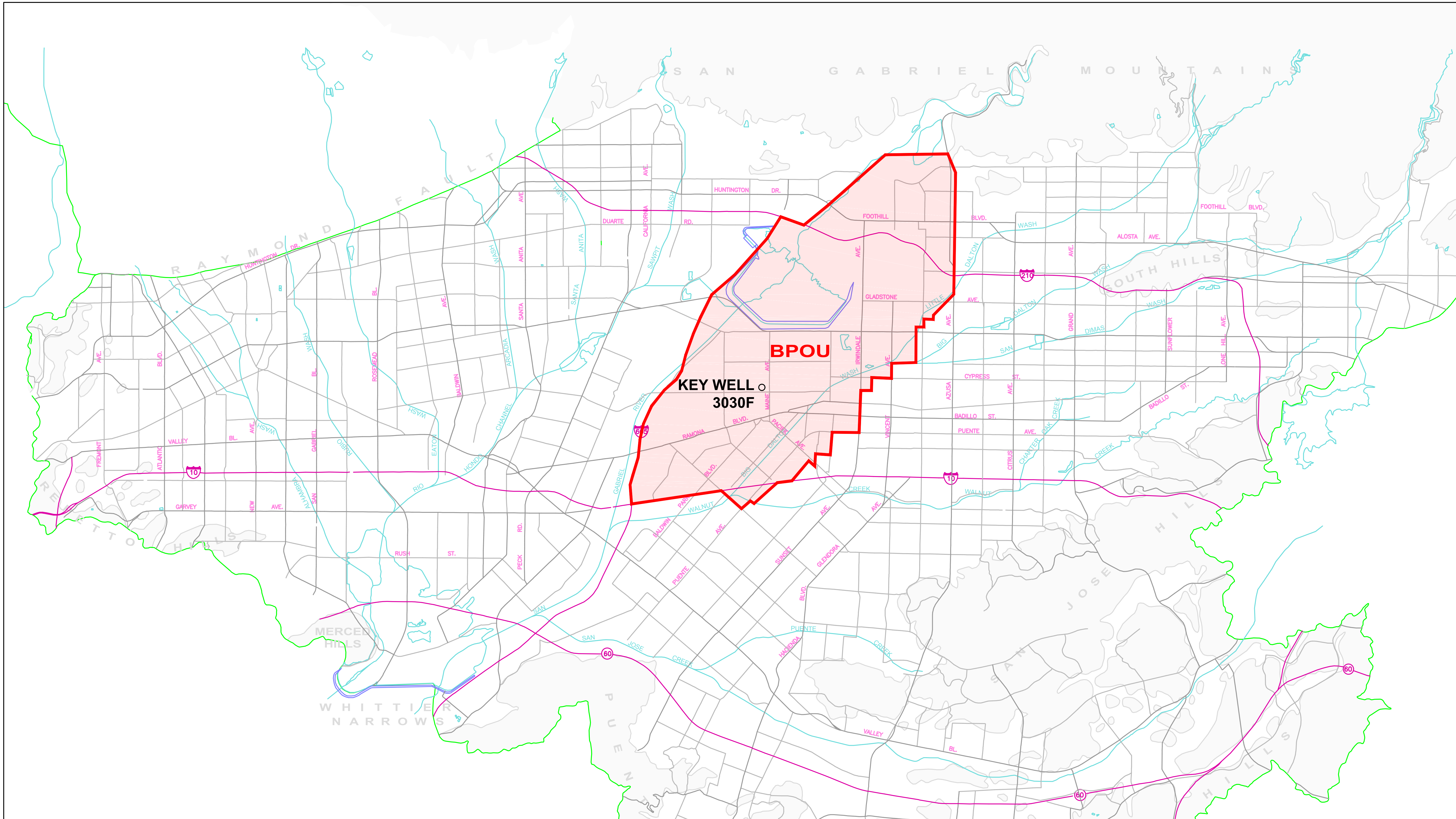
Figure 1



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NOT TO SCALE

MAIN SAN GABRIEL BASIN WATERMASTER

MAIN SAN GABRIEL BASIN AND EPA BALDWIN PARK OPERABLE UNIT (BPOU)

MainSanGabrielBasin WATERMASTER

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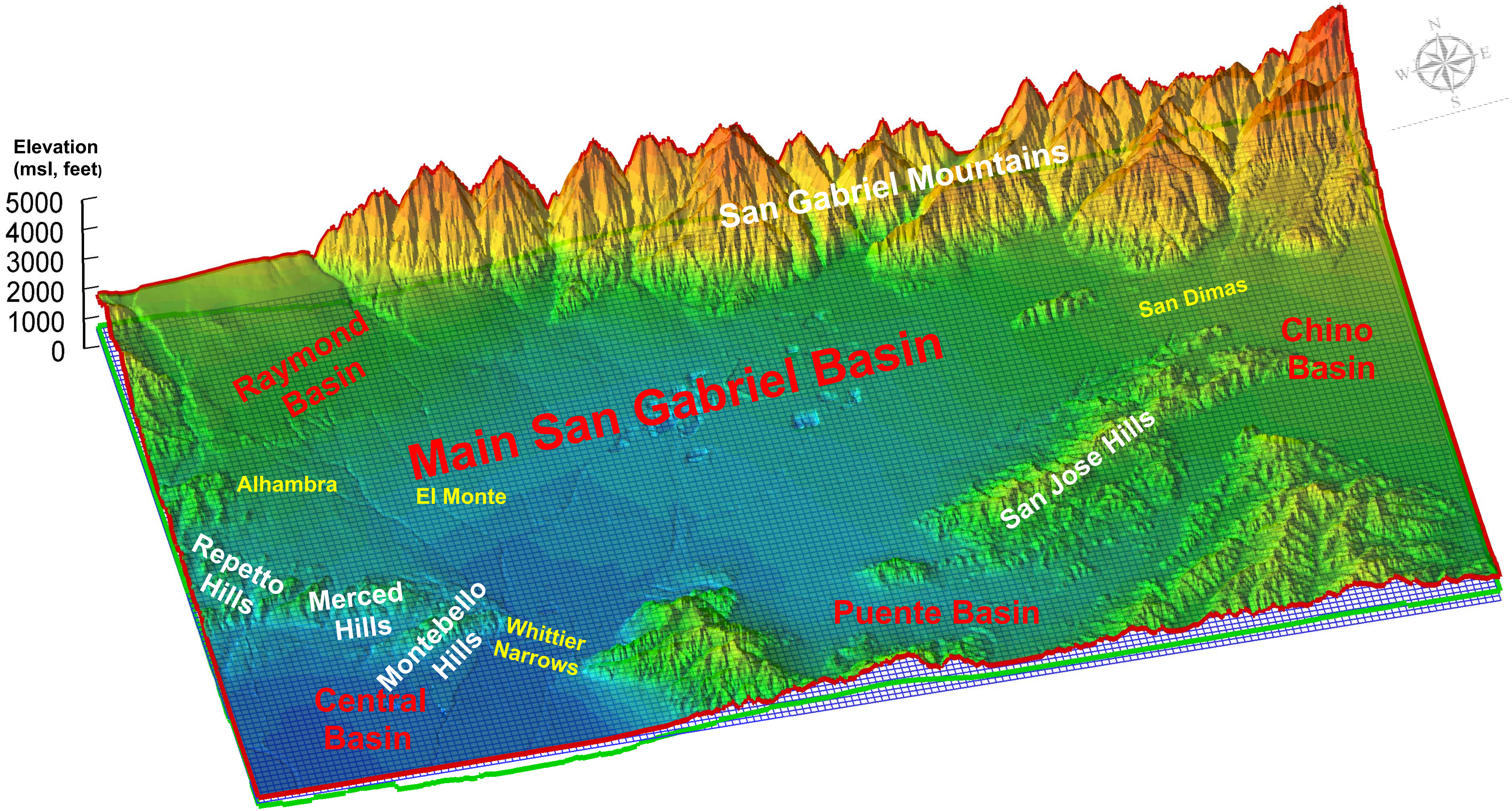
Figure 2



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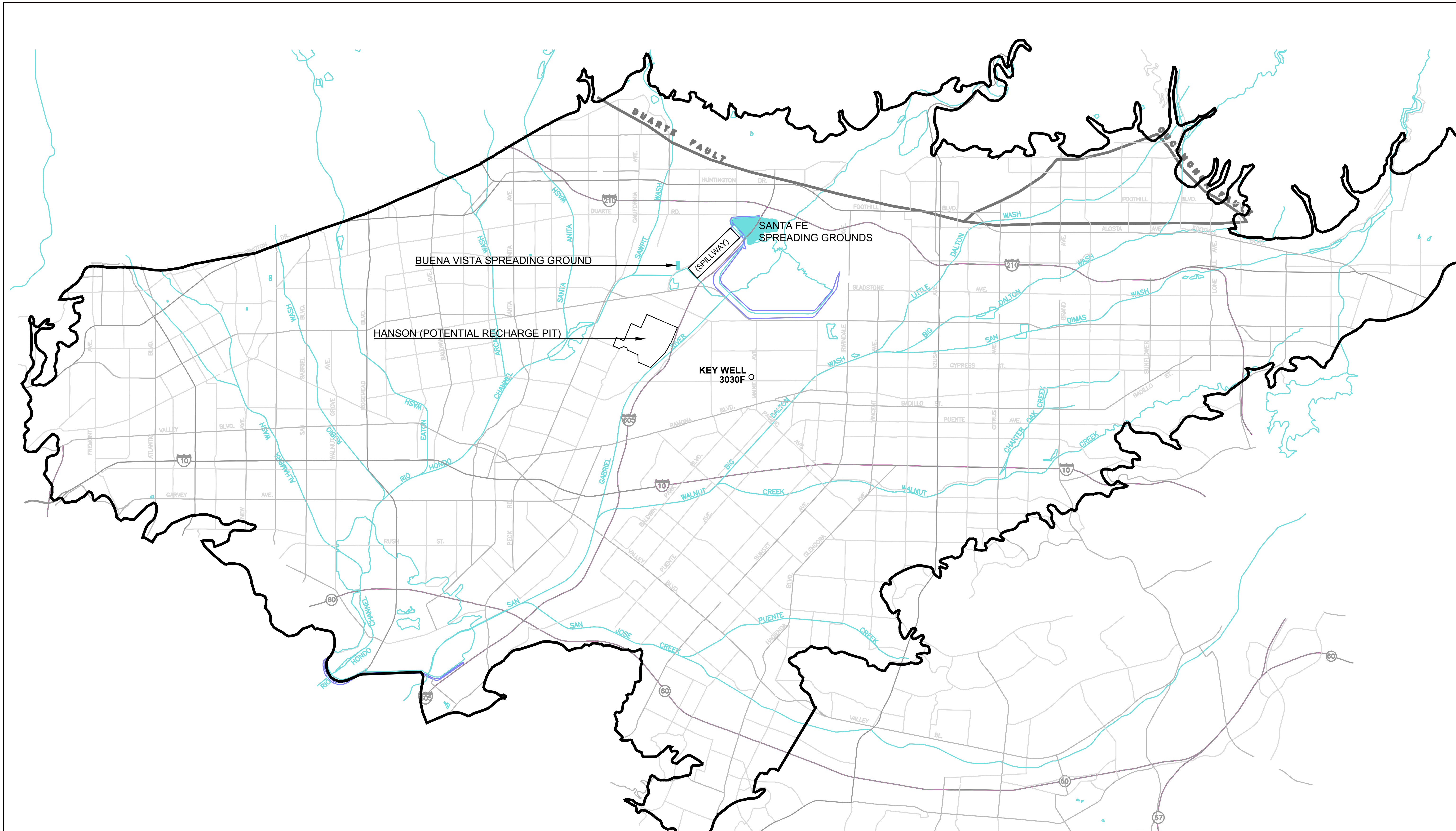
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Domain

MainSanGabrielBasin WATERMASTER

Figure 3



861 VILLAGE OAKS DRIVE, SUITE 100
COVINA, CALIFORNIA 91724
TEL: (626) 967-6202
FAX: (626) 331-7065

2171 E Francisco Blvd., Suite K
San Rafael California 94901

2651 W Guadalupe Rd., Suite A209
Mesa Arizona 85202

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ENGINEERS INC.

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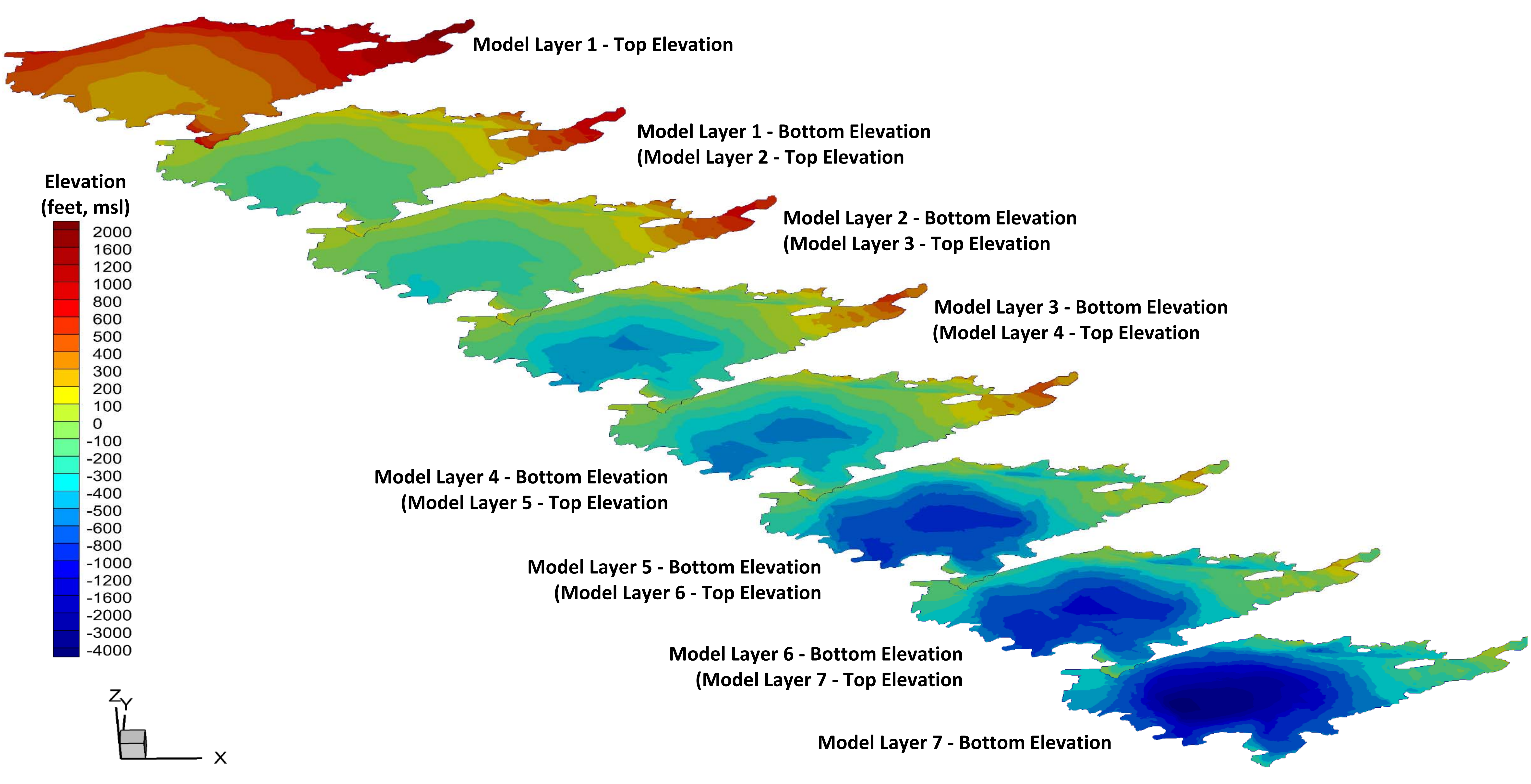
APPROXIMATE SCALE
4,000' 0 4,000'

MAIN SAN GABRIEL BASIN WATERMASTER

LOCATION OF SPREADING GROUNDS AND SANTA FE DAM SPILLWAY

MainSanGabrielBasin
WATERMASTER

J:\1205\1205-98\Contour Figures\FIGURE 1.dwg



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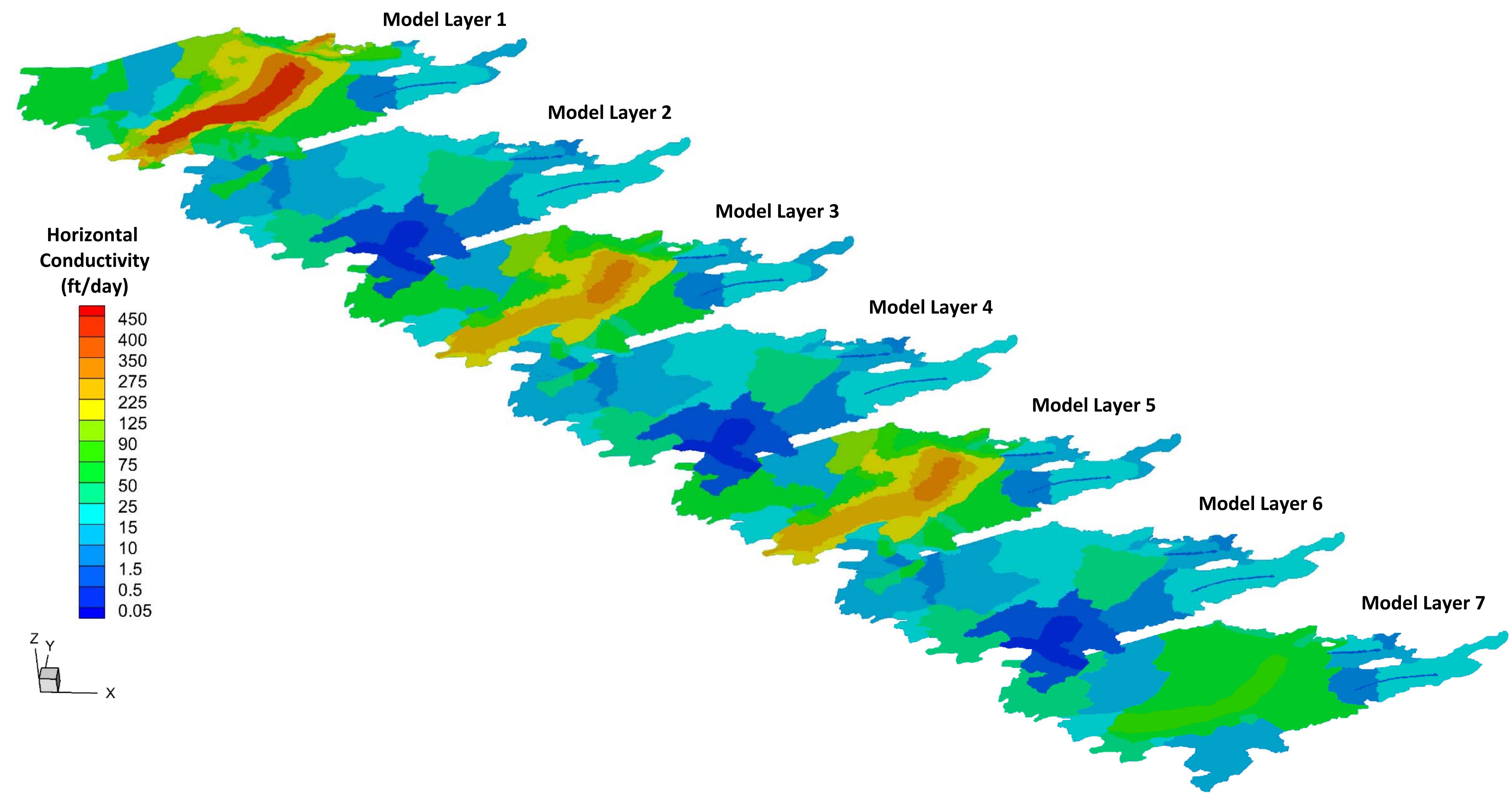
MAIN SAN GABRIEL BASIN WATERMASTER

Model Layer Elevations of the 3D Basin Model

MainSanGabrielBasin WATERMASTER



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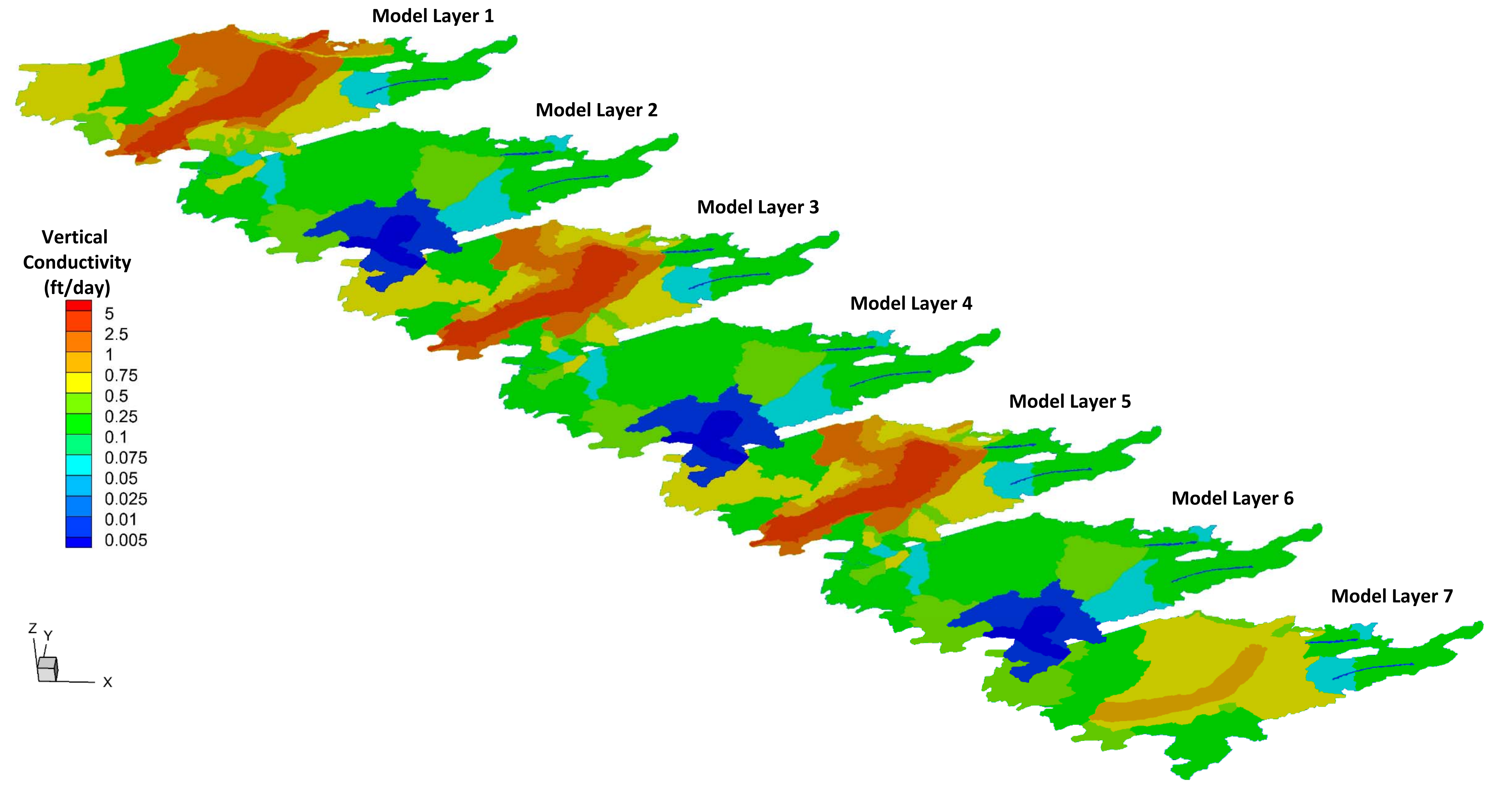
MAIN SAN GABRIEL BASIN WATERMASTER

Horizontal Hydraulic Conductivity (Kx and Ky) of the 3D Basin Model

MainSanGabrielBasin WATERMASTER



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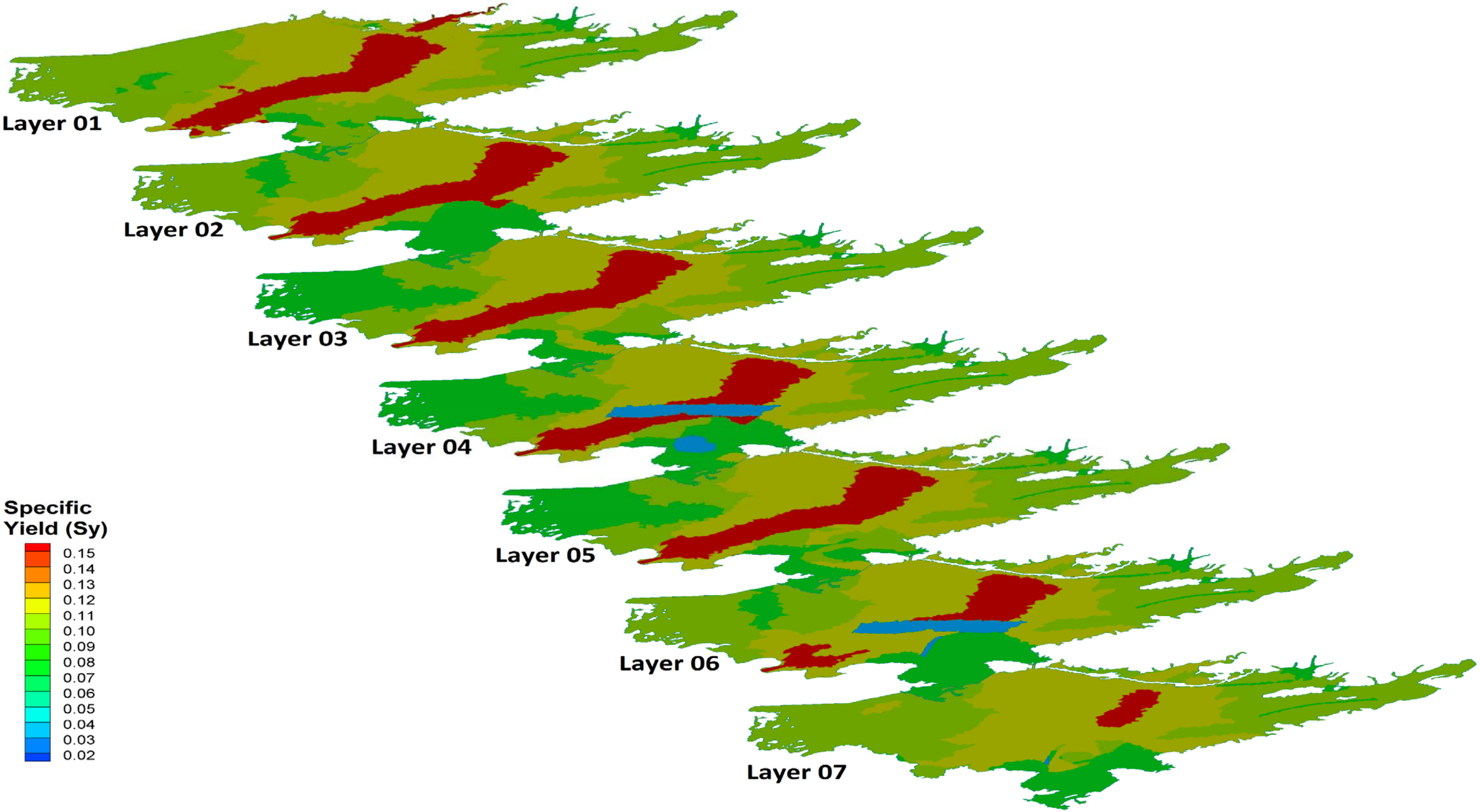
MAIN SAN GABRIEL BASIN WATERMASTER

Vertical Conductivity (Kz) of the 3D Basin Model

MainSanGabrielBasin WATERMASTER



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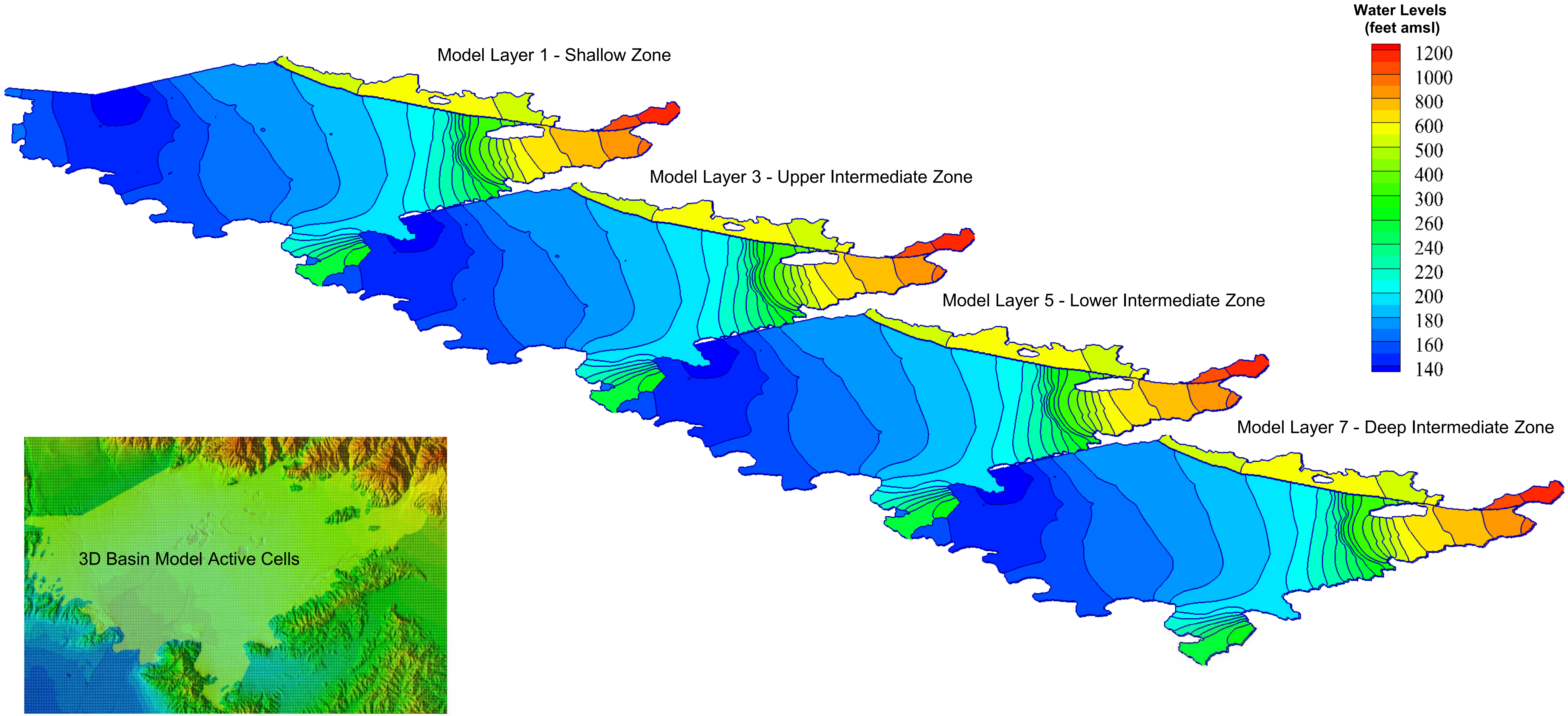
MAIN SAN GABRIEL BASIN WATERMASTER

Specific Yield of the 3D Basin Model

MainSanGabrielBasin WATERMASTER

3D Basin Model Transient Simulation



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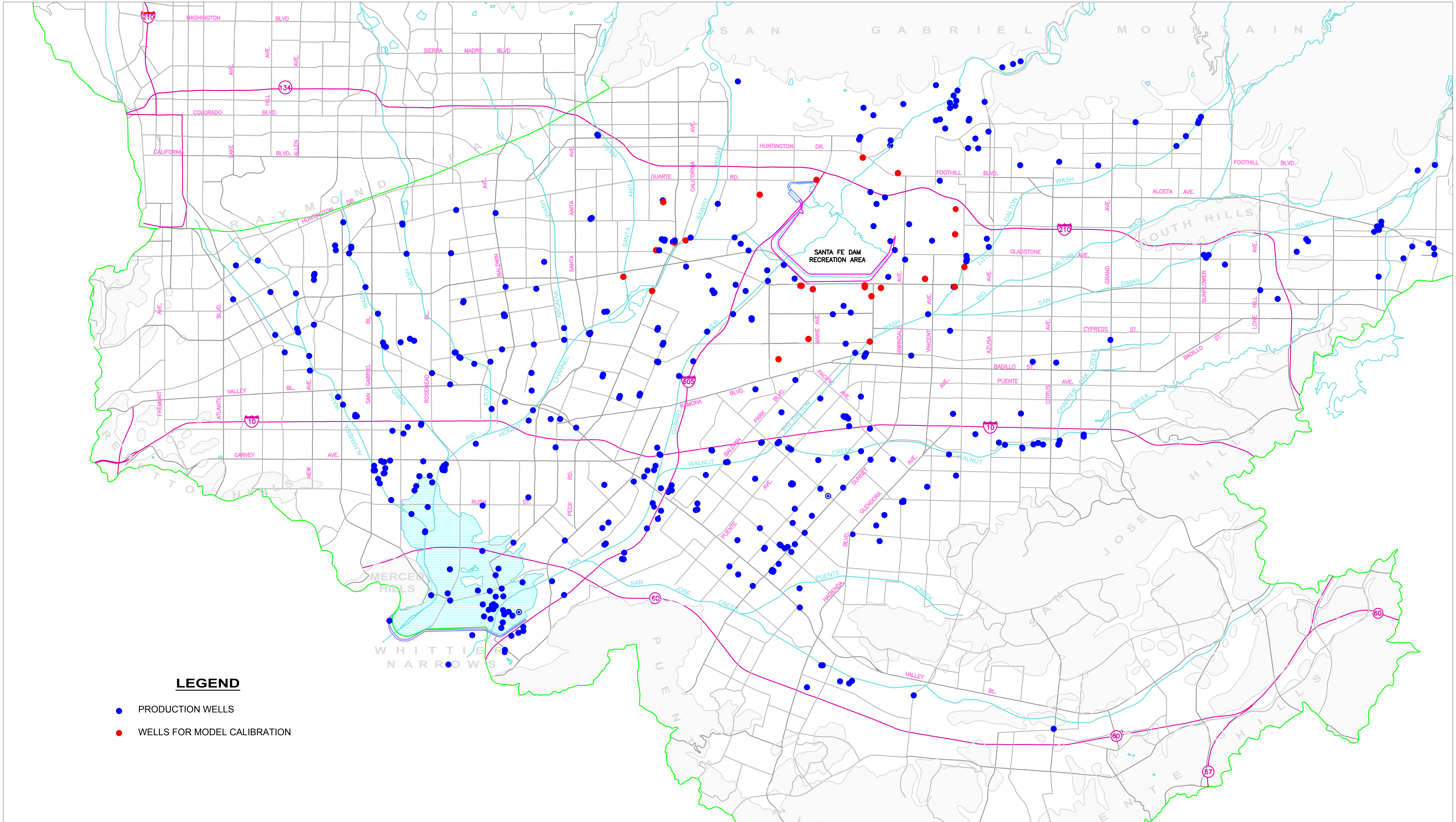
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model FY2014-15 Groundwater Contours in the Shallow, Upper Intermediate, Lower Intermediate, and Deep Aquifers

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 8 - 3D Basin Model Simulated Contours FY2014-15.xlsx

Figure 9



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Mesa Arizona 85202

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APPROXIMATE SCALE
4,000' 0 4,000'

MAIN SAN GABRIEL BASIN WATERMASTER

Locations of Wells for Model Calibration

Main San Gabriel Basin WATERMASTER

J:\1205\1205-98\.05.02.2\Figure 7.dwg

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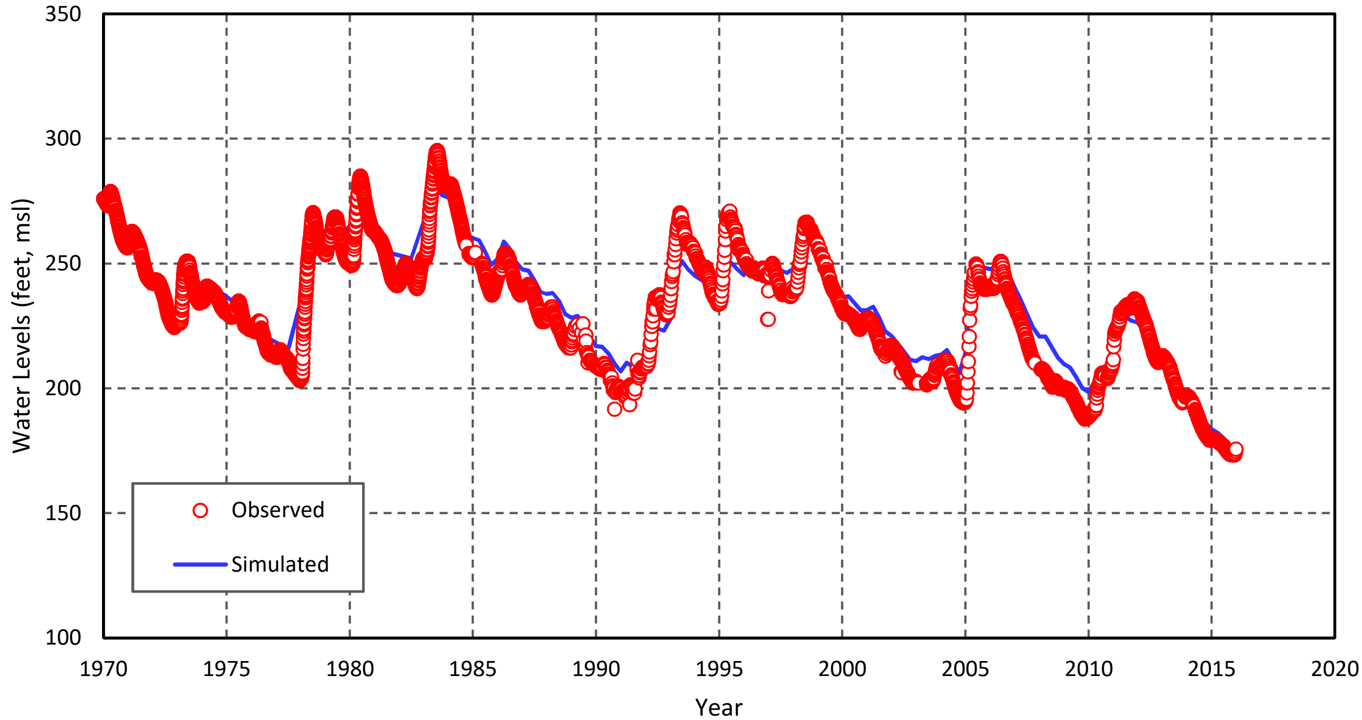
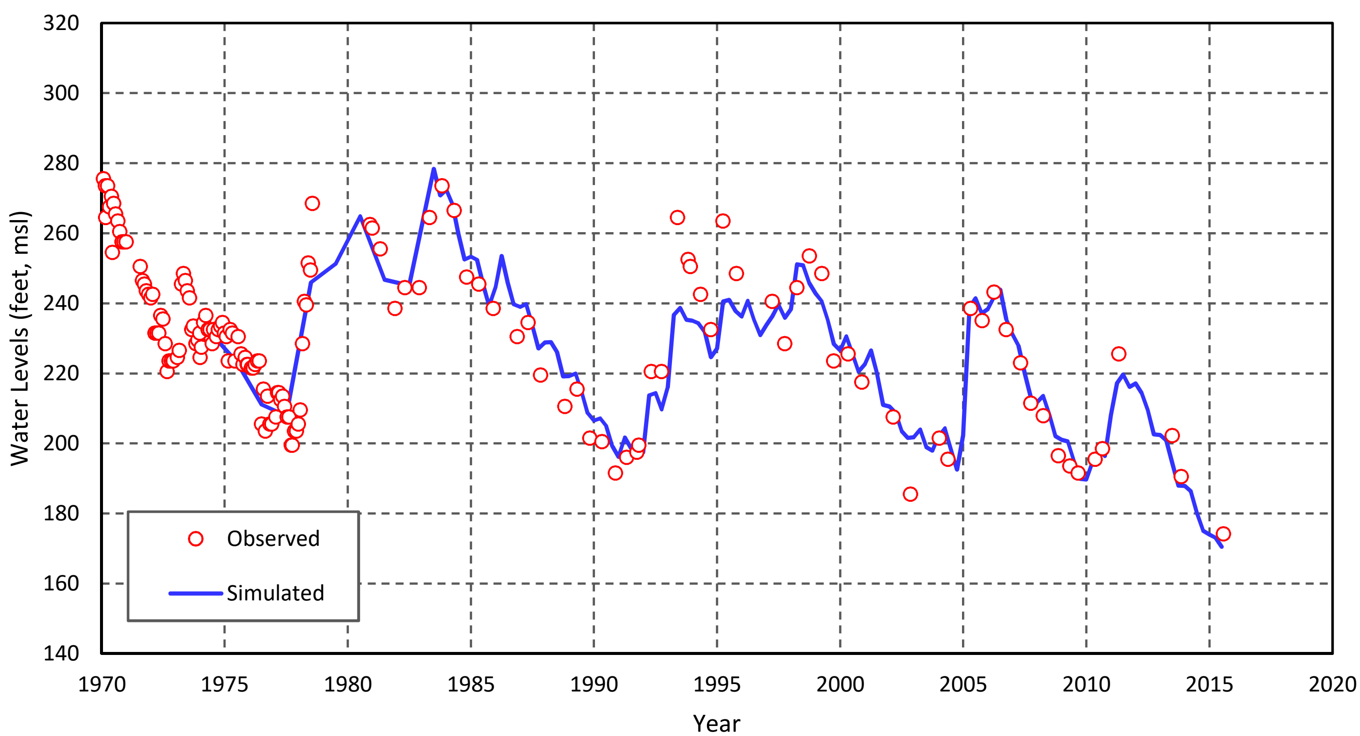
LA County Well 3030F (Key Well)



City of Monrovia Well 03 (1900419) - LA County 4198K



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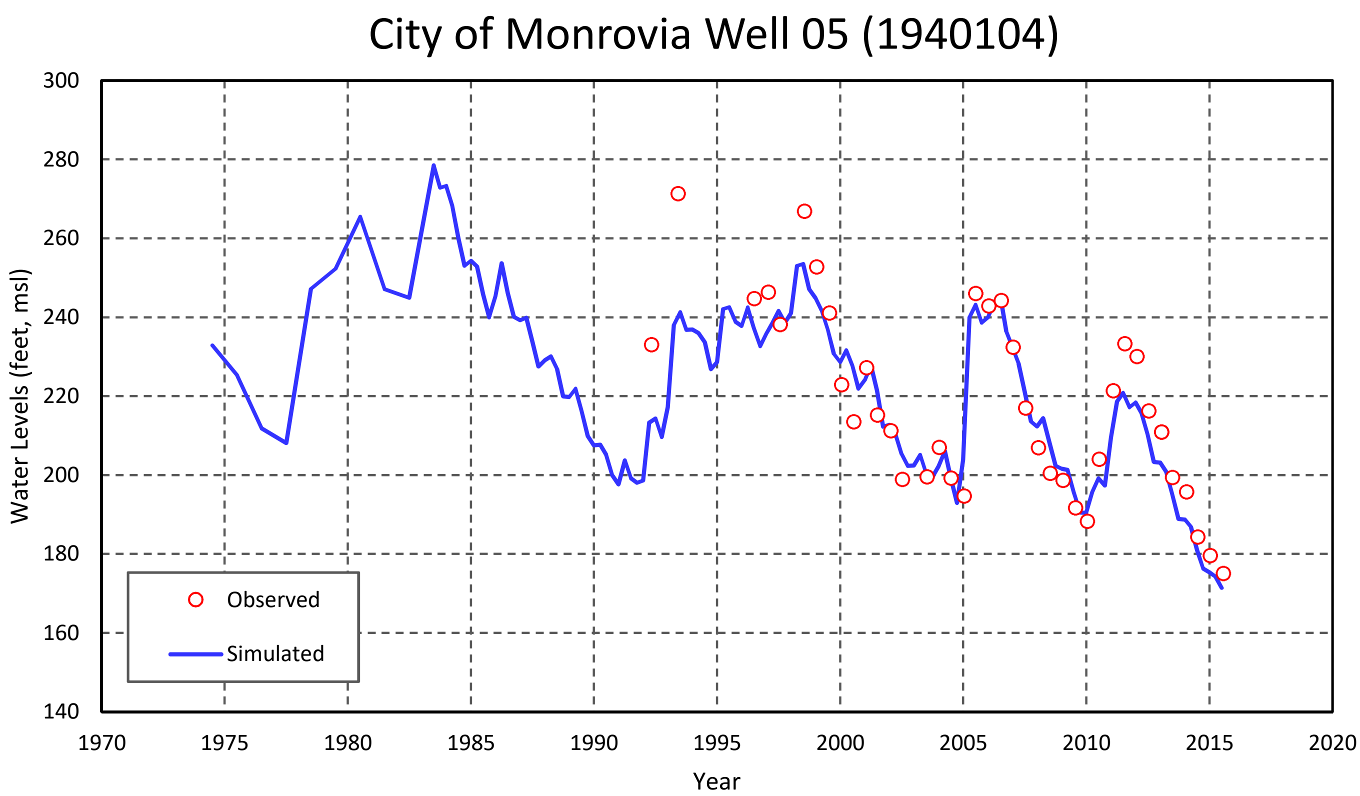
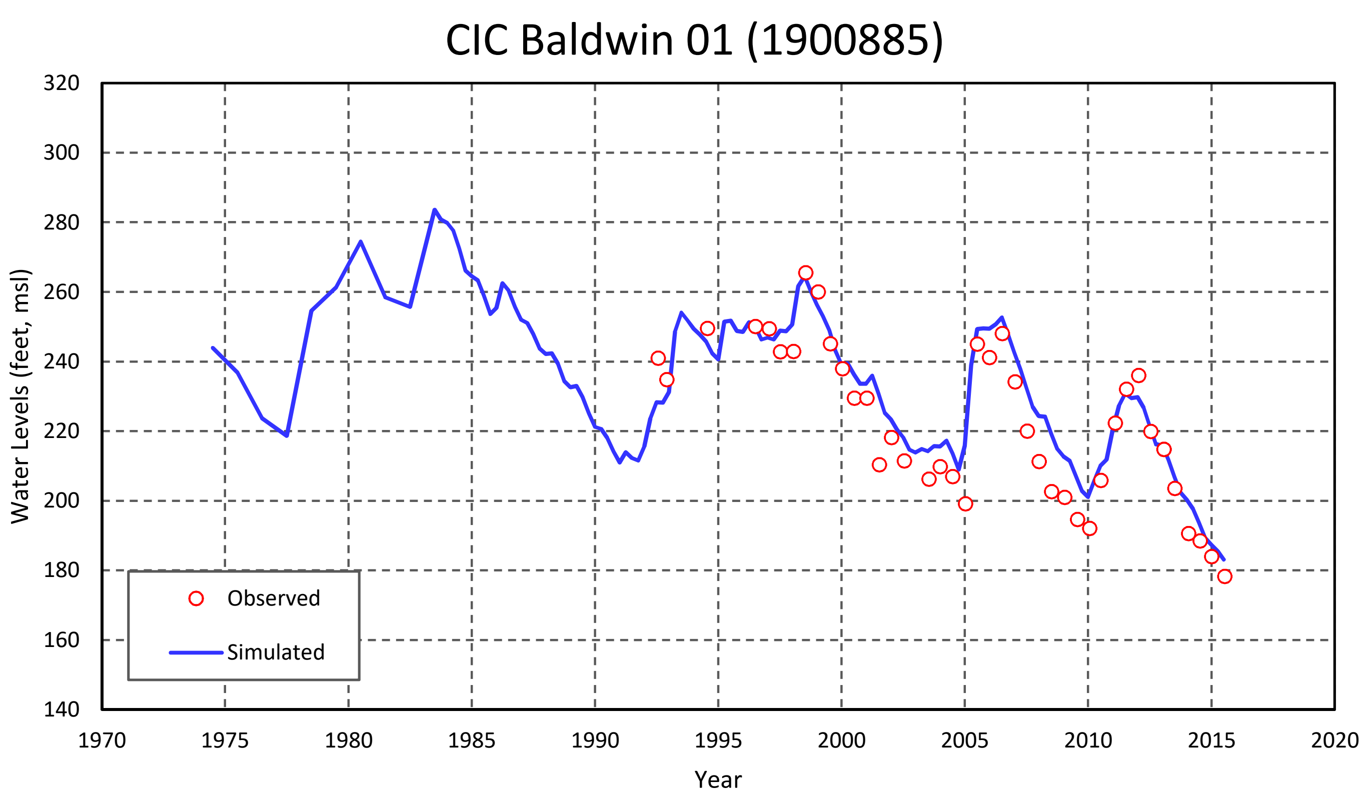
MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results
Observed versus Simulated

MainSanGabrielBasin WATERMASTER





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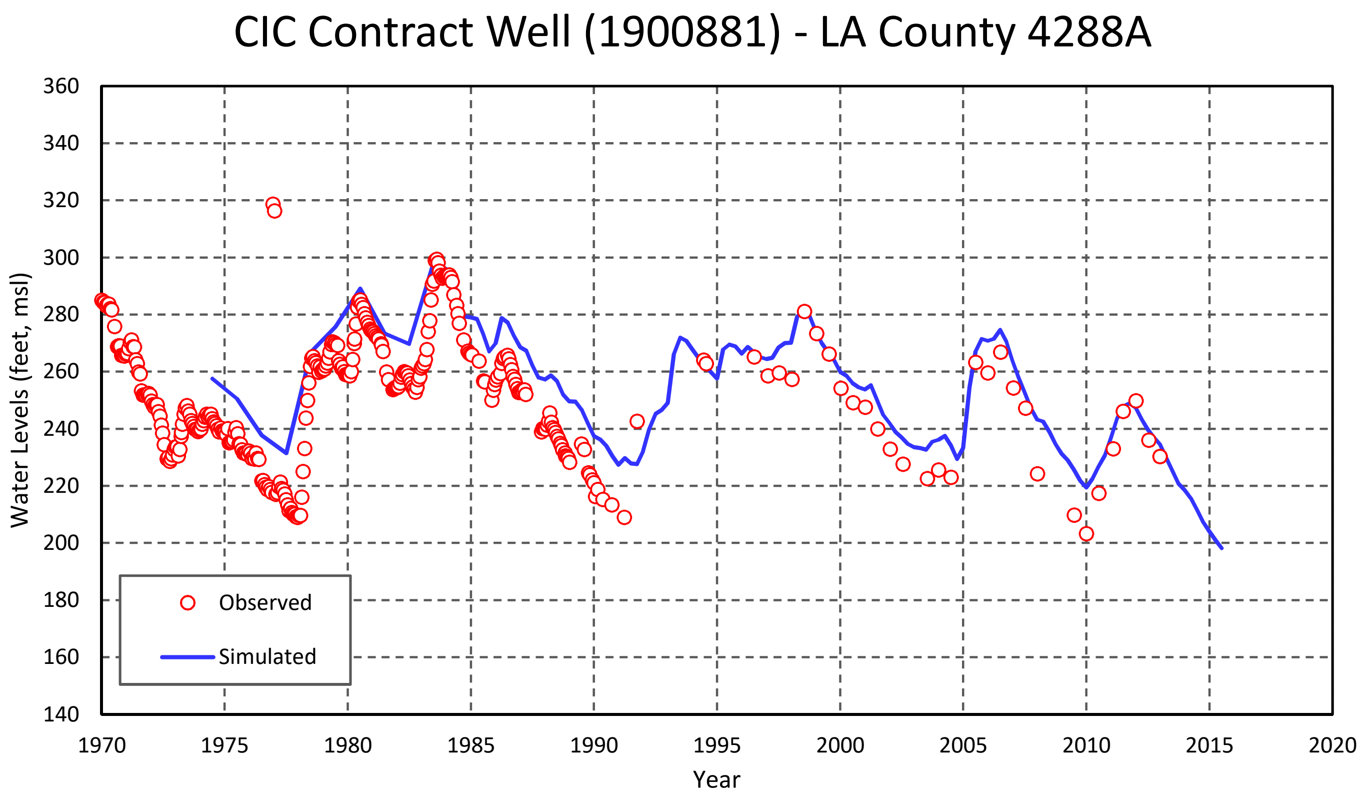
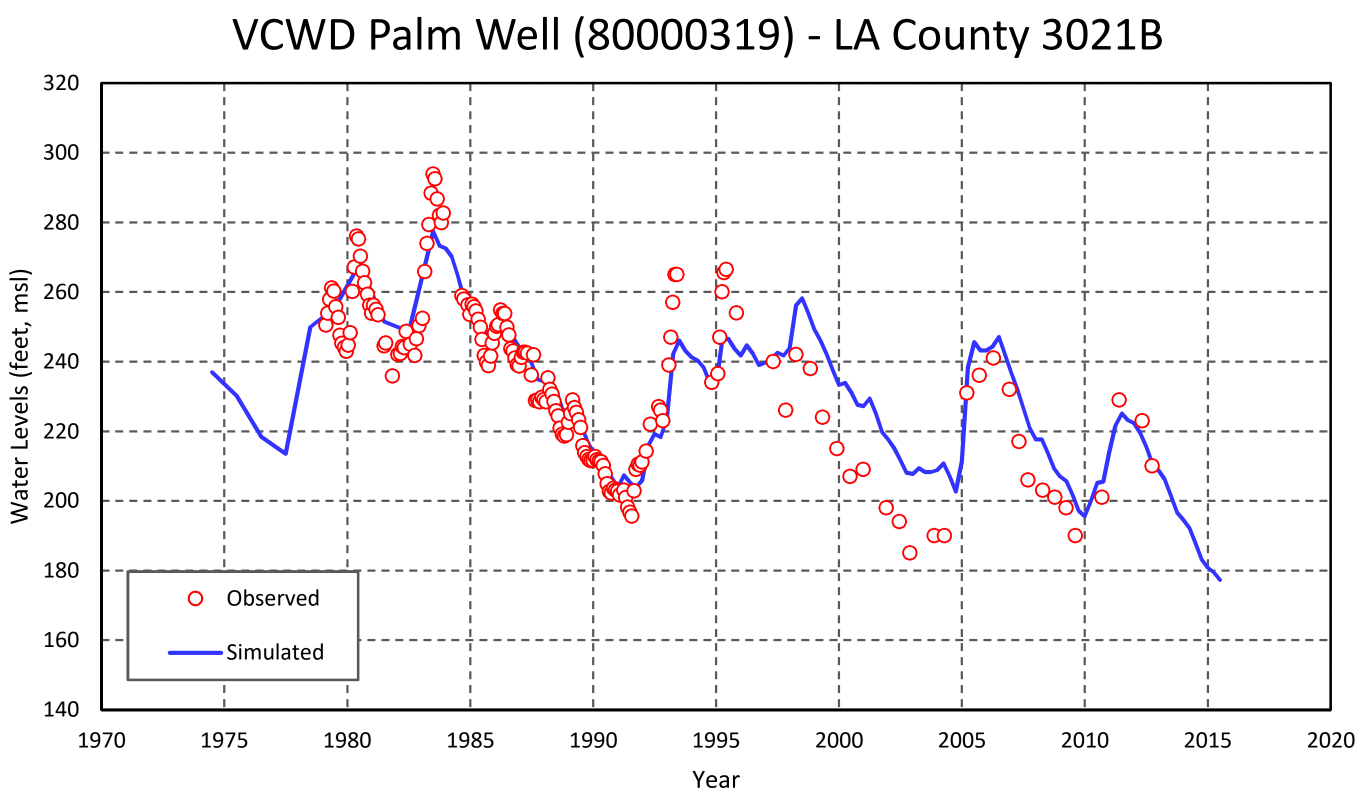
MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results
Observed versus Simulated

MainSanGabrielBasin WATERMASTER





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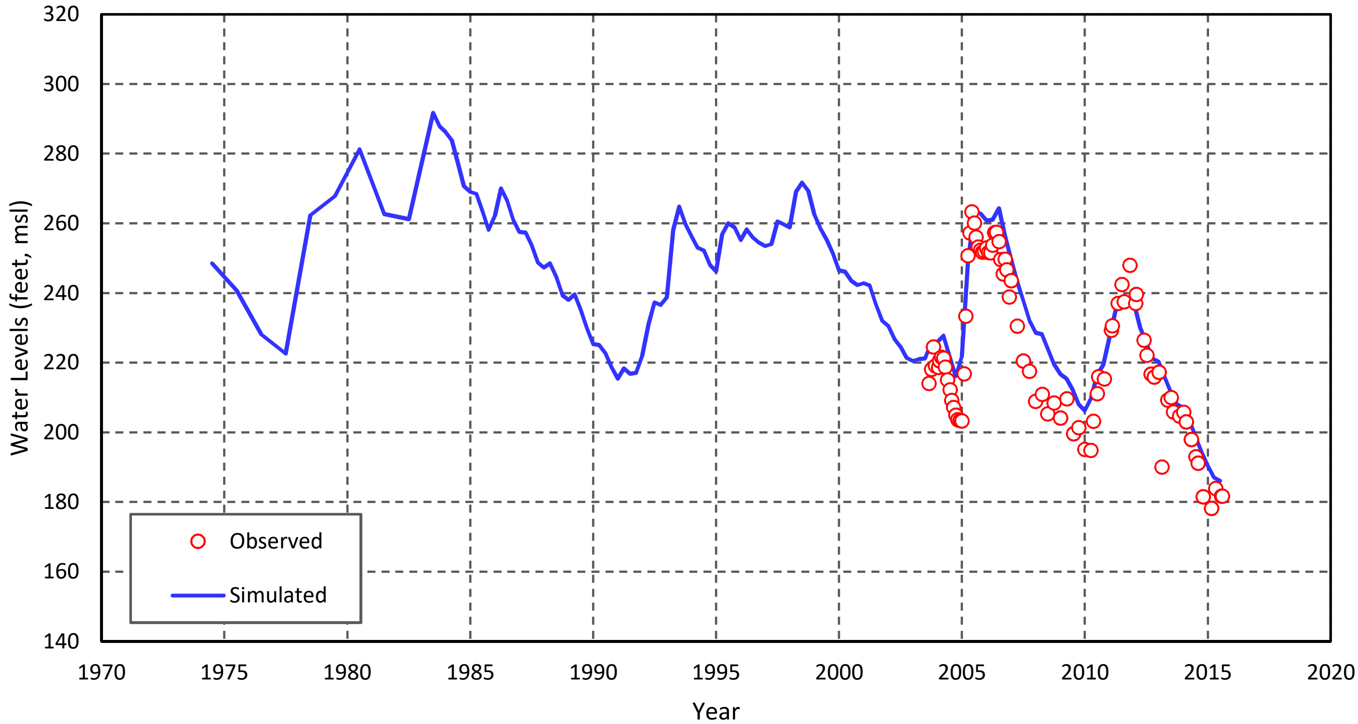
MAIN SAN GABRIEL BASIN WATERMASTER

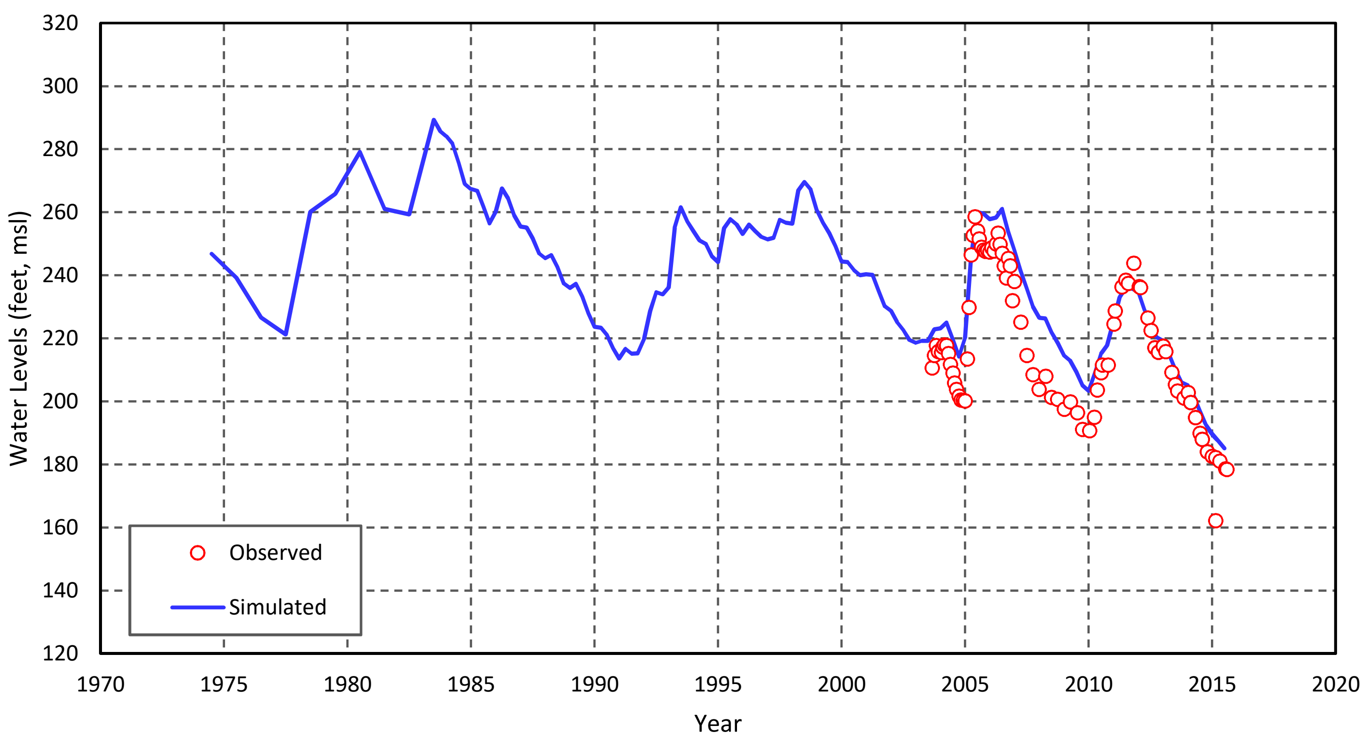
Calibration Results
Observed versus Simulated

MainSanGabrielBasin WATERMASTER

VCWD SA1-1 (8000185)



VCWD SA1-2 (8000186)



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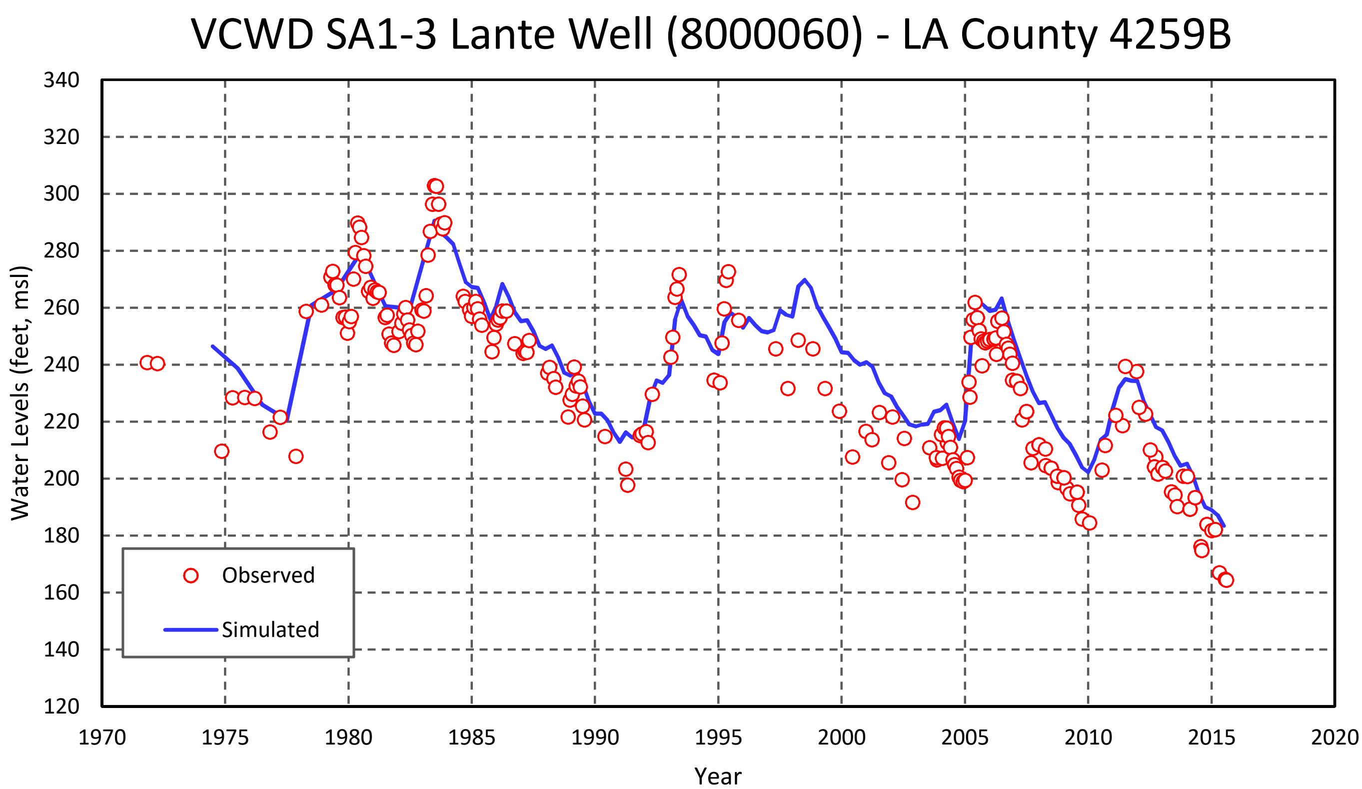
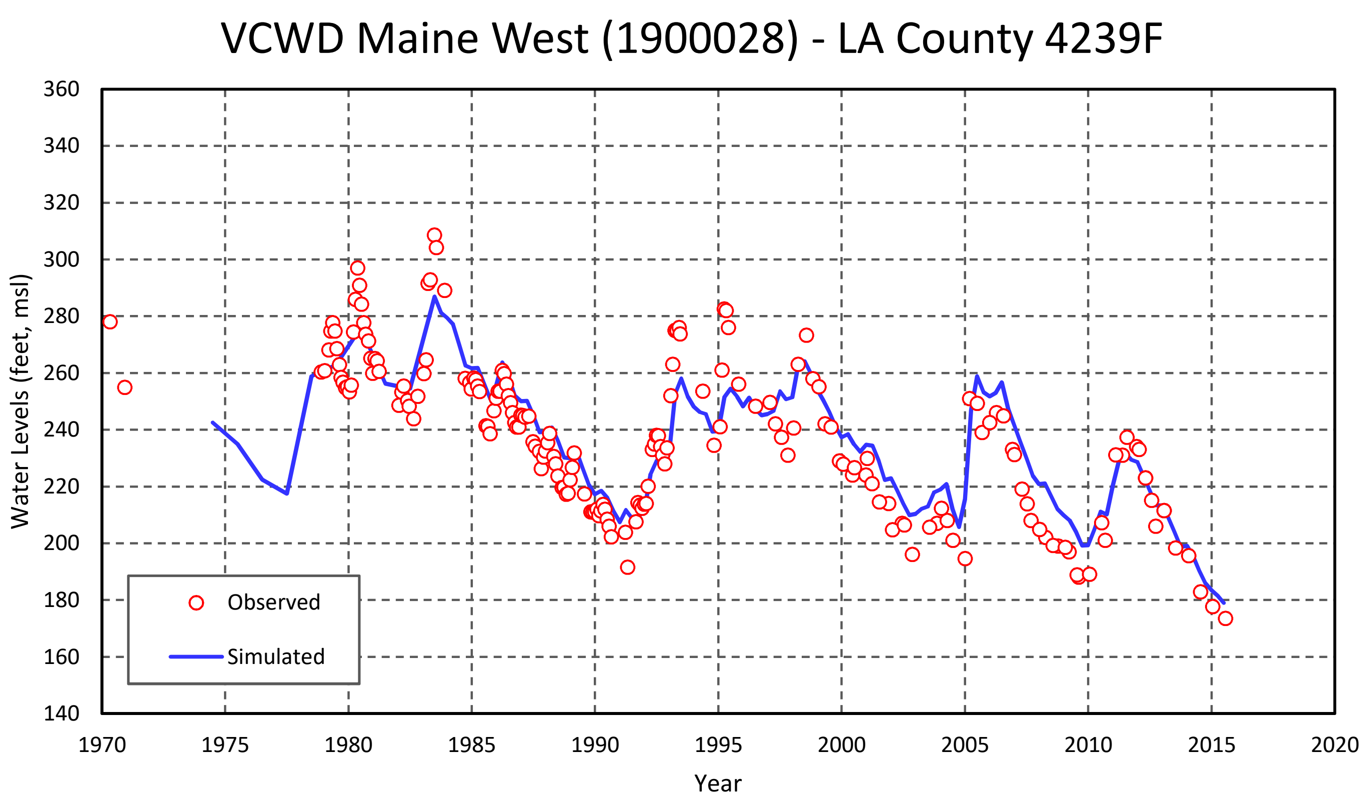
MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results
Observed versus Simulated

MainSanGabrielBasin WATERMASTER

FIGURE 10





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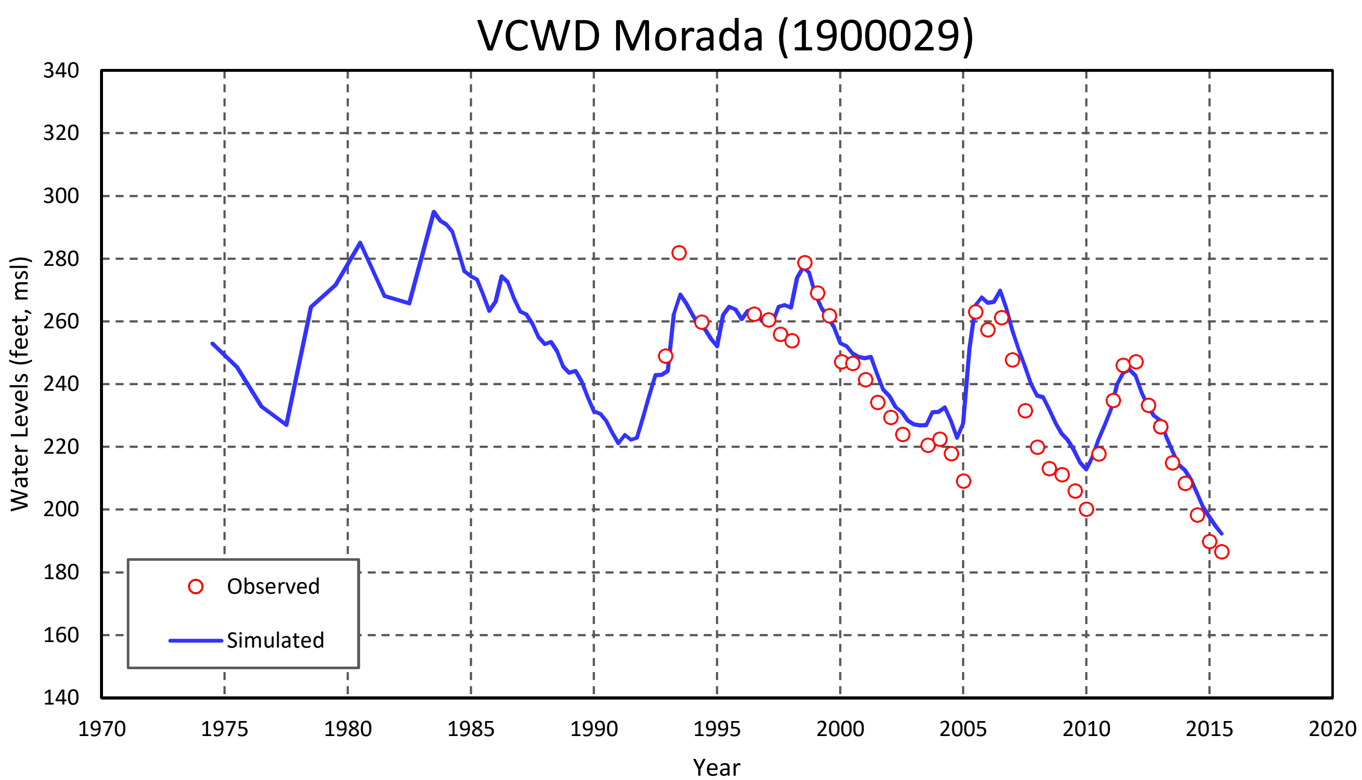
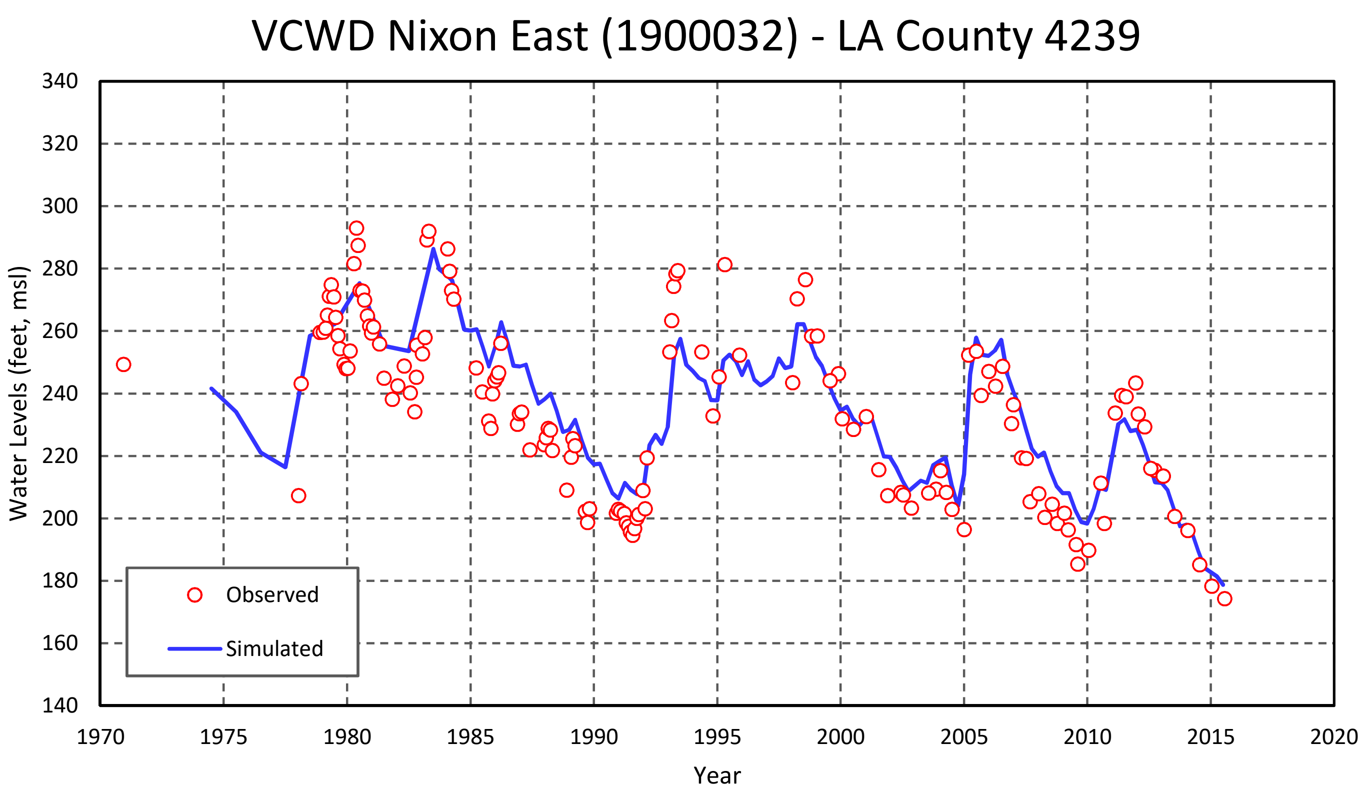
MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results
Observed versus Simulated

MainSanGabrielBasin WATERMASTER



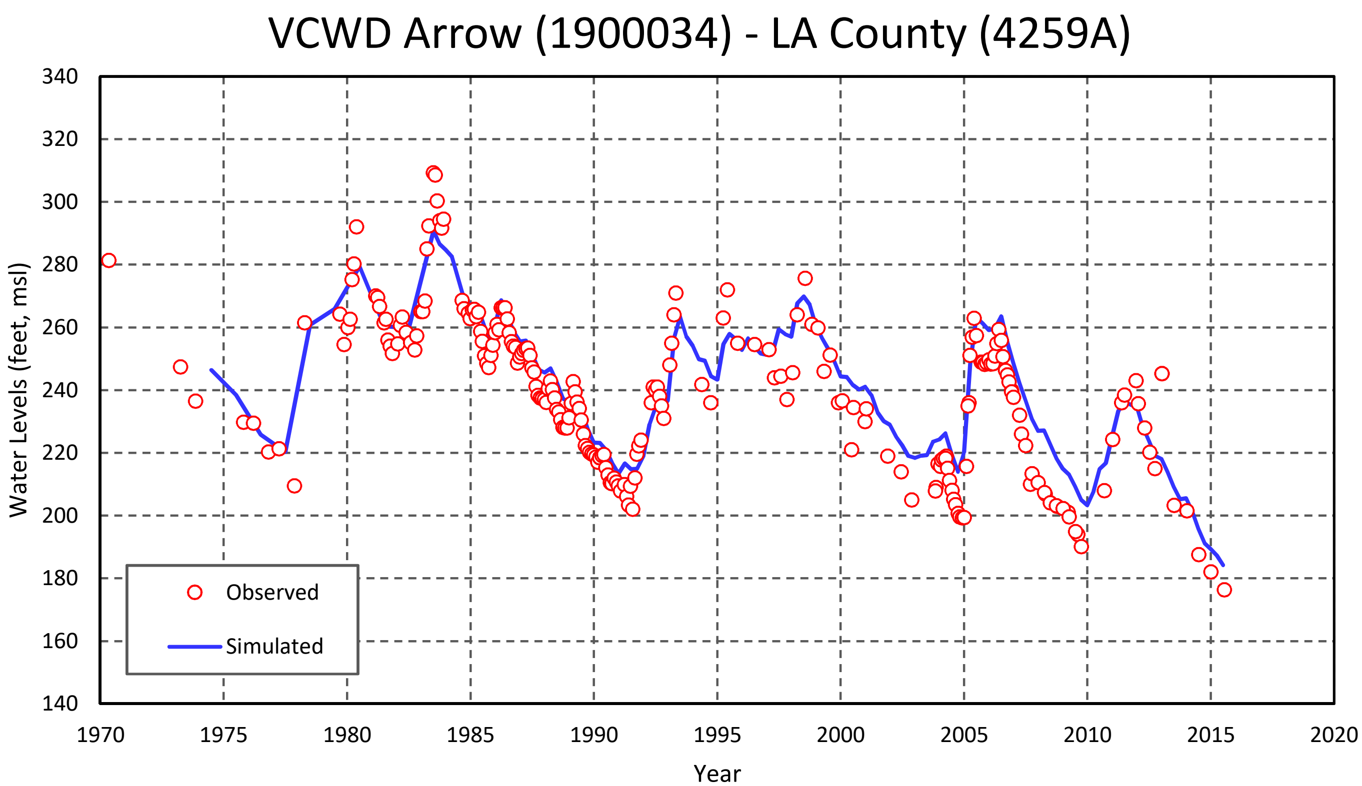


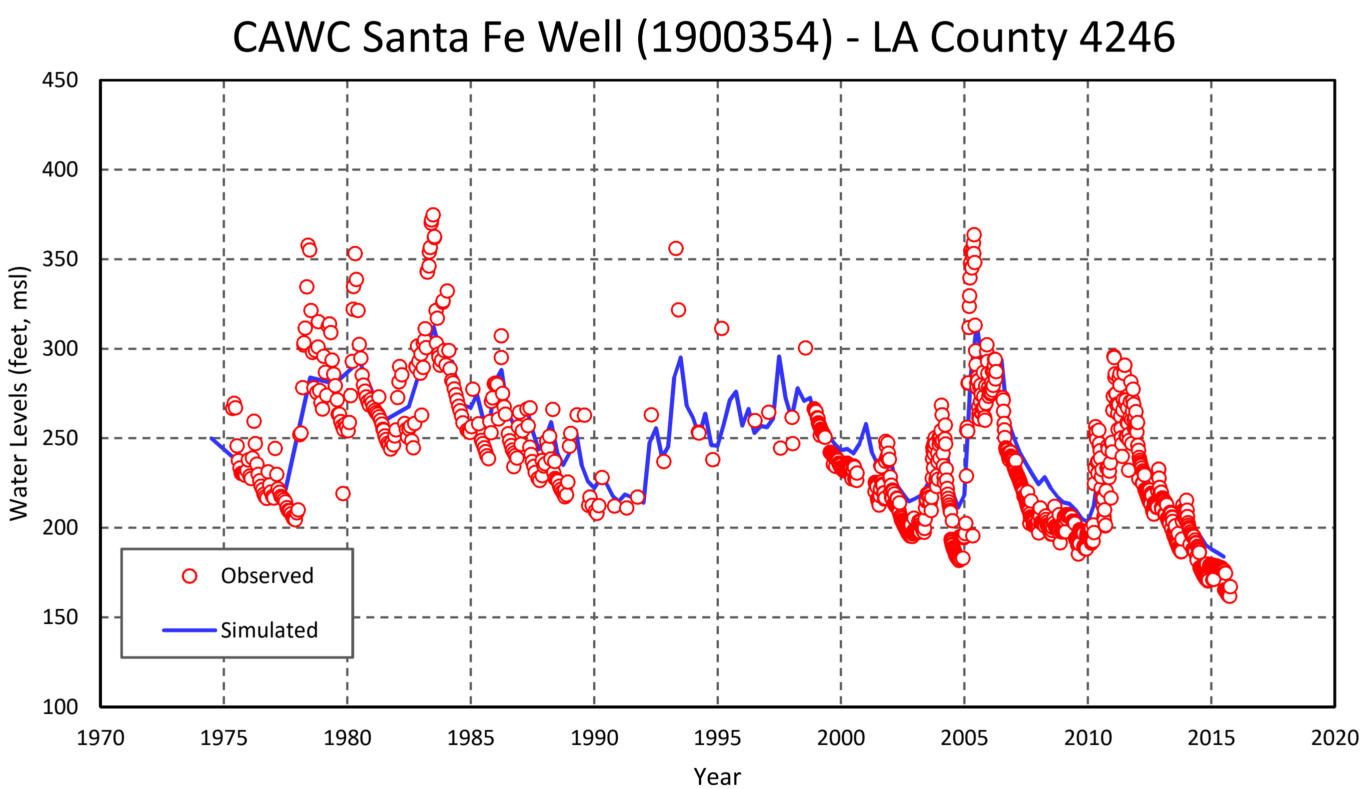
STETSON ENGINEERS INC.

MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results
Observed versus Simulated

MainSanGabrielBasin WATERMASTER





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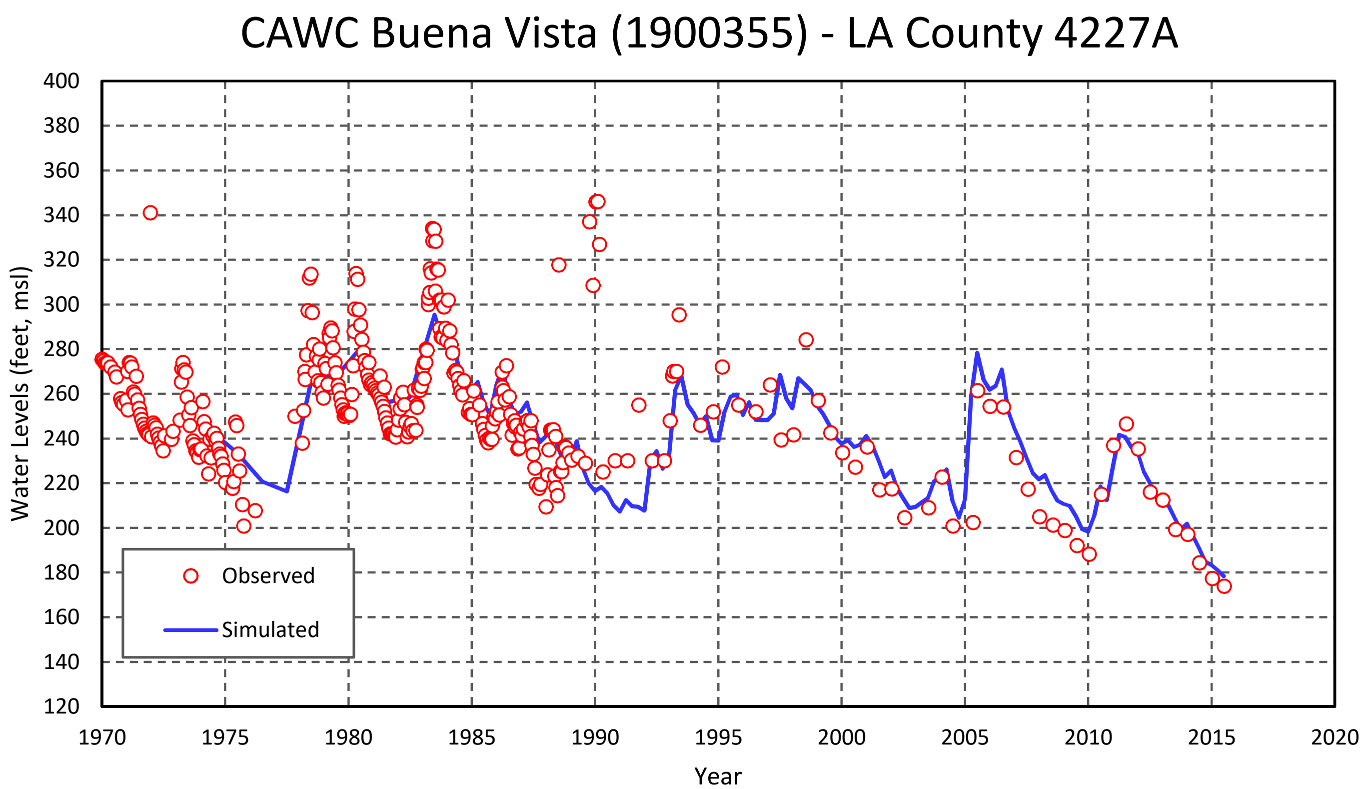
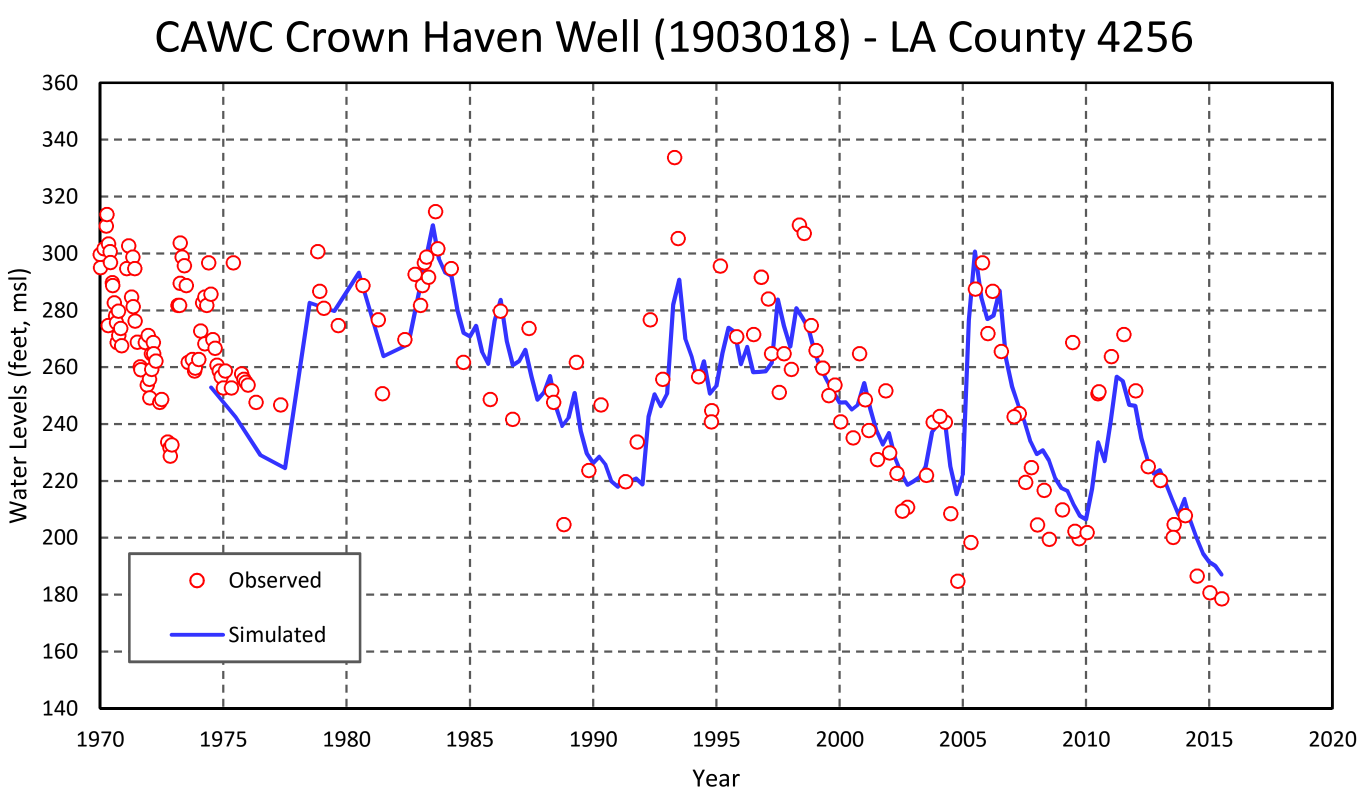
MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results
Observed versus Simulated

MainSanGabrielBasin WATERMASTER

FIGURE 10



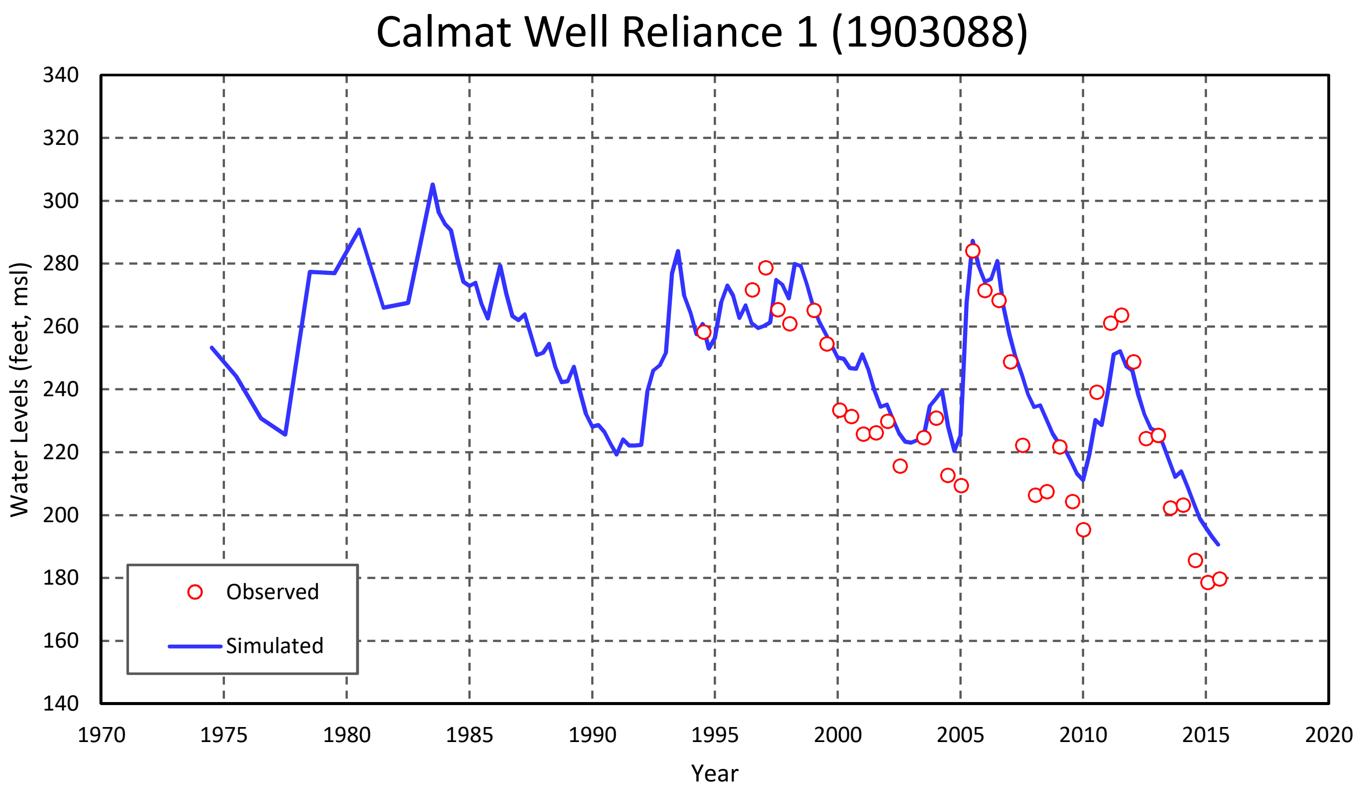


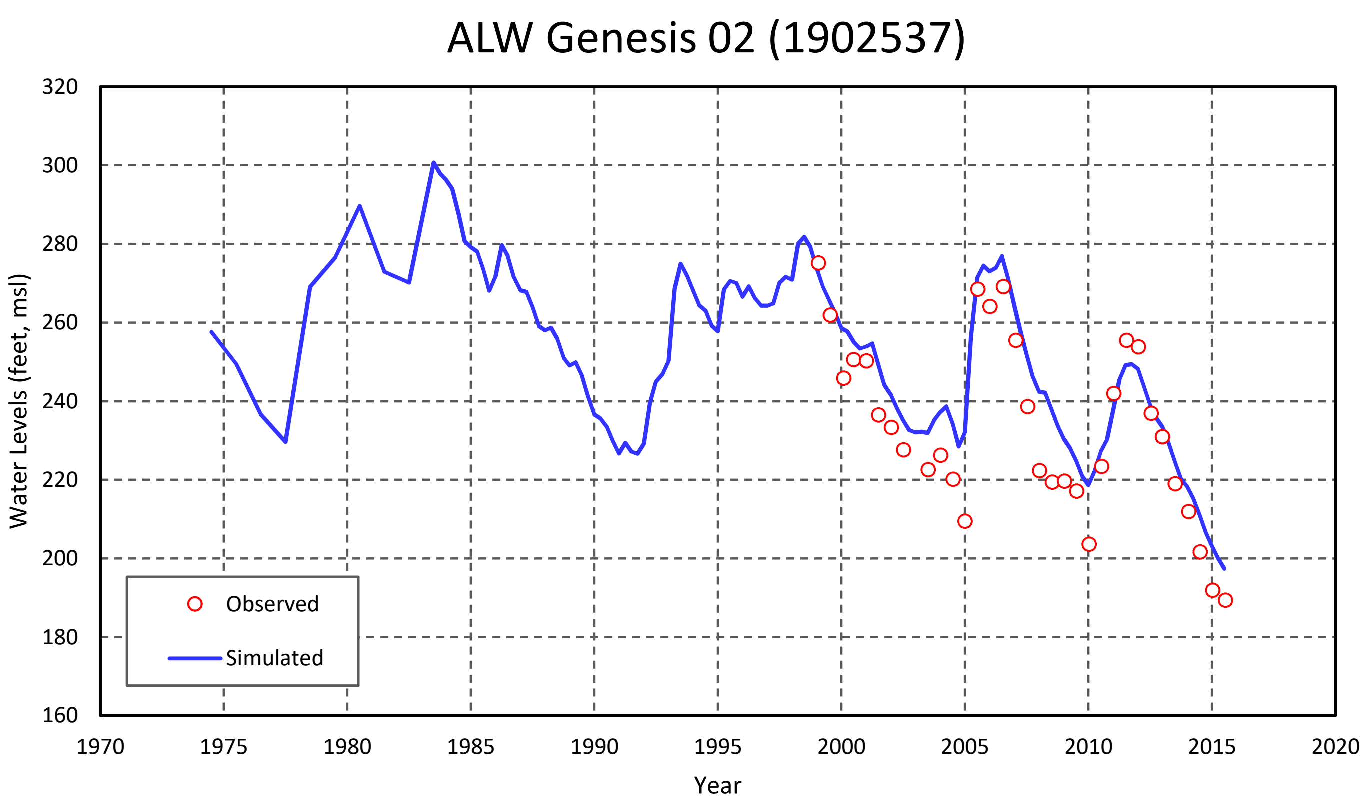
STETSON ENGINEERS INC.

MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results
Observed versus Simulated

MainSanGabrielBasin WATERMASTER





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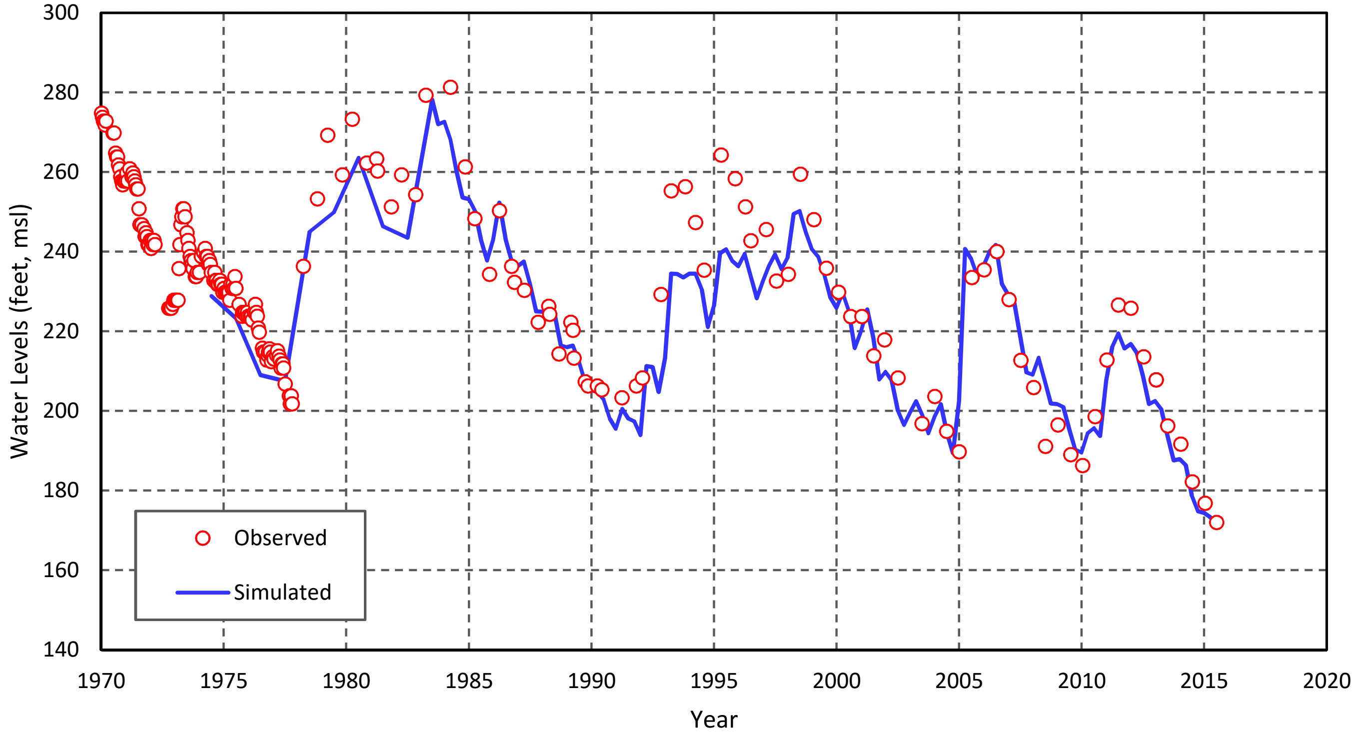
MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results
Observed versus Simulated

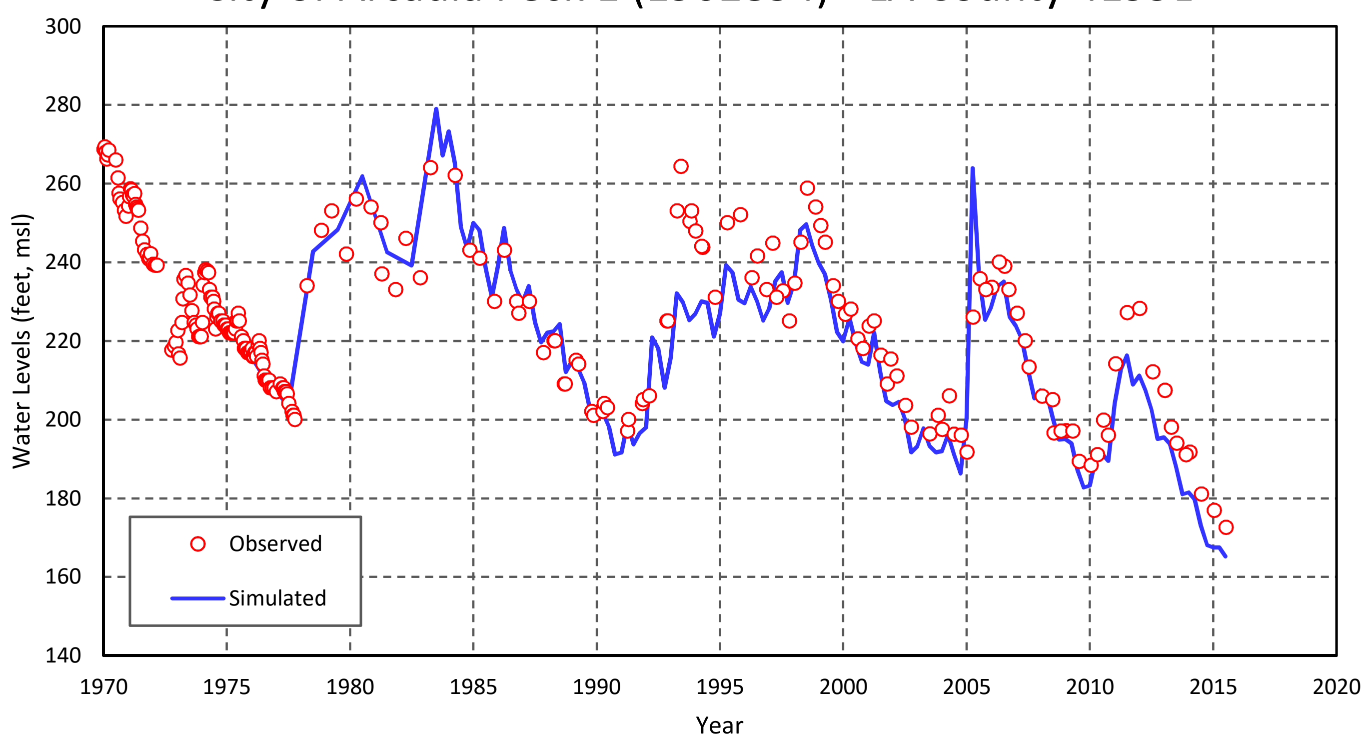
MainSanGabrielBasin WATERMASTER

FIGURE 10

City of Arcadia Longden 2 (1901014) - LA County 4198G



City of Arcadia Peck 1 (1902854) - LA County 4199L

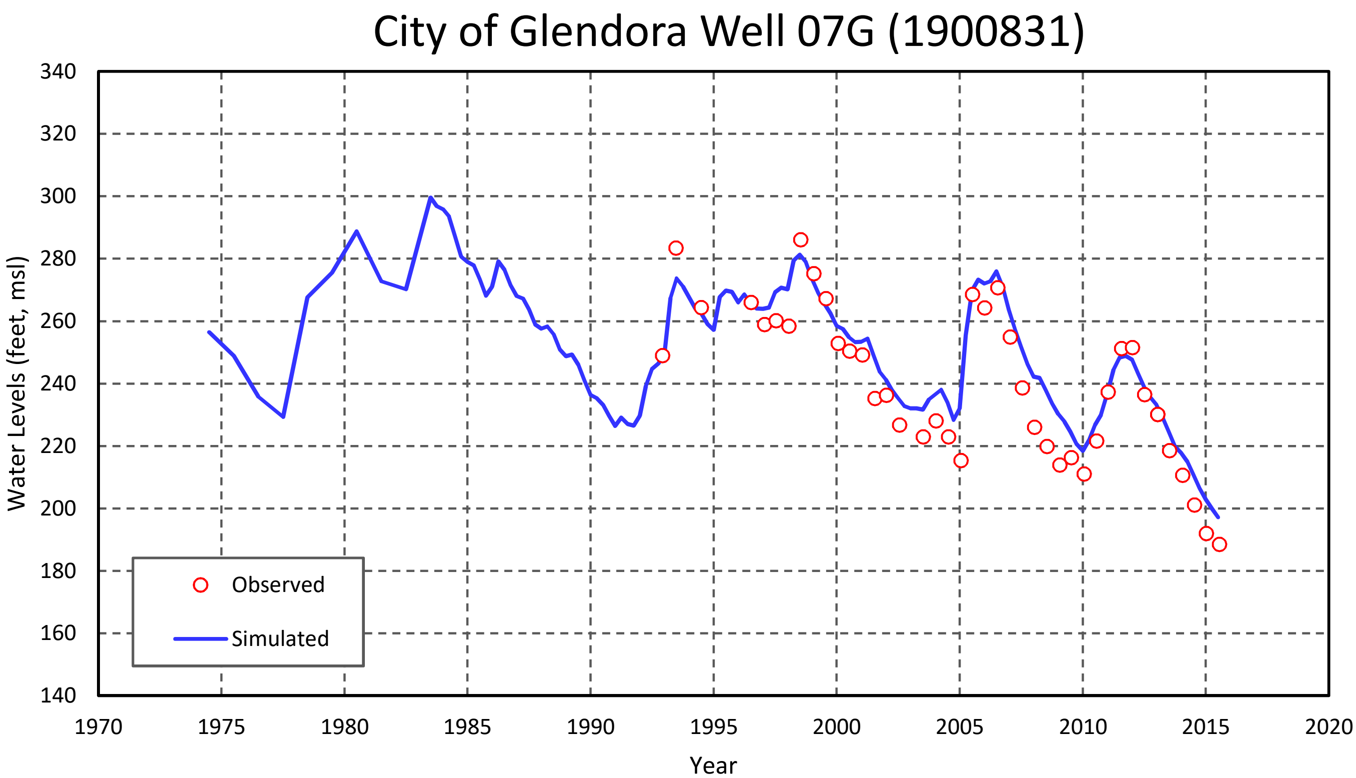


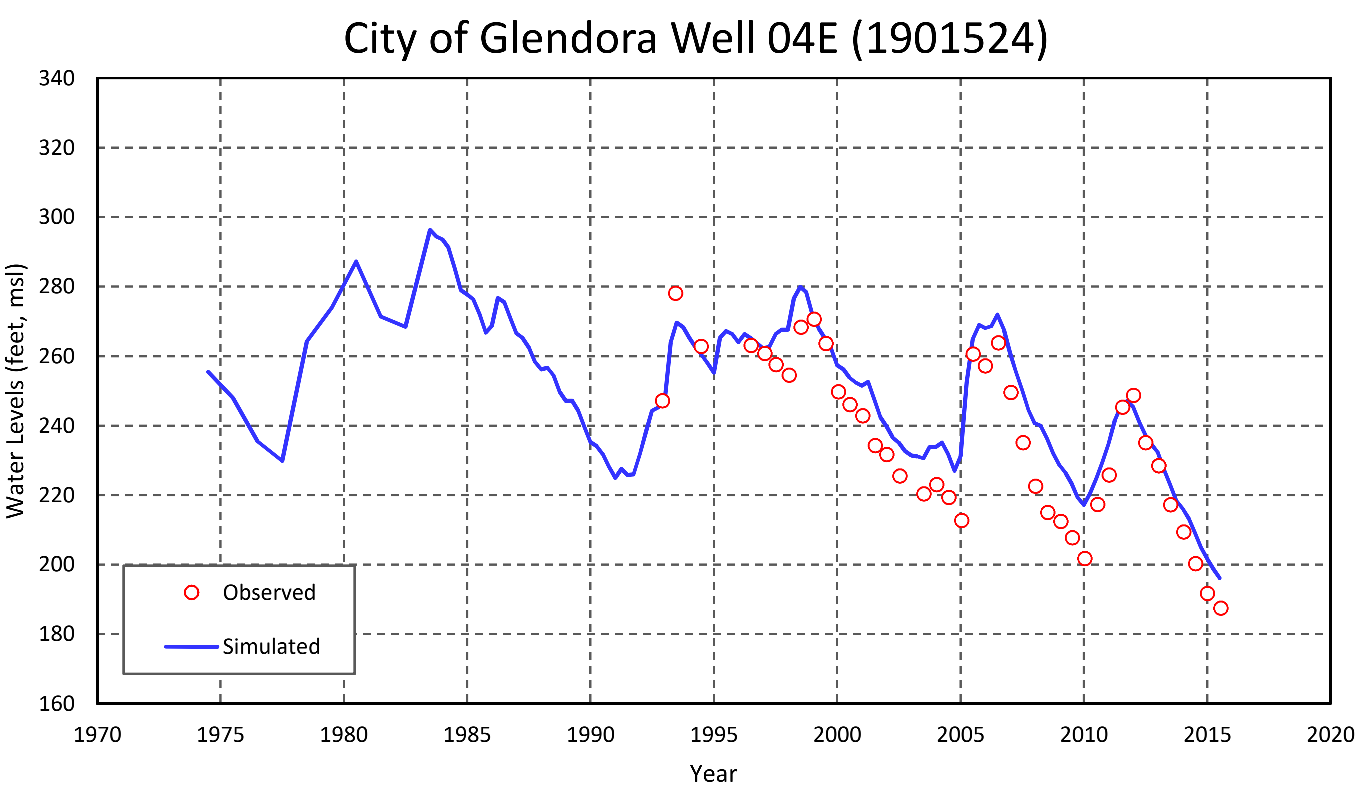
STETSON ENGINEERS INC.

MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results
Observed versus Simulated

MainSanGabrielBasin WATERMASTER





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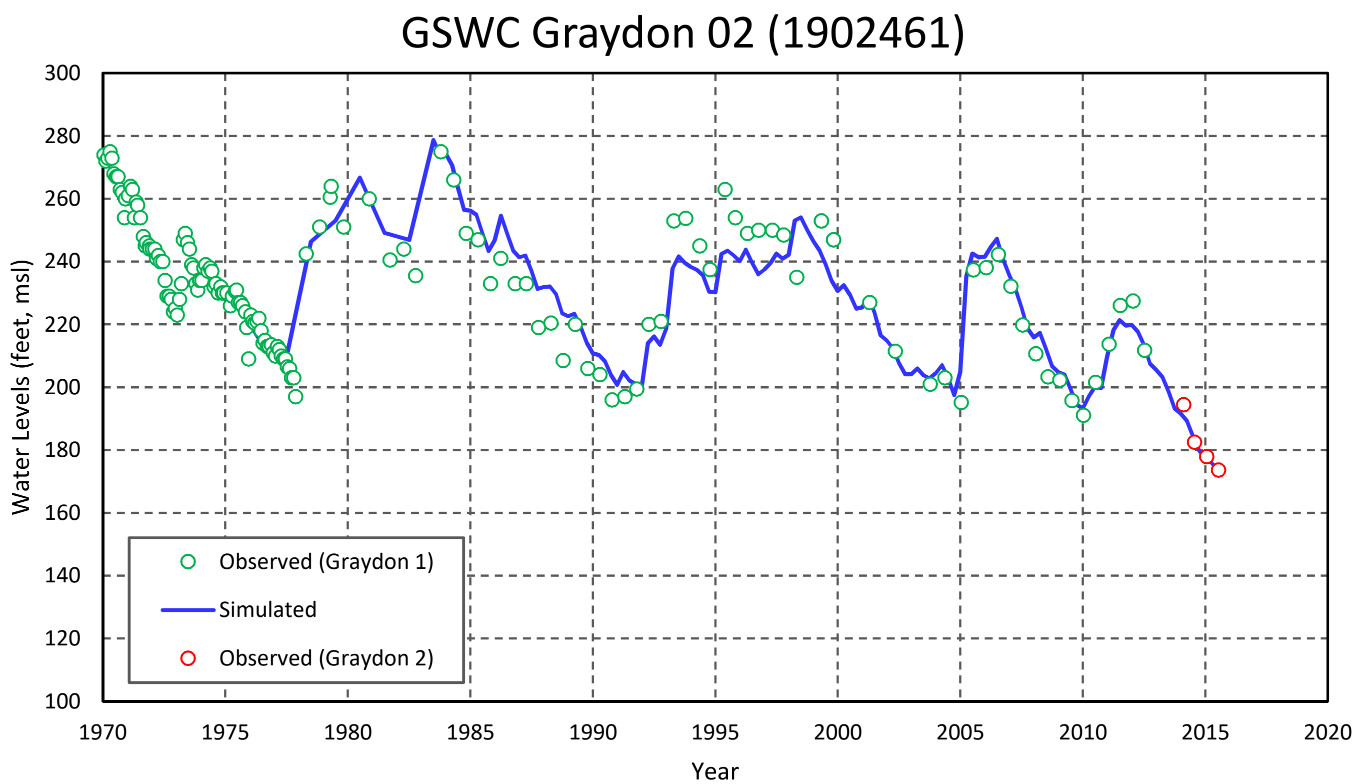
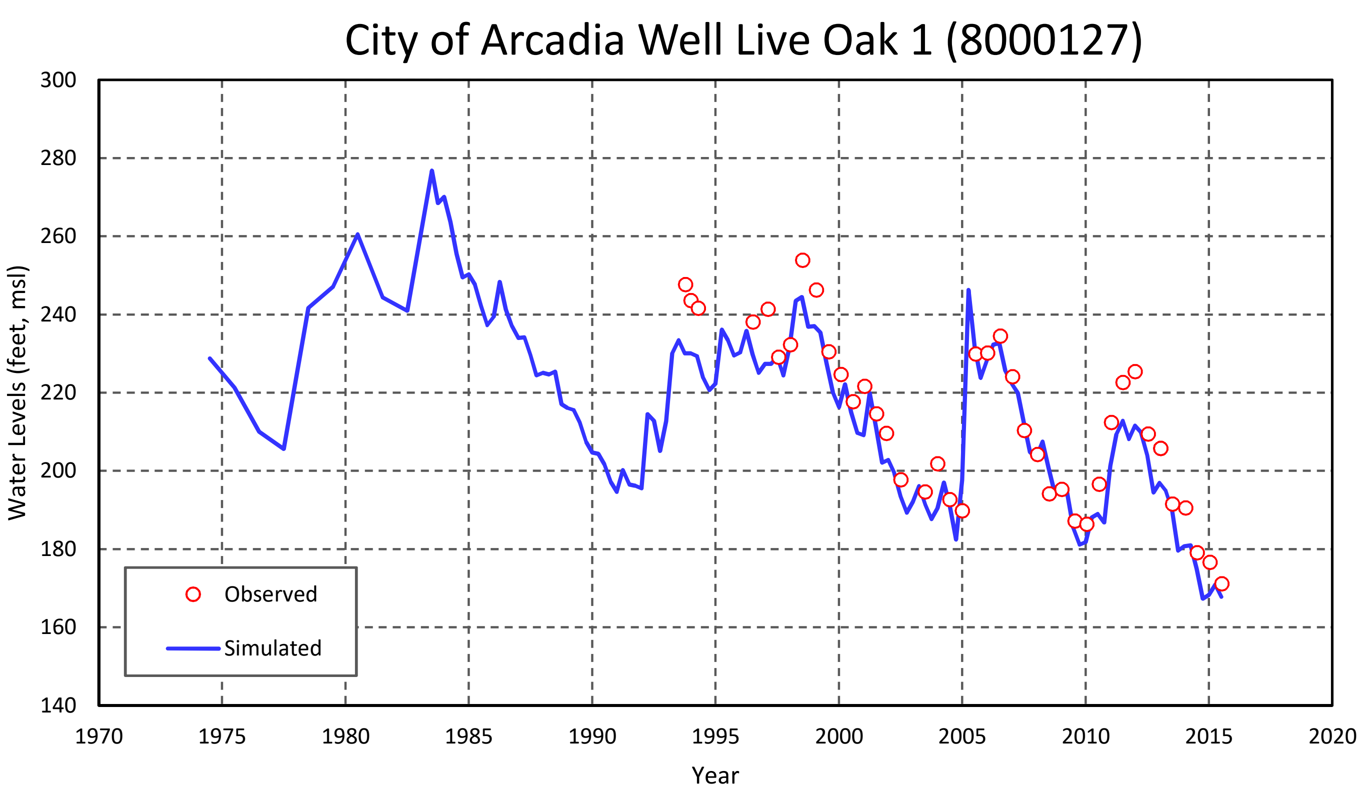
MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results
Observed versus Simulated

MainSanGabrielBasin WATERMASTER

FIGURE 10



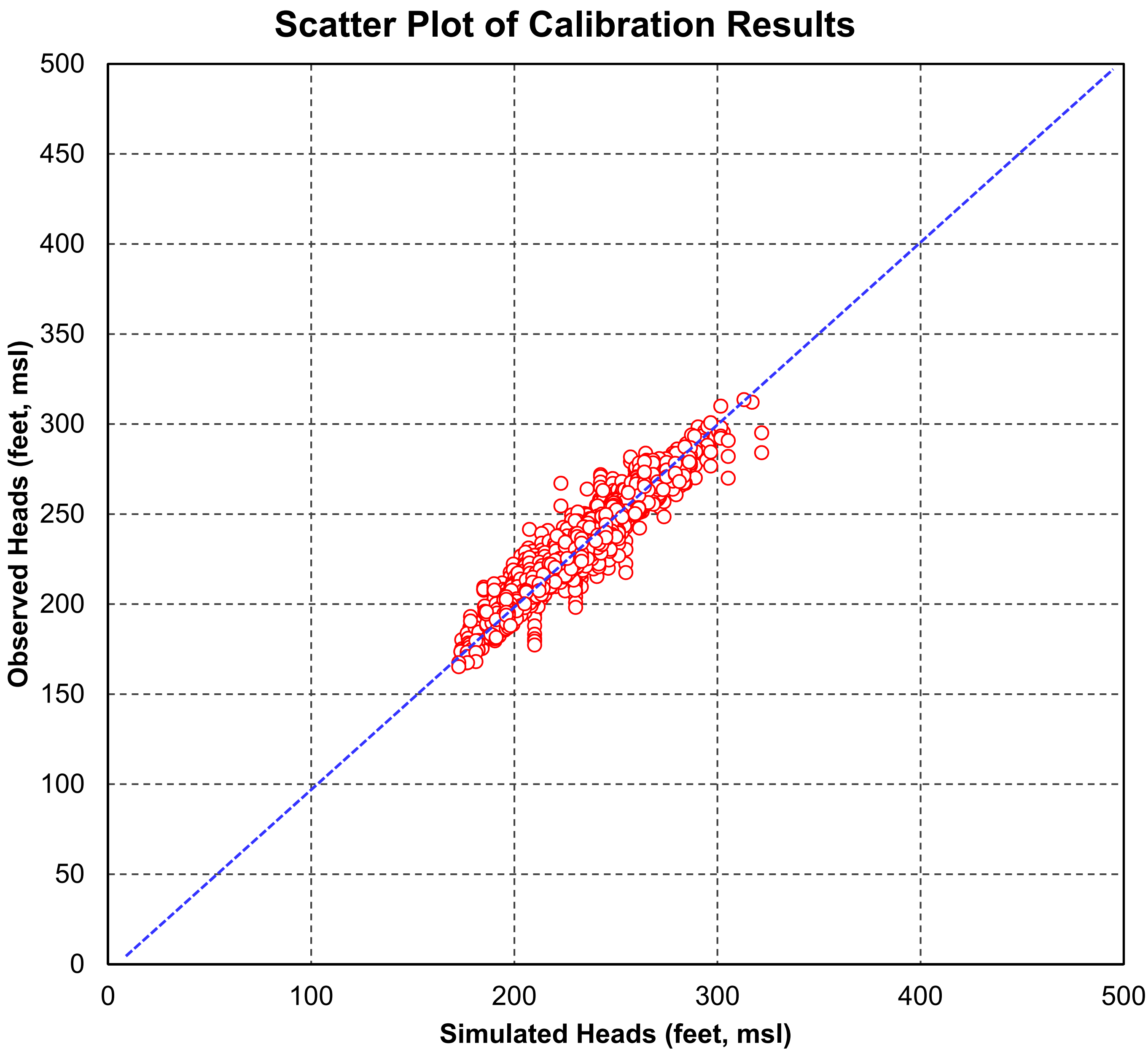


STETSON ENGINEERS INC.

MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results
Observed versus Simulated

MainSanGabrielBasin WATERMASTER



Root Mean Square Error (RMSE) : 8.04 ft
Residual Mean (RM) : -1.37 ft
Residual Standard Deviation (σ_R) : 8.04 ft

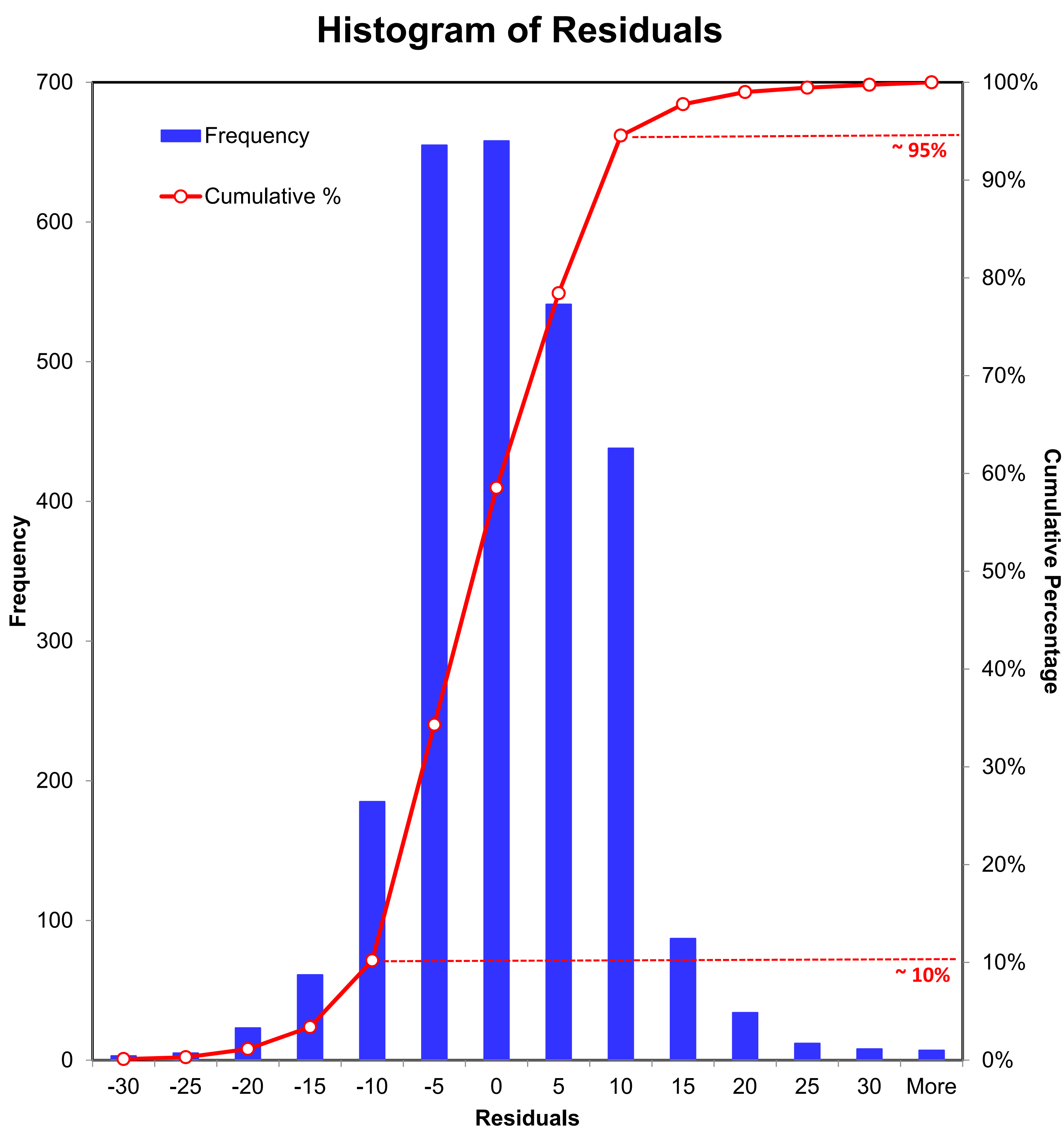
MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results

Scatter Plot of Simulated Heads versus Observed Heads

STETSON ENGINEERS INC.

MainSanGabrielBasin WATERMASTER



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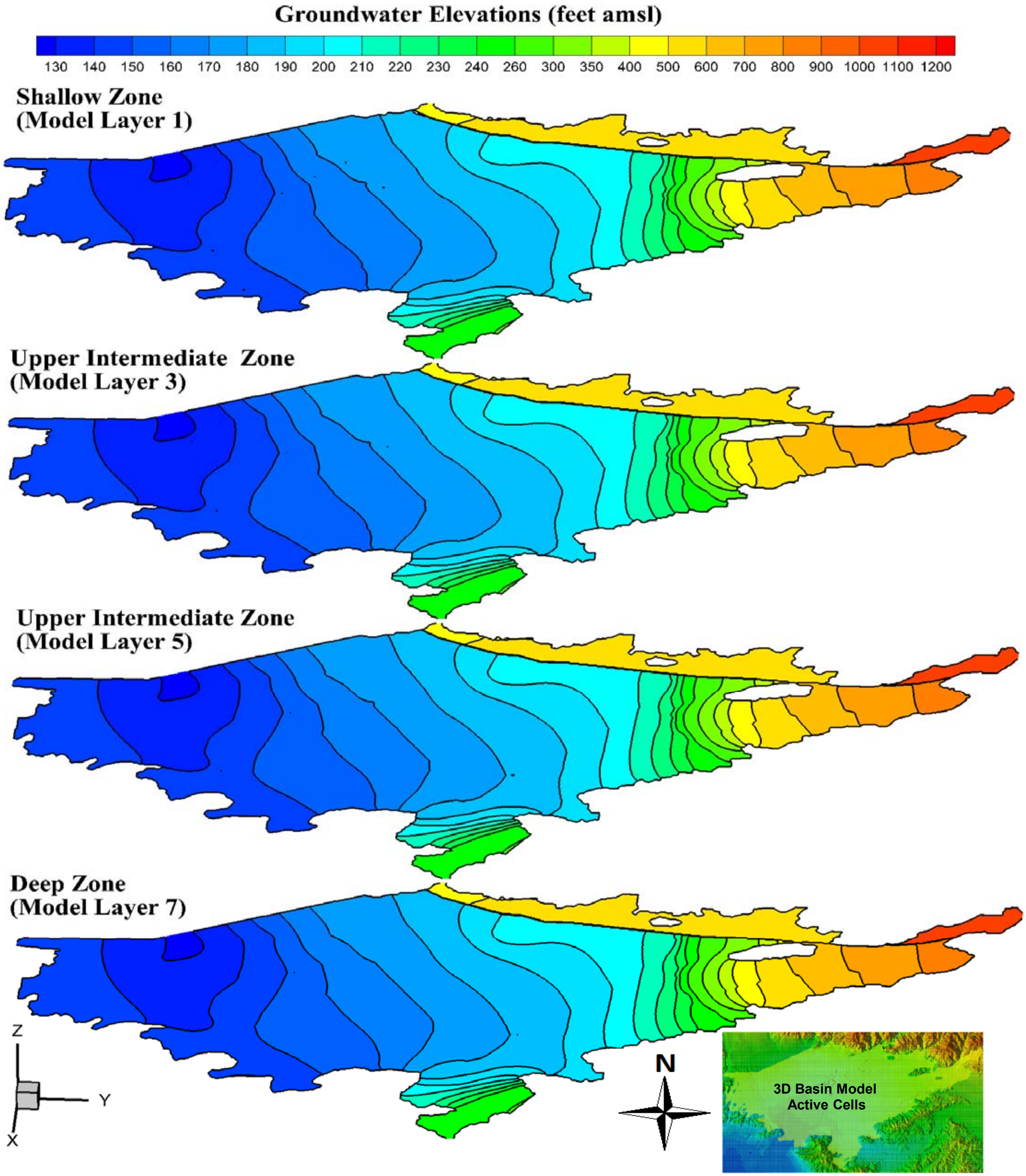
MAIN SAN GABRIEL BASIN WATERMASTER

Calibration Results
Residual of Histogram
Simulated Head versus Observed Head

MainSanGabrielBasin WATERMASTER



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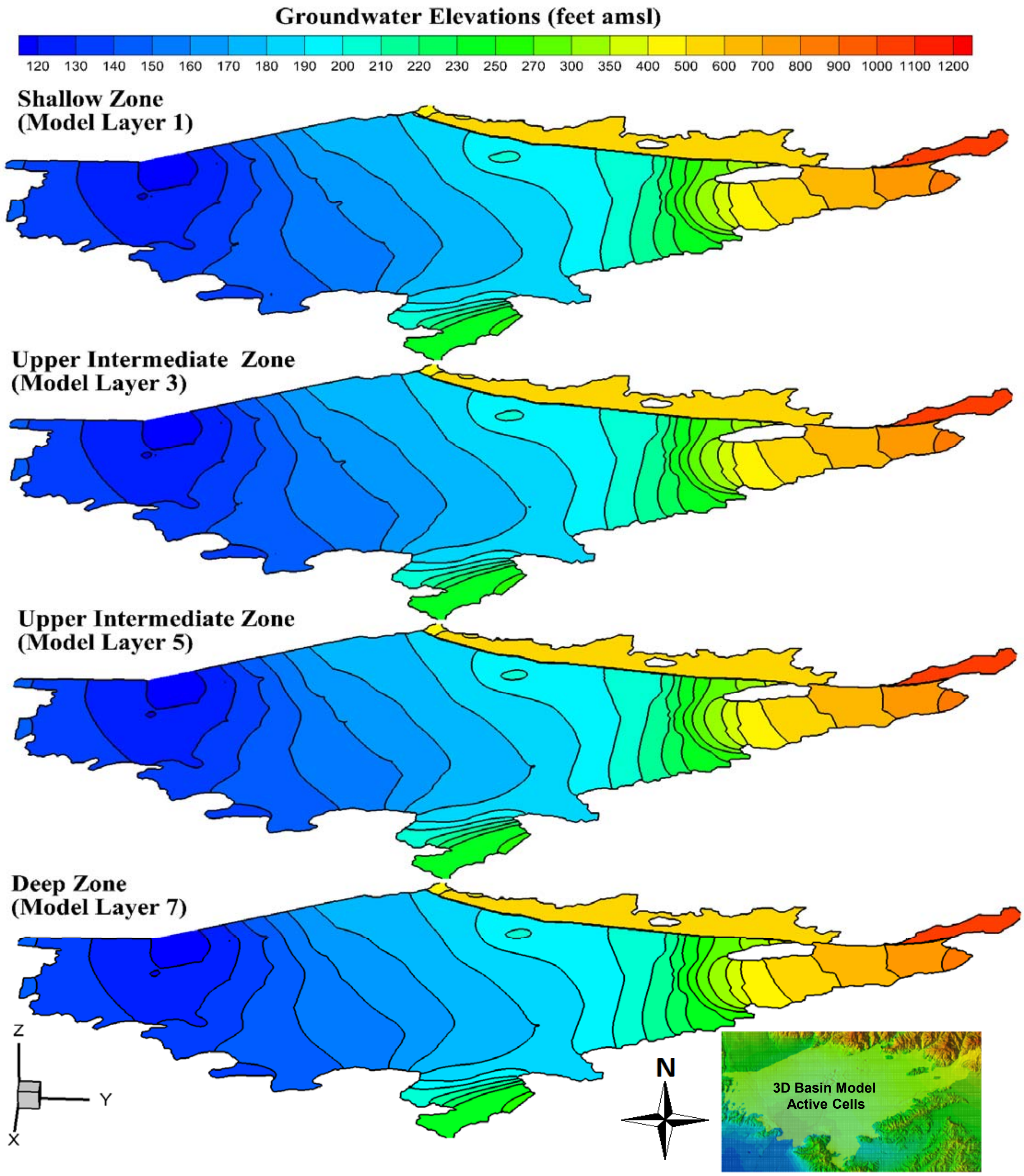
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2015-16 Groundwater Elevation Contours

MainSanGabrielBasin WATERMASTER



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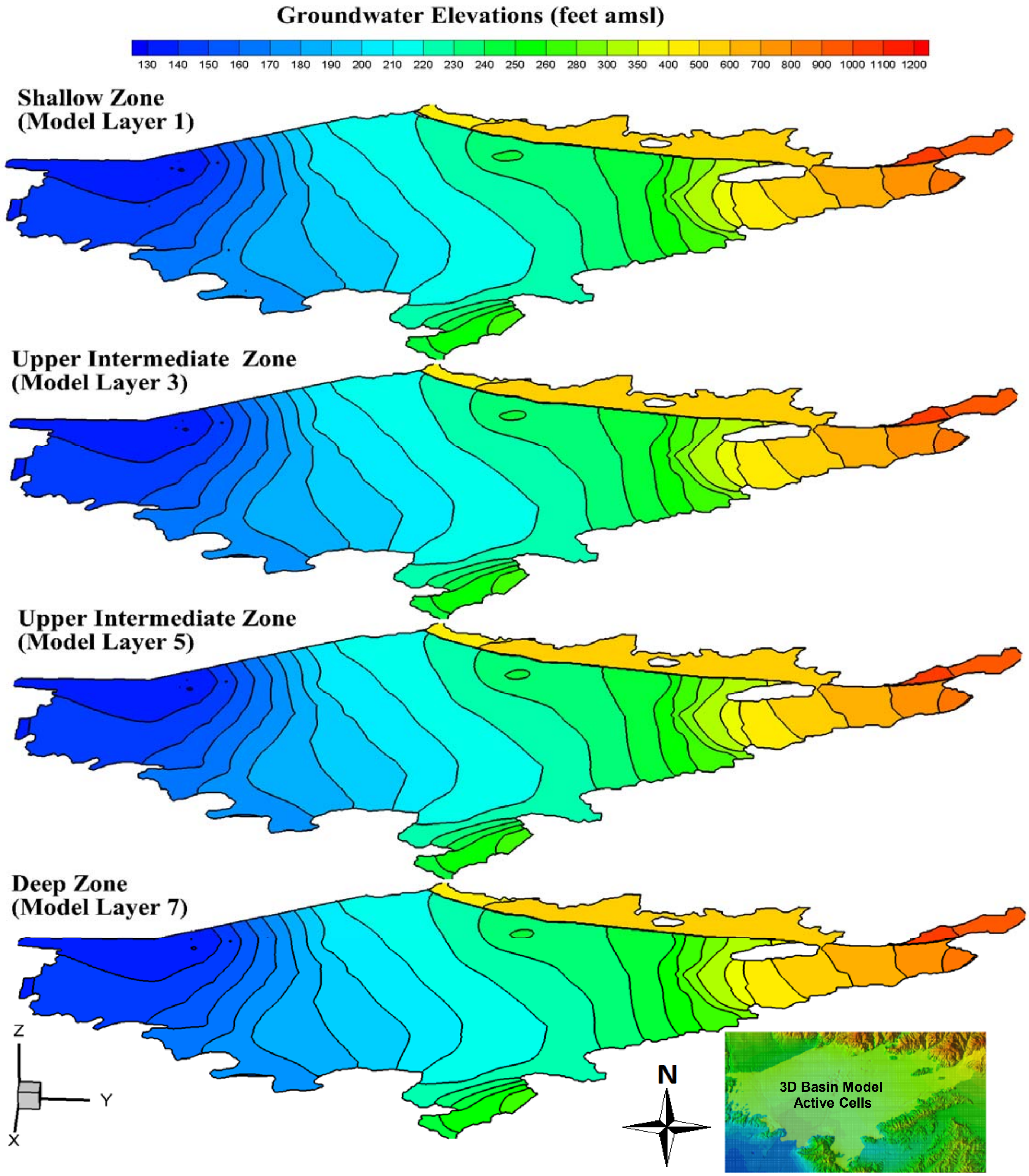
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2020-21 Groundwater Elevation Contours

MainSanGabrielBasin WATERMASTER



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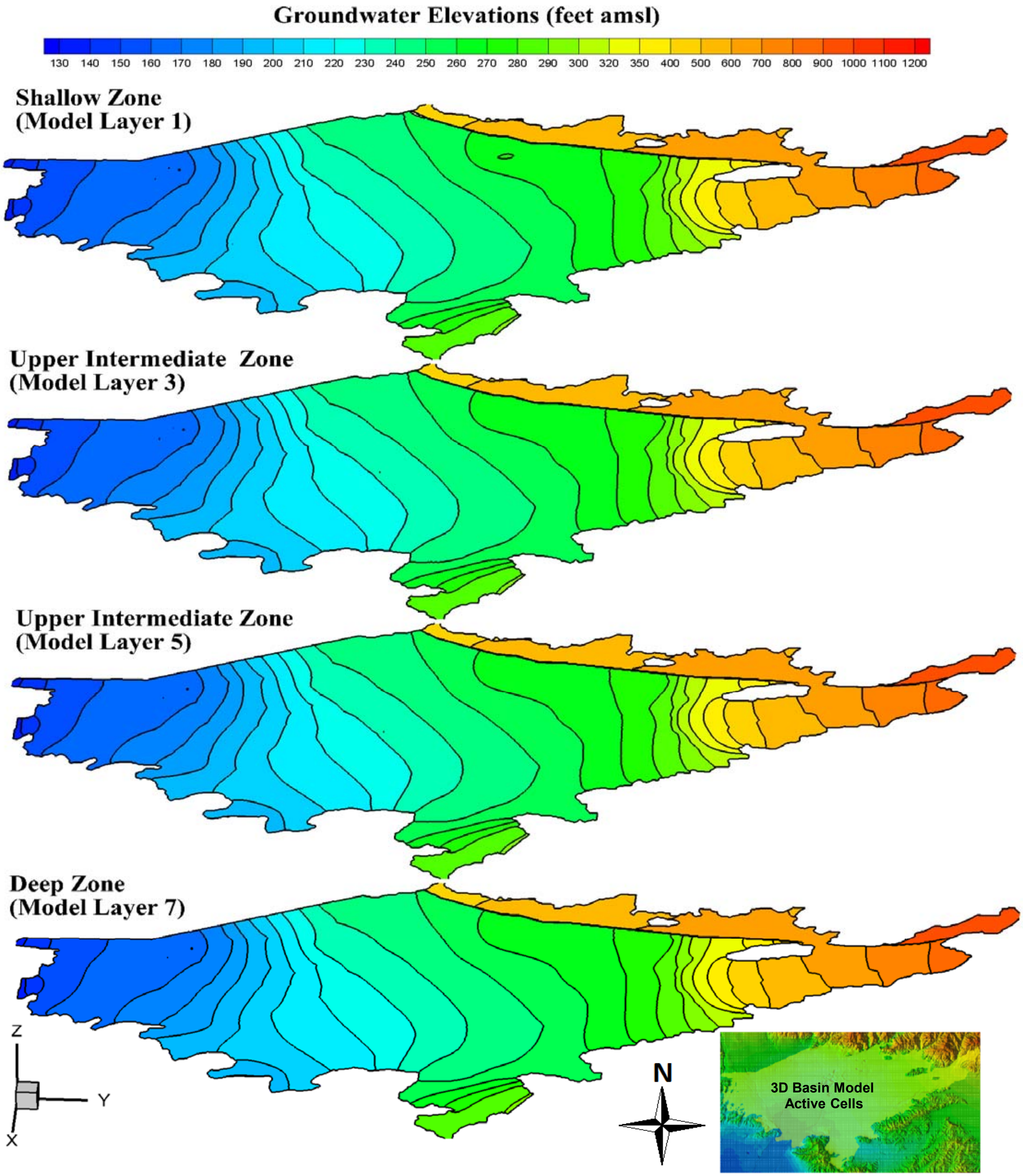
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2025-26
Groundwater Elevation Contours

MainSanGabrielBasin WATERMASTER



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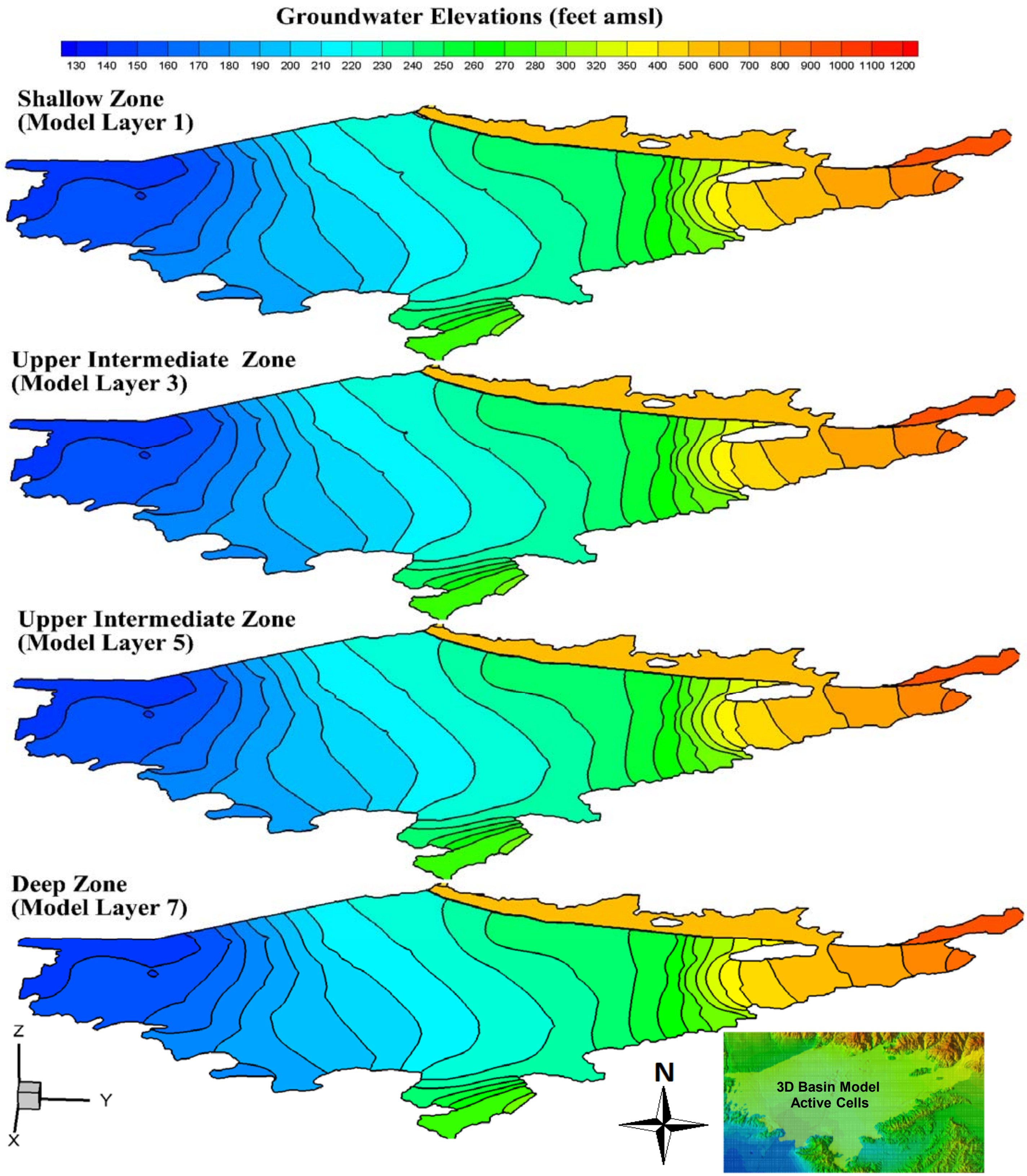
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2030-31 Groundwater Elevation Contours

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 13 - 3D Basin Model Simulated Contours(39MGD).xlsx

Figure 13e



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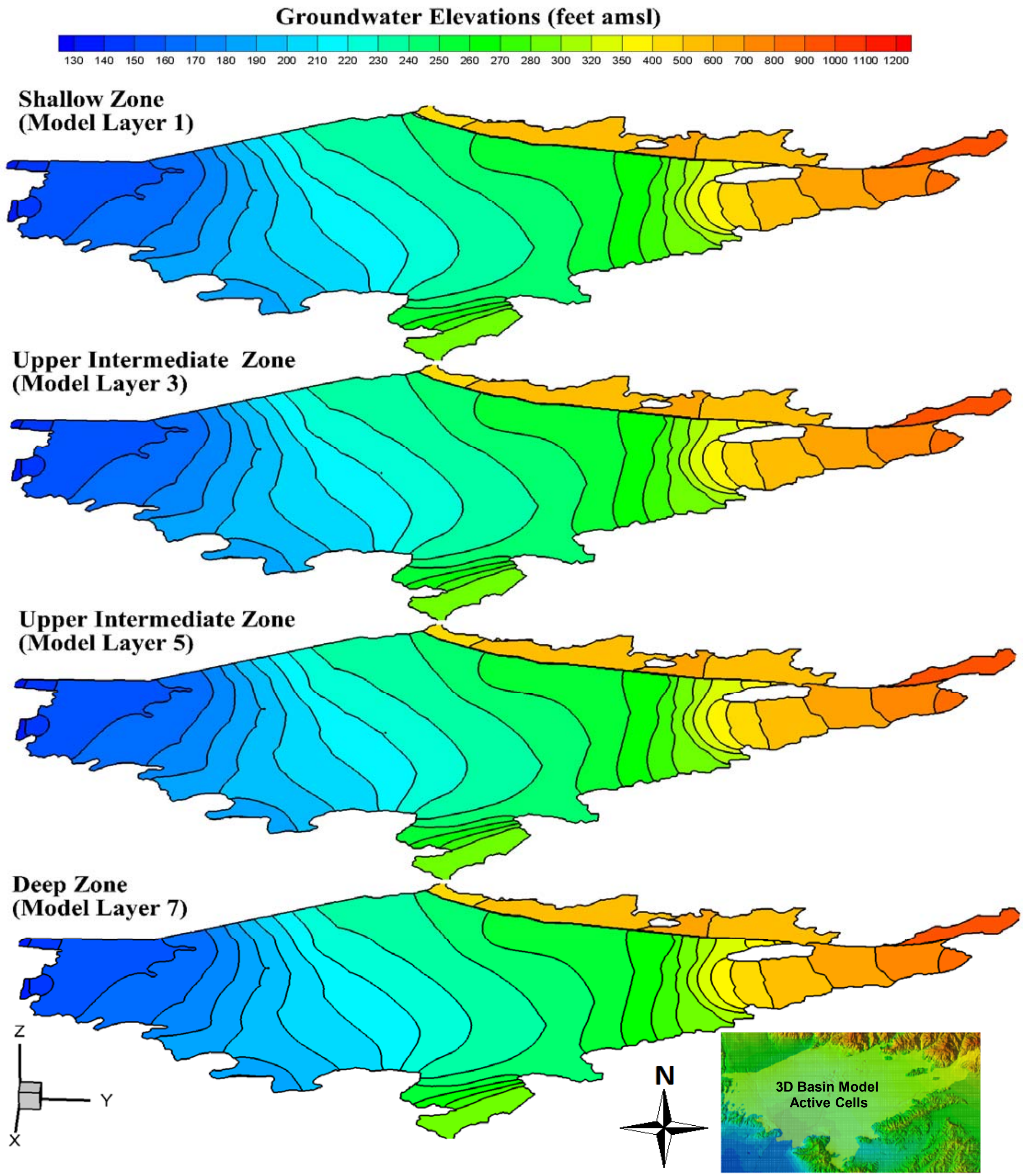
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2035-36 Groundwater Elevation Contours

MainSanGabrielBasin WATERMASTER

Figure 13f



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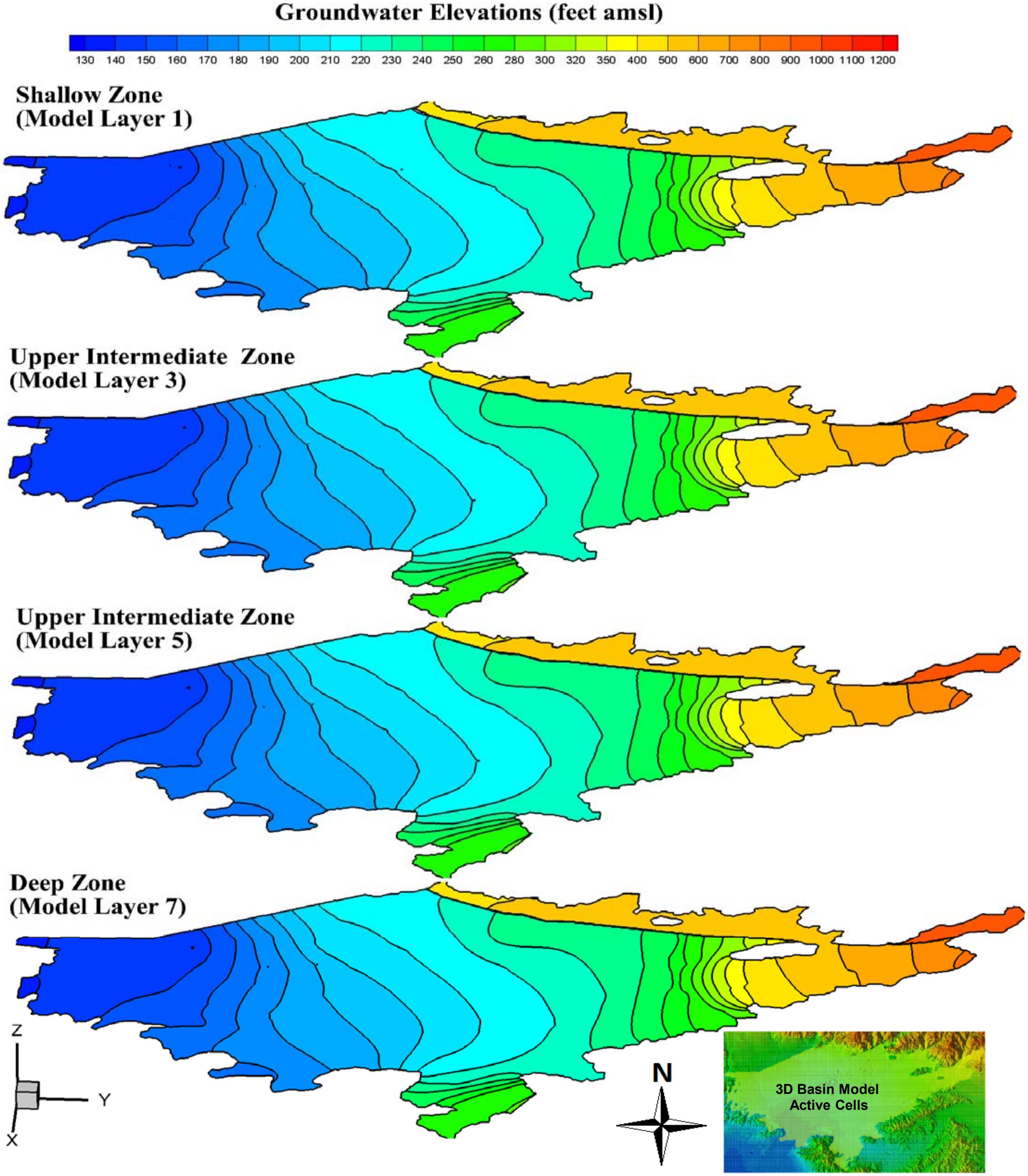
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2040-41
Groundwater Elevation Contours

MainSanGabrielBasin WATERMASTER

Figure 13g



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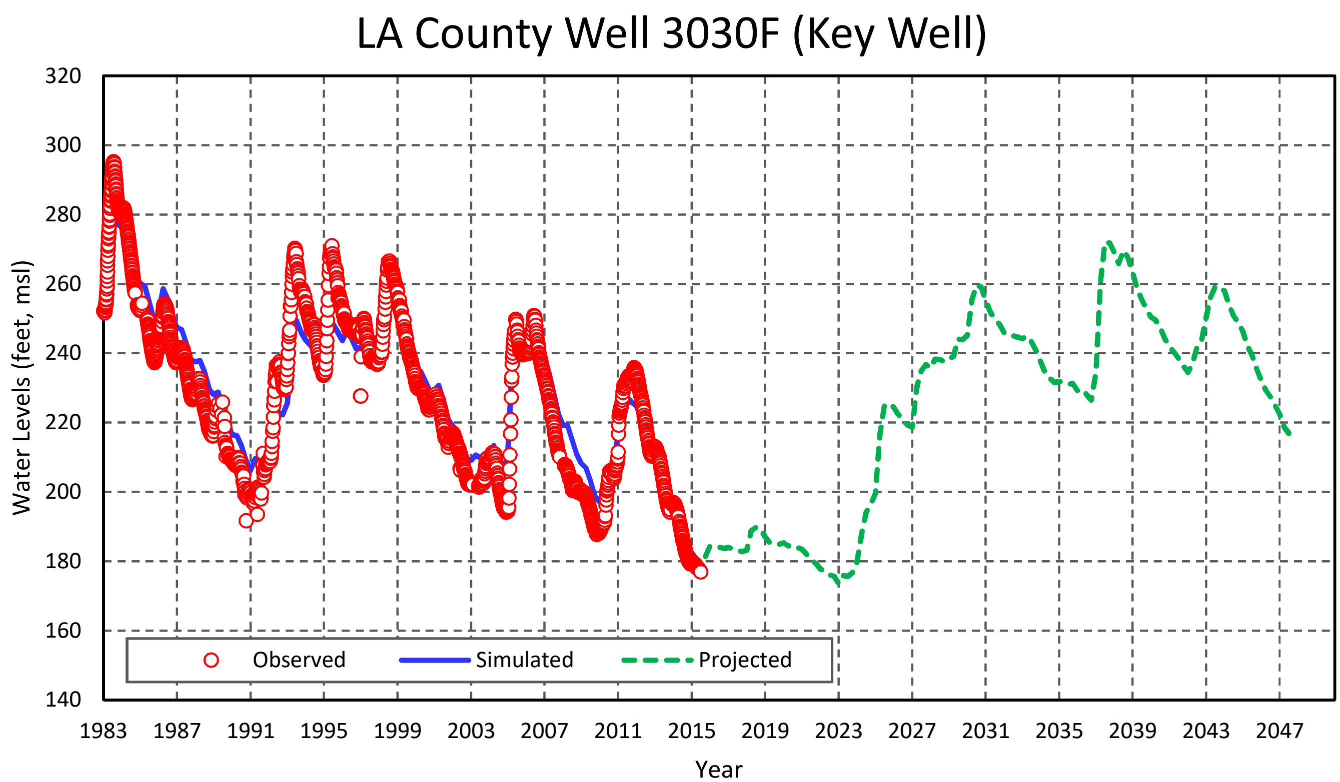
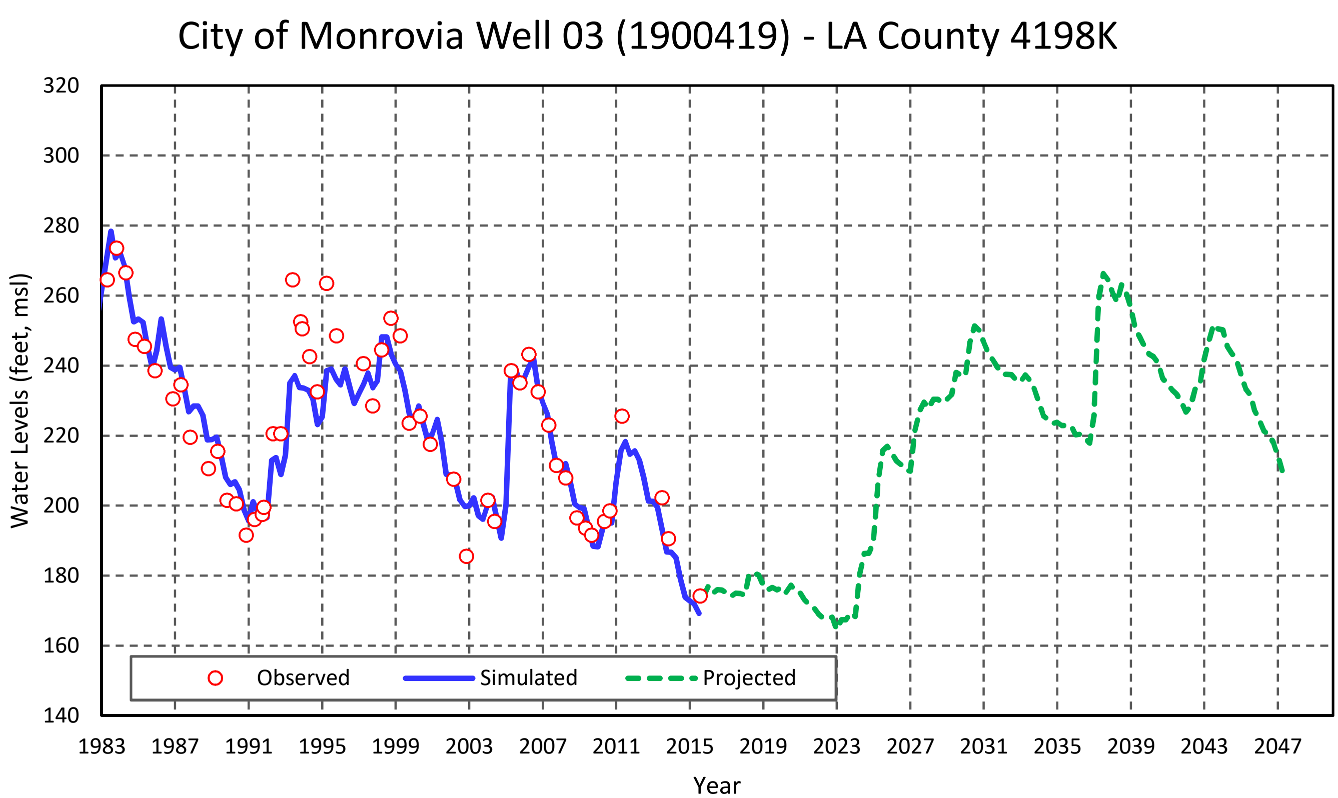
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2046-47
Groundwater Elevation Contours

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 13 - 3D Basin Model Simulated Contours(39MGD).xlsx





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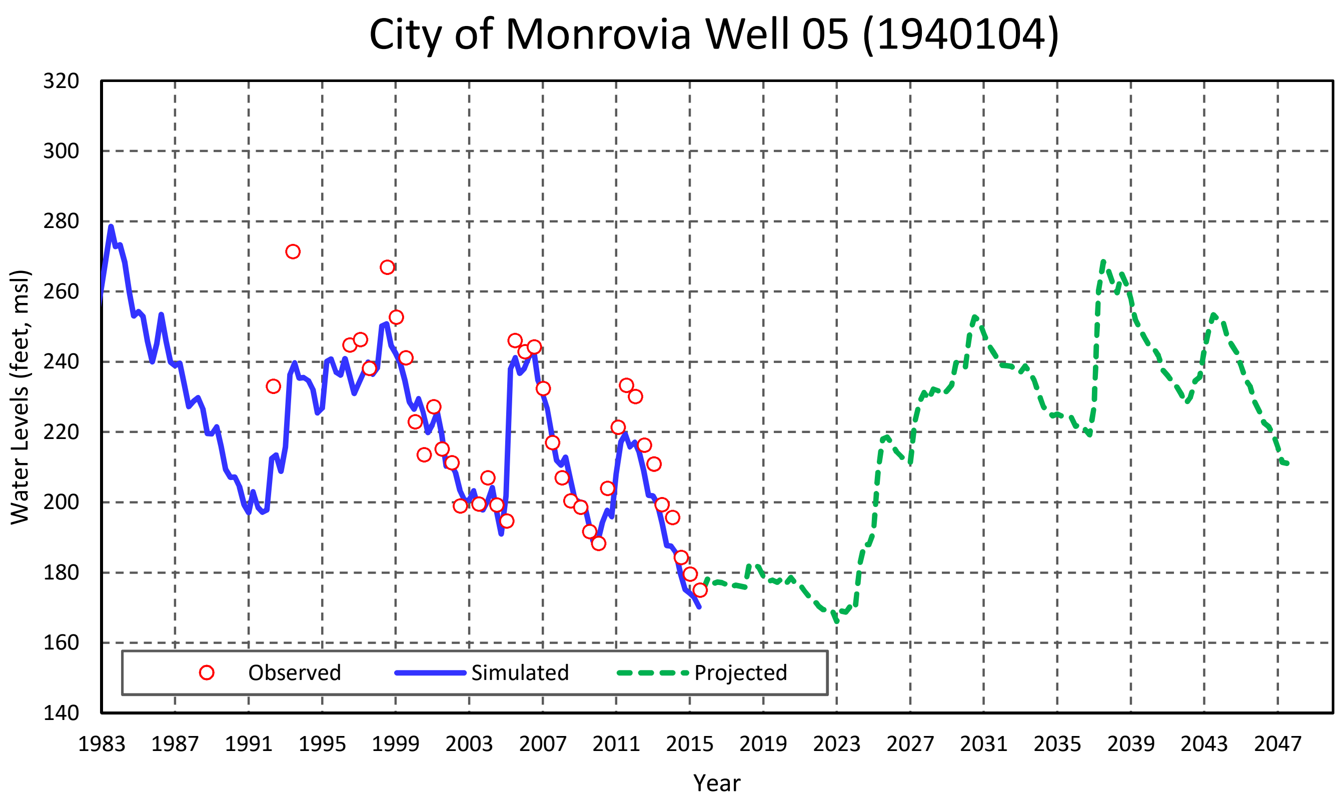
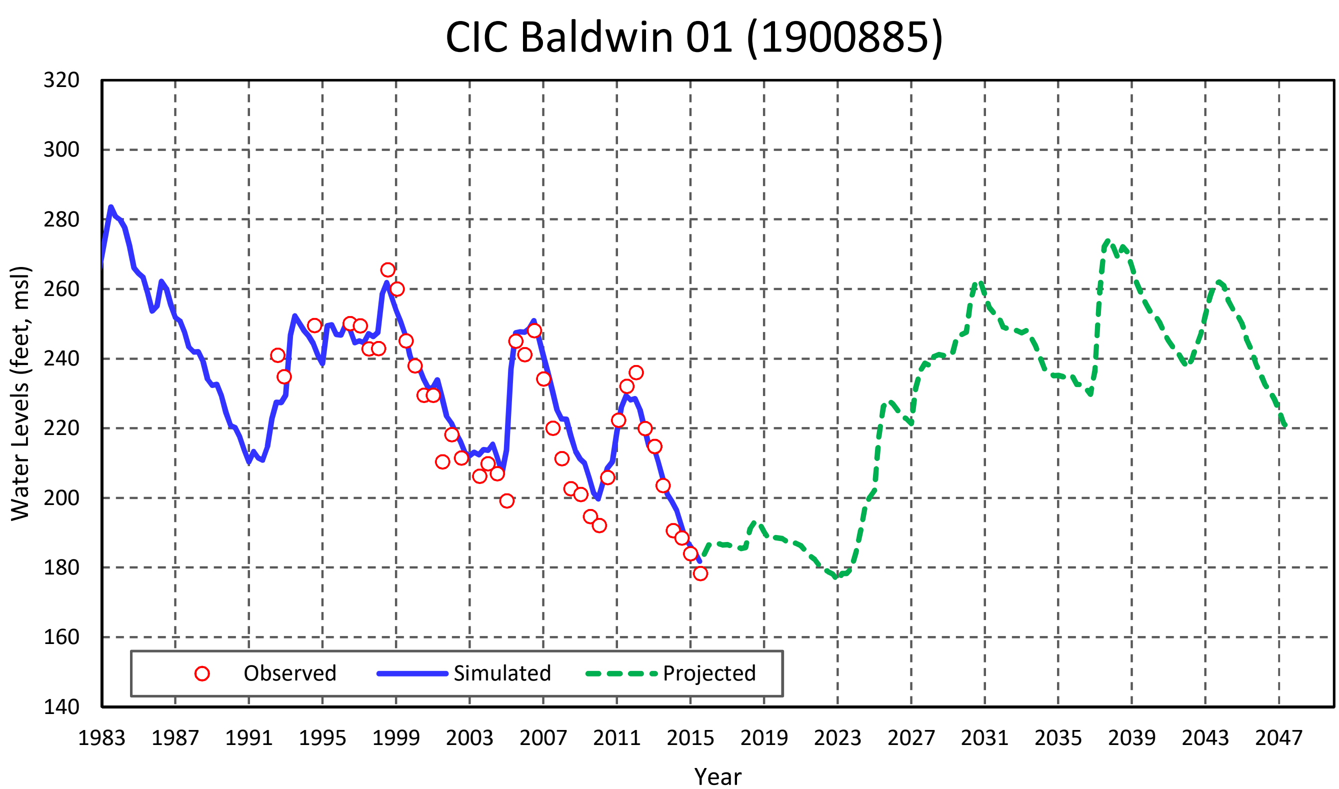
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results (FY 2015-16 to FY 2046-27)

MainSanGabrielBasin WATERMASTER





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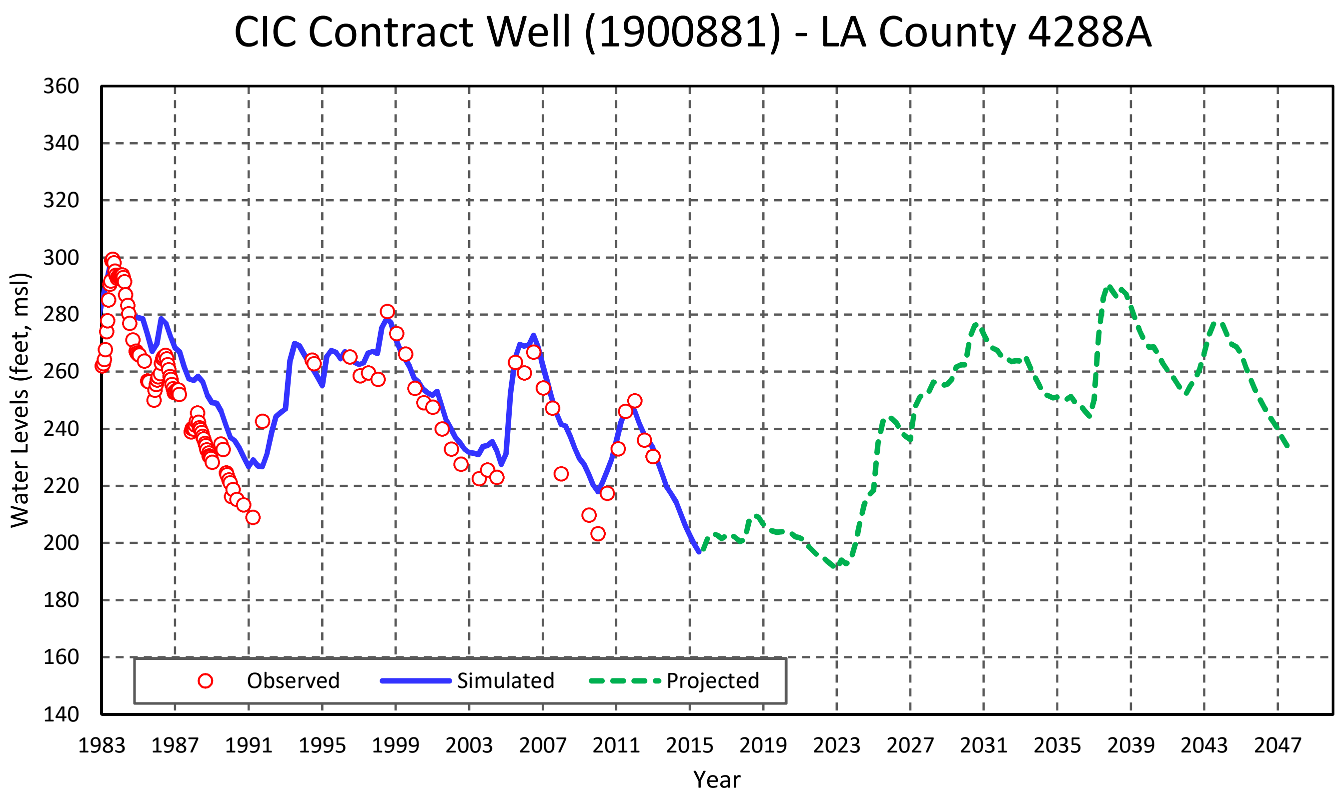
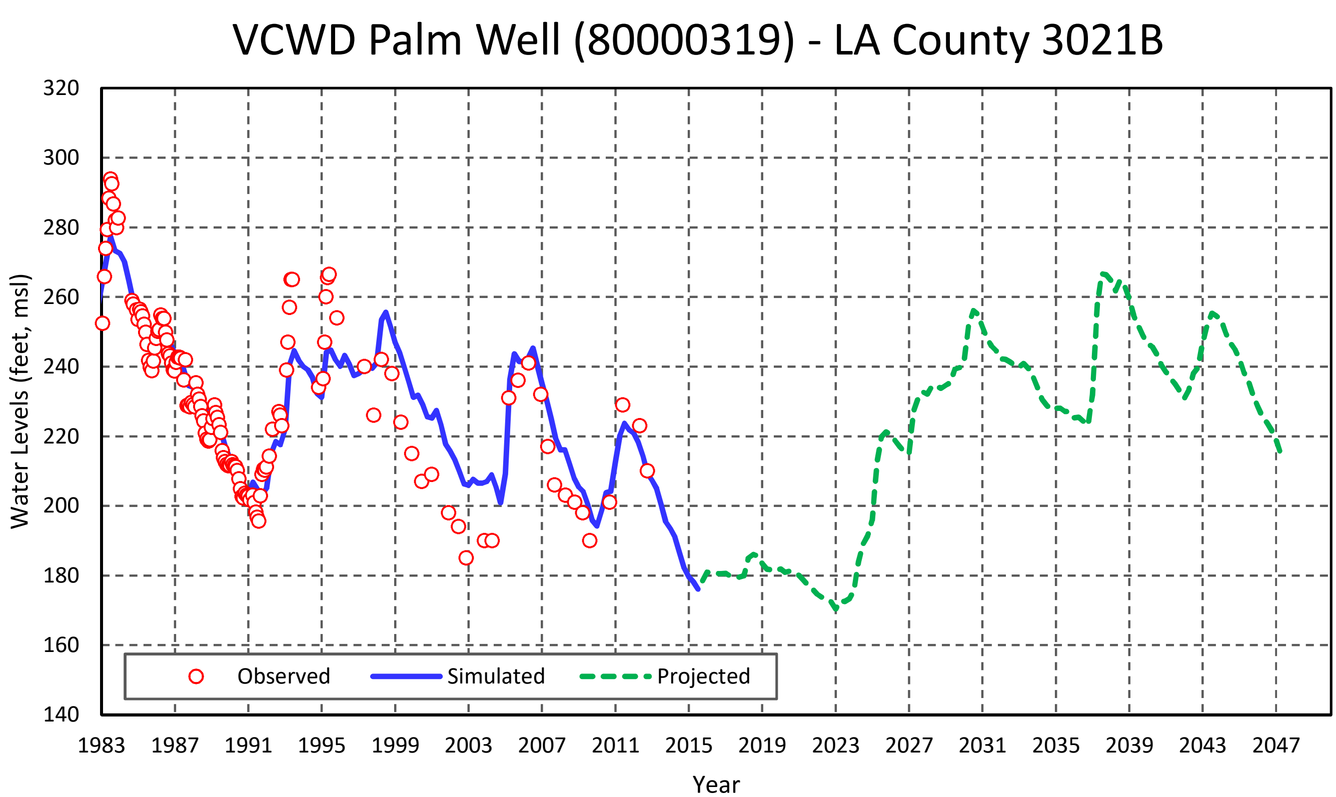
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
(FY 2015-16 to FY 2046-27)

MainSanGabrielBasin WATERMASTER





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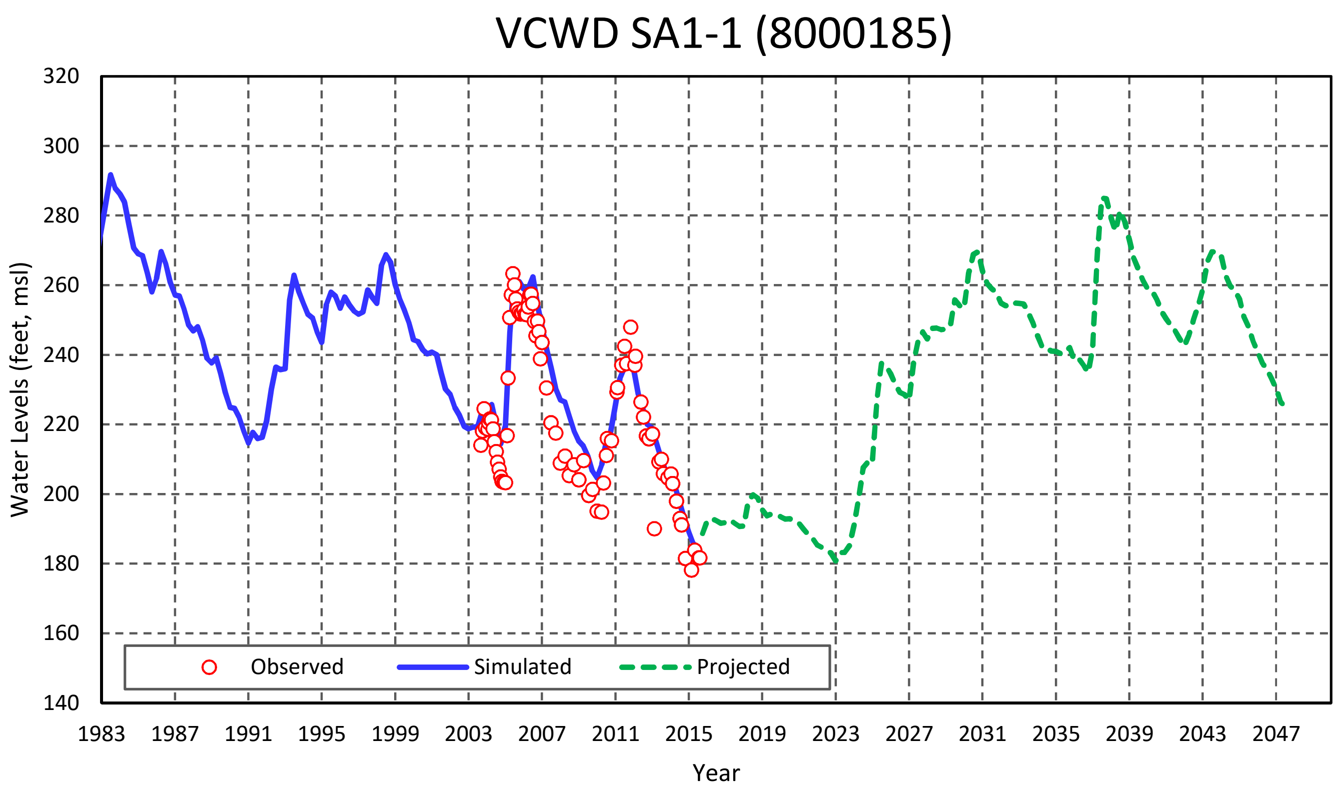
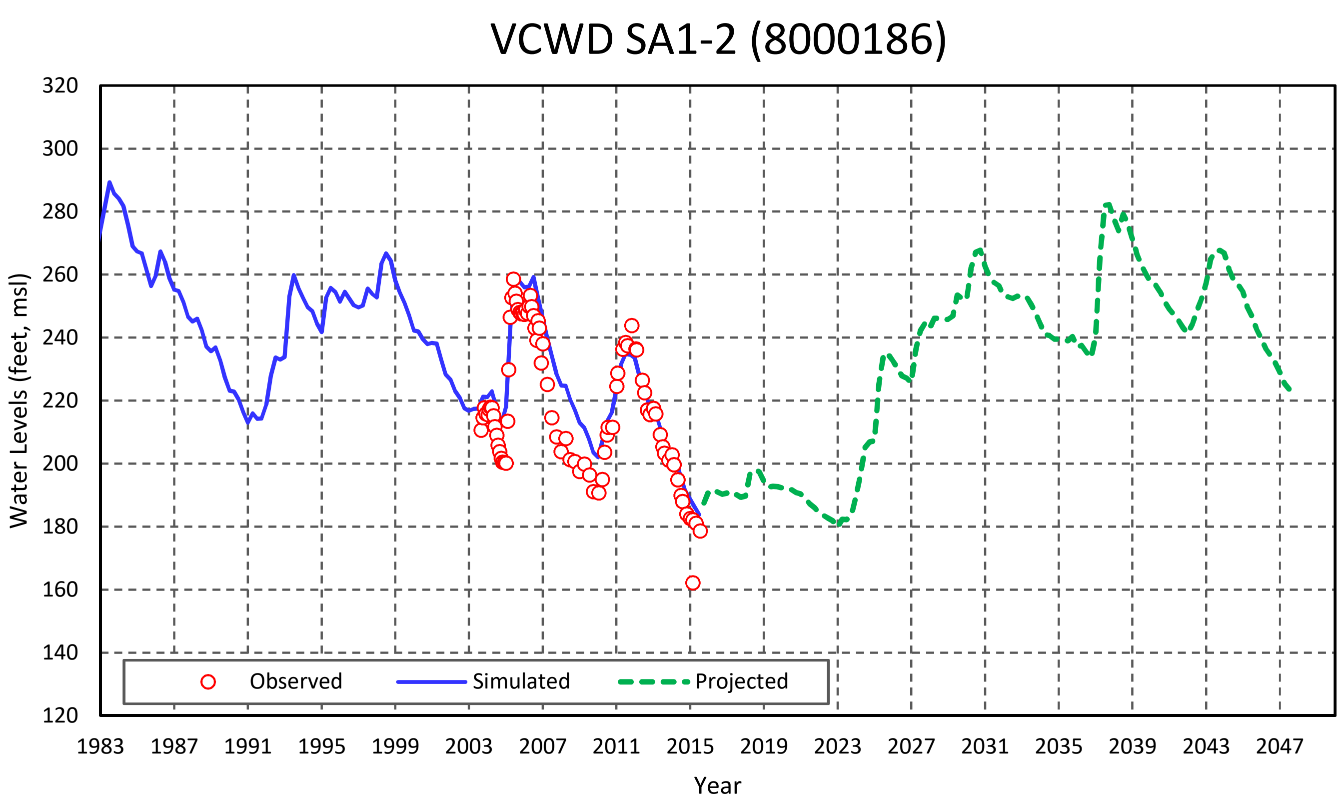
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
(FY 2015-16 to FY 2046-27)

MainSanGabrielBasin WATERMASTER

FIGURE 14a



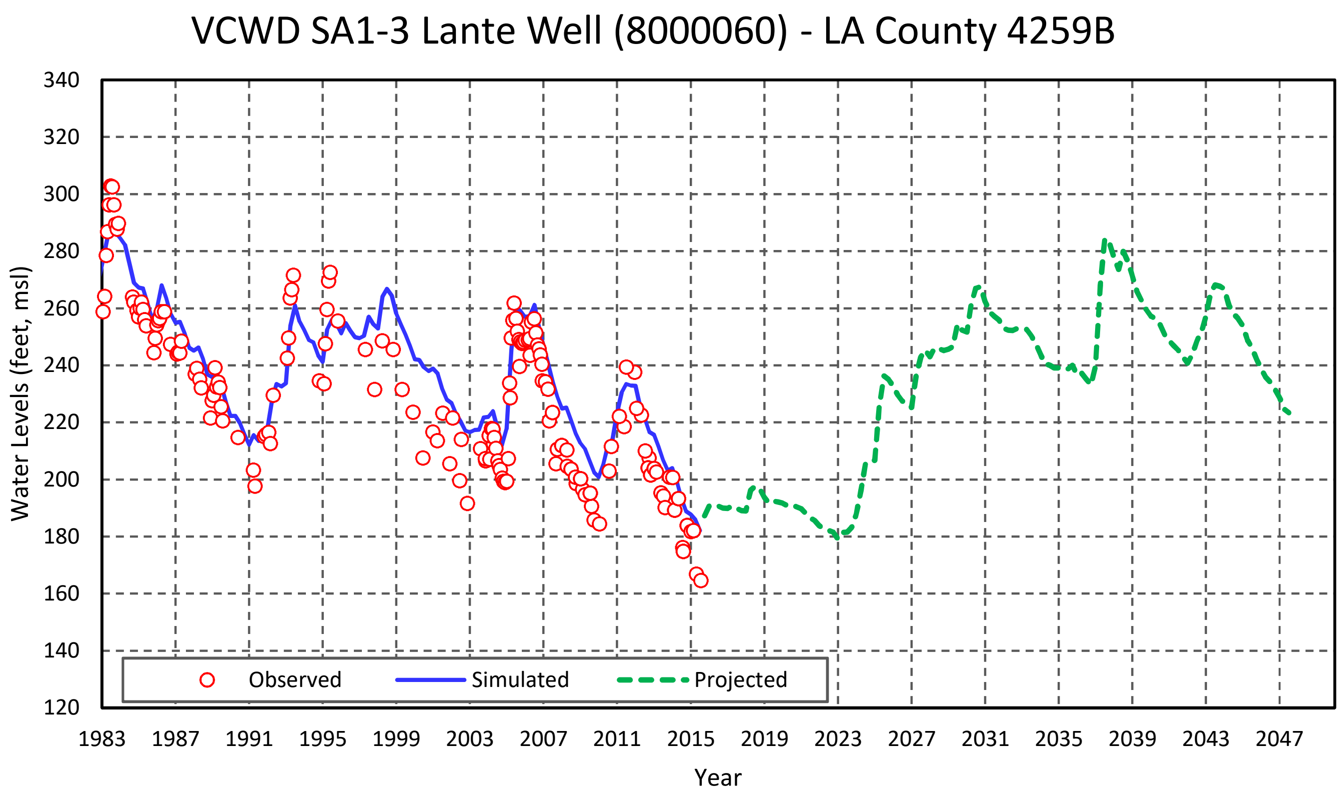


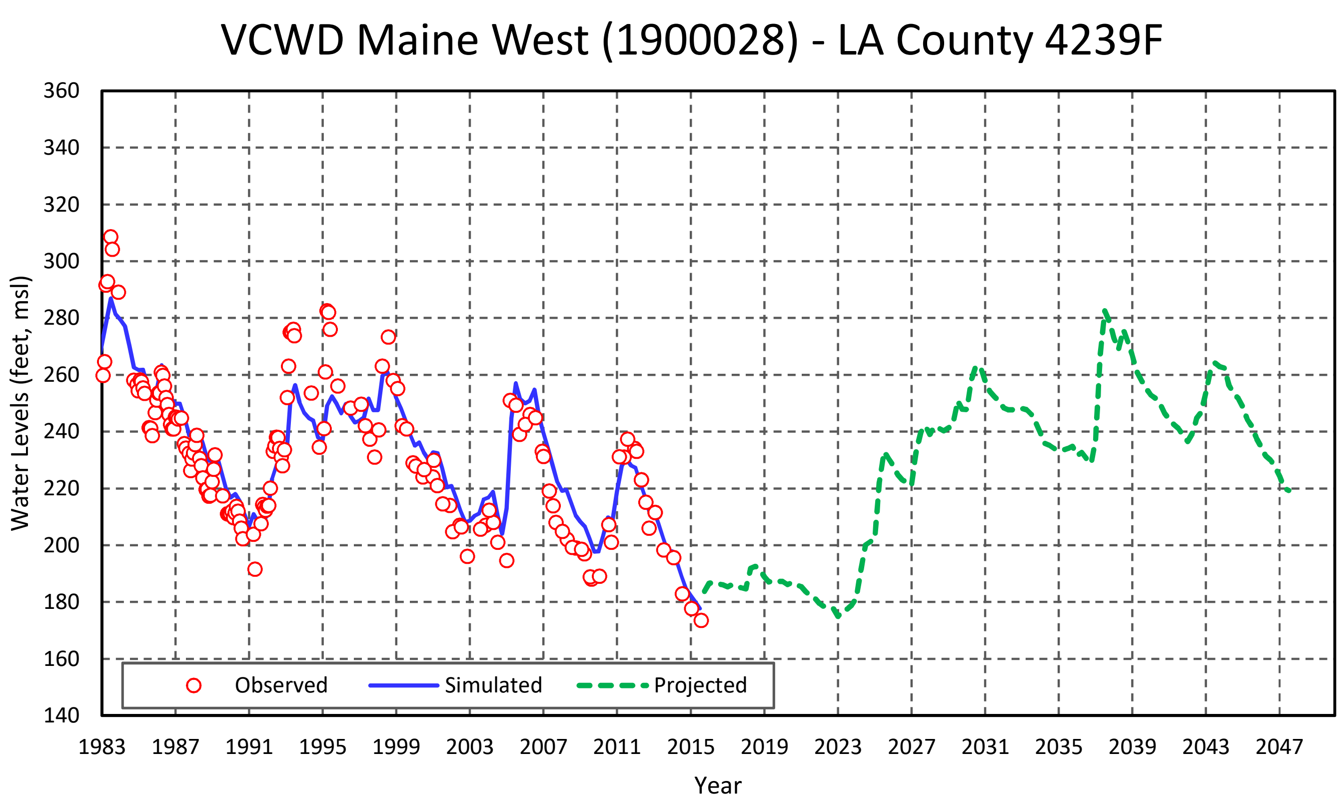
STETSON ENGINEERS INC.

MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
(FY 2015-16 to FY 2046-27)

MainSanGabrielBasin WATERMASTER



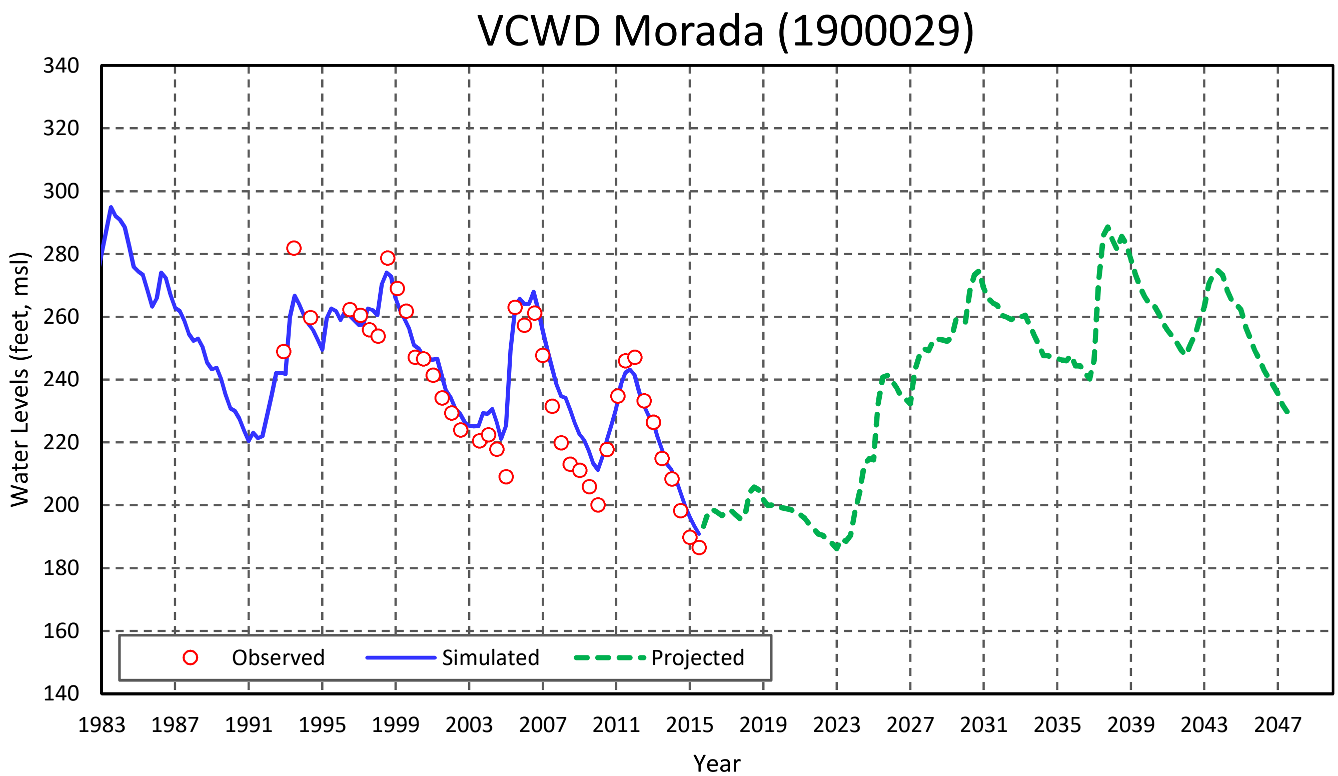


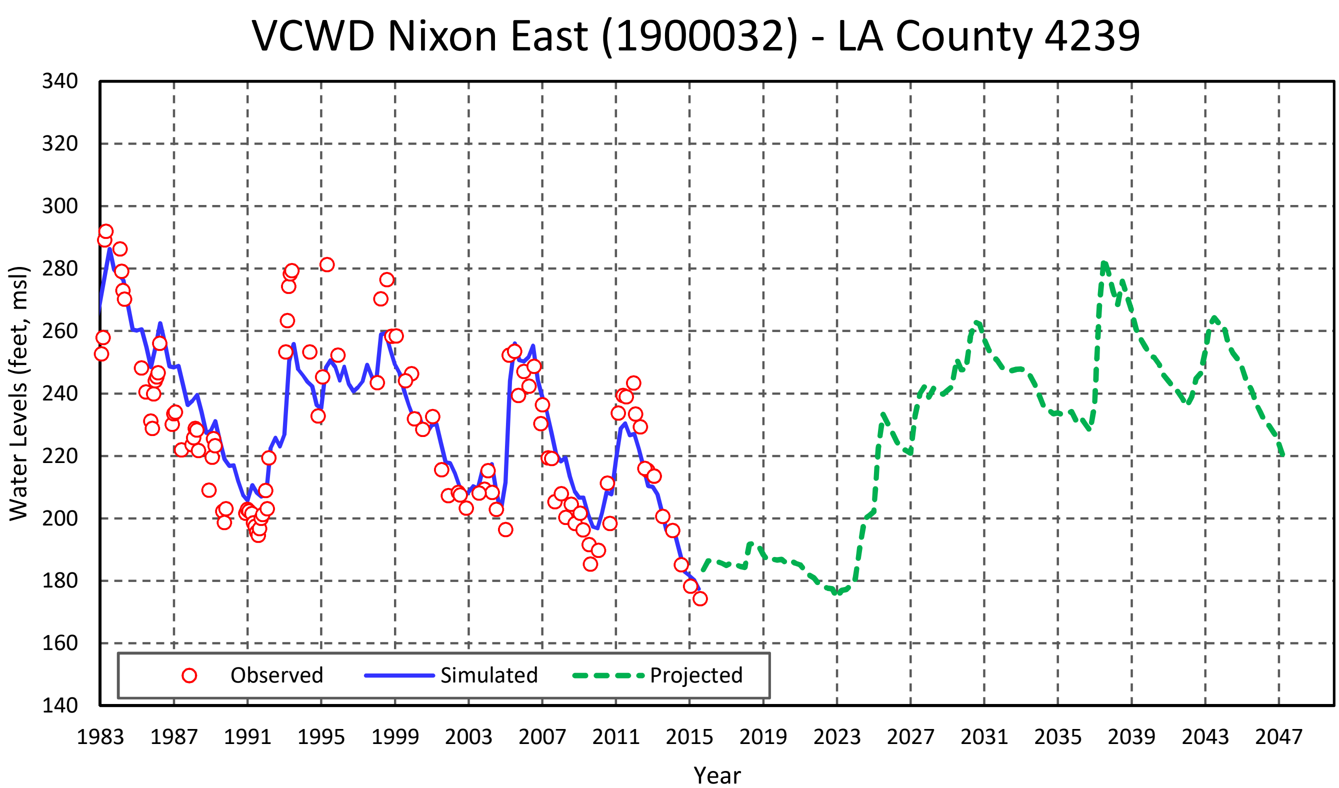
STETSON ENGINEERS INC.

MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
(FY 2015-16 to FY 2046-27)

MainSanGabrielBasin WATERMASTER



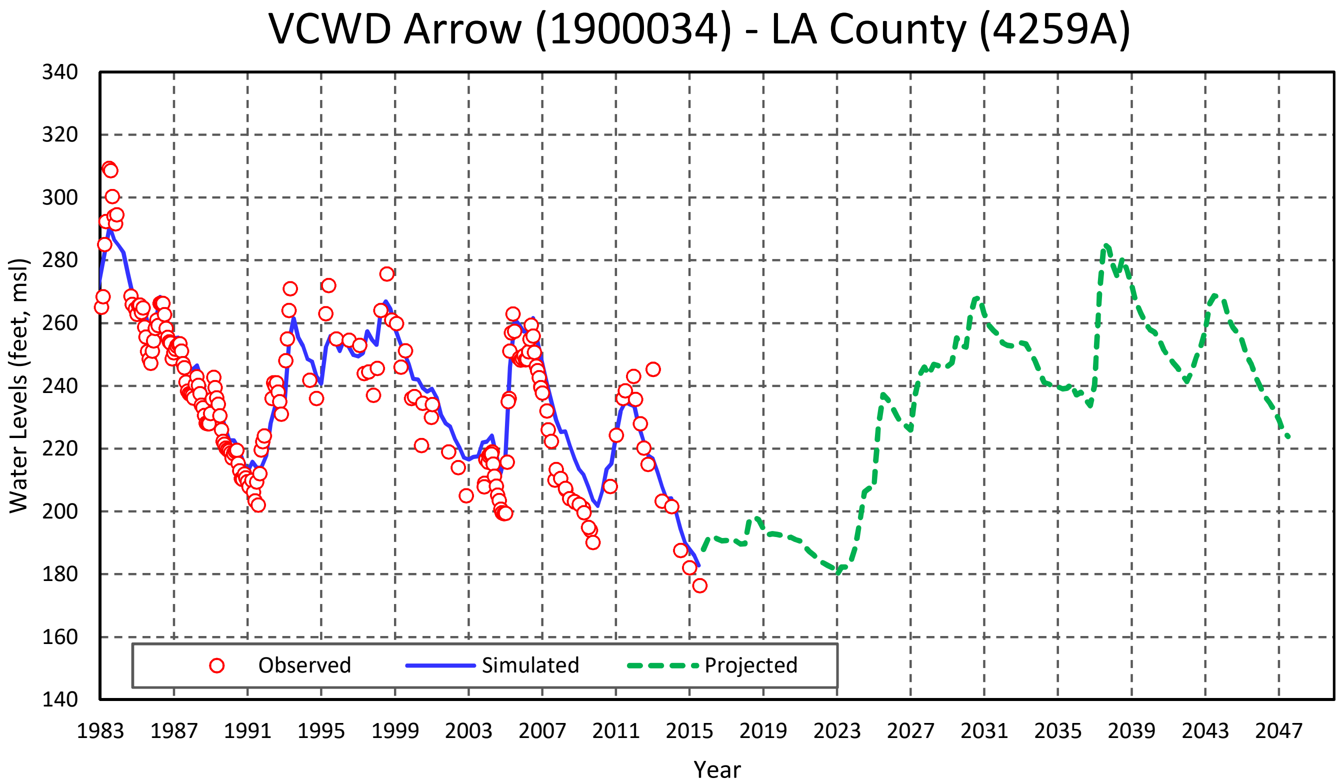


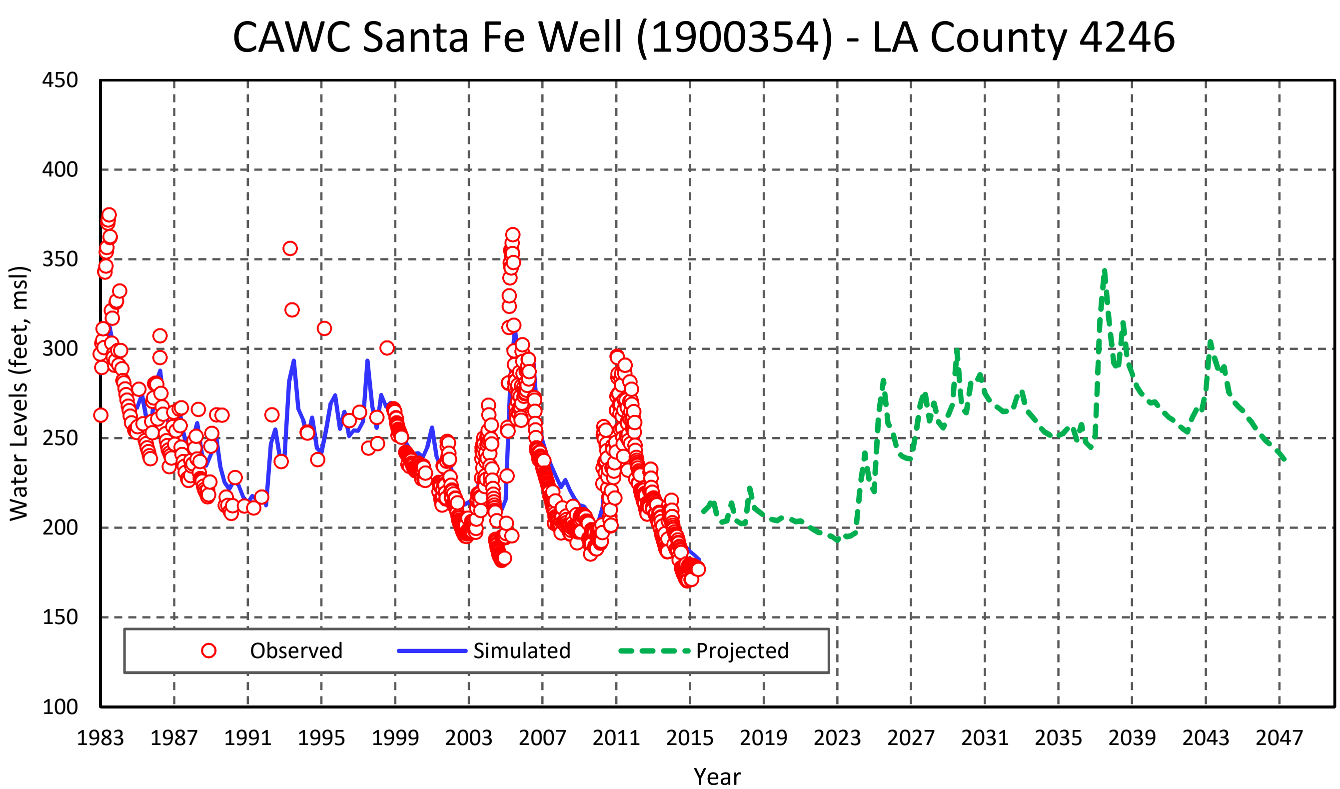
STETSON ENGINEERS INC.

MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
(FY 2015-16 to FY 2046-27)

MainSanGabrielBasin WATERMASTER





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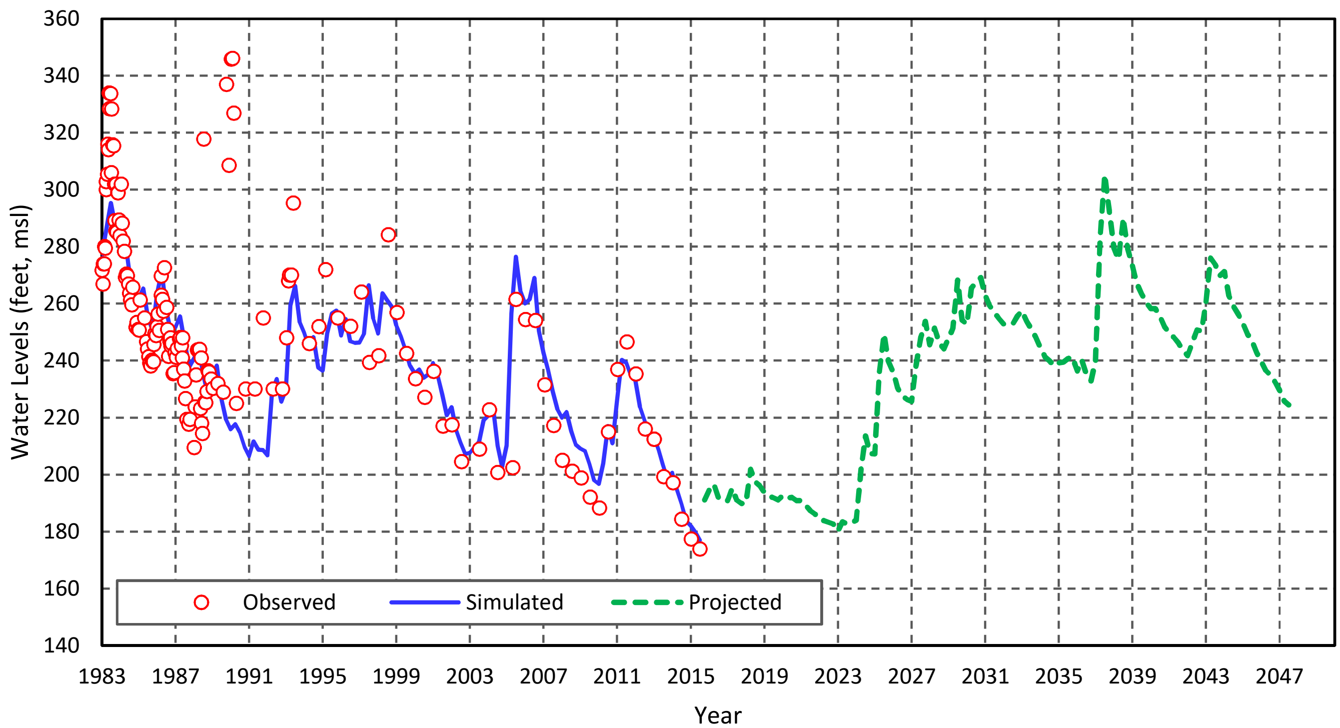
MAIN SAN GABRIEL BASIN WATERMASTER

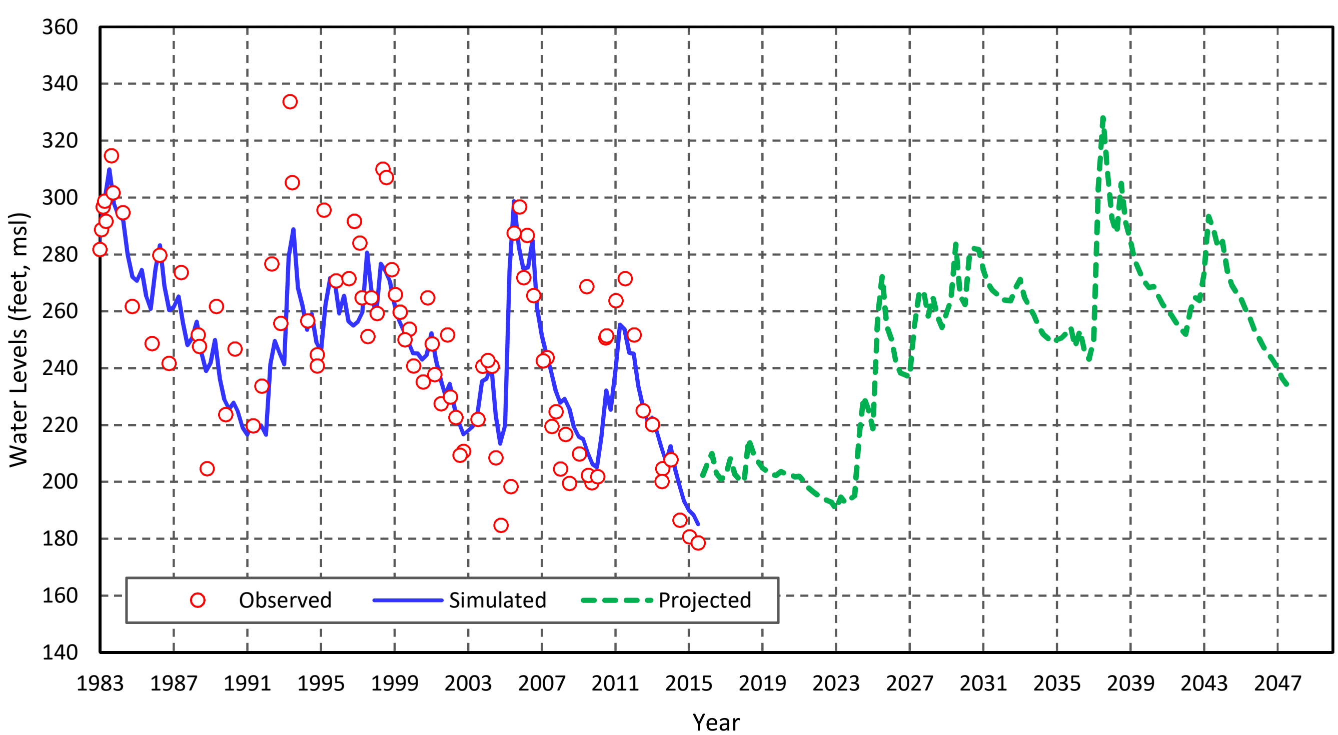
Projected Simulation Results (FY 2015-16 to FY 2046-27)

MainSanGabrielBasin WATERMASTER

CAWC Buena Vista (1900355) - LA County 4227A



CAWC Crown Haven Well (1903018) - LA County 4256



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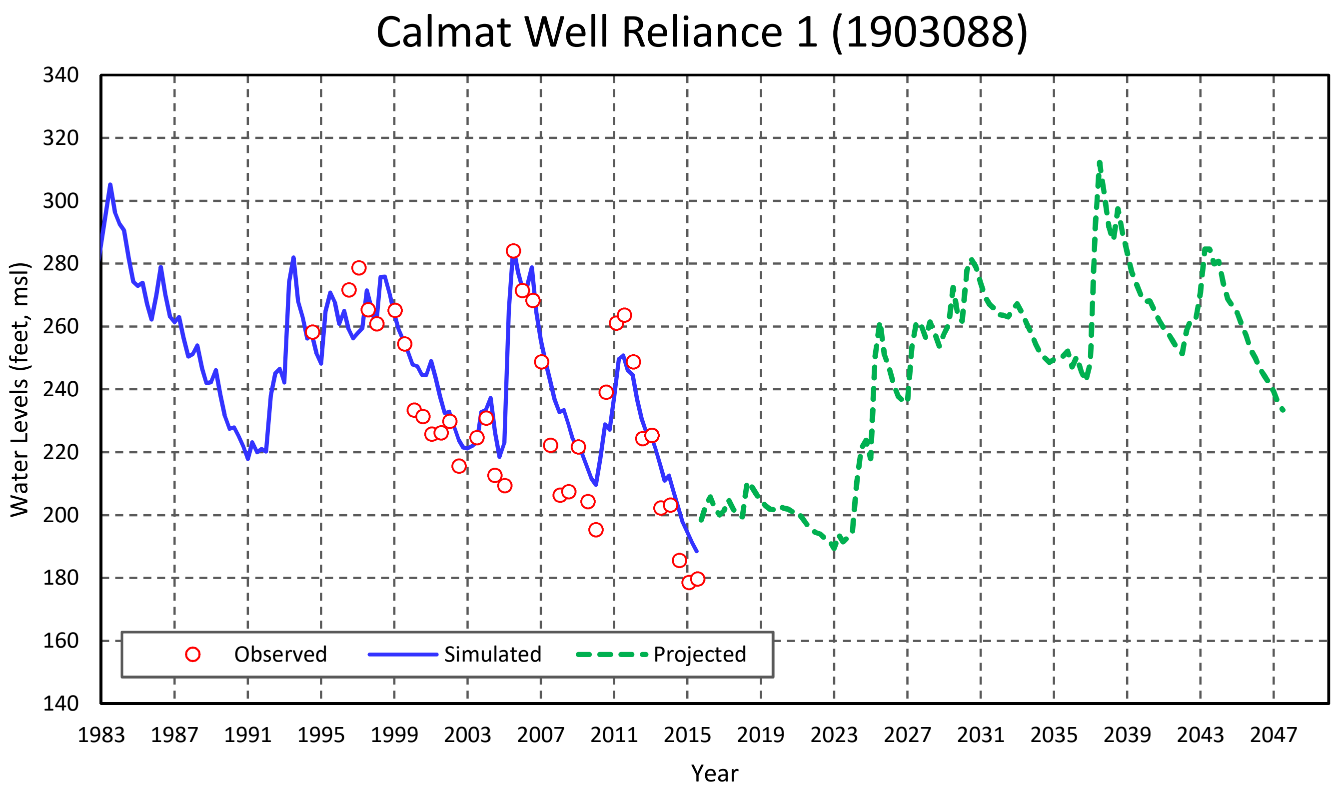
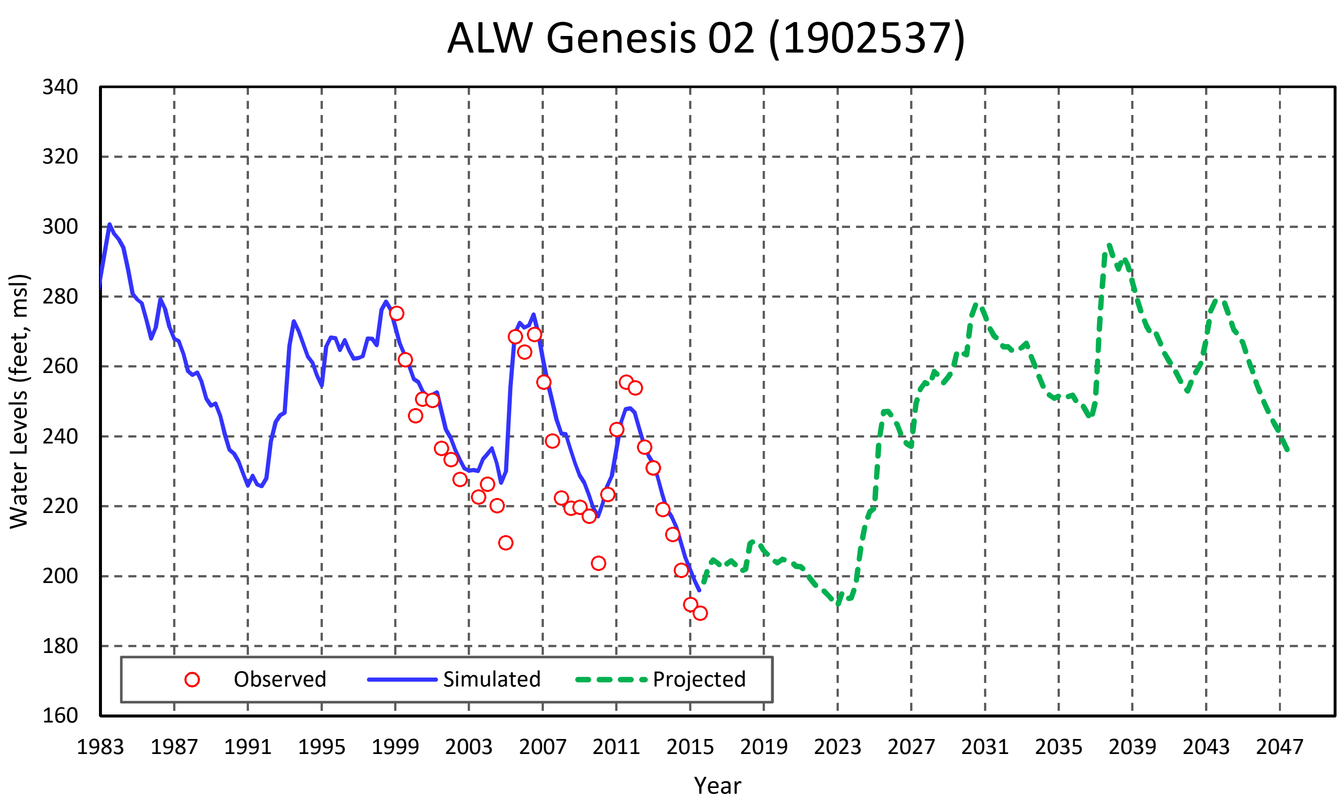
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results (FY 2015-16 to FY 2046-27)

MainSanGabrielBasin WATERMASTER





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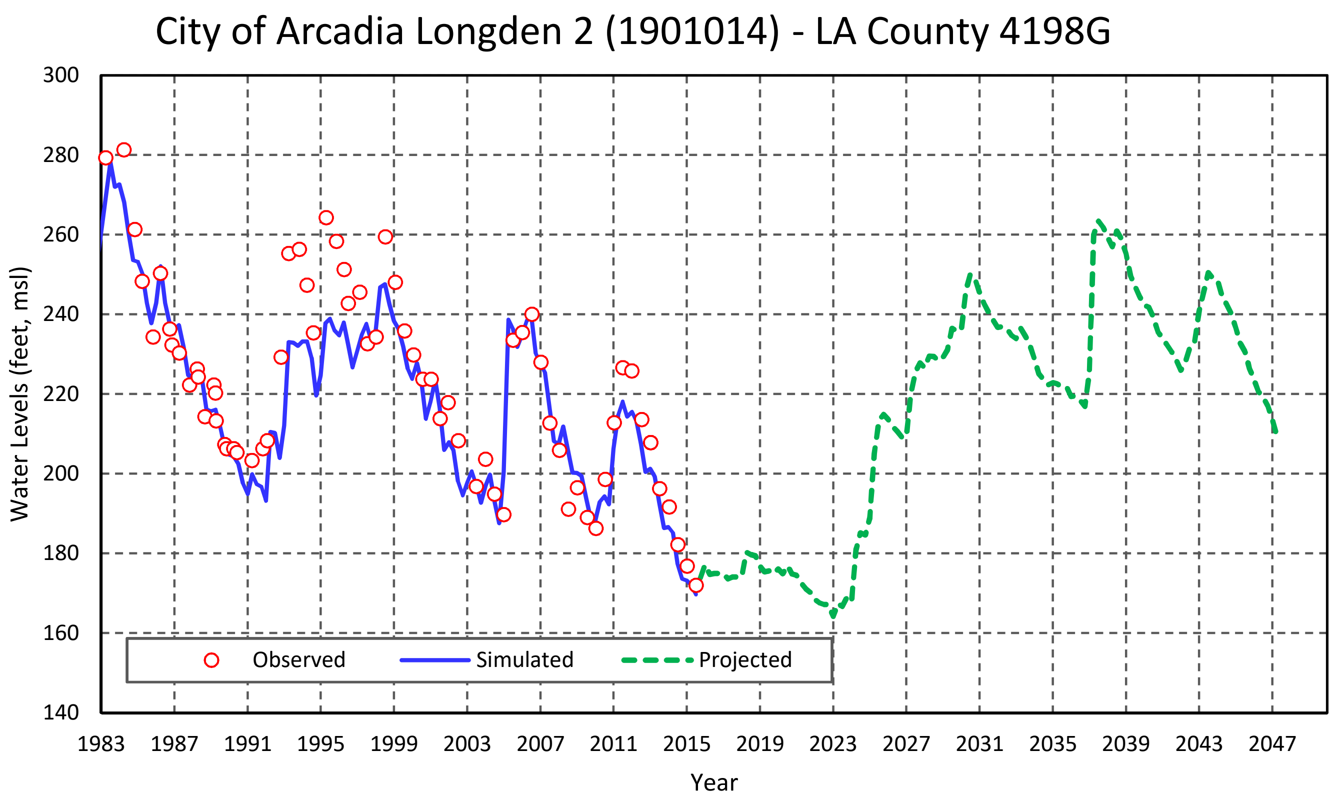
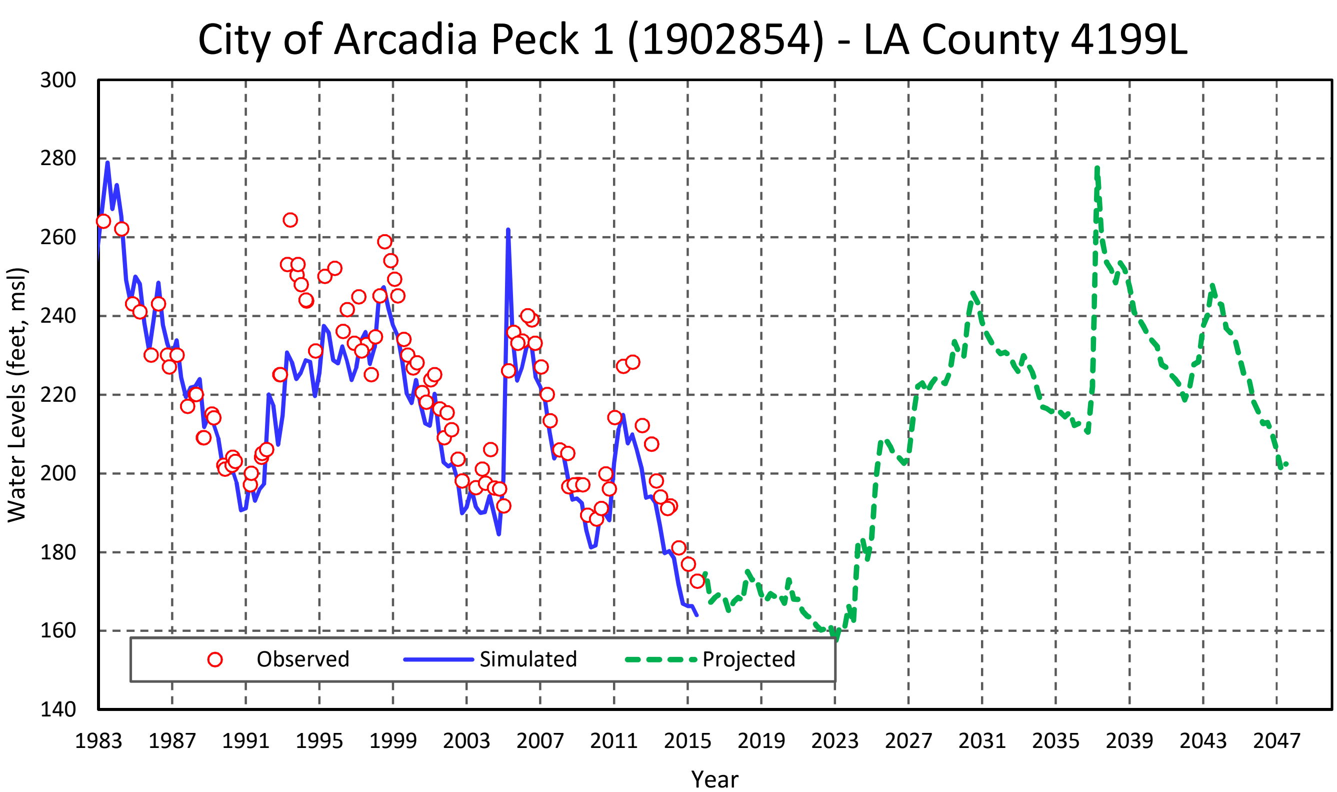
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
(FY 2015-16 to FY 2046-27)

MainSanGabrielBasin WATERMASTER





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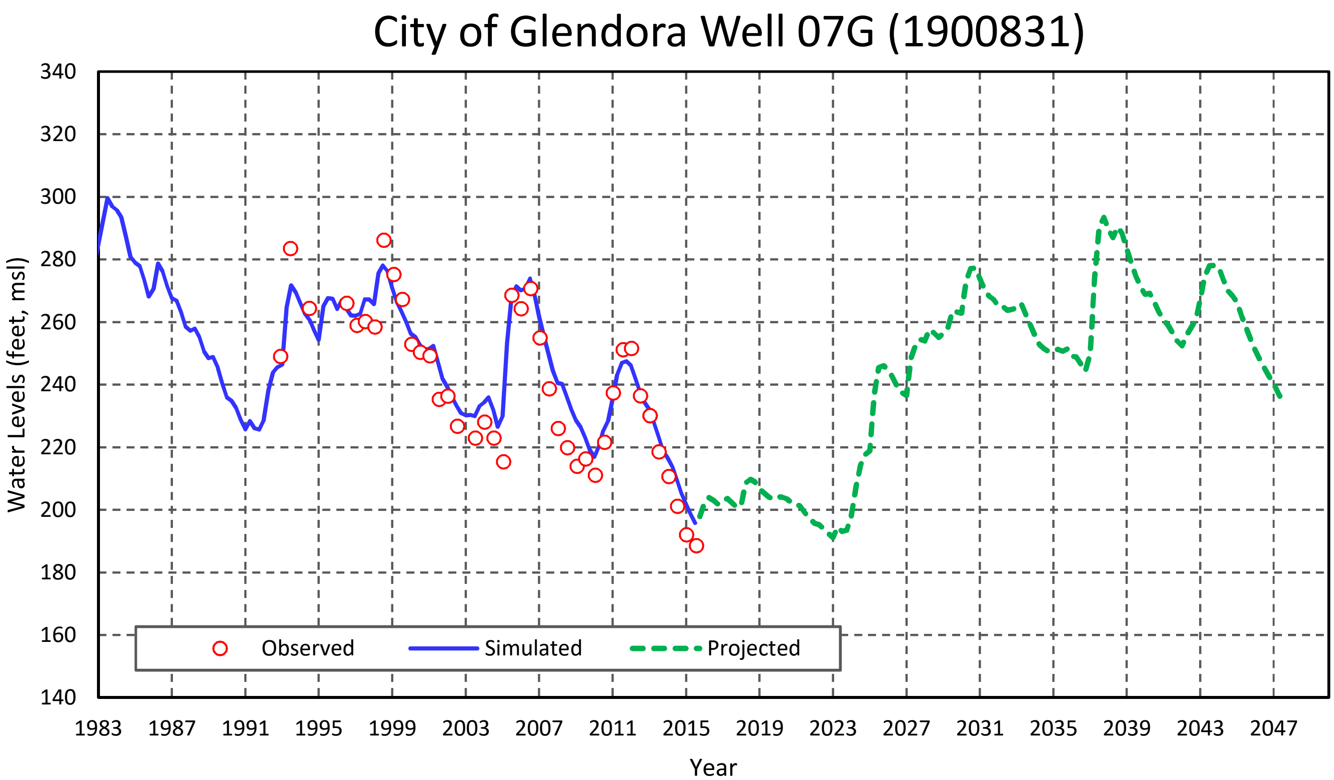
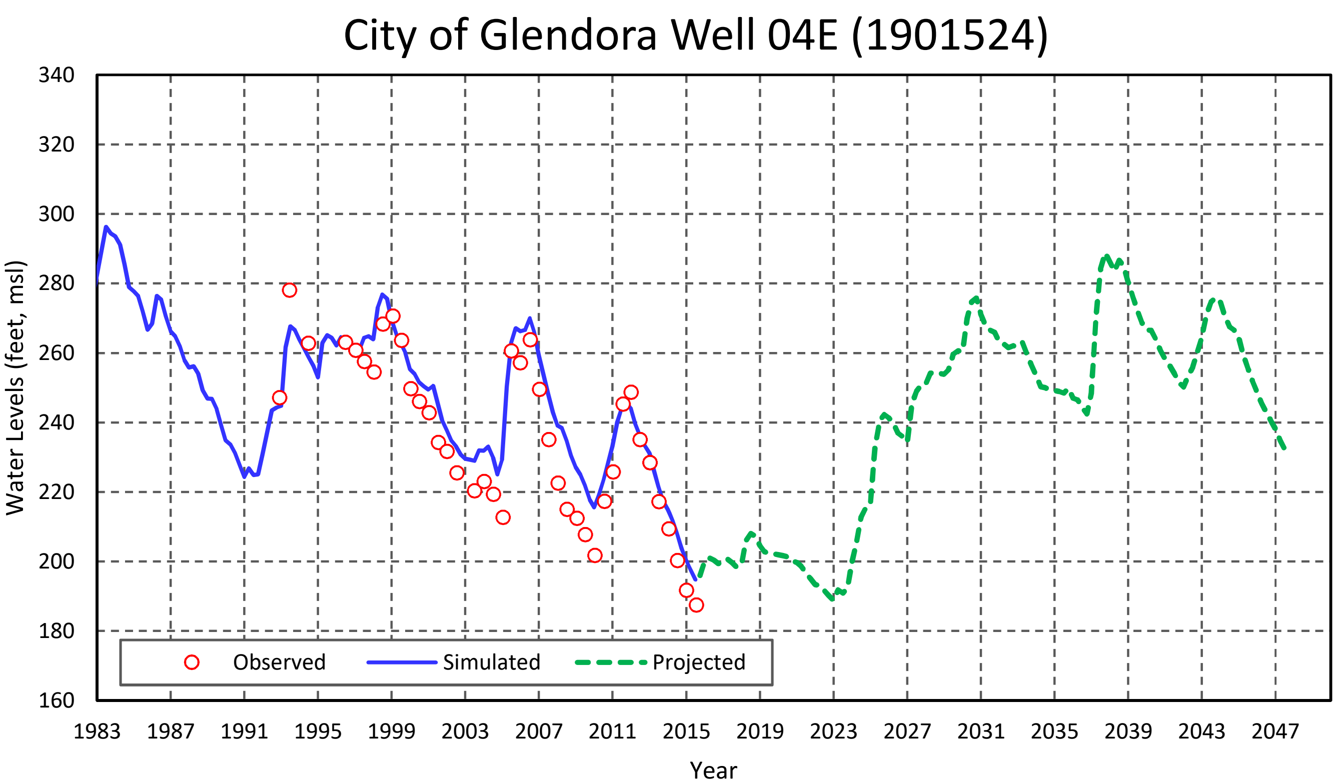
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results (FY 2015-16 to FY 2046-27)

MainSanGabrielBasin WATERMASTER





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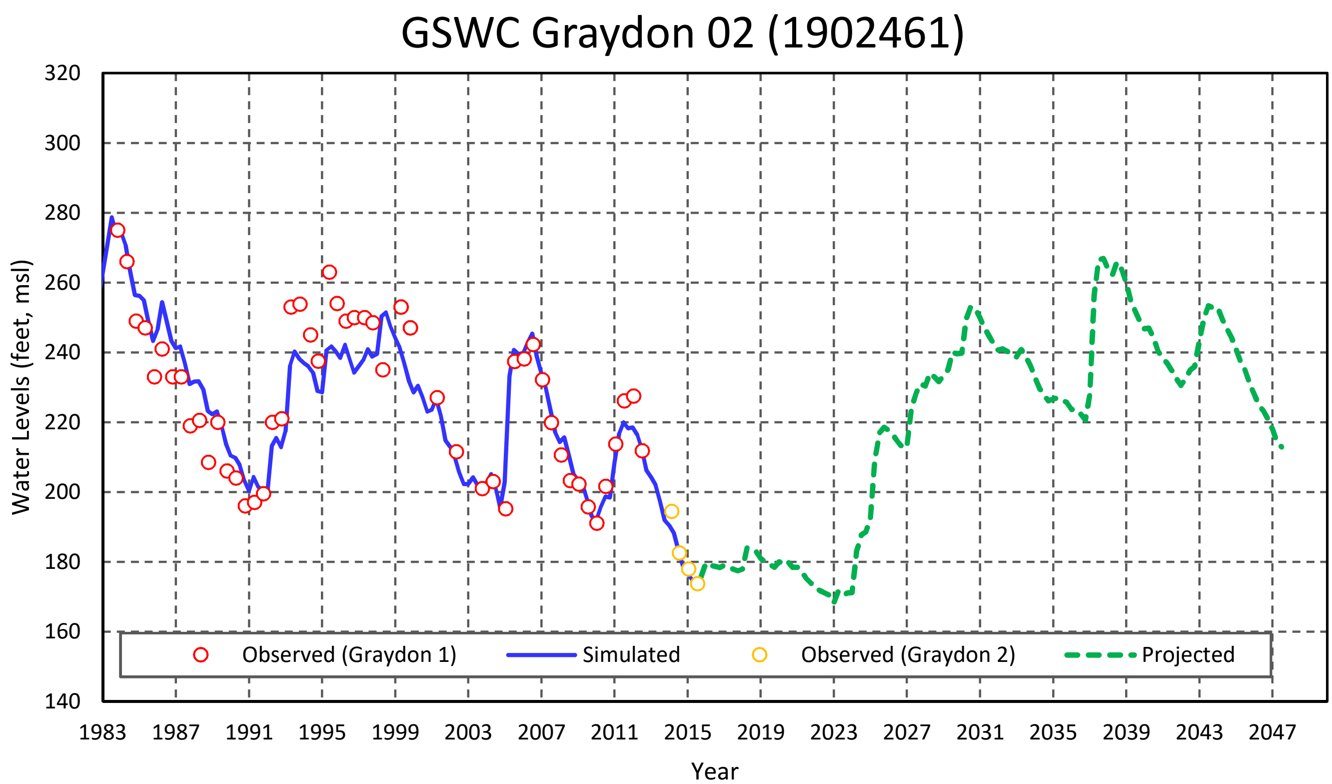
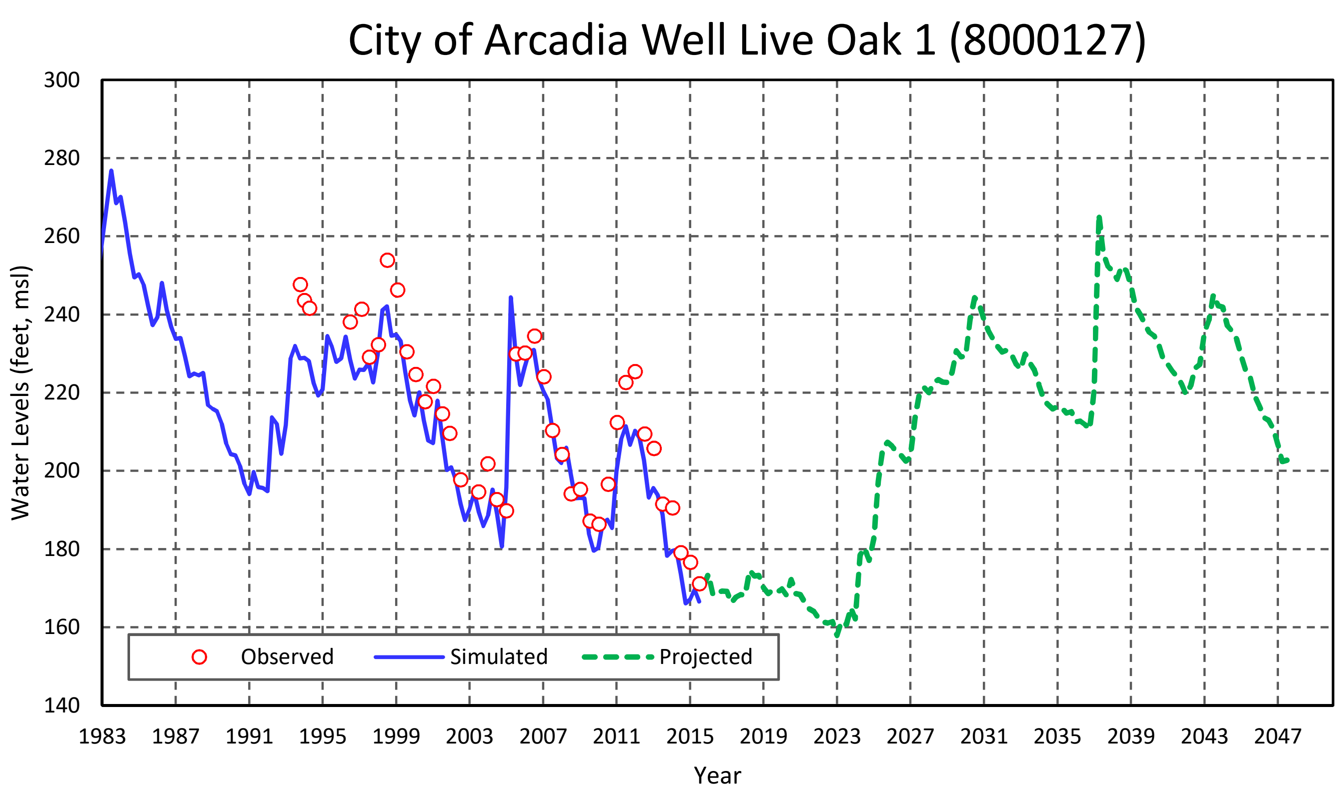
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
(FY 2015-16 to FY 2046-27)

MainSanGabrielBasin WATERMASTER

FIGURE 14a





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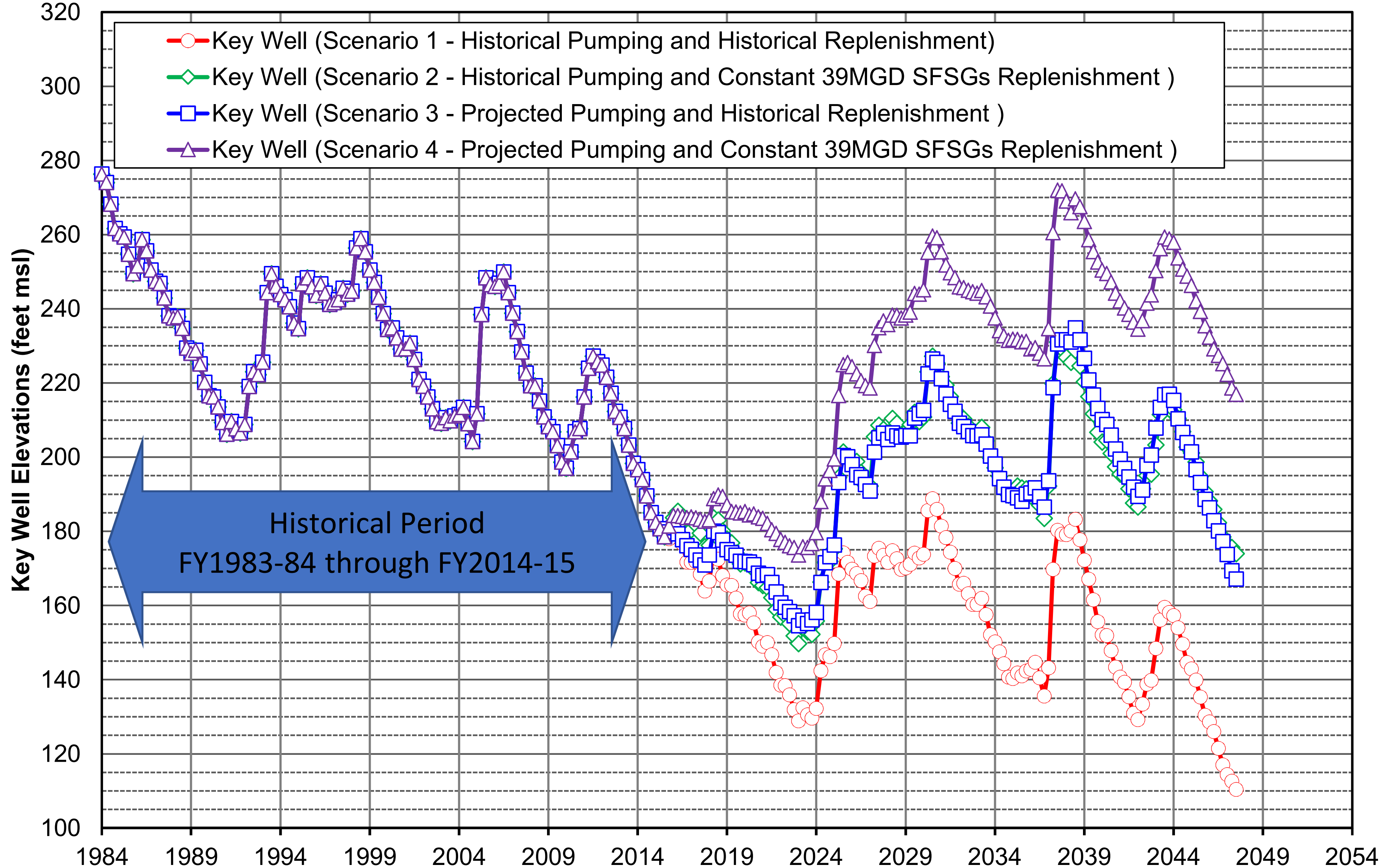
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results (FY 2015-16 to FY 2046-27)

MainSanGabrielBasin WATERMASTER

Figure 14b



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MAIN SAN GABRIEL BASIN WATERMASTER

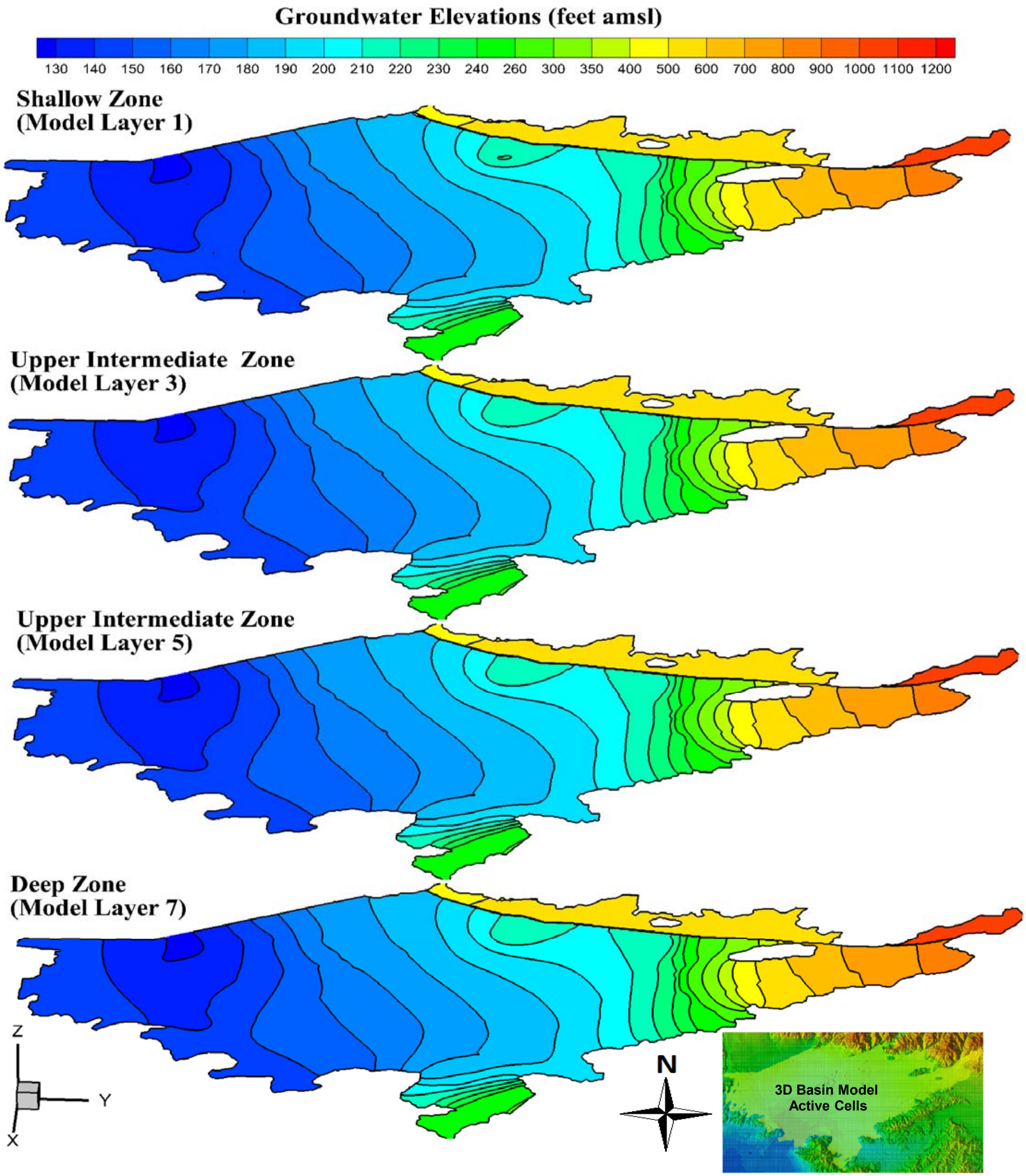
3D Basin Model

Comparisons of Simulated Key Well Elevations

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 14b - KeyWell Comparison.xlsx

Figure 15a



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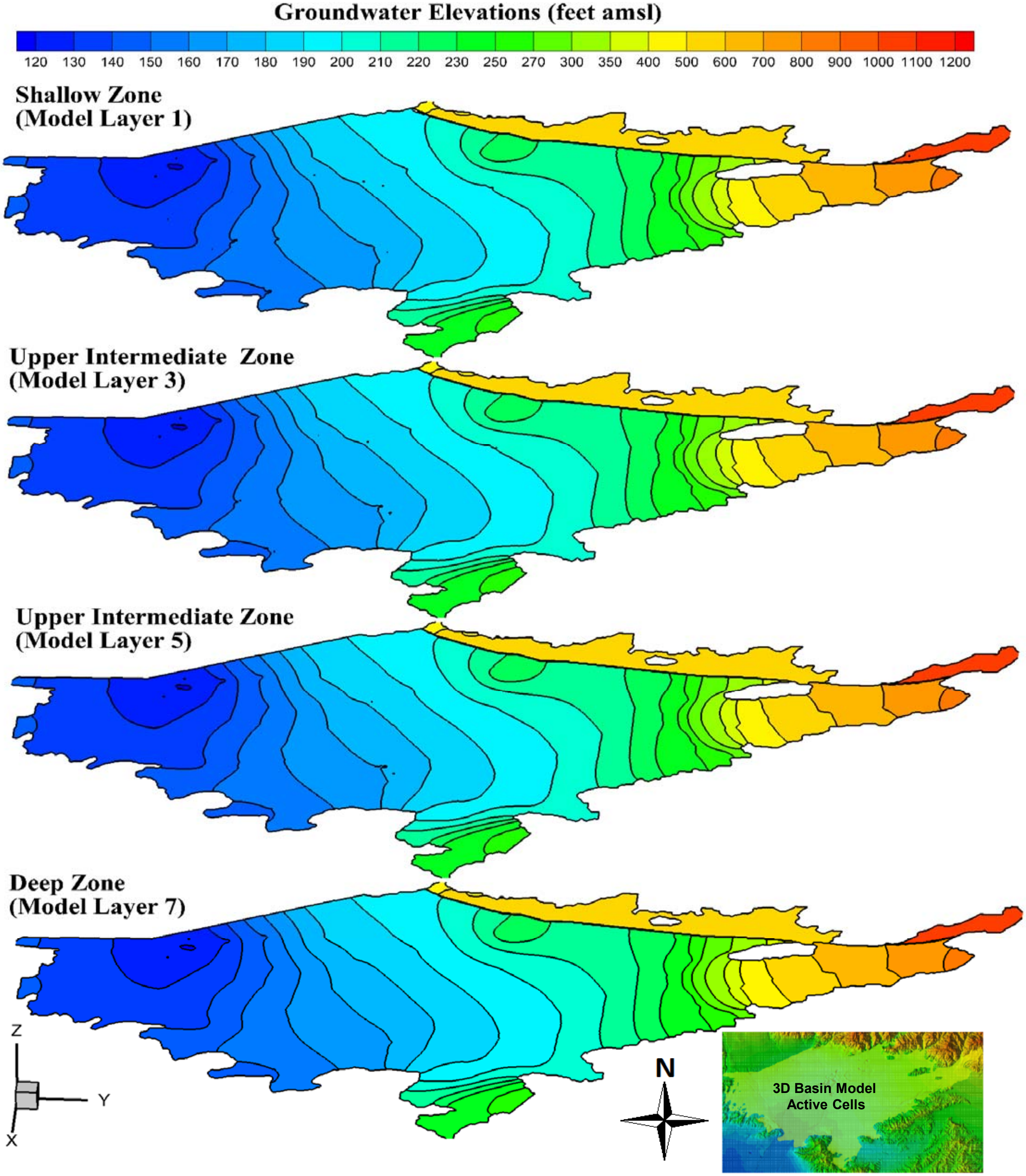
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2015-16
Groundwater Elevation Contours (Scenario 1)
(Sub-Task No. 2.4 Baseline Sustainability)

MainSanGabrielBasin WATERMASTER



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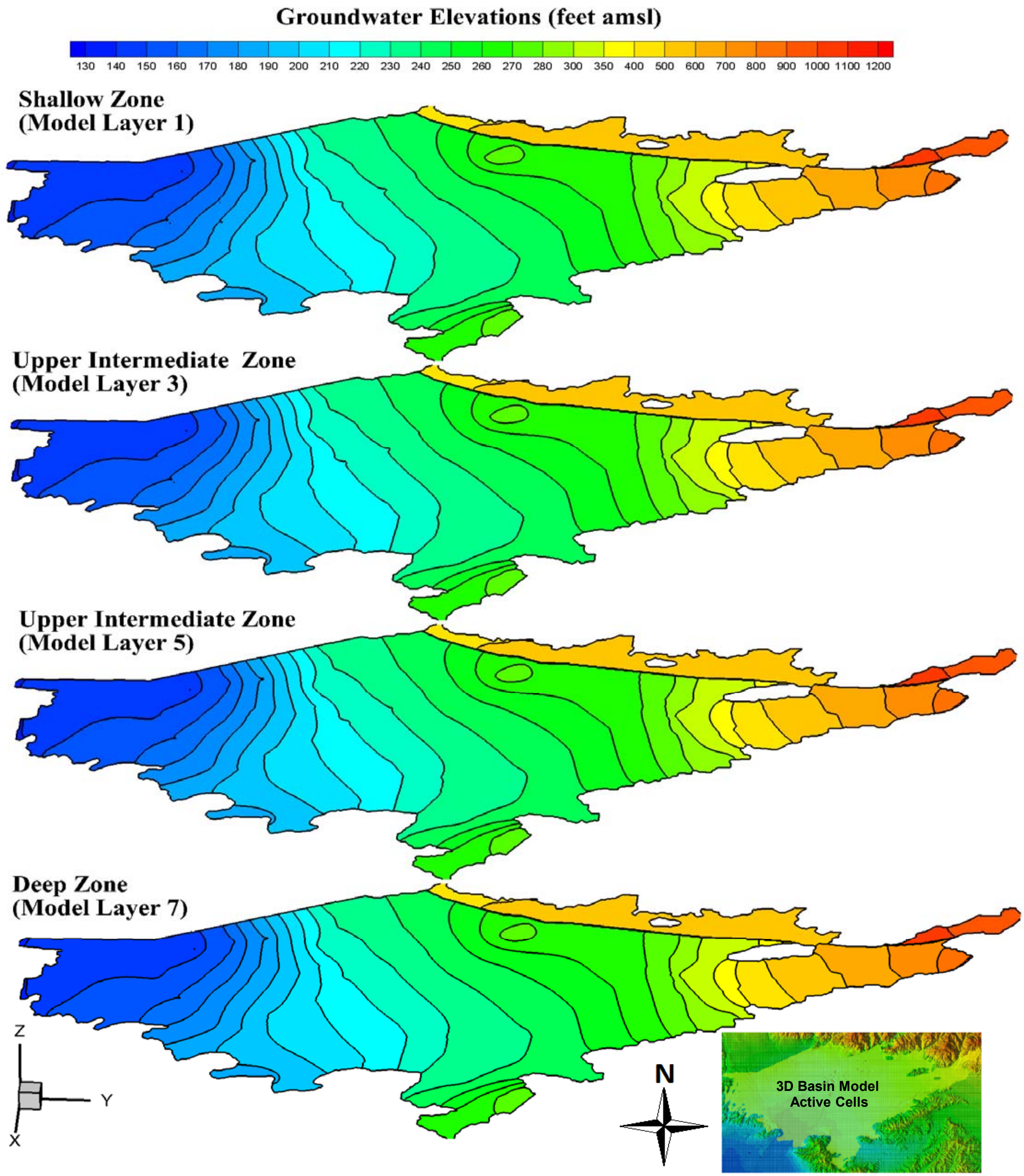
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2020-21
Groundwater Elevation Contours (Scenario 1)
(Sub-Task No. 2.4 Baseline Sustainability)

MainSanGabrielBasin WATERMASTER



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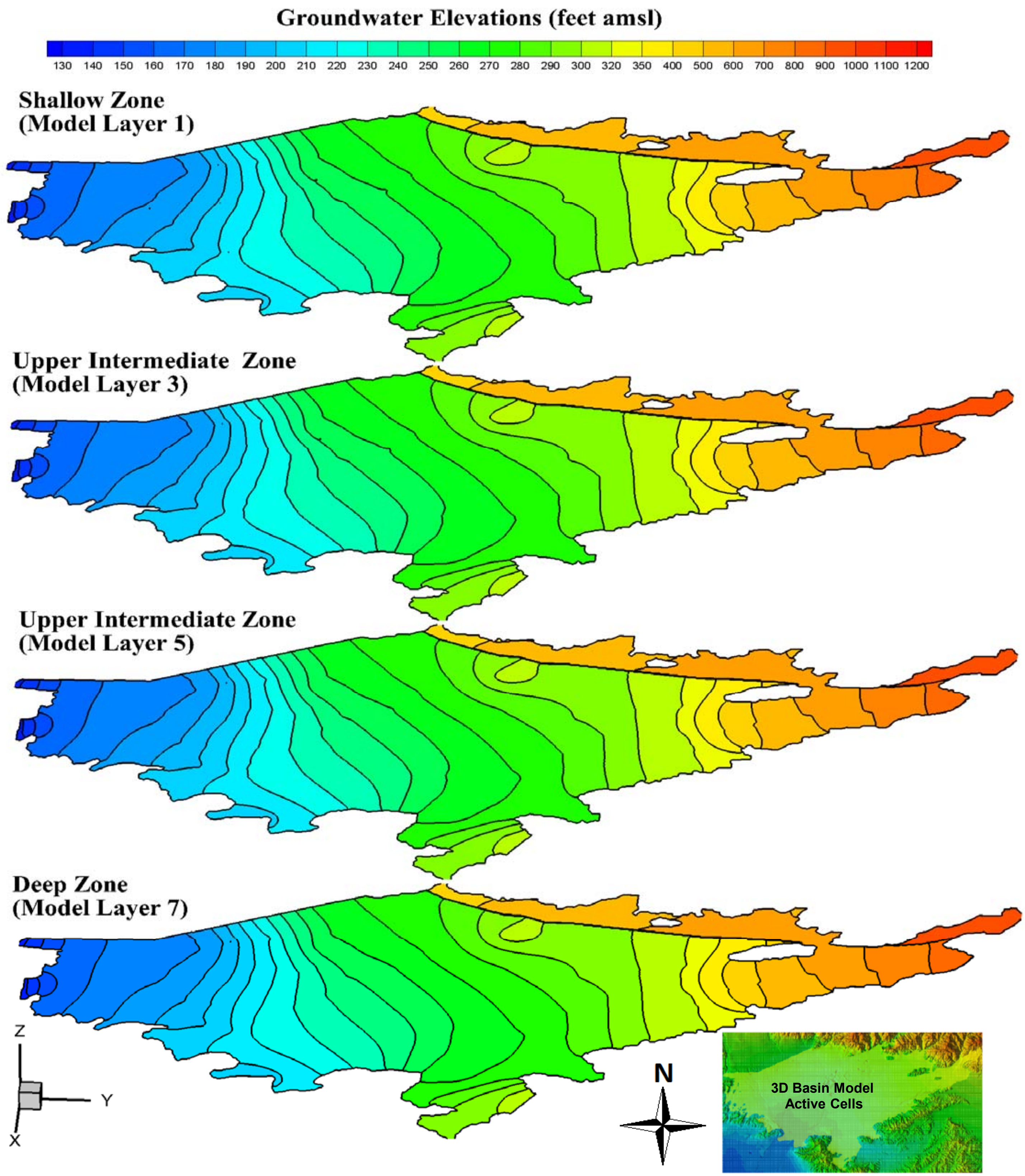
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2025-26
Groundwater Elevation Contours (Scenario 1)
(Sub-Task No. 2.4 Baseline Sustainability)

MainSanGabrielBasin WATERMASTER

Figure 15d



MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2030-31
Groundwater Elevation Contours (Scenario 1)
(Sub-Task No. 2.4 Baseline Sustainability)

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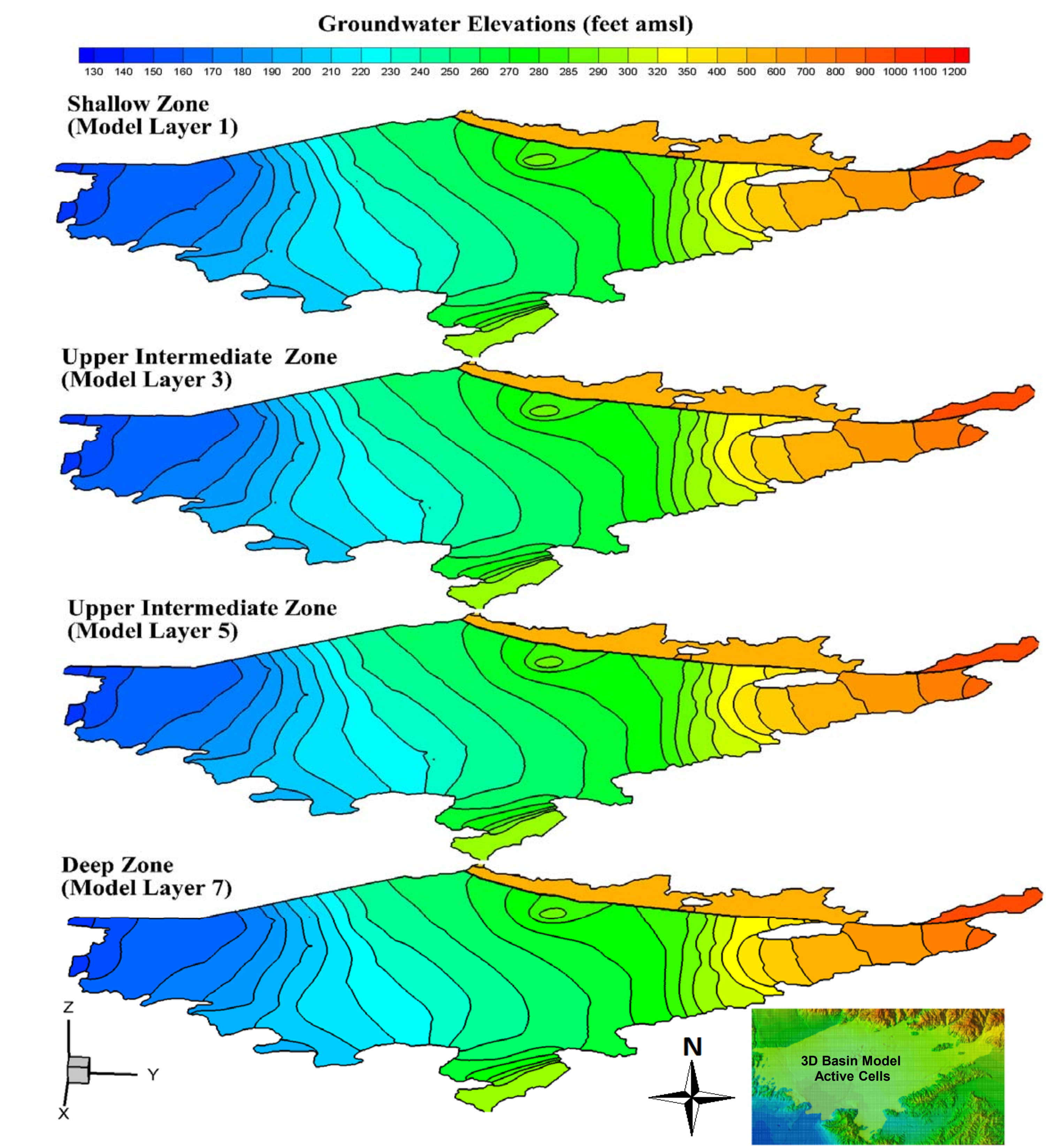
MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 15 - 3D Basin Model Simulated Contours(625MGD).xlsx

Figure 15e



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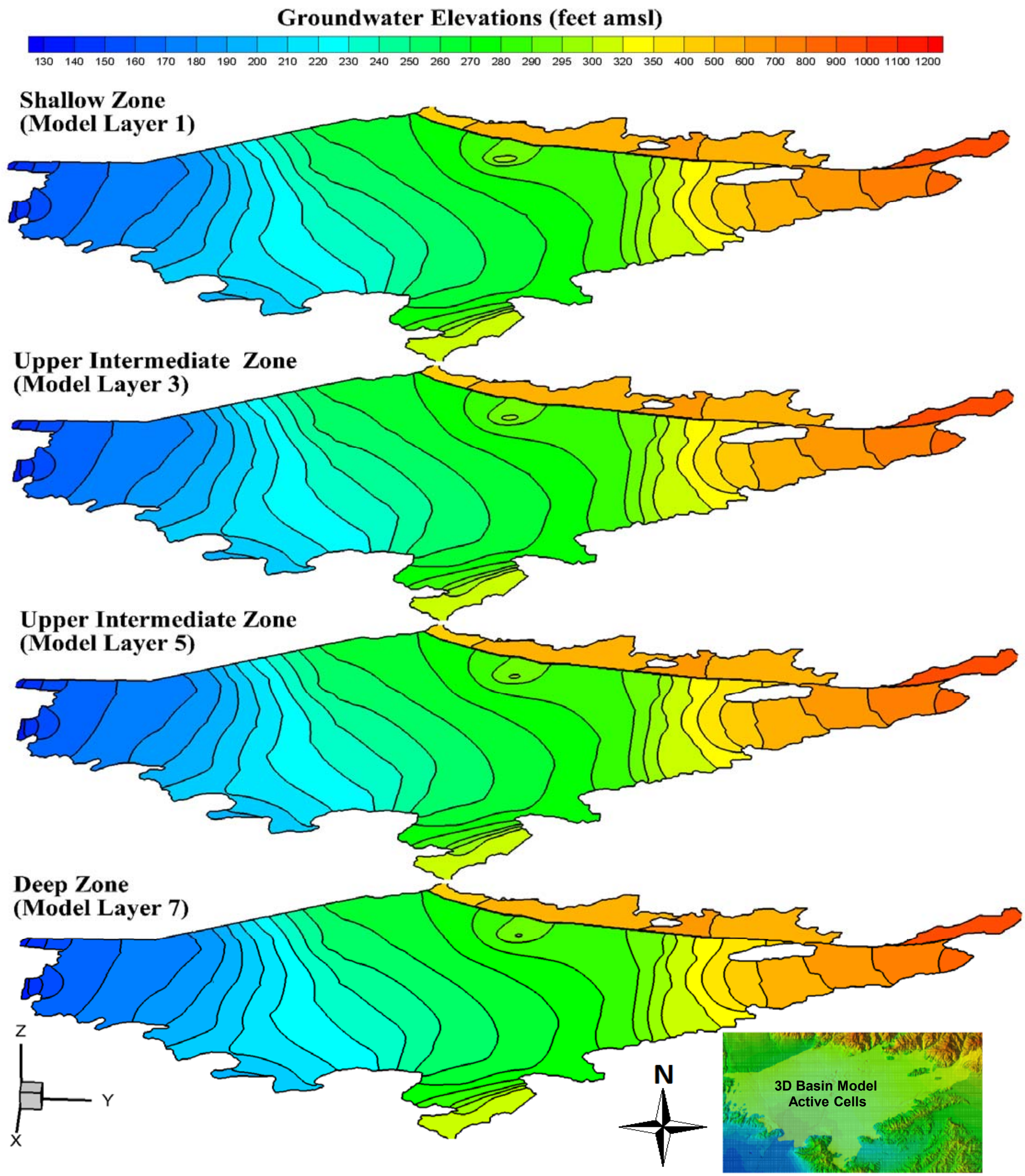
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2035-36
Groundwater Elevation Contours (Scenario 1)
(Sub-Task No. 2.4 Baseline Sustainability)

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 15 - 3D Basin Model Simulated Contours(625MGD).xlsx



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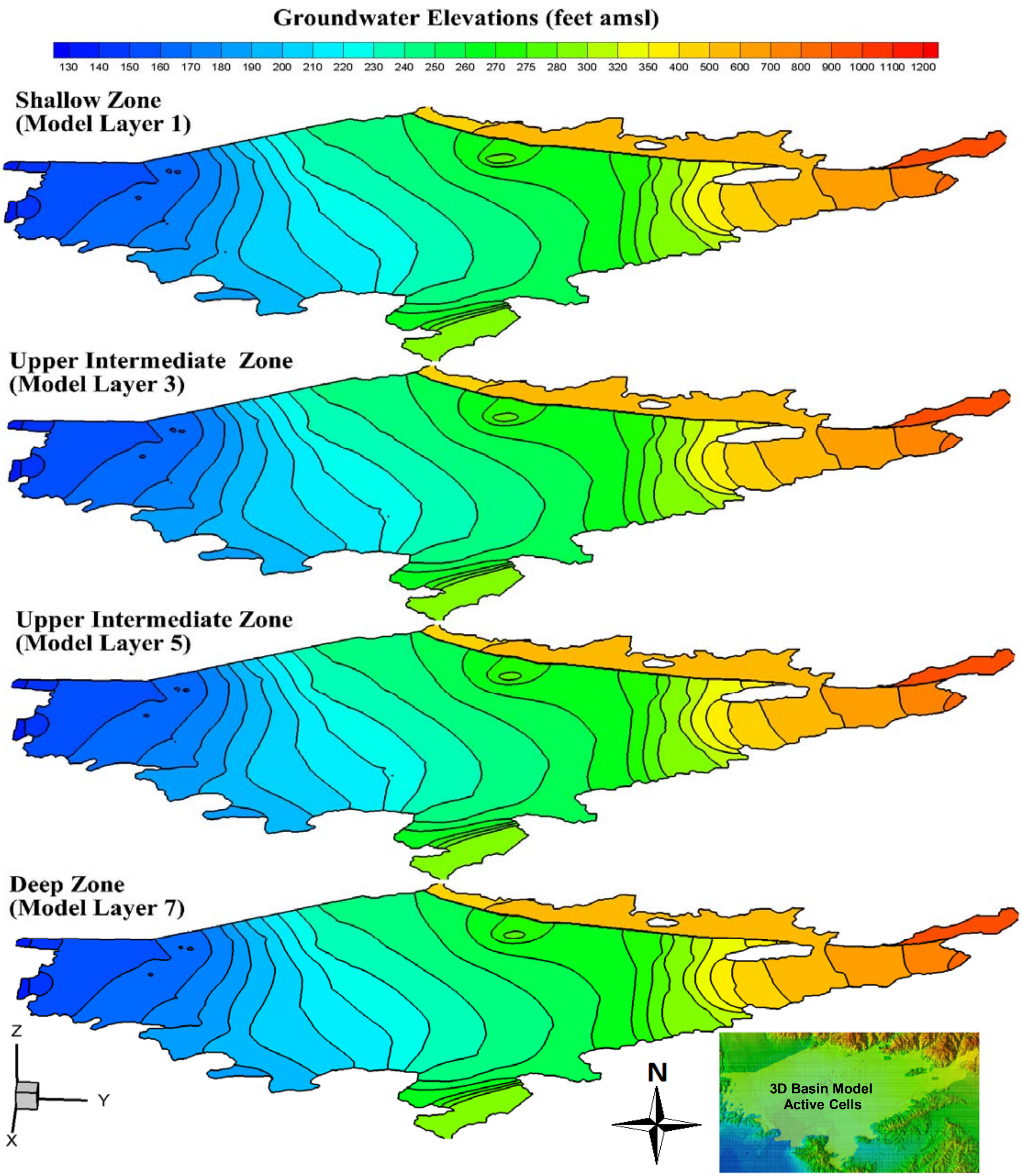
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2040-41
Groundwater Elevation Contours (Scenario 1)
(Sub-Task No. 2.4 Baseline Sustainability)

MainSanGabrielBasin WATERMASTER

Figure 15g



MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2046-47
Groundwater Elevation Contours (Scenario 1)
(Sub-Task No. 2.4 Baseline Sustainability)

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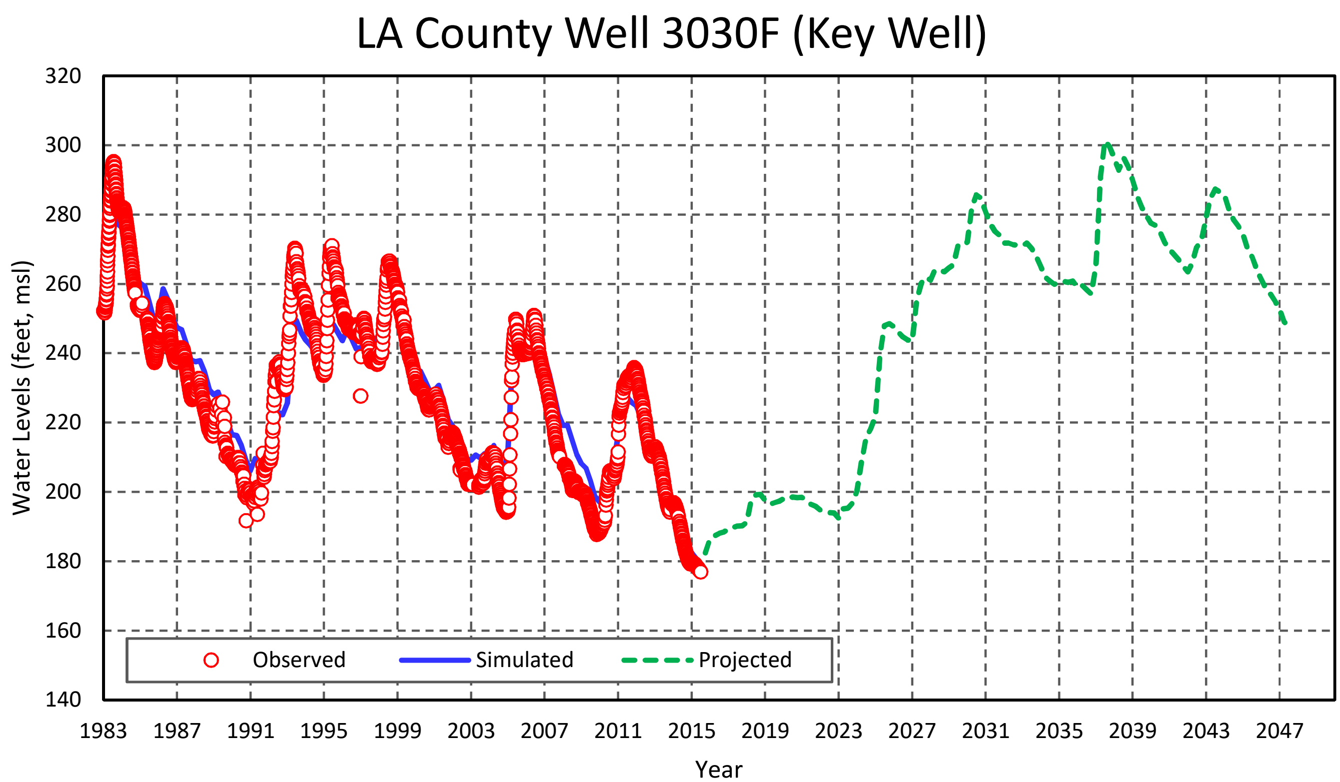
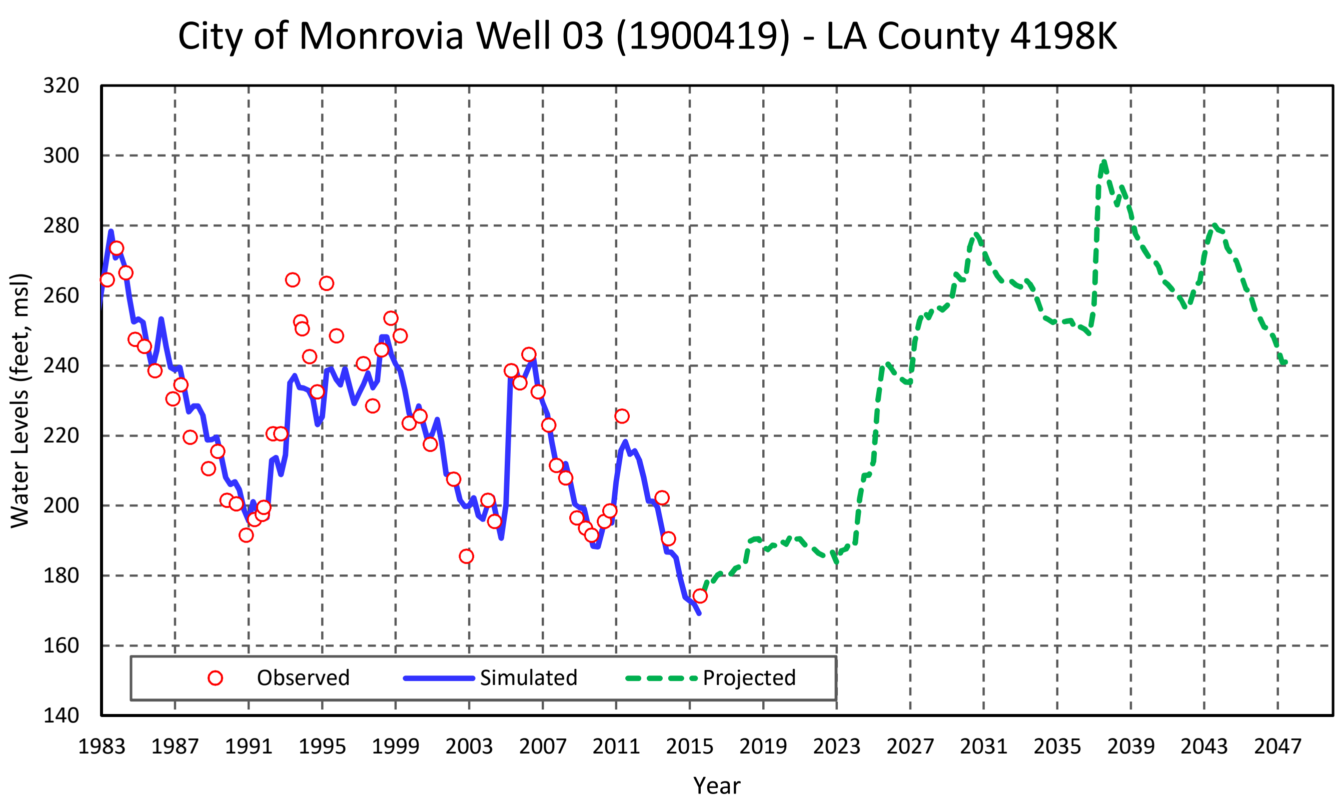
MainSanGabrielBasin WATERMASTER





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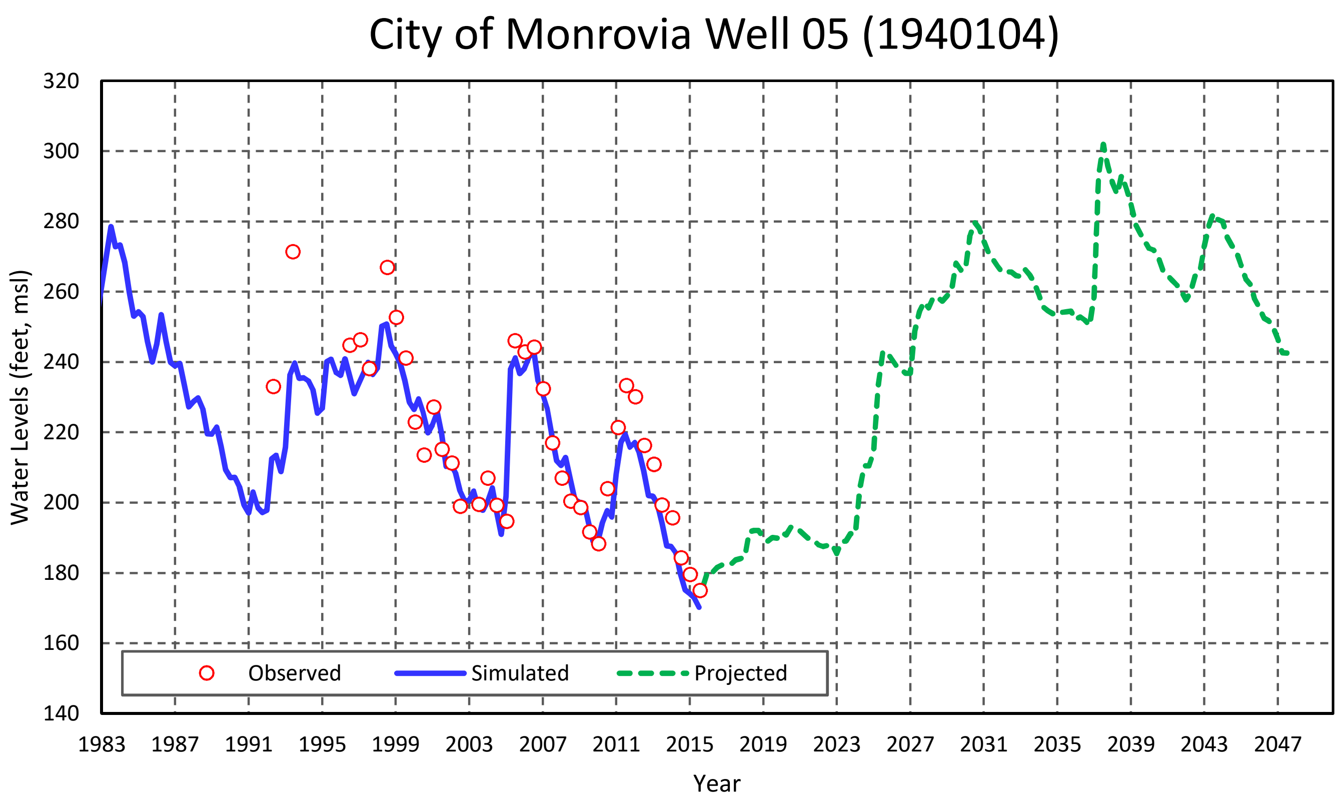
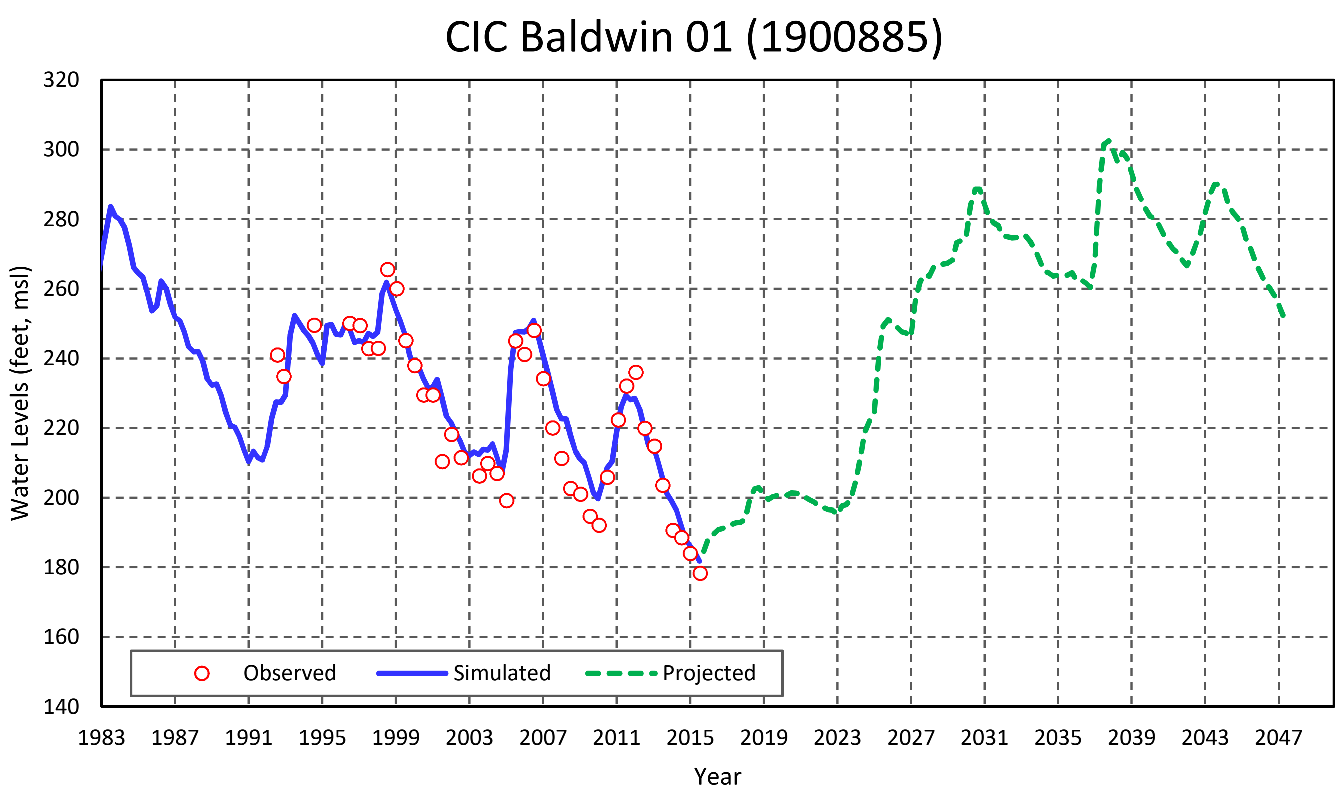
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Baseline Sustainability (Scenario 5)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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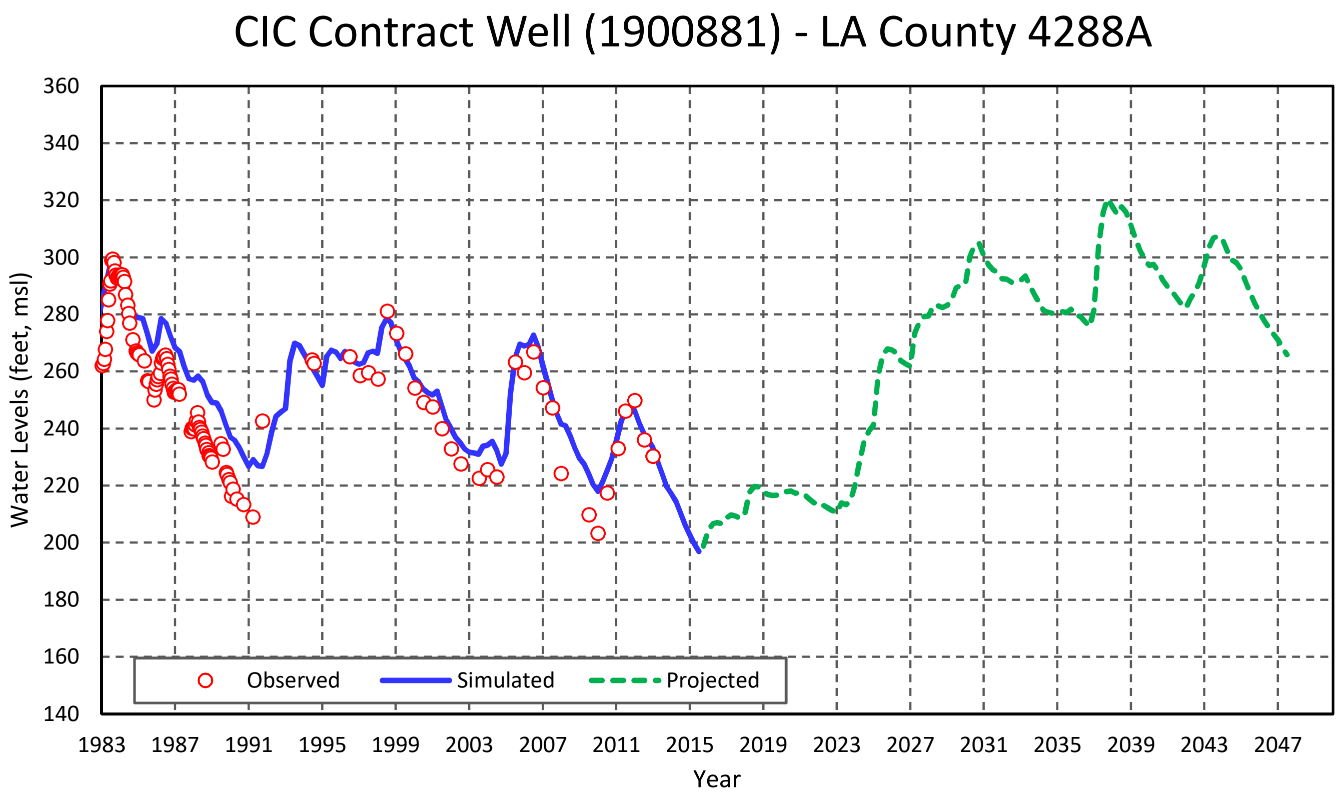
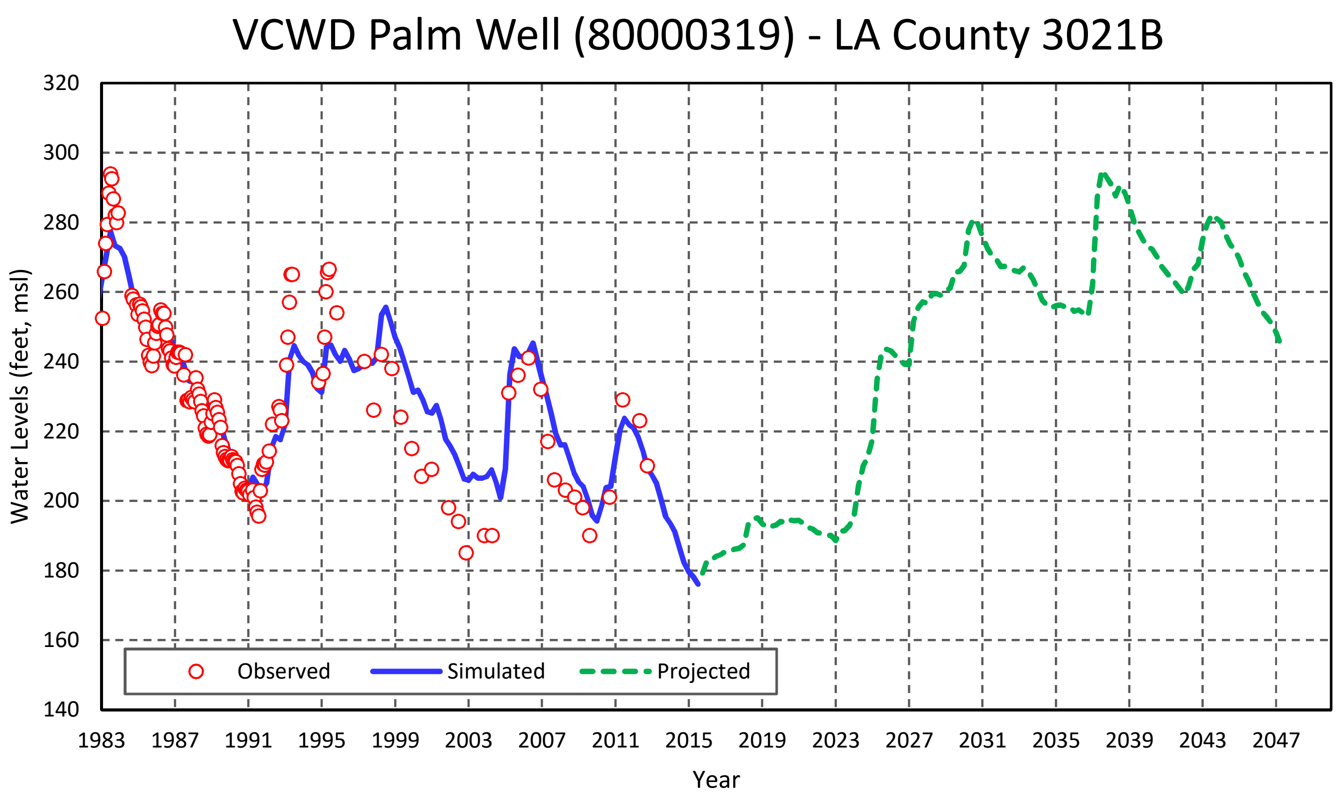
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Baseline Sustainability (Scenario 5)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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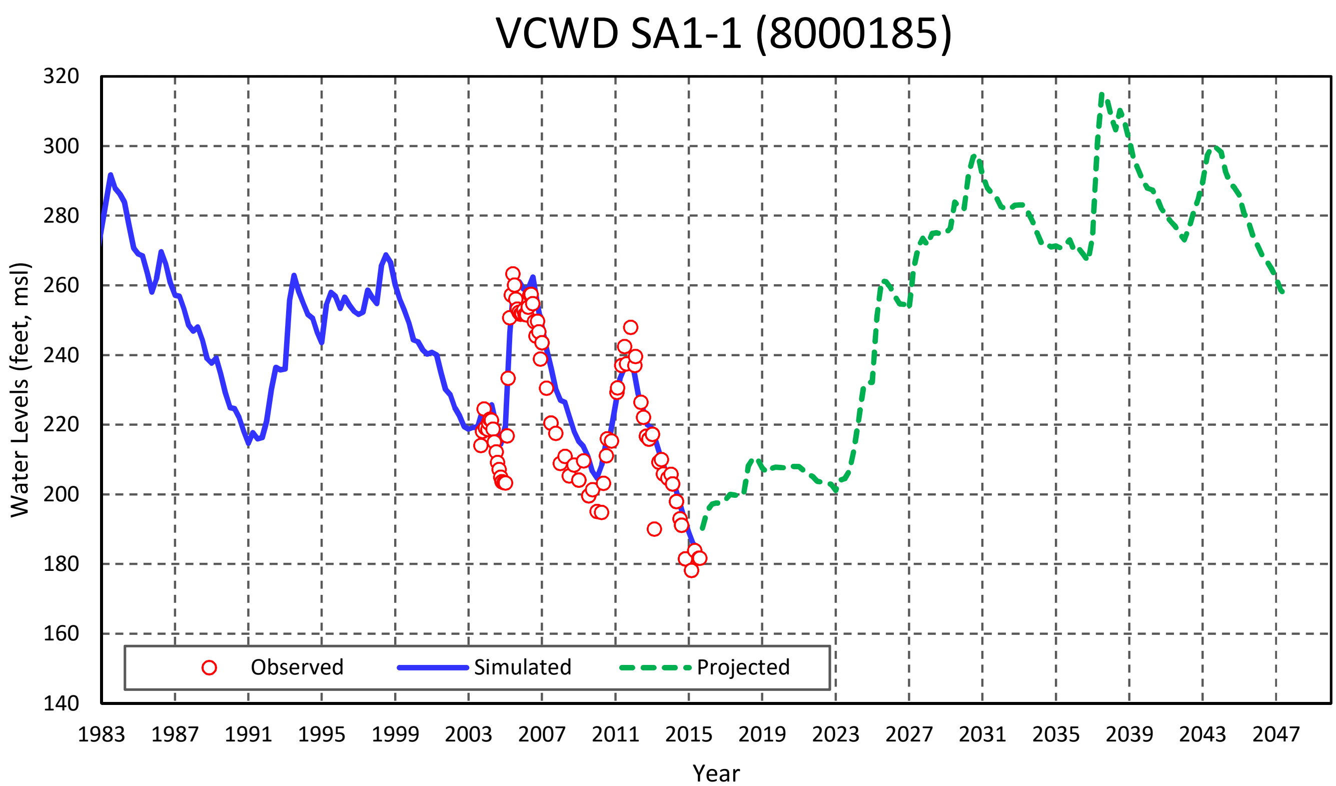
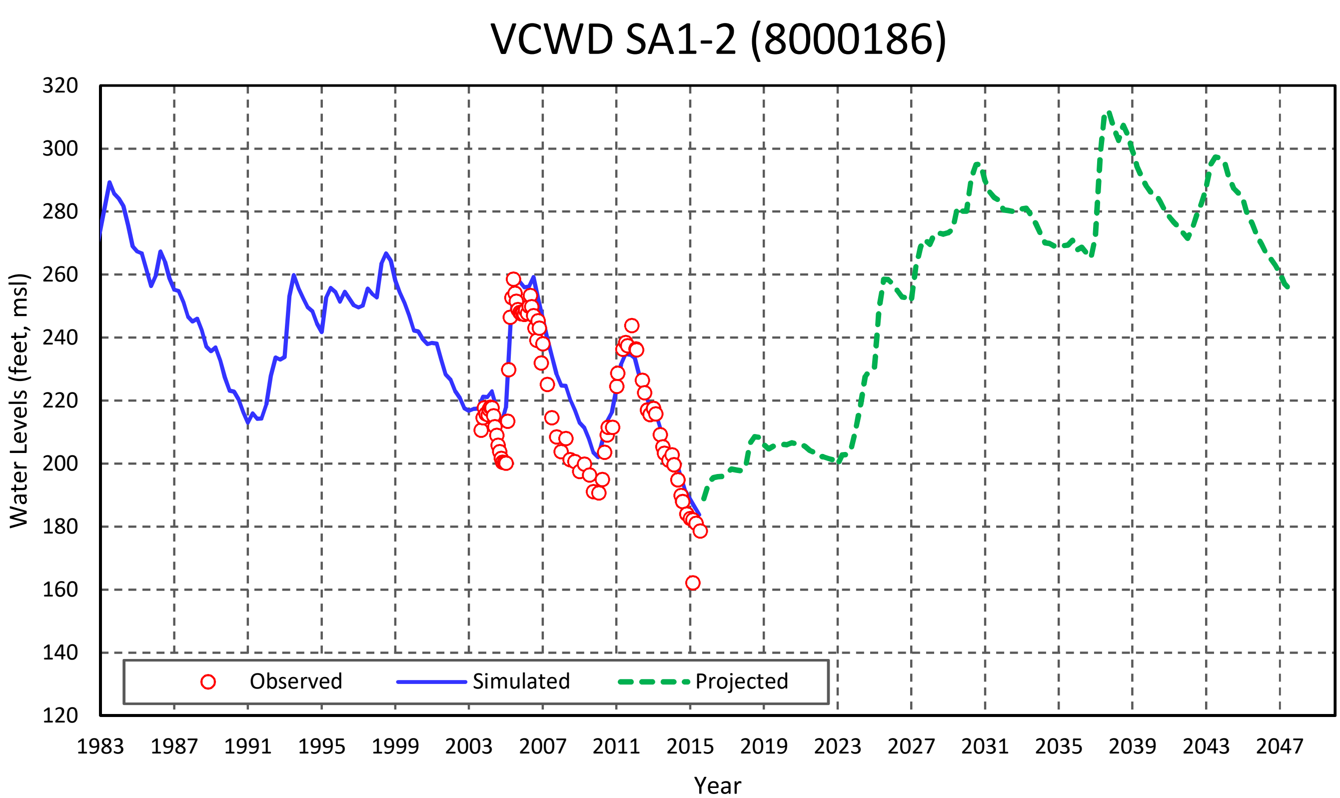
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Baseline Sustainability (Scenario 5)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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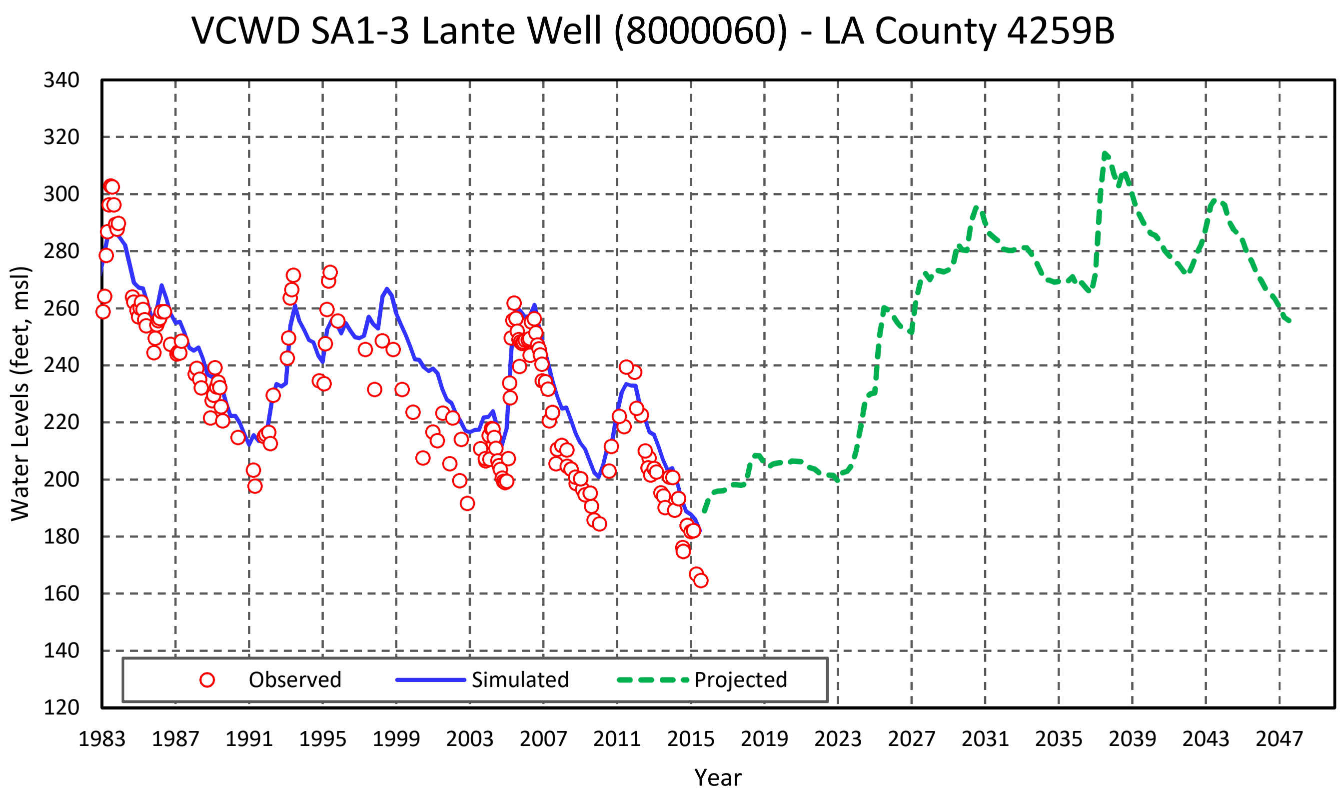
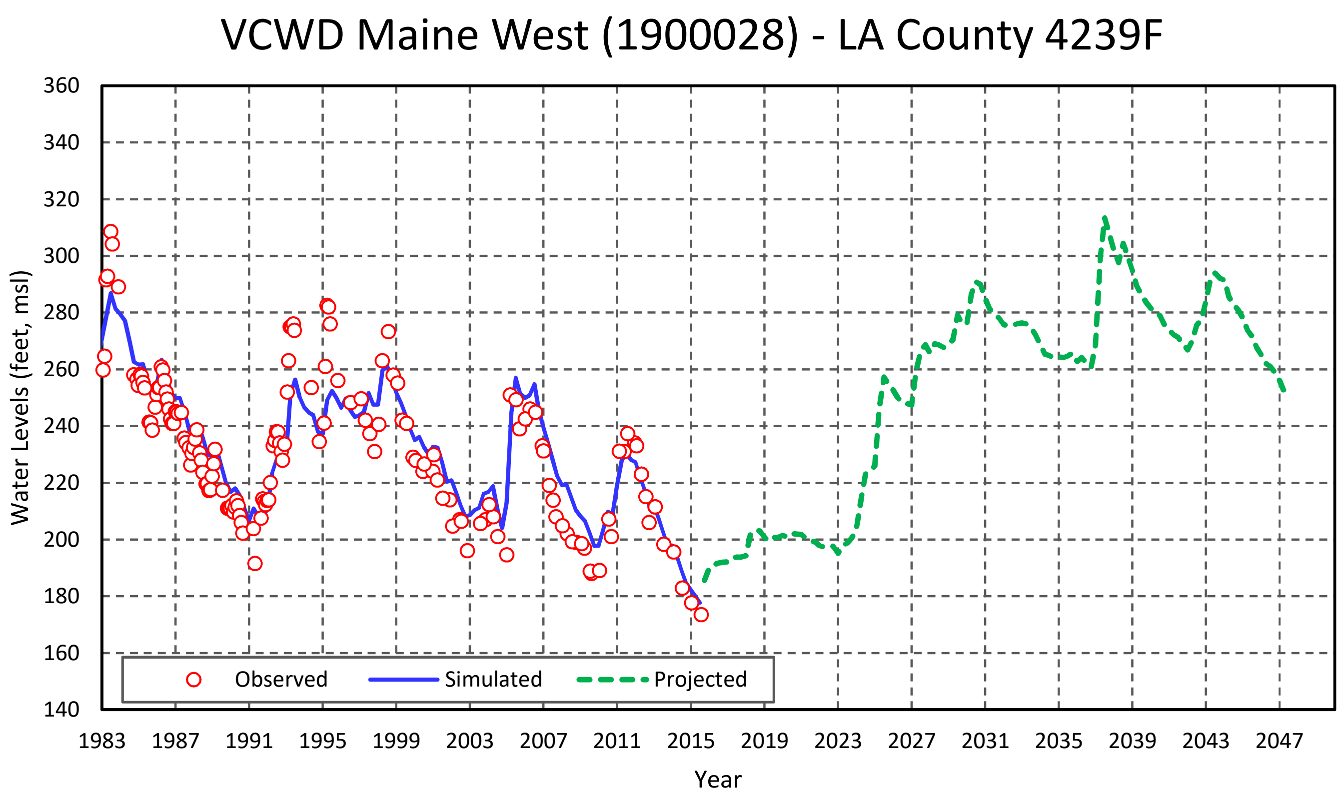
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Baseline Sustainability (Scenario 5)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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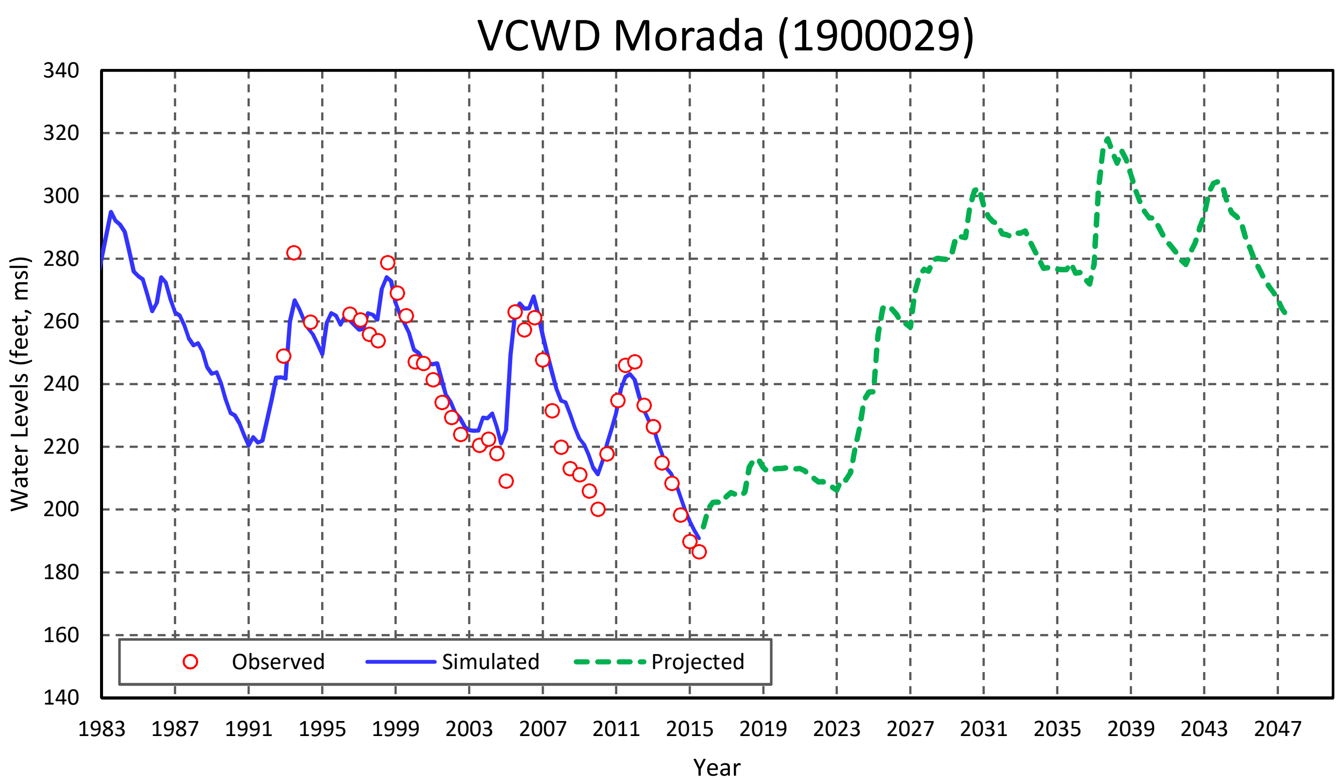
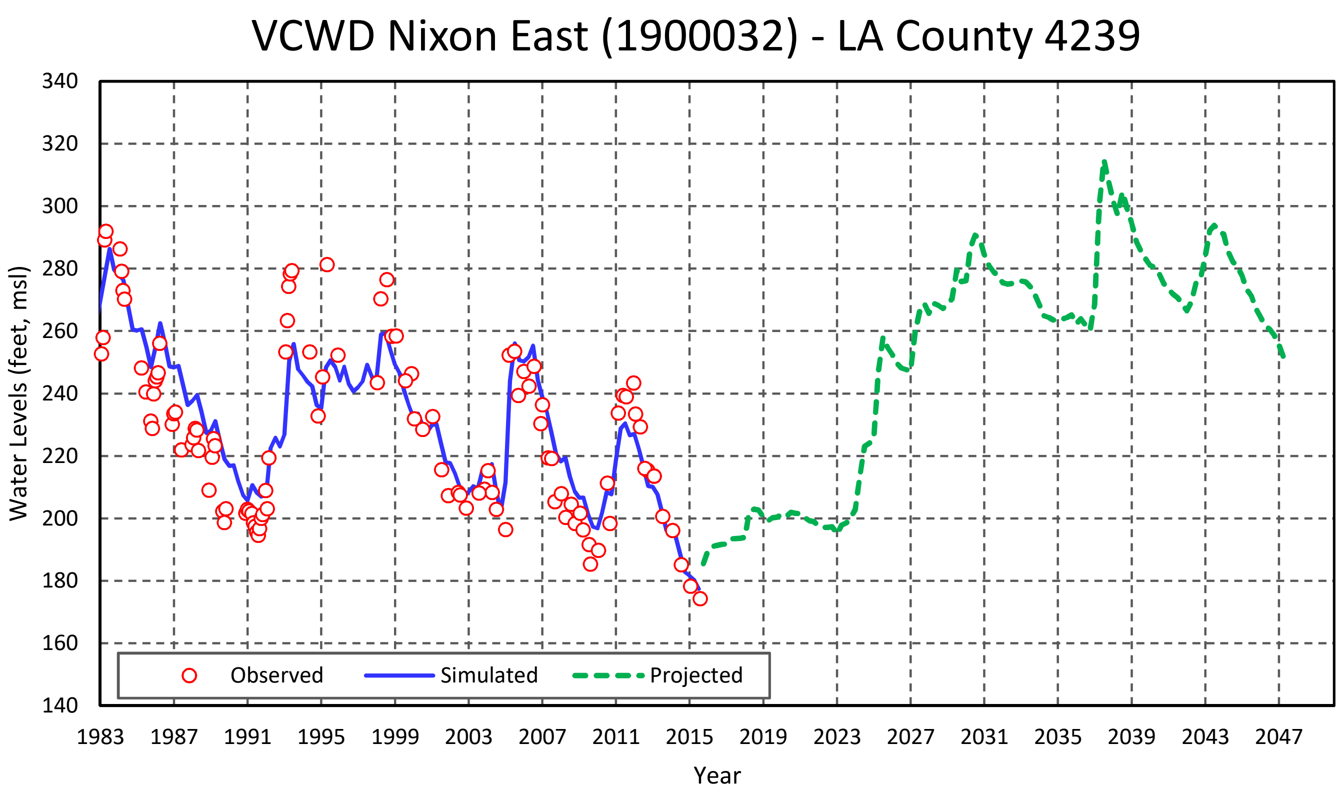
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Baseline Sustainability (Scenario 5)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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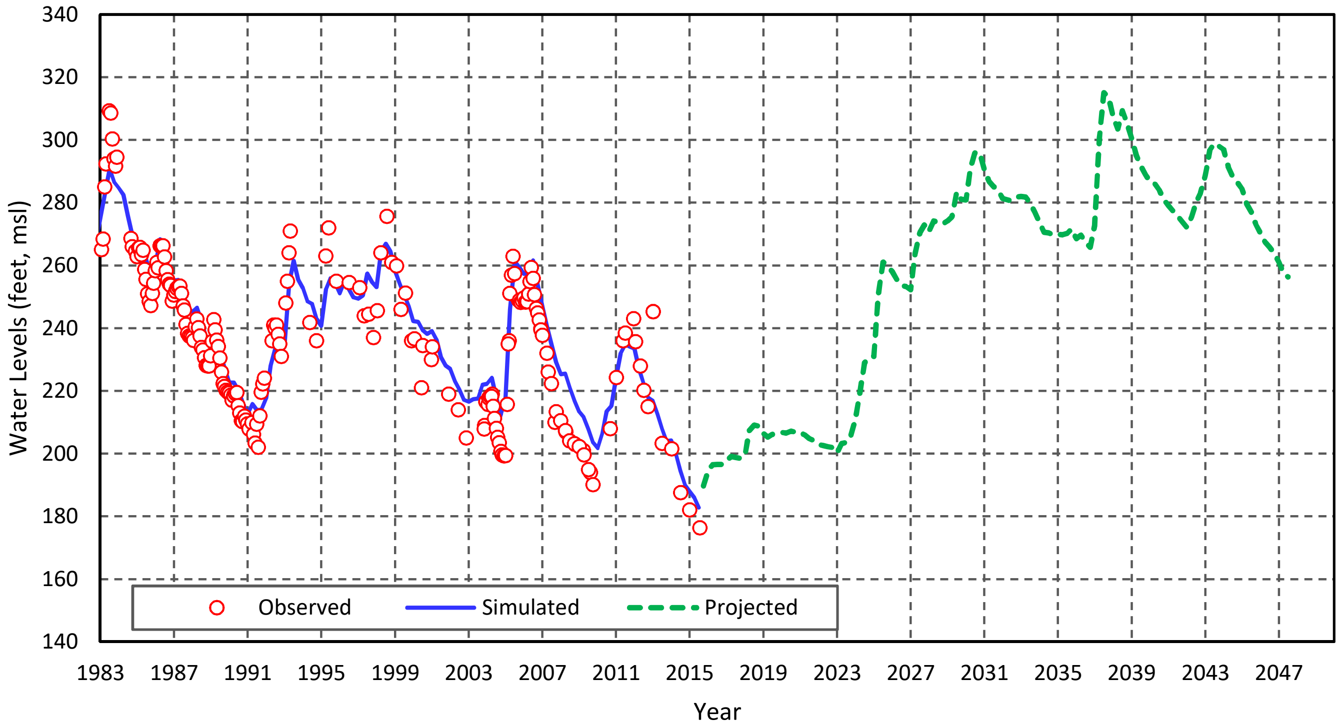
MAIN SAN GABRIEL BASIN WATERMASTER

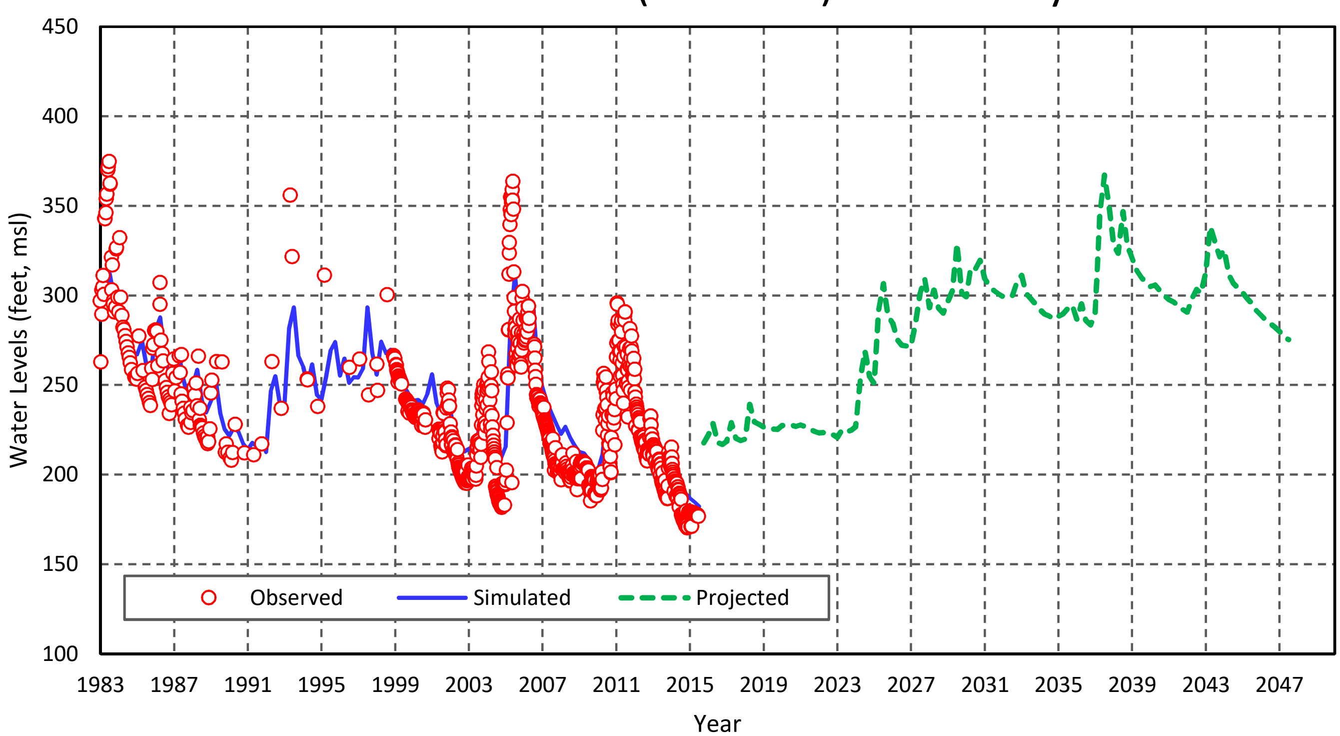
Projected Simulation Results
Baseline Sustainability (Scenario 5)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER

VCWD Arrow (1900034) - LA County (4259A)



CAWC Santa Fe Well (1900354) - LA County 4246



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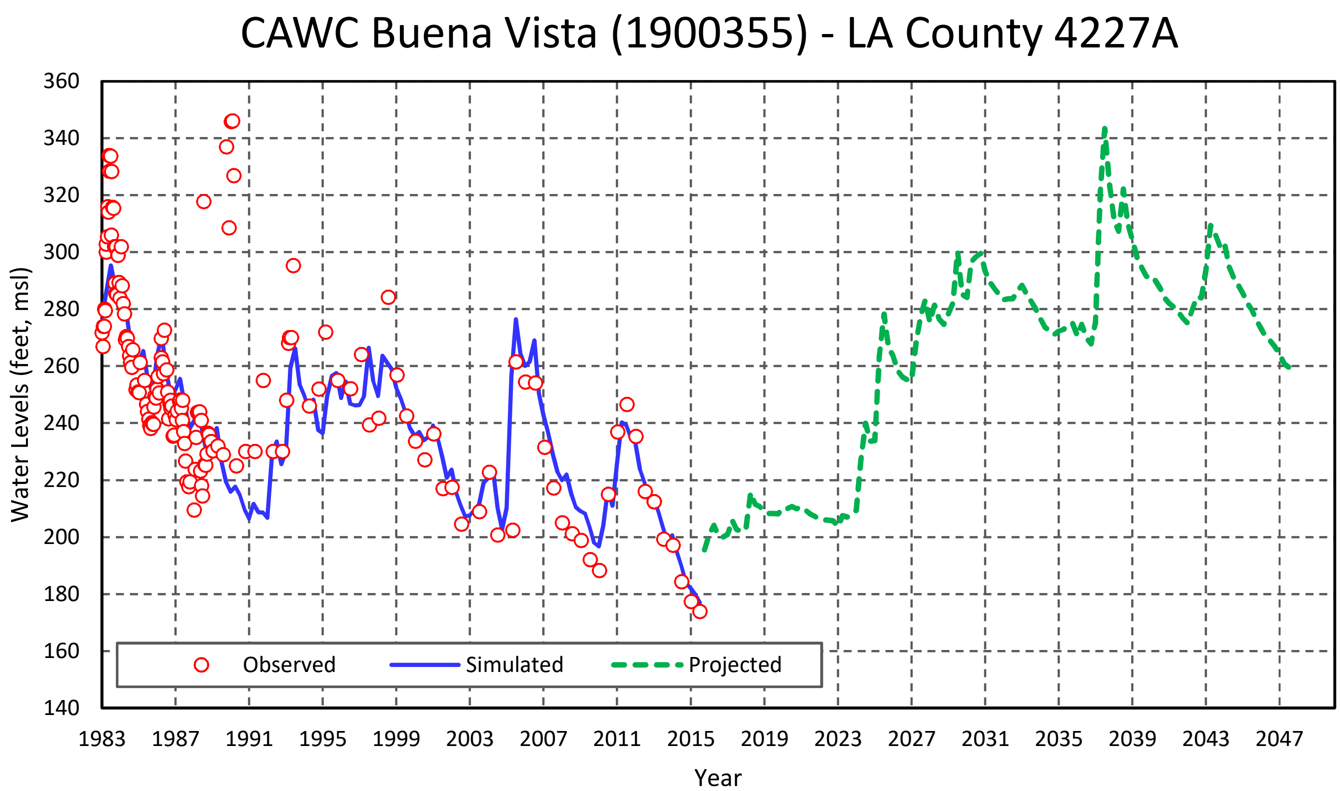
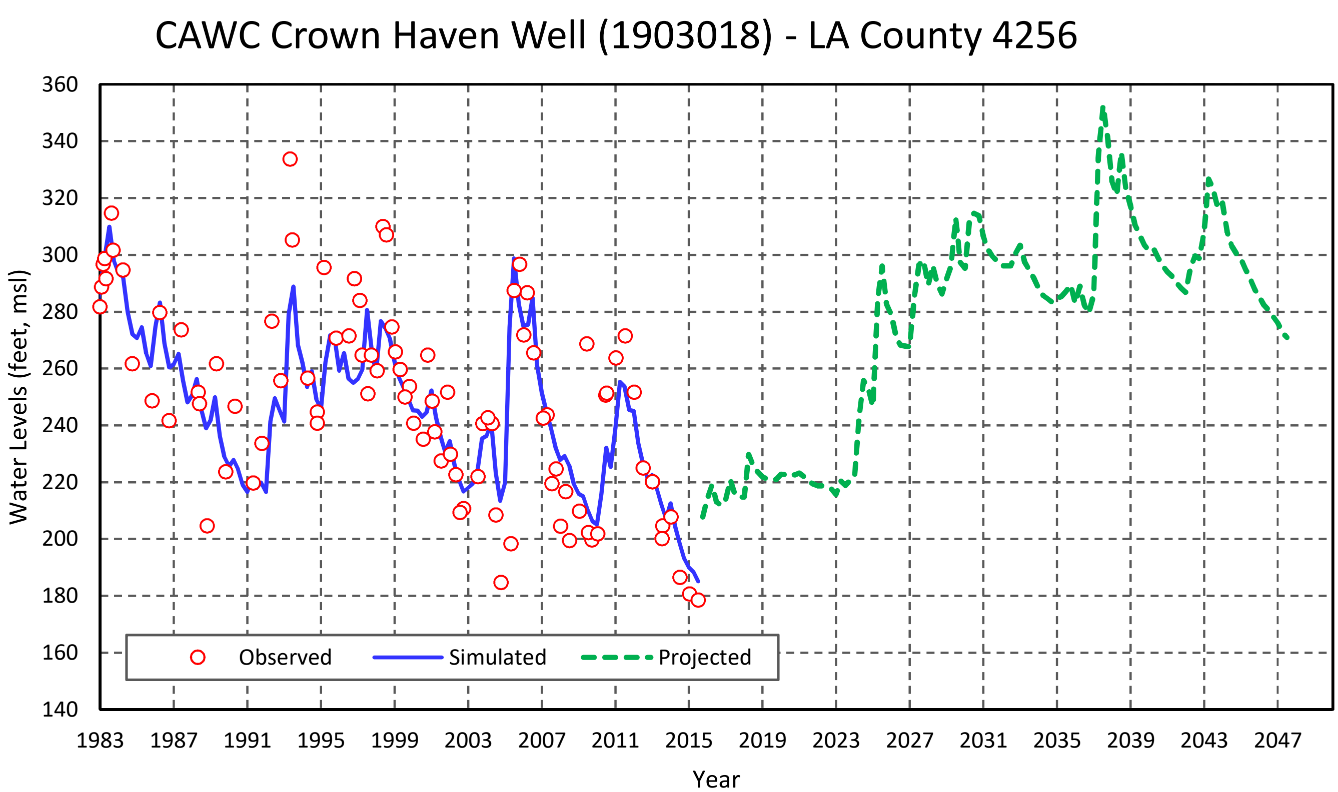
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Baseline Sustainability (Scenario 5)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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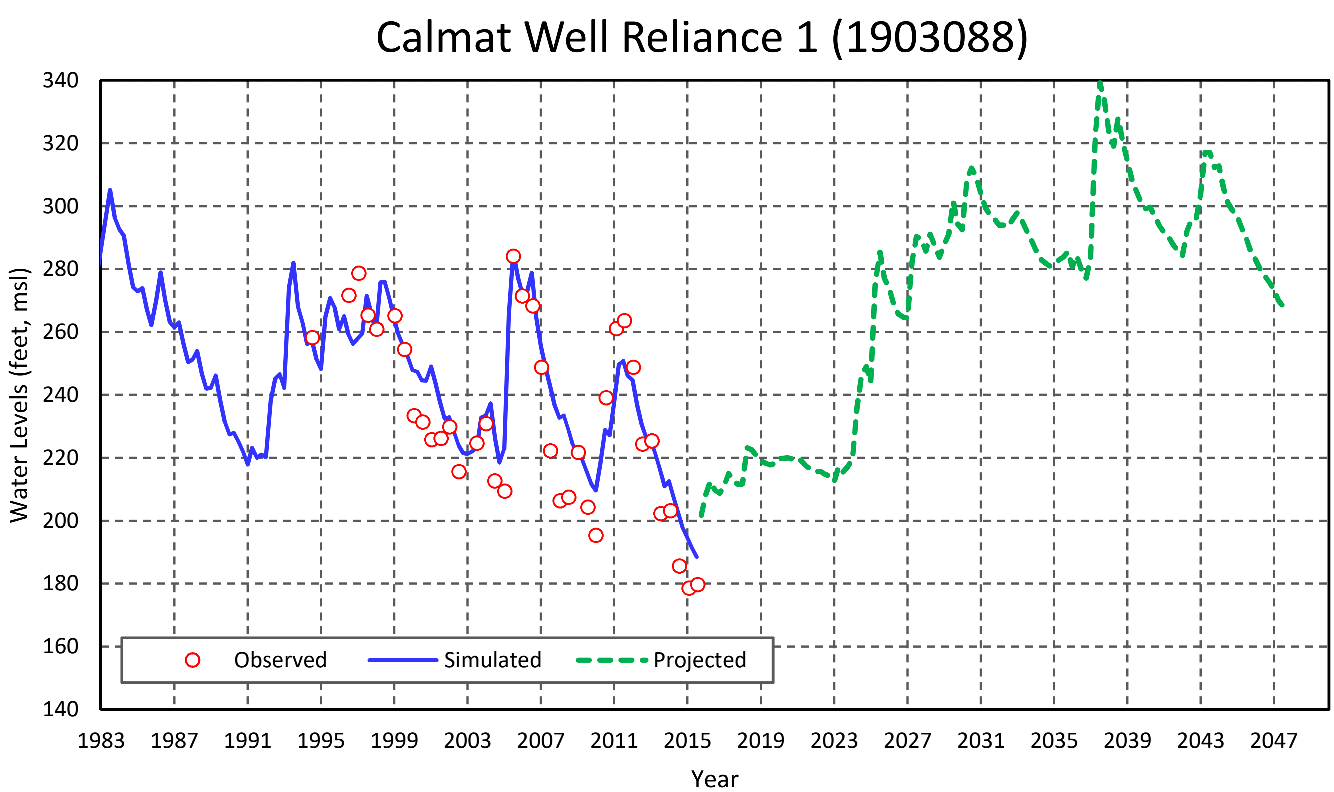
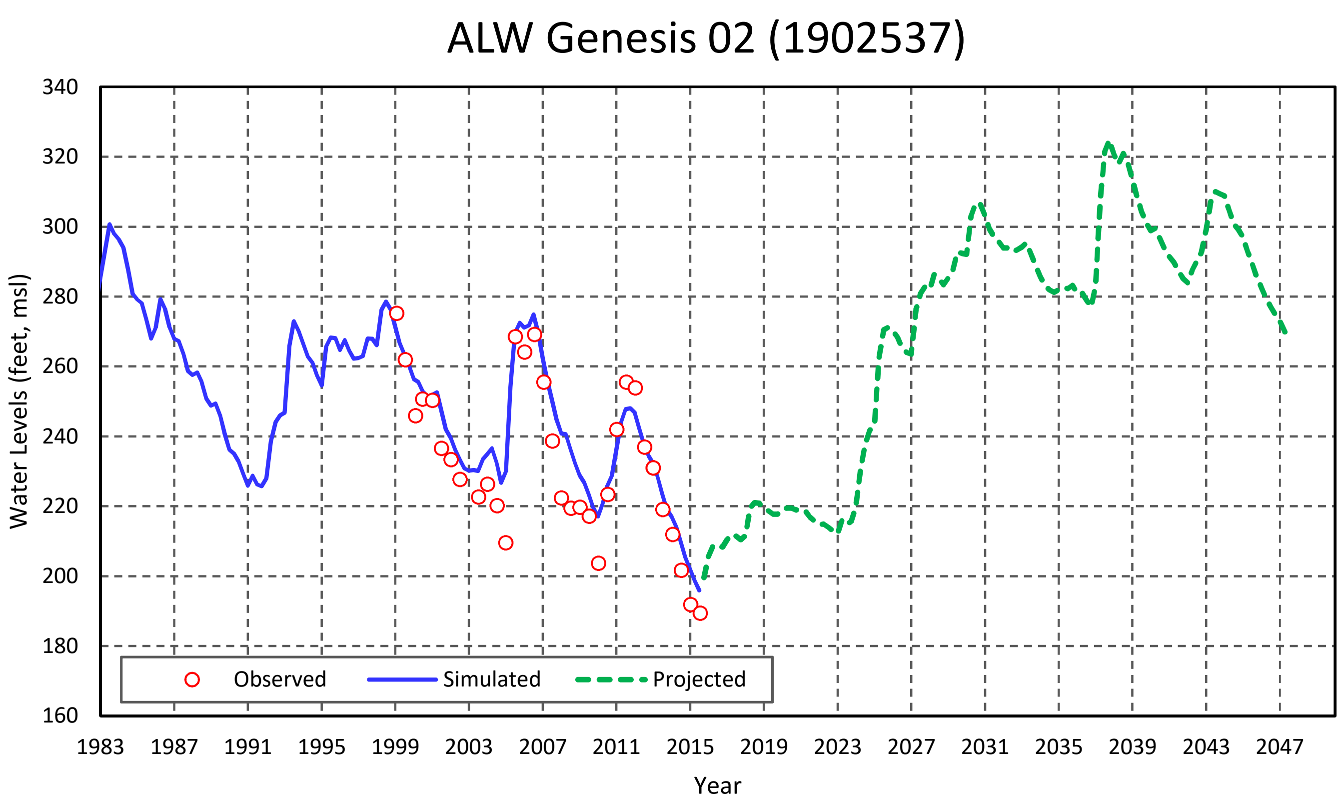
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Baseline Sustainability (Scenario 5)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER



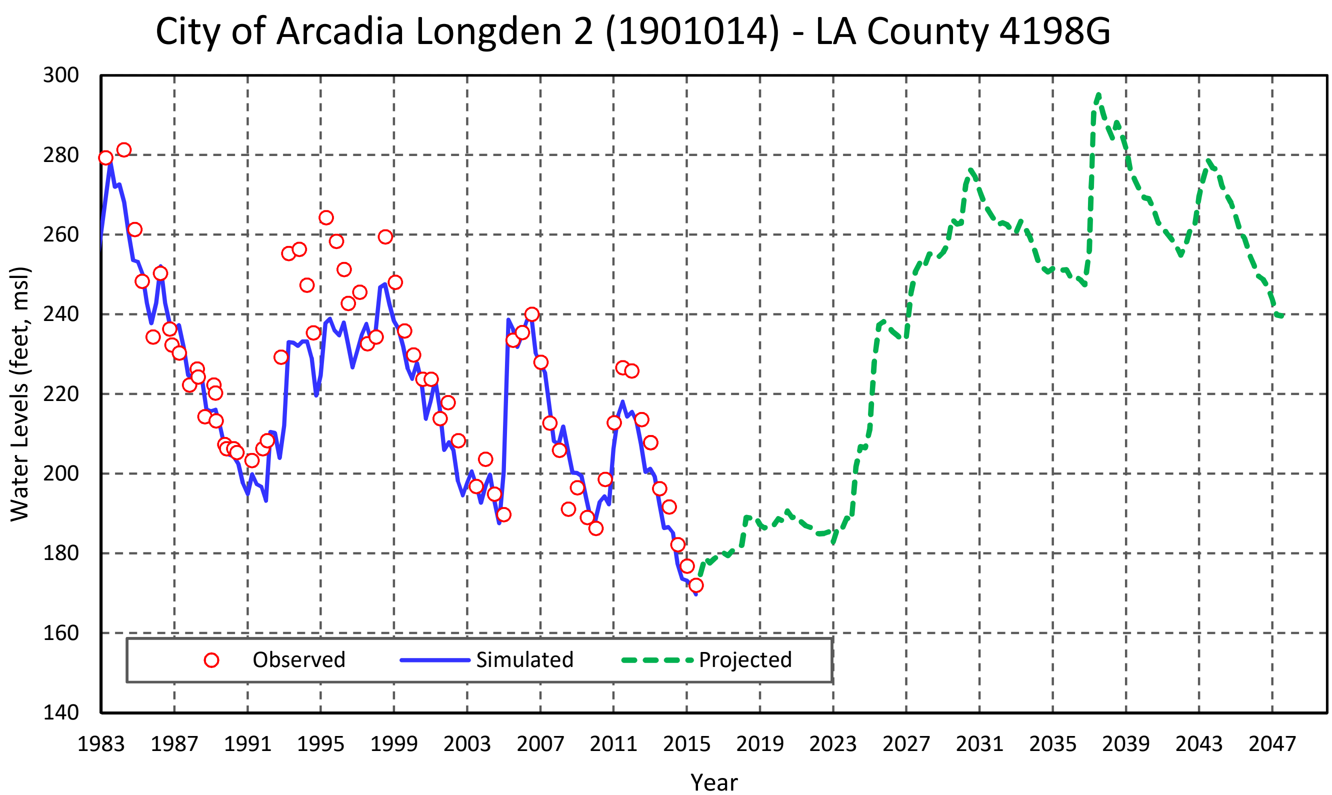


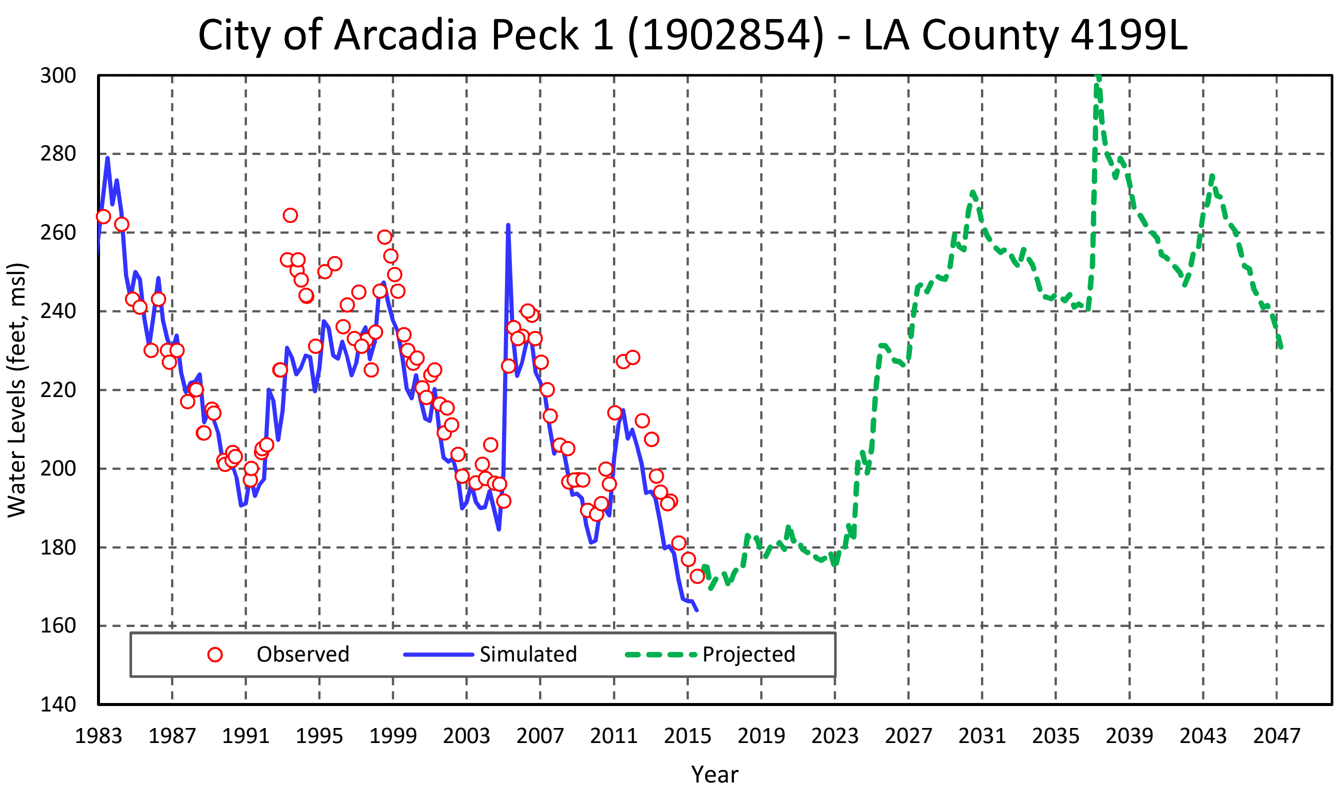
STETSON ENGINEERS INC.

MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Baseline Sustainability (Scenario 5)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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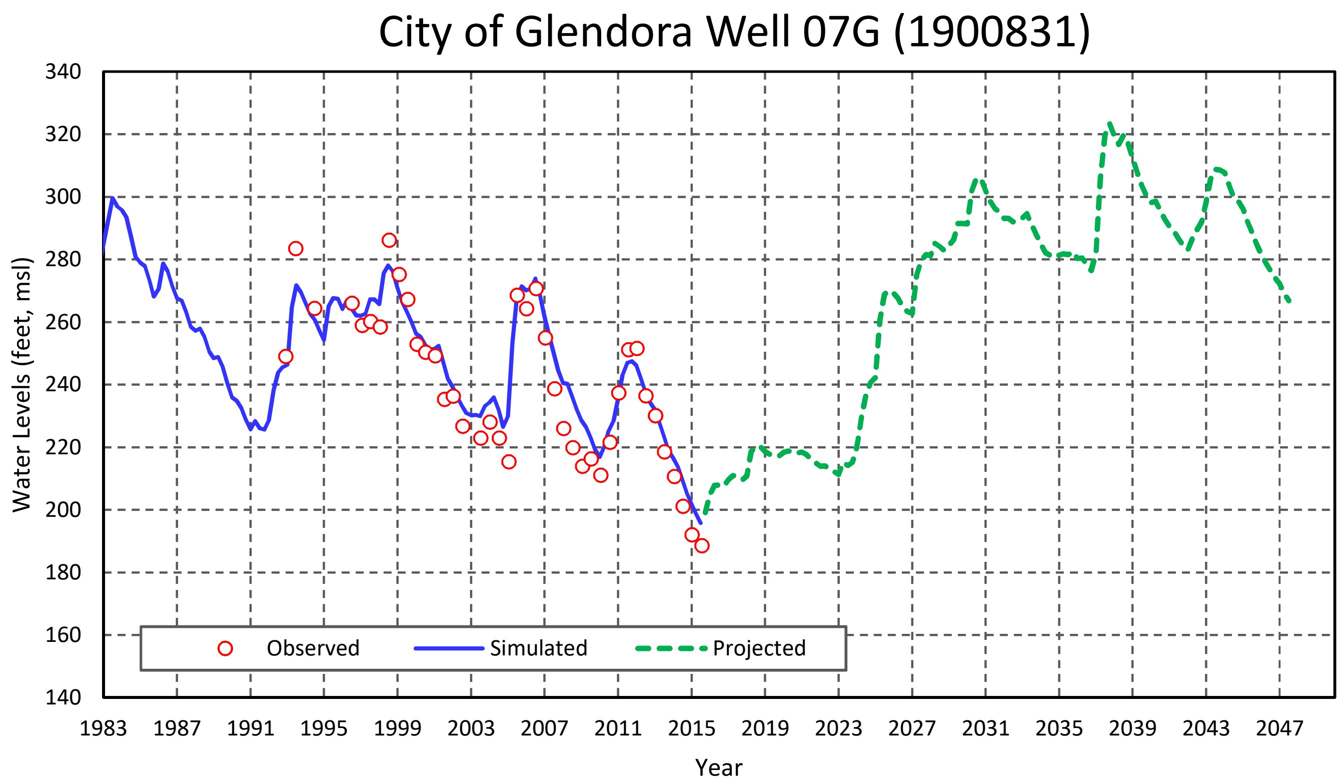
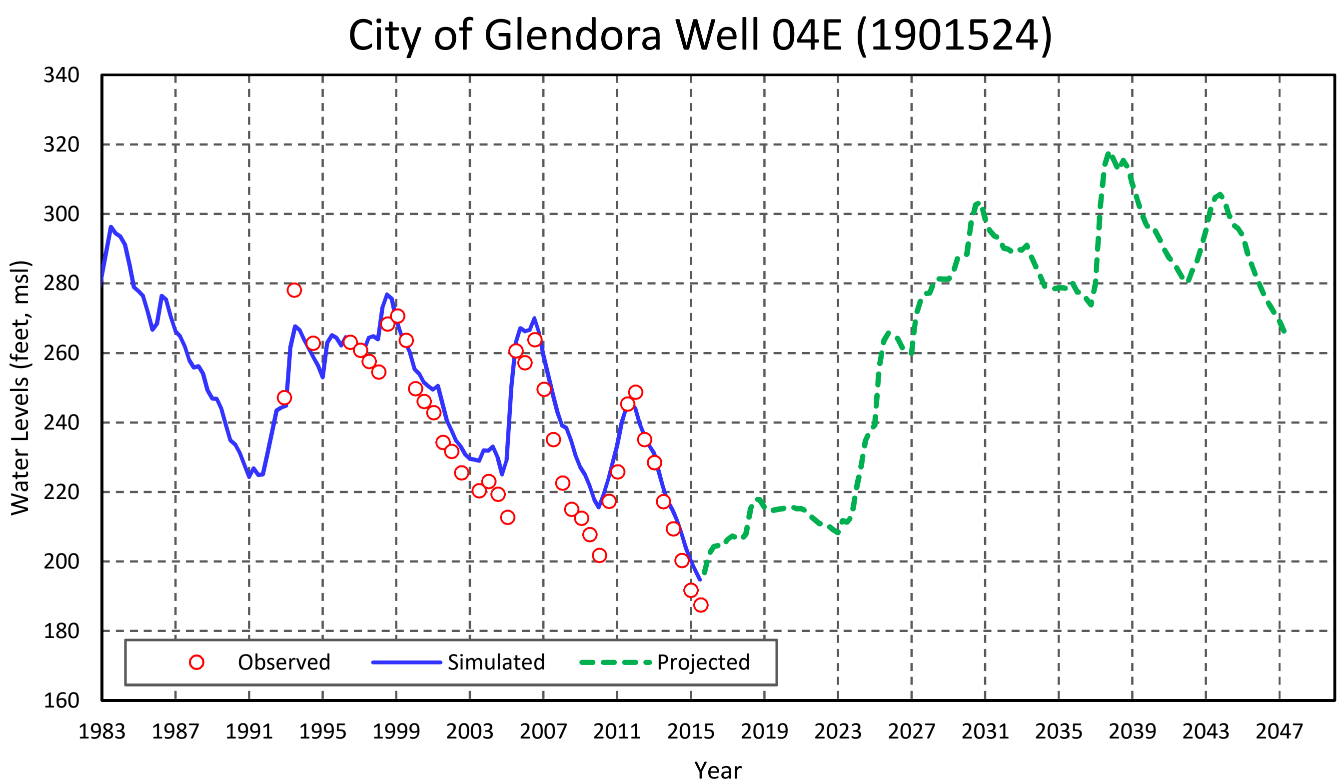
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Baseline Sustainability (Scenario 5)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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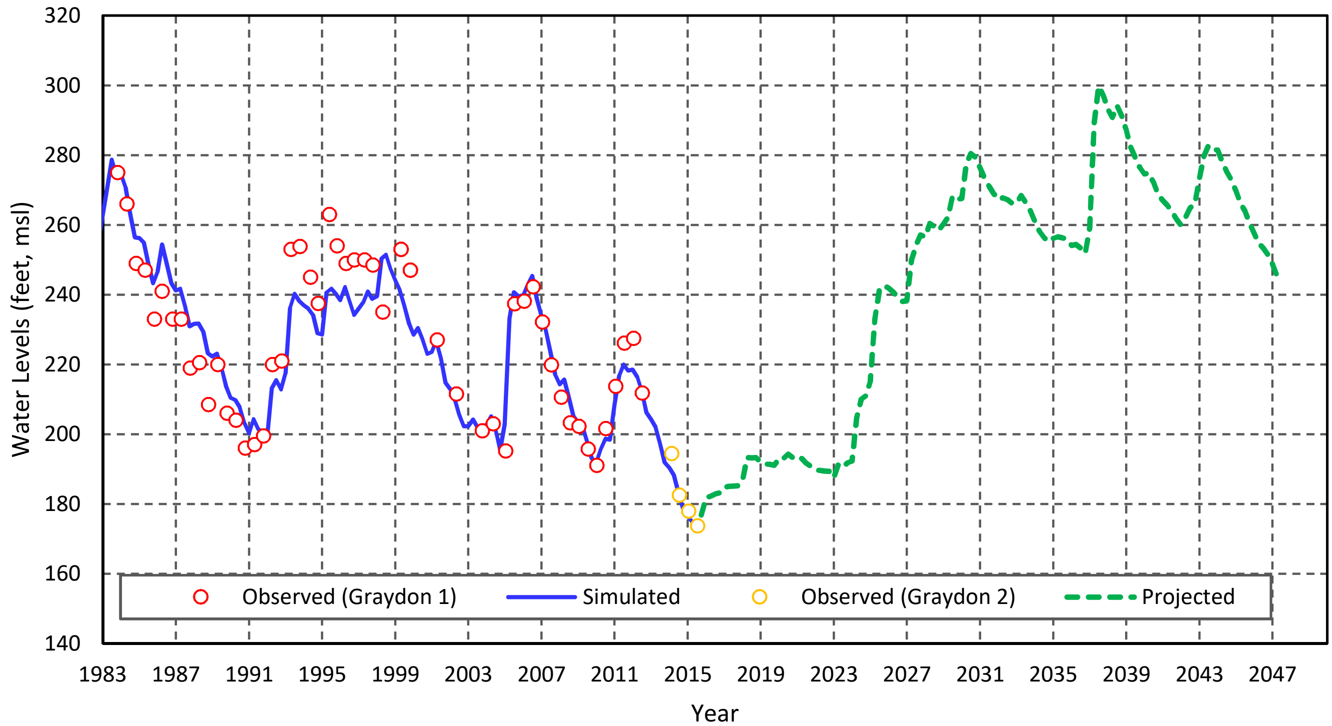
MAIN SAN GABRIEL BASIN WATERMASTER

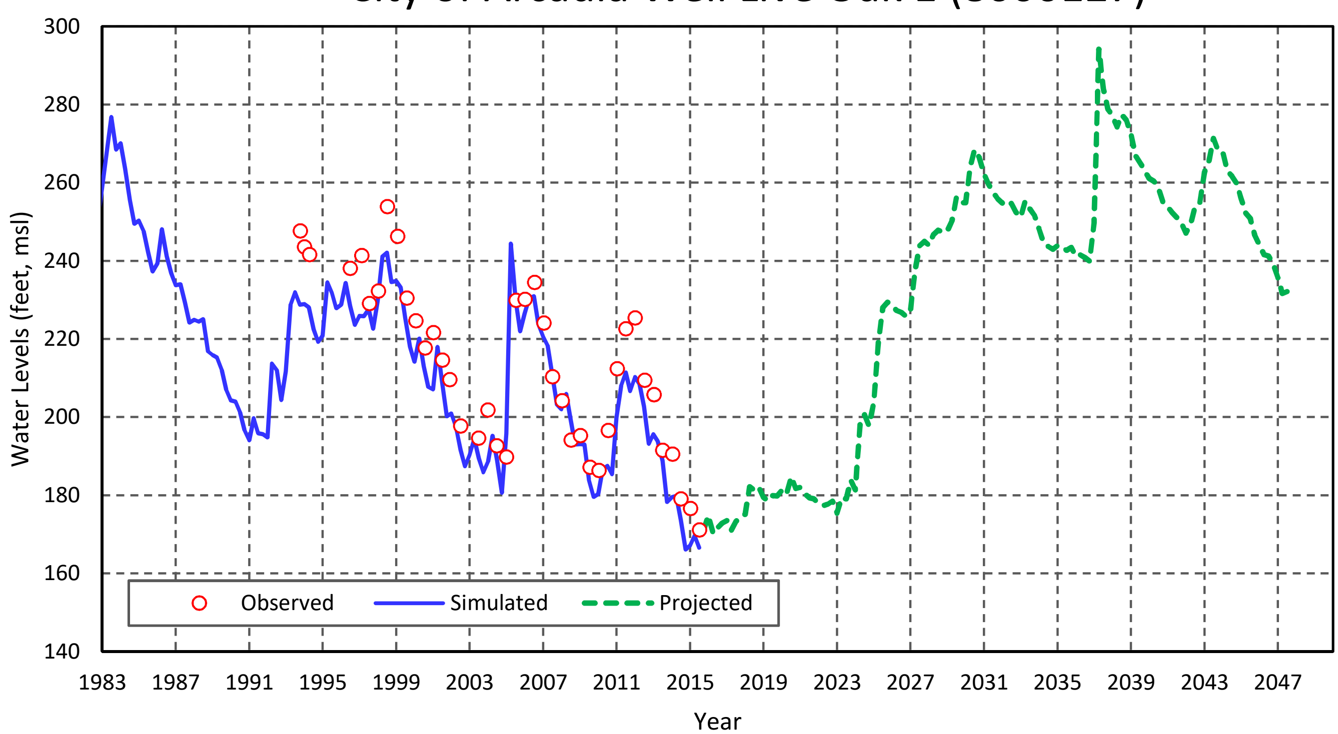
Projected Simulation Results
Baseline Sustainability (Scenario 5)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER

GSWC Graydon 02 (1902461)



City of Arcadia Well Live Oak 1 (8000127)



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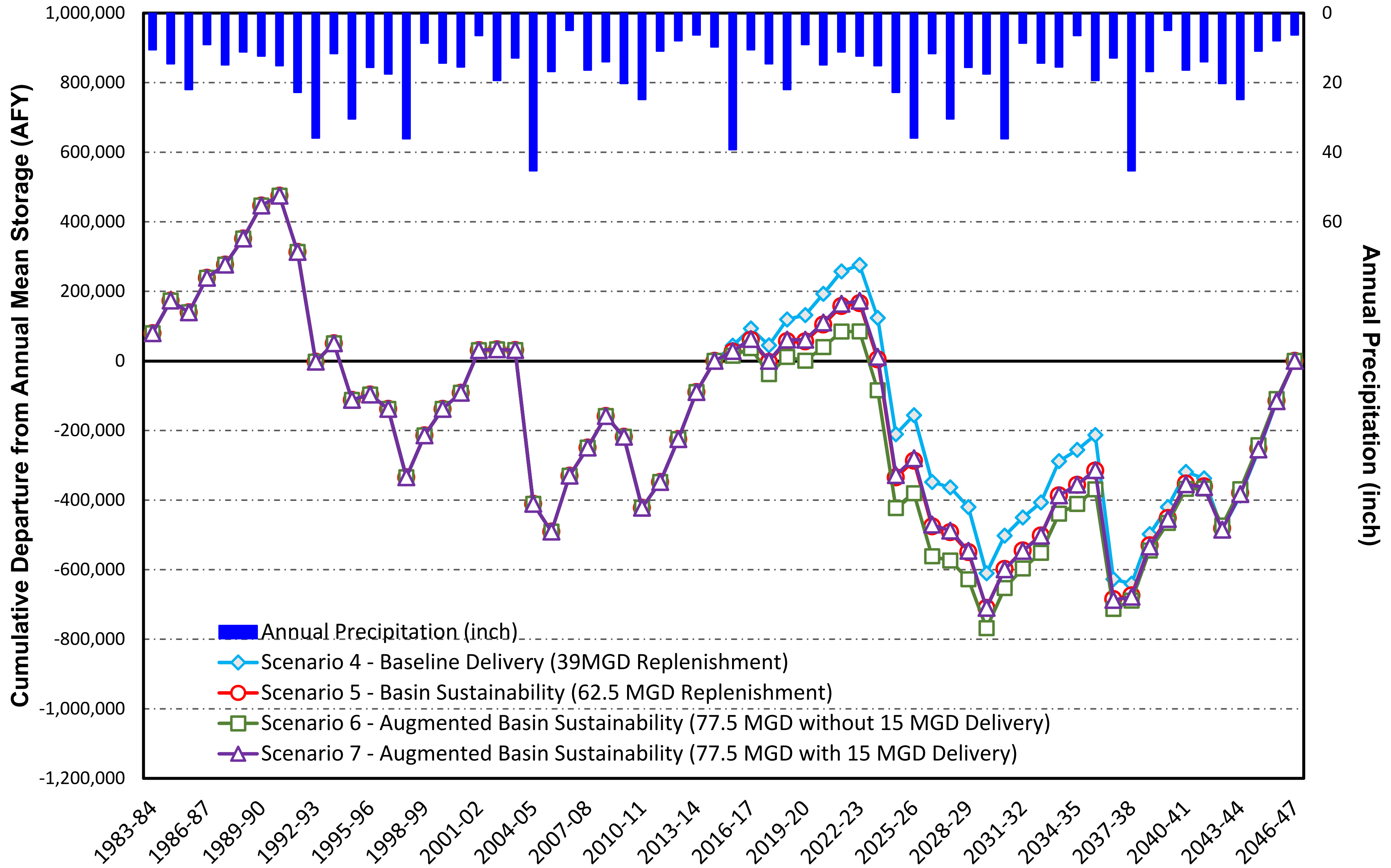
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Baseline Sustainability (Scenario 5)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER

Figure 17



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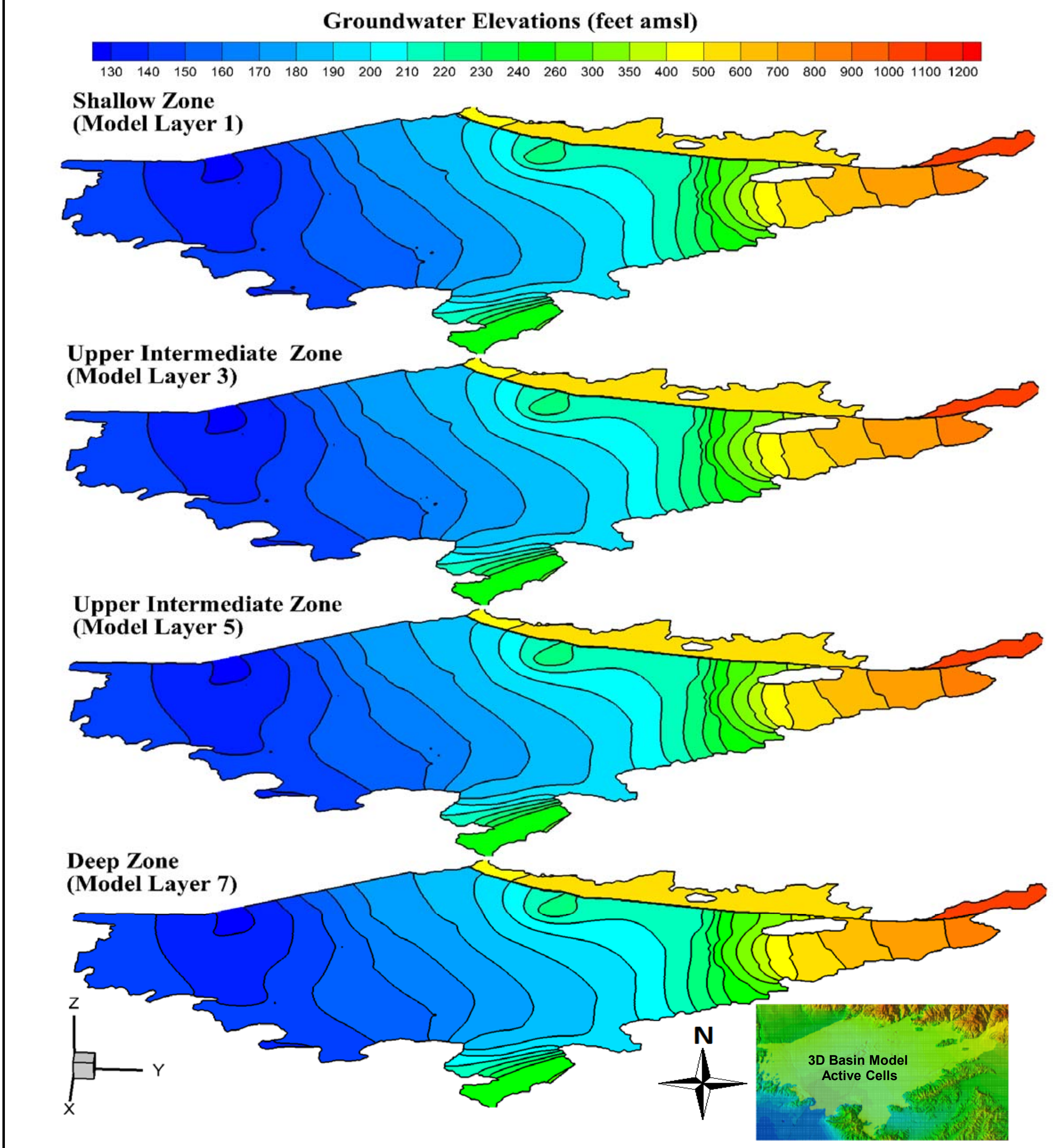
MAIN SAN GABRIEL BASIN WATERMASTER

Comparison of Cumulative Departure from Mean Change of Storage from FY1973-74 to FY2014-15

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 17 - Change of Storage.xlsx



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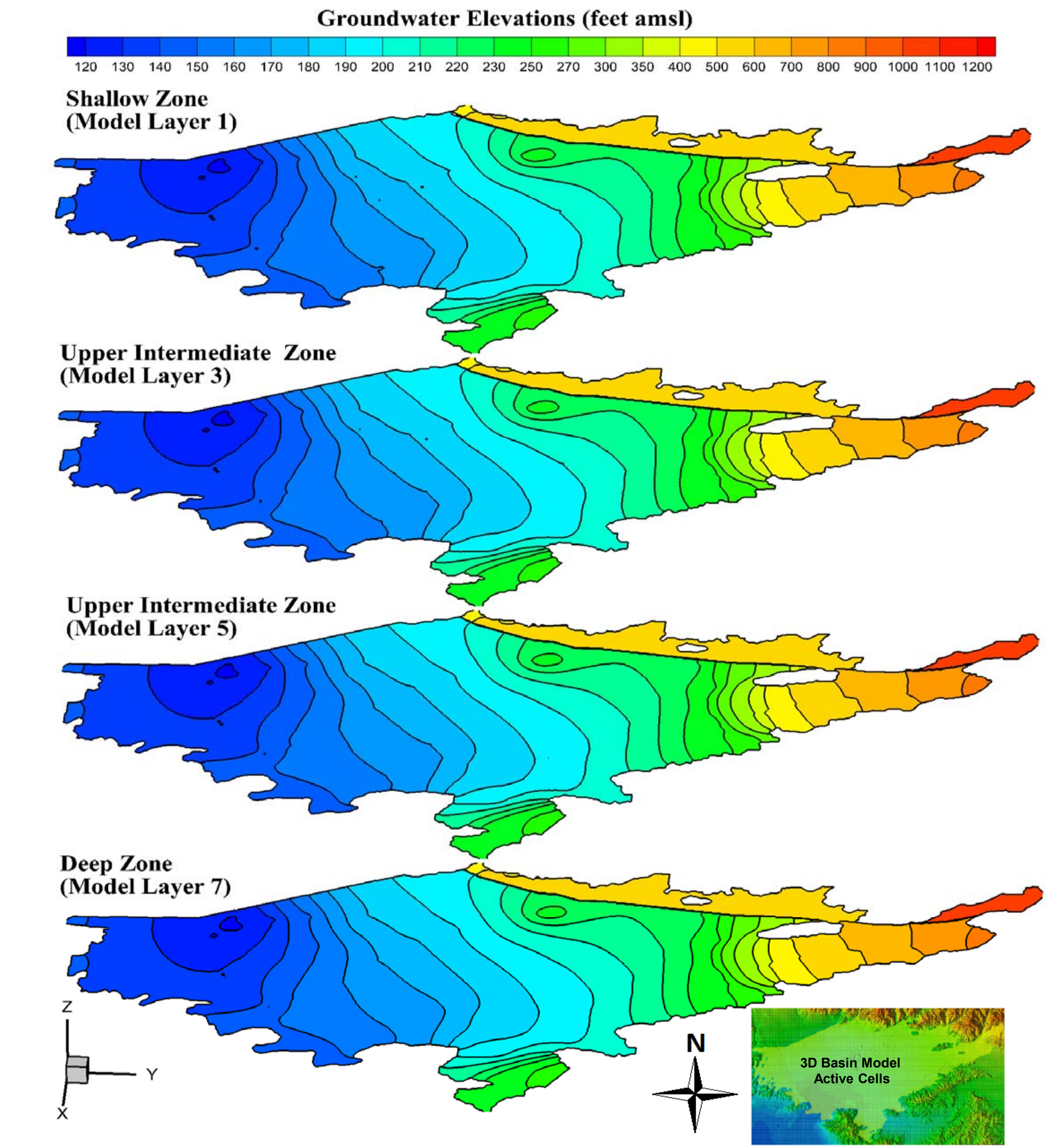
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2015-16
Groundwater Elevation Contours (Scenario 7)
(Sub-Task No. 2.5 Augmented Basin Sustainability)

MainSanGabrielBasin WATERMASTER

Figure 18b



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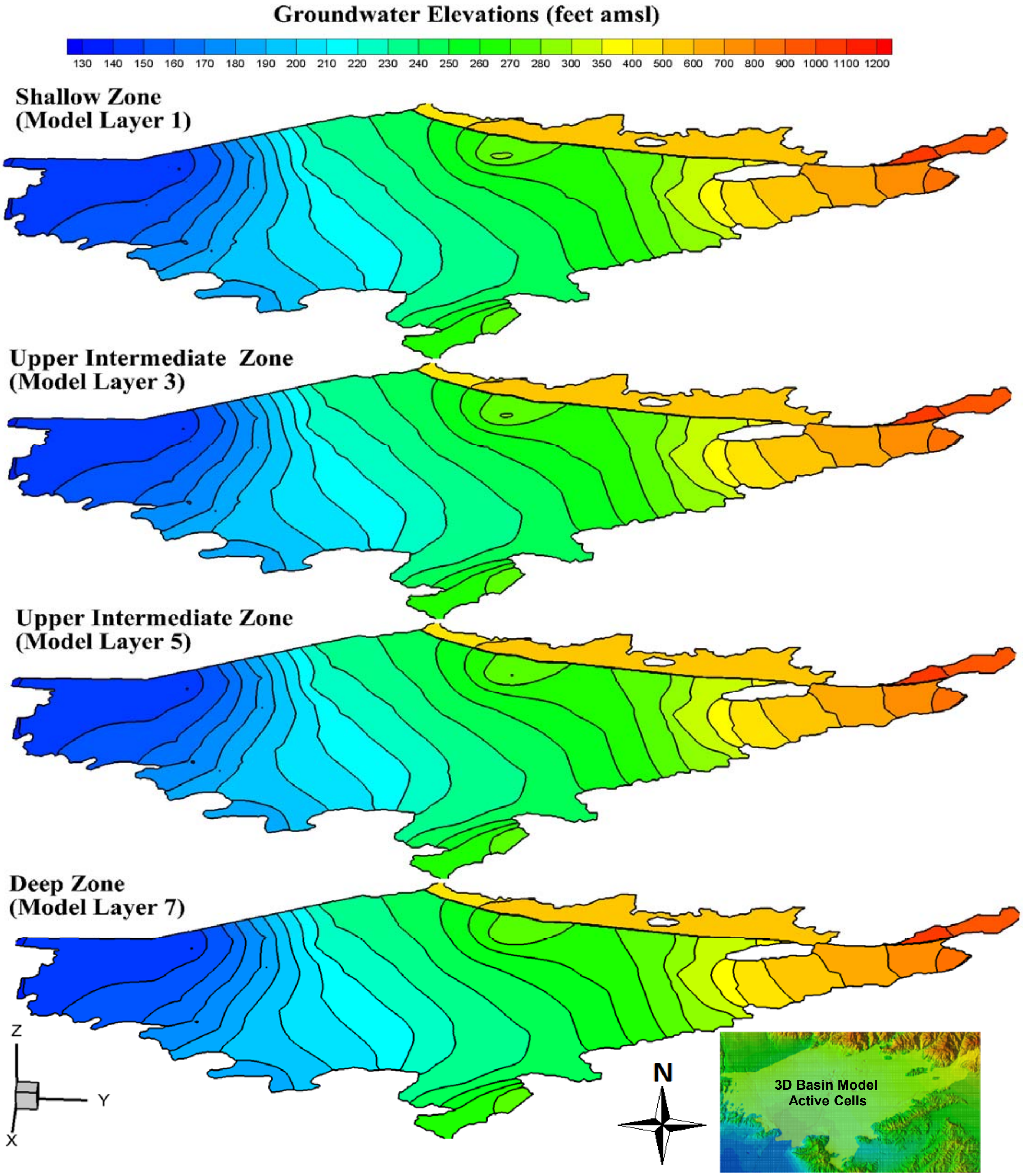
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2020-21
Groundwater Elevation Contours (Scenario 7)
(Sub-Task No. 2.5 Augmented Basin Sustainability)

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 18 - 3D Basin Model Simulated Contours(775MGD-15MGD_Delivery).xlsx



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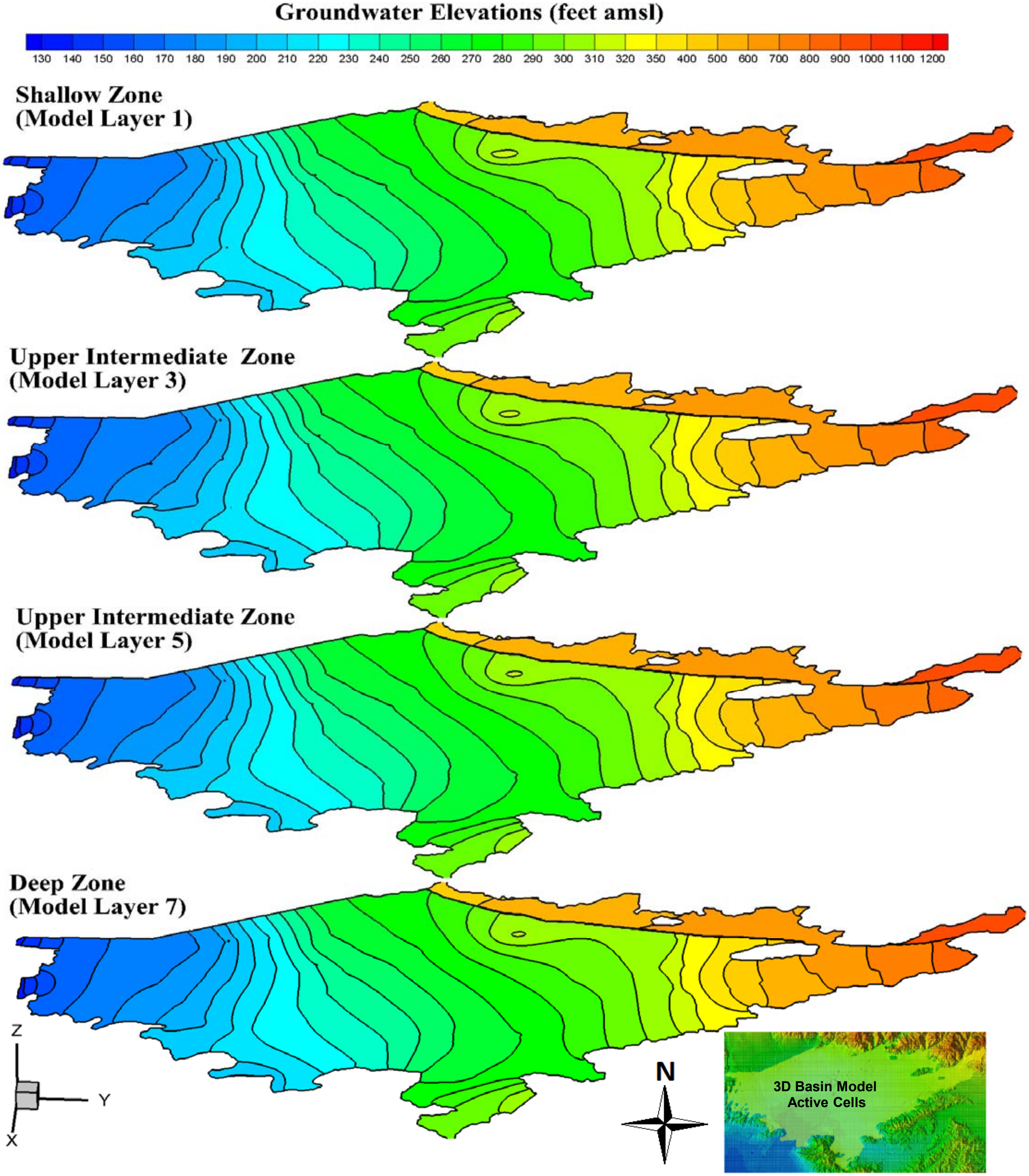
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2025-26
Groundwater Elevation Contours (Scenario 7)
(Sub-Task No. 2.5 Augmented Basin Sustainability)

MainSanGabrielBasin WATERMASTER



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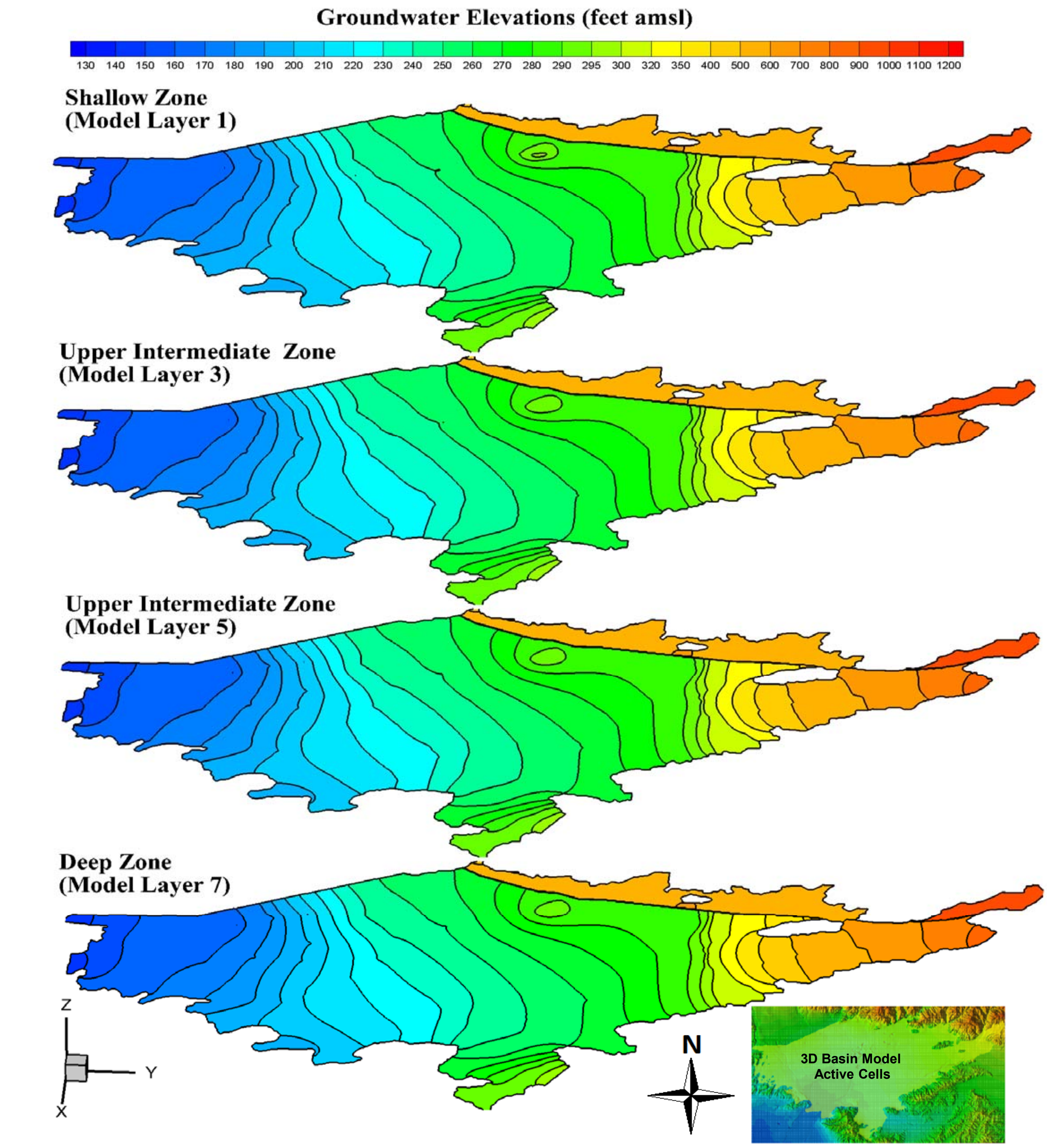
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2030-31
Groundwater Elevation Contours (Scenario 7)
(Sub-Task No. 2.5 Augmented Basin Sustainability)

MainSanGabrielBasin WATERMASTER

Figure 18e



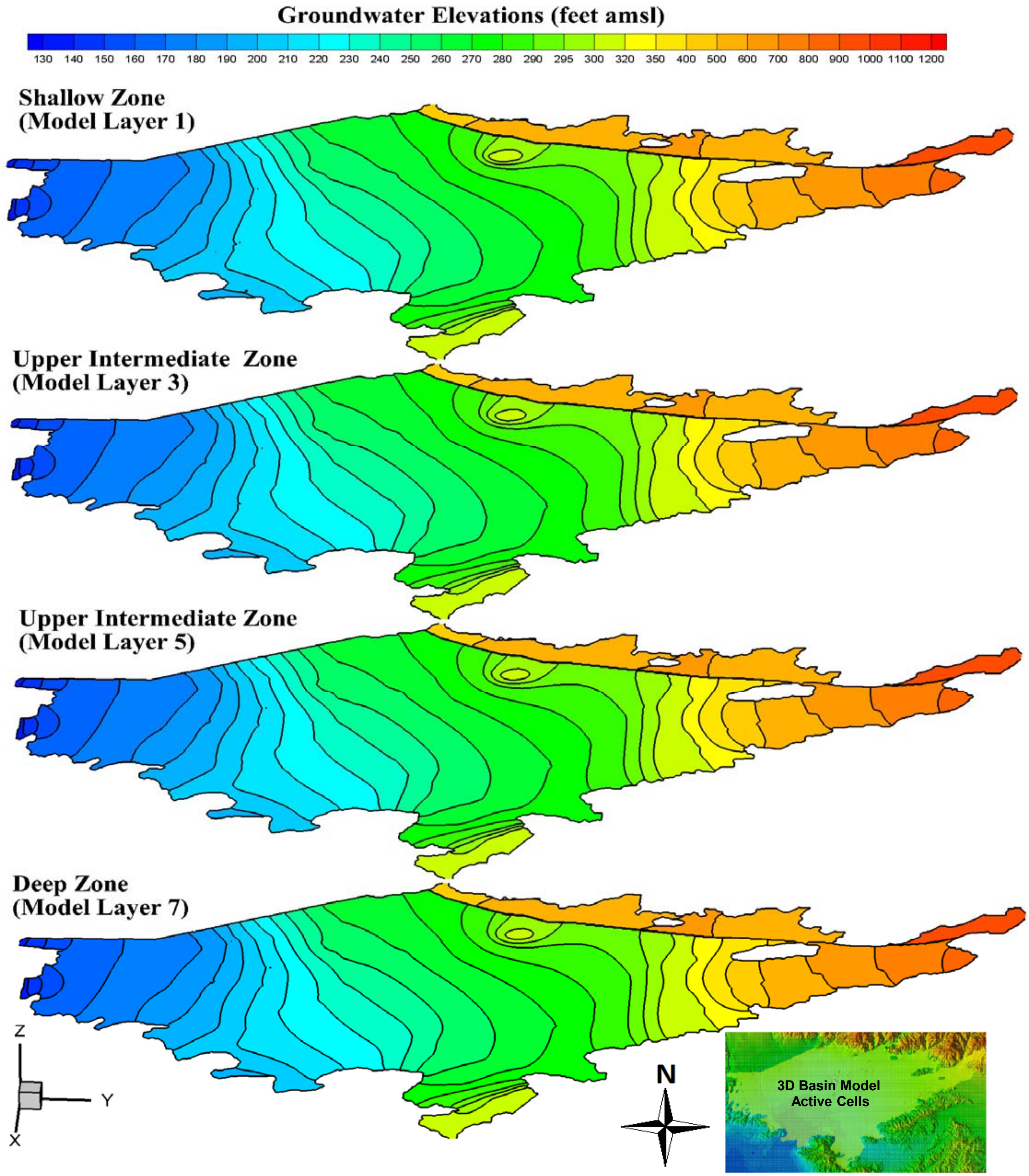
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2035-36
Groundwater Elevation Contours (Scenario 7)
(Sub-Task No. 2.5 Augmented Basin Sustainability)

STETSON ENGINEERS INC.

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 18 - 3D Basin Model Simulated Contours(775MGD-15MGD_Delivery).xlsx



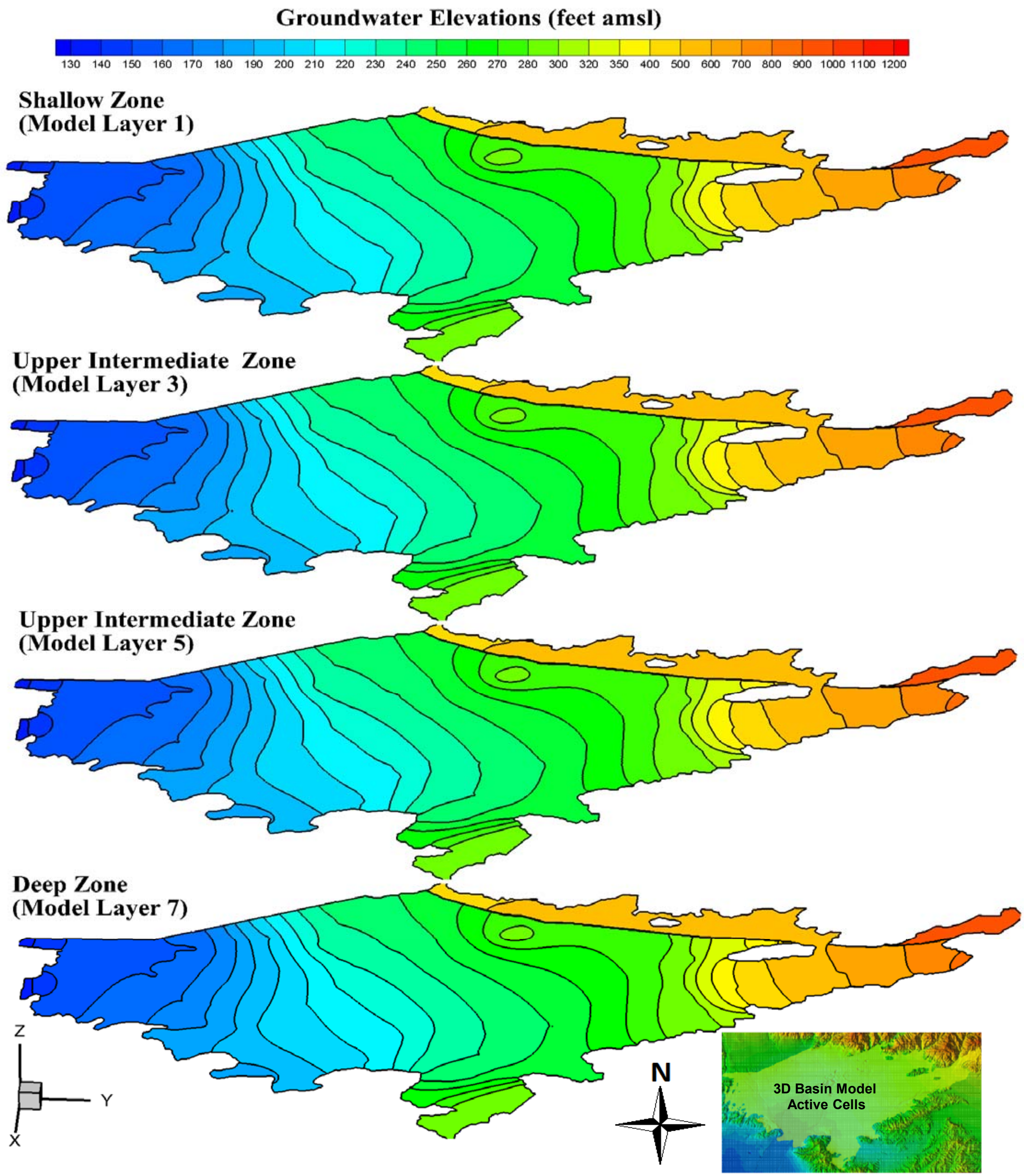
STETSON ENGINEERS INC.

MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Simulated FY2040-41
Groundwater Elevation Contours (Scenario 7)
(Sub-Task No. 2.5 Augmented Basin Sustainability)

MainSanGabrielBasin WATERMASTER

Figure 18g



MAIN SAN GABRIEL BASIN WATERMASTER

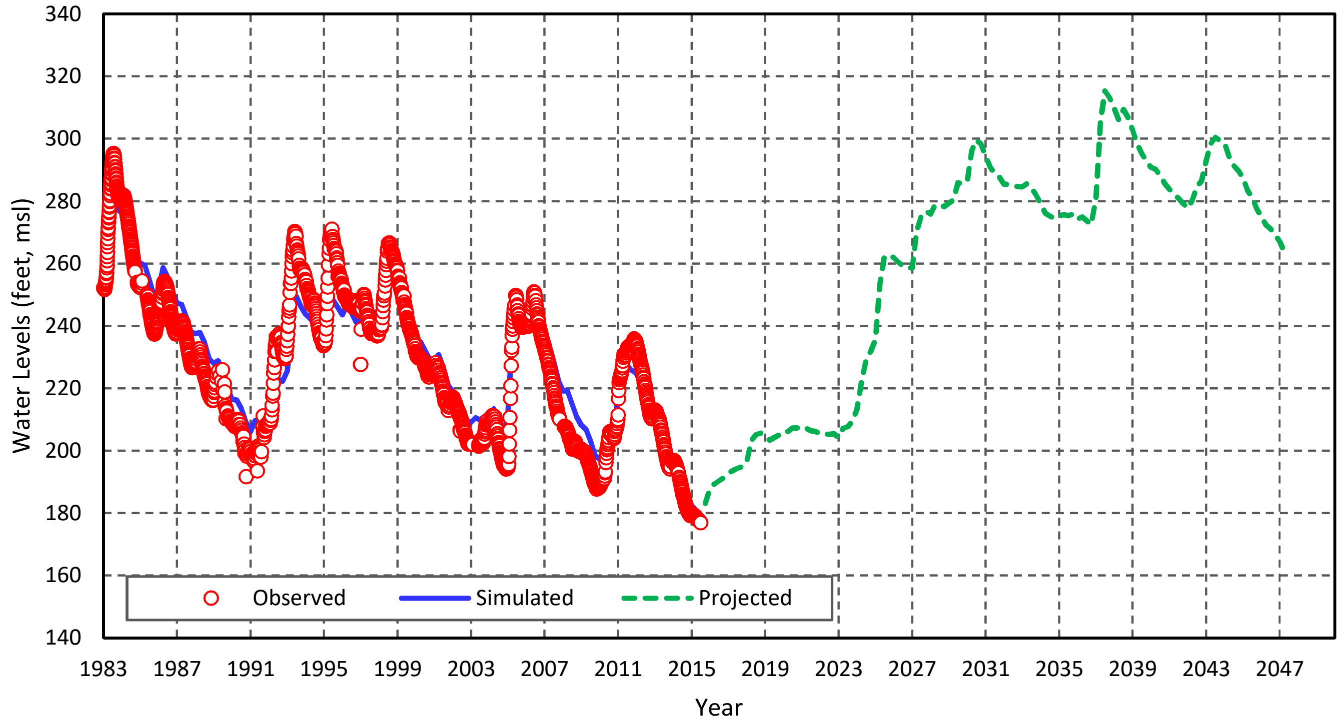
3D Basin Model Simulated FY2046-47
Groundwater Elevation Contours (Scenario 7)
(Sub-Task No. 2.5 Augmented Basin Sustainability)

STETSON ENGINEERS INC.

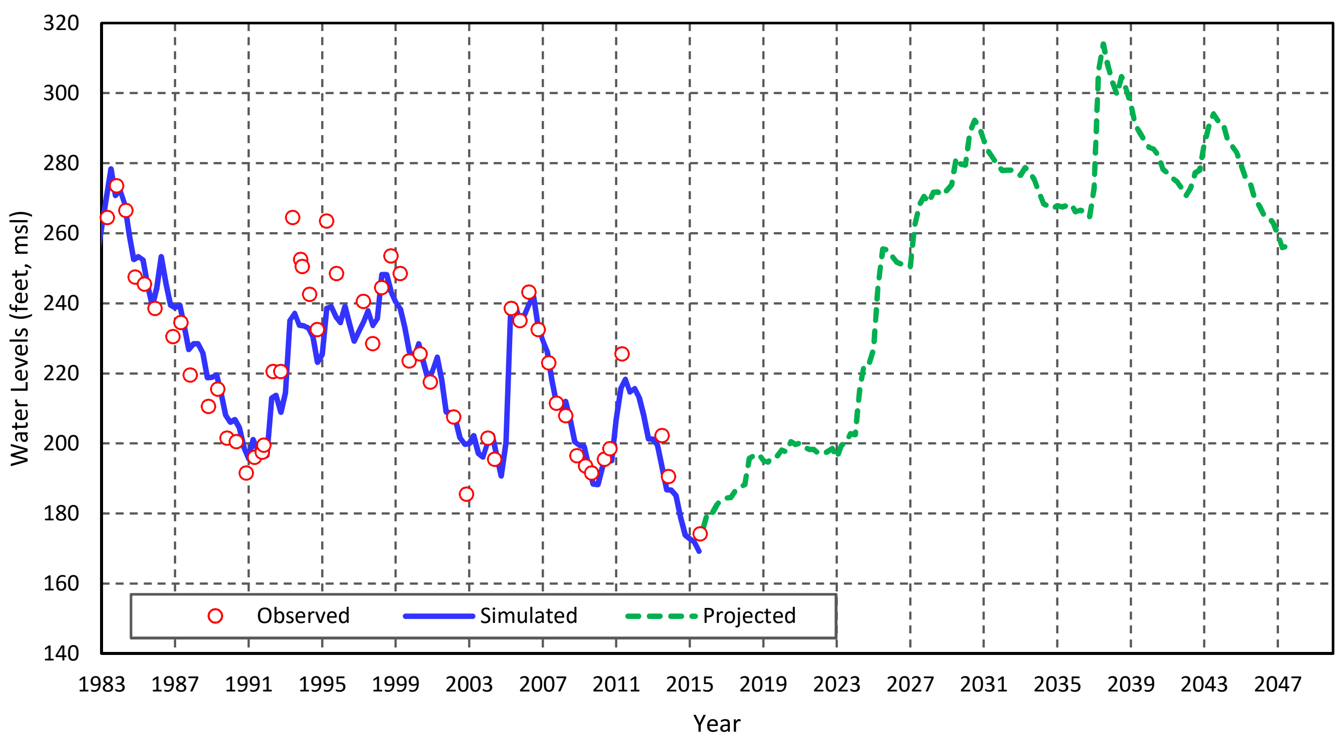
MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 18 - 3D Basin Model Simulated Contours(775MGD-15MGD_Delivery).xlsx

LA County Well 3030F (Key Well)



City of Monrovia Well 03 (1900419) - LA County 4198K



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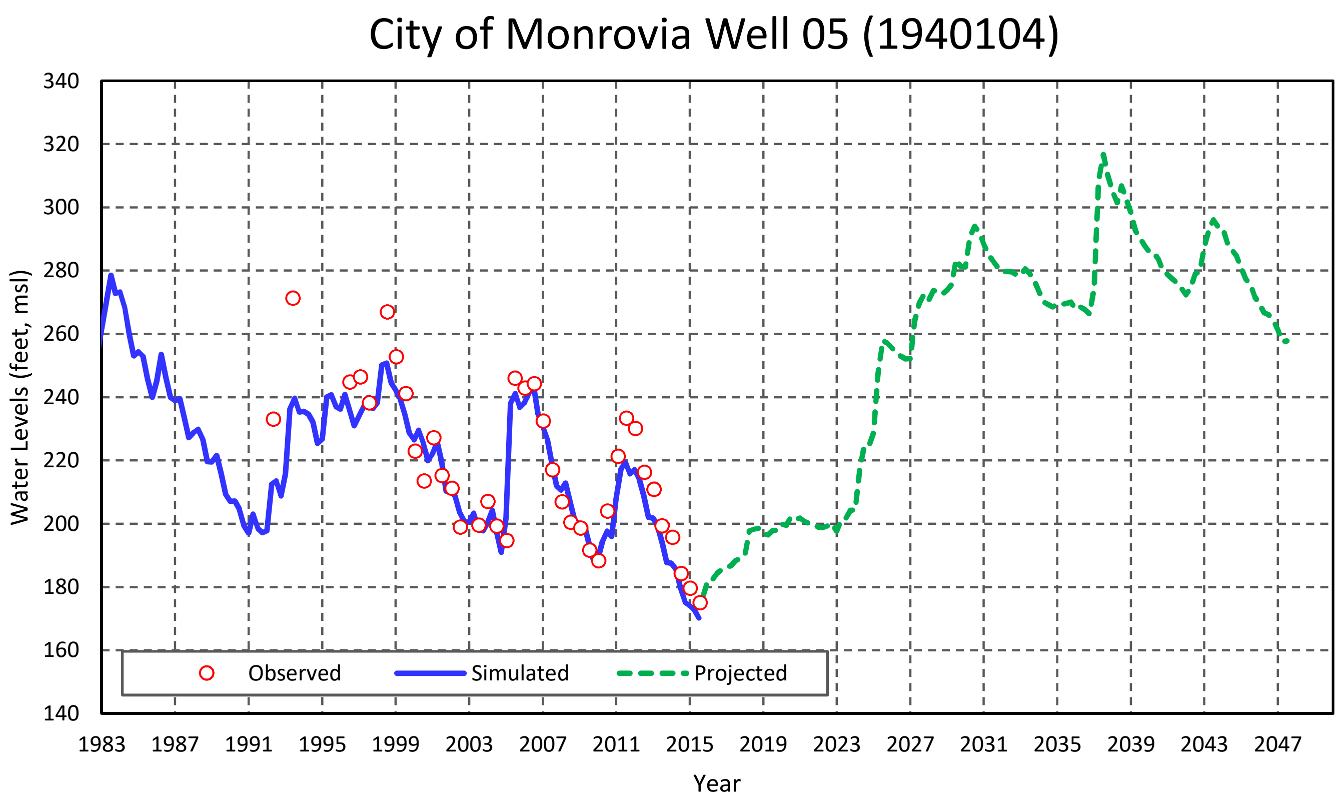
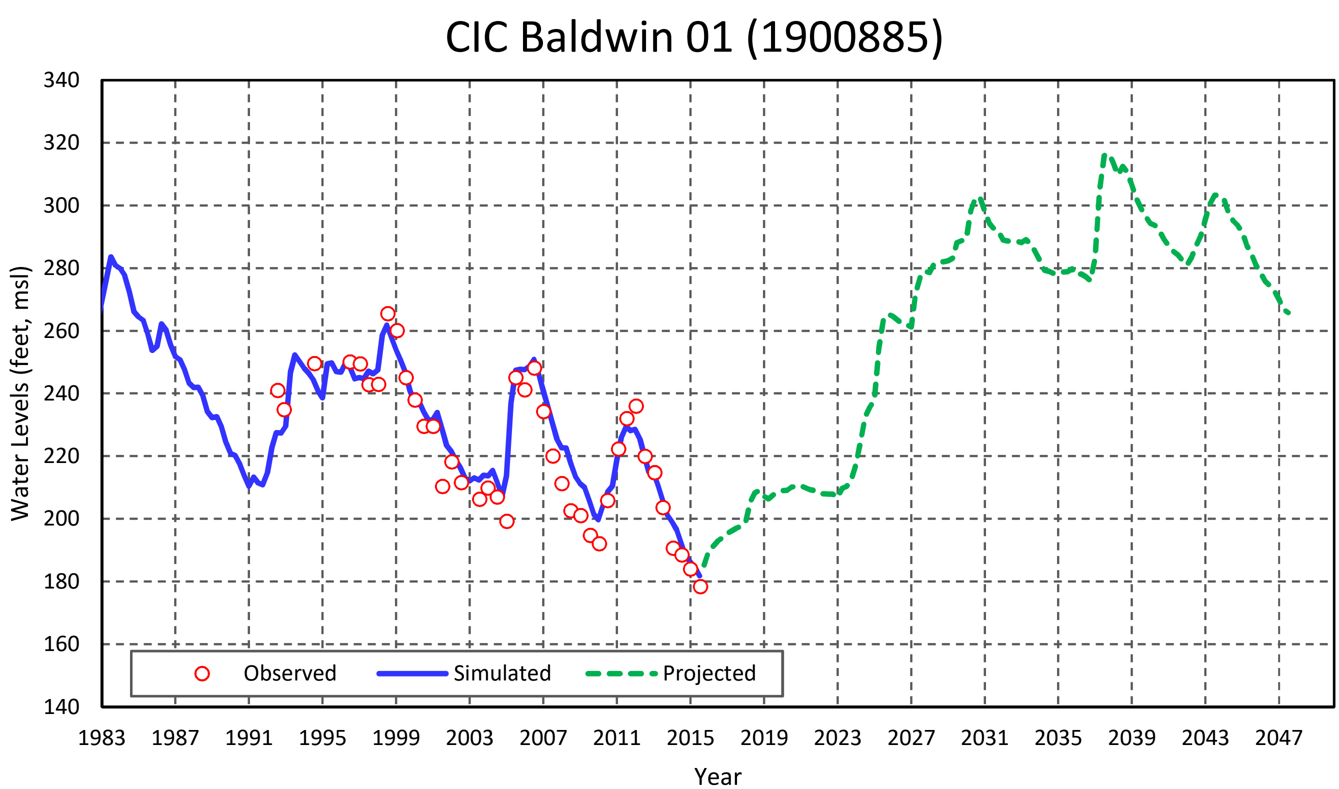
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Augmented Basin Sustainability (Scenario 6)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER



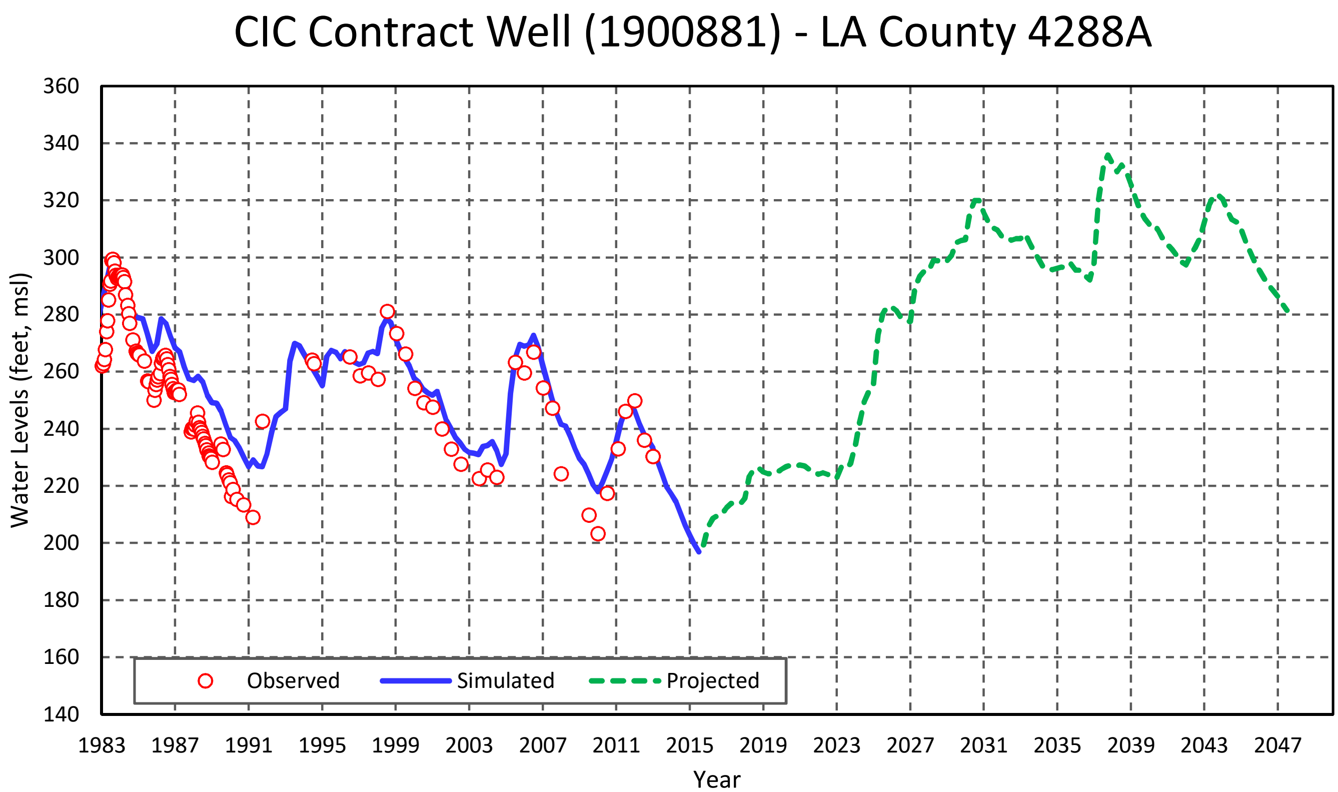


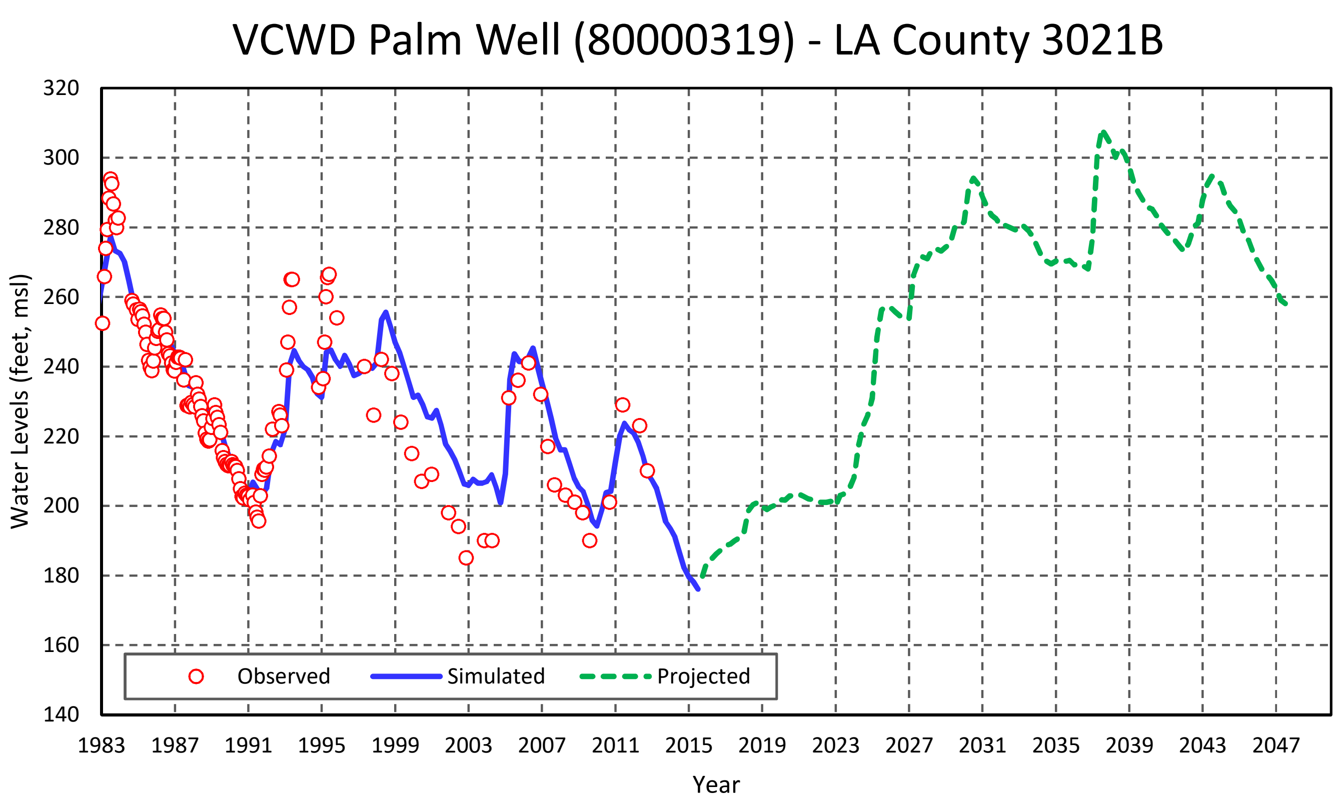
STETSON ENGINEERS INC.

MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Augmented Basin Sustainability (Scenario 6)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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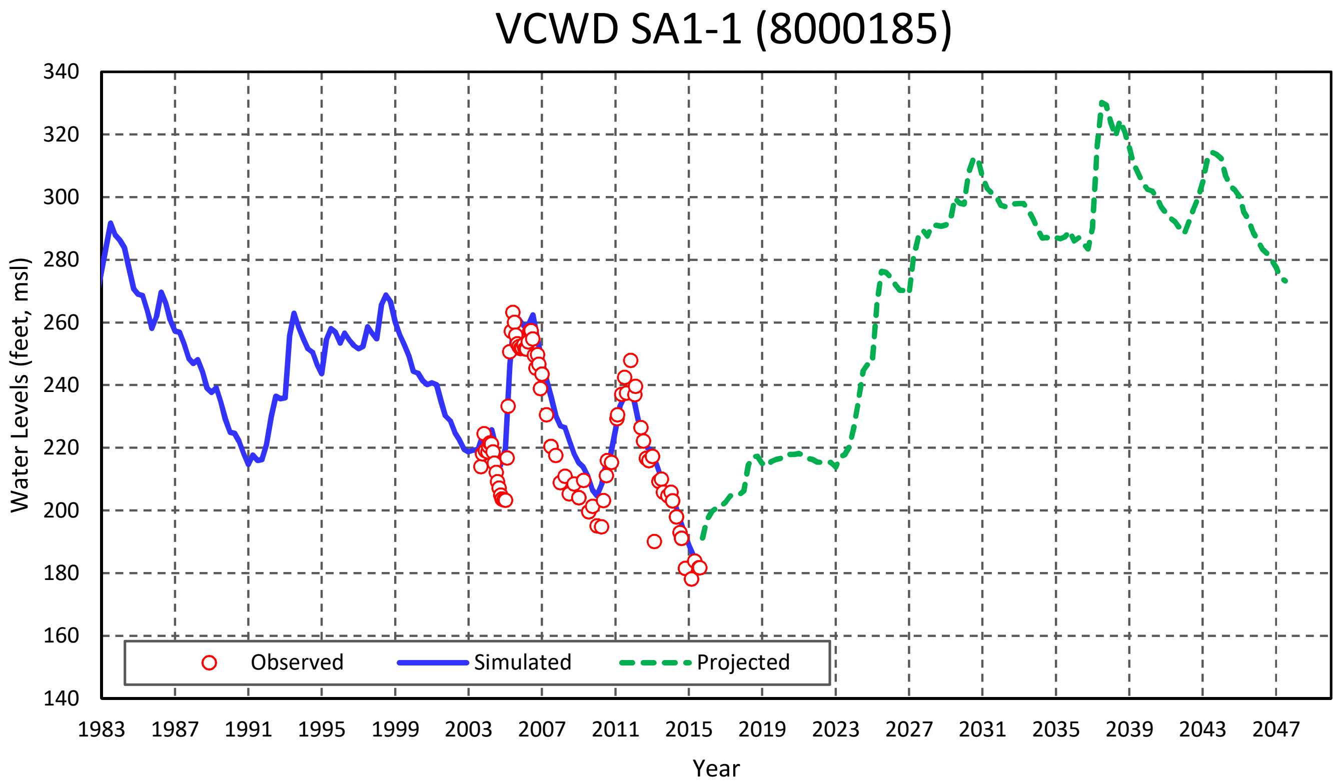
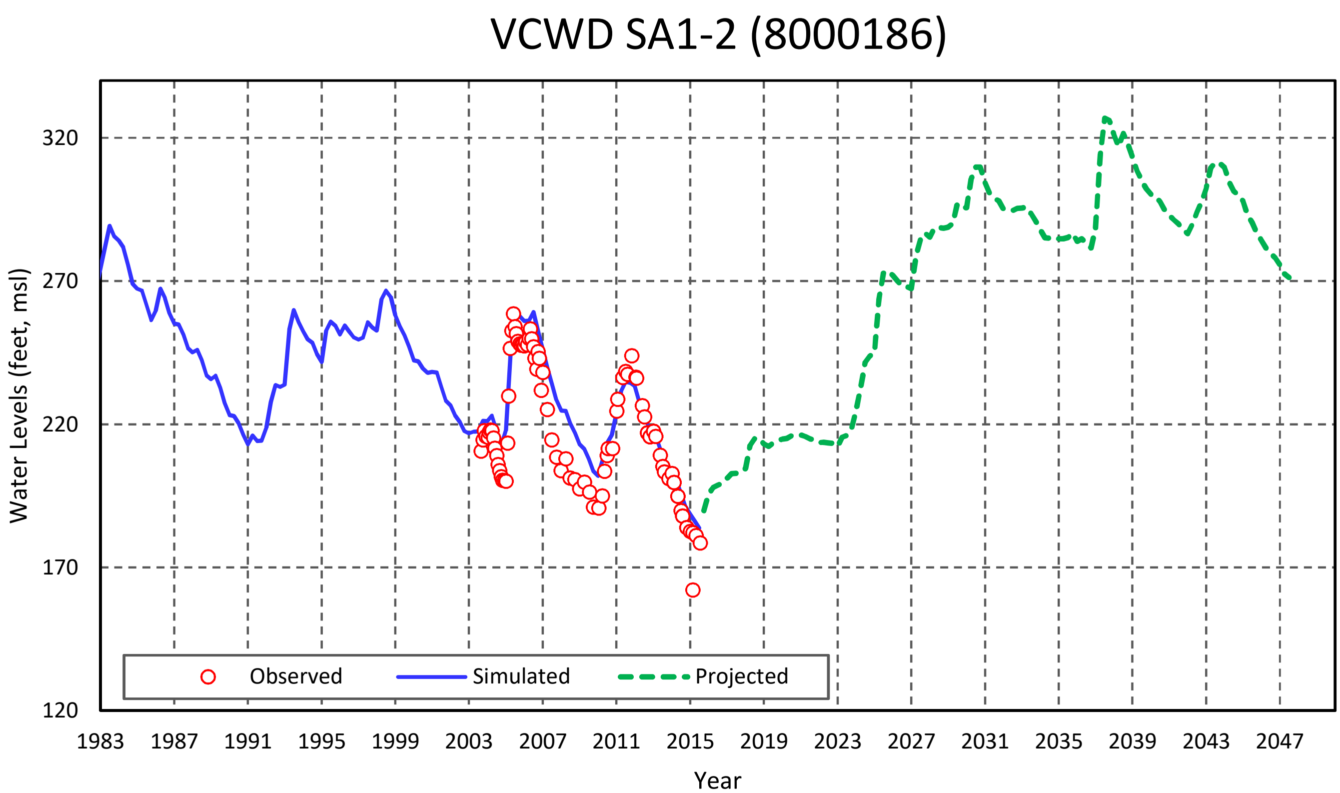
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Augmented Basin Sustainability (Scenario 6)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER



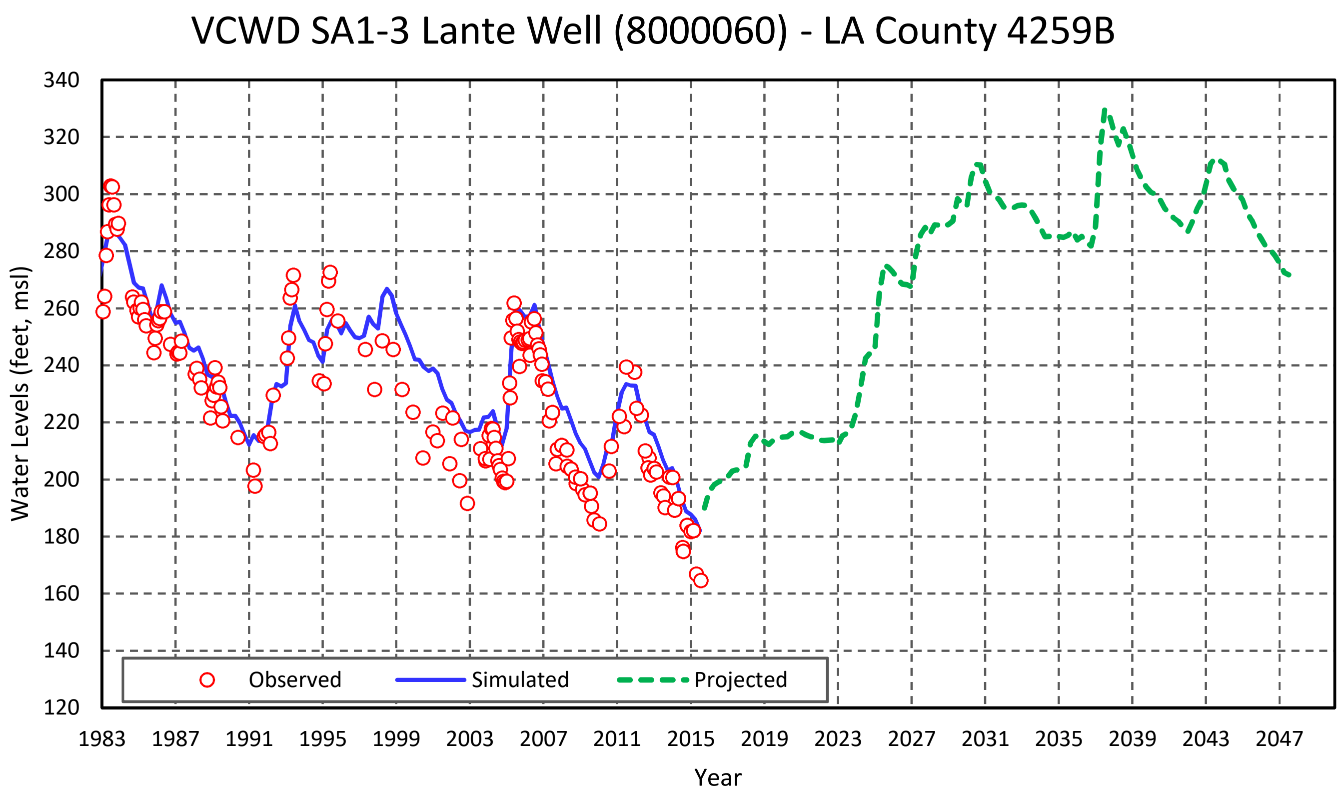


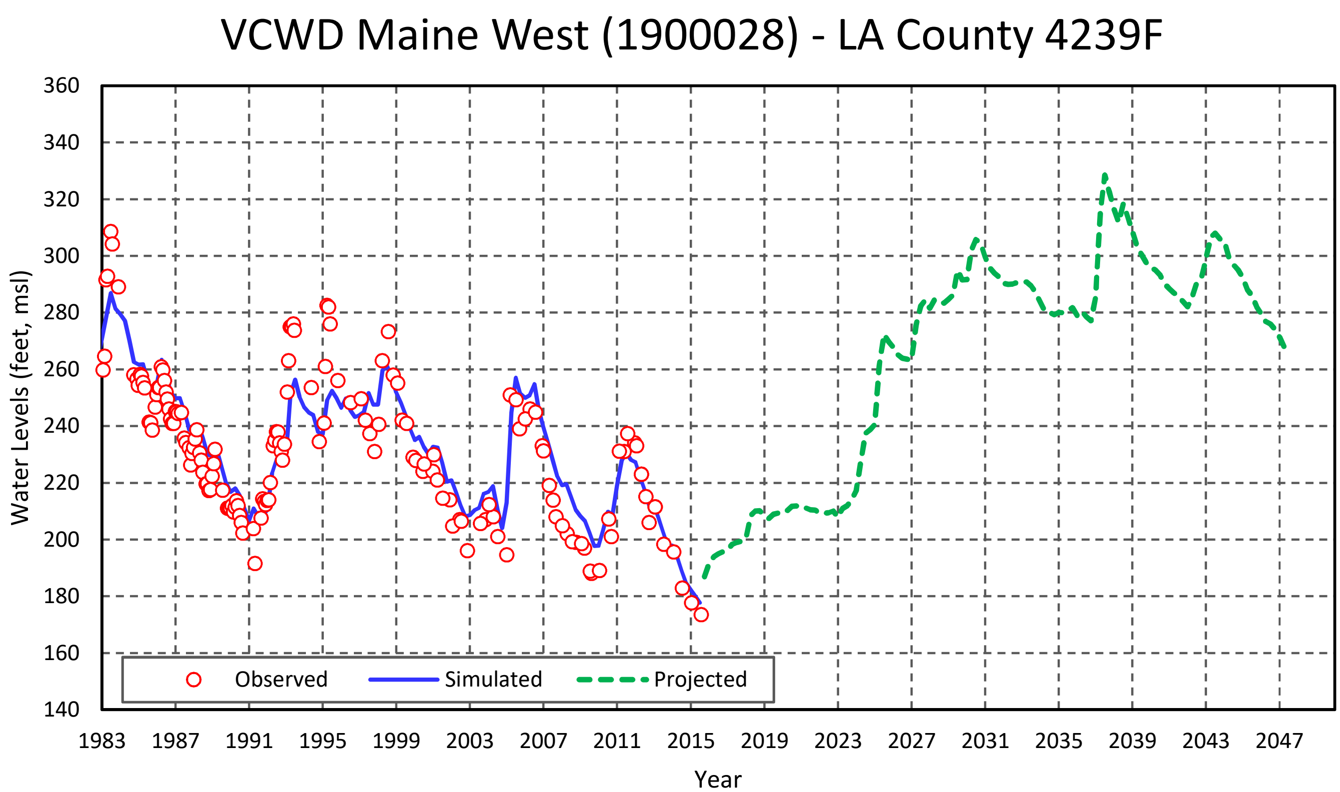
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Augmented Basin Sustainability (Scenario 6)
FY 2015-16 to FY 2046-27

STETSON ENGINEERS INC.

MainSanGabrielBasin WATERMASTER





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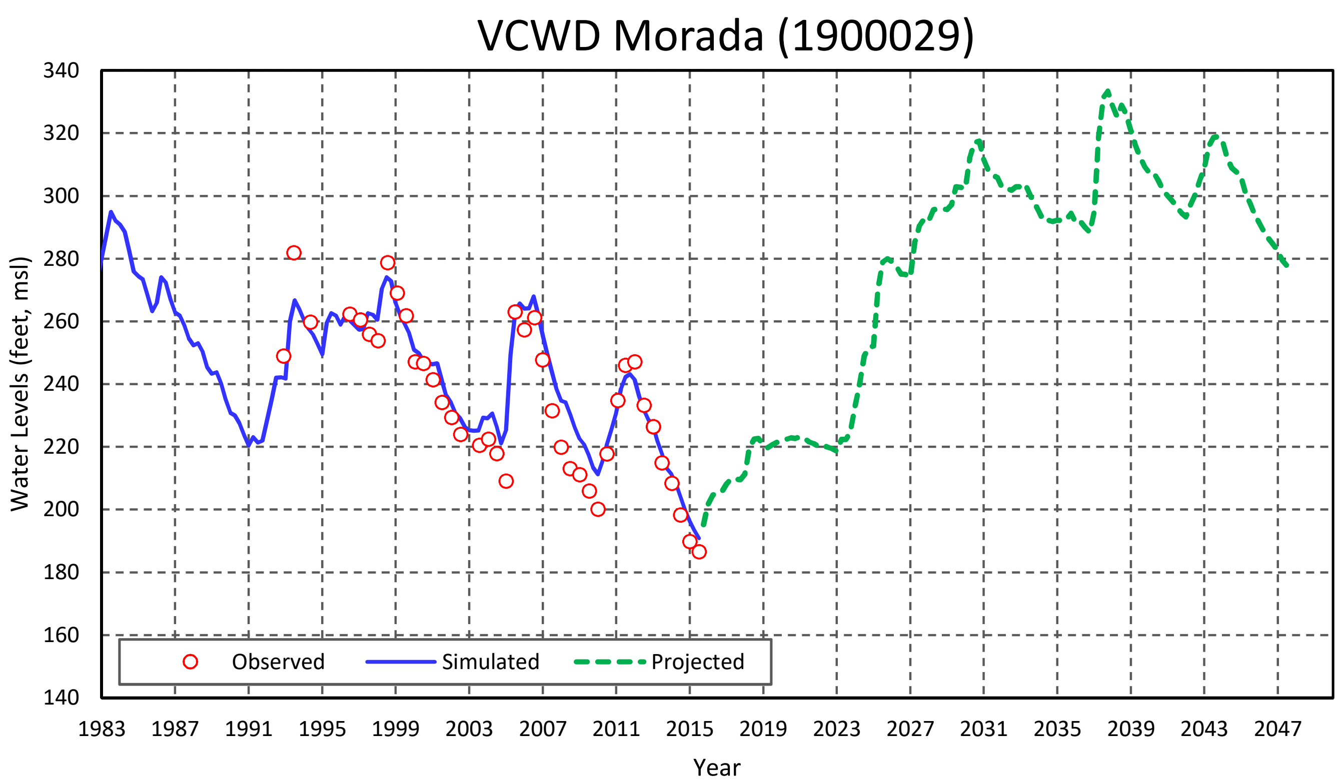
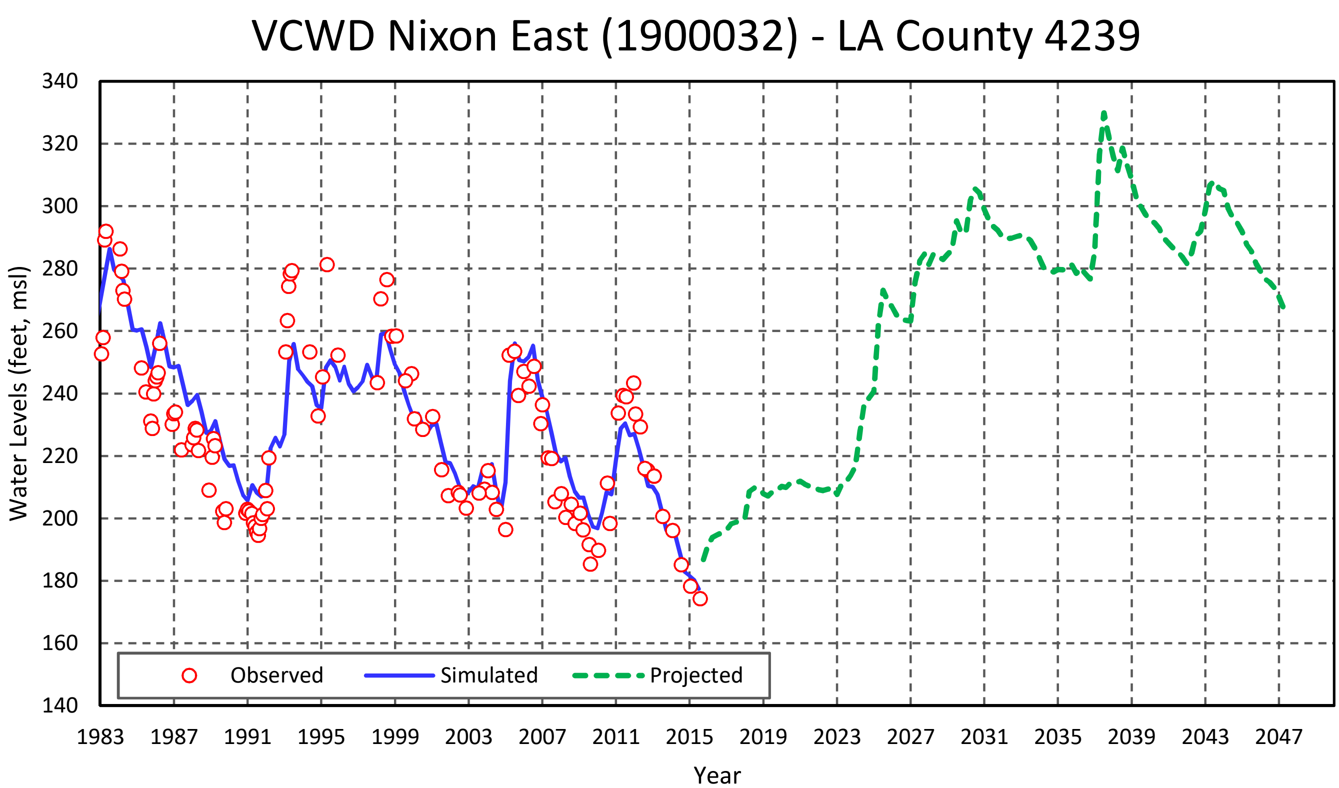
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Augmented Basin Sustainability (Scenario 6)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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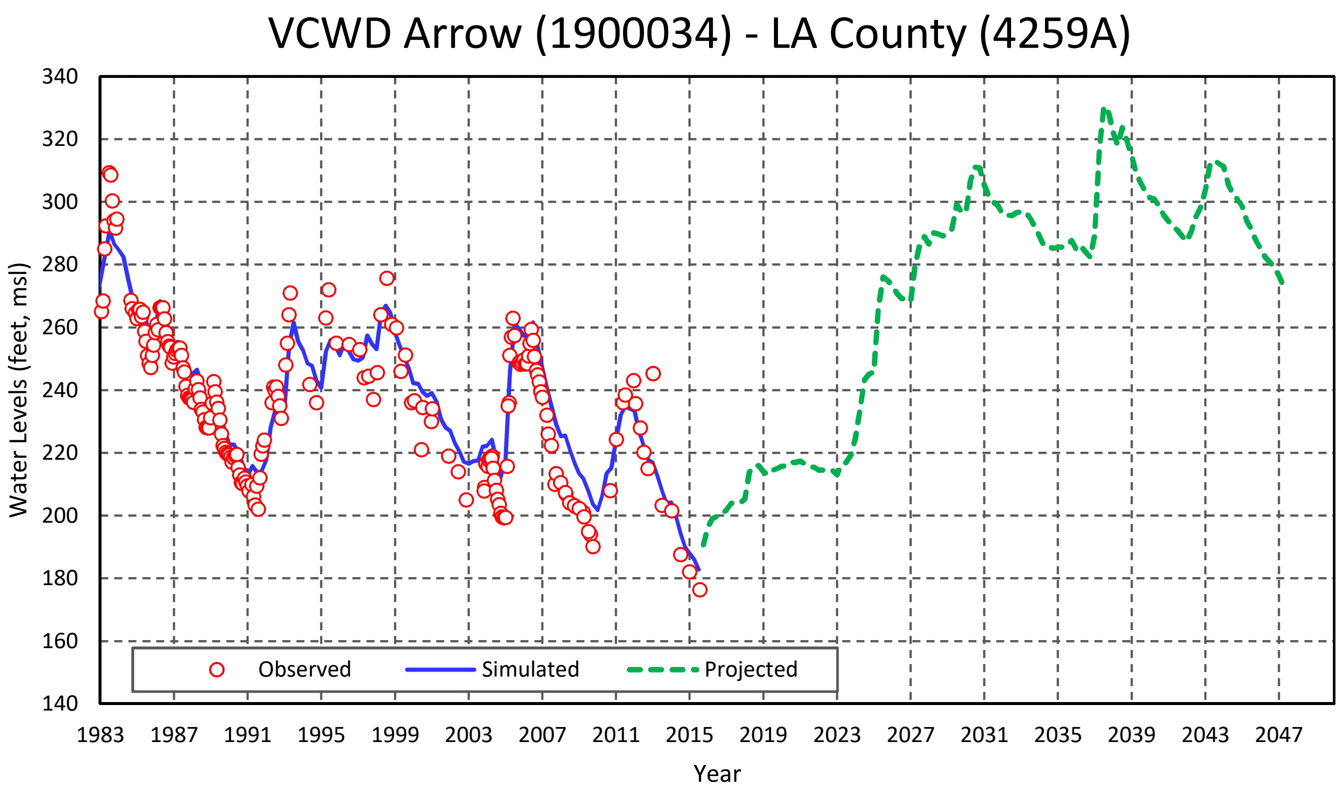
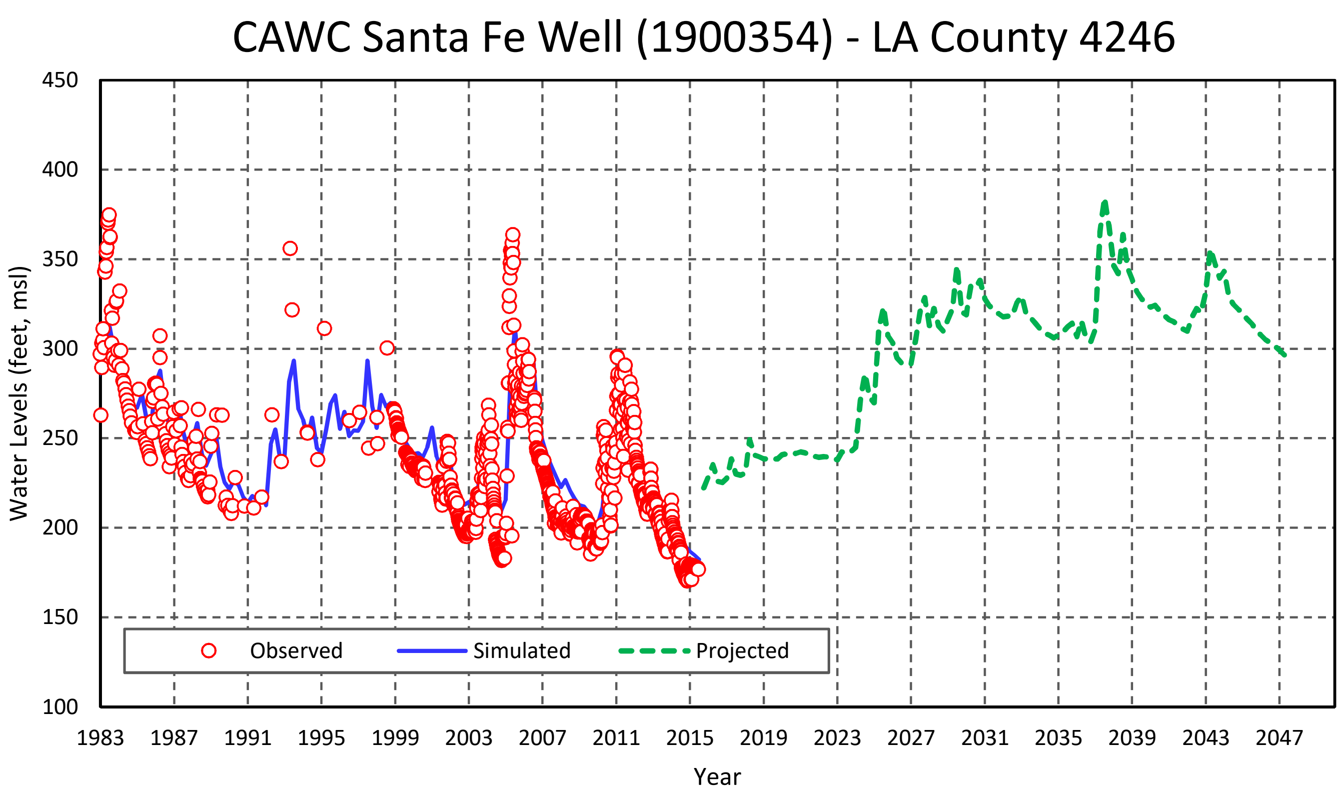
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Augmented Basin Sustainability (Scenario 6)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER

FIGURE 19





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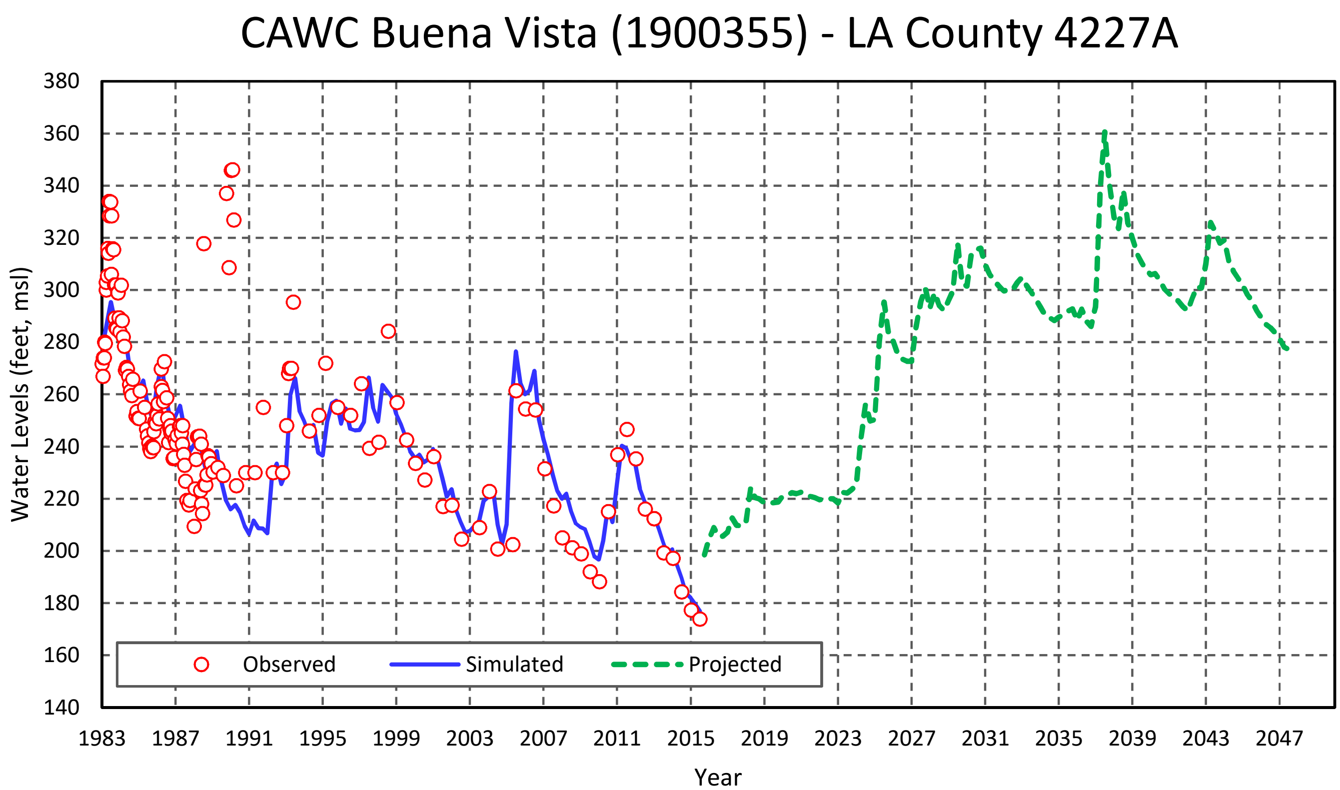
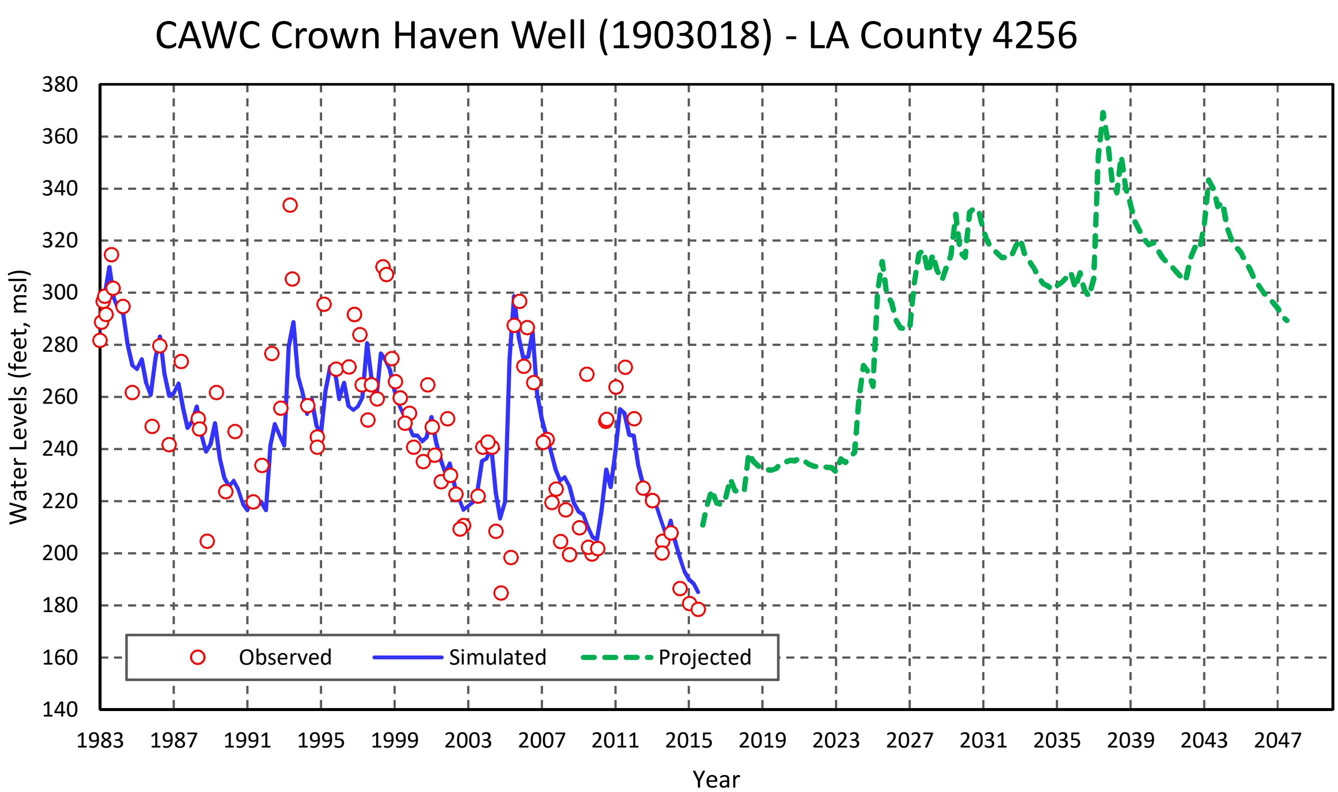
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Augmented Basin Sustainability (Scenario 6)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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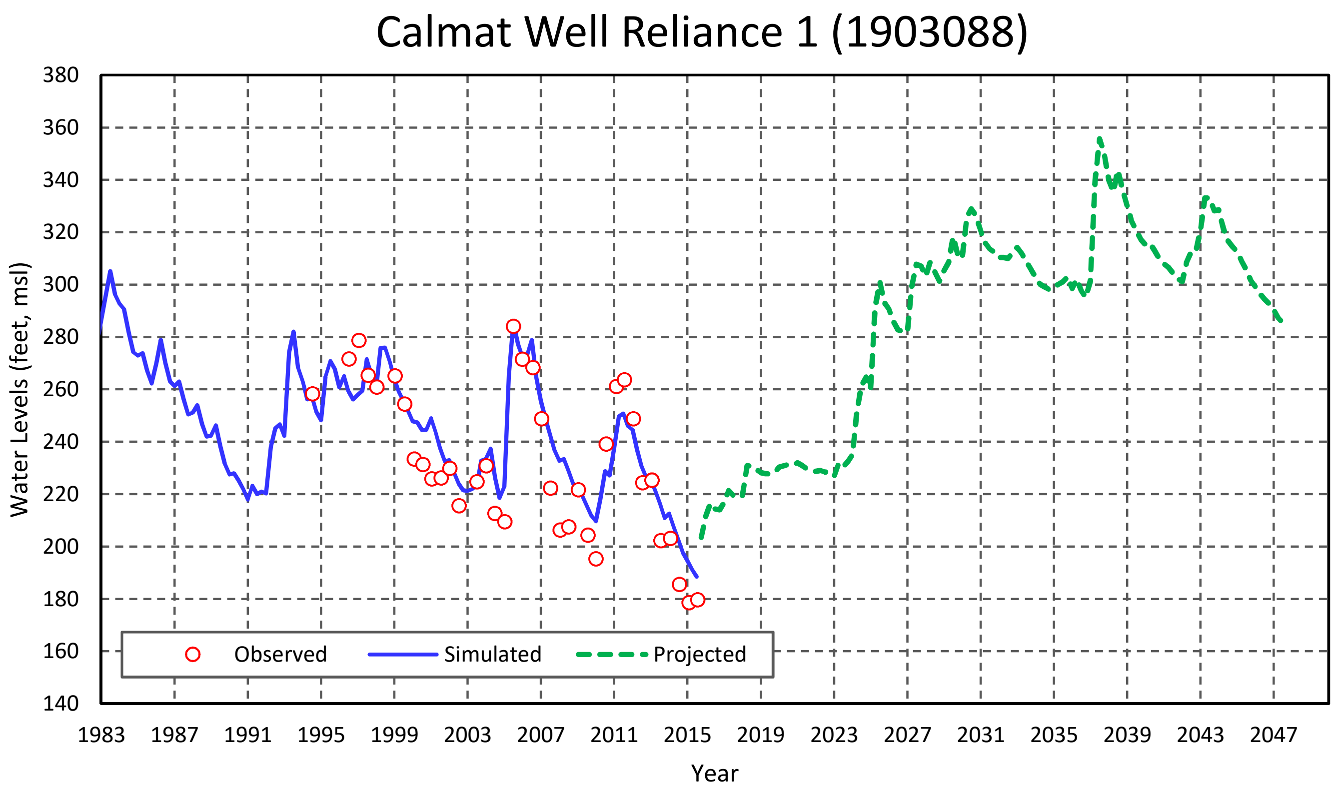
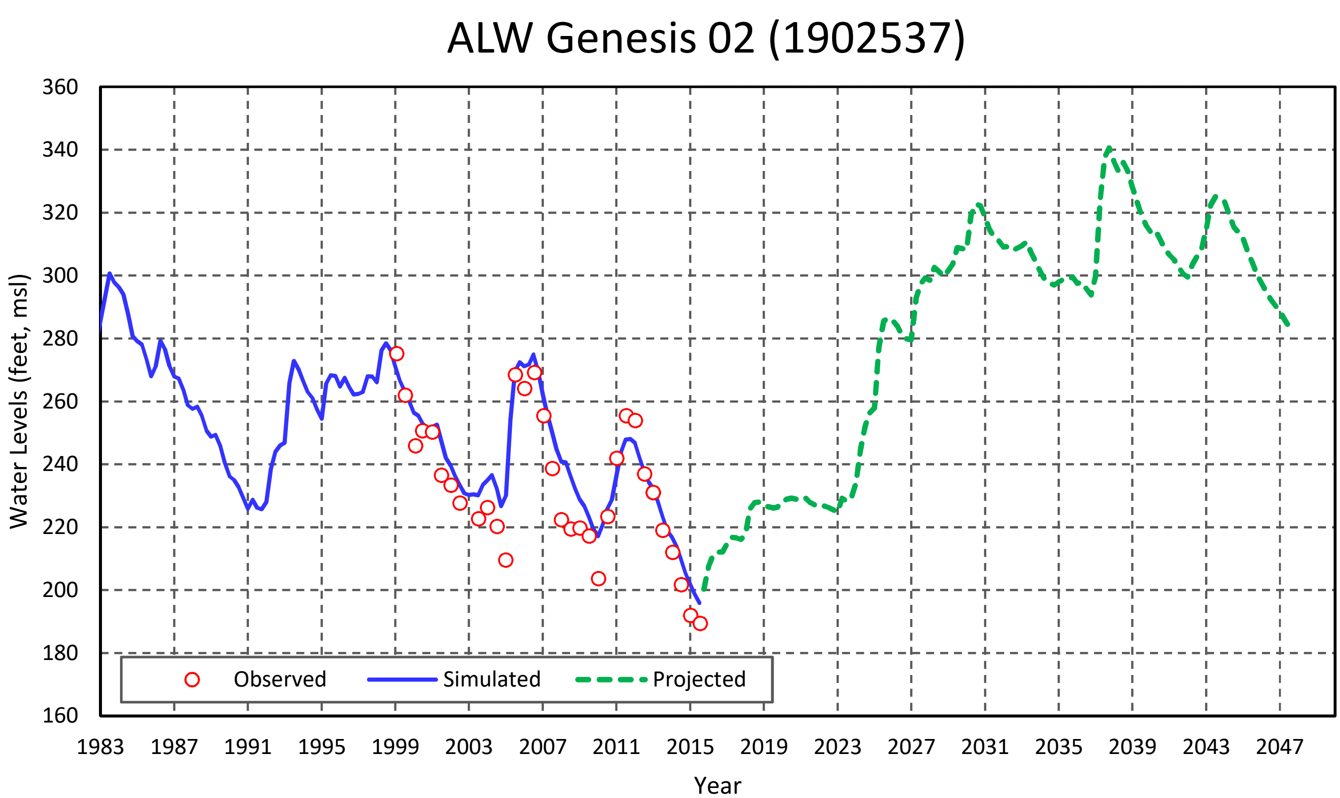
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Augmented Basin Sustainability (Scenario 6)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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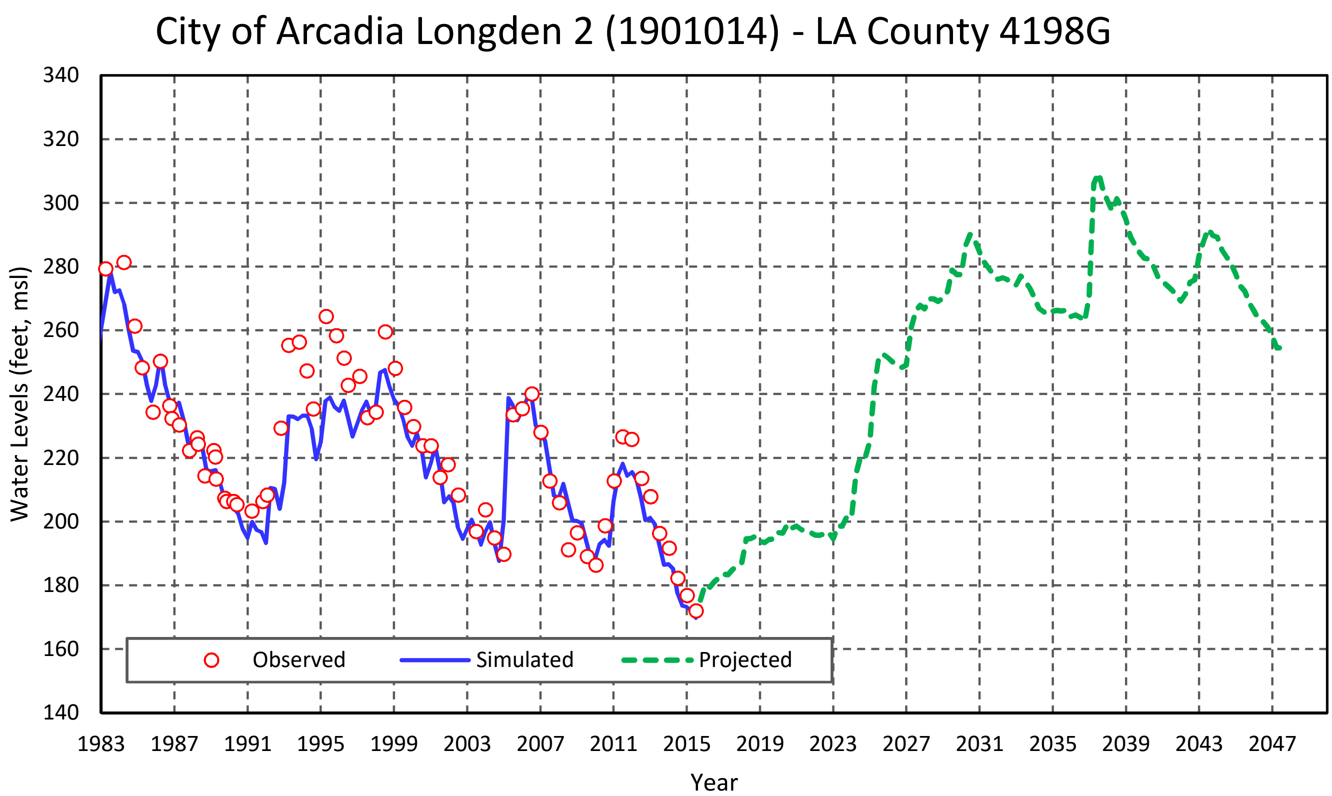
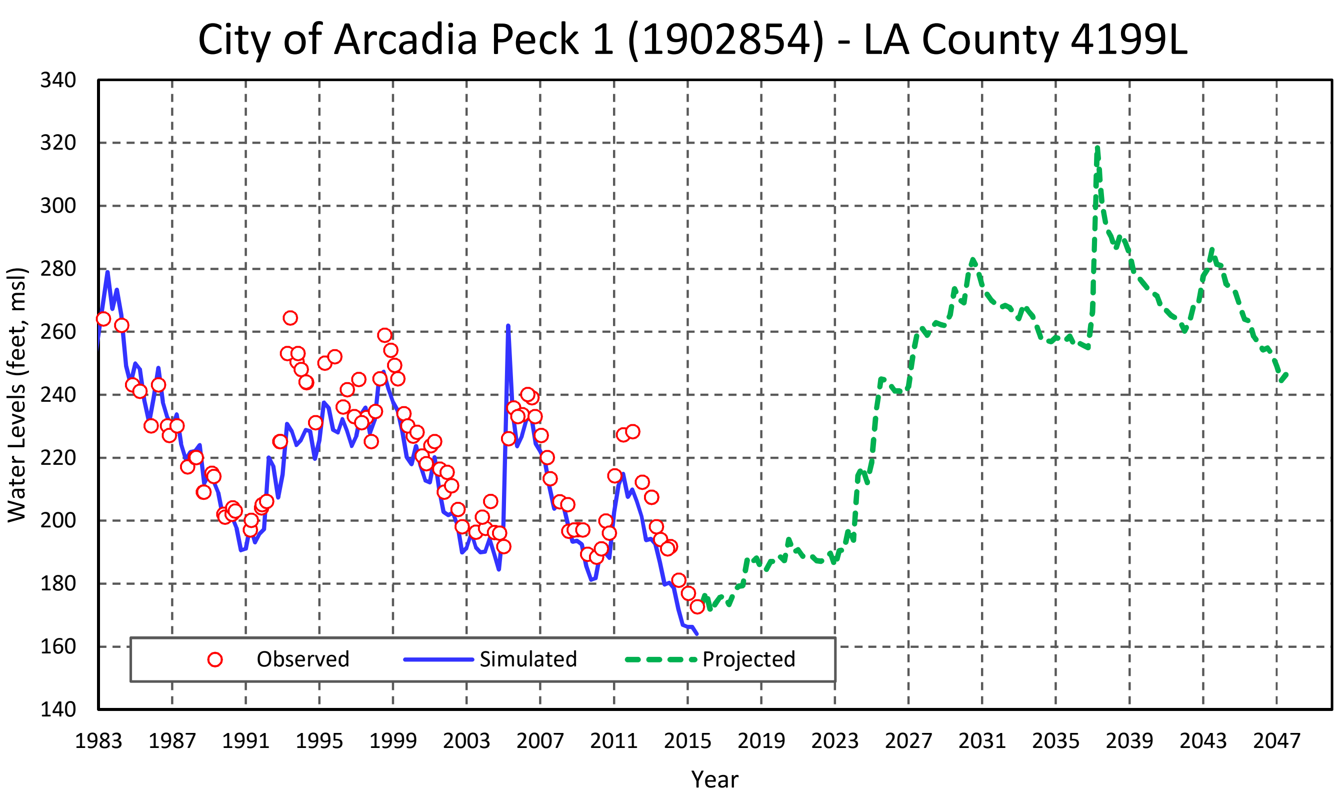
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Augmented Basin Sustainability (Scenario 6)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Augmented Basin Sustainability (Scenario 6)
FY 2015-16 to FY 2046-27

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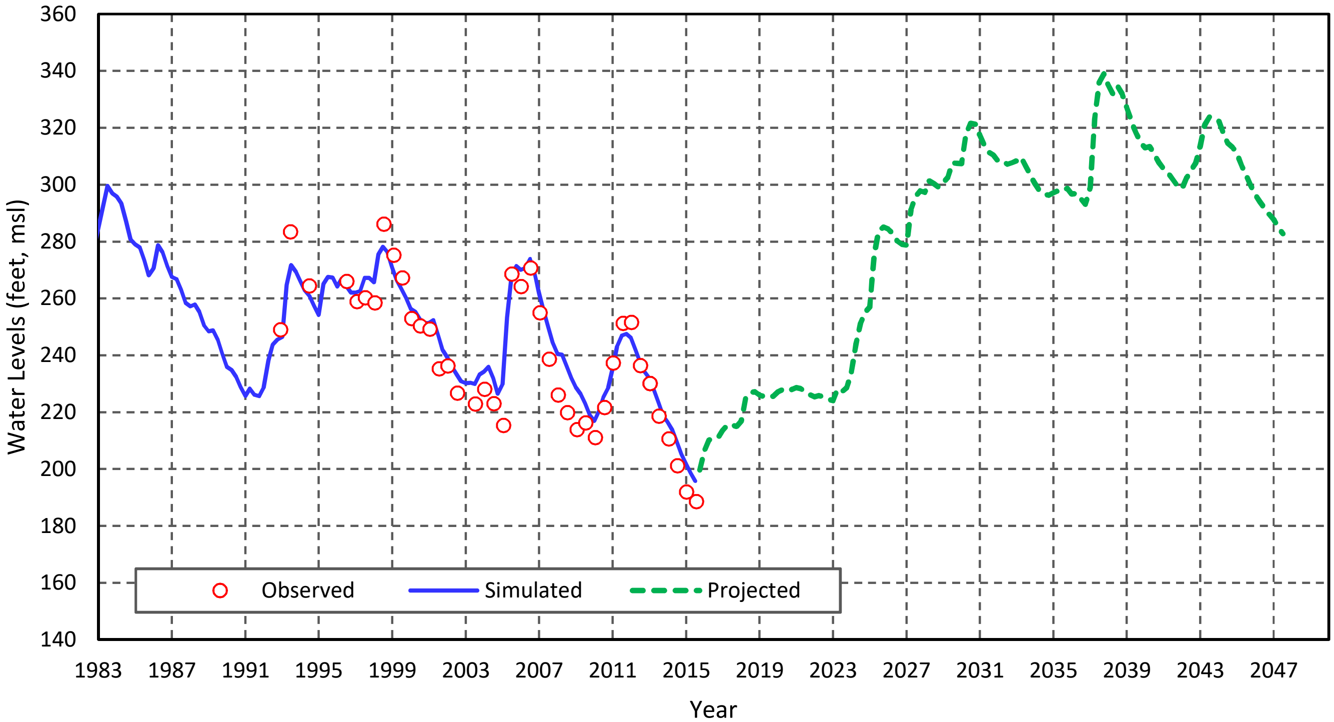
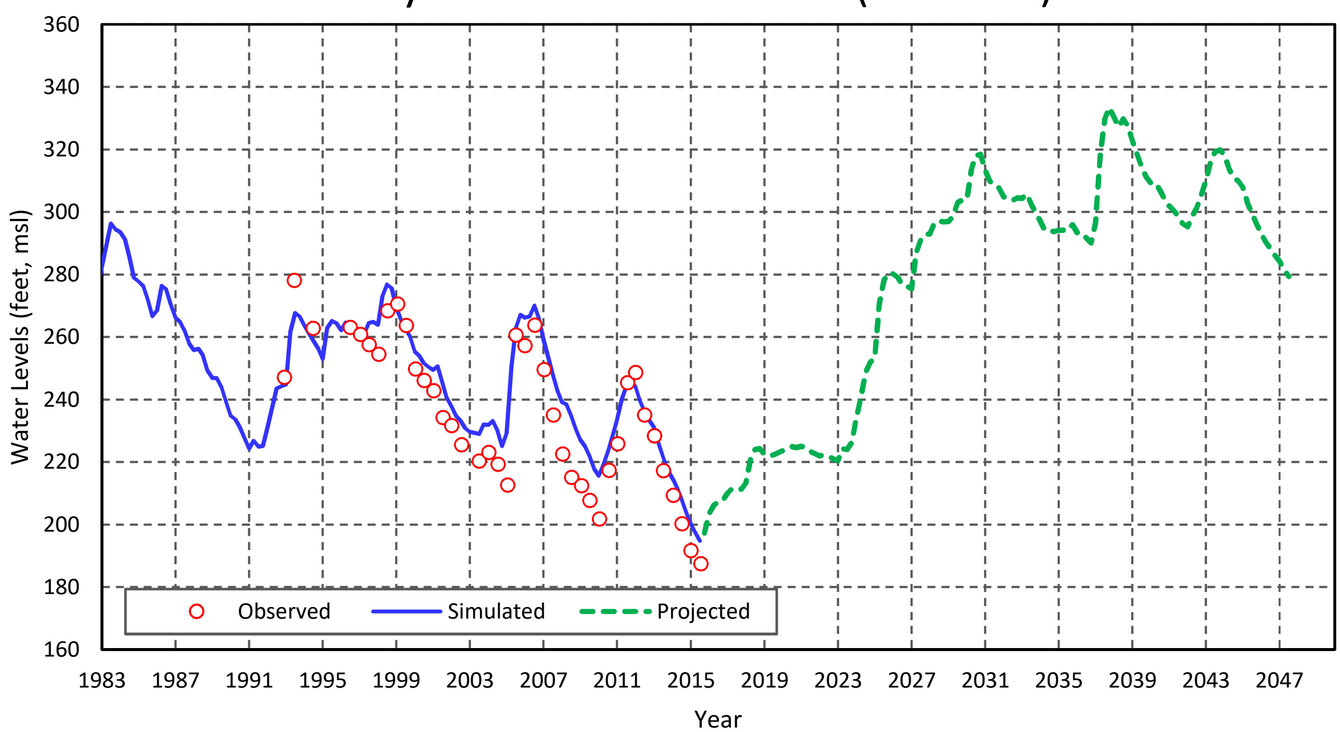
City of Glendora Well 07G (1900831)



City of Glendora Well 04E (1901524)



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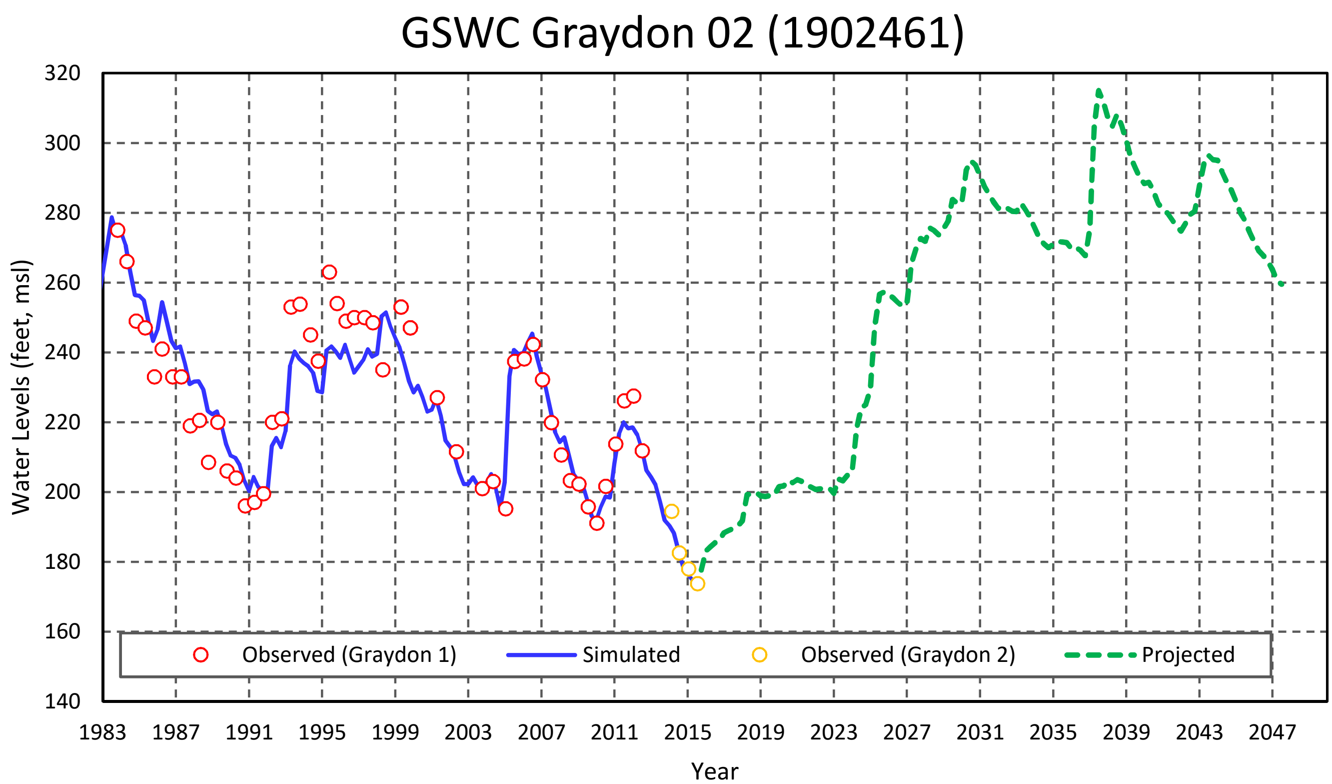
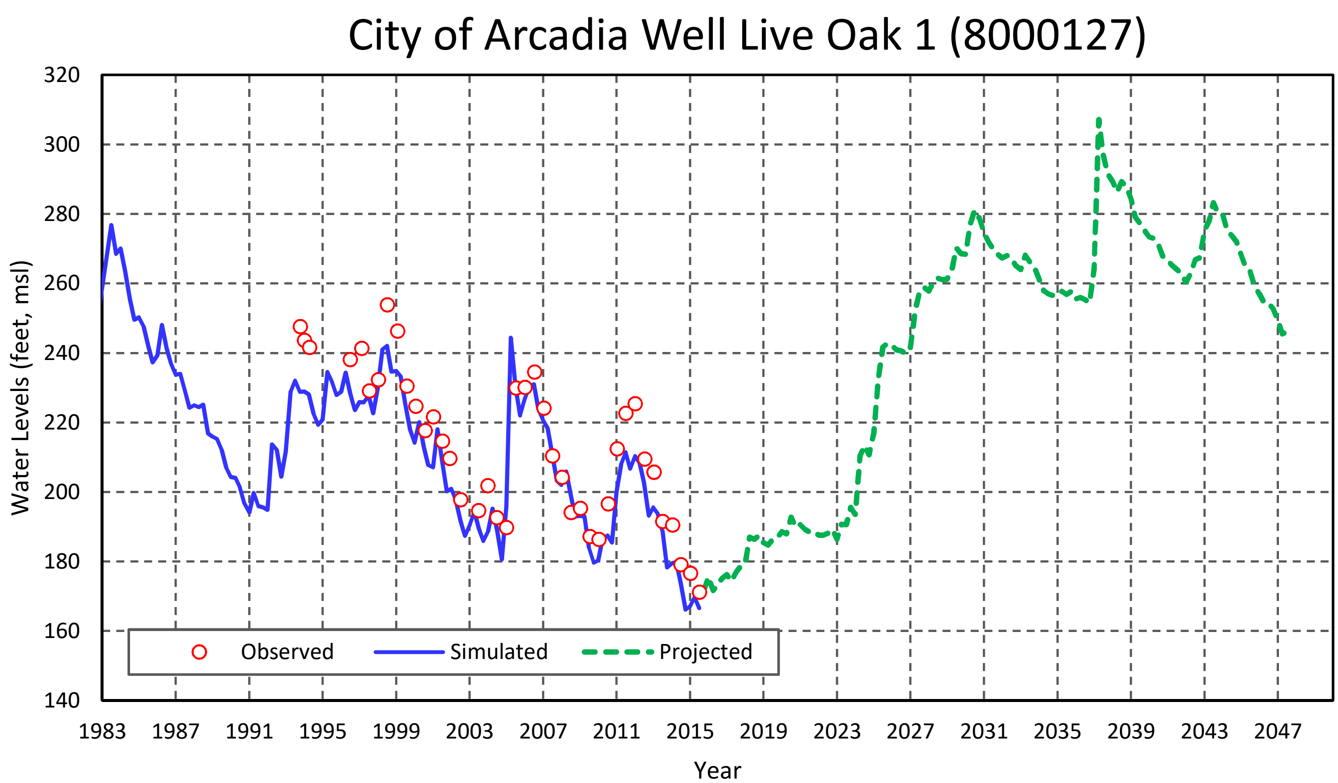
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Augmented Basin Sustainability (Scenario 6)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER





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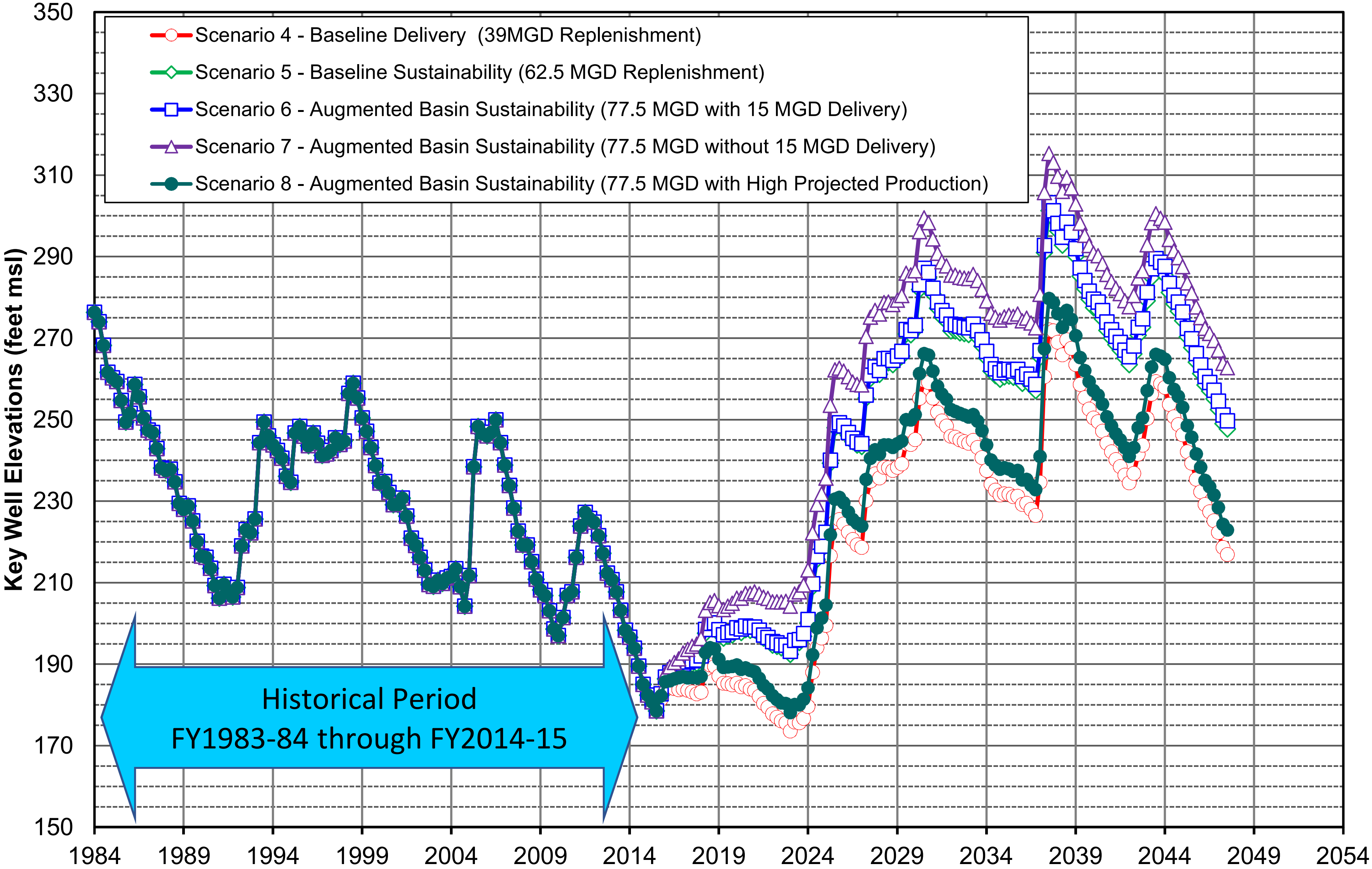
MAIN SAN GABRIEL BASIN WATERMASTER

Projected Simulation Results
Augmented Basin Sustainability (Scenario 6)
FY 2015-16 to FY 2046-27

MainSanGabrielBasin WATERMASTER

Figure 20



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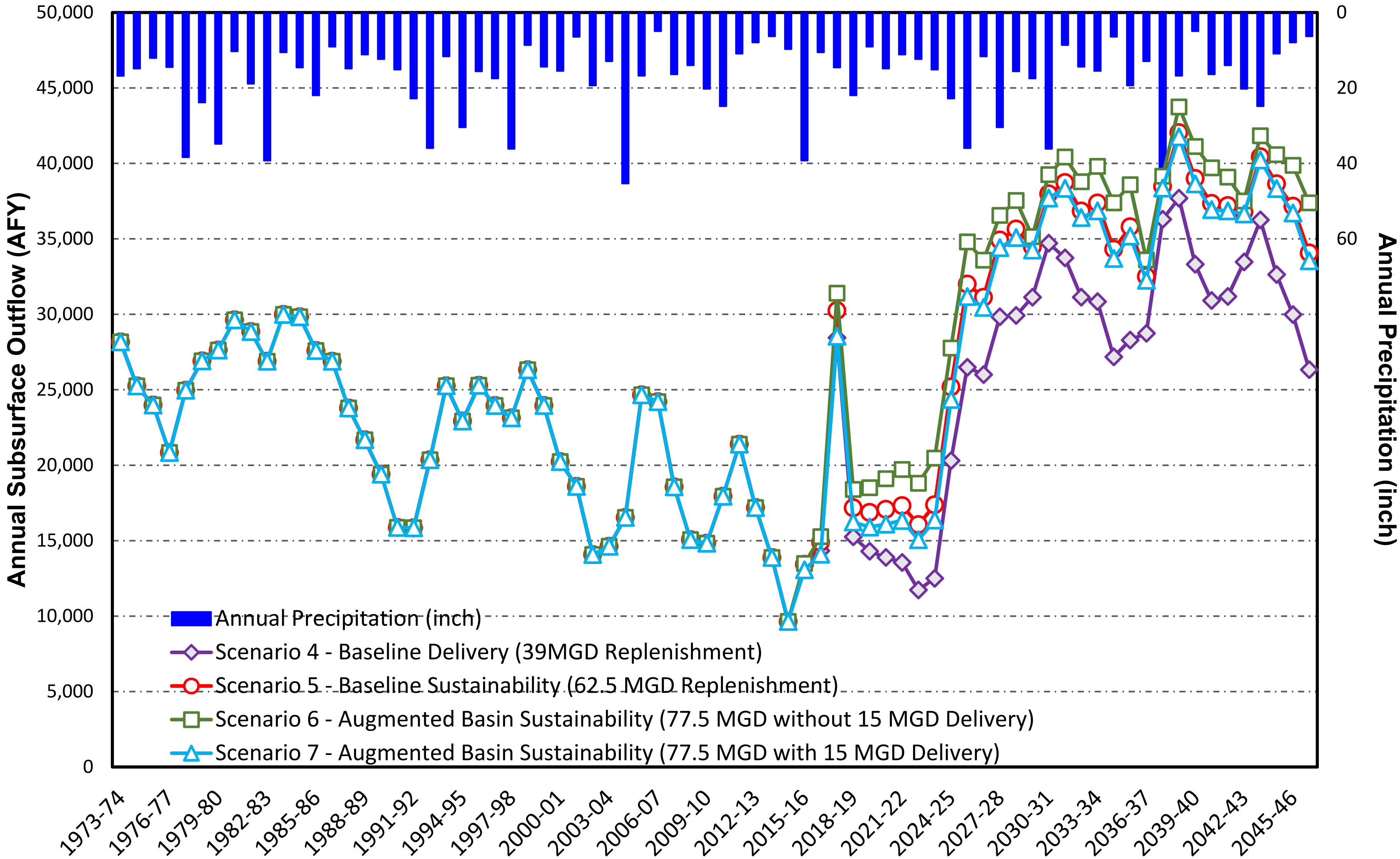
MAIN SAN GABRIEL BASIN WATERMASTER

Three-Dimensional Basin Model
Comparisons of Simulated Key Well Elevations

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 20 - KeyWell Comparison.xlsx

Figure 21



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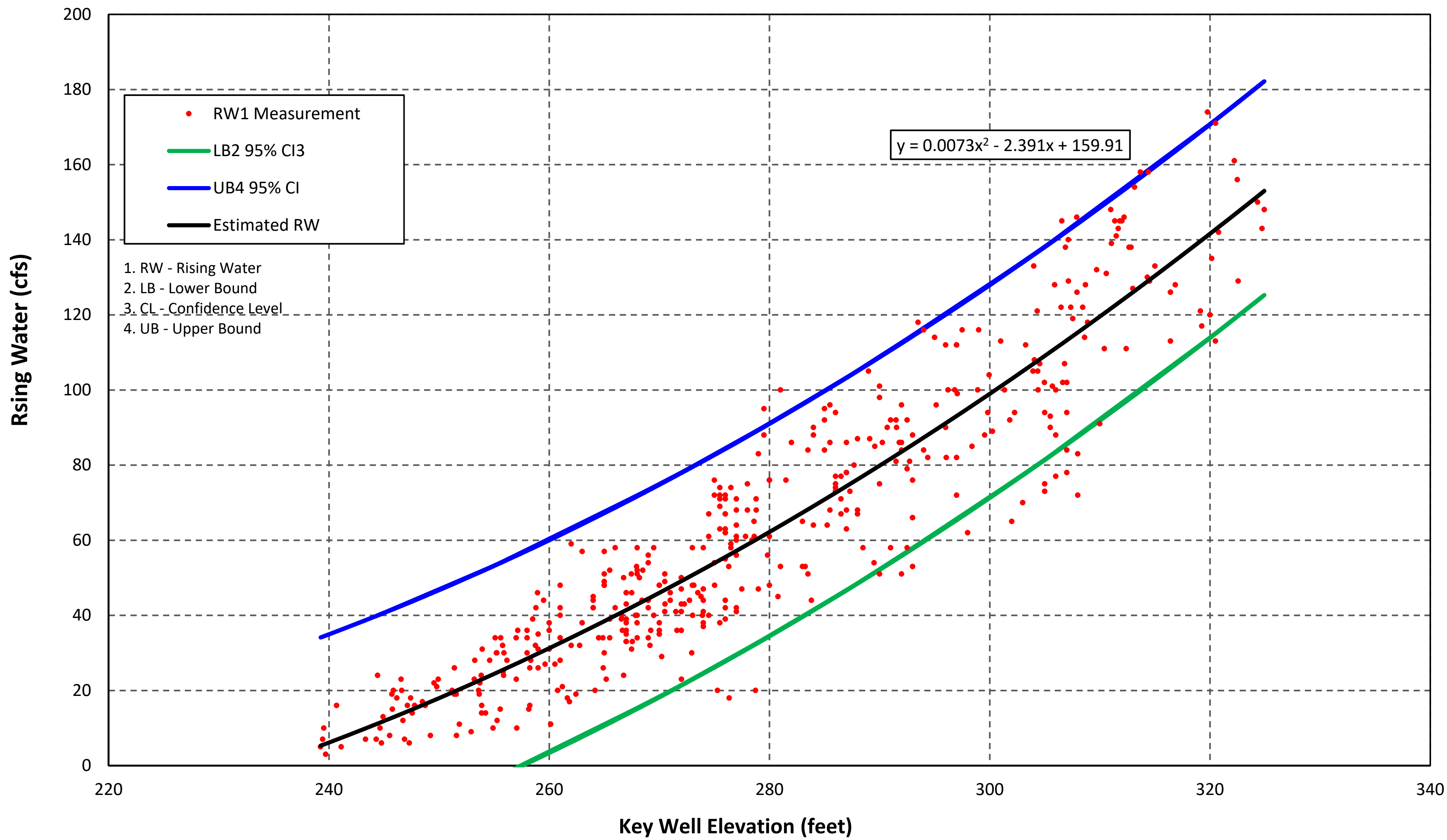
MAIN SAN GABRIEL BASIN WATERMASTER

Comparison of Model Simulated Whittier Narrows Subsurface Outflows from FY1973-74 to FY2046-47

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 21 - Subsurface Outflow.xlsx

Figure 22



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MAIN SAN GABRIEL BASIN WATERMASTER

Relationships of the Key Well Elevations and Impacts to Rising Water at Whittier Narrows (with Upper and Lower 95% Confidence Interval)

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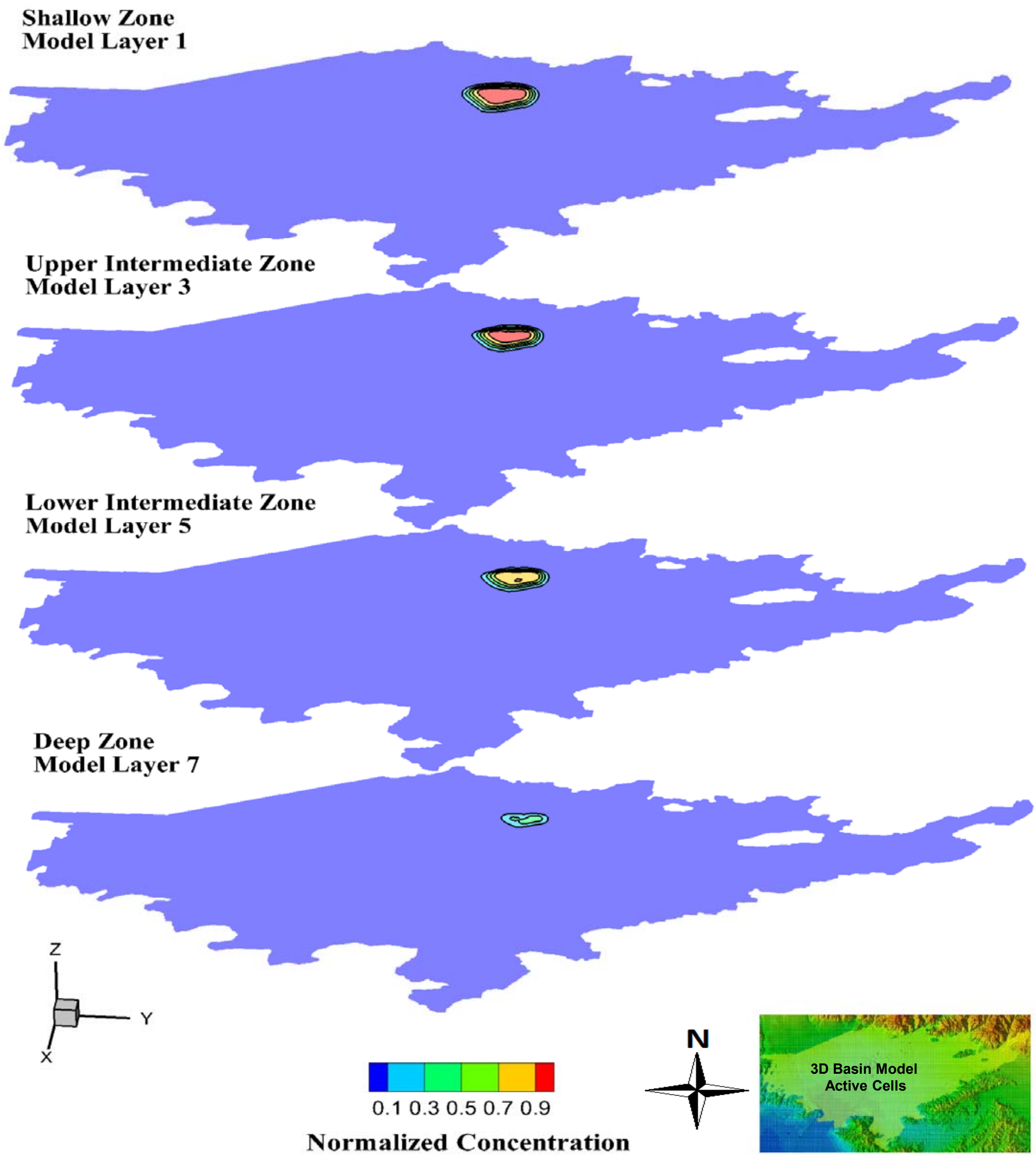
J:\1205\1205-98\.05.02.6\Figure 22 - Key Well Elev vs Rising Water 95%.xlsx

Figure 23a



MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 4 (Baseline Delivery)
Simulated FY2015-16 Plume Distribitions

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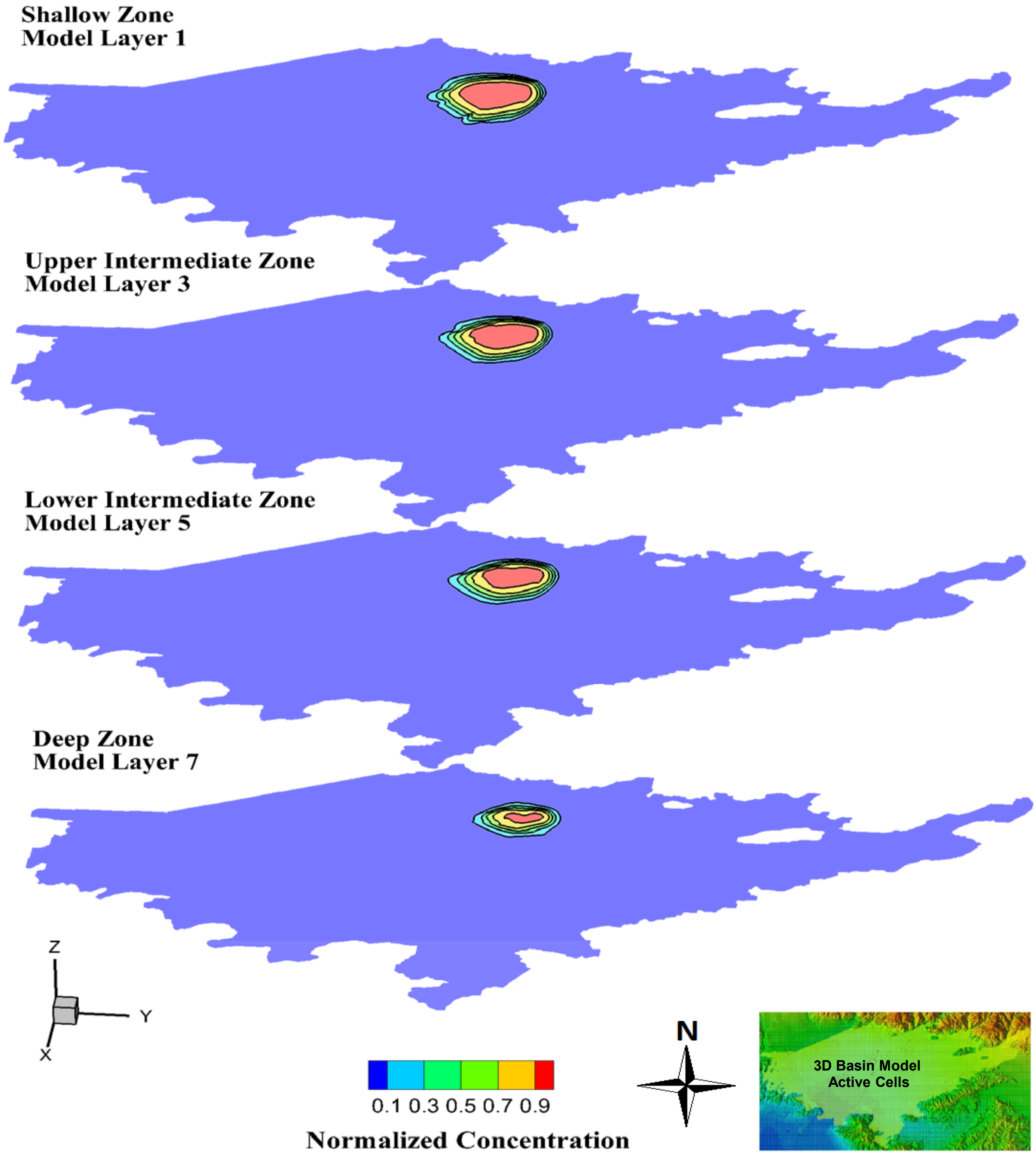
MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 23 - 3D Basin Model Simulated Plume (39MGD).xlsx

Figure 23b



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MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 4 (Baseline Delivery)
Simulated FY2020-21 Plume Distribitions

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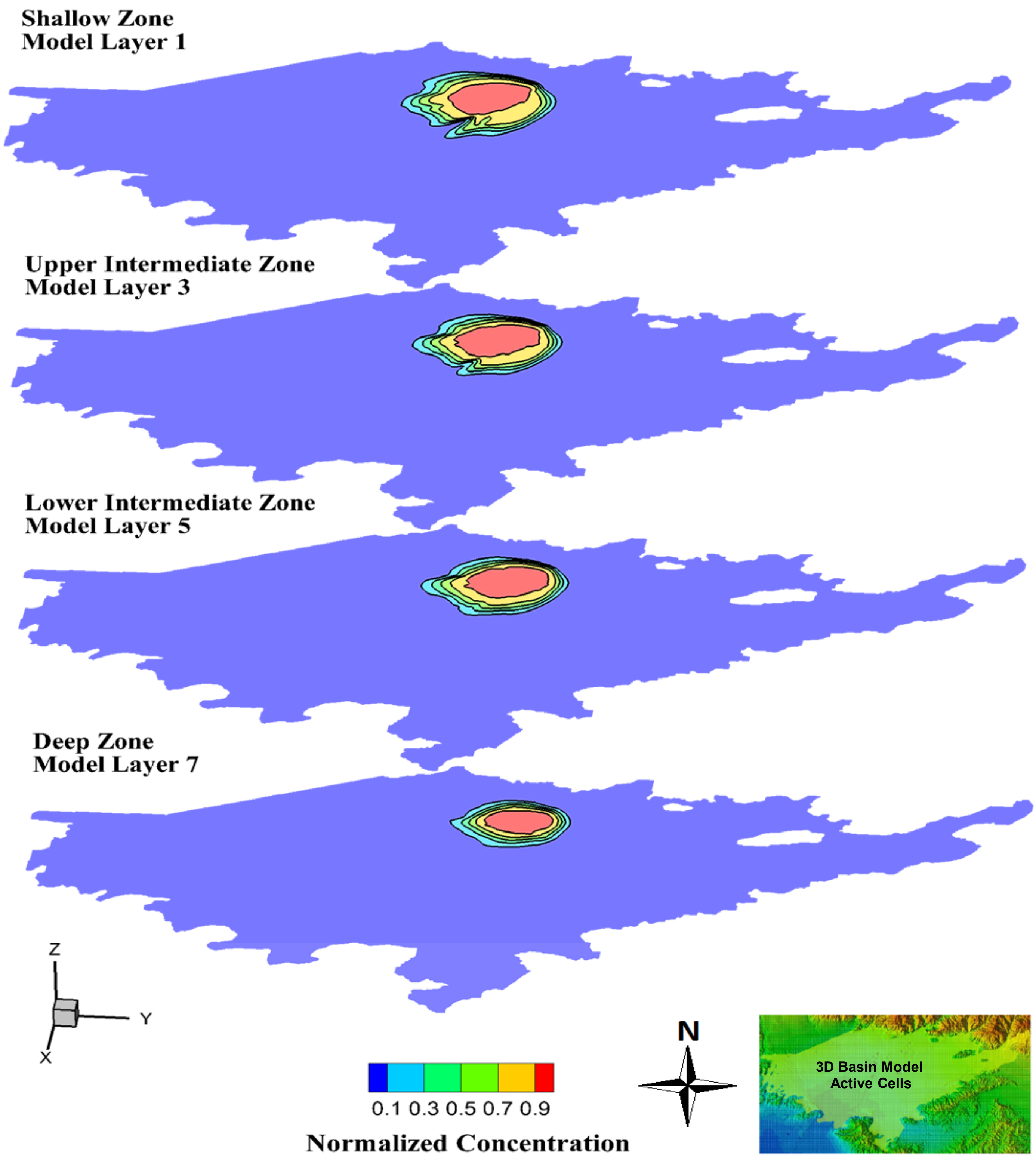
Figure 23c



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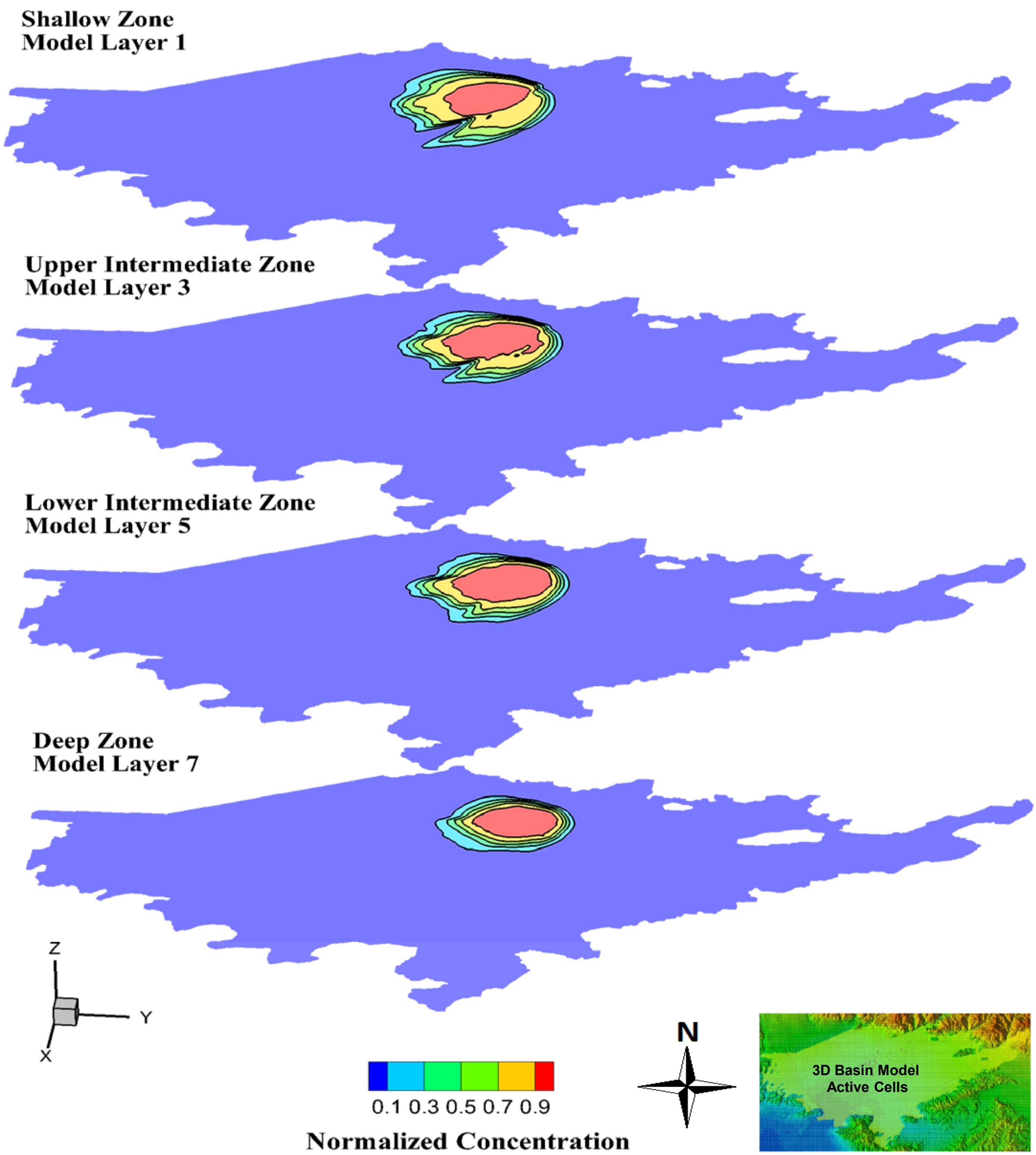
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 4 (Baseline Delivery)
Simulated FY2025-26 Plume Distribitions

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 23 - 3D Basin Model Simulated Plume (39MGD).xlsx

Figure 23d



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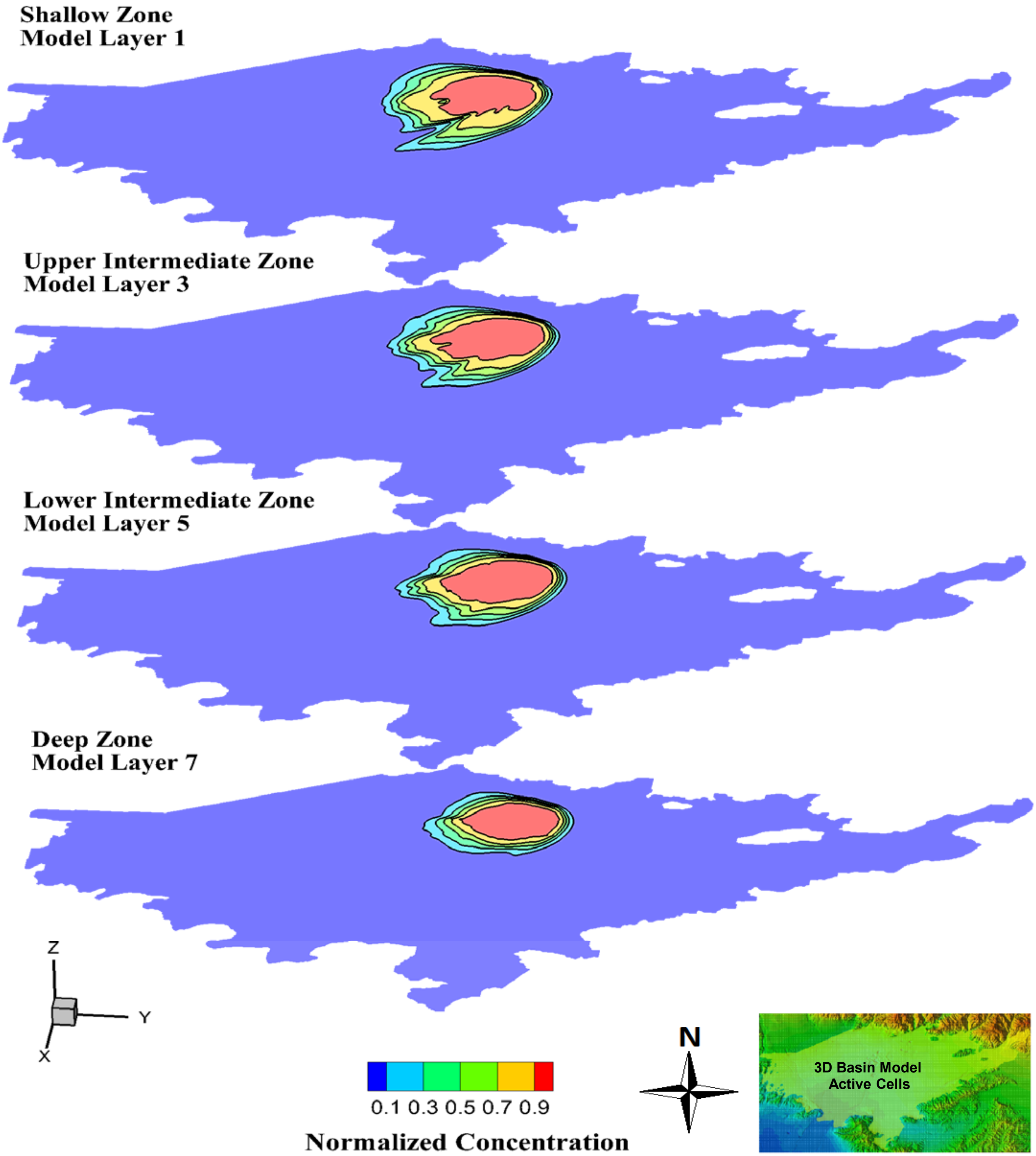
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 4 (Baseline Delivery)
Simulated FY2030-31 Plume Distribitions

MainSanGabrielBasin WATERMASTER

Figure 23e



MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 4 (Baseline Delivery)
Simulated FY2035-36 Plume Distribitions

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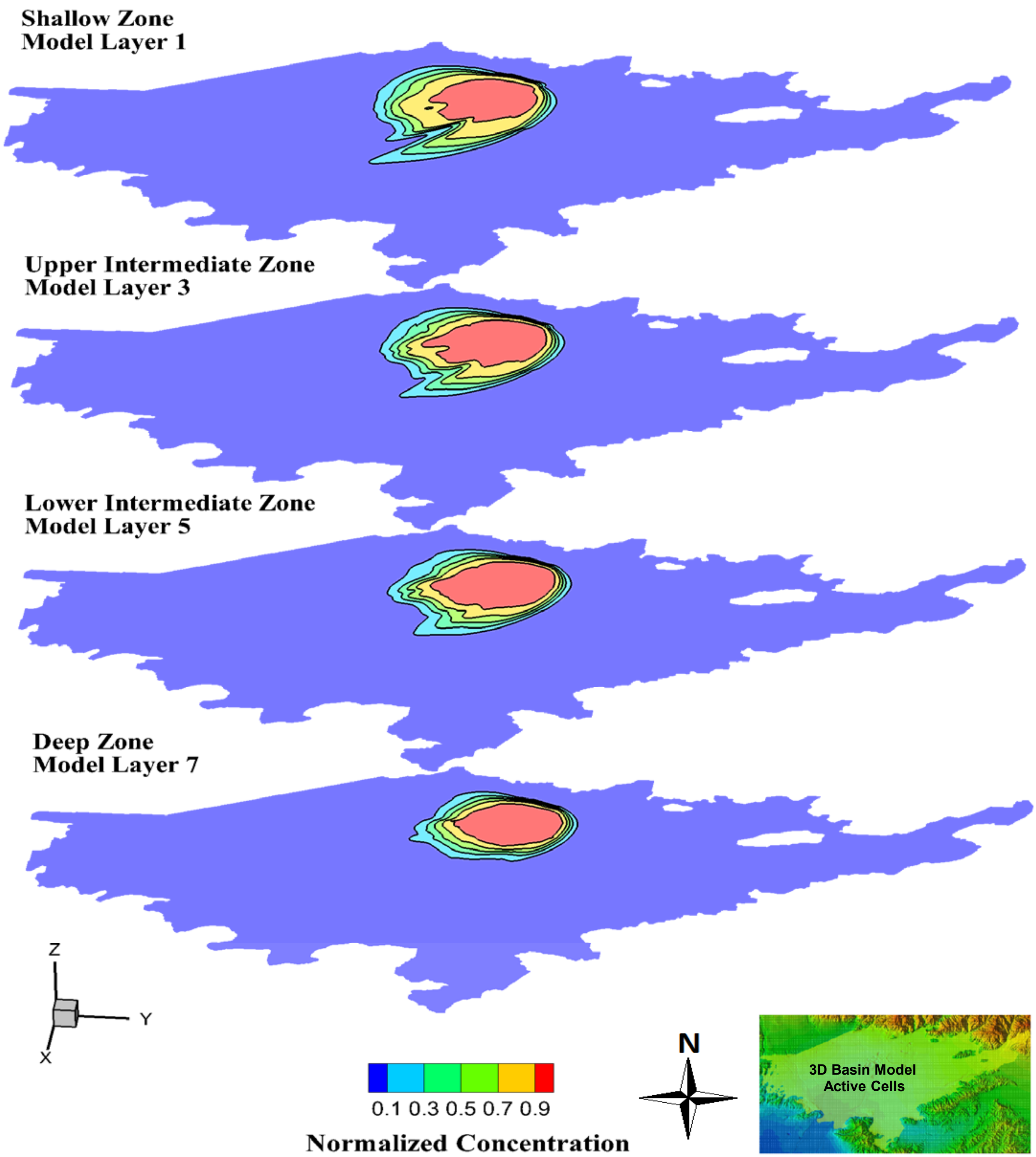
MainSanGabrielBasin WATERMASTER



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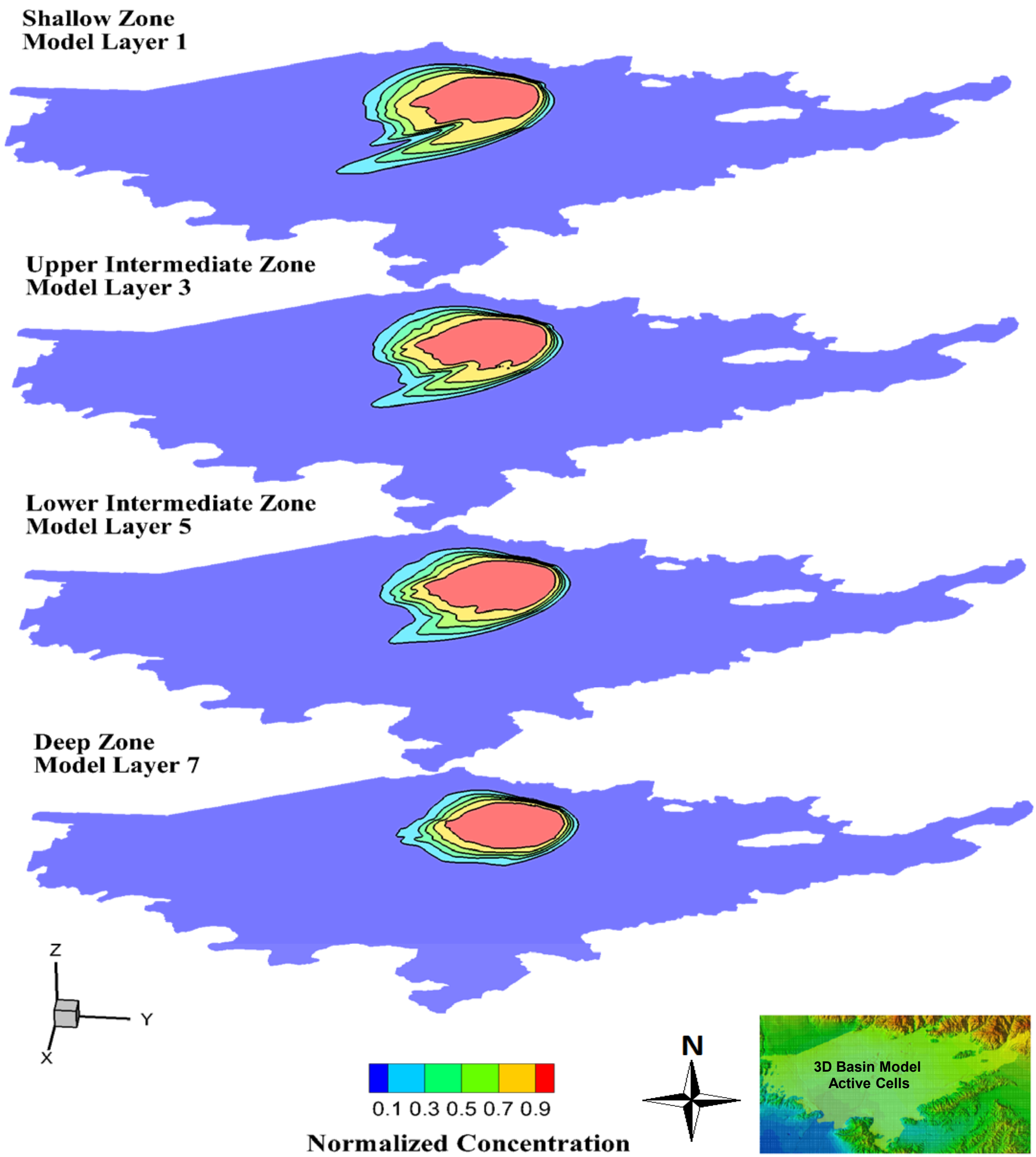
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 4 (Baseline Delivery)
Simulated FY2040-41 Plume Distribitions

MainSanGabrielBasin WATERMASTER



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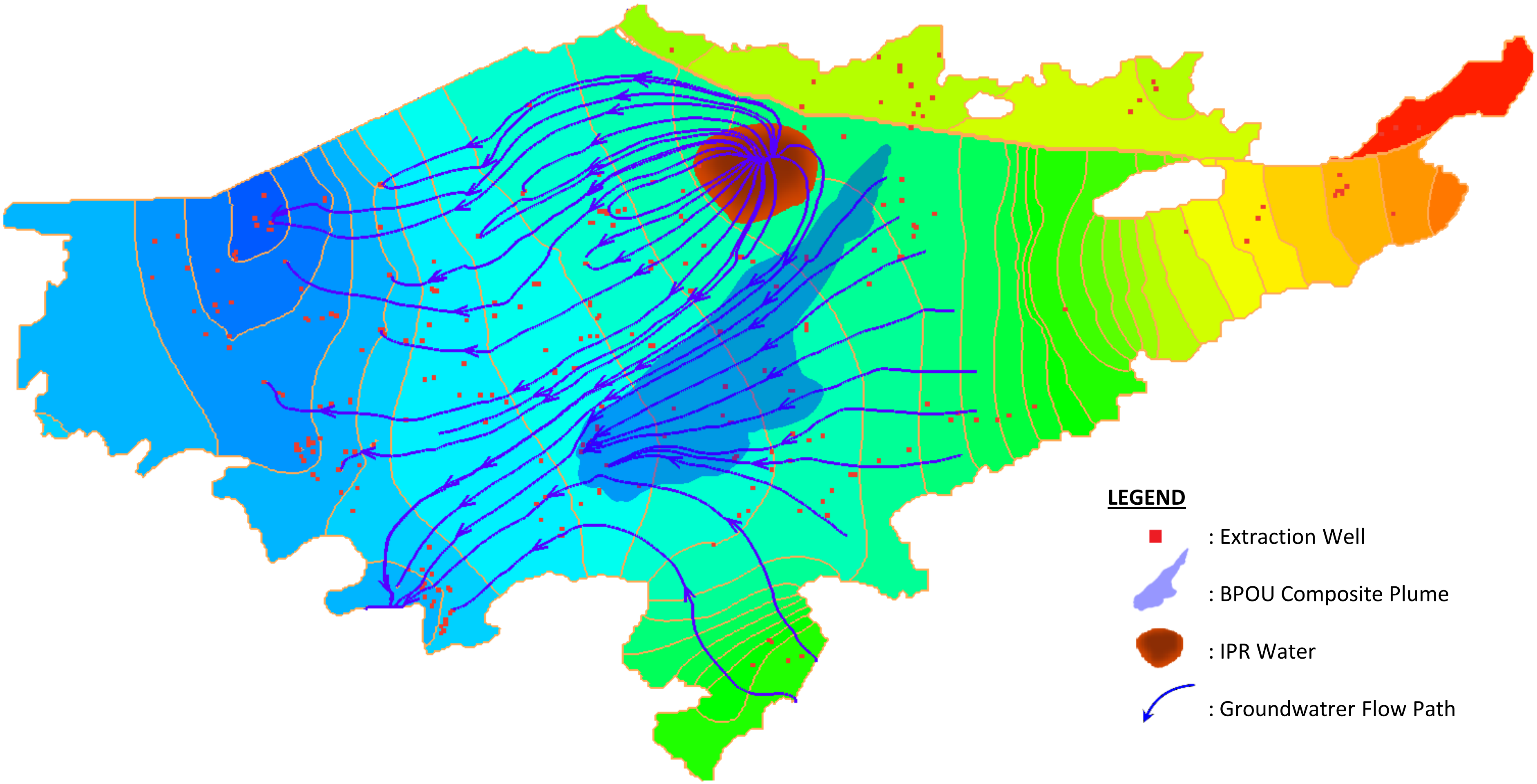
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 4 (Baseline Delivery)
Simulated FY2046-47 Plume Distribitions

MainSanGabrielBasin WATERMASTER

Model Run I – Baseline Delivery of 39 MGD



LEGEND

- : Extraction Well
- : BPOU Composite Plume
- : IPR Water
- : Groundwatrer Flow Path

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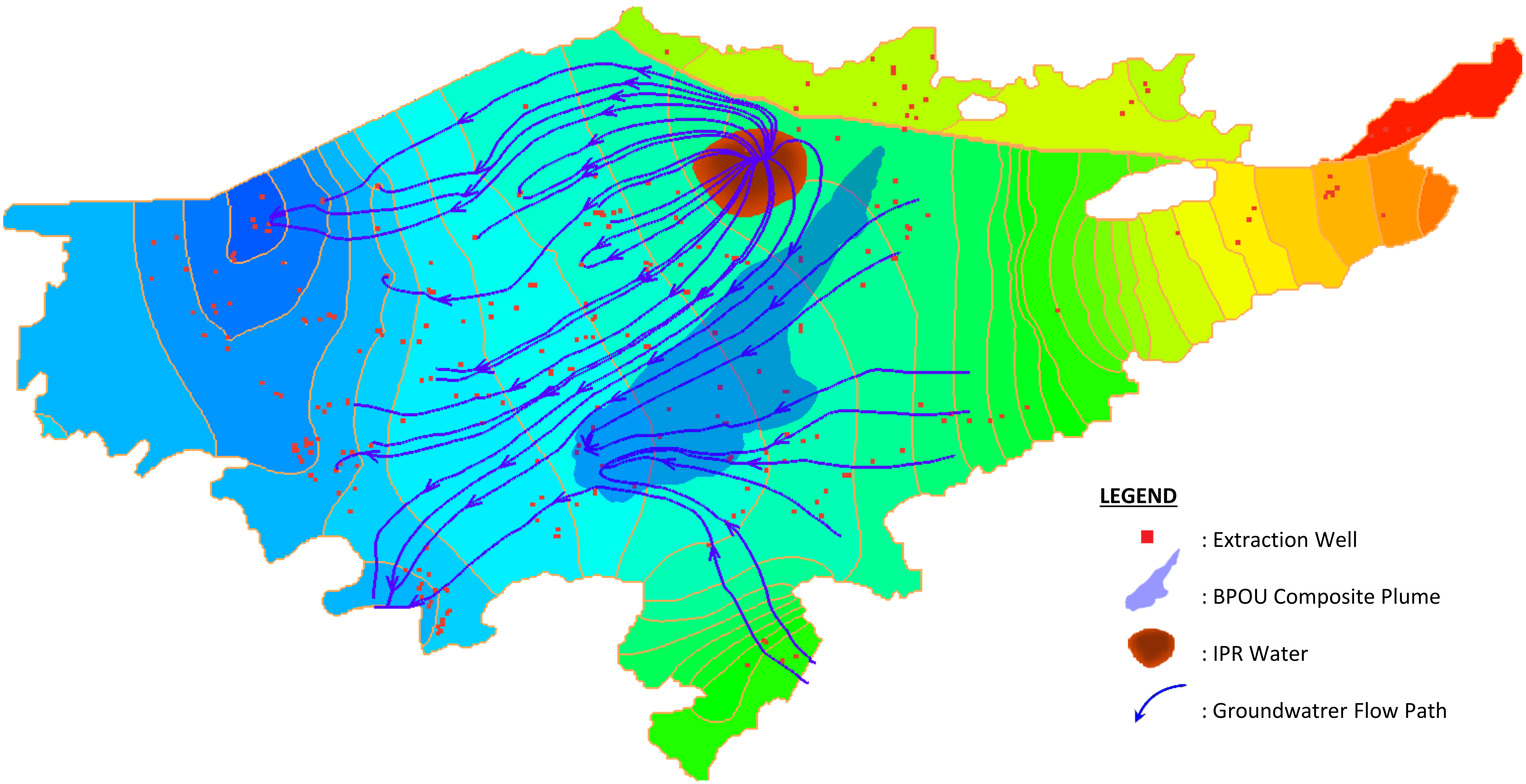
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 1 Fiscal Year 2015-2016
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run I – Baseline Delivery of 39 MGD



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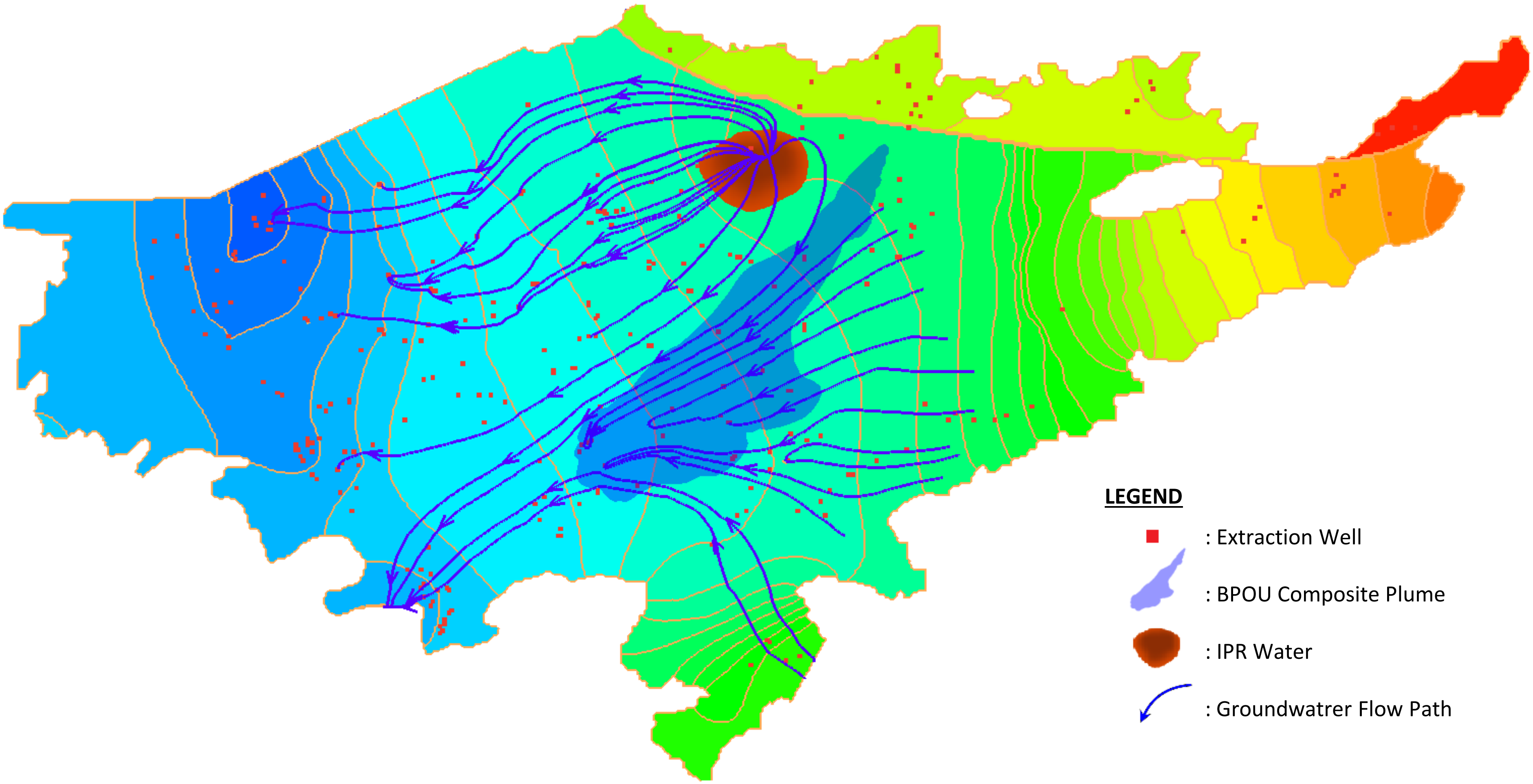
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 3 Fiscal Year 2015-2016
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run I – Baseline Delivery of 39 MGD



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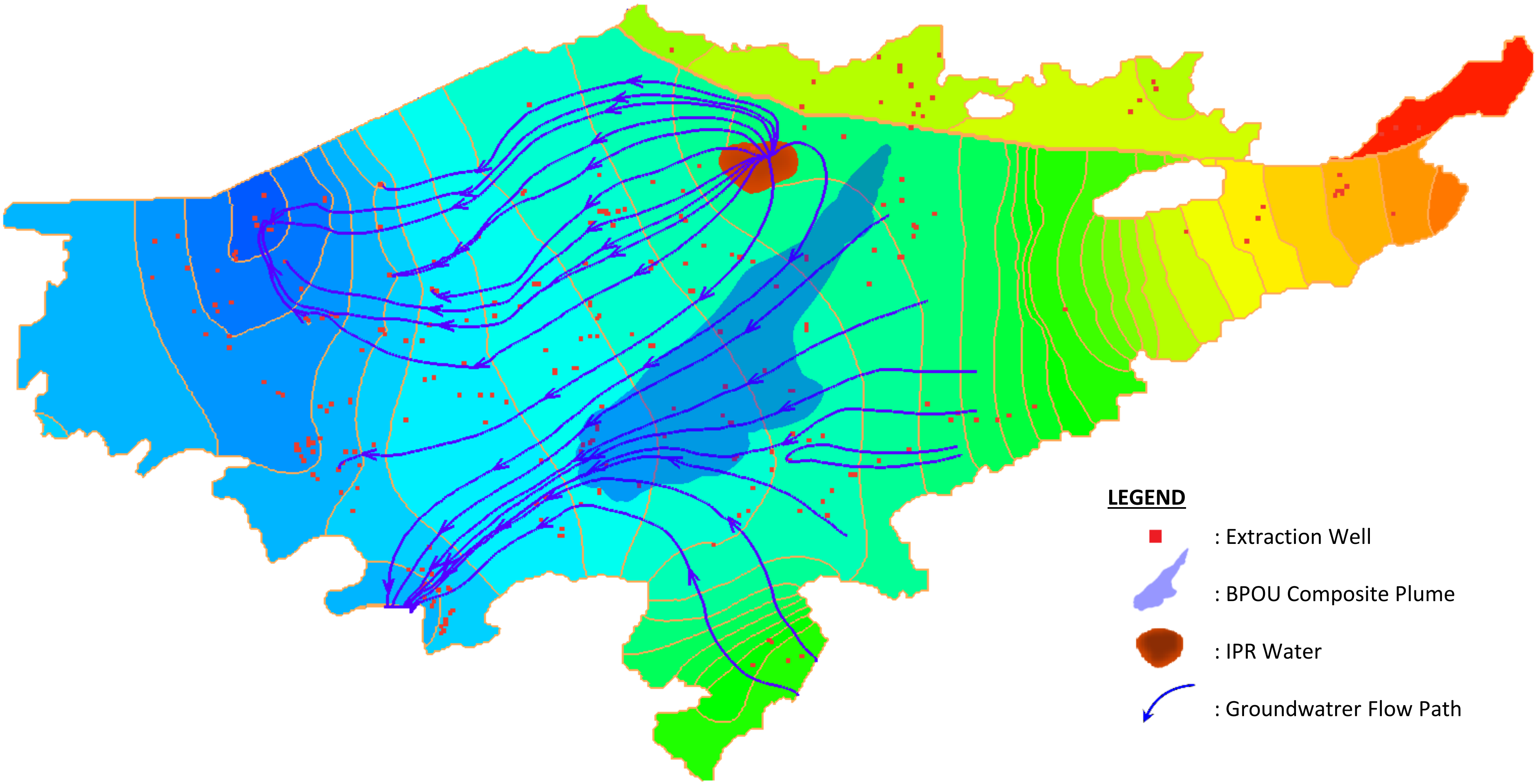
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 5 Fiscal Year 2015-2016
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run I – Baseline Delivery of 39 MGD



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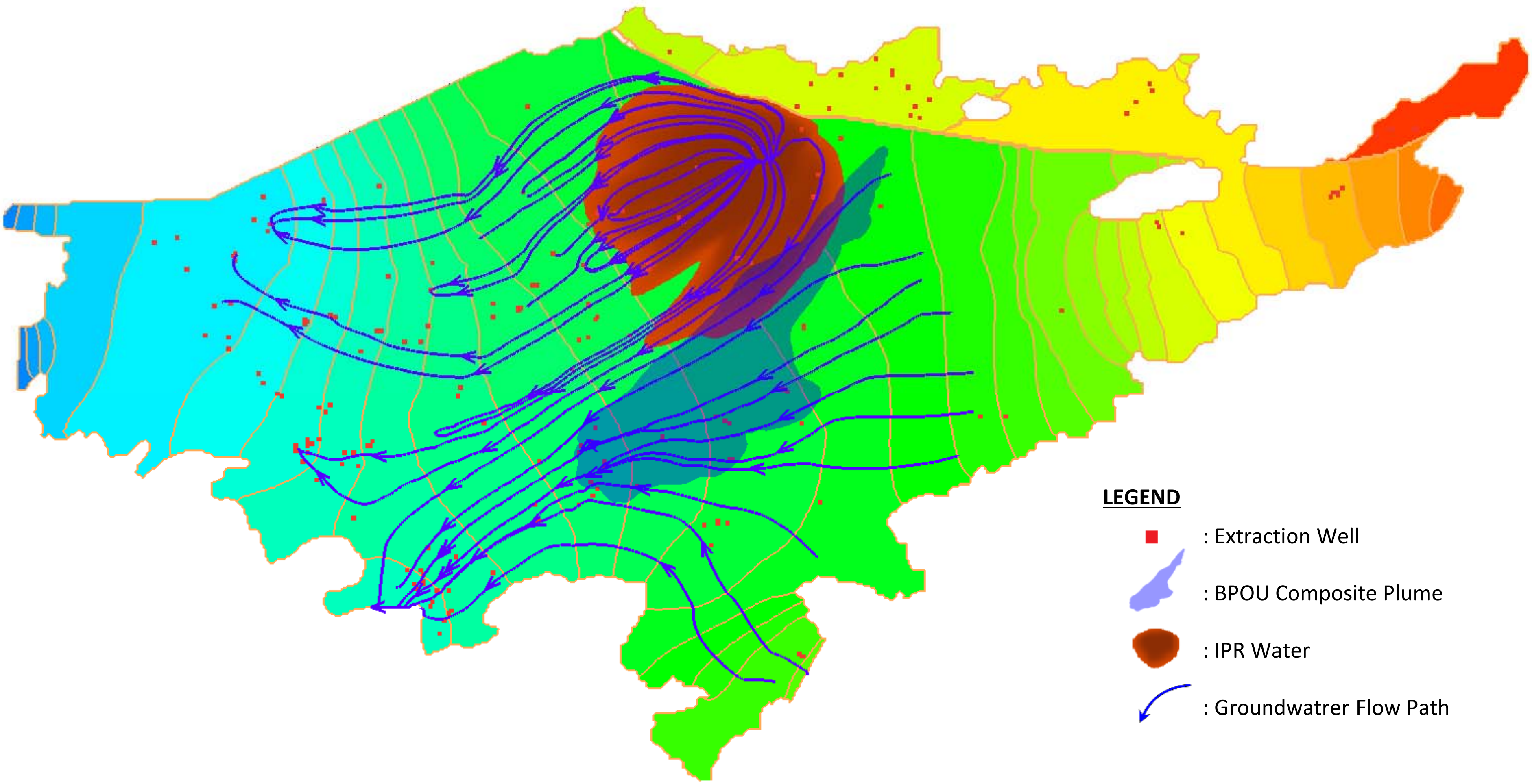
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 7 Fiscal Year 2015-2016
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run I – Baseline Delivery of 39 MGD



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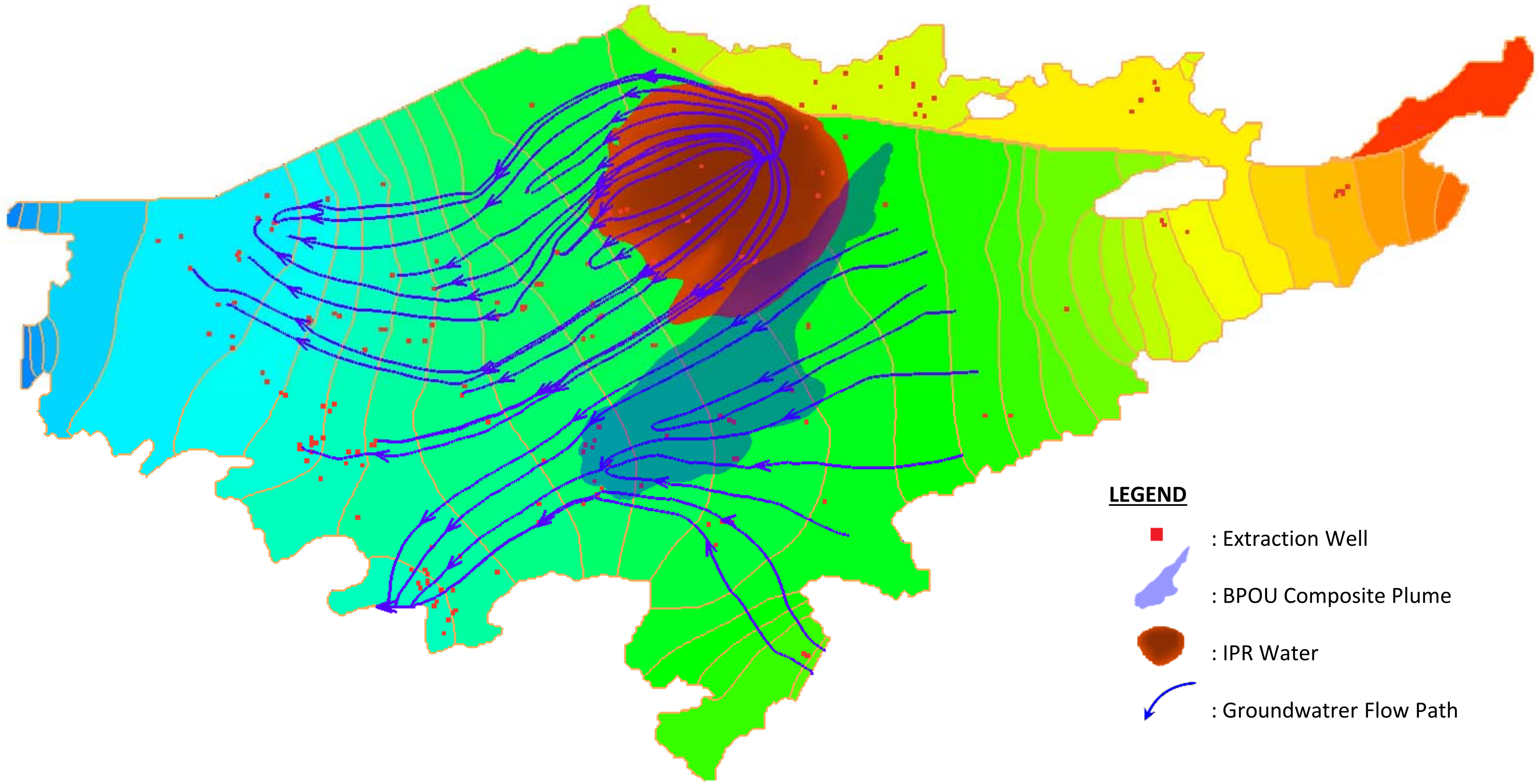
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 1 Fiscal Year 2030-2031
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run I – Baseline Delivery of 39 MGD



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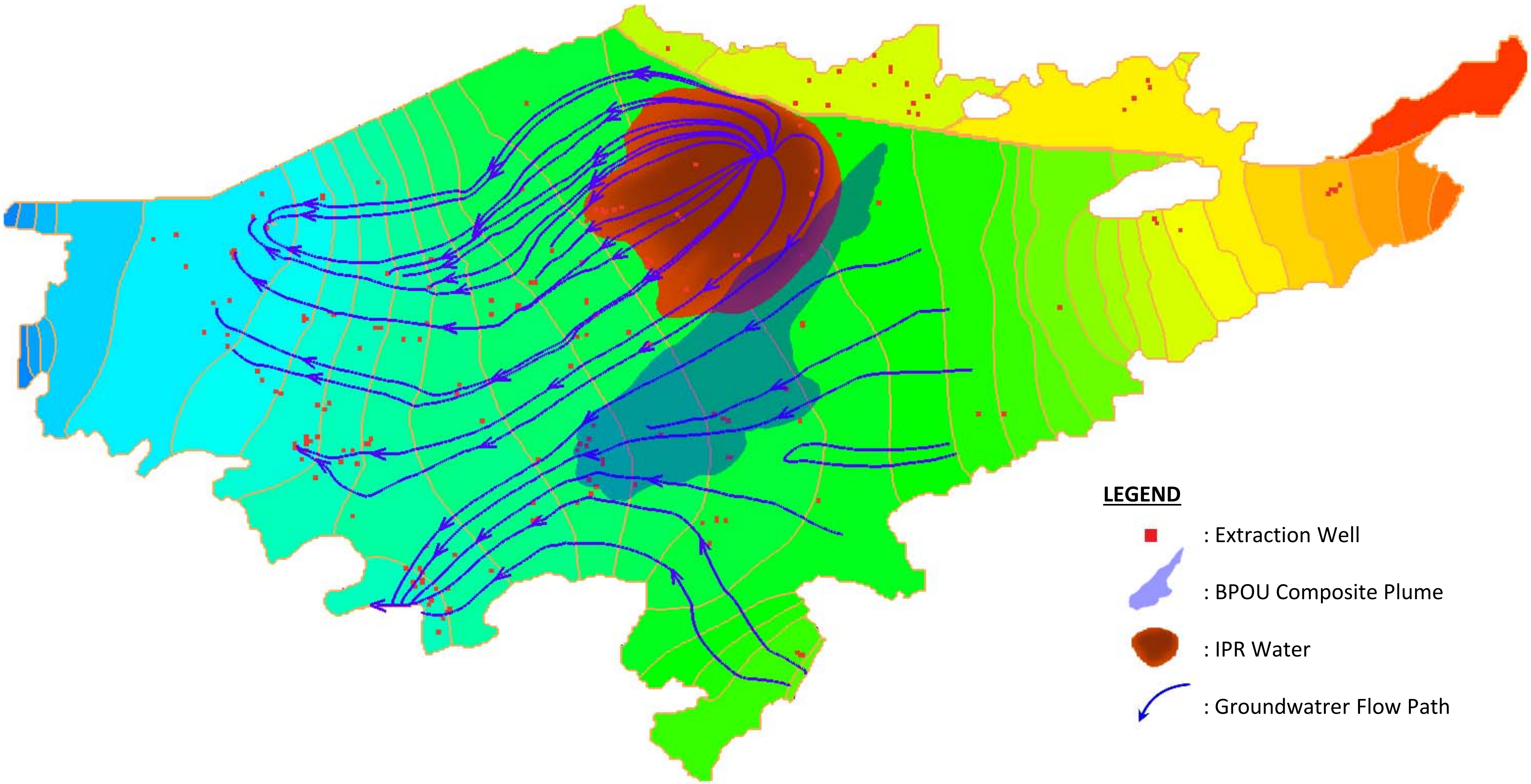
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 3 Fiscal Year 2030-2031
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run I – Baseline Delivery of 39 MGD



MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 5 Fiscal Year 2030-2031
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

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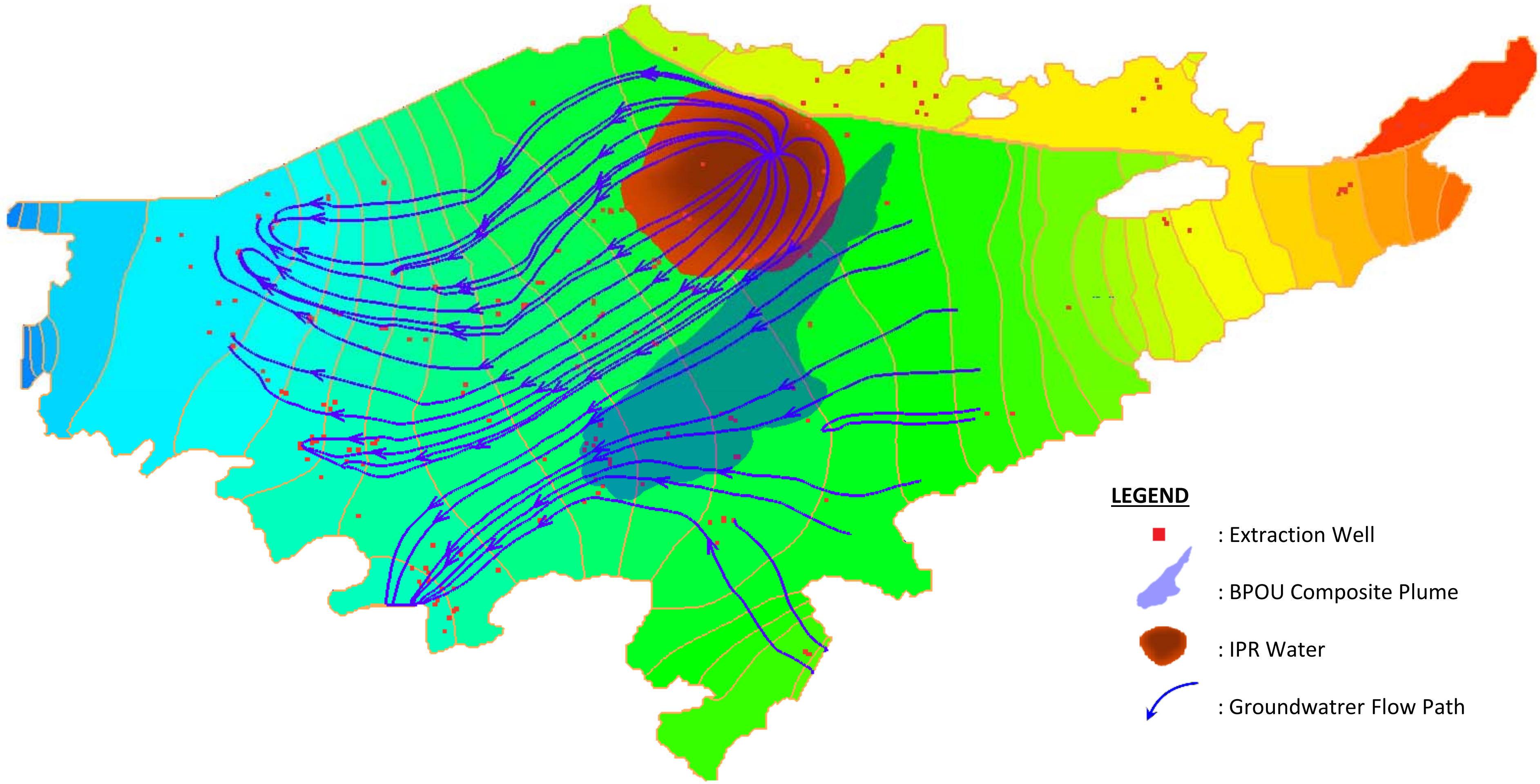
Model Run I – Baseline Delivery of 39 MGD



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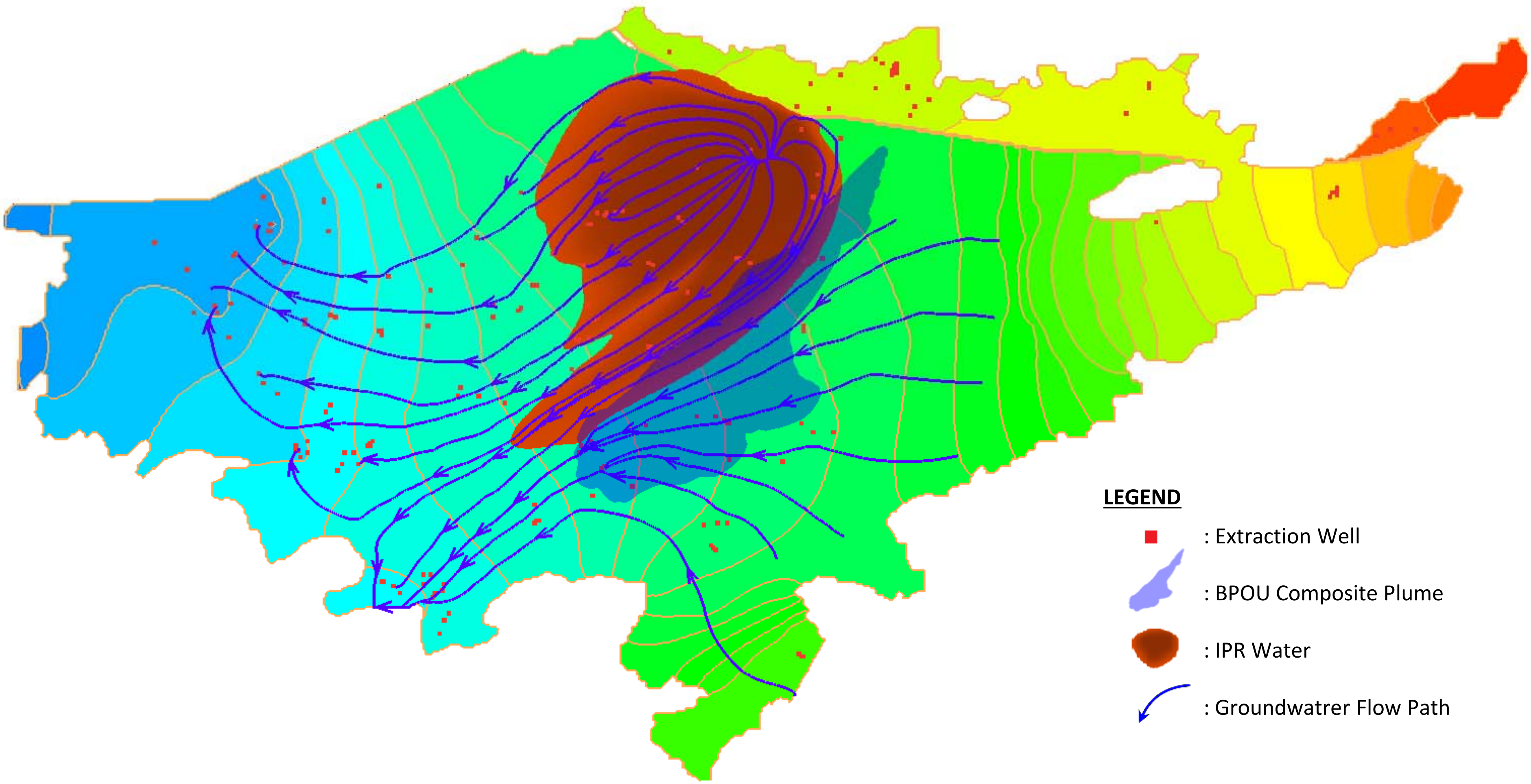
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 7 Fiscal Year 2030-2031
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run I – Baseline Delivery of 39 MGD



LEGEND

: Extraction Well

: BPOU Composite Plume

: IPR Water

: Groundwatrer Flow Path

STETSON ENGINEERS INC.

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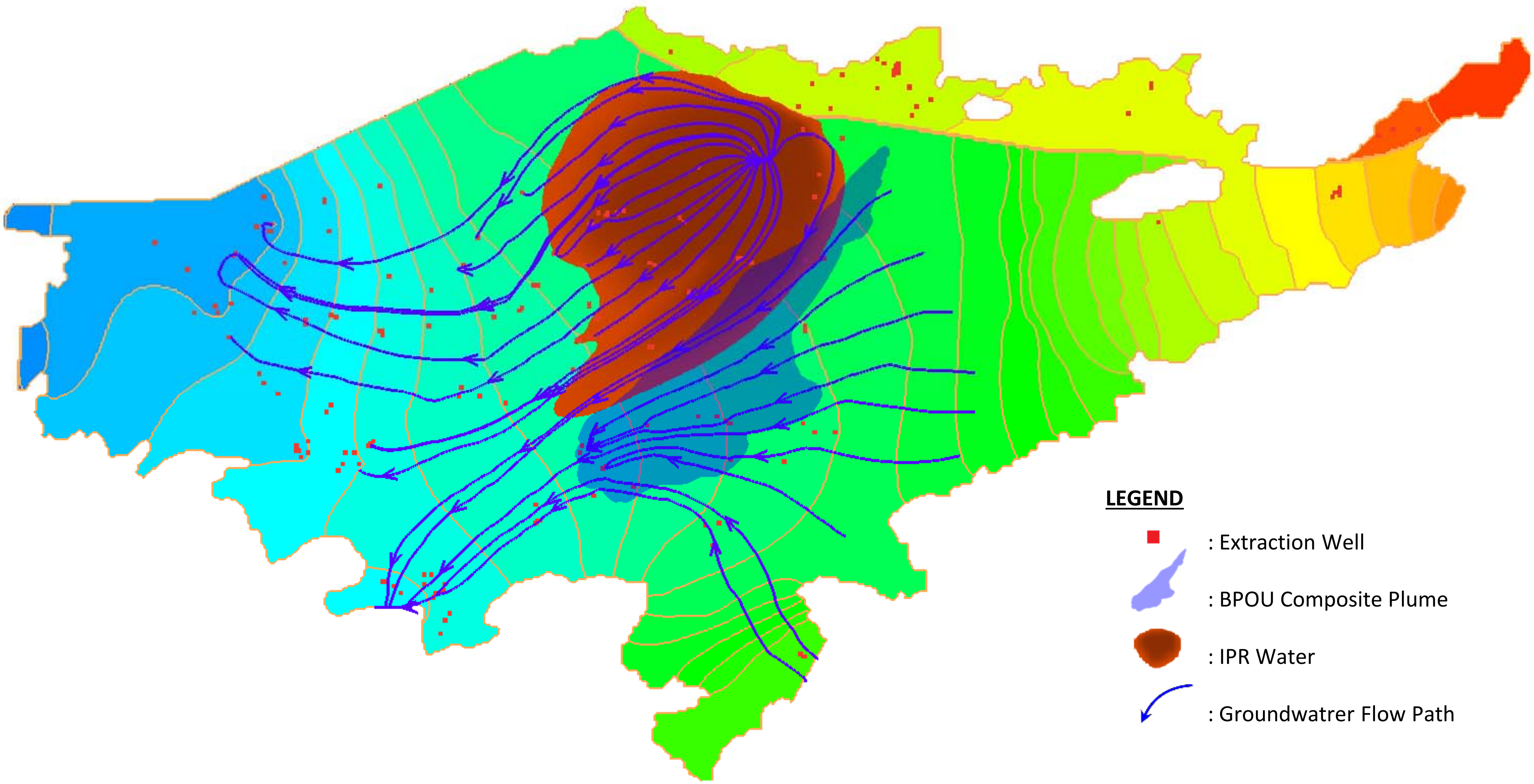
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 1 Fiscal Year 2046-2047
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run I – Baseline Delivery of 39 MGD



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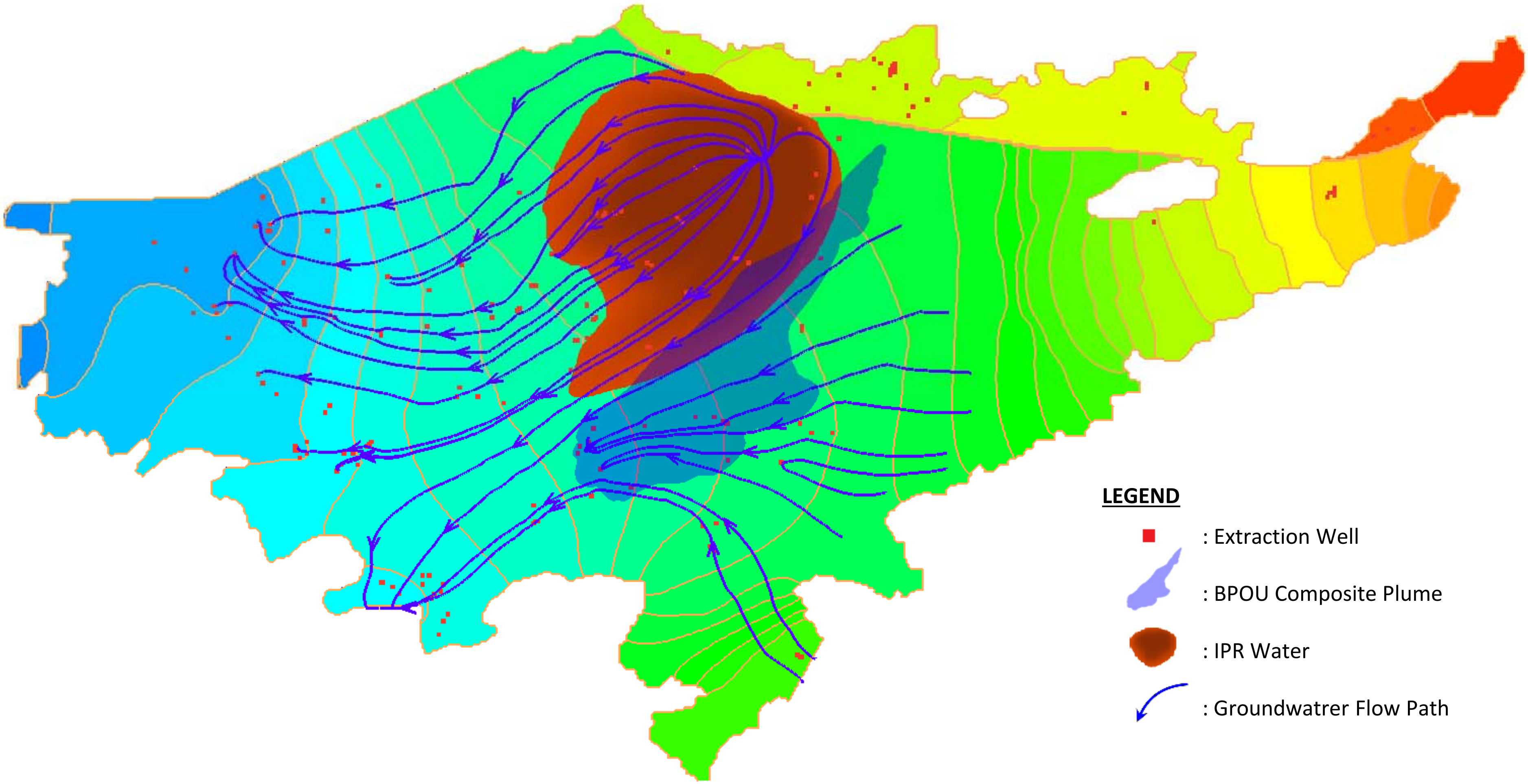
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 3 Fiscal Year 2046-2047
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

Model Run I – Baseline Delivery of 39 MGD



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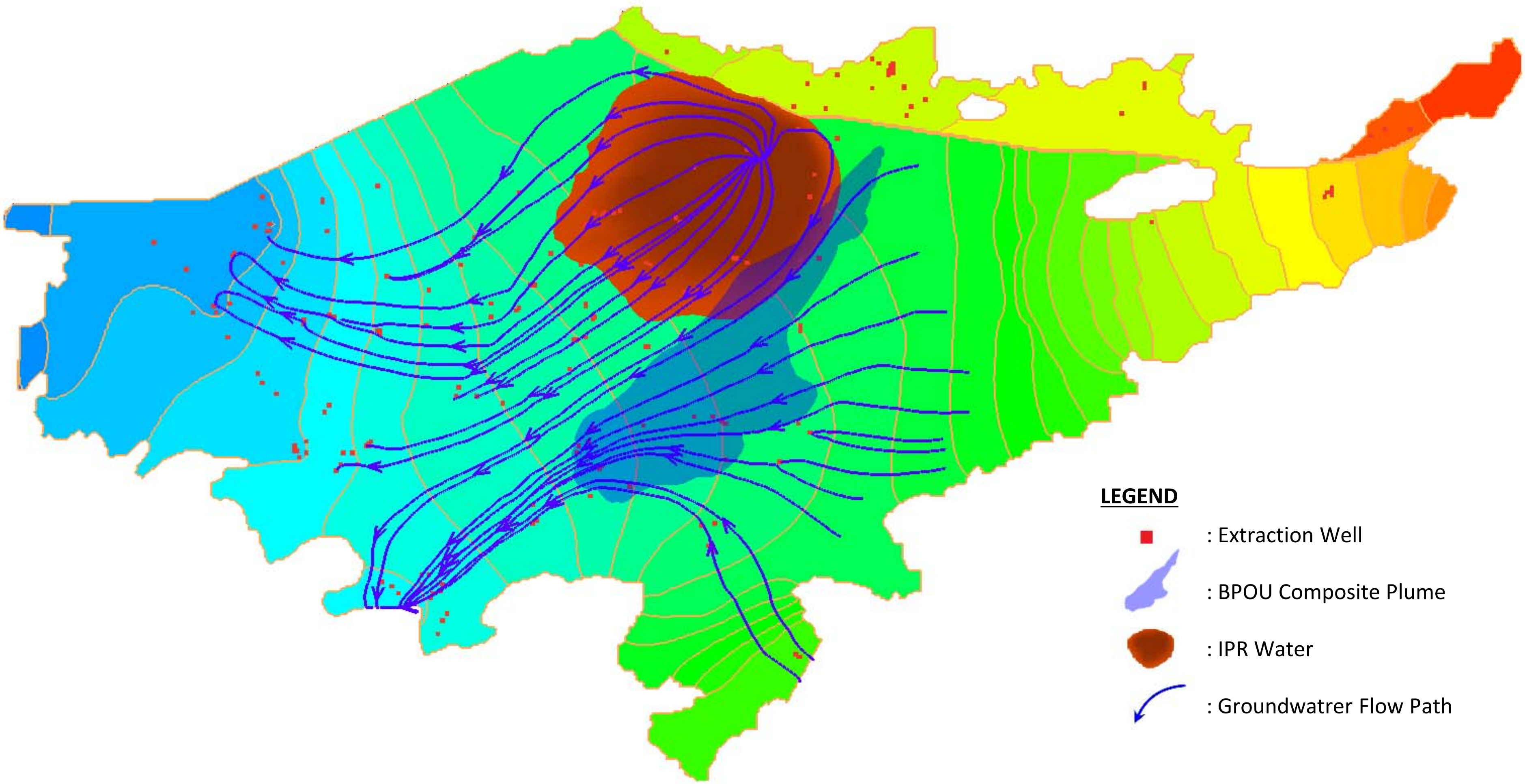
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 5 Fiscal Year 2046-2047
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run I – Baseline Delivery of 39 MGD



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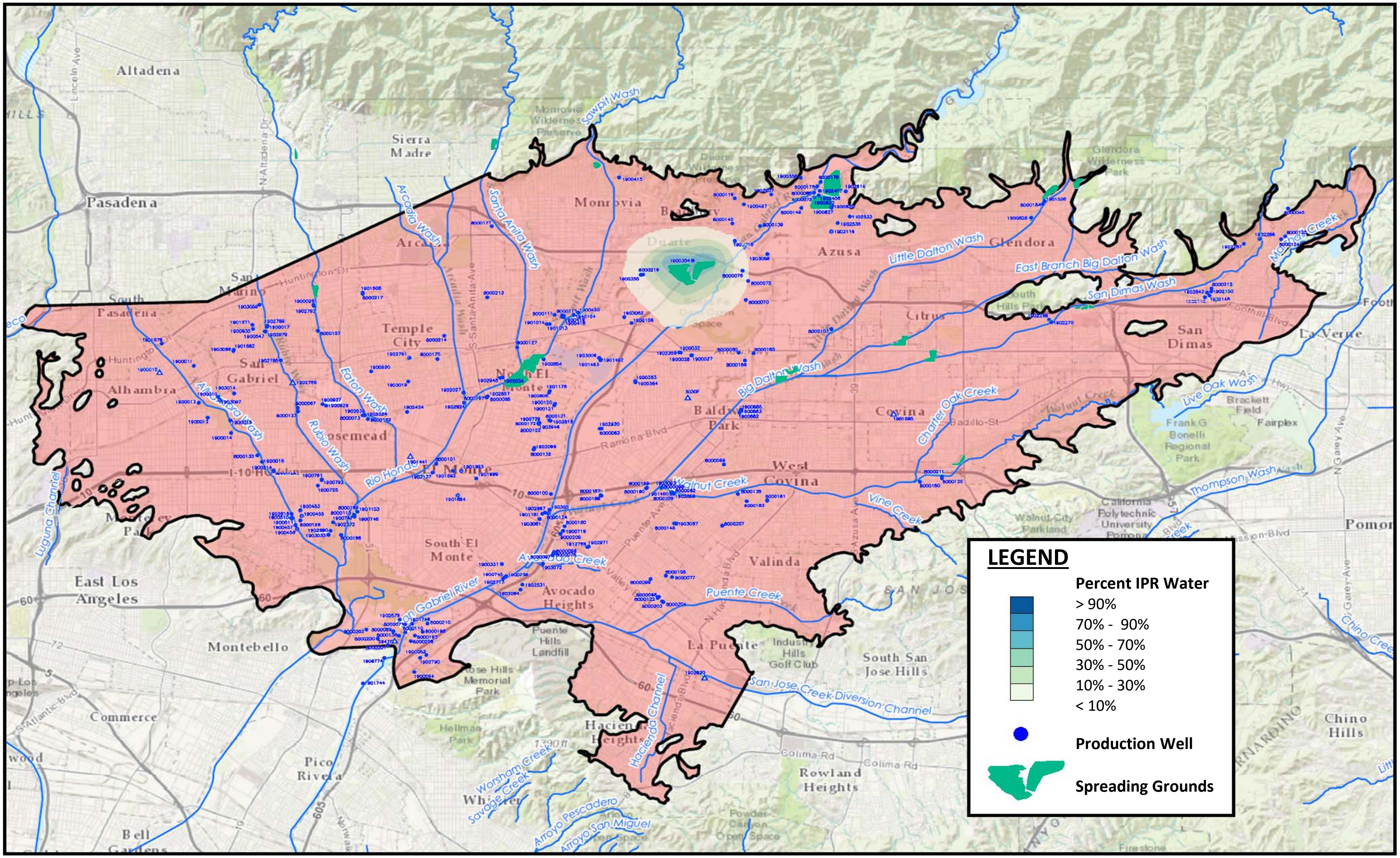
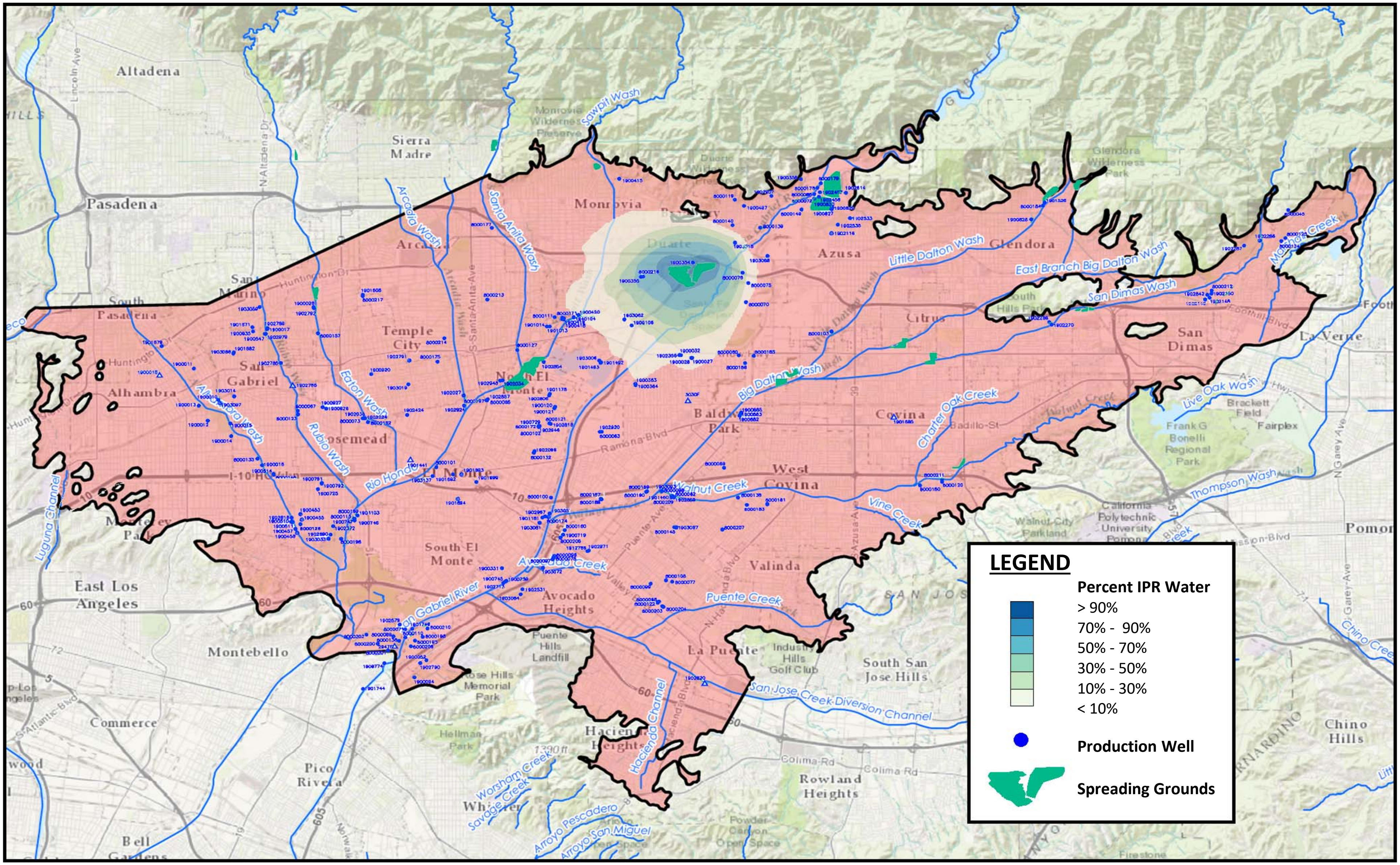
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 7 Fiscal Year 2046-2047
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER



STETSON ENGINEERS INC.	N W E S Not in Scale	**MAIN SAN GABRIEL BASIN WATERMASTER** **Baseline Delivery of 39 MGD (Scenario 4)** **Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2015-16**	MainSanGabrielBasin WATERMASTER



MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 39 MGD (Scenario 4)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2020-21

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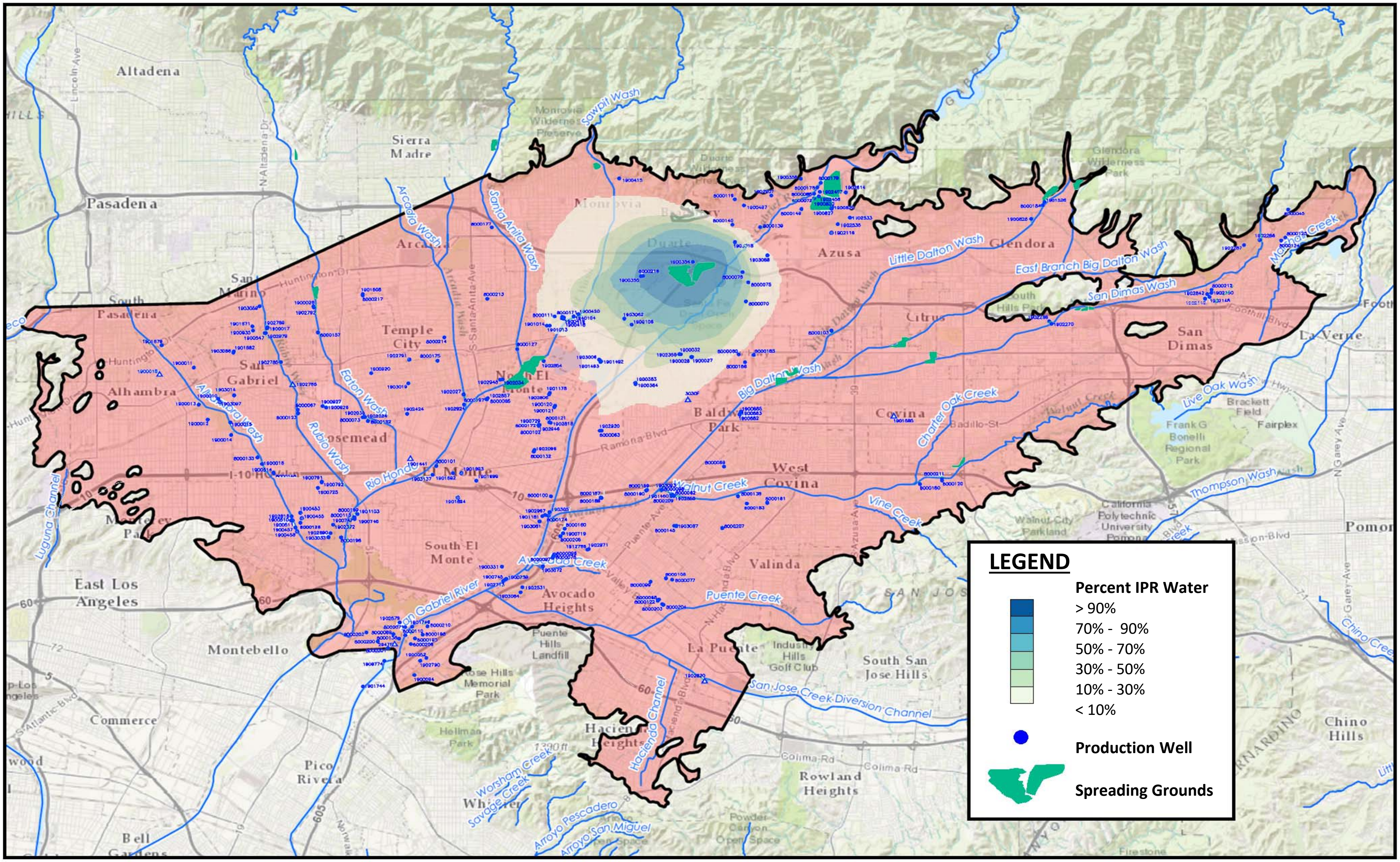
MainSanGabrielBasin WATERMASTER



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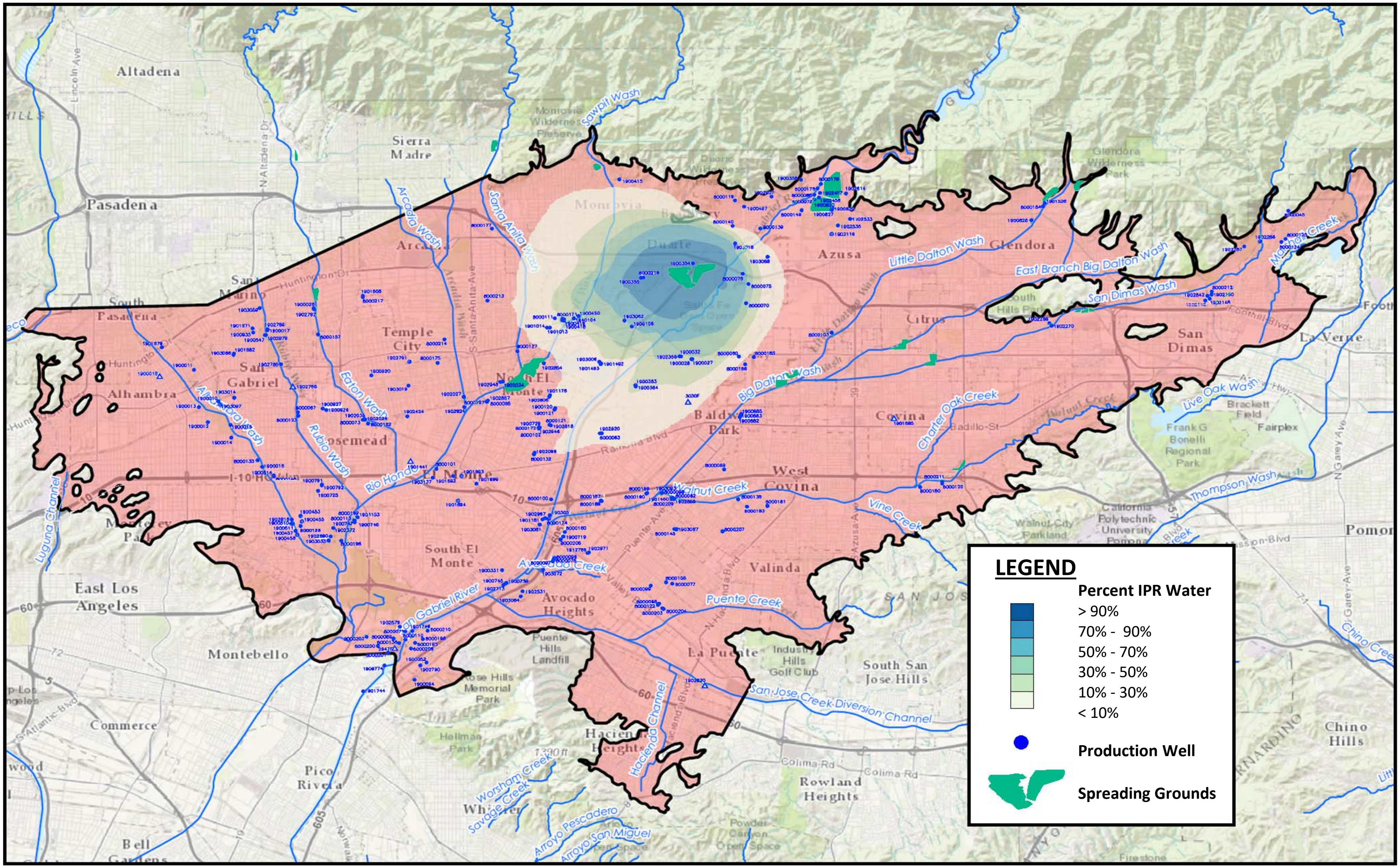
MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 39 MGD (Scenario 4)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2025-26

STETSON ENGINEERS INC.

MainSanGabrielBasin WATERMASTER



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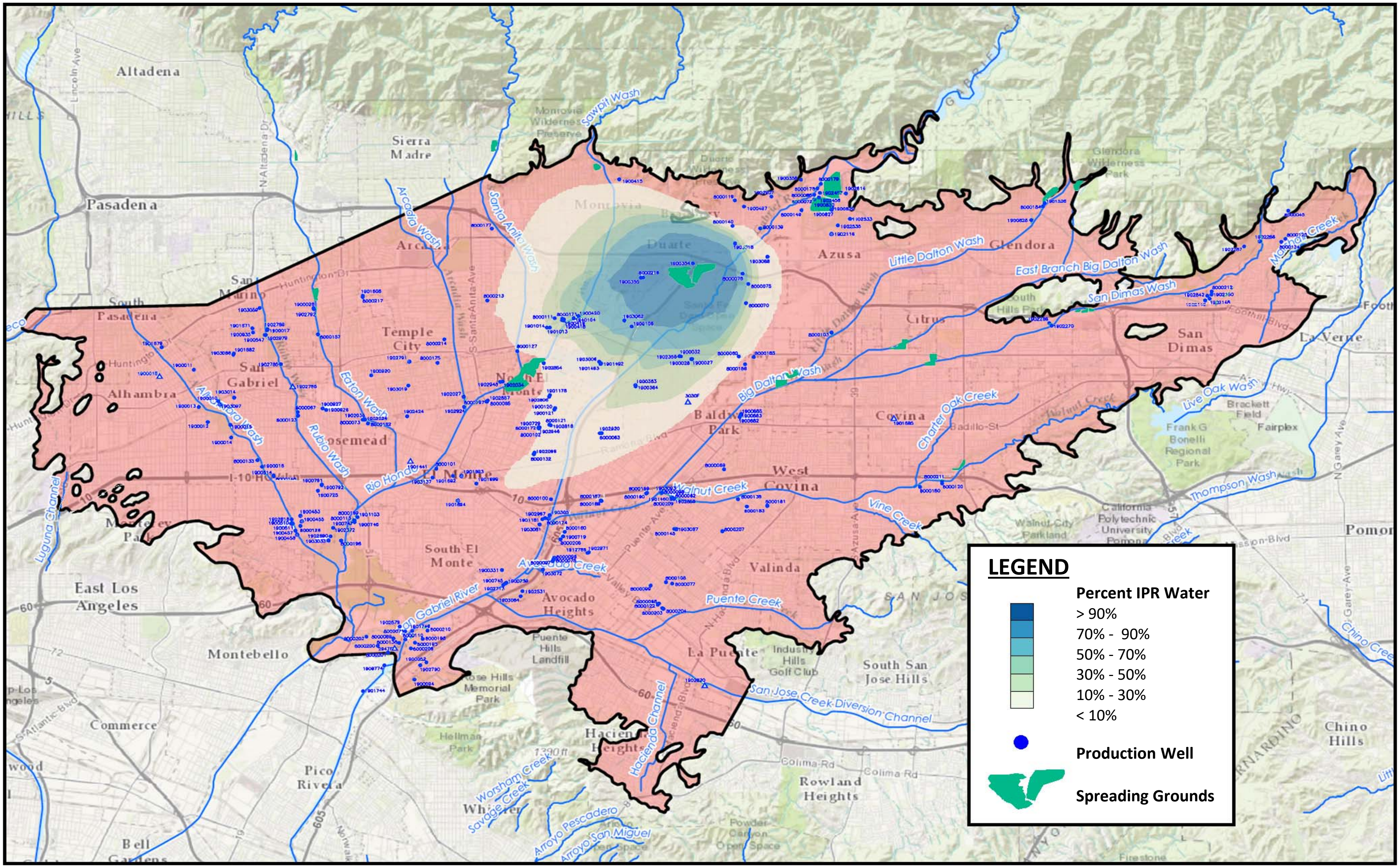
MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 39 MGD (Scenario 4)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2030-31

MainSanGabrielBasin WATERMASTER



MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 39 MGD (Scenario 4)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2035-36

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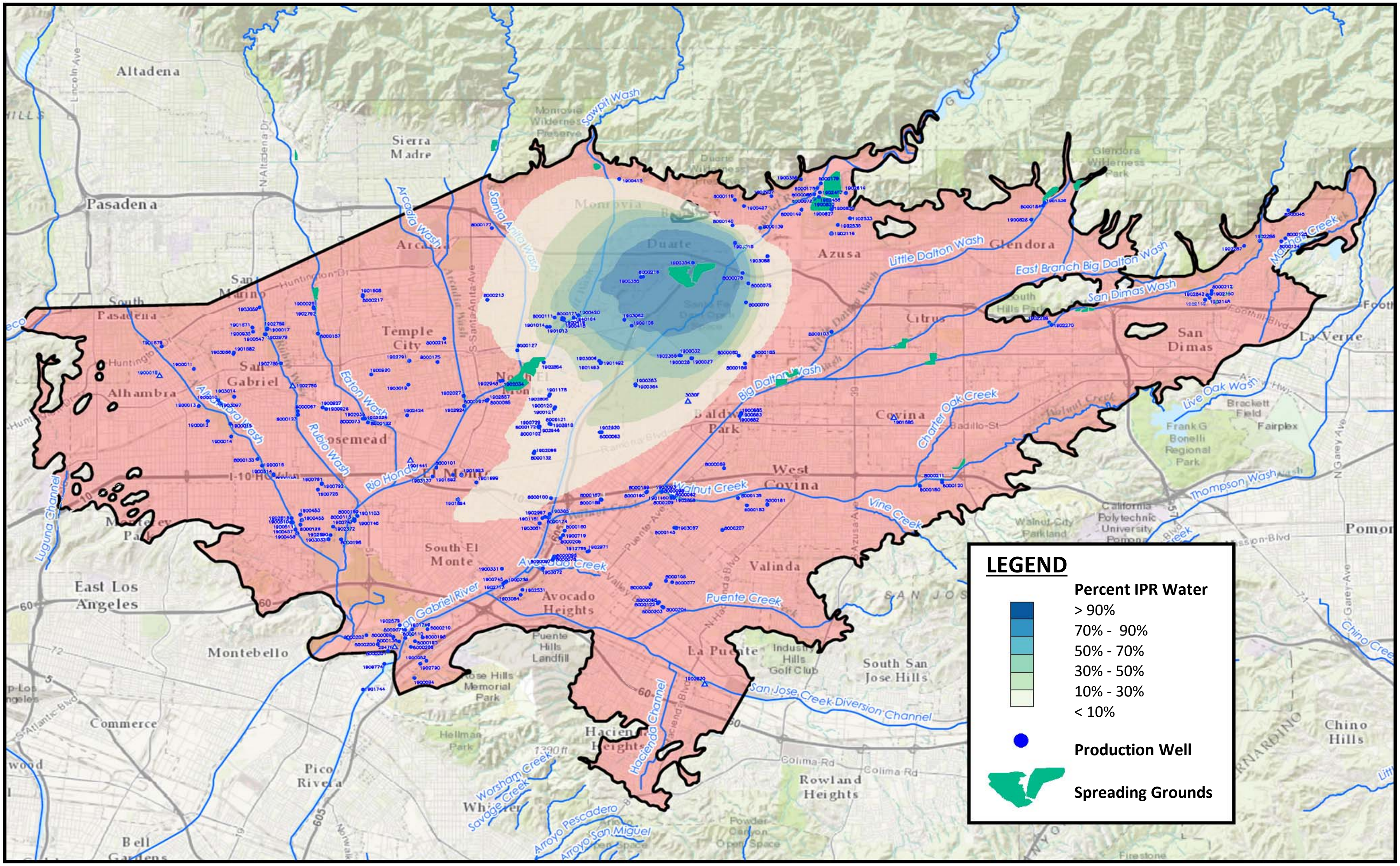
STETSON ENGINEERS INC.

MainSanGabrielBasin WATERMASTER



MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 39 MGD (Scenario 4)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2040-41

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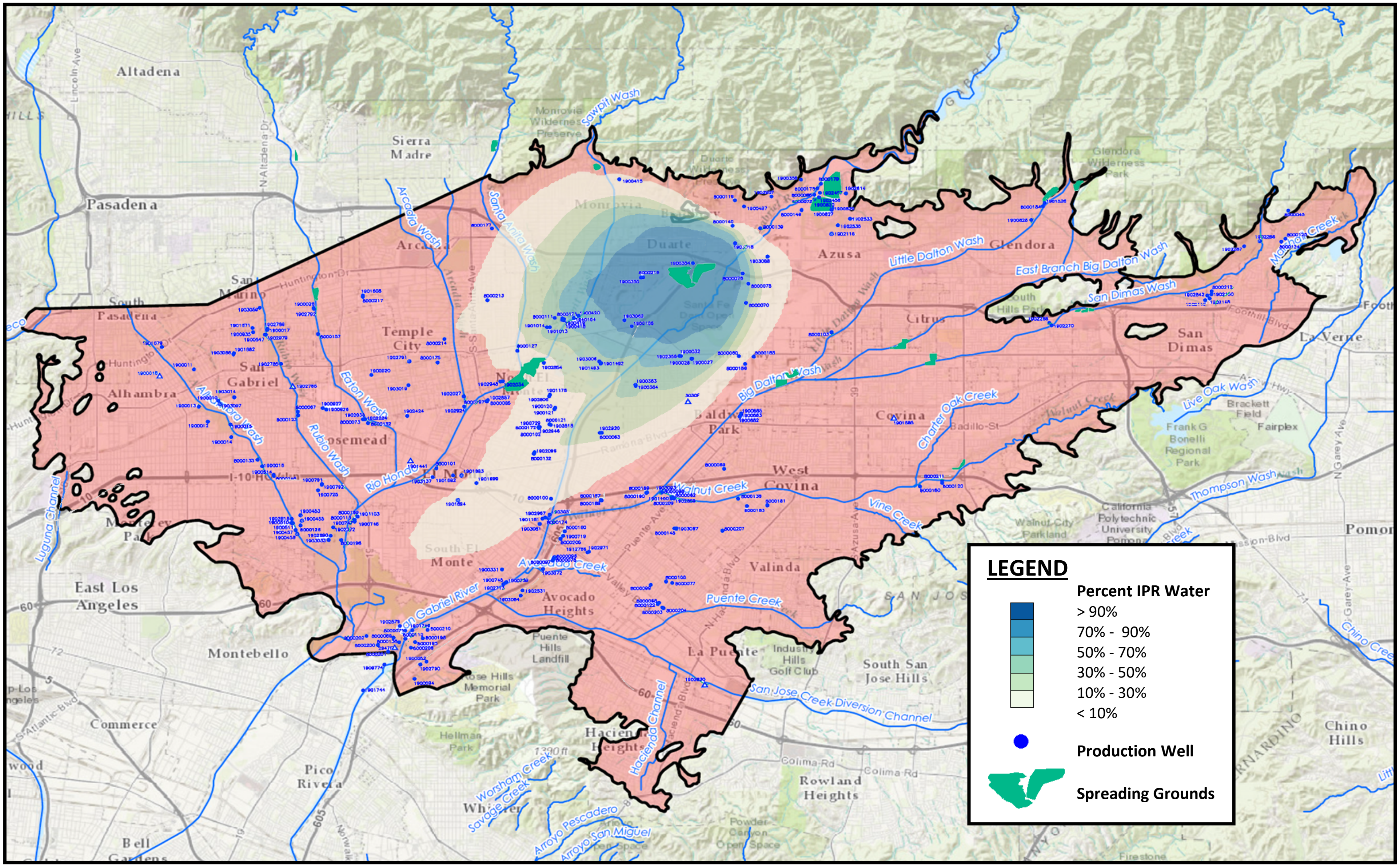

MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 39 MGD (Scenario 4)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2046-47

STETSON ENGINEERS INC.

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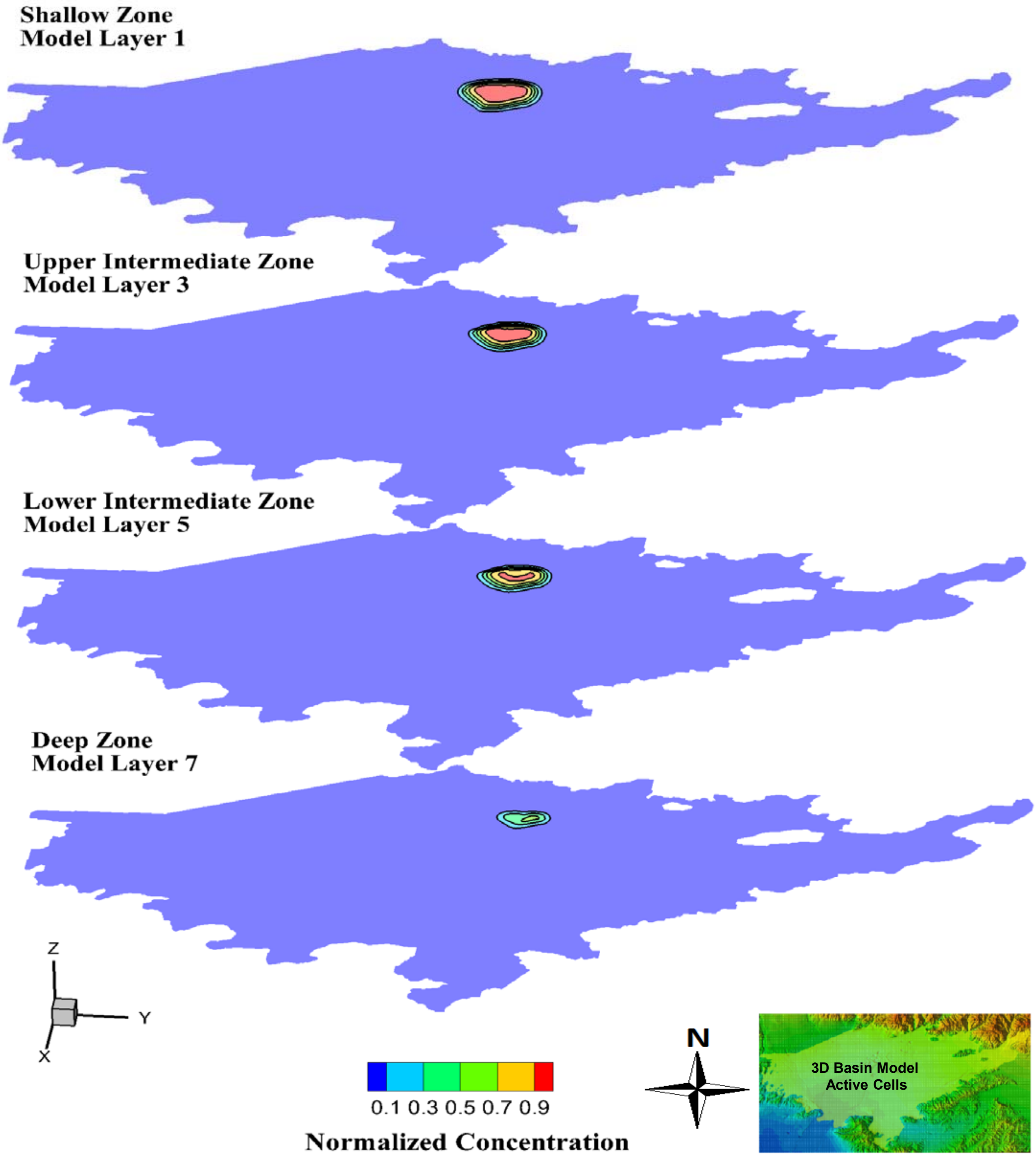
MainSanGabrielBasin WATERMASTER

Figure 26a

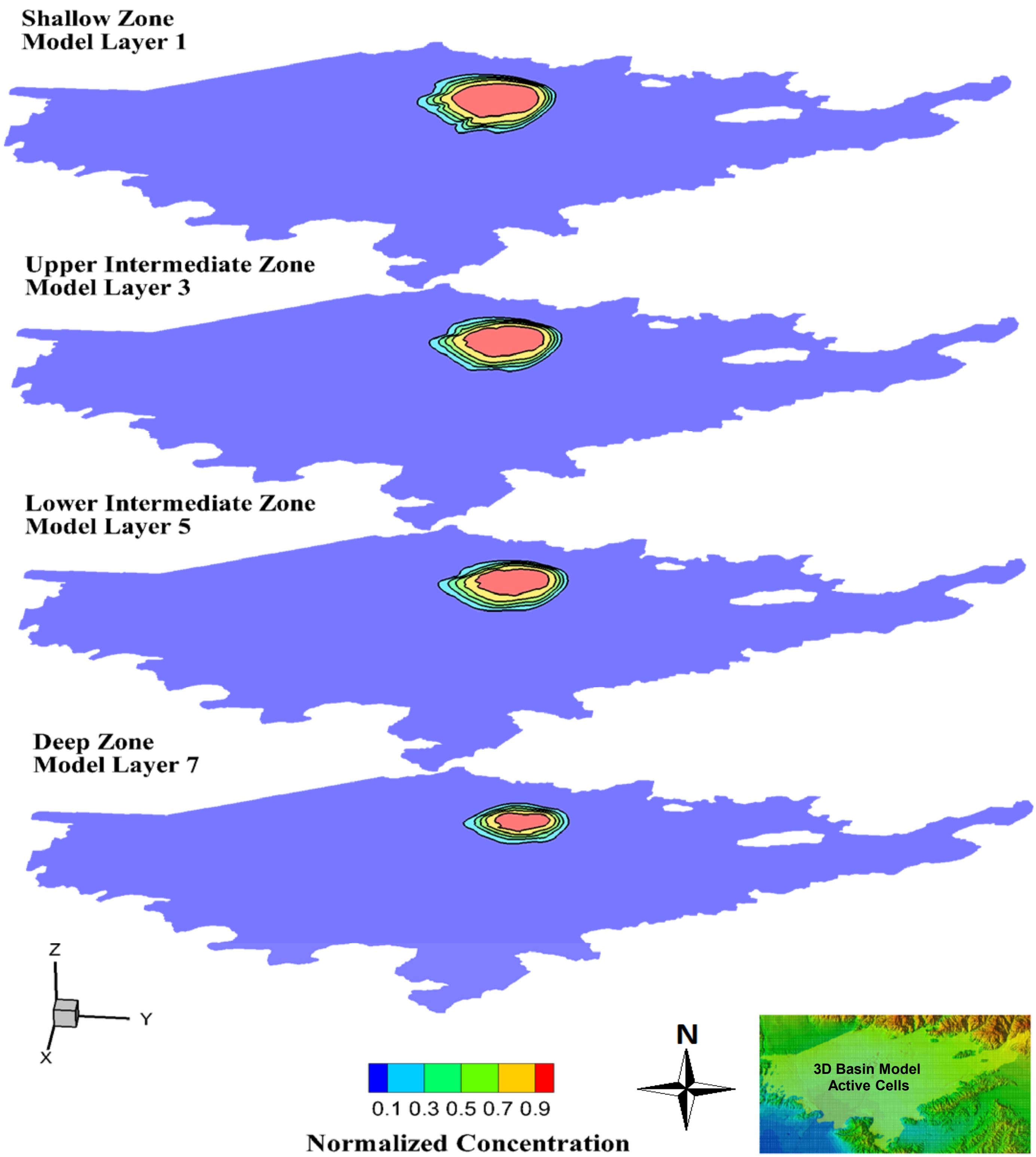


MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 5 (Basin Sustainability)
Simulated FY2015-16 Plume Distribitions

STETSON ENGINEERS INC.

MainSanGabrielBasin WATERMASTER



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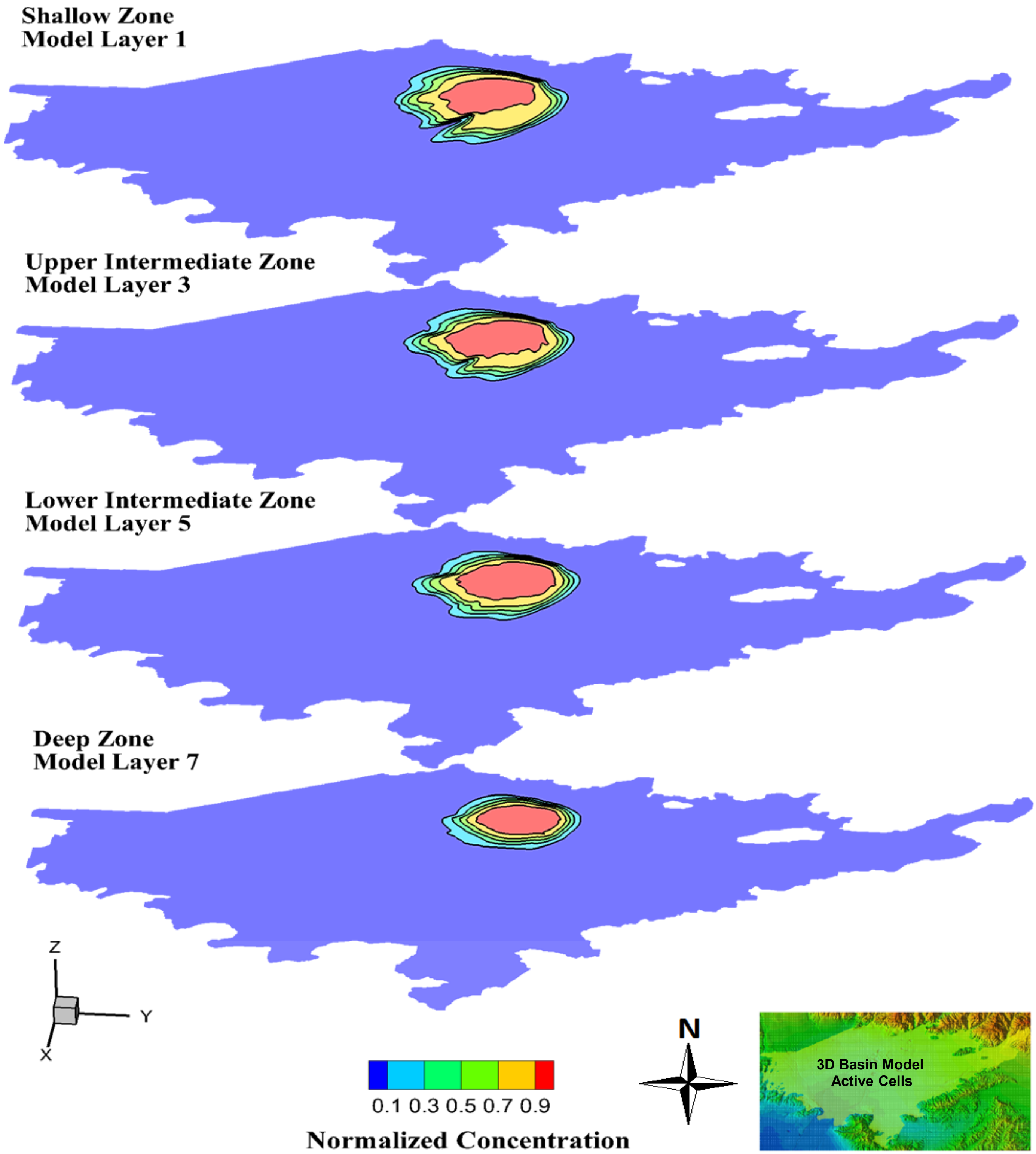
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 5 (Basin Sustainability)
Simulated FY2020-21 Plume Distribitions

MainSanGabrielBasin WATERMASTER



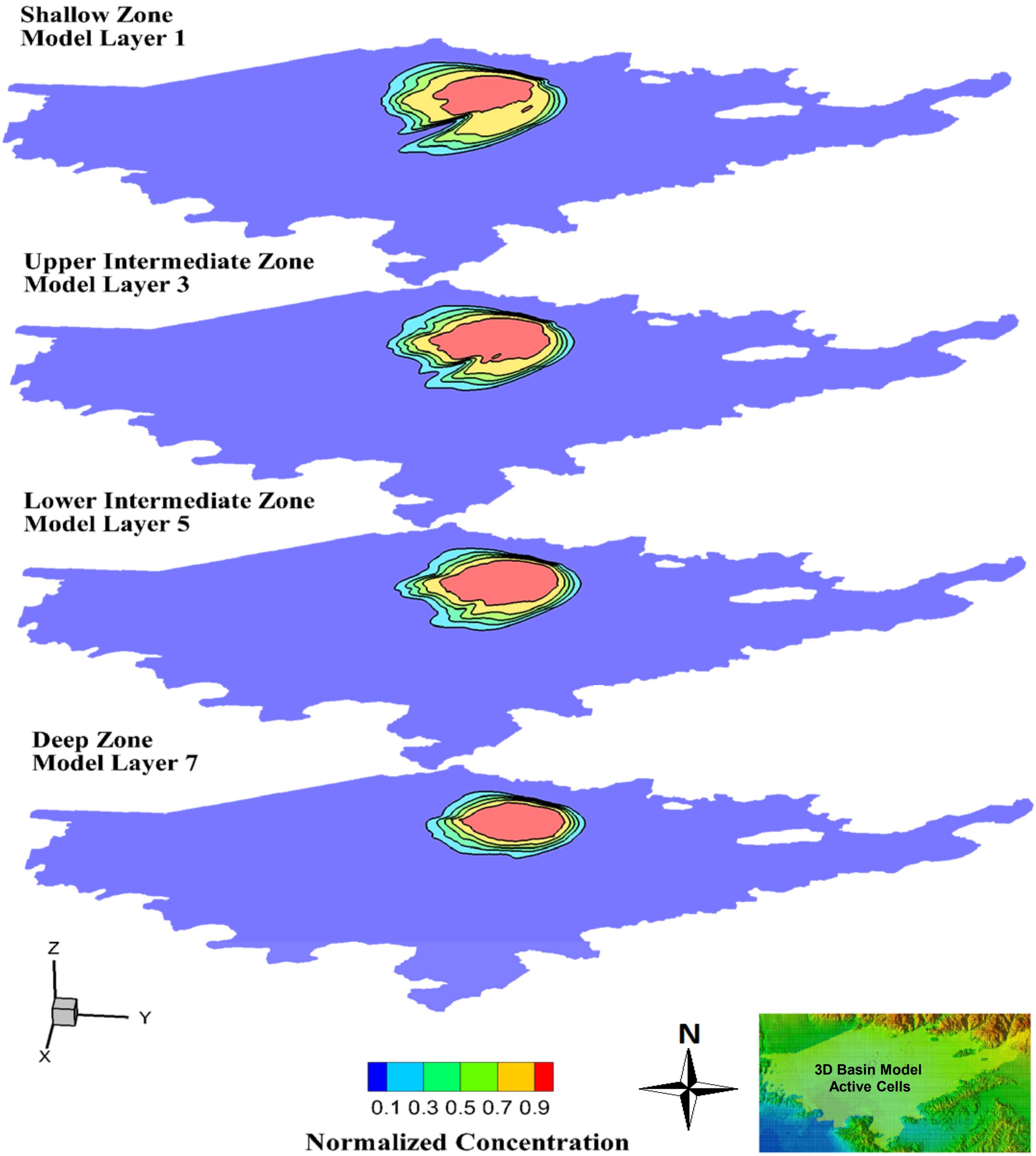
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 5 (Basin Sustainability)
Simulated FY2025-26 Plume Distribitions

STETSON ENGINEERS INC.

MainSanGabrielBasin WATERMASTER

Figure 26d



STETSON ENGINEERS INC.

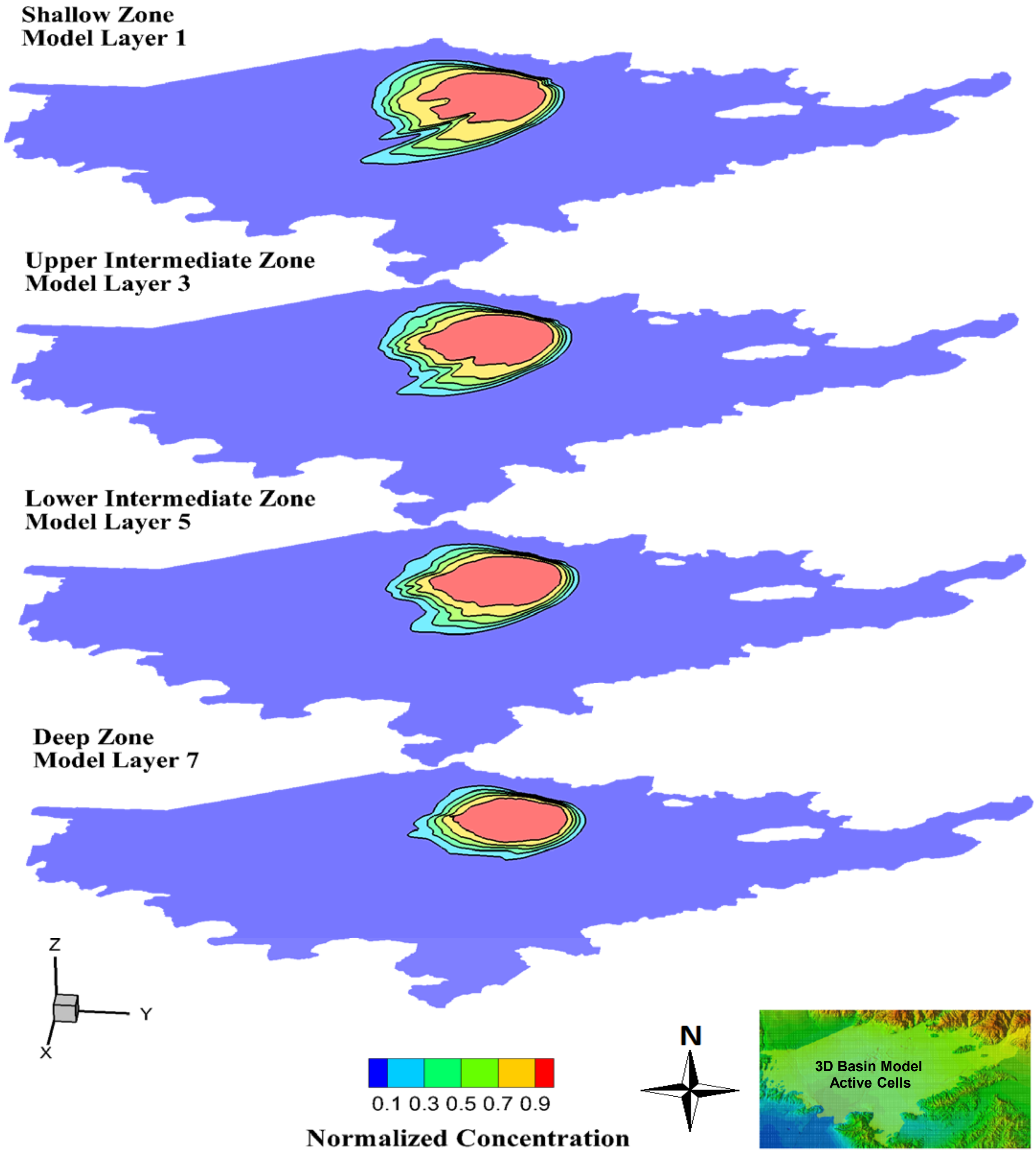
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 5 (Basin Sustainability)
Simulated FY2030-31 Plume Distribitions

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 27 - 3D Basin Model Simulated Plume (63MGD).xlsx

Figure 26e



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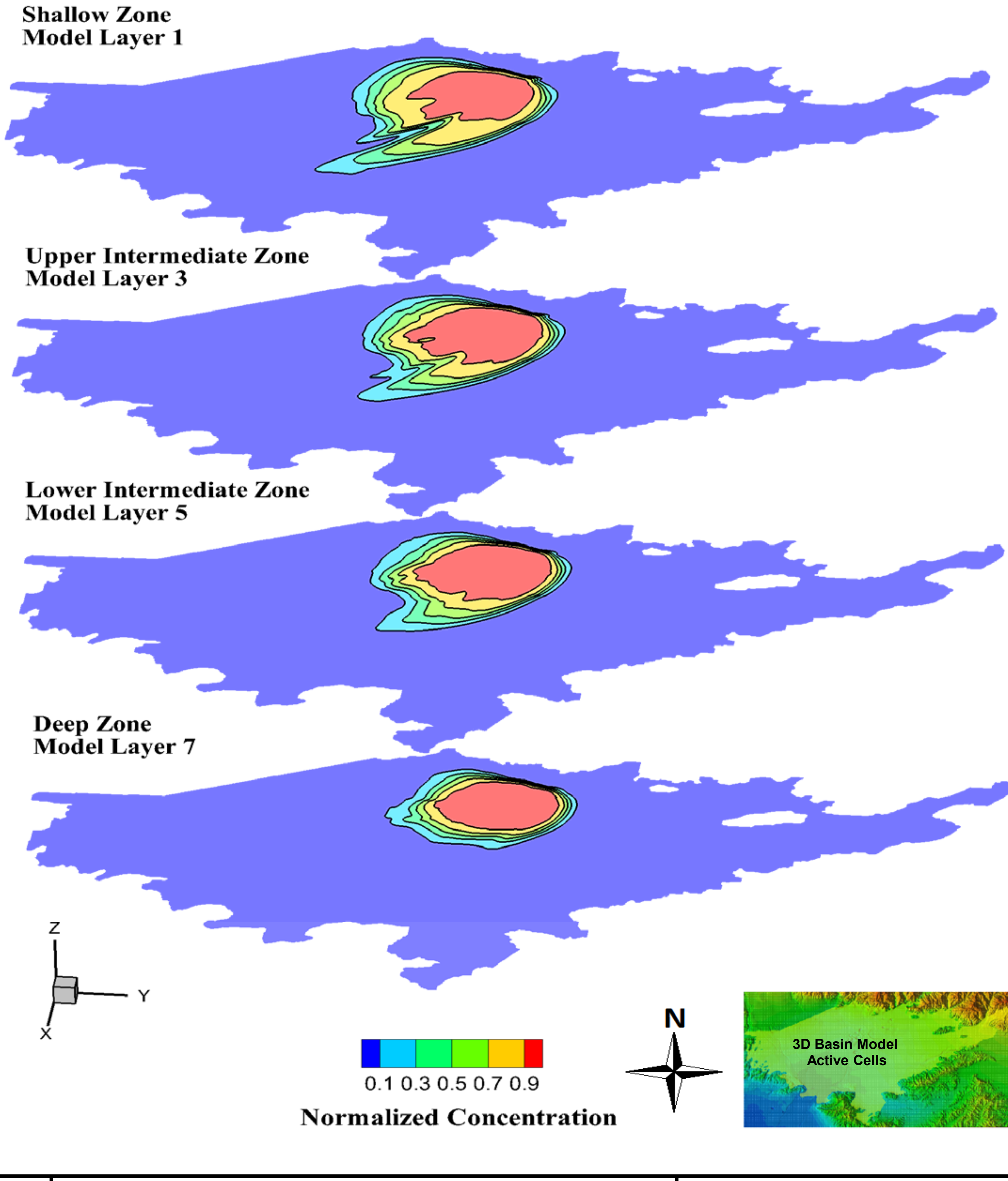
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 5 (Basin Sustainability)
Simulated FY2035-36 Plume Distribitions

MainSanGabrielBasin WATERMASTER



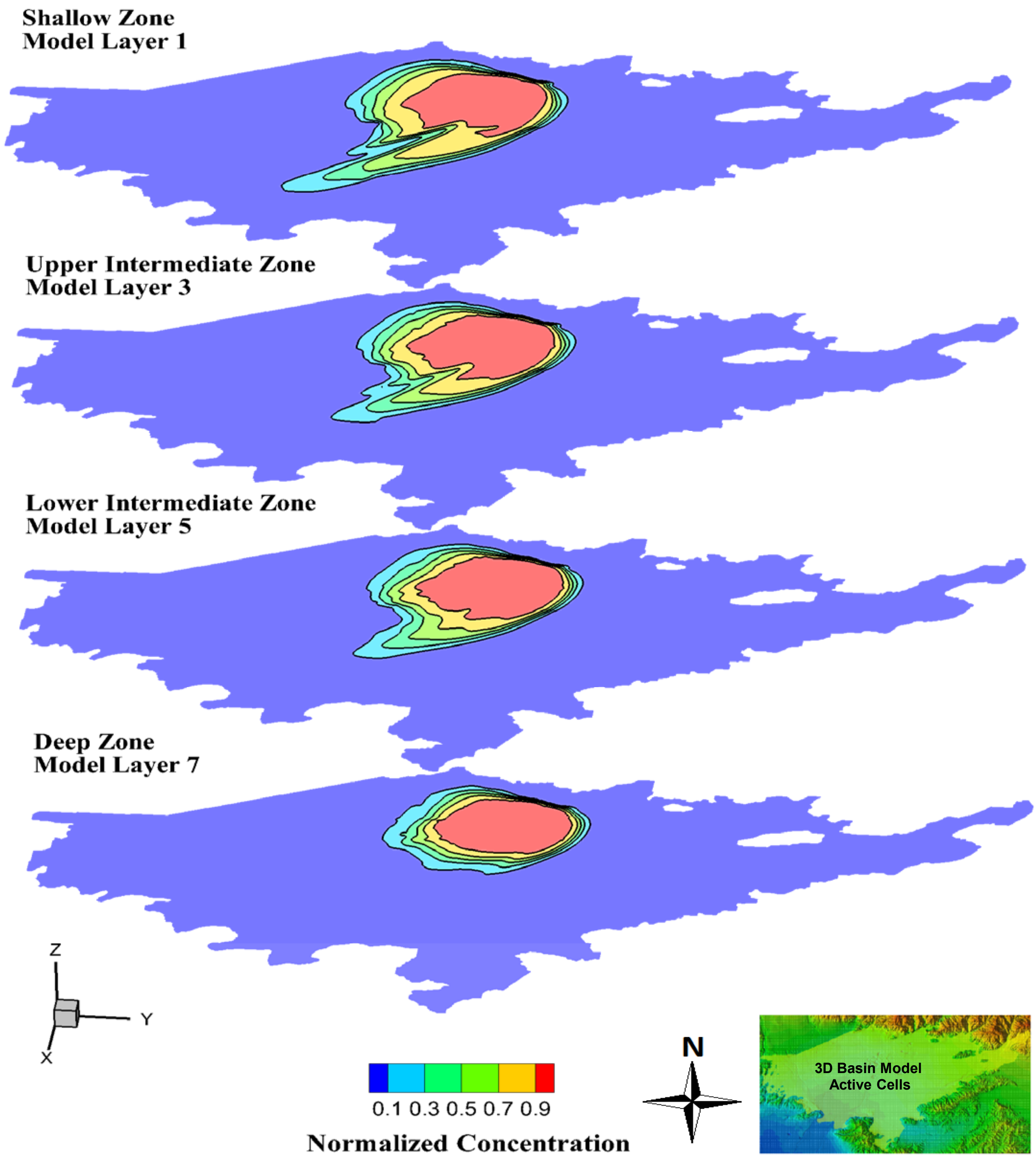
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 5 (Basin Sustainability)
Simulated FY2040-41 Plume Distribitions

STETSON ENGINEERS INC.

MainSanGabrielBasin WATERMASTER

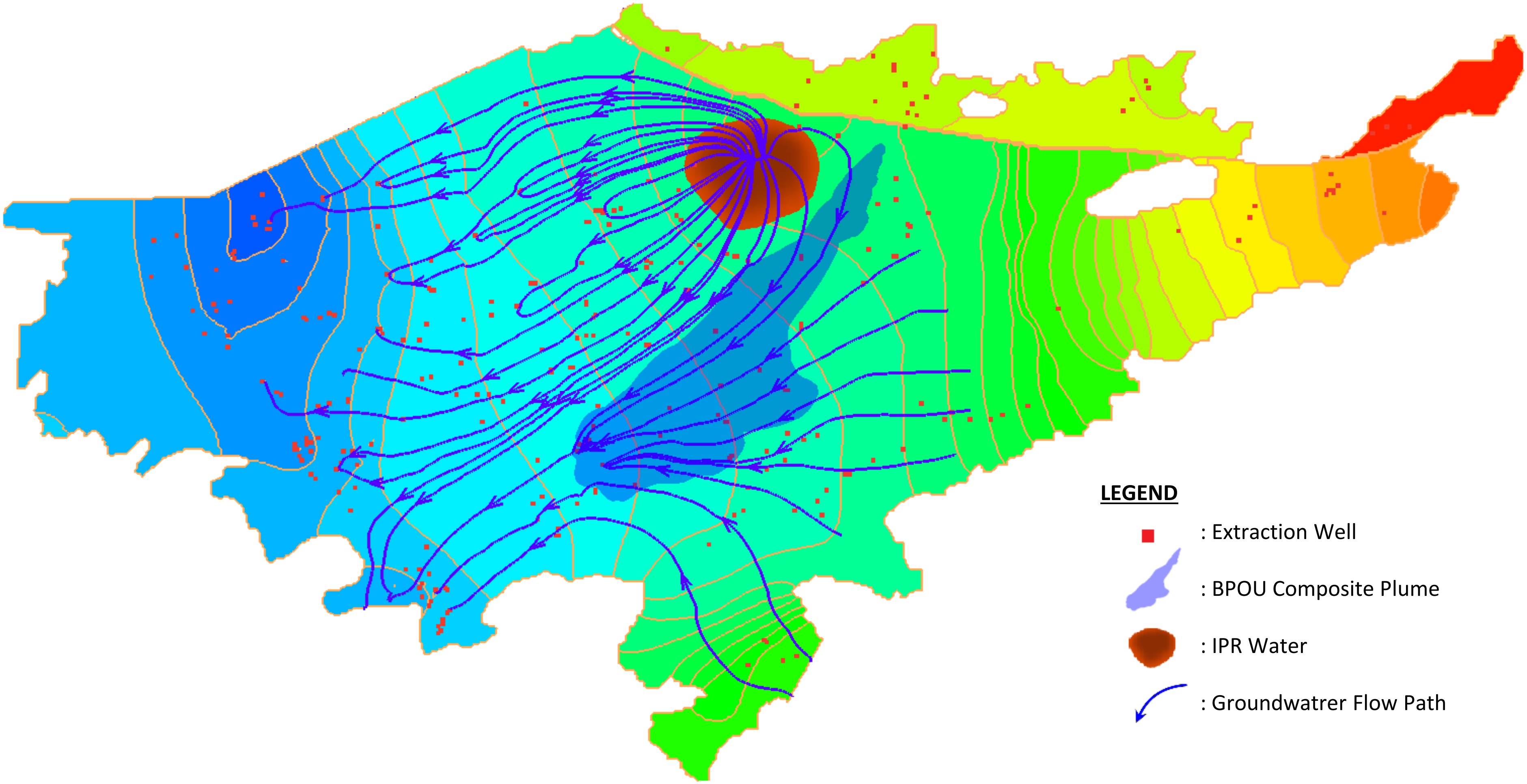
Figure 26g



STETSON ENGINEERS INC.	MAIN SAN GABRIEL BASIN WATERMASTER	MainSanGabrielBasin WATERMASTER
	Solute Transport Simulation Scenario 5 (Basin Sustainability) Simulated FY2046-47 Plume Distribitions	

J:\1205\1205-98\.05.02.6\Figure 27 - 3D Basin Model Simulated Plume (63MGD).xlsx

Model Run II – Basin Sustainability of 62.5 MGD



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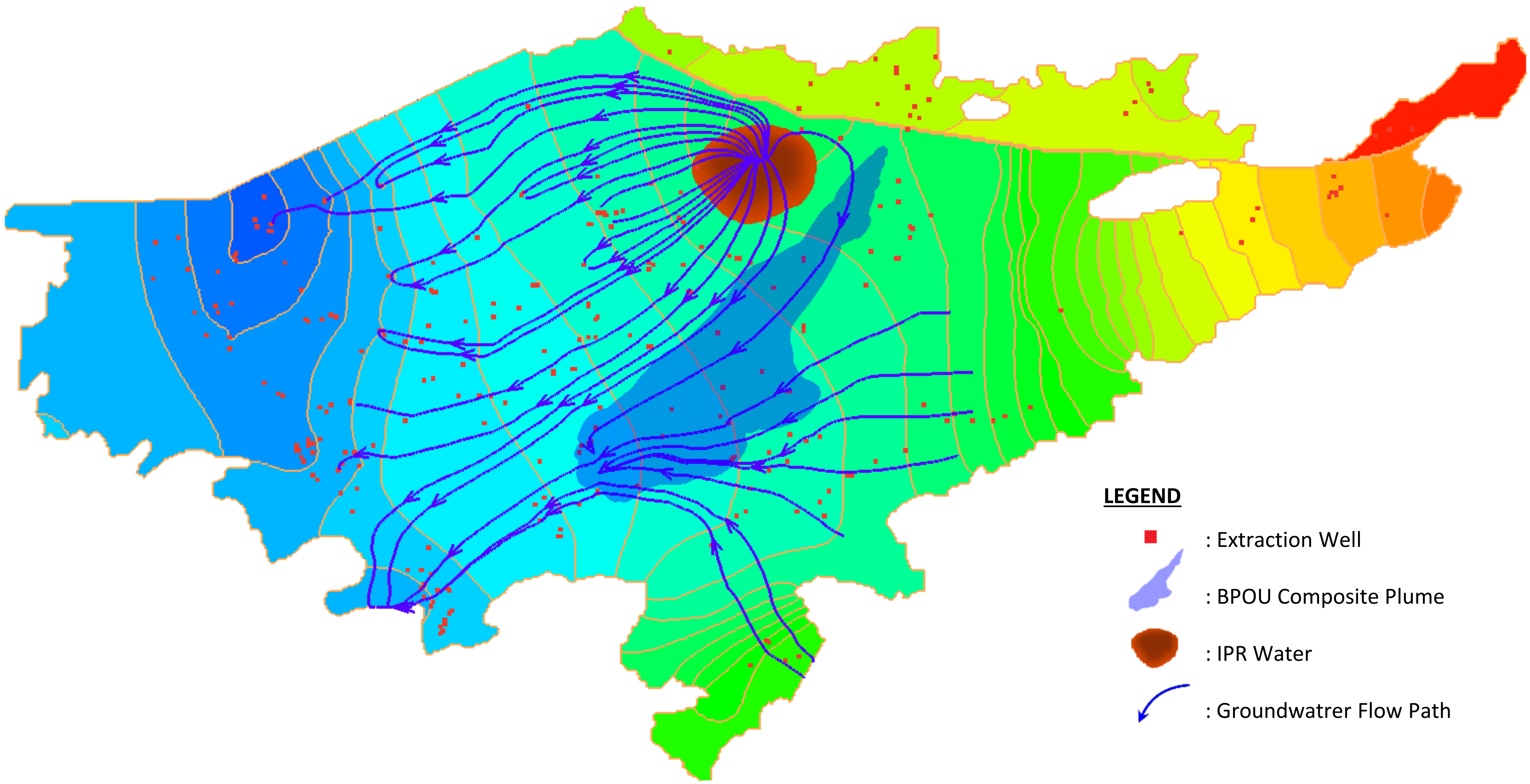
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 1 Fiscal Year 2015-2016
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run II – Basin Sustainability of 62.5 MGD



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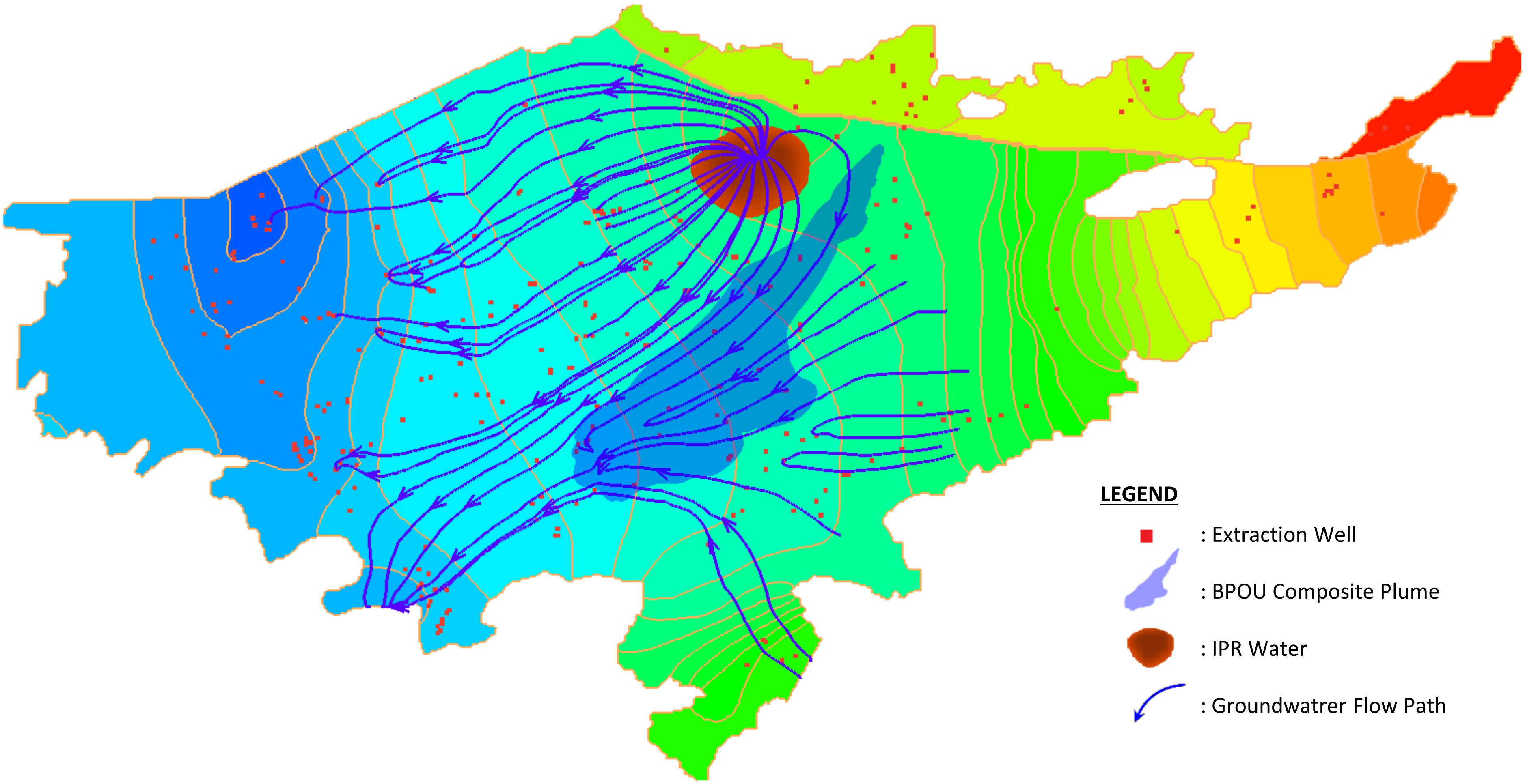
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 3 Fiscal Year 2015-2016
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Figure 27a

Model Run II – Basin Sustainability of 62.5 MGD



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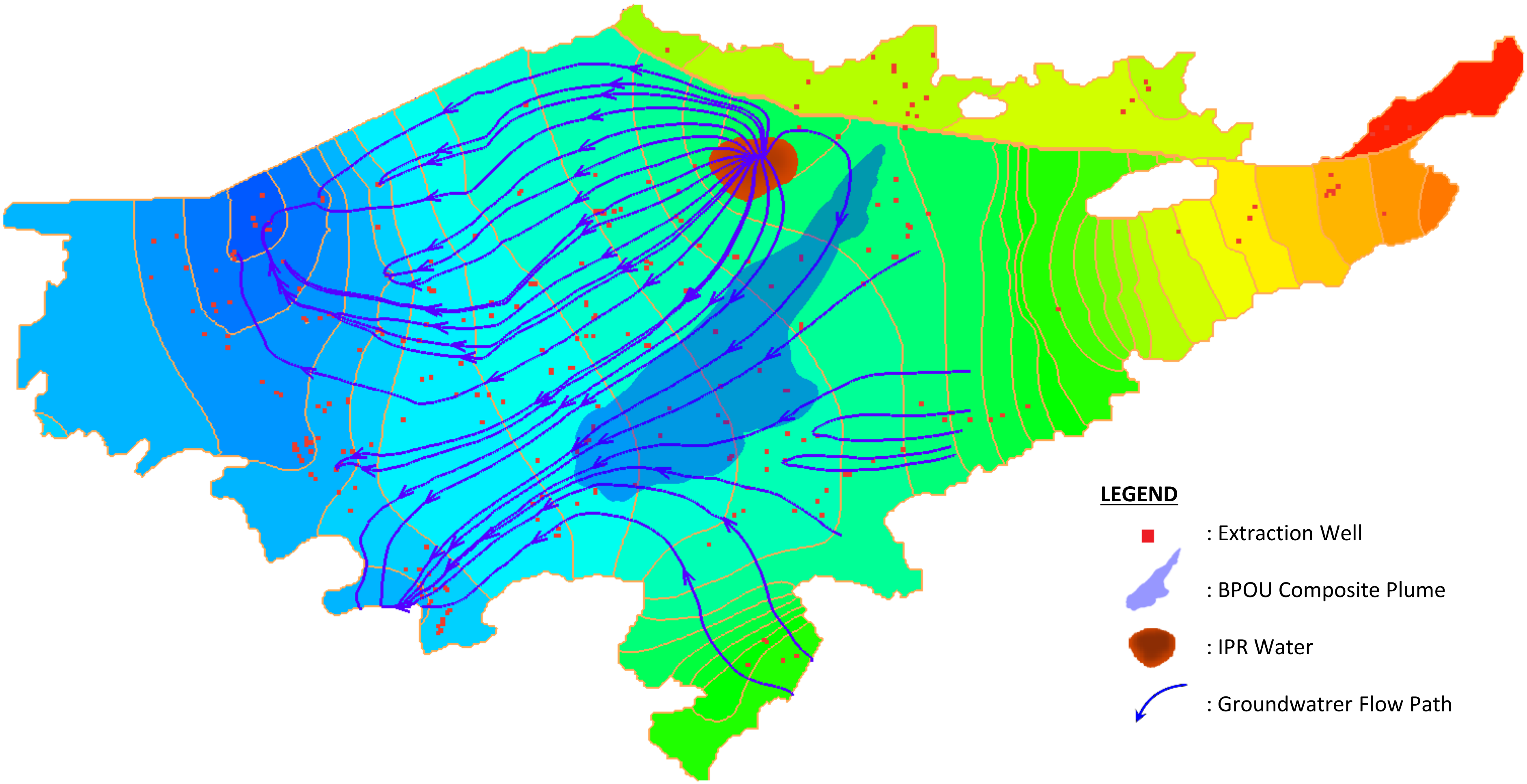
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 5 Fiscal Year 2015-2016
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

J:\1205\1205-98\.05.02.6\Figure 28 - IPR Water Migration (63MGD).xlsx

Model Run II – Basin Sustainability of 62.5 MGD



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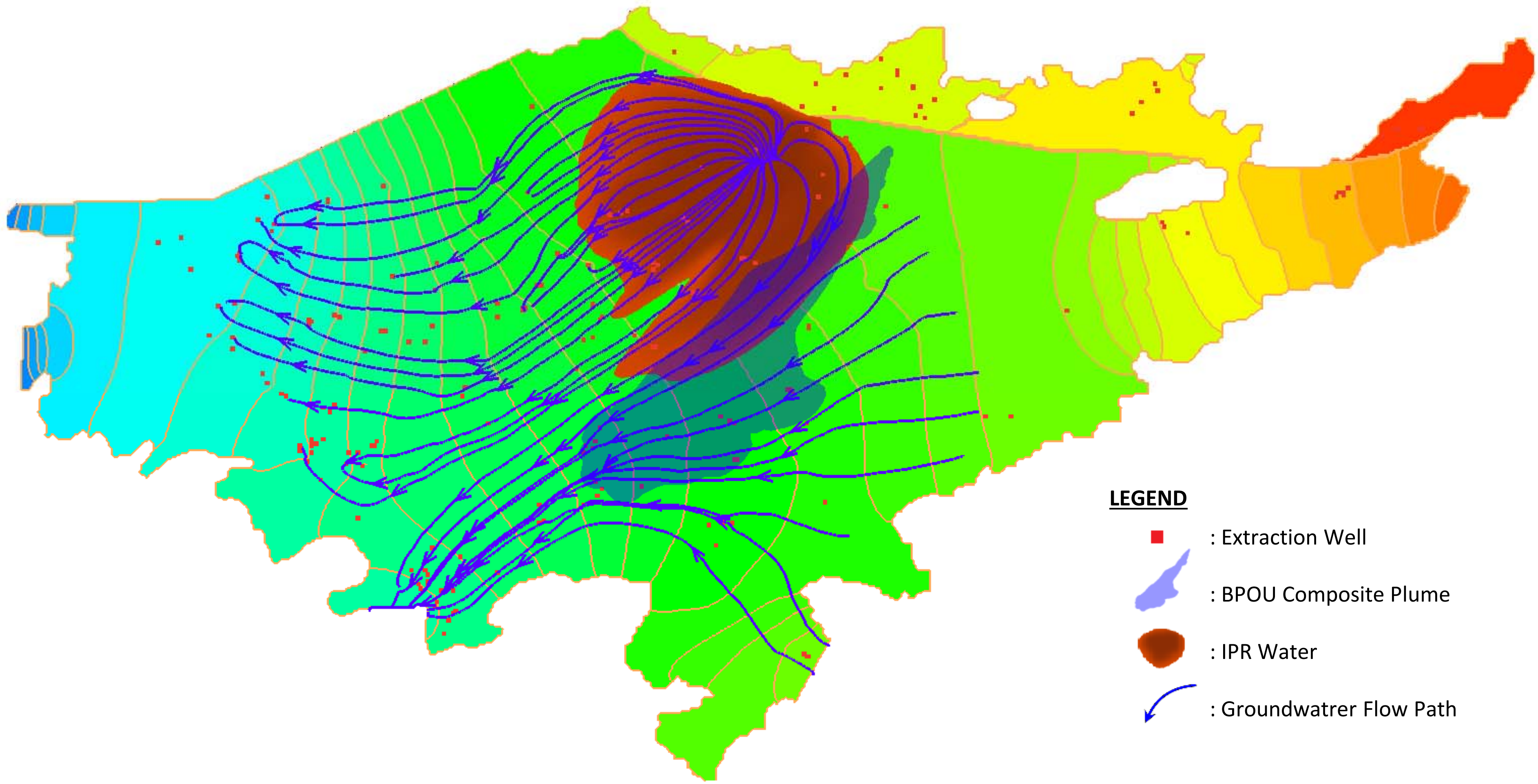
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 7 Fiscal Year 2015-2016
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run II – Basin Sustainability of 62.5 MGD



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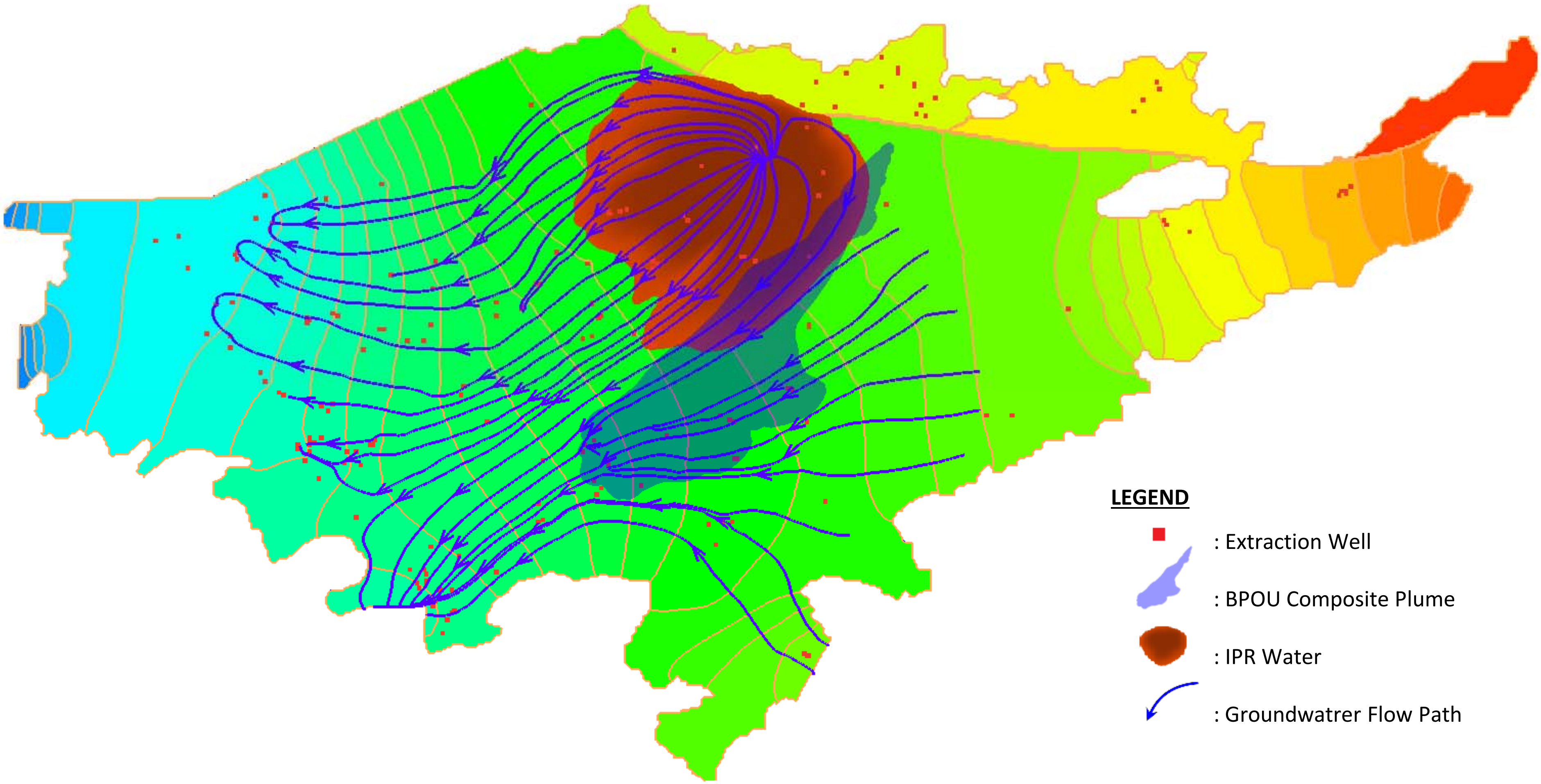
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 1 Fiscal Year 2030-2031
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run II – Basin Sustainability of 62.5 MGD



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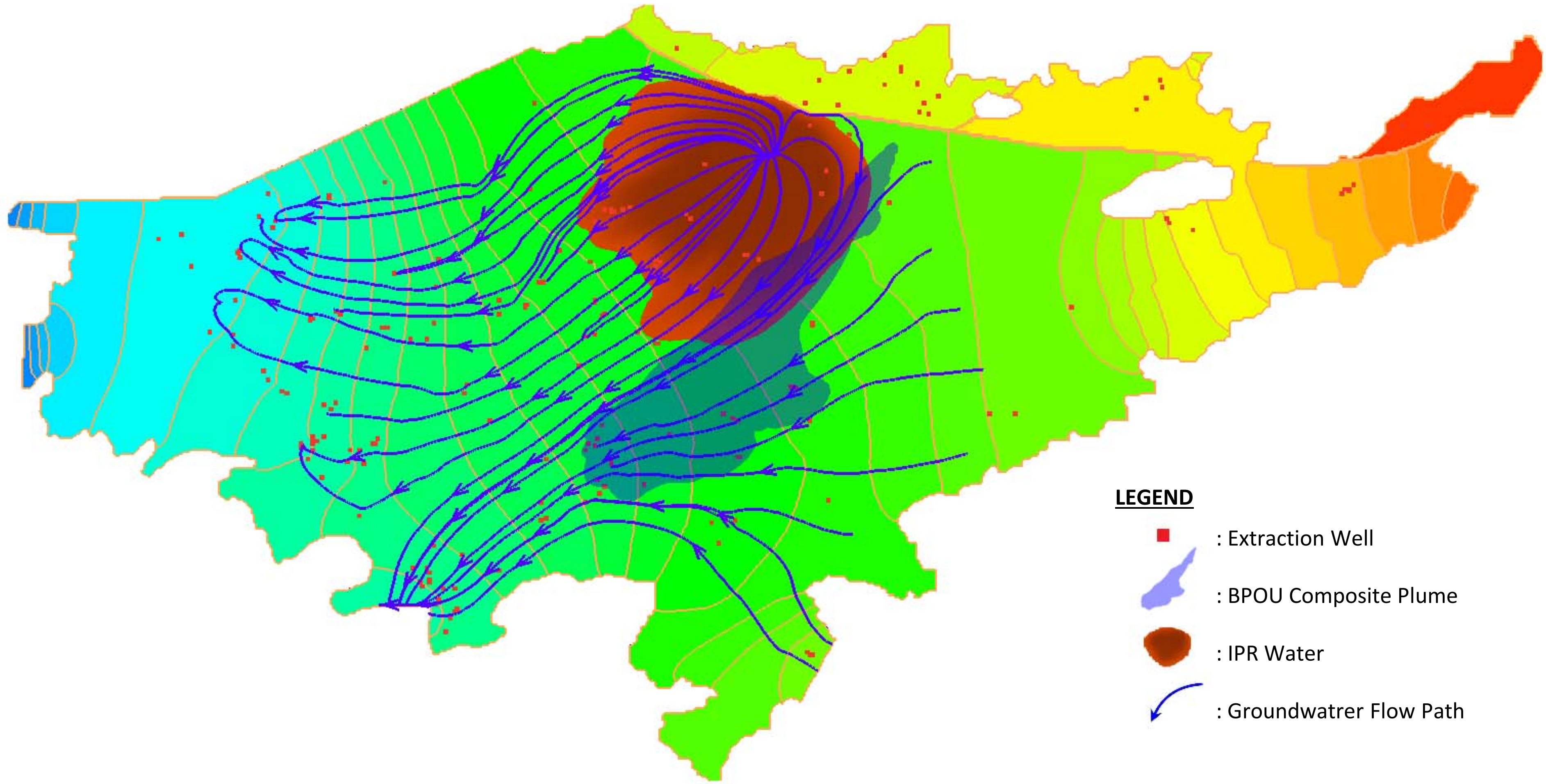
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 3 Fiscal Year 2030-2031
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run II – Basin Sustainability of 62.5 MGD



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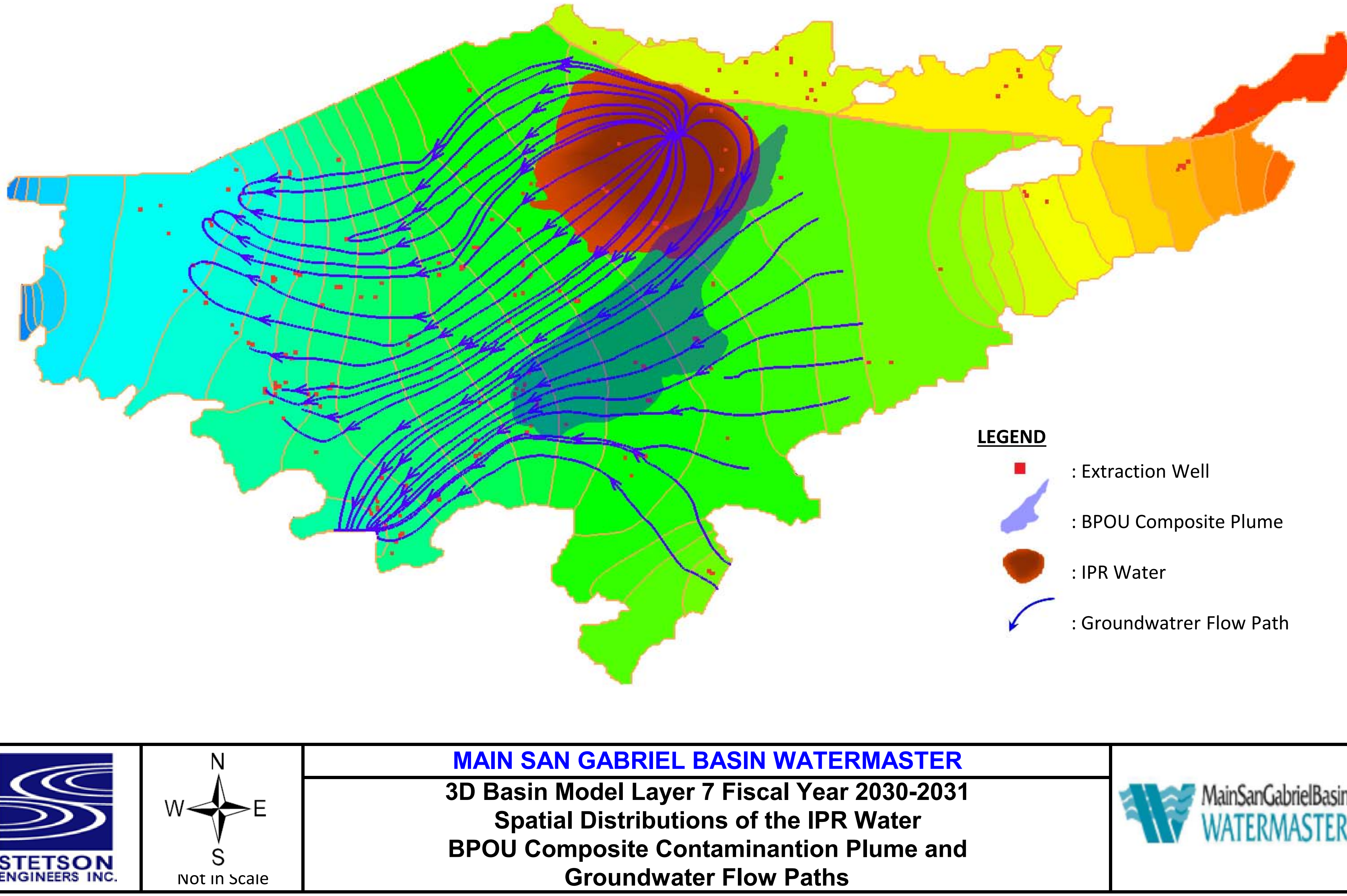
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 5 Fiscal Year 2030-2031
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run II – Basin Sustainability of 62.5 MGD



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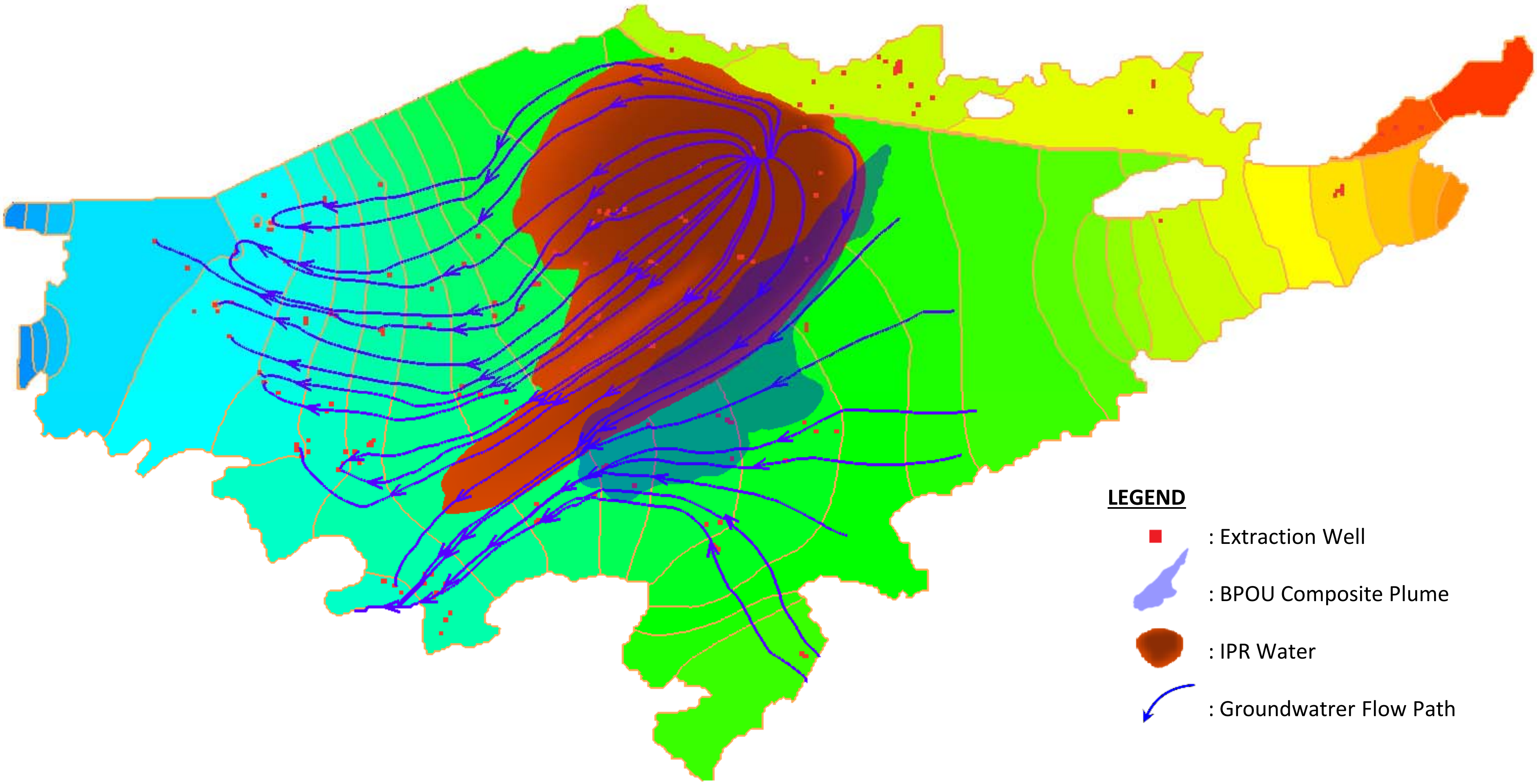
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 7 Fiscal Year 2030-2031
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run II – Basin Sustainability of 62.5 MGD



STETSON ENGINEERS INC.

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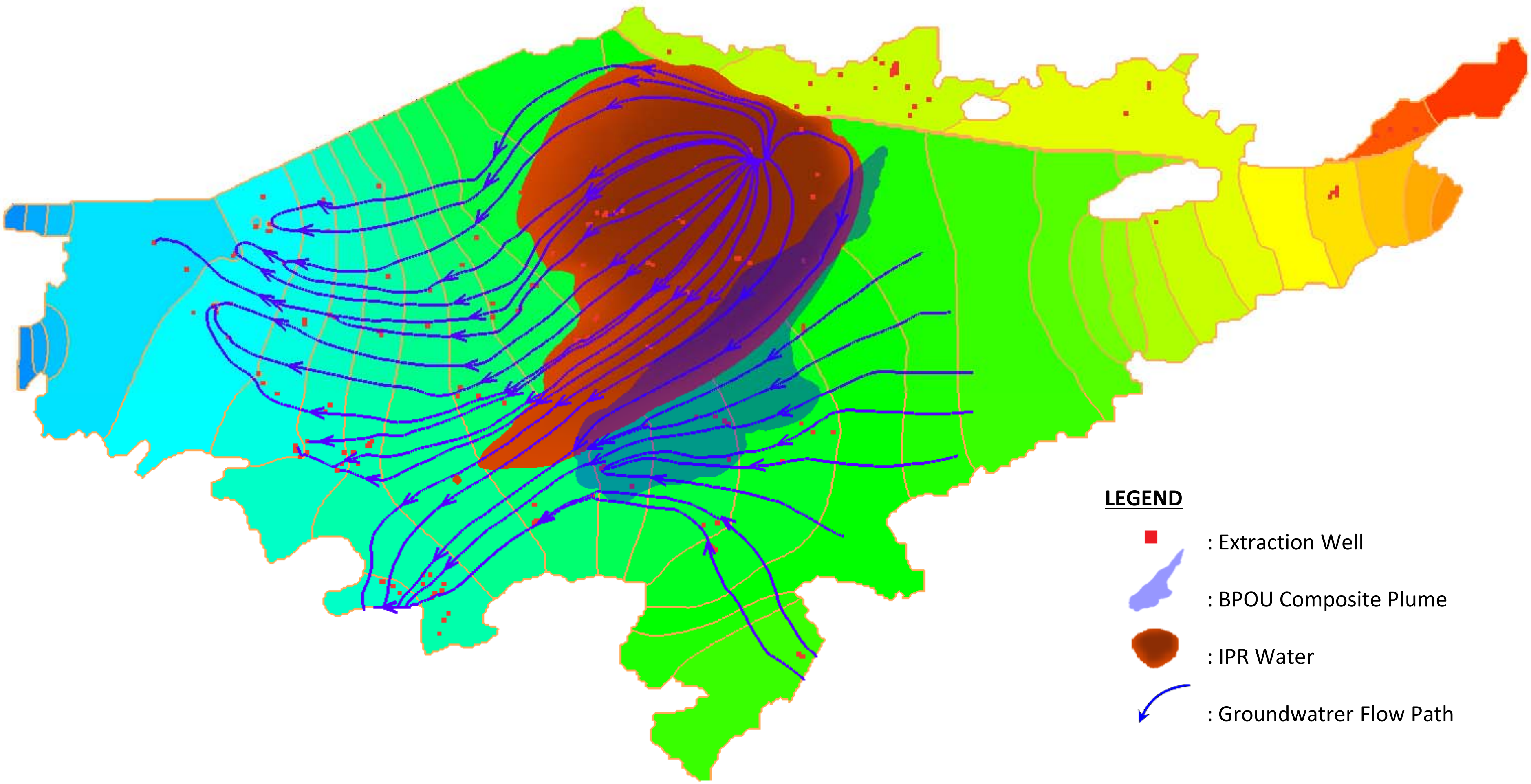
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 1 Fiscal Year 2046-2047
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run II – Basin Sustainability of 62.5 MGD



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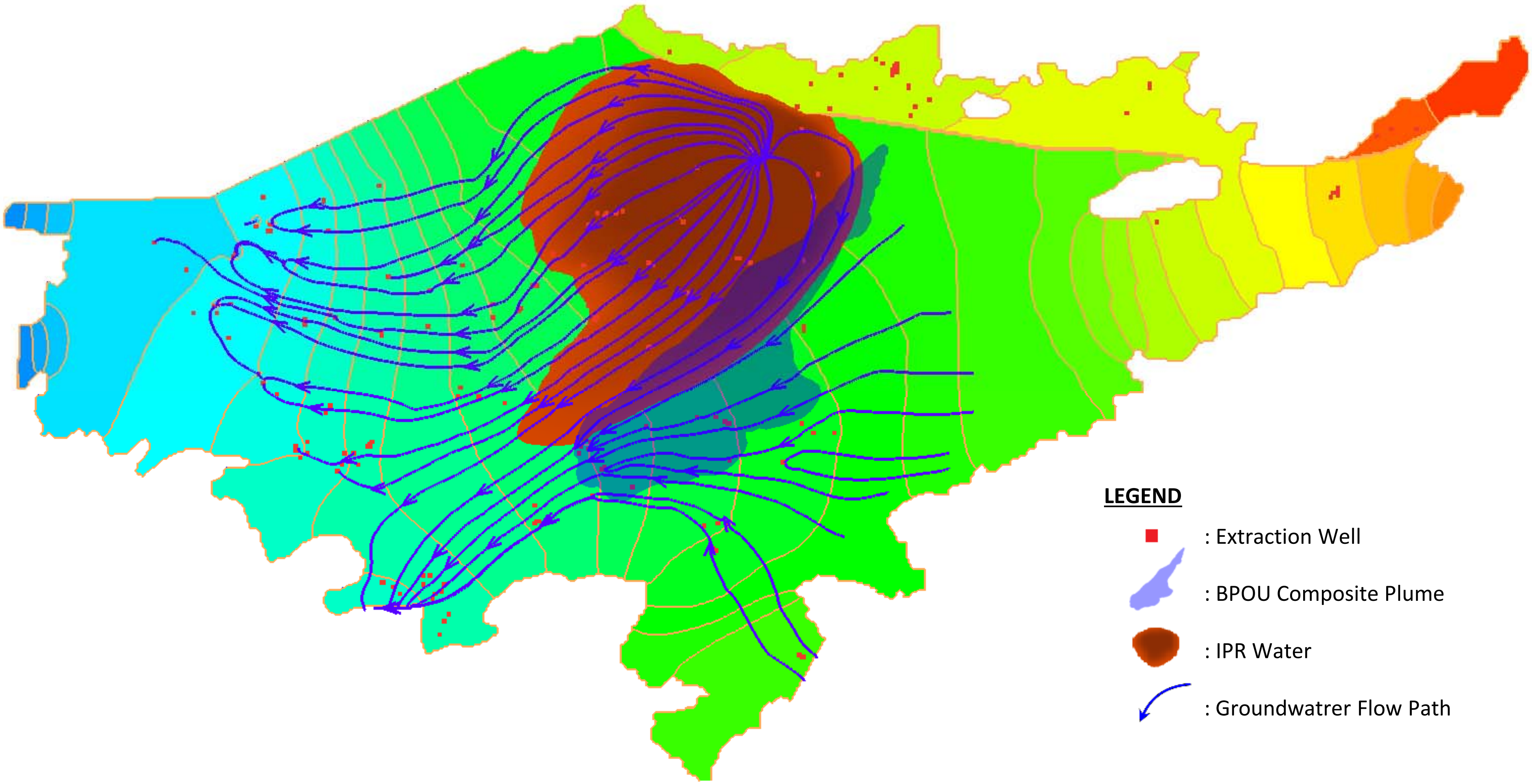
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 3 Fiscal Year 2046-2047 Spatial Distributions of the IPR Water BPOU Composite Contaminantion Plume and Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run II – Basin Sustainability of 62.5 MGD



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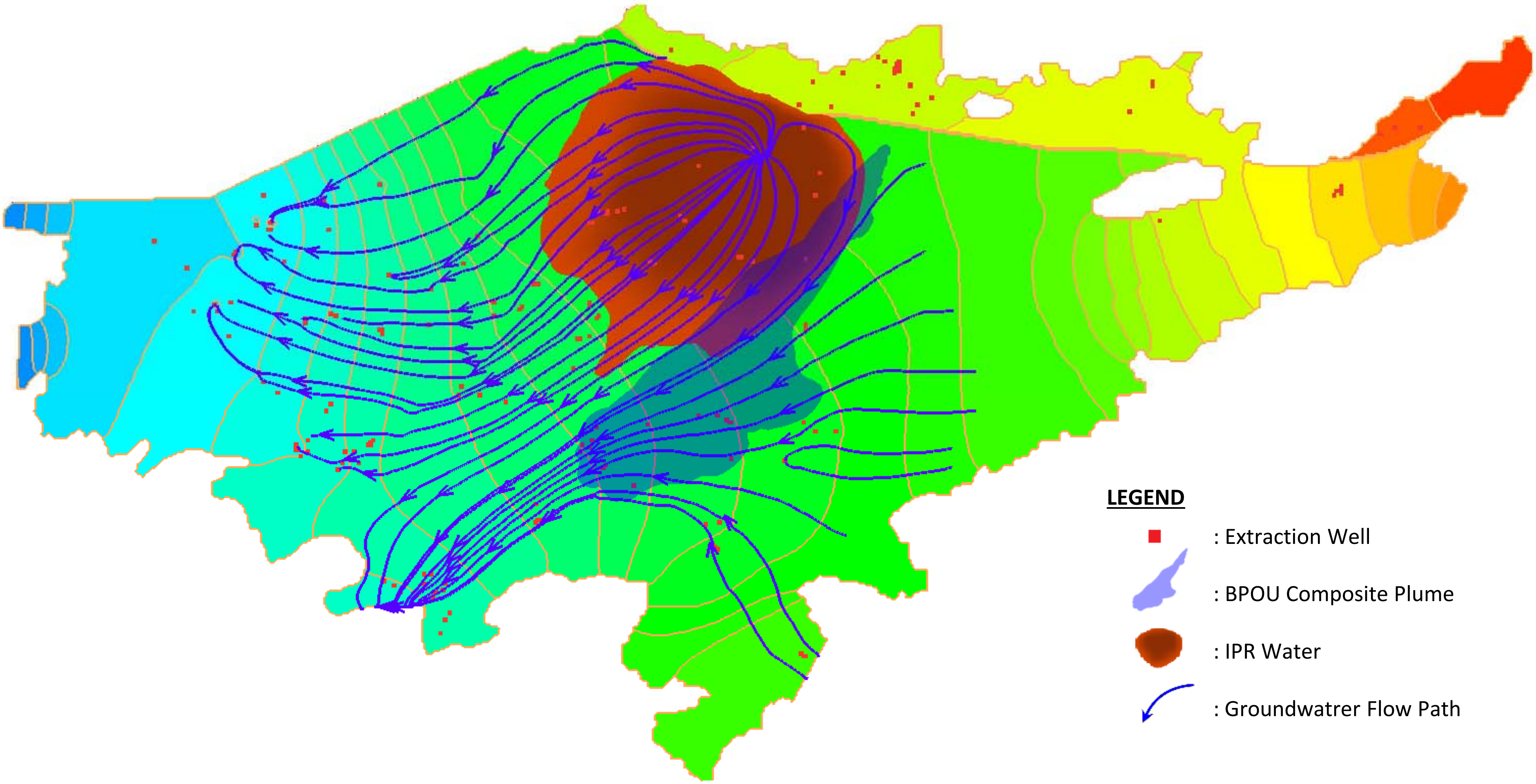
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 5 Fiscal Year 2046-2047
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run II – Basin Sustainability of 62.5 MGD



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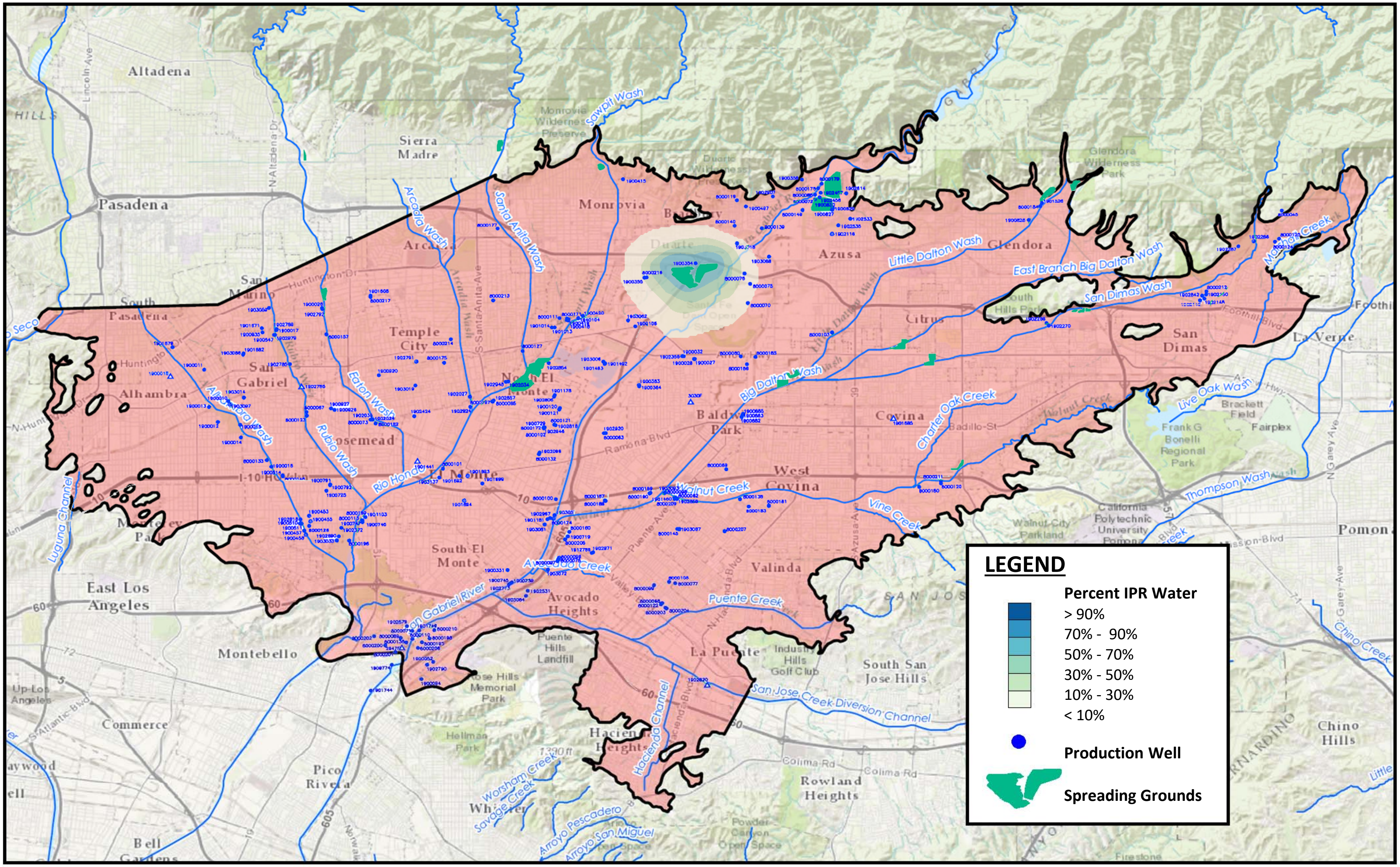
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 7 Fiscal Year 2046-2047
Spatial Distributions of the IPR Water
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER



STETSON ENGINEERS INC.

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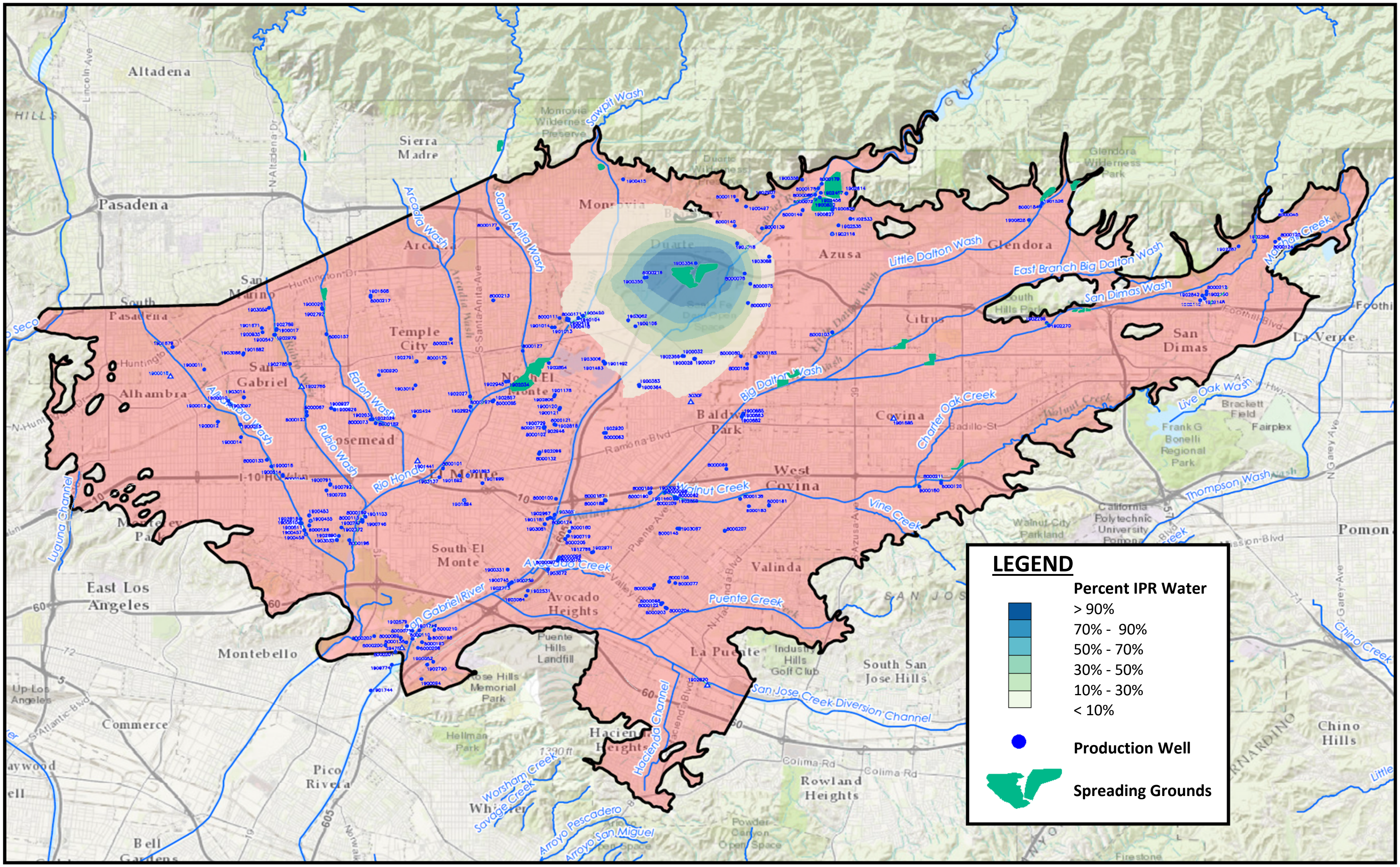
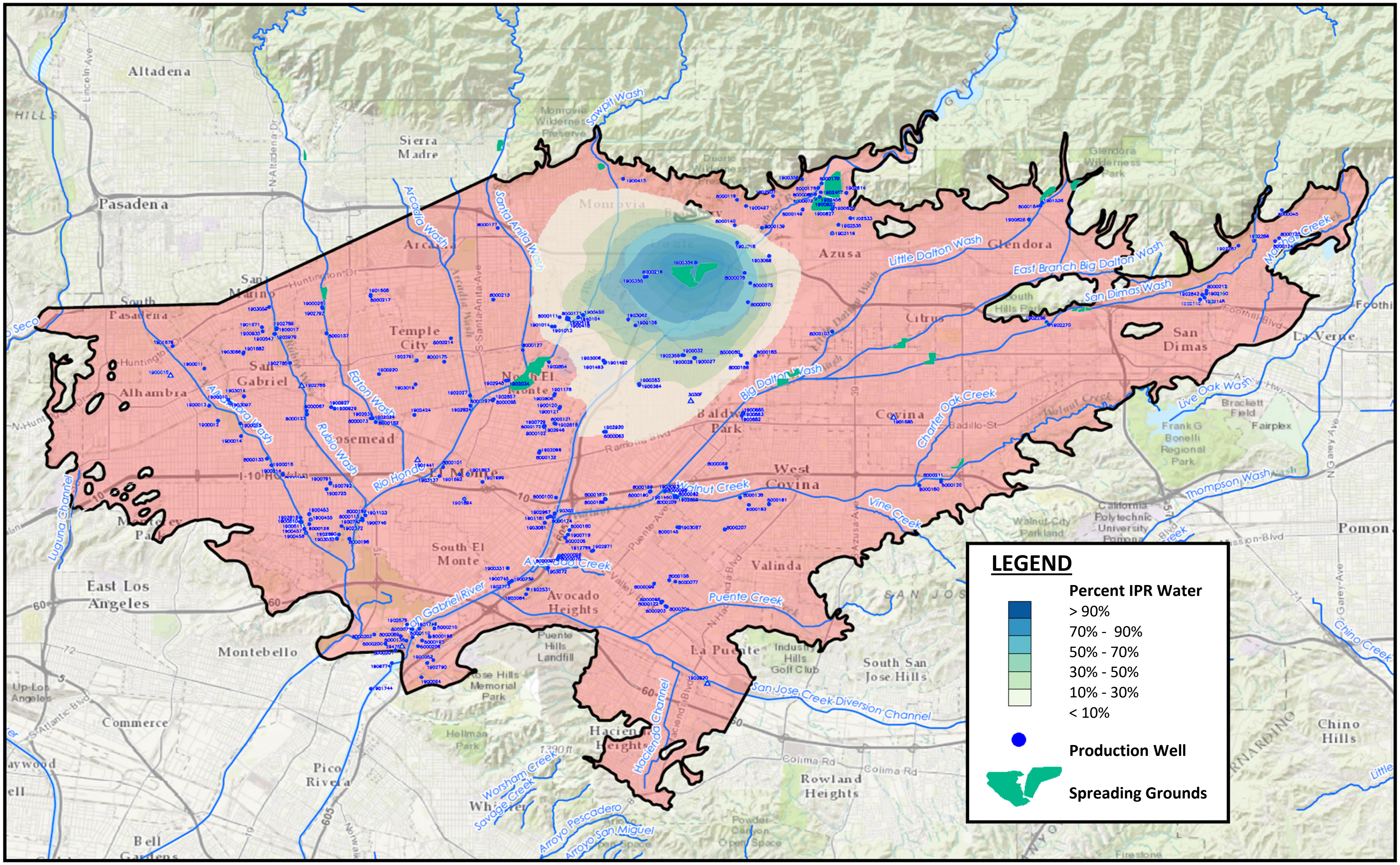
MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 62.5 MGD (Scenario 5)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2015-16

MainSanGabrielBasin WATERMASTER



STETSON ENGINEERS INC.	N W E S Not in Scale	**MAIN SAN GABRIEL BASIN WATERMASTER** **Baseline Delivery of 62.5 MGD (Scenario 5)** **Model Simulated Percent IPR Water Spatial Distribution** **and Impacted Wells in Fiscal Year 2020-21**	MainSanGabrielBasin WATERMASTER



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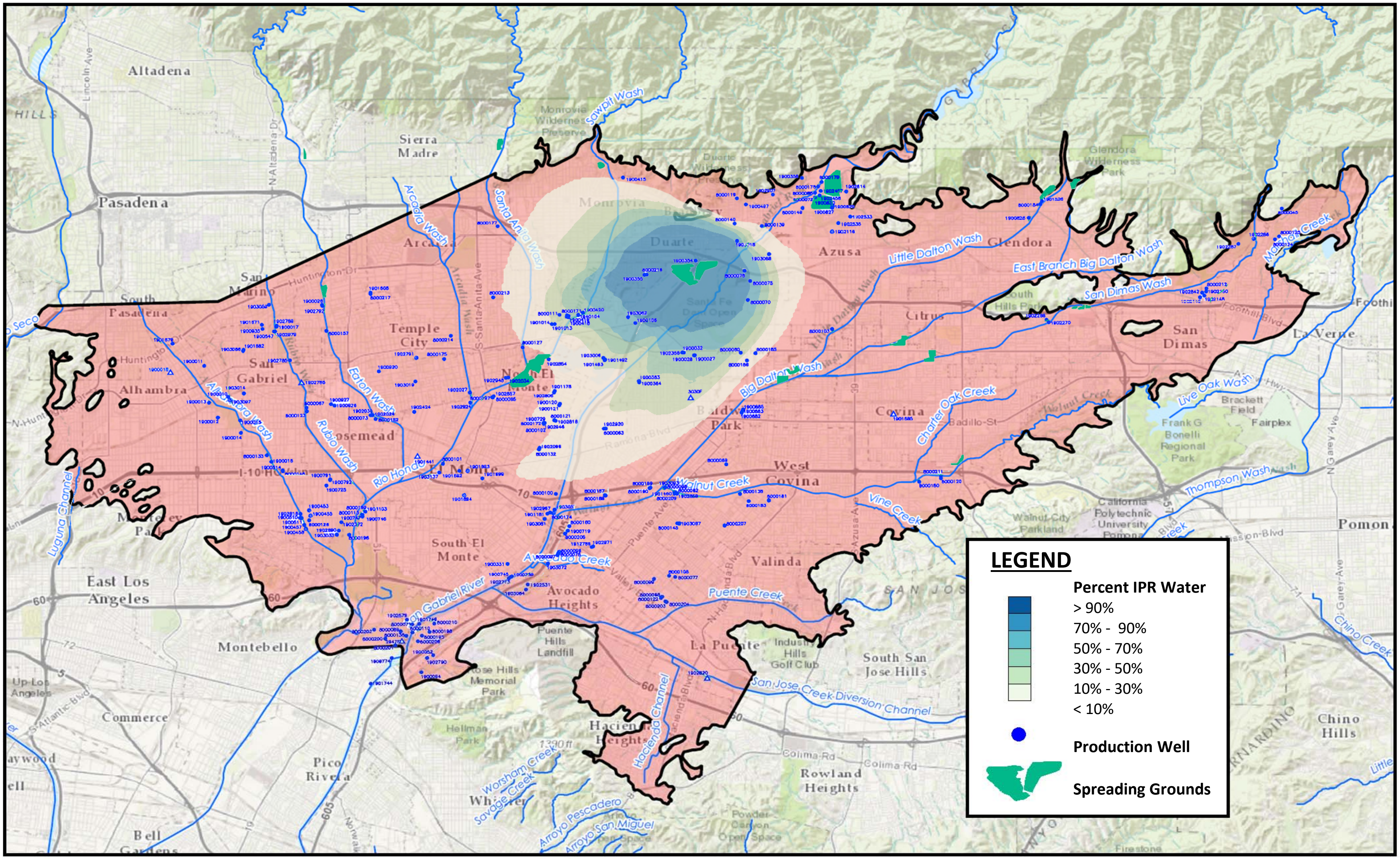
MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 62.5 MGD (Scenario 5)
Model Simulated Percent IPR Water Spatial Distribution
and Impacted Wells in Fiscal Year 2025-26

MainSanGabrielBasin WATERMASTER



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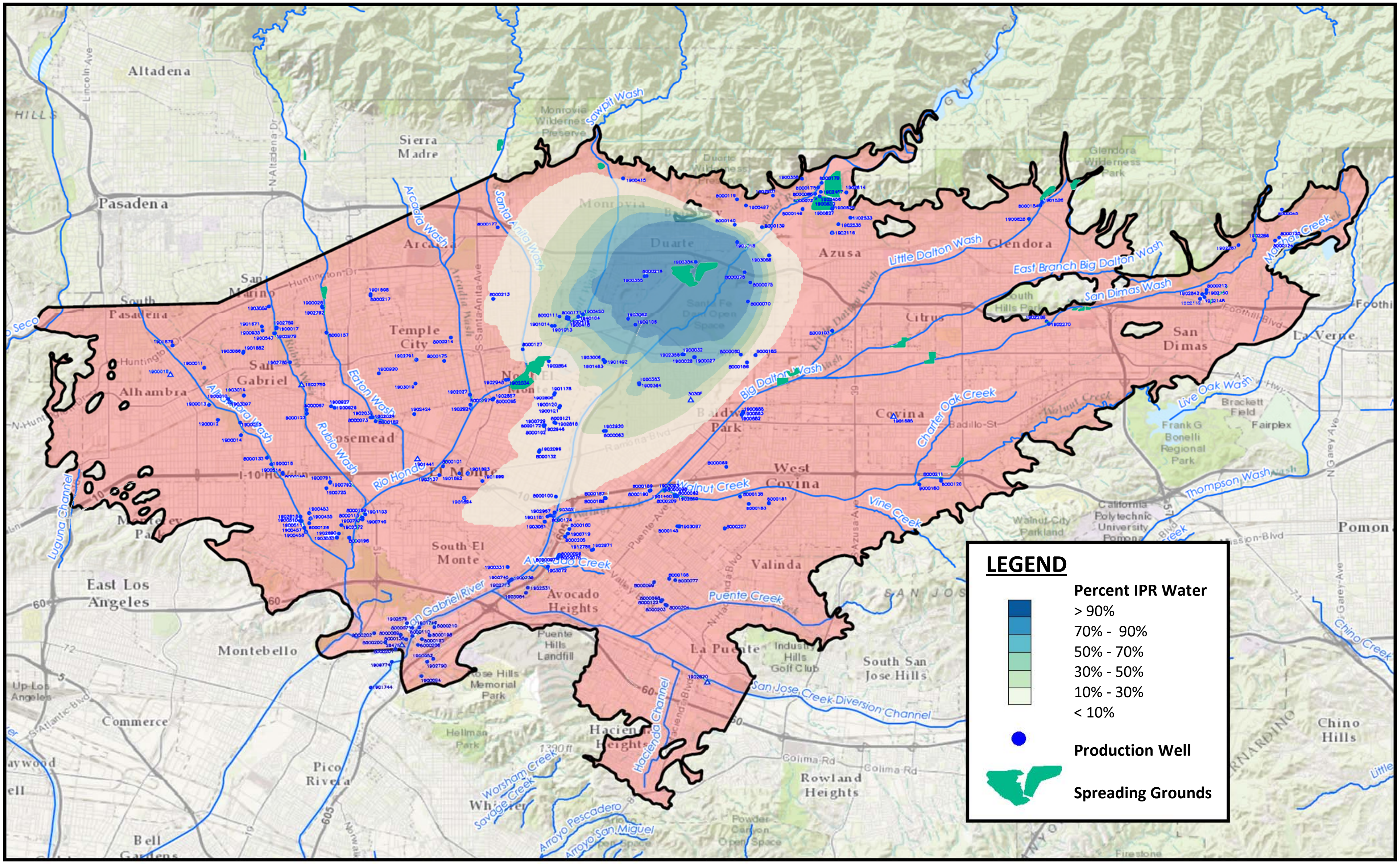
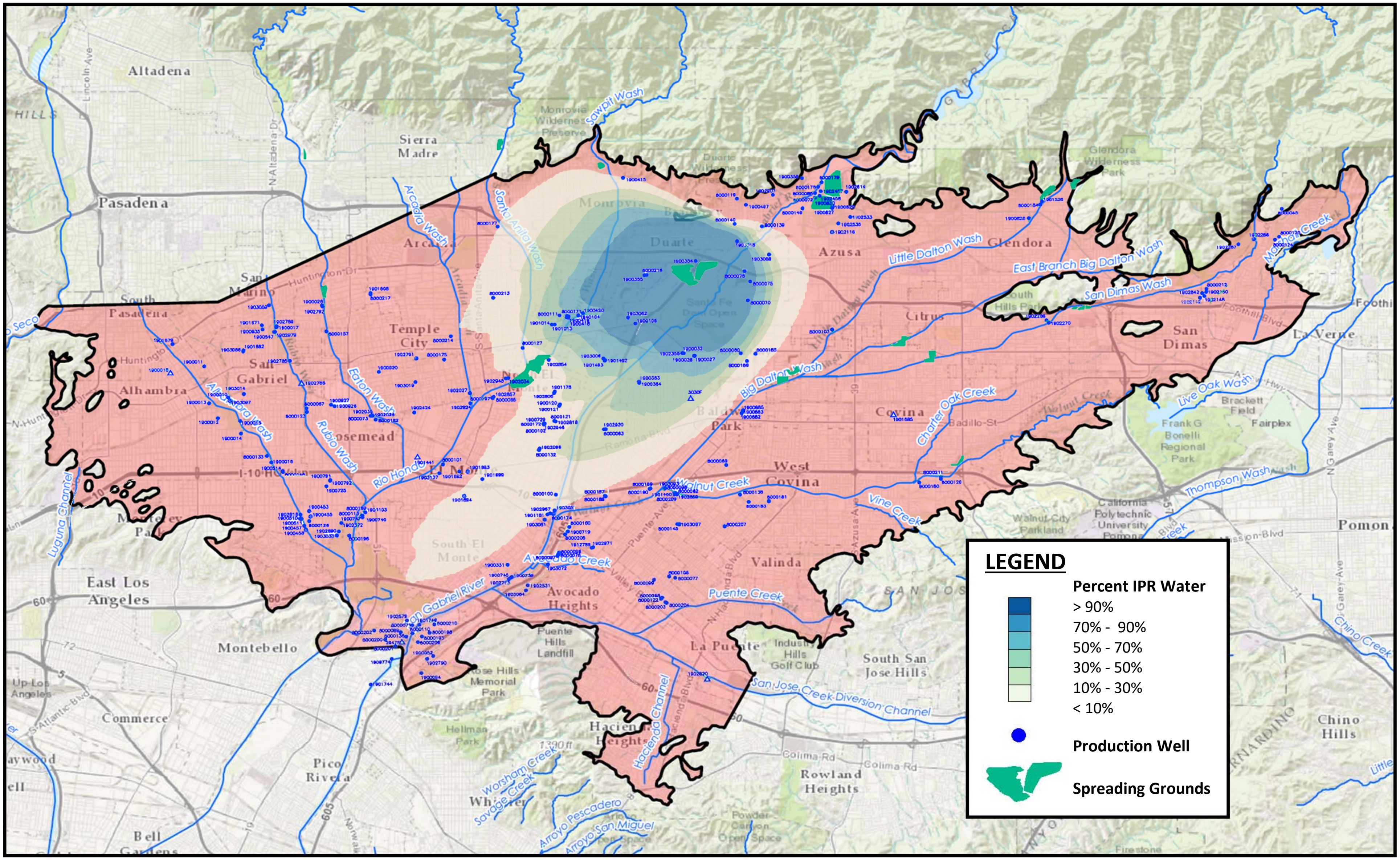
MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 62.5 MGD (Scenario 5)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2030-31

MainSanGabrielBasin WATERMASTER

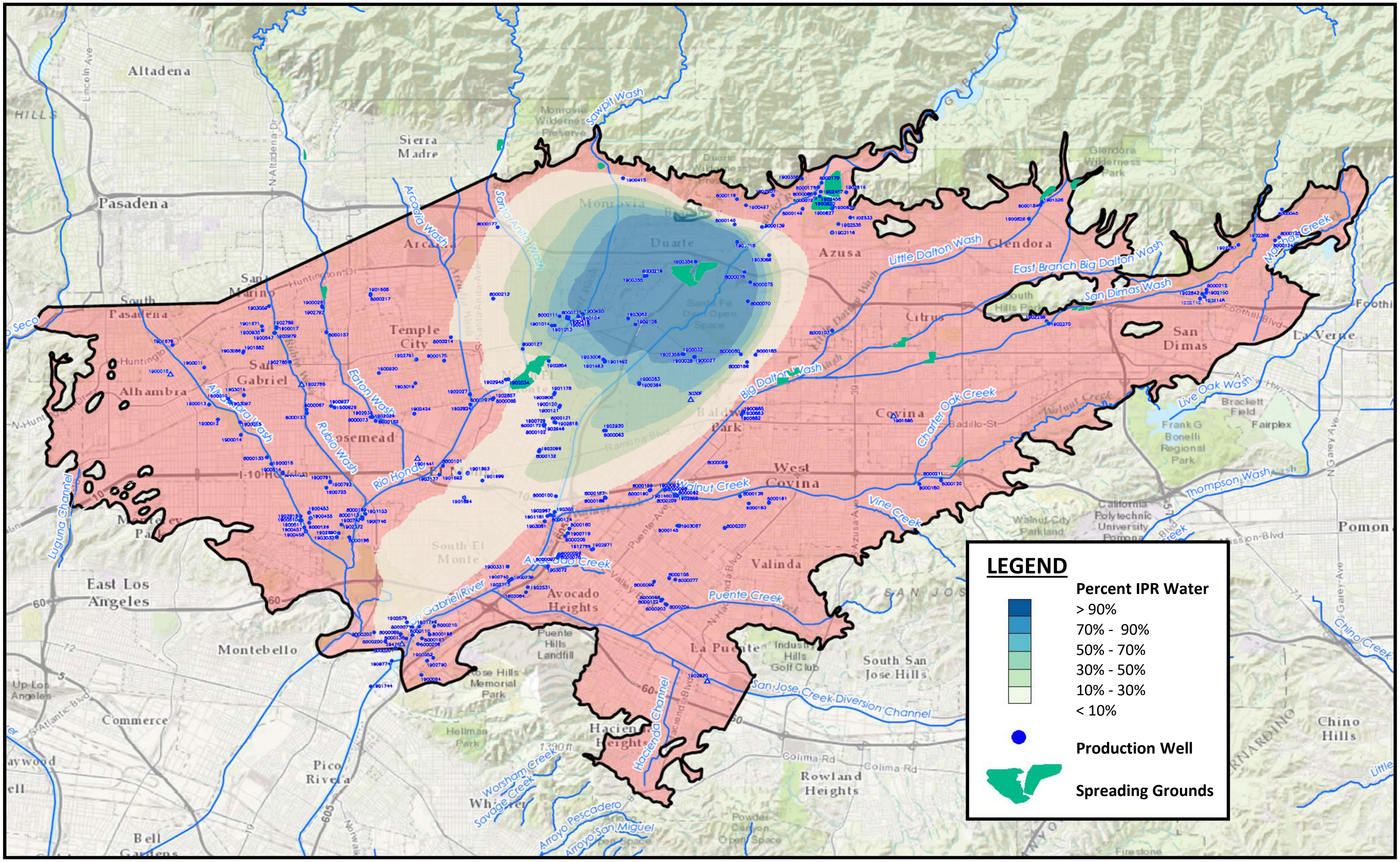


STETSON ENGINEERS INC.	N W E S Not in Scale	**MAIN SAN GABRIEL BASIN WATERMASTER** **Baseline Delivery of 62.5 MGD (Scenario 5)** **Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2035-36**	MainSanGabrielBasin WATERMASTER



STETSON ENGINEERS INC.	N W E S Not in Scale	**MAIN SAN GABRIEL BASIN WATERMASTER** Baseline Delivery of 62.5 MGD (Scenario 5) Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2040-41

MainSanGabrielBasin WATERMASTER



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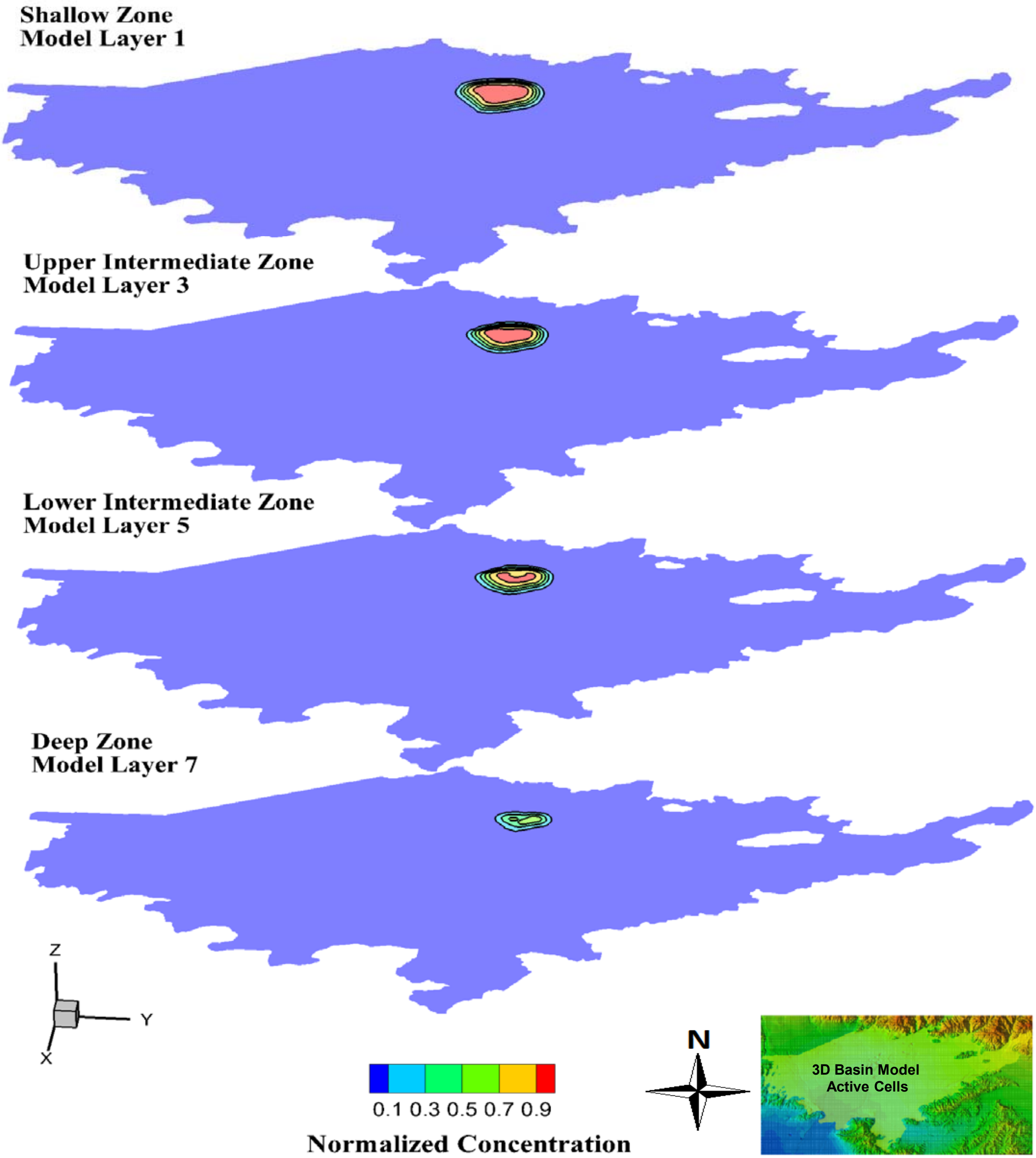
MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 62.5 MGD (Scenario 5)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2046-47

MainSanGabrielBasin WATERMASTER



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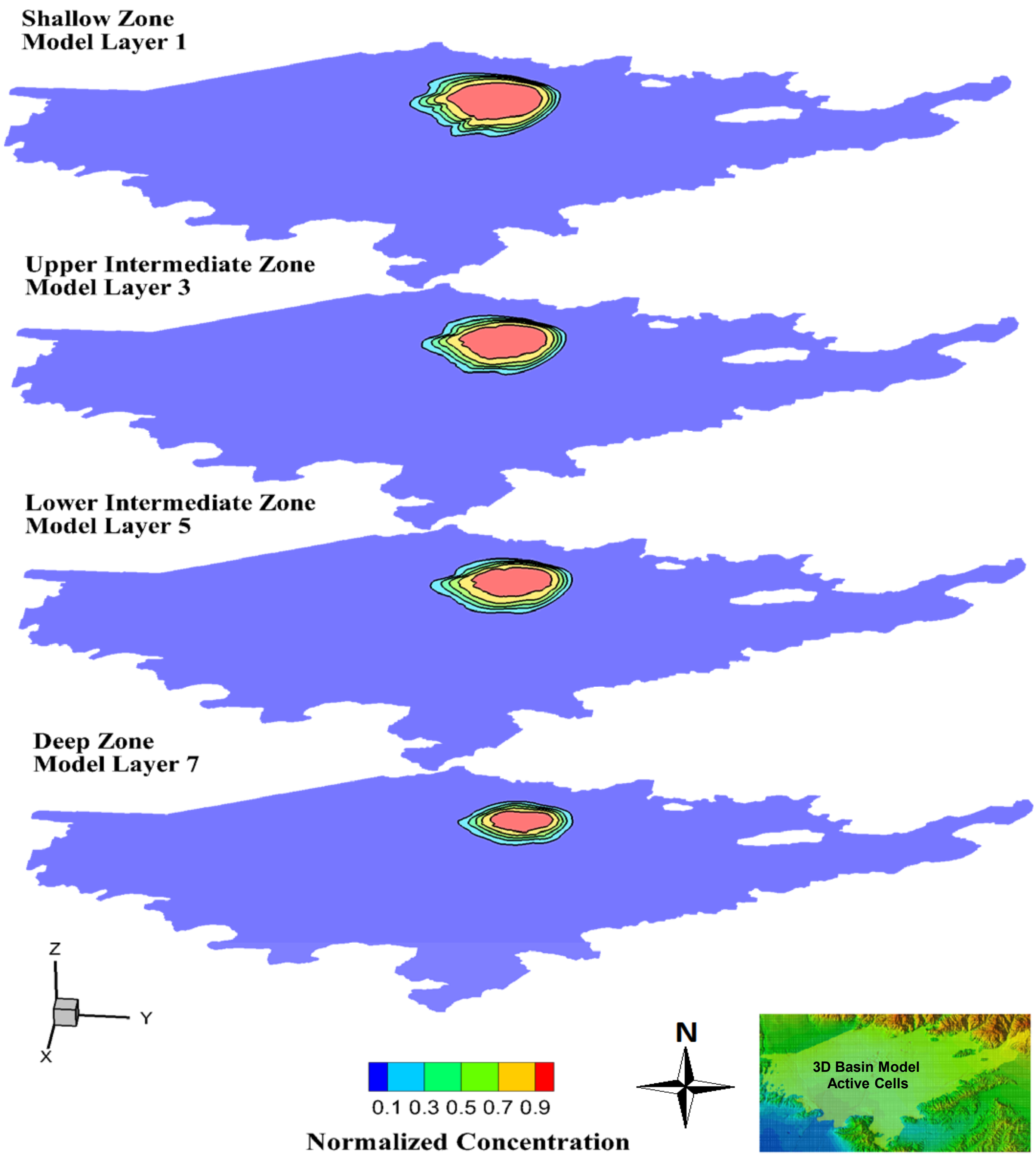
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 7 (Augmented Basin Sustainability)
Simulated FY2015-16 Plume Distribitions

MainSanGabrielBasin WATERMASTER

Figure 29b



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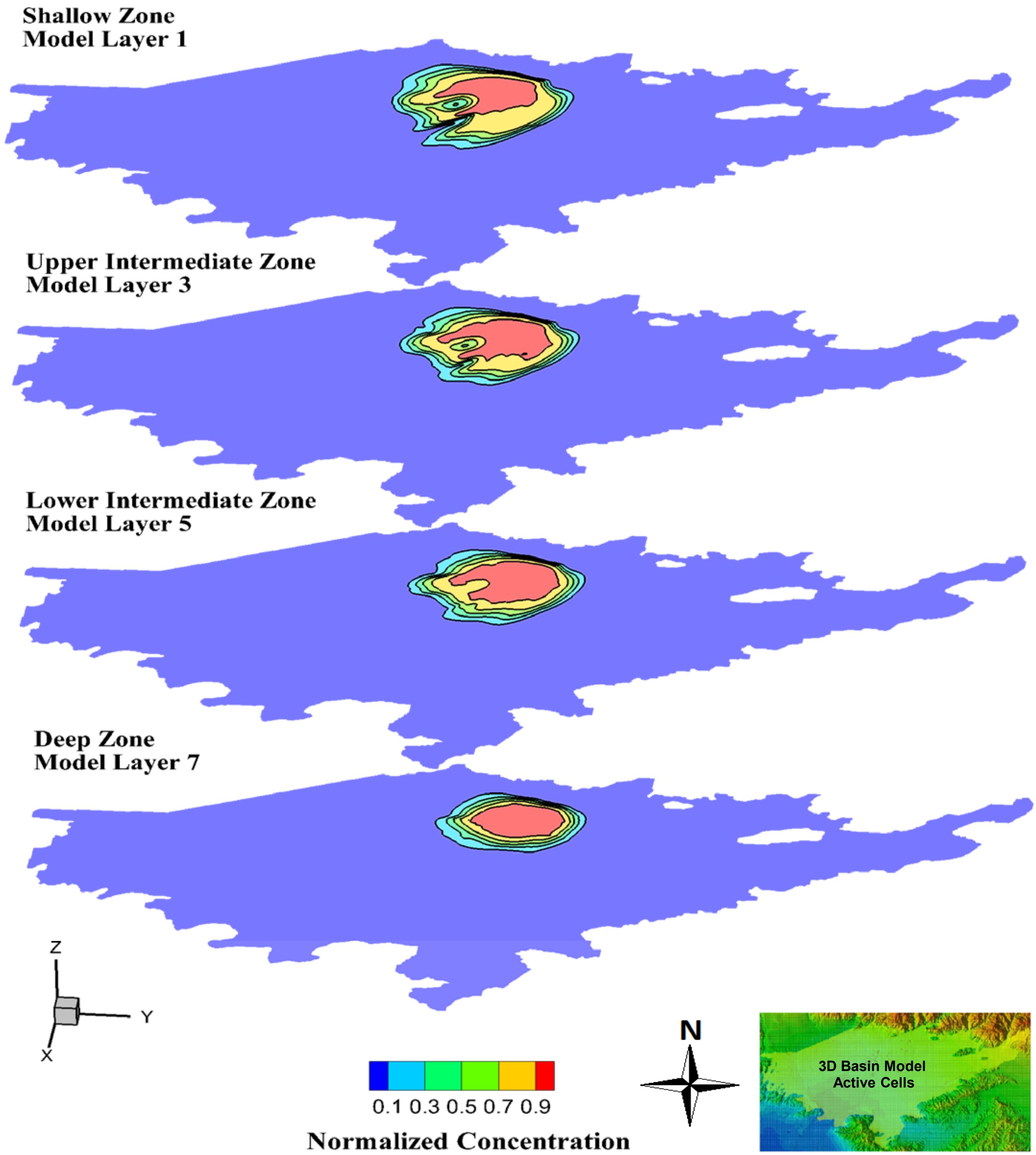
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 7 (Augmented Basin Sustainability)
Simulated FY2020-21 Plume Distribitions

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 30 - 3D Basin Model Simulated Plume (78MGD with Delivery).xlsx



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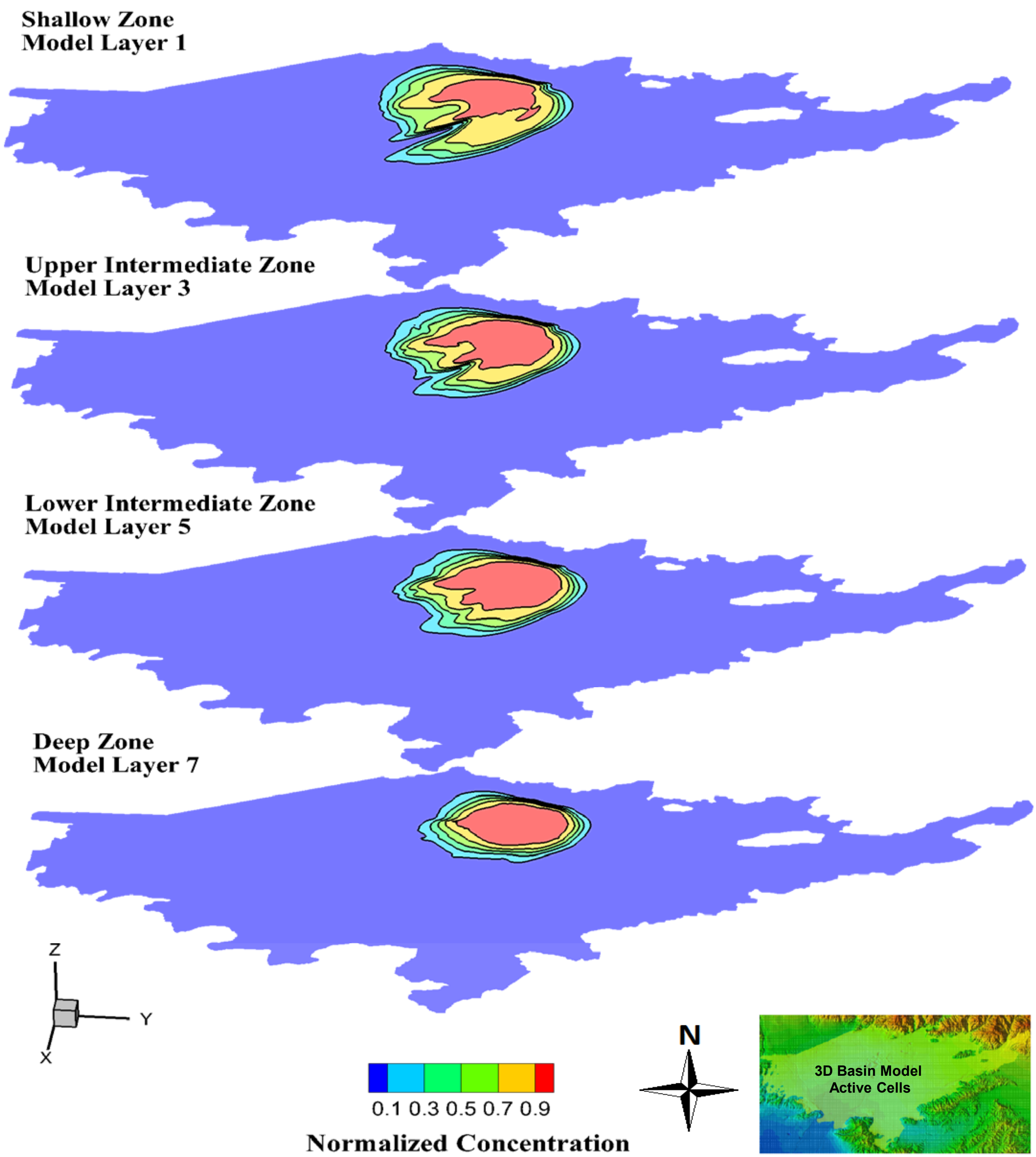
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 7 (Augmented Basin Sustainability)
Simulated FY2025-26 Plume Distribitions

Main San Gabriel Basin WATERMASTER

Figure 29d



STETSON ENGINEERS INC.

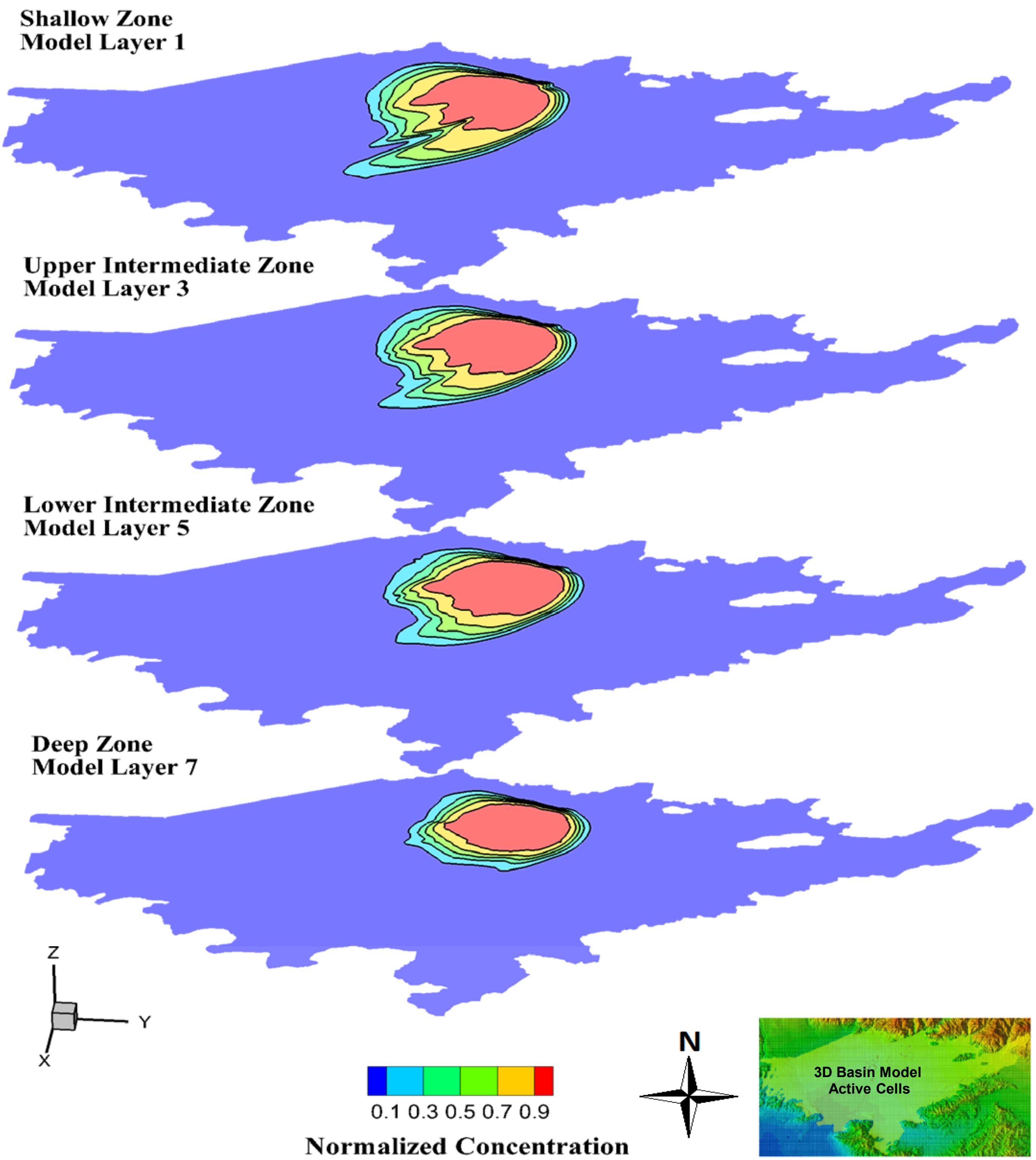
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 7 (Augmented Basin Sustainability)
Simulated FY2030-31 Plume Distribitions

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 30 - 3D Basin Model Simulated Plume (78MGD with Delivery).xlsx

Figure 29e

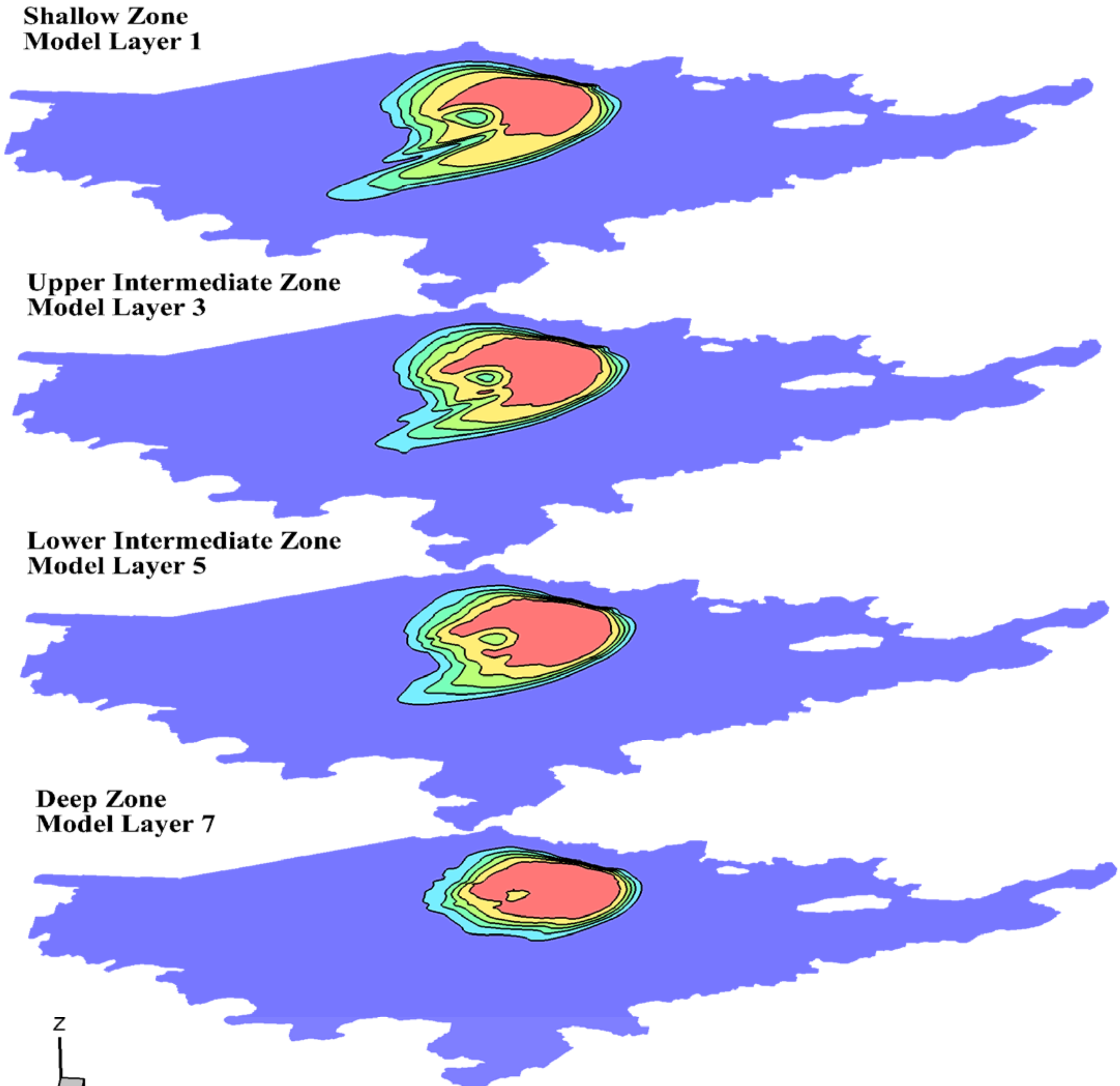


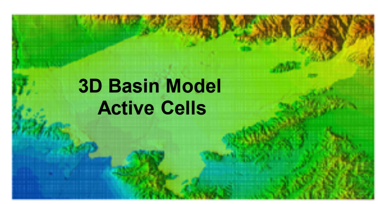
MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 7 (Augmented Basin Sustainability)
Simulated FY2035-36 Plume Distribitions

J:\1205\1205-98\.05.02.6\Figure 30 - 3D Basin Model Simulated Plume (78MGD with Delivery).xlsx

Figure 29f





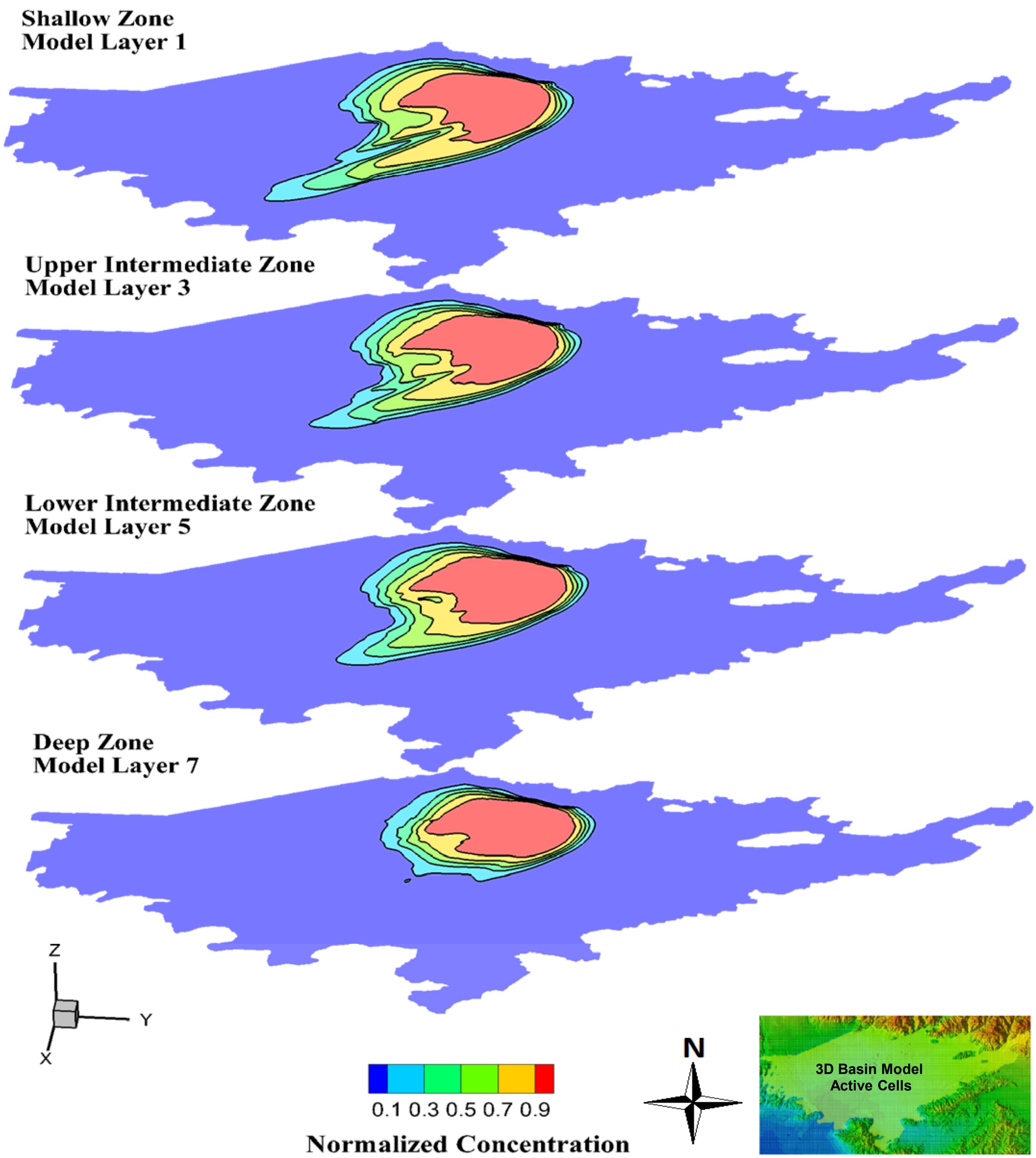
MAIN SAN GABRIEL BASIN WATERMASTER
Solute Transport Simulation Scenario 7 (Augmented Basin Sustainability) Simulated FY2040-41 Plume Distribitions

STETSON ENGINEERS INC.

MainSanGabrielBasin WATERMASTER

J:\1205\1205-98\.05.02.6\Figure 30 - 3D Basin Model Simulated Plume (78MGD with Delivery).xlsx

Figure 29g



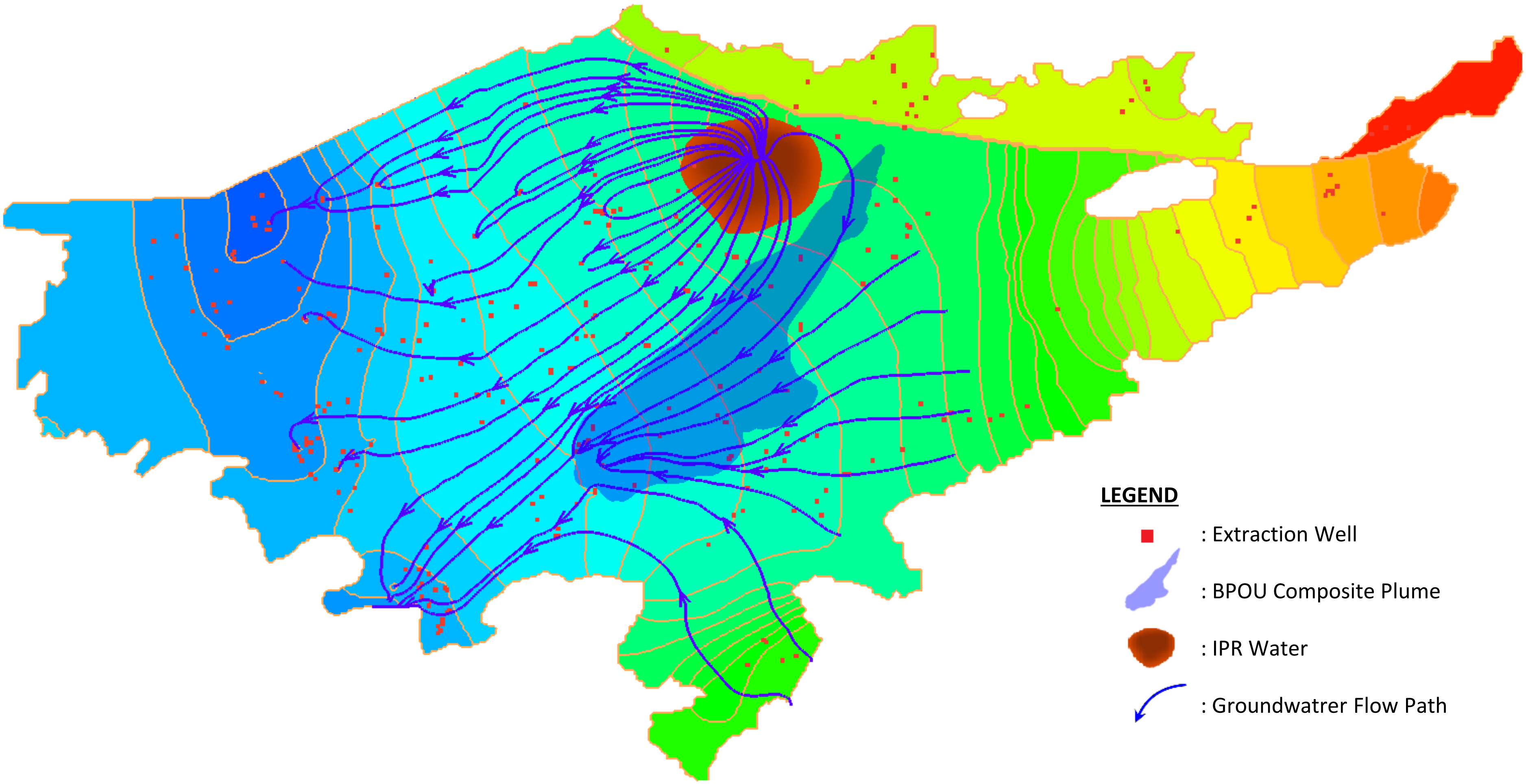
STETSON ENGINEERS INC.

MAIN SAN GABRIEL BASIN WATERMASTER

Solute Transport Simulation
Scenario 7 (Augmented Basin Sustainability)
Simulated FY2046-47 Plume Distribitions

MainSanGabrielBasin WATERMASTER

Model Run III – Augmented Basin Sustainability of 77.5 MGD



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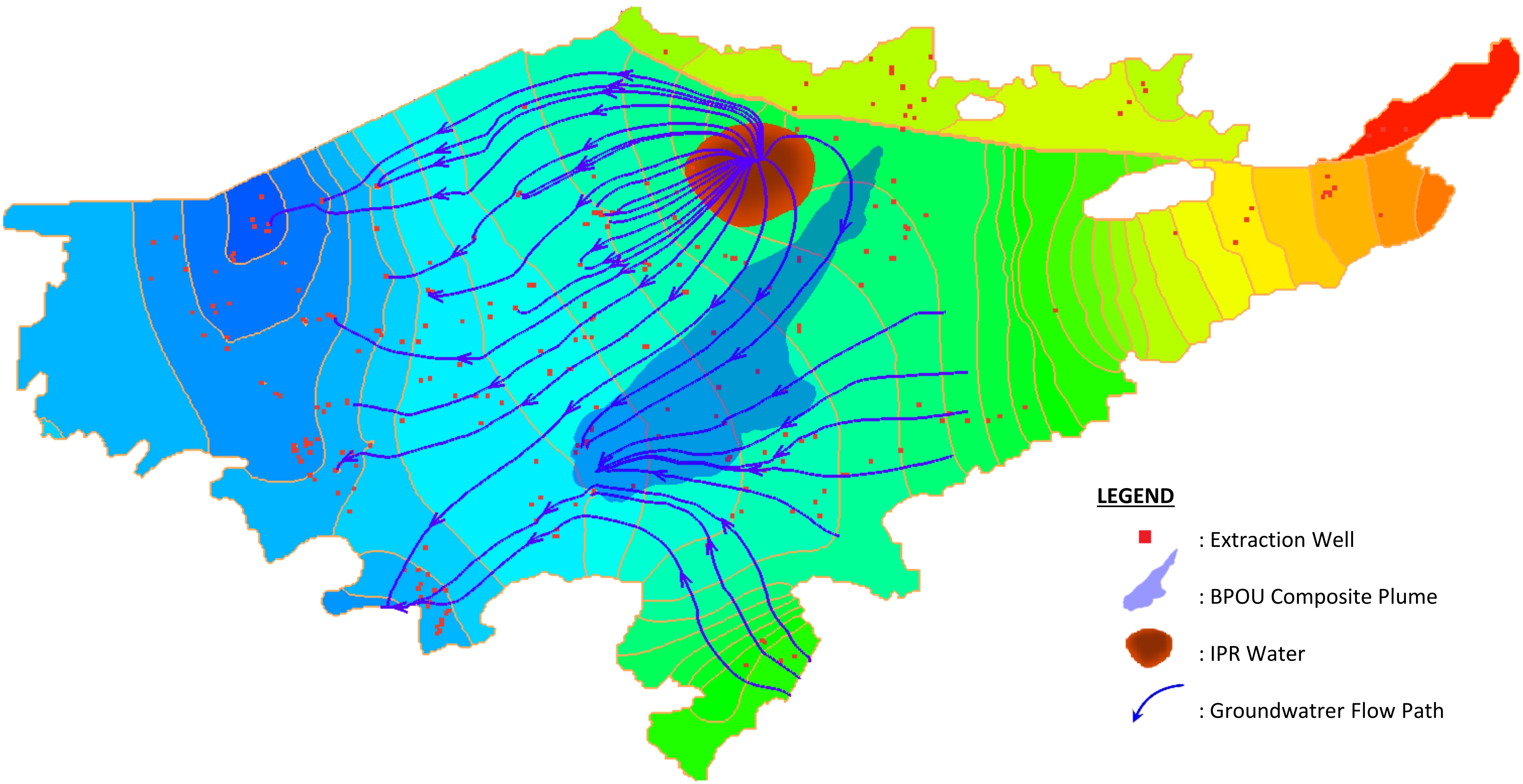
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 1 Fiscal Year 2015-2016
Spatial Distributions of the IPR Water (Scenario 7)
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run III – Augmented Basin Sustainability of 77.5 MGD



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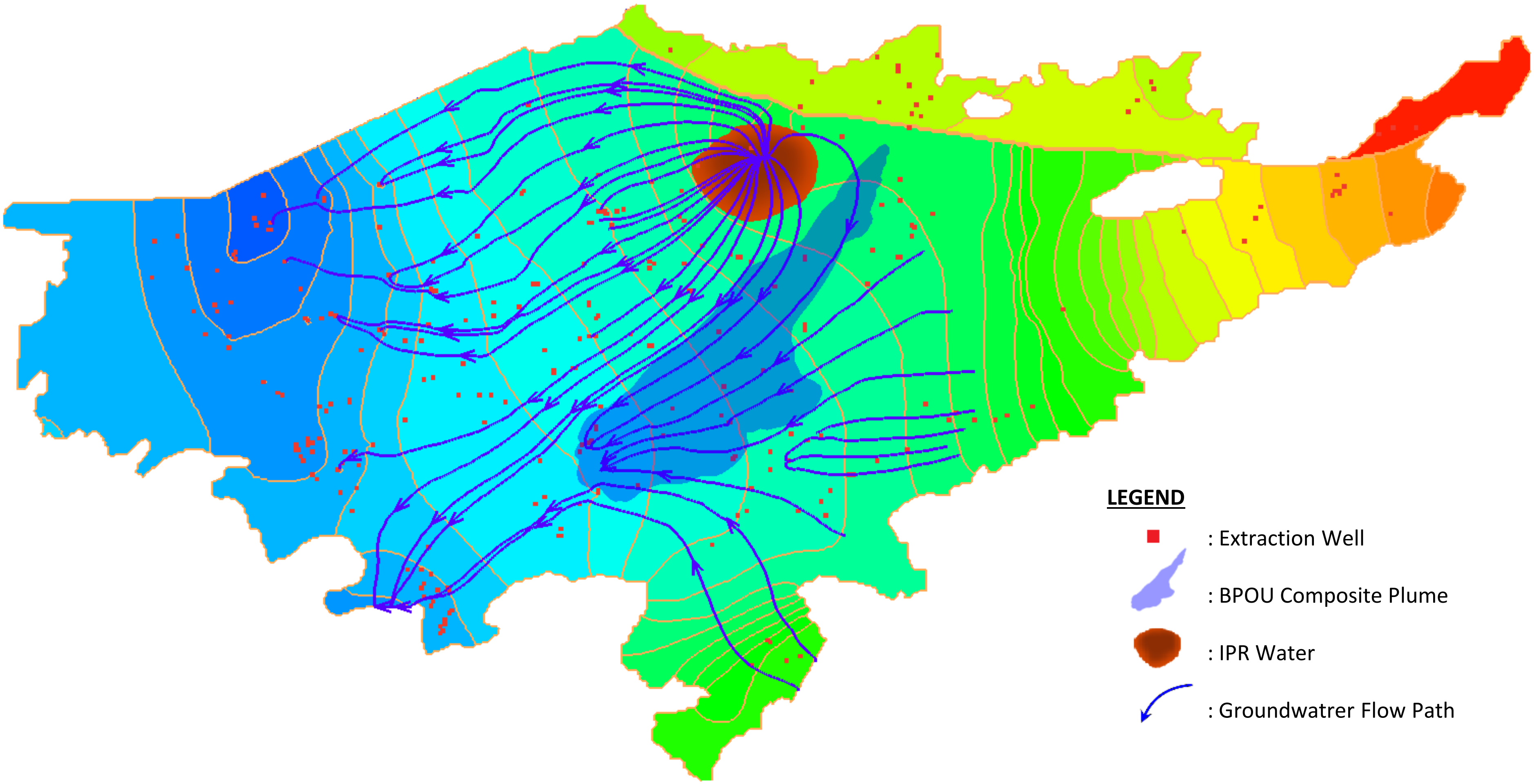
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 3 Fiscal Year 2015-2016
Spatial Distributions of the IPR Water (Scenario 7)
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run III – Augmented Basin Sustainability of 77.5 MGD



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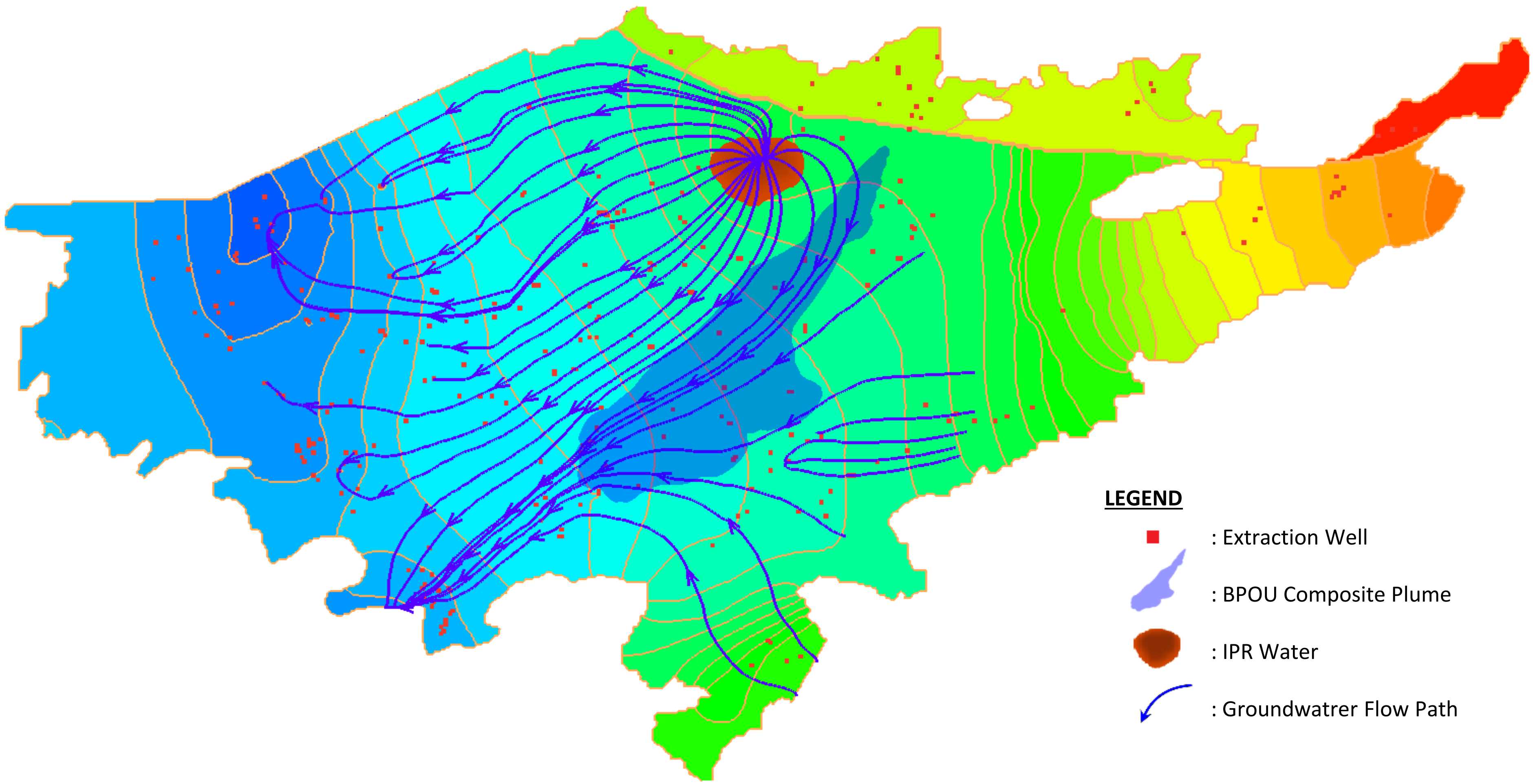
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 5 Fiscal Year 2015-2016
Spatial Distributions of the IPR Water (Scenario 7)
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run III – Augmented Basin Sustainability of 77.5 MGD



STETSON ENGINEERS INC.

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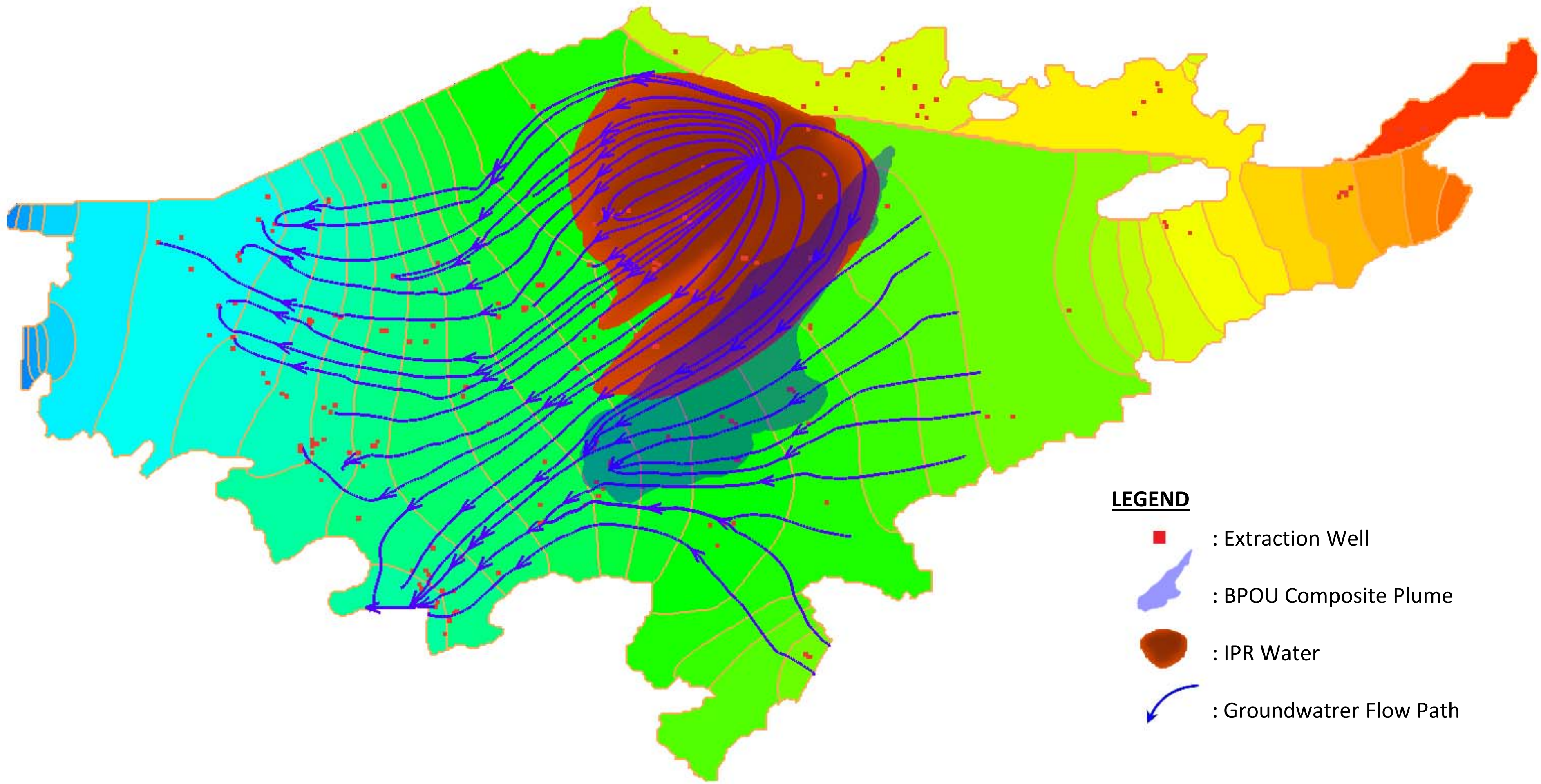
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 7 Fiscal Year 2015-2016
Spatial Distributions of the IPR Water (Scenario 7)
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run III – Augmented Basin Sustainability of 77.5 MGD



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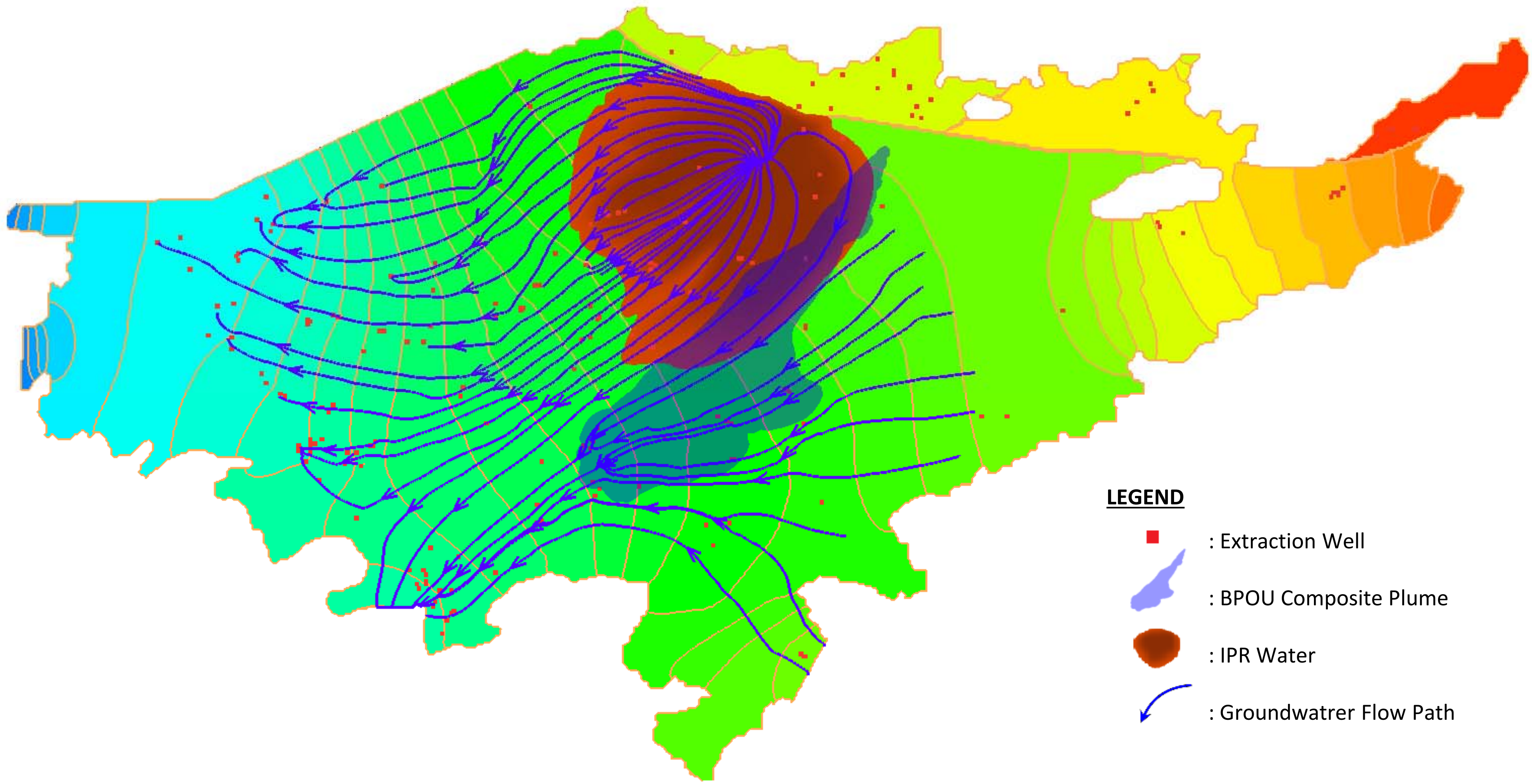
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 1 Fiscal Year 2030-2031
Spatial Distributions of the IPR Water (Scenario 7)
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

STETSON ENGINEERS INC.

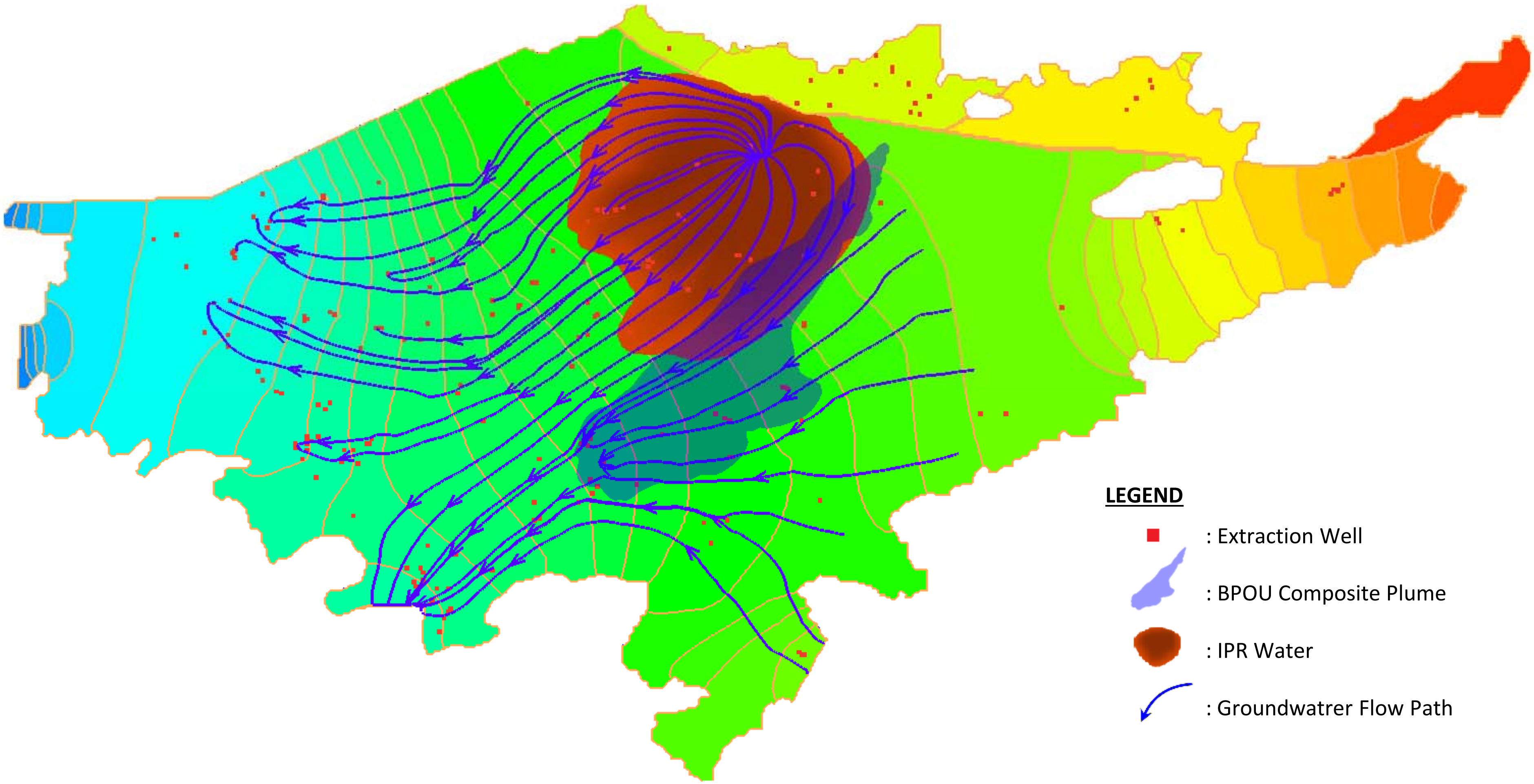
MainSanGabrielBasin WATERMASTER

Model Run III – Augmented Basin Sustainability of 77.5 MGD



STETSON ENGINEERS INC.	N W E S Not in Scale	MAIN SAN GABRIEL BASIN WATERMASTER 3D Basin Model Layer 3 Fiscal Year 2030-2031 Spatial Distributions of the IPR Water (Scenario 7) BPOU Composite Contaminantion Plume and Groundwater Flow Paths	MainSanGabrielBasin WATERMASTER

Model Run III – Augmented Basin Sustainability of 77.5 MGD



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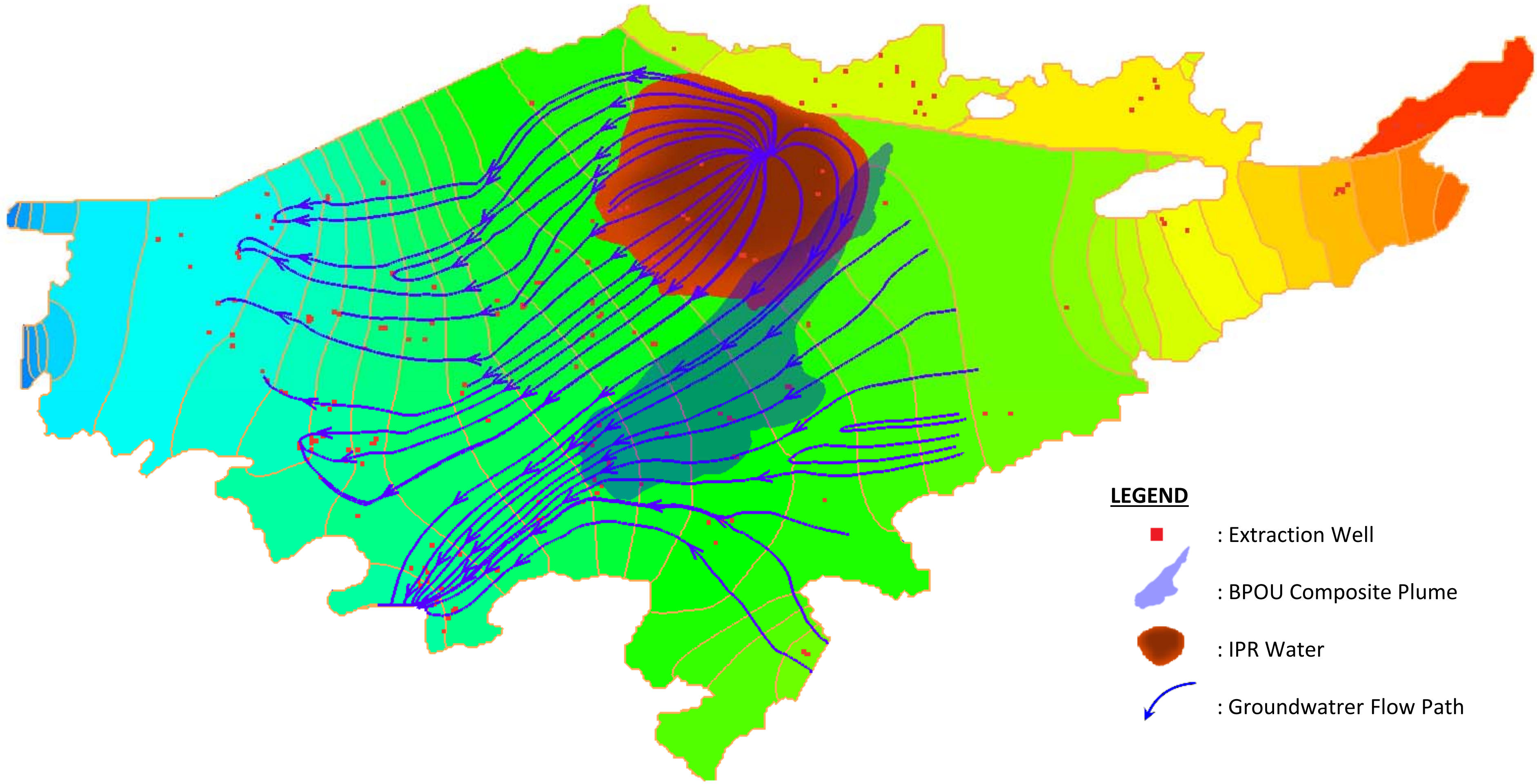
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 5 Fiscal Year 2030-2031
Spatial Distributions of the IPR Water (Scenario 7)
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run III – Augmented Basin Sustainability of 77.5 MGD



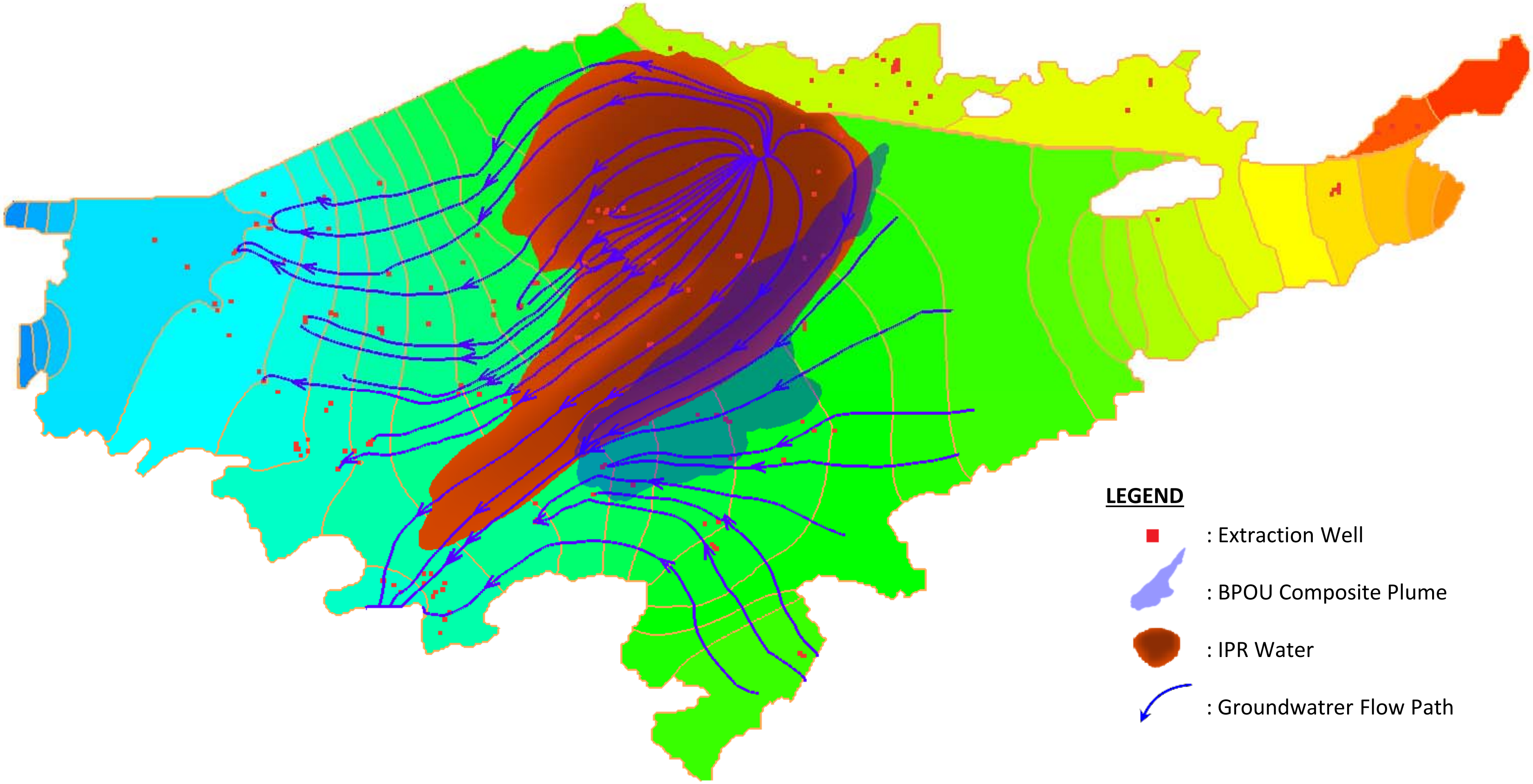
STETSON ENGINEERS INC.

MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 7 Fiscal Year 2030-2031
Spatial Distributions of the IPR Water (Scenario 7)
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run III – Augmented Basin Sustainability of 77.5 MGD



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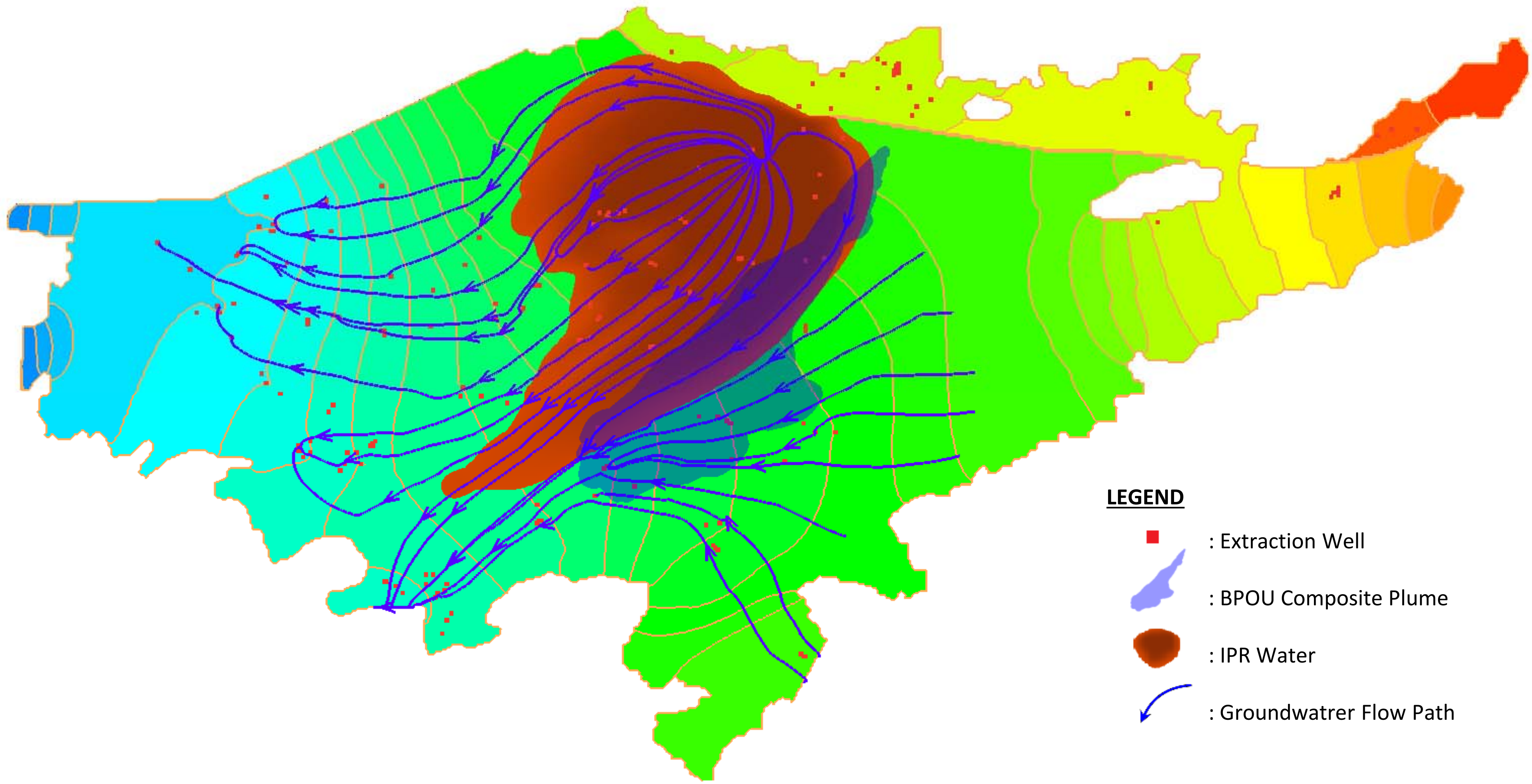
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 1 Fiscal Year 2046-2047
Spatial Distributions of the IPR Water (Scenario 7)
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run III – Augmented Basin Sustainability of 77.5 MGD



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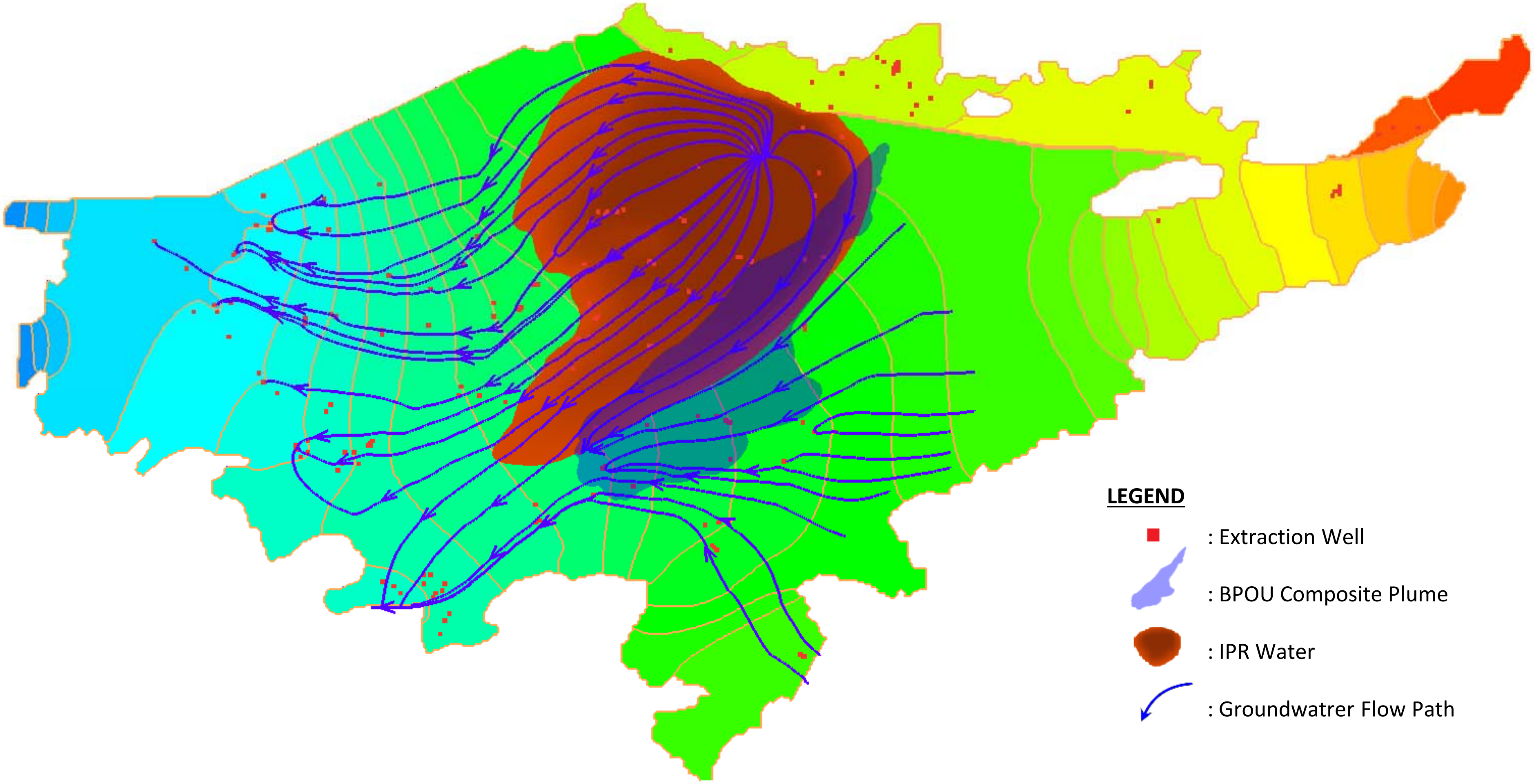
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 3 Fiscal Year 2046-2047
Spatial Distributions of the IPR Water (Scenario 7)
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run III – Augmented Basin Sustainability of 77.5 MGD



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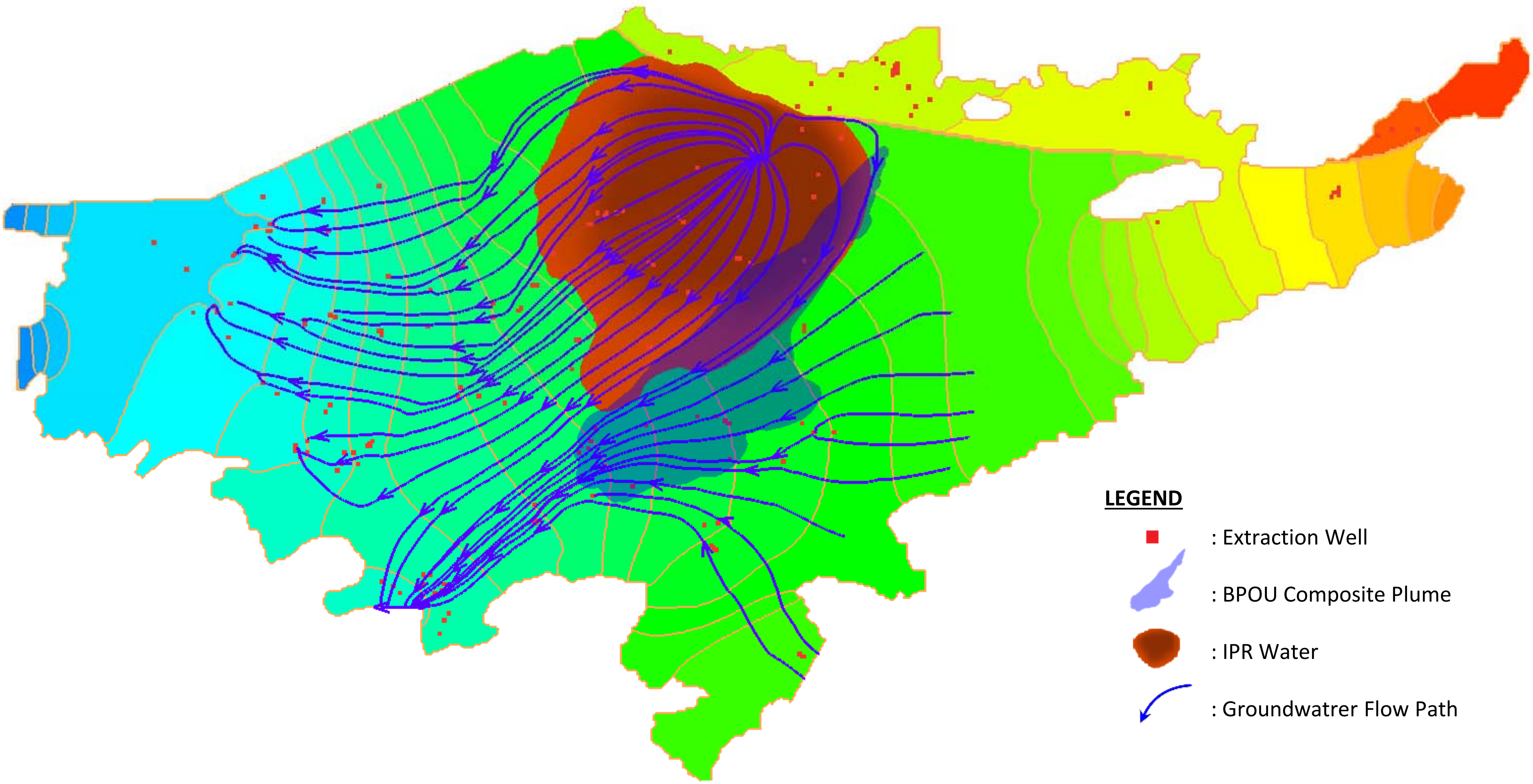
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 5 Fiscal Year 2046-2047
Spatial Distributions of the IPR Water (Scenario 7)
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

MainSanGabrielBasin WATERMASTER

Model Run III – Augmented Basin Sustainability of 77.5 MGD



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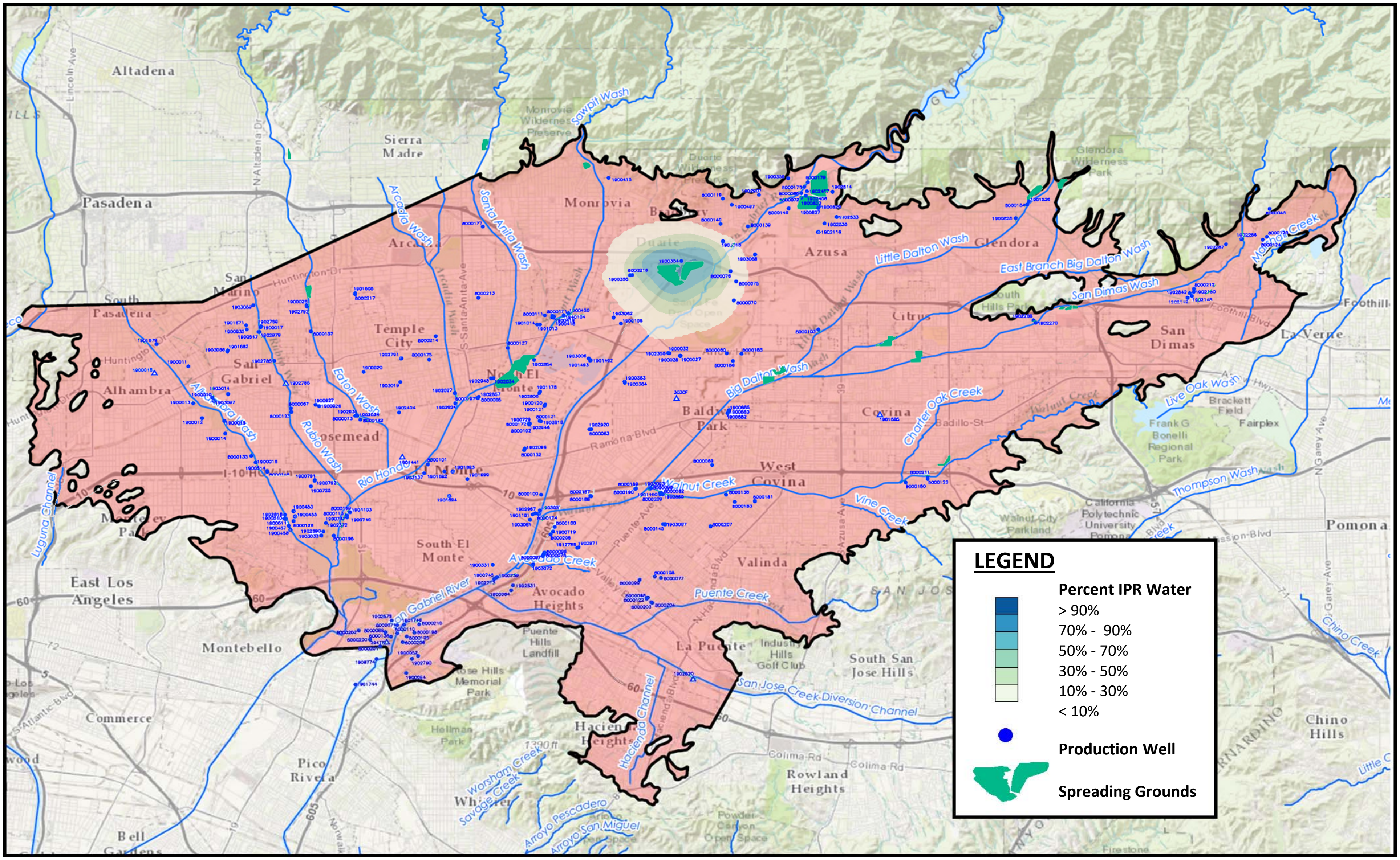
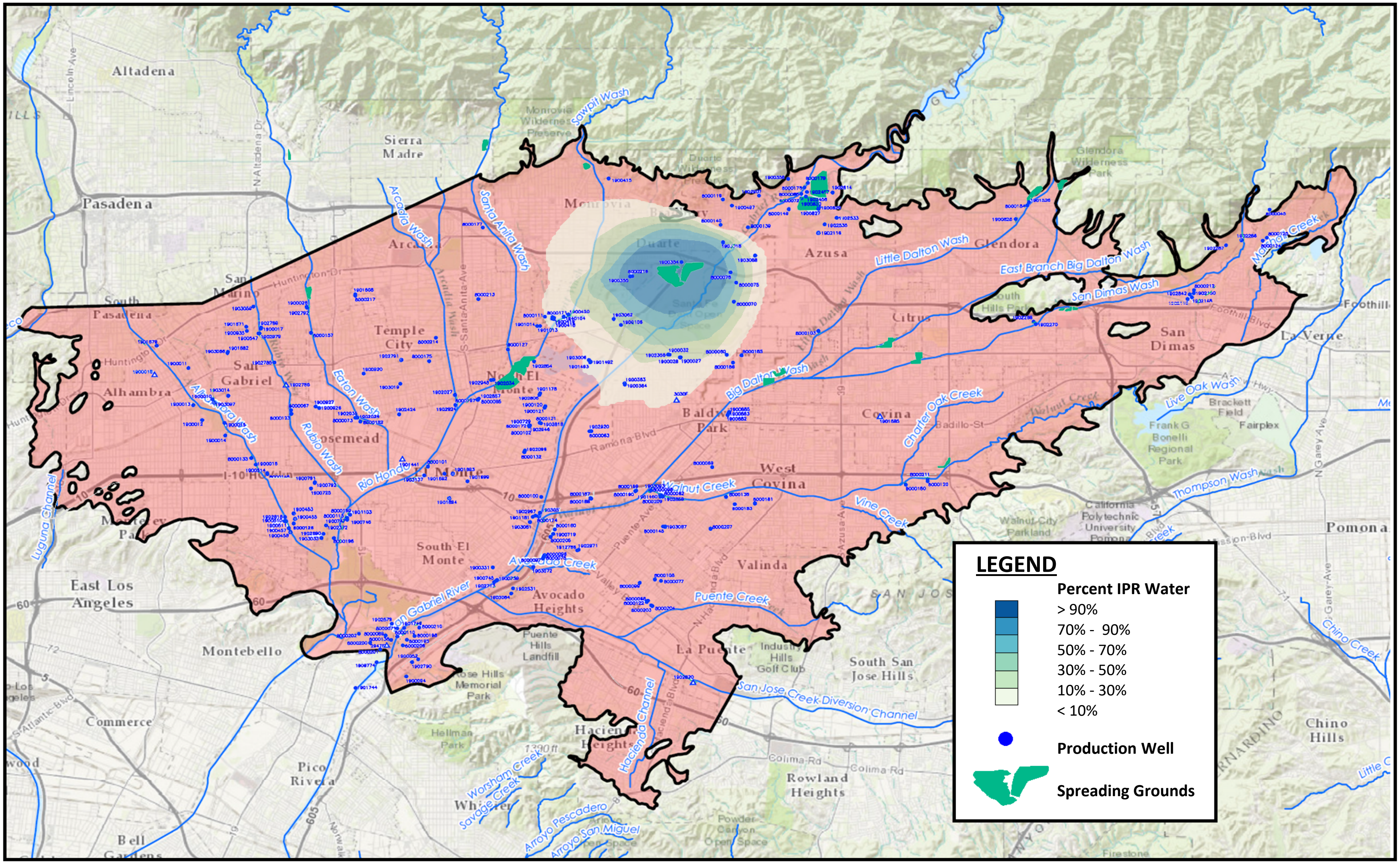
MAIN SAN GABRIEL BASIN WATERMASTER

3D Basin Model Layer 7 Fiscal Year 2046-2047
Spatial Distributions of the IPR Water (Scenario 7)
BPOU Composite Contaminantion Plume and
Groundwater Flow Paths

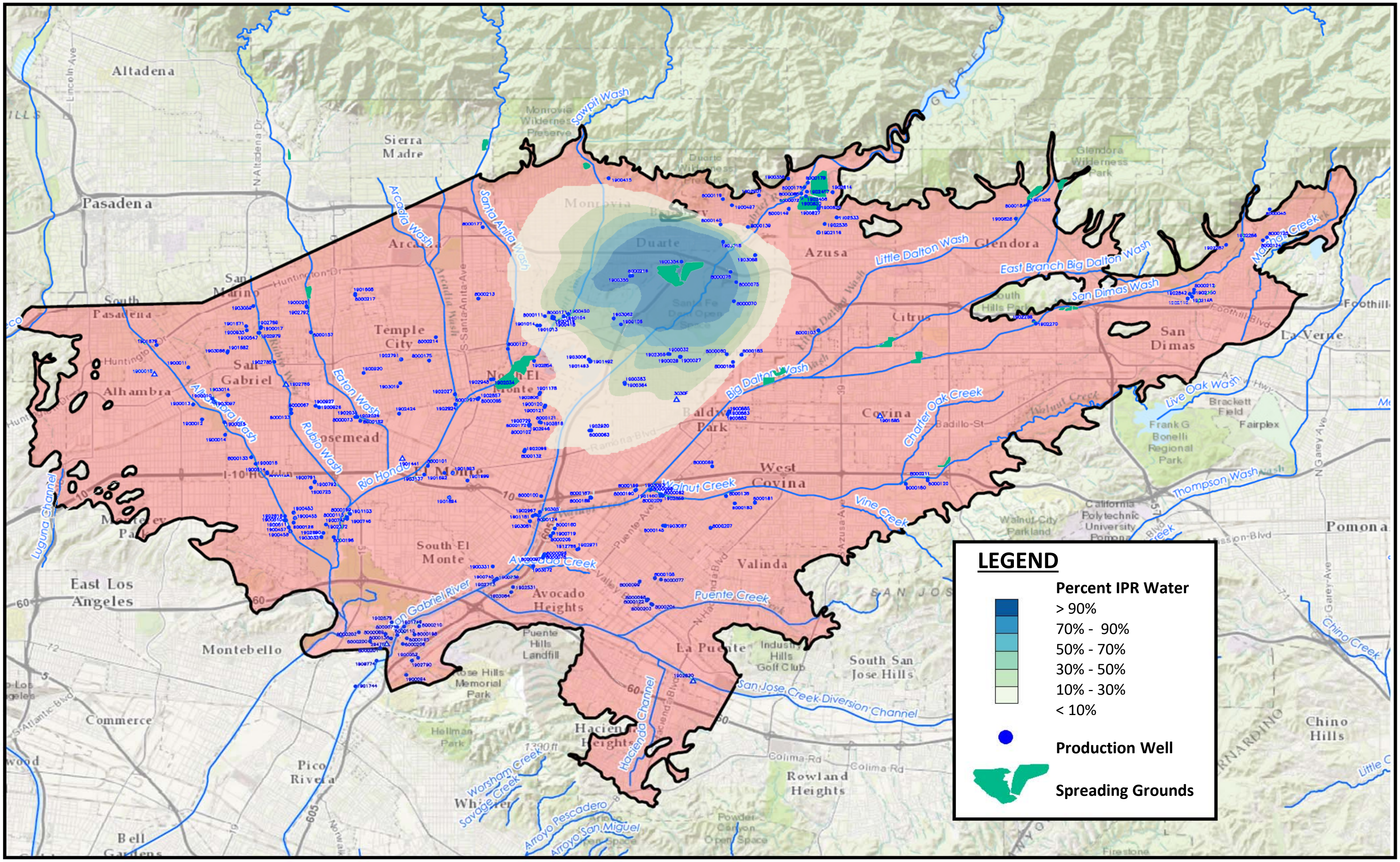
MainSanGabrielBasin WATERMASTER



STETSON ENGINEERS INC.	N / W / E / S Not in Scale	**MAIN SAN GABRIEL BASIN WATERMASTER** **Baseline Delivery of 77.5 MGD (Scenario 7)** **Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2015-16**	MainSanGabrielBasin WATERMASTER



STETSON ENGINEERS INC.	N W E S Not in Scale	**MAIN SAN GABRIEL BASIN WATERMASTER** **Baseline Delivery of 77.5 MGD (Scenario 7)** **Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2020-21**	MainSanGabrielBasin WATERMASTER



MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 77.5 MGD (Scenario 7)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2025-26

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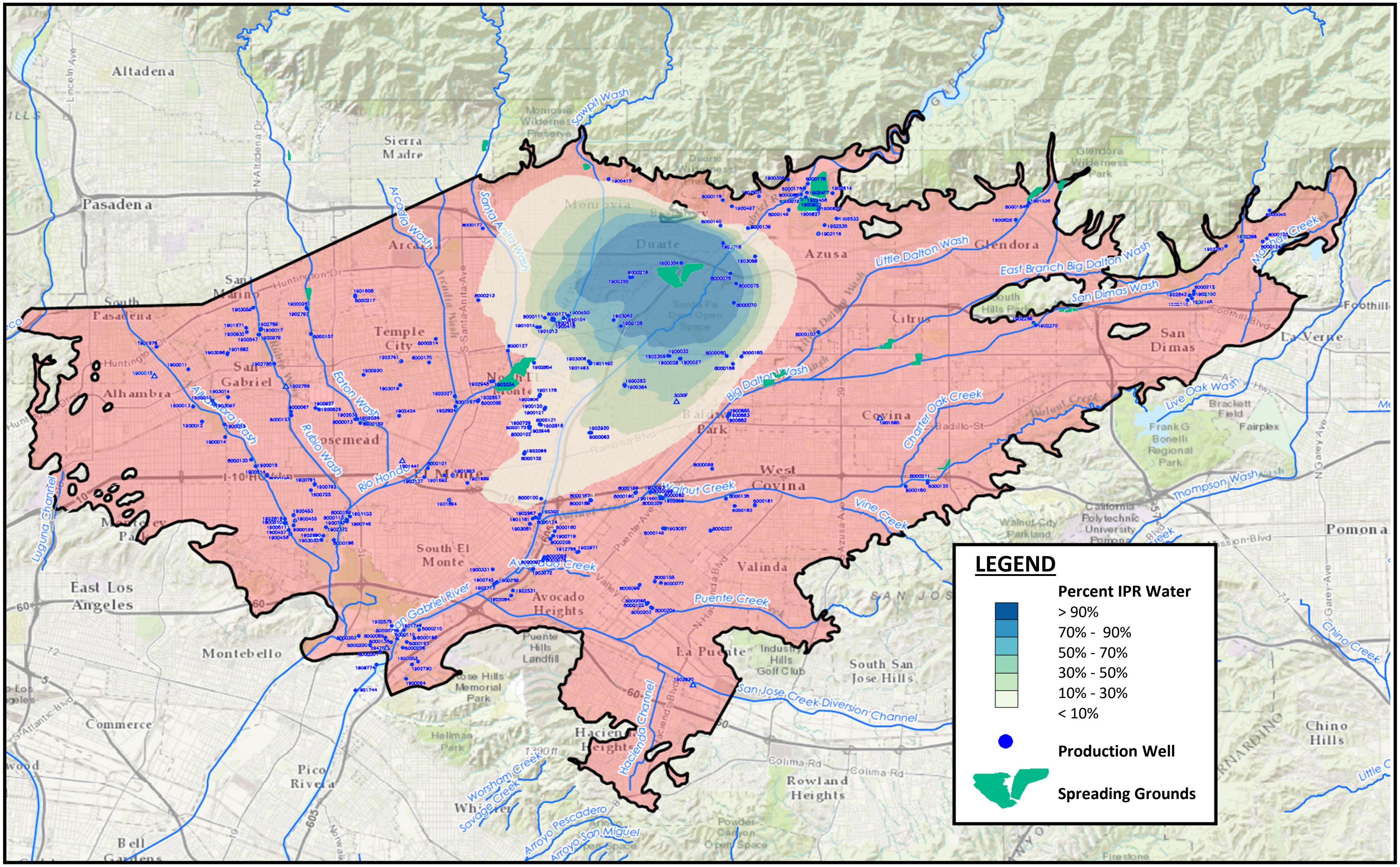
MainSanGabrielBasin WATERMASTER

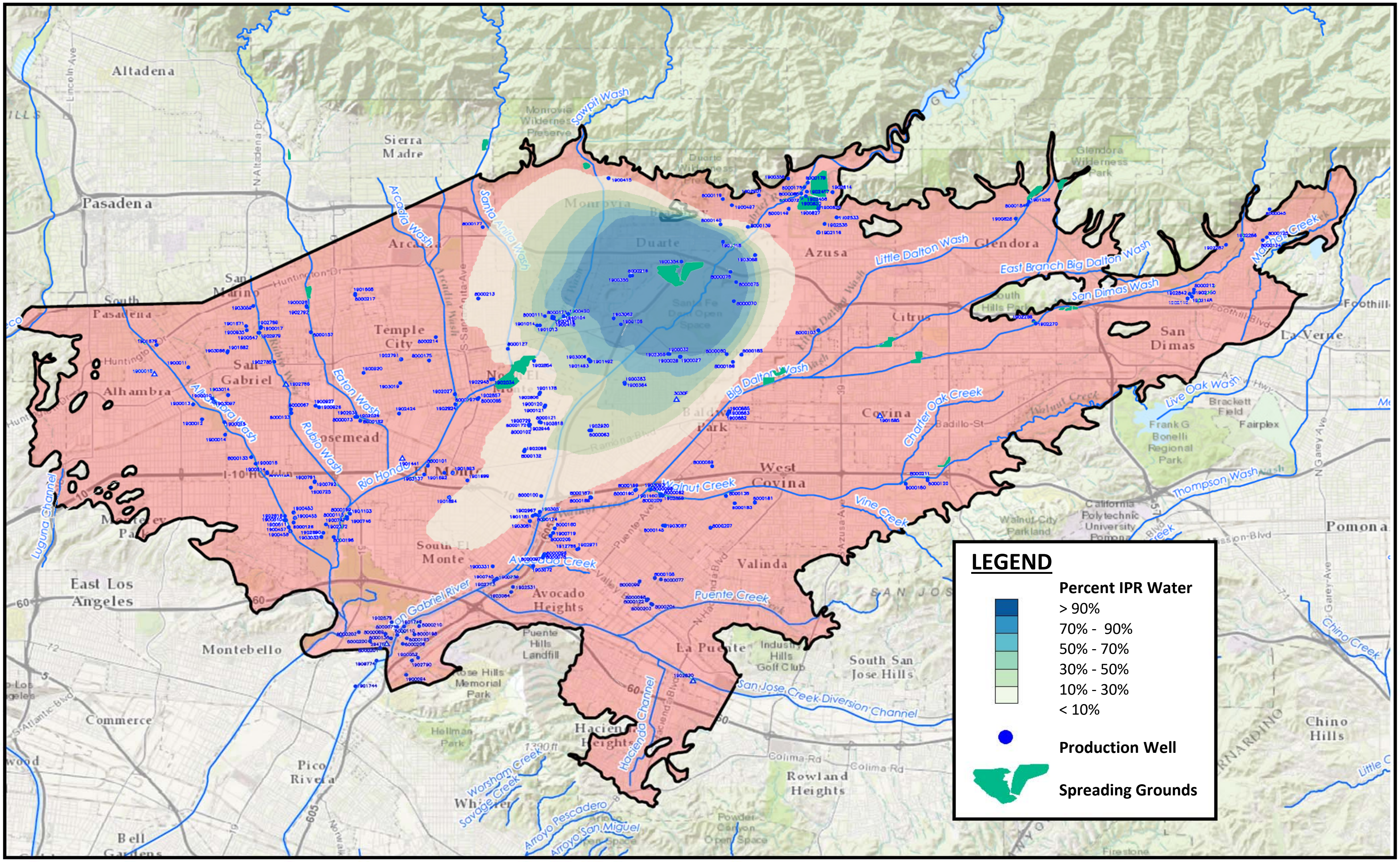


MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 77.5 MGD (Scenario 7)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2030-31

STETSON ENGINEERS INC.

MainSanGabrielBasin WATERMASTER



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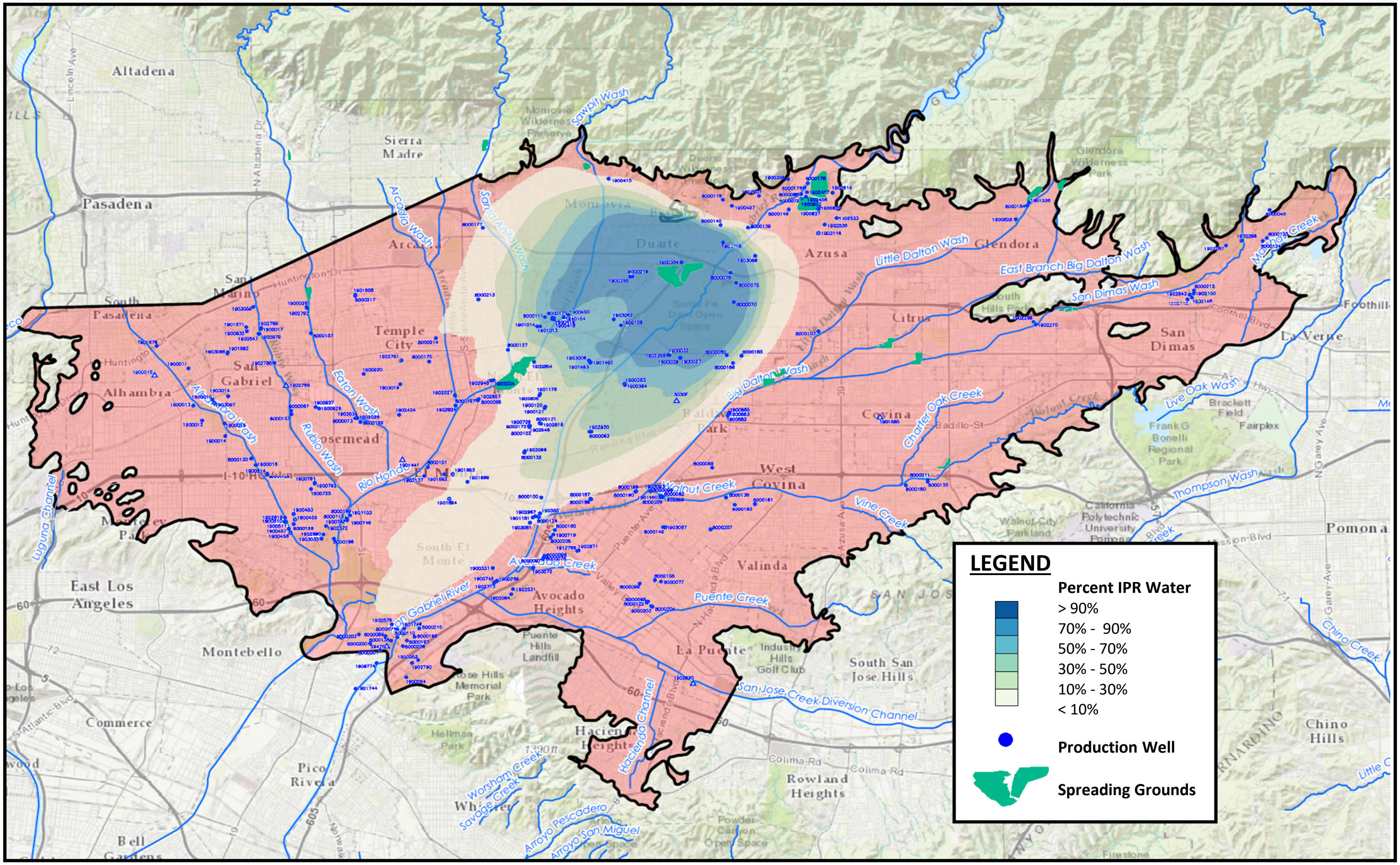
MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 77.5 MGD (Scenario 7)
Model Simulated Percent IPR Water Spatial Distribution
and Impacted Wells in Fiscal Year 2035-36

MainSanGabrielBasin WATERMASTER



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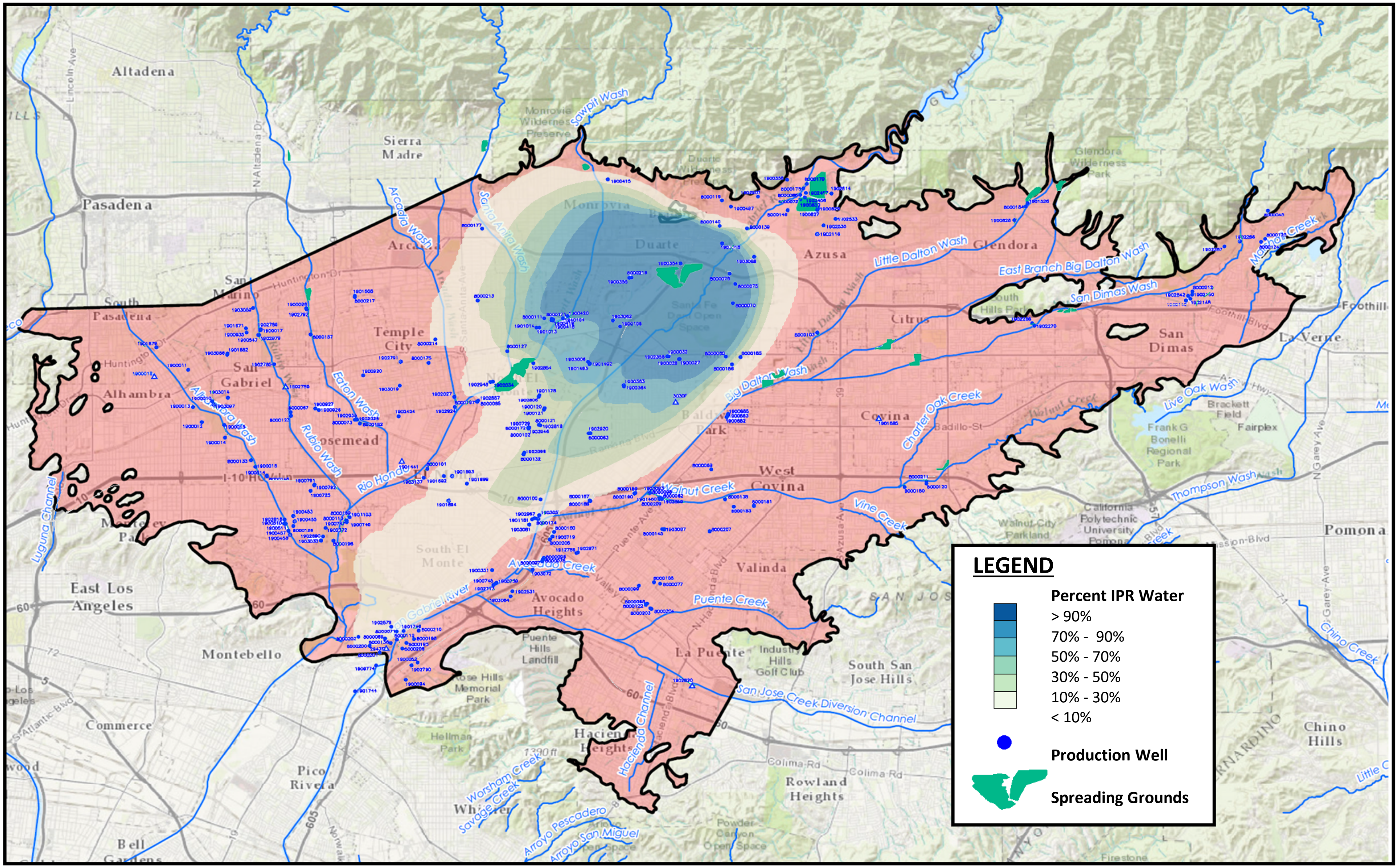
MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 77.5 MGD (Scenario 7)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2040-41

MainSanGabrielBasin WATERMASTER



MAIN SAN GABRIEL BASIN WATERMASTER

Baseline Delivery of 77.5 MGD (Scenario 7)
Model Simulated Percent IPR Water Spatial Distribution and Impacted Wells in Fiscal Year 2046-47

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STETSON ENGINEERS INC.

MainSanGabrielBasin WATERMASTER

Table 1: Projected Groundwater Production from FY2015-16 through FY2046-47.

Fiscal Year	**Projected Main Basin Groundwater Production (AF)**		**Difference**
	Water Resources Management Plan	**Regression Analysis**	
2015-16	193,187	244,793	51,606
2016-17	191,058	242,579	51,521
2017-18	189,109	239,487	50,378
2018-19	187,342	246,313	58,971
2019-20	189,993	244,632	54,639
2020-21	188,566	245,684	57,118
2021-22	188,601	245,024	56,423
2022-23	188,630	245,108	56,478
2023-24	188,658	242,534	53,877
2024-25	188,697	234,343	45,646
2025-26	189,124	247,251	58,127
2026-27	189,548	236,742	47,194
2027-28	189,974	245,559	55,585
2028-29	190,402	244,640	54,238
2029-30	190,826	234,199	43,373
2030-31	191,073	249,858	58,786
2031-32	191,320	247,597	56,277
2032-33	191,570	246,135	54,566
2033-34	191,821	252,283	60,462
2034-35	192,073	245,280	53,206
2035-36	191,676	250,665	58,989
2036-37	192,130	235,691	43,561
2037-38	192,585	248,767	56,182
2038-39	193,043	254,382	61,339
2039-40	193,539	248,999	55,460
2040-41	194,001	250,906	56,906
2041-42	194,465	249,662	55,197
2042-43	194,931	247,917	52,987
2043-44	195,399	253,101	57,702
2044-45	195,869	253,722	57,853
2045-46	196,337	255,981	59,644
2046-47	196,811	253,790	56,978
Maximum:	196,811	255,981	61,339
Minimun:	187,342	234,199	43,373
Mean:	191,636	246,363	54,727

Tabe 2. Estimated San Gabriel River Flow Rates between Morris Dam and Gaging Station F190 (unit: AF).

3D Basin Model Period Year/ Month	Between USG-3 and U8-R			Between U8-R and F-190R		Projected Model Period Year/ Month
	(1) Measured USG-3 Imported	(2) U8-R Gaging Station	(3)* Estimated Morris Dam Release (2) - (1)	(5) Measured F190 Gaging Station	(6)* Estimated F190R Gaging Station (No USG-3)	
1983/07	0.0	23,795.9	23,795.9	21,223.9	21,223.9	2015/07
1983/08	0.0	0.0	0.0	236.6	236.6	2015/08
1983/09	0.0	0.0	0.0	196.0	196.0	2015/09
1983/10	0.0	19,961.0	19,961.0	14,880.2	14,880.2	2015/10
1983/11	0.0	11,254.0	11,254.0	10,278.7	10,278.7	2015/11
1983/12	0.0	46.4	46.4	498.2	498.2	2015/12
1984/01	0.0	15,580.2	15,580.2	10,910.3	10,910.3	2016/01
1984/02	0.0	761.7	761.7	115.0	115.0	2016/02
1984/03	0.0	0.0	0.0	0.0	0.0	2016/03
1984/04	0.0	0.0	0.0	0.0	0.0	2016/04
1984/05	0.0	0.0	0.0	0.0	0.0	2016/05
1984/06	0.0	0.0	0.0	0.0	0.0	2016/06
1984/07	0.0	0.0	0.0	0.0	0.0	2016/07
1984/08	0.0	0.0	0.0	0.0	0.0	2016/08
1984/09	0.0	816.8	816.8	0.0	0.0	2016/09
1984/10	0.0	2,308.0	2,308.0	0.0	0.0	2016/10
1984/11	0.0	1,462.2	1,462.2	0.0	0.0	2016/11
1984/12	0.0	1,220.6	1,220.6	153.3	153.3	2016/12
1985/01	0.0	11,897.0	11,897.0	9,167.2	9,167.2	2017/01
1985/02	0.0	0.0	0.0	76.2	76.2	2017/02
1985/03	0.0	0.0	0.0	0.0	0.0	2017/03
1985/04	0.0	771.8	771.8	0.0	0.0	2017/04
1985/05	0.0	2,418.3	2,418.3	0.0	0.0	2017/05
1985/06	0.0	2,432.6	2,432.6	0.0	0.0	2017/06
1985/07	0.0	2,209.8	2,209.8	0.0	0.0	2017/07
1985/08	0.0	2,136.6	2,136.6	0.0	0.0	2017/08
1985/09	5,214.3	8,243.4	3,029.1	2,368.5	0.0	2017/09
1985/10	11,572.1	11,821.7	249.6	6,934.2	0.0	2017/10
1985/11	11,247.4	8,671.1	0.0	8,295.7	0.0	2017/11
1985/12	12,325.7	10,530.4	0.0	9,552.4	0.0	2017/12
1986/01	7,663.5	7,470.1	0.0	5,744.3	0.0	2018/01
1986/02	6,427.6	14,236.2	7,808.5	12,826.7	4,274.7	2018/02
1986/03	208.4	16,750.3	16,541.9	18,968.9	13,008.0	2018/03
1986/04	895.3	15,012.5	14,117.2	13,871.2	10,583.4	2018/04
1986/05	0.0	10,219.0	10,219.0	8,776.5	6,685.2	2018/05
1986/06	0.0	0.0	0.0	0.0	0.0	2018/06
1986/07	0.0	0.0	0.0	0.0	0.0	2018/07
1986/08	0.0	0.0	0.0	0.0	0.0	2018/08
1986/09	0.0	68.4	68.4	45.8	45.8	2018/09
1986/10	0.0	117.4	117.4	0.0	0.0	2018/10

Tabe 2. Estimated San Gabriel River Flow Rates between Morris Dam and Gaging Station F190 (unit: AF).

3D Basin Model Period Year/ Month	Between USG-3 and U8-R			Between U8-R and F-190R		Projected Model Period Year/ Month
	(1) Measured USG-3 Imported	(2) U8-R Gaging Station	(3)* Estimated Morris Dam Release (2) - (1)	(5) Measured F190 Gaging Station	(6)* Estimated F190R Gaging Station (No USG-3)	
1986/11	6,615.8	4,098.9	0.0	2,420.0	0.0	2018/11
1986/12	9,175.9	8,152.8	0.0	4,533.8	0.0	2018/12
1987/01	8,201.7	6,581.3	0.0	3,558.0	0.0	2019/01
1987/02	7,982.8	8,142.3	159.5	3,789.4	0.0	2019/02
1987/03	9,533.7	8,630.2	0.0	4,892.2	0.0	2019/03
1987/04	7,685.3	6,062.0	0.0	3,341.2	0.0	2019/04
1987/05	0.0	0.0	0.0	0.0	0.0	2019/05
1987/06	0.0	0.0	0.0	0.0	0.0	2019/06
1987/07	0.0	257.1	257.1	37.7	37.7	2019/07
1987/08	0.0	668.4	668.4	0.0	0.0	2019/08
1987/09	0.0	1,285.1	1,285.1	66.6	66.6	2019/09
1987/10	0.0	1,376.2	1,376.2	299.3	299.3	2019/10
1987/11	4,968.8	8,150.8	3,182.0	2,535.5	0.0	2019/11
1987/12	10,883.0	7,314.4	0.0	6,579.4	0.0	2019/12
1988/01	18,167.2	13,908.3	0.0	14,162.0	0.0	2020/01
1988/02	13,668.6	11,490.8	0.0	9,916.0	0.0	2020/02
1988/03	0.0	3,281.5	3,281.5	0.0	0.0	2020/03
1988/04	0.0	2,880.6	2,880.6	0.0	0.0	2020/04
1988/05	0.0	2,216.2	2,216.2	0.0	0.0	2020/05
1988/06	0.0	14,198.7	14,198.7	9,538.1	9,538.1	2020/06
1988/07	0.0	0.8	0.8	0.0	0.0	2020/07
1988/08	0.0	0.0	0.0	348.3	348.3	2020/08
1988/09	0.0	2,951.2	2,951.2	783.3	783.3	2020/09
1988/10	0.0	1,927.6	1,927.6	589.3	589.3	2020/10
1988/11	0.0	601.2	601.2	375.9	375.9	2020/11
1988/12	8,433.1	11,463.0	3,029.9	7,346.0	0.0	2020/12
1989/01	12,643.8	12,969.1	325.3	9,560.5	0.0	2021/01
1989/02	12,774.4	9,330.4	0.0	8,589.4	0.0	2021/02
1989/03	6,746.7	5,261.2	0.0	3,923.3	0.0	2021/03
1989/04	7,173.4	6,289.7	0.0	2,978.6	0.0	2021/04
1989/05	4,699.8	219.0	0.0	1,383.1	0.0	2021/05
1989/06	1,703.4	176.9	0.0	354.1	0.0	2021/06
1989/07	0.0	126.0	126.0	347.3	347.3	2021/07
1989/08	0.0	102.3	102.3	569.7	569.7	2021/08
1989/09	0.0	592.3	592.3	519.5	519.5	2021/09
1989/10	5,173.9	2,530.2	0.0	1,125.8	0.0	2021/10
1989/11	5,154.3	284.6	0.0	1,256.5	0.0	2021/11
1989/12	168.6	2,373.9	2,205.2	18.6	0.0	2021/12
1990/01	501.1	1,993.2	1,492.1	51.2	0.0	2022/01
1990/02	5,332.1	6,212.1	880.0	1,434.6	0.0	2022/02

Tabe 2. Estimated San Gabriel River Flow Rates between Morris Dam and Gaging Station F190 (unit: AF).

3D Basin Model Period Year/ Month	Between USG-3 and U8-R			Between U8-R and F-190R		Projected Model Period Year/ Month
	(1) Measured USG-3 Imported	(2) U8-R Gaging Station	(3)* Estimated Morris Dam Release (2) - (1)	(5) Measured F190 Gaging Station	(6)* Estimated F190R Gaging Station (No USG-3)	
1990/03	9,220.2	8,348.4	0.0	4,878.7	0.0	2022/03
1990/04	10,195.9	8,964.4	0.0	5,705.9	0.0	2022/04
1990/05	2,742.3	155.5	0.0	645.6	0.0	2022/05
1990/06	0.0	95.2	95.2	0.0	0.0	2022/06
1990/07	0.0	13.5	13.5	0.0	0.0	2022/07
1990/08	6,442.3	8,165.3	1,723.0	2,396.4	0.0	2022/08
1990/09	6,147.0	6,967.8	820.9	1,649.9	0.0	2022/09
1990/10	6,332.5	6,925.8	593.3	2,587.0	0.0	2022/10
1990/11	0.0	0.0	0.0	0.0	0.0	2022/11
1990/12	0.0	0.0	0.0	0.0	0.0	2022/12
1991/01	0.0	3,430.3	3,430.3	203.9	203.9	2023/01
1991/02	360.8	13.7	0.0	60.9	0.0	2023/02
1991/03	12,791.2	11,484.9	0.0	8,155.4	0.0	2023/03
1991/04	5,285.1	3,920.4	0.0	3,341.0	0.0	2023/04
1991/05	0.0	325.7	325.7	0.0	0.0	2023/05
1991/06	1,780.2	2,078.7	298.5	1,032.0	0.0	2023/06
1991/07	7,714.3	11,449.0	3,734.7	7,928.1	200.9	2023/07
1991/08	15,283.3	26,009.6	10,726.4	18,256.1	7,192.5	2023/08
1991/09	9,777.8	15,358.2	5,580.5	11,284.4	2,046.6	2023/09
1991/10	2,029.8	3,788.0	1,758.3	3,060.1	0.0	2023/10
1991/11	0.0	289.0	289.0	29.8	29.8	2023/11
1991/12	0.0	241.0	241.0	15.3	15.3	2023/12
1992/01	5,192.6	13,461.0	8,268.4	11,998.0	4,734.6	2024/01
1992/02	1,371.8	20,340.0	18,968.2	22,084.6	15,434.3	2024/02
1992/03	2,235.5	20,409.0	18,173.5	22,813.9	14,639.6	2024/03
1992/04	0.0	24,224.0	24,224.0	23,436.7	23,436.7	2024/04
1992/05	0.0	20,045.0	20,045.0	19,582.8	19,582.8	2024/05
1992/06	0.0	22,134.0	22,134.0	21,062.5	21,062.5	2024/06
1992/07	0.0	15,835.0	15,835.0	14,628.5	14,628.5	2024/07
1992/08	0.0	552.0	552.0	6.0	6.0	2024/08
1992/09	8,536.0	8,190.0	0.0	6,146.8	0.0	2024/09
1992/10	12,869.0	13,721.0	852.0	8,233.4	0.0	2024/10
1992/11	15,837.5	18,339.0	2,501.5	11,357.4	0.0	2024/11
1992/12	14,804.0	16,032.0	1,228.0	10,171.8	0.0	2024/12
1993/01	3,935.3	126,773.0	122,837.7	125,992.7	119,303.8	2025/01
1993/02	0.0	138,109.0	138,109.0	136,968.6	136,968.6	2025/02
1993/03	0.0	44,850.0	44,850.0	41,208.0	41,208.0	2025/03
1993/04	0.0	41,514.0	41,514.0	37,576.9	37,576.9	2025/04
1993/05	0.0	31,226.0	31,226.0	21,725.0	21,725.0	2025/05
1993/06	0.0	9,965.0	9,965.0	9,929.1	9,929.1	2025/06

Tabe 2. Estimated San Gabriel River Flow Rates between Morris Dam and Gaging Station F190 (unit: AF).

3D Basin Model Period Year/ Month	Between USG-3 and U8-R			Between U8-R and F-190R		Projected Model Period Year/ Month
	(1) Measured USG-3 Imported	(2) U8-R Gaging Station	(3)* Estimated Morris Dam Release (2) - (1)	(5) Measured F190 Gaging Station	(6)* Estimated F190R Gaging Station (No USG-3)	
1993/07	0.0	11,745.0	11,745.0	10,206.1	10,206.1	2025/07
1993/08	0.0	11,473.0	11,473.0	9,501.6	9,501.6	2025/08
1993/09	0.0	10,560.0	10,560.0	9,721.8	9,721.8	2025/09
1993/10	0.0	10,596.0	10,596.0	9,582.0	9,582.0	2025/10
1993/11	0.0	2,836.0	2,836.0	2,630.5	2,630.5	2025/11
1993/12	0.0	2,007.0	2,007.0	1,648.7	1,648.7	2025/12
1994/01	0.0	261.0	261.0	208.3	208.3	2026/01
1994/02	0.0	1,069.0	1,069.0	1,103.6	1,103.6	2026/02
1994/03	0.0	40.5	40.5	57.9	57.9	2026/03
1994/04	5,756.7	4,106.0	0.0	4,650.8	0.0	2026/04
1994/05	16,861.8	13,916.0	0.0	13,009.6	0.0	2026/05
1994/06	7,025.1	6,224.0	0.0	5,091.8	0.0	2026/06
1994/07	0.0	387.0	387.0	285.8	285.8	2026/07
1994/08	0.0	376.0	376.0	393.9	393.9	2026/08
1994/09	0.0	39.1	39.1	0.0	0.0	2026/09
1994/10	4,434.7	430.0	0.0	1,236.9	0.0	2026/10
1994/11	3,287.1	4,380.0	1,092.9	2,090.8	0.0	2026/11
1994/12	8,076.9	13,488.0	5,411.1	9,186.1	1,877.3	2026/12
1995/01	0.0	19,296.0	19,296.0	17,493.6	17,493.6	2027/01
1995/02	0.0	36,526.0	36,526.0	31,124.6	31,124.6	2027/02
1995/03	0.0	29,720.0	29,720.0	69,318.3	69,318.3	2027/03
1995/04	0.0	20,967.0	20,967.0	27,477.0	27,477.0	2027/04
1995/05	0.0	11,263.0	11,263.0	17,189.4	17,189.4	2027/05
1995/06	0.0	18,522.0	18,522.0	8,167.1	8,167.1	2027/06
1995/07	0.0	3,288.0	3,288.0	14,494.8	14,494.8	2027/07
1995/08	0.0	384.0	384.0	3,280.1	3,280.1	2027/08
1995/09	0.0	0.0	0.0	0.0	0.0	2027/09
1995/10	0.0	6,742.9	6,742.9	8,784.2	8,784.2	2027/10
1995/11	0.0	6,352.5	6,352.5	0.0	0.0	2027/11
1995/12	0.0	5,192.3	5,192.3	0.0	0.0	2027/12
1996/01	0.0	14,806.8	14,806.8	113.5	113.5	2028/01
1996/02	0.0	17,234.6	17,234.6	2,586.4	2,586.4	2028/02
1996/03	0.0	17,745.9	17,745.9	1,596.1	1,596.1	2028/03
1996/04	9,799.9	11,718.2	1,918.3	6,190.4	0.0	2028/04
1996/05	10,404.8	12,043.5	1,638.7	7,684.8	0.0	2028/05
1996/06	0.0	7,966.0	7,966.0	11,513.9	11,513.9	2028/06
1996/07	8,163.3	5,960.4	0.0	5,247.0	0.0	2028/07
1996/08	14,551.5	4,611.9	0.0	10,835.7	0.0	2028/08
1996/09	16,518.8	5,153.3	0.0	13,393.8	0.0	2028/09
1996/10	0.0	3,230.0	3,230.0	2,104.0	2,104.0	2028/10

Tabe 2. Estimated San Gabriel River Flow Rates between Morris Dam and Gaging Station F190 (unit: AF).

3D Basin Model Period Year/ Month	Between USG-3 and U8-R			Between U8-R and F-190R		Projected Model Period Year/ Month
	(1) Measured USG-3 Imported	(2) U8-R Gaging Station	(3)* Estimated Morris Dam Release (2) - (1)	(5) Measured F190 Gaging Station	(6)* Estimated F190R Gaging Station (No USG-3)	
1996/11	0.0	155.0	155.0	13.4	13.4	2028/11
1996/12	6,799.2	6,440.0	0.0	5,037.0	0.0	2028/12
1997/01	1,058.6	8,020.0	6,961.4	8,423.5	3,427.6	2029/01
1997/02	0.0	7,420.0	7,420.0	6,331.7	6,331.7	2029/02
1997/03	0.0	1,010.0	1,010.0	717.6	717.6	2029/03
1997/04	0.0	53.0	53.0	13.7	13.7	2029/04
1997/05	0.0	47.0	47.0	0.0	0.0	2029/05
1997/06	4,767.4	5,690.0	922.6	3,123.6	0.0	2029/06
1997/07	16,223.8	18,450.0	2,226.2	12,950.9	0.0	2029/07
1997/08	8,455.2	10,470.0	2,014.8	4,863.8	0.0	2029/08
1997/09	3,620.6	4,360.0	739.4	1,523.3	0.0	2029/09
1997/10	6,388.5	7,030.0	641.5	3,845.2	0.0	2029/10
1997/11	5,223.8	5,770.0	546.2	2,834.2	0.0	2029/11
1997/12	10,632.0	10,090.0	0.0	5,992.5	0.0	2029/12
1998/01	9,467.8	8,790.0	0.0	5,836.0	0.0	2030/01
1998/02	0.0	39,040.0	39,040.0	43,325.9	43,325.9	2030/02
1998/03	0.0	26,040.0	26,040.0	25,336.0	25,336.0	2030/03
1998/04	0.0	24,840.0	24,840.0	23,366.8	23,366.8	2030/04
1998/05	0.0	76,300.0	76,300.0	66,801.0	66,801.0	2030/05
1998/06	0.0	29,970.0	29,970.0	26,871.5	26,871.5	2030/06
1998/07	0.0	19,470.0	19,470.0	10,115.7	10,115.7	2030/07
1998/08	0.0	13,210.0	13,210.0	9,244.7	9,244.7	2030/08
1998/09	0.0	3,410.0	3,410.0	2,275.0	2,275.0	2030/09
1998/10	0.0	2,660.0	2,660.0	2,451.8	2,451.8	2030/10
1998/11	0.0	4,660.0	4,660.0	3,911.3	3,911.3	2030/11
1998/12	0.0	2,000.0	2,000.0	1,672.9	1,672.9	2030/12
1999/01	0.0	53.0	53.0	144.8	144.8	2031/01
1999/02	0.0	218.0	218.0	190.4	190.4	2031/02
1999/03	0.0	1,680.0	1,680.0	1,215.6	1,215.6	2031/03
1999/04	0.0	1,670.0	1,670.0	1,242.6	1,242.6	2031/04
1999/05	0.0	157.0	157.0	75.3	75.3	2031/05
1999/06	0.0	194.0	194.0	160.8	160.8	2031/06
1999/07	0.0	2,240.0	2,240.0	2,266.1	2,266.1	2031/07
1999/08	0.0	4,450.0	4,450.0	3,891.2	3,891.2	2031/08
1999/09	0.0	3,990.0	3,990.0	3,209.1	3,209.1	2031/09
1999/10	0.0	2,880.0	2,880.0	476.0	476.0	2031/10
1999/11	0.0	1,400.0	1,400.0	19.4	19.4	2031/11
1999/12	0.0	380.0	380.0	168.4	168.4	2031/12
2000/01	1,290.9	4,110.0	2,819.1	591.0	0.0	2032/01
2000/02	6,569.4	4,870.0	0.0	2,659.0	0.0	2032/02

Tabe 2. Estimated San Gabriel River Flow Rates between Morris Dam and Gaging Station F190 (unit: AF).

3D Basin Model Period Year/ Month	Between USG-3 and U8-R			Between U8-R and F-190R		Projected Model Period Year/ Month
	(1) Measured USG-3 Imported	(2) U8-R Gaging Station	(3)* Estimated Morris Dam Release (2) - (1)	(5) Measured F190 Gaging Station	(6)* Estimated F190R Gaging Station (No USG-3)	
2000/03	7,737.4	3,350.0	0.0	3,860.4	0.0	2032/03
2000/04	5,982.0	2,680.0	0.0	2,992.9	0.0	2032/04
2000/05	0.0	4,040.0	4,040.0	3,466.3	3,466.3	2032/05
2000/06	0.0	4,390.0	4,390.0	3,098.8	3,098.8	2032/06
2000/07	0.0	1,860.0	1,860.0	1,501.8	1,501.8	2032/07
2000/08	0.0	5,880.0	5,880.0	4,717.2	4,717.2	2032/08
2000/09	0.0	7,110.0	7,110.0	6,136.9	6,136.9	2032/09
2000/10	0.0	4,790.0	4,790.0	4,659.5	4,659.5	2032/10
2000/11	0.0	11,070.0	11,070.0	9,673.4	9,673.4	2032/11
2000/12	10,698.3	9,730.0	0.0	6,722.4	0.0	2032/12
2001/01	2,377.3	1,390.0	0.0	939.5	0.0	2033/01
2001/02	0.0	156.0	156.0	772.0	772.0	2033/02
2001/03	0.0	182.0	182.0	162.8	162.8	2033/03
2001/04	0.0	164.0	164.0	83.3	83.3	2033/04
2001/05	0.0	215.0	215.0	96.7	96.7	2033/05
2001/06	0.0	146.0	146.0	111.9	111.9	2033/06
2001/07	0.0	4,010.0	4,010.0	3,224.9	3,224.9	2033/07
2001/08	0.0	8,630.0	8,630.0	4,831.7	4,831.7	2033/08
2001/09	0.0	6,760.0	6,760.0	1,935.3	1,935.3	2033/09
2001/10	10,883.9	11,920.0	1,036.1	6,695.6	0.0	2033/10
2001/11	10,248.9	8,280.0	0.0	5,759.0	0.0	2033/11
2001/12	3,669.3	1,750.0	0.0	2,793.8	0.0	2033/12
2002/01	0.0	190.0	190.0	77.5	77.5	2034/01
2002/02	0.0	215.0	215.0	33.4	33.4	2034/02
2002/03	0.0	1,940.0	1,940.0	17.3	17.3	2034/03
2002/04	0.0	1,930.0	1,930.0	541.0	541.0	2034/04
2002/05	0.0	3,570.0	3,570.0	0.0	0.0	2034/05
2002/06	0.0	5,340.0	5,340.0	0.0	0.0	2034/06
2002/07	0.0	4,380.0	4,380.0	0.0	0.0	2034/07
2002/08	0.0	4,110.0	4,110.0	0.0	0.0	2034/08
2002/09	0.0	3,790.0	3,790.0	0.0	0.0	2034/09
2002/10	0.0	5,190.0	5,190.0	438.5	438.5	2034/10
2002/11	0.0	6,250.0	6,250.0	1,389.1	1,389.1	2034/11
2002/12	1,017.1	4,940.0	3,922.9	1,122.0	389.1	2034/12
2003/01	1,840.3	3,710.0	1,869.7	837.5	0.0	2035/01
2003/02	0.0	1,660.0	1,660.0	576.4	576.4	2035/02
2003/03	0.0	4,090.0	4,090.0	1,769.5	1,769.5	2035/03
2003/04	0.0	4,180.0	4,180.0	232.4	232.4	2035/04
2003/05	4,533.0	8,580.0	4,047.0	3,970.1	513.1	2035/05
2003/06	0.0	8,100.0	8,100.0	4,275.9	4,275.9	2035/06

Tabe 2. Estimated San Gabriel River Flow Rates between Morris Dam and Gaging Station F190 (unit: AF).

3D Basin Model Period Year/ Month	Between USG-3 and U8-R			Between U8-R and F-190R		Projected Model Period Year/ Month
	(1) Measured USG-3 Imported	(2) U8-R Gaging Station	(3)* Estimated Morris Dam Release (2) - (1)	(5) Measured F190 Gaging Station	(6)* Estimated F190R Gaging Station (No USG-3)	
2003/07	0.0	8,890.0	8,890.0	4,070.2	4,070.2	2035/07
2003/08	3,448.7	11,830.0	8,381.3	6,748.6	4,847.4	2035/08
2003/09	14,804.3	17,850.0	3,045.7	11,674.7	0.0	2035/09
2003/10	12,986.1	15,680.0	2,693.9	2,793.0	0.0	2035/10
2003/11	6,059.4	5,780.0	0.0	4,001.9	0.0	2035/11
2003/12	7,573.1	6,300.0	0.0	5,368.5	0.0	2035/12
2004/01	4,509.6	14,560.0	10,050.4	11,059.4	6,516.6	2036/01
2004/02	4,412.7	3,560.0	0.0	3,570.7	0.0	2036/02
2004/03	4,668.0	7,290.0	2,622.0	6,121.0	0.0	2036/03
2004/04	0.0	169.0	169.0	0.0	0.0	2036/04
2004/05	0.0	568.0	568.0	0.0	0.0	2036/05
2004/06	0.0	1,960.0	1,960.0	10.5	10.5	2036/06
2004/07	0.0	2,710.0	2,710.0	0.0	0.0	2036/07
2004/08	0.0	2,760.0	2,760.0	0.0	0.0	2036/08
2004/09	0.0	2,920.0	2,920.0	0.0	0.0	2036/09
2004/10	0.0	3,540.0	3,540.0	1,010.4	1,010.4	2036/10
2004/11	4,001.5	5,810.0	1,808.5	3,250.3	0.0	2036/11
2004/12	3,049.9	4,120.0	1,070.1	3,823.7	0.0	2036/12
2005/01	0.0	195,500.0	195,500.0	183,683.5	183,683.5	2037/01
2005/02	0.0	138,500.0	138,500.0	132,478.0	132,478.0	2037/02
2005/03	0.0	55,610.0	55,610.0	52,409.3	52,409.3	2037/03
2005/04	0.0	42,120.0	42,120.0	38,757.8	38,757.8	2037/04
2005/05	0.0	35,810.0	35,810.0	29,904.8	29,904.8	2037/05
2005/06	0.0	19,560.0	19,560.0	14,987.1	14,987.1	2037/06
2005/07	0.0	8,010.0	8,010.0	5,357.8	5,357.8	2037/07
2005/08	6,836.8	17,870.0	11,033.2	12,511.3	7,499.4	2037/08
2005/09	0.0	14,840.0	14,840.0	10,097.9	10,097.9	2037/09
2005/10	4,459.2	11,140.0	6,680.8	7,637.2	3,146.9	2037/10
2005/11	13,453.1	15,340.0	1,886.9	11,929.2	0.0	2037/11
2005/12	9,581.9	14,370.0	4,788.1	7,676.5	1,254.3	2037/12
2006/01	8,154.2	11,440.0	3,285.8	5,917.0	0.0	2038/01
2006/02	9,324.9	10,660.0	1,335.1	7,853.4	0.0	2038/02
2006/03	12,949.6	12,390.0	0.0	12,649.6	0.0	2038/03
2006/04	5,049.0	23,410.0	18,361.0	21,522.4	14,827.2	2038/04
2006/05	0.0	31,740.0	31,740.0	24,616.9	24,616.9	2038/05
2006/06	0.0	8,610.0	8,610.0	2,385.7	2,385.7	2038/06
2006/07	0.0	6,270.0	6,270.0	2,489.5	2,489.5	2038/07
2006/08	0.0	5,060.0	5,060.0	876.0	876.0	2038/08
2006/09	0.0	5,160.0	5,160.0	1,488.0	1,488.0	2038/09
2006/10	0.0	3,660.0	3,660.0	1,495.9	1,495.9	2038/10

Tabe 2. Estimated San Gabriel River Flow Rates between Morris Dam and Gaging Station F190 (unit: AF).

3D Basin Model Period Year/ Month	Between USG-3 and U8-R			Between U8-R and F-190R		Projected Model Period Year/ Month
	(1) Measured USG-3 Imported	(2) U8-R Gaging Station	(3)* Estimated Morris Dam Release (2) - (1)	(5) Measured F190 Gaging Station	(6)* Estimated F190R Gaging Station (No USG-3)	
2006/11	0.0	5,170.0	5,170.0	1,467.3	1,467.3	2038/11
2006/12	0.0	1,370.0	1,370.0	0.0	0.0	2038/12
2007/01	0.0	190.0	190.0	0.0	0.0	2039/01
2007/02	0.0	143.0	143.0	0.0	0.0	2039/02
2007/03	0.0	157.0	157.0	0.0	0.0	2039/03
2007/04	0.0	727.0	727.0	0.0	0.0	2039/04
2007/05	0.0	680.0	680.0	0.0	0.0	2039/05
2007/06	0.0	563.0	563.0	0.0	0.0	2039/06
2007/07	0.0	2,570.0	2,570.0	0.0	0.0	2039/07
2007/08	0.0	2,610.0	2,610.0	0.0	0.0	2039/08
2007/09	0.0	2,510.0	2,510.0	0.0	0.0	2039/09
2007/10	0.0	2,770.0	2,770.0	0.0	0.0	2039/10
2007/11	0.0	3,420.0	3,420.0	0.0	0.0	2039/11
2007/12	0.0	3,410.0	3,410.0	0.0	0.0	2039/12
2008/01	0.0	3,440.0	3,440.0	1,045.8	1,045.8	2040/01
2008/02	0.0	4,780.0	4,780.0	27.3	27.3	2040/02
2008/03	2,793.8	4,500.0	1,706.2	2,047.3	0.0	2040/03
2008/04	797.1	2,010.0	1,212.9	146.4	0.0	2040/04
2008/05	0.0	2,860.0	2,860.0	100.7	100.7	2040/05
2008/06	0.0	2,680.0	2,680.0	0.0	0.0	2040/06
2008/07	0.0	21,910.0	21,910.0	8,854.2	8,854.2	2040/07
2008/08	0.0	13,290.0	13,290.0	6,951.0	6,951.0	2040/08
2008/09	0.0	13,180.0	13,180.0	6,728.0	6,728.0	2040/09
2008/10	0.0	7,830.0	7,830.0	1,718.2	1,718.2	2040/10
2008/11	0.0	1,790.0	1,790.0	0.0	0.0	2040/11
2008/12	0.0	1,400.0	1,400.0	0.0	0.0	2040/12
2009/01	0.0	878.0	878.0	0.0	0.0	2041/01
2009/02	0.0	239.0	239.0	1,097.3	1,097.3	2041/02
2009/03	0.0	2,030.0	2,030.0	100.1	100.1	2041/03
2009/04	0.0	723.0	723.0	0.0	0.0	2041/04
2009/05	0.0	79.0	79.0	0.0	0.0	2041/05
2009/06	0.0	70.0	70.0	0.0	0.0	2041/06
2009/07	0.0	10,090.0	10,090.0	4,722.6	4,722.6	2041/07
2009/08	0.0	81.0	81.0	0.0	0.0	2041/08
2009/09	0.0	274.0	274.0	0.0	0.0	2041/09
2009/10	0.0	1,330.0	1,330.0	0.0	0.0	2041/10
2009/11	0.0	277.0	277.0	0.0	0.0	2041/11
2009/12	0.0	1,760.0	1,760.0	51.3	51.3	2041/12
2010/01	0.0	3,830.0	3,830.0	364.3	364.3	2042/01
2010/02	0.0	3,730.0	3,730.0	211.3	211.3	2042/02

Tabe 2. Estimated San Gabriel River Flow Rates between Morris Dam and Gaging Station F190 (unit: AF).

3D Basin Model Period Year/ Month	Between USG-3 and U8-R			Between U8-R and F-190R		Projected Model Period Year/ Month
	(1) Measured USG-3 Imported	(2) U8-R Gaging Station	(3)* Estimated Morris Dam Release (2) - (1)	(5) Measured F190 Gaging Station	(6)* Estimated F190R Gaging Station (No USG-3)	
2010/03	0.0	12,420.0	12,420.0	6,598.9	6,598.9	2042/03
2010/04	9,345.2	28,200.0	18,854.8	19,392.4	15,321.0	2042/04
2010/05	3,263.4	20,020.0	16,756.6	12,887.3	13,222.8	2042/05
2010/06	4,324.8	23,020.0	18,695.2	15,522.6	15,161.3	2042/06
2010/07	0.0	16,150.0	16,150.0	9,736.7	9,736.7	2042/07
2010/08	0.0	3,370.0	3,370.0	0.0	0.0	2042/08
2010/09	9,577.3	15,100.0	5,522.7	7,189.9	1,988.9	2042/09
2010/10	13,050.8	20,920.0	7,869.2	13,825.0	4,335.3	2042/10
2010/11	10,283.3	22,470.0	12,186.7	16,429.1	8,652.9	2042/11
2010/12	0.0	24,550.0	24,550.0	22,056.4	22,056.4	2042/12
2011/01	0.0	24,110.0	24,110.0	20,318.3	20,318.3	2043/01
2011/02	0.0	10,750.0	10,750.0	9,899.1	9,899.1	2043/02
2011/03	1,715.0	27,680.0	25,965.0	24,866.8	22,431.2	2043/03
2011/04	4,768.4	26,950.0	22,181.6	23,345.5	18,647.7	2043/04
2011/05	1,708.9	22,410.0	20,701.1	19,134.5	17,167.2	2043/05
2011/06	285.8	21,310.0	21,024.2	19,560.0	17,490.3	2043/06
2011/07	18,717.8	16,870.0	0.0	15,006.1	0.0	2043/07
2011/08	9,493.4	11,200.0	1,706.6	8,813.4	0.0	2043/08
2011/09	0.0	17,380.0	17,380.0	11,750.9	11,750.9	2043/09
2011/10	0.0	17,430.0	17,430.0	12,576.1	12,576.1	2043/10
2011/11	0.0	10,960.0	10,960.0	8,000.2	8,000.2	2043/11
2011/12	0.0	3,460.0	3,460.0	2,406.8	2,406.8	2043/12
2012/01	0.0	348.0	348.0	26.5	26.5	2044/01
2012/02	0.0	466.0	466.0	0.0	0.0	2044/02
2012/03	0.0	758.0	758.0	259.9	259.9	2044/03
2012/04	0.0	154.0	154.0	0.0	0.0	2044/04
2012/05	0.0	129.0	129.0	9.0	9.0	2044/05
2012/06	0.0	117.0	117.0	0.0	0.0	2044/06
2012/07	0.0	96.0	96.0	0.0	0.0	2044/07
2012/08	0.0	78.0	78.0	0.0	0.0	2044/08
2012/09	0.0	1,160.0	1,160.0	0.0	0.0	2044/09
2012/10	6,256.2	10,550.0	4,293.8	3,712.7	760.0	2044/10
2012/11	2,601.2	3,210.0	608.8	1,403.6	0.0	2044/11
2012/12	2,383.7	376.0	0.0	584.7	0.0	2044/12
2013/01	0.0	2,240.0	2,240.0	0.0	0.0	2045/01
2013/02	0.0	1,060.0	1,060.0	0.0	0.0	2045/02
2013/03	0.0	1,030.0	1,030.0	0.0	0.0	2045/03
2013/04	0.0	1,570.0	1,570.0	0.0	0.0	2045/04
2013/05	0.0	745.0	745.0	0.0	0.0	2045/05
2013/06	0.0	475.0	475.0	0.0	0.0	2045/06

Tabe 2. Estimated San Gabriel River Flow Rates between Morris Dam and Gaging Station F190 (unit: AF).

3D Basin Model Period Year/ Month	Between USG-3 and U8-R			Between U8-R and F-190R		Projected Model Period Year/ Month
	(1) Measured USG-3 Imported	(2) U8-R Gaging Station	(3)* Estimated Morris Dam Release (2) - (1)	(5) Measured F190 Gaging Station	(6)* Estimated F190R Gaging Station (No USG-3)	
2013/07	0.0	686.0	686.0	0.0	0.0	2045/07
2013/08	0.0	190.0	190.0	0.0	0.0	2045/08
2013/09	0.0	1.2	1.2	0.0	0.0	2045/09
2013/10	9,871.0	15,880.0	6,009.0	5,530.7	2,475.1	2045/10
2013/11	5,231.8	6,740.0	1,508.2	3,588.6	0.0	2045/11
2013/12	2,775.9	3,770.0	994.2	1,879.1	0.0	2045/12
2014/01	0.0	27.0	27.0	0.0	0.0	2046/01
2014/02	0.0	2,600.0	2,600.0	12.2	12.2	2046/02
2014/03	4,193.4	3,370.0	0.0	474.3	0.0	2046/03
2014/04	502.9	945.0	442.1	53.0	0.0	2046/04
2014/05	0.0	1,100.0	1,100.0	0.0	0.0	2046/05
2014/06	0.0	1,280.0	1,280.0	0.0	0.0	2046/06
2014/07	0.0	1,620.0	1,620.0	0.0	0.0	2046/07
2014/08	0.0	2,200.0	2,200.0	0.0	0.0	2046/08
2014/09	0.0	1,680.0	1,680.0	0.0	0.0	2046/09
2014/10	1,338.2	2,690.0	1,351.9	0.0	0.0	2046/10
2014/11	3,617.5	3,510.0	0.0	0.0	0.0	2046/11
2014/12	3,232.5	3,230.0	0.0	70.9	0.0	2046/12
2015/01	2,859.2	3,210.0	350.8	0.0	0.0	2047/01
2015/02	3,000.6	3,230.0	229.4	0.0	0.0	2047/02
2015/03	3,638.8	3,620.0	0.0	0.0	0.0	2047/03
2015/04	3,575.5	3,590.0	14.5	0.0	0.0	2047/04
2015/05	3,630.4	3,730.0	99.6	0.0	0.0	2047/05
2015/06	3,355.2	3,440.0	84.8	139.1	0.0	2047/06

Note:
* Estimated flow data will be applied to the predictive simulation between 2015/Q3 and 2047/Q2.

Table 3. Simulation Period (FY2015-16 to FY2046-47) Baseline Delivery (39 MGD or 43,250 AFY).

Historical Spreading at SFSG (unit: acre-feet)

Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]
1983/Q3	10,369	0	0	10,369
1983/Q4	7,141	0	0	7,141
1984/Q1	9,982	0	0	9,982
1984/Q2	0	0	0	0
Subtotal	***27,492***	***0***	***0***	***27,492***
1984/Q3	0	0	0	0
1984/Q4	0	0	0	0
1985/Q1	8,468	0	0	8,468
1985/Q2	0	0	0	0
Subtotal	8,468	0	0	8,468
1985/Q3	0	2,153	0	2,153
1985/Q4	0	22,827	0	22,827
1986/Q1	11,604	8,428	0	20,031
1986/Q2	0	0	0	0
Subtotal	11,604	33,408	0	45,011
1986/Q3	0	0	0	0
1986/Q4	0	6,908	0	6,908
1987/Q1	0	13,630	0	13,630
1987/Q2	0	3,475	0	3,475
Subtotal	0	24,013	0	24,013
1987/Q3	0	0	0	0
1987/Q4	188	5,496	0	5,684
1988/Q1	19	13,320	0	13,339
1988/Q2	97	0	0	97
Subtotal	304	18,816	0	19,120
1988/Q3	0	0	0	0
1988/Q4	231	6,748	0	6,979
1989/Q1	0	18,114	0	18,114
1989/Q2	0	2,286	0	2,286
Subtotal	231	27,148	0	27,379

Projected Spreading with MWD Delivery (unit: acre-feet)

Projected Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Annual Production
2015/Q3	10,369	0	10,813	21,181	
2015/Q4	7,141	0	10,813	17,954	
2016/Q1	9,982	0	10,813	20,794	
2016/Q2	0	0	10,813	10,813	
Subtotal	***27,492***	***0***	***43,250***	***70,742***	***193,187***
2016/Q3	0	0	10,813	10,813	
2016/Q4	0	0	10,813	10,813	
2017/Q1	8,468	0	10,813	19,280	
2017/Q2	0	0	10,813	10,813	
Subtotal	***8,468***	***0***	***43,250***	***51,718***	***191,058***
2017/Q3	0	0	10,813	10,813	
2017/Q4	0	0	10,813	10,813	
2018/Q1	11,604	0	10,813	22,416	
2018/Q2	0	0	10,813	10,813	
Subtotal	***11,604***	***0***	***43,250***	***54,854***	***189,109***
2018/Q3	0	0	10,813	10,813	
2018/Q4	0	0	10,813	10,813	
2019/Q1	0	0	10,813	10,813	
2019/Q2	0	0	10,813	10,813	
Subtotal	***0***	***0***	***43,250***	***43,250***	***187,342***
2019/Q3	0	0	10,813	10,813	
2019/Q4	188	0	10,813	11,000	
2020/Q1	19	0	10,813	10,832	
2020/Q2	97	0	10,813	10,909	
Subtotal	***304***	***0***	***43,250***	***43,554***	***189,993***
2020/Q3	0	0	10,813	10,813	
2020/Q4	231	0	10,813	11,044	
2021/Q1	0	0	10,813	10,813	
2021/Q2	0	0	10,813	10,813	
Subtotal	***231***	***0***	***43,250***	***43,481***	***188,566***

Table 3. Simulation Period (FY2015-16 to FY2046-47) Baseline Delivery (39 MGD or 43,250 AFY).

Historical Spreading at SFSG (unit: acre-feet)					Projected Spreading with MWD Delivery (unit: acre-feet)					
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Annual Production
1989/Q3	0	0	0	0	2021/Q3	0	0	10,813	10,813	
1989/Q4	0	0	0	0	2021/Q4	0	0	10,813	10,813	
1990/Q1	0	5,196	0	5,196	2022/Q1	0	0	10,813	10,813	
1990/Q2	0	5,271	0	5,271	2022/Q2	0	0	10,813	10,813	
Subtotal	0	10,467	0	10,467	***Subtotal***	***0***	***0***	***43,250***	***43,250***	***188,601***
1990/Q3	0	3,130	0	3,130	2022/Q3	0	0	10,813	10,813	
1990/Q4	0	2,640	0	2,640	2022/Q4	0	0	10,813	10,813	
1991/Q1	122	2,094	0	2,216	2023/Q1	122	0	10,813	10,935	
1991/Q2	0	3,070	0	3,070	2023/Q2	0	0	10,813	10,813	
Subtotal	122	10,934	0	11,056	***Subtotal***	***122***	***0***	***43,250***	***43,372***	***188,630***
1991/Q3	0	6,466	0	6,466	2023/Q3	0	0	10,813	10,813	
1991/Q4	0	0	0	0	2023/Q4	0	0	10,813	10,813	
1992/Q1	13,913	6,297	0	20,210	2024/Q1	13,913	0	10,813	24,725	
1992/Q2	24,020	0	0	24,020	2024/Q2	24,020	0	10,813	34,833	
Subtotal	37,933	12,763	0	50,696	***Subtotal***	***37,933***	***0***	***43,250***	***81,183***	***188,658***
1992/Q3	3,150	2,100	0	5,250	2024/Q3	3,150	0	10,813	13,963	
1992/Q4	0	7,363	0	7,363	2024/Q4	0	0	10,813	10,813	
1993/Q1	22,298	3,935	0	26,233	2025/Q1	22,298	0	10,813	33,110	
1993/Q2	31,510	0	0	31,510	2025/Q2	31,510	0	10,813	42,323	
Subtotal	56,958	13,398	0	70,356	***Subtotal***	***56,958***	***0***	***43,250***	***100,208***	***188,697***
1993/Q3	8,420	0	0	8,420	2025/Q3	8,420	0	10,813	19,233	
1993/Q4	7,110	0	0	7,110	2025/Q4	7,110	0	10,813	17,923	
1994/Q1	0	0	0	0	2026/Q1	0	0	10,813	10,813	
1994/Q2	0	13,720	0	13,720	2026/Q2	0	0	10,813	10,813	
Subtotal	15,530	13,720	0	29,250	***Subtotal***	***15,530***	***0***	***43,250***	***58,780***	***189,124***
1994/Q3	338	0	0	338	2026/Q3	338	0	10,813	11,151	
1994/Q4	0	0	0	0	2026/Q4	0	0	10,813	10,813	
1995/Q1	0	0	0	0	2027/Q1	0	0	10,813	10,813	
1995/Q2	11,862	0	0	11,862	2027/Q2	11,862	0	10,813	22,675	
Subtotal	12,200	0	0	12,200	***Subtotal***	***12,200***	***0***	***43,250***	***55,450***	***189,548***

Table 3. Simulation Period (FY2015-16 to FY2046-47) Baseline Delivery (39 MGD or 43,250 AFY).

Historical Spreading at SFSG (unit: acre-feet)					Projected Spreading with MWD Delivery (unit: acre-feet)					
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Annual Production
1995/Q3	19,085	0	0	19,085	2027/Q3	19,085	0	10,813	29,898	
1995/Q4	2,420	0	0	2,420	2027/Q4	2,420	0	10,813	13,233	
1996/Q1	9,223	0	0	9,223	2028/Q1	9,223	0	10,813	20,036	
1996/Q2	0	0	0	0	2028/Q2	0	0	10,813	10,813	
Subtotal	30,728	0	0	30,728	***Subtotal***	***30,728***	***0***	***43,250***	***73,978***	***189,974***
1996/Q3	0	7,760	0	7,760	2028/Q3	0	0	10,813	10,813	
1996/Q4	4,280	915	0	5,195	2028/Q4	4,280	0	10,813	15,093	
1997/Q1	8,688	0	0	8,688	2029/Q1	8,688	0	10,813	19,501	
1997/Q2	34,723	4,767	0	39,490	2029/Q2	34,723	0	10,813	45,535	
Subtotal	47,691	13,442	0	61,133	***Subtotal***	***47,691***	***0***	***43,250***	***90,941***	***190,402***
1997/Q3	385	12,475	0	12,860	2029/Q3	385	0	10,813	11,197	
1997/Q4	0	2,420	0	2,420	2029/Q4	0	0	10,813	10,813	
1998/Q1	5,013	4,210	0	9,223	2030/Q1	5,013	0	10,813	15,826	
1998/Q2	0	0	0	0	2030/Q2	0	0	10,813	10,813	
Subtotal	5,398	19,105	0	24,503	***Subtotal***	***5,398***	***0***	***43,250***	***48,648***	***190,826***
1998/Q3	7,760	0	0	7,760	2030/Q3	7,760	0	10,813	18,573	
1998/Q4	0	0	0	0	2030/Q4	0	0	10,813	10,813	
1999/Q1	0	0	0	0	2031/Q1	0	0	10,813	10,813	
1999/Q2	0	0	0	0	2031/Q2	0	0	10,813	10,813	
Subtotal	7,760	0	0	7,760	***Subtotal***	***7,760***	***0***	***43,250***	***51,010***	***191,073***
1999/Q3	0	0	0	0	2031/Q3	0	0	10,813	10,813	
1999/Q4	131	0	0	131	2031/Q4	131	0	10,813	10,944	
2000/Q1	0	554	0	554	2032/Q1	0	0	10,813	10,813	
2000/Q2	928	0	0	928	2032/Q2	928	0	10,813	11,741	
Subtotal	1,059	554	0	1,613	***Subtotal***	***1,059***	***0***	***43,250***	***44,309***	***191,320***
2000/Q3	9,162	0	0	9,162	2032/Q3	9,162	0	10,813	19,975	
2000/Q4	12,280	5,950	0	18,230	2032/Q4	12,280	0	10,813	23,093	
2001/Q1	0	576	0	576	2033/Q1	0	0	10,813	10,813	
2001/Q2	0	0	0	0	2033/Q2	0	0	10,813	10,813	
Subtotal	21,442	6,526	0	27,968	***Subtotal***	***21,442***	***0***	***43,250***	***64,692***	***191,570***

Table 3. Simulation Period (FY2015-16 to FY2046-47) Baseline Delivery (39 MGD or 43,250 AFY).

Historical Spreading at SFSG (unit: acre-feet)					**Projected Spreading with MWD Delivery (unit: acre-feet)**					
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Annual Production
2001/Q3	0	0	0	0	2033/Q3	0	0	10,813	10,813	
2001/Q4	0	10,685	0	10,685	2033/Q4	0	0	10,813	10,813	
2002/Q1	0	0	0	0	2034/Q1	0	0	10,813	10,813	
2002/Q2	448	0	0	448	2034/Q2	448	0	10,813	11,261	
Subtotal	448	10,685	0	11,133	***Subtotal***	***448***	***0***	***43,250***	***43,698***	***191,821***
2002/Q3	0	0	0	0	2034/Q3	0	0	10,813	10,813	
2002/Q4	673	516	0	1,189	2034/Q4	673	0	10,813	11,486	
2003/Q1	1,170	514	0	1,684	2035/Q1	1,170	0	10,813	11,983	
2003/Q2	4,285	3,110	0	7,395	2035/Q2	4,285	0	10,813	15,098	
Subtotal	6,128	4,140	0	10,268	***Subtotal***	***6,128***	***0***	***43,250***	***49,378***	***192,073***
2003/Q3	5,971	15,149	0	21,120	2035/Q3	5,971	0	10,813	16,784	
2003/Q4	0	18,785	0	18,785	2035/Q4	0	0	10,813	10,813	
2004/Q1	8,002	12,345	0	20,347	2036/Q1	8,002	0	10,813	18,815	
2004/Q2	0	0	0	0	2036/Q2	0	0	10,813	10,813	
Subtotal	13,974	46,278	0	60,252	***Subtotal***	***13,974***	***0***	***43,250***	***57,224***	***191,676***
2004/Q3	0	0	0	0	2036/Q3	0	0	10,813	10,813	
2004/Q4	0	29	0	29	2036/Q4	0	0	10,813	10,813	
2005/Q1	38,690	0	0	38,690	2037/Q1	38,690	0	10,813	49,503	
2005/Q2	50,860	0	0	50,860	2037/Q2	50,860	0	10,813	61,673	
Subtotal	89,550	29	0	89,579	***Subtotal***	***89,550***	***0***	***43,250***	***132,800***	***192,130***
2005/Q3	18,903	6,837	0	25,740	2037/Q3	18,903	0	10,813	29,716	
2005/Q4	0	17,783	0	17,783	2037/Q4	0	0	10,813	10,813	
2006/Q1	0	19,140	0	19,140	2038/Q1	0	0	10,813	10,813	
2006/Q2	24,284	5,049	0	29,333	2038/Q2	24,284	0	10,813	35,097	
Subtotal	43,187	48,809	0	91,996	***Subtotal***	***43,187***	***0***	***43,250***	***86,437***	***192,585***
2006/Q3	3,373	0	0	3,373	2038/Q3	3,373	0	10,813	14,186	
2006/Q4	1,981	0	0	1,981	2038/Q4	1,981	0	10,813	12,794	
2007/Q1	0	0	0	0	2039/Q1	0	0	10,813	10,813	
2007/Q2	0	0	0	0	2039/Q2	0	0	10,813	10,813	
Subtotal	5,354	0	0	5,354	***Subtotal***	***5,354***	***0***	***43,250***	***48,604***	***193,043***

Table 3. Simulation Period (FY2015-16 to FY2046-47) Baseline Delivery (39 MGD or 43,250 AFY).

Historical Spreading at SFSG (unit: acre-feet)

Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]
2007/Q3	0	0	0	0
2007/Q4	0	0	0	0
2008/Q1	166	1,710	0	1,876
2008/Q2	7	32	0	39
Subtotal	173	1,742	0	1,915
2008/Q3	605	0	0	605
2008/Q4	0	0	0	0
2009/Q1	26	0	0	26
2009/Q2	0	0	0	0
Subtotal	631	0	0	631
2009/Q3	0	0	0	0
2009/Q4	0	0	0	0
2010/Q1	3,780	0	0	3,780
2010/Q2	5,447	16,933	0	22,380
Subtotal	9,227	16,933	0	26,160
2010/Q3	1,597	5,053	0	6,650
2010/Q4	7,050	9,900	0	16,950
2011/Q1	27,495	1,715	0	29,210
2011/Q2	12,417	6,763	0	19,180
Subtotal	48,559	23,431	0	71,990
2011/Q3	6,670	7,330	0	14,000
2011/Q4	11,690	0	0	11,690
2012/Q1	191	0	0	191
2012/Q2	0	0	0	0
Subtotal	18,551	7,330	0	25,881
2012/Q3	0	0	0	0
2012/Q4	0	4,305	0	4,305
2013/Q1	0	0	0	0
2013/Q2	0	0	0	0
Subtotal	0	4,305	0	4,305

Projected Spreading with MWD Delivery (unit: acre-feet)

Projected Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Annual Production
2039/Q3	0	0	10,813	10,813	
2039/Q4	0	0	10,813	10,813	
2040/Q1	166	0	10,813	10,979	
2040/Q2	7	0	10,813	10,820	
Subtotal	***173***	***0***	***43,250***	***43,423***	***193,539***
2040/Q3	605	0	10,813	11,418	
2040/Q4	0	0	10,813	10,813	
2041/Q1	26	0	10,813	10,839	
2041/Q2	0	0	10,813	10,813	
Subtotal	***631***	***0***	***43,250***	***43,881***	***194,001***
2041/Q3	0	0	10,813	10,813	
2041/Q4	0	0	10,813	10,813	
2042/Q1	3,780	0	10,813	14,593	
2042/Q2	5,447	0	10,813	16,259	
Subtotal	***9,227***	***0***	***43,250***	***52,477***	***194,465***
2042/Q3	1,597	0	10,813	12,410	
2042/Q4	7,050	0	10,813	17,863	
2043/Q1	27,495	0	10,813	38,308	
2043/Q2	12,417	0	10,813	23,229	
Subtotal	***48,559***	***0***	***43,250***	***91,809***	***194,931***
2043/Q3	6,670	0	10,813	17,483	
2043/Q4	11,690	0	10,813	22,503	
2044/Q1	191	0	10,813	11,004	
2044/Q2	0	0	10,813	10,813	
Subtotal	***18,551***	***0***	***43,250***	***61,801***	***195,399***
2044/Q3	0	0	10,813	10,813	
2044/Q4	0	0	10,813	10,813	
2045/Q1	0	0	10,813	10,813	
2045/Q2	0	0	10,813	10,813	
Subtotal	***0***	***0***	***43,250***	***43,250***	***195,869***

Table 3. Simulation Period (FY2015-16 to FY2046-47) Baseline Delivery (39 MGD or 43,250 AFY).

Historical Spreading at SFSG (unit: acre-feet)				
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]
2013/Q3	0	0	0	0
2013/Q4	0	9,440	0	9,440
2014/Q1	0	0	0	0
2014/Q2	0	0	0	0
Subtotal	0	9,440	0	9,440
2014/Q3	0	0	0	0
2014/Q4	0	0	0	0
2015/Q1	0	0	0	0
2015/Q2	0	0	0	0
Subtotal	0	0	0	0
GRAND TOTAL	***520,699***	***377,418***	***0***	***898,117***

Projected Spreading with MWD Delivery (unit: acre-feet)					
Projected Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Annual Production
2045/Q3	0	0	10,813	10,813	
2045/Q4	0	0	10,813	10,813	
2046/Q1	0	0	10,813	10,813	
2046/Q2	0	0	10,813	10,813	
Subtotal	***0***	***0***	***43,250***	***43,250***	***196,337***
2046/Q3	0	0	10,813	10,813	
2046/Q4	0	0	10,813	10,813	
2047/Q1	0	0	10,813	10,813	
2047/Q2	0	0	10,813	10,813	
Subtotal	***0***	***0***	***43,250***	***43,250***	***196,811***
GRAND TOTAL	***520,699***	***0***	***1,384,000***	***1,904,699***	***6,132,357***

Table 4. 3D Basin Model Simulated Maximum and Minimum Groundwater Elevations Between FY2015-16 and FY2046-47.

Owner	Well ID	Recordation Number	Land Elev. (feet amsl)	Simulated Water Elevations (feet amsl)			
				Maximum	Date	Minimum	Date
LA County	Key Well (Well 3030F)	NA	389.00	272.20	2037/Q2	173.60	2022/Q4
City of Monrovia	Well 03	1900419	371.00	267.20	2037/Q2	164.60	2015/Q3
City of Monrovia	Well 05	1940104	374.00	269.20	2037/Q2	166.10	2015/Q3
Covina Irrigating Co.	Baldwin 01	1900885	401.00	274.70	2037/Q3	176.20	2015/Q3
Covina Irrigating Co.	Contract Well	1900881	496.00	290.80	2037/Q3	190.90	2015/Q3
Valley County Water District	Palm Well	8000039	364.00	266.80	2037/Q2	170.40	2015/Q3
Valley County Water District	Well SA1-1	8000185	465.00	285.50	2037/Q2	180.80	2015/Q3
Valley County Water District	Well SA1-2	8000186	448.00	282.20	2037/Q3	179.80	2015/Q3
Valley County Water District	Well SA1-3 (Lante Well)	8000060	457.00	285.10	2037/Q3	179.10	2015/Q3
Valley County Water District	Maine West	1900028	426.00	283.20	2037/Q2	174.90	2015/Q3
Valley County Water District	Morada	1900029	484.00	288.60	2037/Q3	186.20	2015/Q3
Valley County Water District	Nixon East	1900032	424.00	283.90	2037/Q2	174.60	2015/Q3
Valley County Water District	Arrow	1900034	456.00	285.60	2037/Q2	179.80	2015/Q3
California American Water Co.	Santa Fe	1900354	513.00	344.70	2037/Q2	192.90	2015/Q3
California American Water Co.	Buena Vista	1900355	451.00	305.50	2037/Q2	180.10	2015/Q3
California American Water Co.	Crown Haven	1903018	572.00	328.10	2037/Q2	190.40	2015/Q3
Conrock (CalMat) Co.	Reliance 1	1903088	550.00	312.40	2037/Q2	189.40	2015/Q3
Azusa Light & Water	Genesis 02	1902537	525.00	294.70	2037/Q3	191.60	2015/Q3
City of Arcadia	Longden 2	1901014	499.00	263.70	2037/Q2	164.20	2015/Q3
City of Arcadia	Peck 1	1902854	336.00	277.80	2037/Q1	156.60	2015/Q3
City of Glendora	Well 07G	1900831	533.00	293.40	2037/Q3	191.10	2015/Q3
City of Glendora	Well 04E	1901524	475.00	288.80	2037/Q3	188.80	2015/Q3
Golden State Water Co.	Graydon 02	1902461	403.00	266.90	2037/Q3	168.20	2015/Q3
City of Arcadia	Live Oak 1	8000127	340.00	267.20	2037/Q1	157.90	2014/Q3

Table 5. The IPR Water Replenishment for Basin Sustainability (62.5 MGD or 70,000 AFY, Scenario 5) from Simulation Period FY2015-16 to FY2046-47.

Historical Spreading at SFSGs (unit: acre-feet)					Modeling with MWD Delivery at SFSGs (62.5 MGD or 70,000 AFY)							
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Simulation Period	(1) SFSGs Delivery	(2) Spillway Delivery	(3) Buena Vista SG Delivery	(4) Hanson Pit Delivery	(5) Peck Road SG Delivery	Total Delivery [(1) to (5)]	Projected Annual Production
1983/Q3	10,369	0	0	10,369	2015/Q3	27,869	0	0	0	0	27,869	
1983/Q4	7,141	0	0	7,141	2015/Q4	24,641	0	0	0	0	24,641	
1984/Q1	9,982	0	0	9,982	2016/Q1	27,482	0	0	0	0	27,482	
1984/Q2	0	0	0	0	2016/Q2	17,500	0	0	0	0	17,500	
Subtotal	***27,492***	***0***	***0***	***27,492***	***Subtotal***	***97,492***	***0***	***0***	***0***	***0***	***97,492***	***193,187***
1984/Q3	0	0	0	0	2016/Q3	17,500	0	0	0	0	17,500	
1984/Q4	0	0	0	0	2016/Q4	17,500	0	0	0	0	17,500	
1985/Q1	8,468	0	0	8,468	2017/Q1	25,968	0	0	0	0	25,968	
1985/Q2	0	0	0	0	2017/Q2	17,500	0	0	0	0	17,500	
Subtotal	***8,468***	***0***	***0***	***8,468***	***Subtotal***	***78,468***	***0***	***0***	***0***	***0***	***78,468***	***191,058***
1985/Q3	0	2,153	0	2,153	2017/Q3	17,500	0	0	0	0	17,500	
1985/Q4	0	22,827	0	22,827	2017/Q4	17,500	0	0	0	0	17,500	
1986/Q1	11,604	8,428	0	20,031	2018/Q1	28,167	937	0	0	0	29,104	
1986/Q2	0	0	0	0	2018/Q2	17,500	0	0	0	0	17,500	
Subtotal	***11,604***	***33,408***	***0***	***45,011***	***Subtotal***	***80,667***	***937***	***0***	***0***	***0***	***81,604***	***189,109***
1986/Q3	0	0	0	0	2018/Q3	17,500	0	0	0	0	17,500	
1986/Q4	0	6,908	0	6,908	2018/Q4	17,500	0	0	0	0	17,500	
1987/Q1	0	13,630	0	13,630	2019/Q1	17,500	0	0	0	0	17,500	
1987/Q2	0	3,475	0	3,475	2019/Q2	17,500	0	0	0	0	17,500	
Subtotal	***0***	***24,013***	***0***	***24,013***	***Subtotal***	***70,000***	***0***	***0***	***0***	***0***	***70,000***	***187,342***
1987/Q3	0	0	0	0	2019/Q3	17,500	0	0	0	0	17,500	
1987/Q4	188	5,496	0	5,684	2019/Q4	17,688	0	0	0	0	17,688	
1988/Q1	19	13,320	0	13,339	2020/Q1	17,519	0	0	0	0	17,519	
1988/Q2	97	0	0	97	2020/Q2	17,597	0	0	0	0	17,597	
Subtotal	***304***	***18,816***	***0***	***19,120***	***Subtotal***	***70,304***	***0***	***0***	***0***	***0***	***70,304***	***189,993***
1988/Q3	0	0	0	0	2020/Q3	17,500	0	0	0	0	17,500	
1988/Q4	231	6,748	0	6,979	2020/Q4	17,731	0	0	0	0	17,731	
1989/Q1	0	18,114	0	18,114	2021/Q1	17,500	0	0	0	0	17,500	
1989/Q2	0	2,286	0	2,286	2021/Q2	17,500	0	0	0	0	17,500	

Table 5. The IPR Water Replenishment for Basin Sustainability (62.5 MGD or 70,000 AFY, Scenario 5) from Simulation Period FY2015-16 to FY2046-47.

Historical Spreading at SFSGs (unit: acre-feet)					Modeling with MWD Delivery at SFSGs (62.5 MGD or 70,000 AFY)							
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Simulation Period	(1) SFSGs Delivery	(2) Spillway Delivery	(3) Buena Vista SG Delivery	(4) Hanson Pit Delivery	(5) Peck Road SG Delivery	Total Delivery [(1) to (5)]	Projected Annual Production
Subtotal	***231***	***27,148***	***0***	***27,379***	***Subtotal***	***70,231***	***0***	***0***	***0***	***0***	***70,231***	***188,566***
1989/Q3	0	0	0	0	2021/Q3	17,500	0	0	0	0	17,500	
1989/Q4	0	0	0	0	2021/Q4	17,500	0	0	0	0	17,500	
1990/Q1	0	5,196	0	5,196	2022/Q1	17,500	0	0	0	0	17,500	
1990/Q2	0	5,271	0	5,271	2022/Q2	17,500	0	0	0	0	17,500	
Subtotal	***0***	***10,467***	***0***	***10,467***	***Subtotal***	***70,000***	***0***	***0***	***0***	***0***	***70,000***	***188,601***
1990/Q3	0	3,130	0	3,130	2022/Q3	17,500	0	0	0	0	17,500	
1990/Q4	0	2,640	0	2,640	2022/Q4	17,500	0	0	0	0	17,500	
1991/Q1	122	2,094	0	2,216	2023/Q1	17,622	0	0	0	0	17,622	
1991/Q2	0	3,070	0	3,070	2023/Q2	17,500	0	0	0	0	17,500	
Subtotal	***122***	***10,934***	***0***	***11,056***	***Subtotal***	***70,122***	***0***	***0***	***0***	***0***	***70,122***	***188,630***
1991/Q3	0	6,466	0	6,466	2023/Q3	17,500	0	0	0	0	17,500	
1991/Q4	0	0	0	0	2023/Q4	17,500	0	0	0	0	17,500	
1992/Q1	13,913	6,297	0	20,210	2024/Q1	31,413	0	0	0	0	31,413	
1992/Q2	24,020	0	0	24,020	2024/Q2	38,877	2,643	0	0	0	41,520	
Subtotal	***37,933***	***12,763***	***0***	***50,696***	***Subtotal***	***105,289***	***2,643***	***0***	***0***	***0***	***107,933***	***188,658***
1992/Q3	3,150	2,100	0	5,250	2024/Q3	20,650	0	0	0	0	20,650	
1992/Q4	0	7,363	0	7,363	2024/Q4	17,500	0	0	0	0	17,500	
1993/Q1	22,298	3,935	0	26,233	2025/Q1	36,755	3,042	0	0	0	39,798	
1993/Q2	31,510	0	0	31,510	2025/Q2	39,632	9,378	0	0	0	49,010	
Subtotal	***56,958***	***13,398***	***0***	***70,356***	***Subtotal***	***114,538***	***12,420***	***0***	***0***	***0***	***126,958***	***188,697***
1993/Q3	8,420	0	0	8,420	2025/Q3	25,920	0	0	0	0	25,920	
1993/Q4	7,110	0	0	7,110	2025/Q4	24,610	0	0	0	0	24,610	
1994/Q1	0	0	0	0	2026/Q1	17,500	0	0	0	0	17,500	
1994/Q2	0	13,720	0	13,720	2026/Q2	17,500	0	0	0	0	17,500	
Subtotal	***15,530***	***13,720***	***0***	***29,250***	***Subtotal***	***85,530***	***0***	***0***	***0***	***0***	***85,530***	***189,124***
1994/Q3	338	0	0	338	2026/Q3	17,838	0	0	0	0	17,838	
1994/Q4	0	0	0	0	2026/Q4	17,500	0	0	0	0	17,500	
1995/Q1	0	0	0	0	2027/Q1	17,500	0	0	0	0	17,500	

Table 5. The IPR Water Replenishment for Basin Sustainability (62.5 MGD or 70,000 AFY, Scenario 5) from Simulation Period FY2015-16 to FY2046-47.

Historical Spreading at SFSGs (unit: acre-feet)				
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]
1995/Q2	11,862	0	0	11,862
Subtotal	***12,200***	***0***	***0***	***12,200***
1995/Q3	19,085	0	0	19,085
1995/Q4	2,420	0	0	2,420
1996/Q1	9,223	0	0	9,223
1996/Q2	0	0	0	0
Subtotal	***30,728***	***0***	***0***	***30,728***
1996/Q3	0	7,760	0	7,760
1996/Q4	4,280	915	0	5,195
1997/Q1	8,688	0	0	8,688
1997/Q2	34,723	4,767	0	39,490
Subtotal	***47,691***	***13,442***	***0***	***61,133***
1997/Q3	385	12,475	0	12,860
1997/Q4	0	2,420	0	2,420
1998/Q1	5,013	4,210	0	9,223
1998/Q2	0	0	0	0
Subtotal	***5,398***	***19,105***	***0***	***24,503***
1998/Q3	7,760	0	0	7,760
1998/Q4	0	0	0	0
1999/Q1	0	0	0	0
1999/Q2	0	0	0	0
Subtotal	***7,760***	***0***	***0***	***7,760***
1999/Q3	0	0	0	0
1999/Q4	131	0	0	131
2000/Q1	0	554	0	554
2000/Q2	928	0	0	928
Subtotal	***1,059***	***554***	***0***	***1,613***
2000/Q3	9,162	0	0	9,162
2000/Q4	12,280	5,950	0	18,230

Modeling with MWD Delivery at SFSGs (62.5 MGD or 70,000 AFY)							
Projected Simulation Period	(1) SFSGs Delivery	(2) Spillway Delivery	(3) Buena Vista SG Delivery	(4) Hanson Pit Delivery	(5) Peck Road SG Delivery	Total Delivery [(1) to (5)]	Projected Annual Production
2027/Q2	29,362	0	0	0	0	29,362	
Subtotal	***82,200***	***0***	***0***	***0***	***0***	***82,200***	***189,548***
2027/Q3	36,585	0	0	0	0	36,585	
2027/Q4	19,920	0	0	0	0	19,920	
2028/Q1	26,723	0	0	0	0	26,723	
2028/Q2	17,500	0	0	0	0	17,500	
Subtotal	***100,728***	***0***	***0***	***0***	***0***	***100,728***	***189,974***
2028/Q3	17,500	0	0	0	0	17,500	
2028/Q4	21,780	0	0	0	0	21,780	
2029/Q1	26,188	0	0	0	0	26,188	
2029/Q2	46,166	6,057	0	0	0	52,223	
Subtotal	***111,634***	***6,057***	***0***	***0***	***0***	***117,691***	***190,402***
2029/Q3	17,885	0	0	0	0	17,885	
2029/Q4	17,500	0	0	0	0	17,500	
2030/Q1	22,513	0	0	0	0	22,513	
2030/Q2	17,500	0	0	0	0	17,500	
Subtotal	***75,398***	***0***	***0***	***0***	***0***	***75,398***	***190,826***
2030/Q3	25,260	0	0	0	0	25,260	
2030/Q4	17,500	0	0	0	0	17,500	
2031/Q1	17,500	0	0	0	0	17,500	
2031/Q2	17,500	0	0	0	0	17,500	
Subtotal	***77,760***	***0***	***0***	***0***	***0***	***77,760***	***191,073***
2031/Q3	17,500	0	0	0	0	17,500	
2031/Q4	17,631	0	0	0	0	17,631	
2032/Q1	17,500	0	0	0	0	17,500	
2032/Q2	18,428	0	0	0	0	18,428	
Subtotal	***71,059***	***0***	***0***	***0***	***0***	***71,059***	***191,320***
2032/Q3	26,662	0	0	0	0	26,662	
2032/Q4	29,780	0	0	0	0	29,780	

Table 5. The IPR Water Replenishment for Basin Sustainability (62.5 MGD or 70,000 AFY, Scenario 5) from Simulation Period FY2015-16 to FY2046-47.

Historical Spreading at SFSGs (unit: acre-feet)					Modeling with MWD Delivery at SFSGs (62.5 MGD or 70,000 AFY)							
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Simulation Period	(1) SFSGs Delivery	(2) Spillway Delivery	(3) Buena Vista SG Delivery	(4) Hanson Pit Delivery	(5) Peck Road SG Delivery	Total Delivery [(1) to (5)]	Projected Annual Production
2001/Q1	0	576	0	576	2033/Q1	17,500	0	0	0	0	17,500	
2001/Q2	0	0	0	0	2033/Q2	17,500	0	0	0	0	17,500	
Subtotal	***21,442***	***6,526***	***0***	***27,968***	***Subtotal***	***91,442***	***0***	***0***	***0***	***0***	***91,442***	***191,570***
2001/Q3	0	0	0	0	2033/Q3	17,500	0	0	0	0	17,500	
2001/Q4	0	10,685	0	10,685	2033/Q4	17,500	0	0	0	0	17,500	
2002/Q1	0	0	0	0	2034/Q1	17,500	0	0	0	0	17,500	
2002/Q2	448	0	0	448	2034/Q2	17,948	0	0	0	0	17,948	
Subtotal	***448***	***10,685***	***0***	***11,133***	***Subtotal***	***70,448***	***0***	***0***	***0***	***0***	***70,448***	***191,821***
2002/Q3	0	0	0	0	2034/Q3	17,500	0	0	0	0	17,500	
2002/Q4	673	516	0	1,189	2034/Q4	18,173	0	0	0	0	18,173	
2003/Q1	1,170	514	0	1,684	2035/Q1	18,670	0	0	0	0	18,670	
2003/Q2	4,285	3,110	0	7,395	2035/Q2	21,785	0	0	0	0	21,785	
Subtotal	***6,128***	***4,140***	***0***	***10,268***	***Subtotal***	***76,128***	***0***	***0***	***0***	***0***	***76,128***	***192,073***
2003/Q3	5,971	15,149	0	21,120	2035/Q3	23,471	0	0	0	0	23,471	
2003/Q4	0	18,785	0	18,785	2035/Q4	17,500	0	0	0	0	17,500	
2004/Q1	8,002	12,345	0	20,347	2036/Q1	25,502	0	0	0	0	25,502	
2004/Q2	0	0	0	0	2036/Q2	17,500	0	0	0	0	17,500	
Subtotal	***13,974***	***46,278***	***0***	***60,252***	***Subtotal***	***83,974***	***0***	***0***	***0***	***0***	***83,974***	***191,676***
2004/Q3	0	0	0	0	2036/Q3	17,500	0	0	0	0	17,500	
2004/Q4	0	29	0	29	2036/Q4	17,500	0	0	0	0	17,500	
2005/Q1	38,690	0	0	38,690	2037/Q1	43,757	12,433	0	0	0	56,190	
2005/Q2	50,860	0	0	50,860	2037/Q2	43,593	24,767	0	0	0	68,360	
Subtotal	***89,550***	***29***	***0***	***89,579***	***Subtotal***	***122,350***	***37,200***	***0***	***0***	***0***	***159,550***	***192,130***
2005/Q3	18,903	6,837	0	25,740	2037/Q3	36,403	0	0	0	0	36,403	
2005/Q4	0	17,783	0	17,783	2037/Q4	17,500	0	0	0	0	17,500	
2006/Q1	0	19,140	0	19,140	2038/Q1	17,500	0	0	0	0	17,500	
2006/Q2	24,284	5,049	0	29,333	2038/Q2	37,781	4,003	0	0	0	41,784	
Subtotal	***43,187***	***48,809***	***0***	***91,996***	***Subtotal***	***109,184***	***4,003***	***0***	***0***	***0***	***113,187***	***192,585***
2006/Q3	3,373	0	0	3,373	2038/Q3	20,873	0	0	0	0	20,873	

Table 5. The IPR Water Replenishment for Basin Sustainability (62.5 MGD or 70,000 AFY, Scenario 5) from Simulation Period FY2015-16 to FY2046-47.

Historical Spreading at SFSGs (unit: acre-feet)					Modeling with MWD Delivery at SFSGs (62.5 MGD or 70,000 AFY)							
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Simulation Period	(1) SFSGs Delivery	(2) Spillway Delivery	(3) Buena Vista SG Delivery	(4) Hanson Pit Delivery	(5) Peck Road SG Delivery	Total Delivery [(1) to (5)]	Projected Annual Production
2006/Q4	1,981	0	0	1,981	2038/Q4	19,481	0	0	0	0	19,481	
2007/Q1	0	0	0	0	2039/Q1	17,500	0	0	0	0	17,500	
2007/Q2	0	0	0	0	2039/Q2	17,500	0	0	0	0	17,500	
Subtotal	***5,354***	***0***	***0***	***5,354***	***Subtotal***	***75,354***	***0***	***0***	***0***	***0***	***75,354***	***193,043***
2007/Q3	0	0	0	0	2039/Q3	17,500	0	0	0	0	17,500	
2007/Q4	0	0	0	0	2039/Q4	17,500	0	0	0	0	17,500	
2008/Q1	166	1,710	0	1,876	2040/Q1	17,666	0	0	0	0	17,666	
2008/Q2	7	32	0	39	2040/Q2	17,507	0	0	0	0	17,507	
Subtotal	***173***	***1,742***	***0***	***1,915***	***Subtotal***	***70,173***	***0***	***0***	***0***	***0***	***70,173***	***193,539***
2008/Q3	605	0	0	605	2040/Q3	18,105	0	0	0	0	18,105	
2008/Q4	0	0	0	0	2040/Q4	17,500	0	0	0	0	17,500	
2009/Q1	26	0	0	26	2041/Q1	17,526	0	0	0	0	17,526	
2009/Q2	0	0	0	0	2041/Q2	17,500	0	0	0	0	17,500	
Subtotal	***631***	***0***	***0***	***631***	***Subtotal***	***70,631***	***0***	***0***	***0***	***0***	***70,631***	***194,001***
2009/Q3	0	0	0	0	2041/Q3	17,500	0	0	0	0	17,500	
2009/Q4	0	0	0	0	2041/Q4	17,500	0	0	0	0	17,500	
2010/Q1	3,780	0	0	3,780	2042/Q1	21,280	0	0	0	0	21,280	
2010/Q2	5,447	16,933	0	22,380	2042/Q2	22,947	0	0	0	0	22,947	
Subtotal	***9,227***	***16,933***	***0***	***26,160***	***Subtotal***	***79,227***	***0***	***0***	***0***	***0***	***79,227***	***194,465***
2010/Q3	1,597	5,053	0	6,650	2042/Q3	19,097	0	0	0	0	19,097	
2010/Q4	7,050	9,900	0	16,950	2042/Q4	24,550	0	0	0	0	24,550	
2011/Q1	27,495	1,715	0	29,210	2043/Q1	42,832	2,163	0	0	0	44,995	
2011/Q2	12,417	6,763	0	19,180	2043/Q2	29,917	0	0	0	0	29,917	
Subtotal	***48,559***	***23,431***	***0***	***71,990***	***Subtotal***	***116,395***	***2,163***	***0***	***0***	***0***	***118,559***	***194,931***
2011/Q3	6,670	7,330	0	14,000	2043/Q3	24,170	0	0	0	0	24,170	
2011/Q4	11,690	0	0	11,690	2043/Q4	29,190	0	0	0	0	29,190	
2012/Q1	191	0	0	191	2044/Q1	17,691	0	0	0	0	17,691	
2012/Q2	0	0	0	0	2044/Q2	17,500	0	0	0	0	17,500	
Subtotal	***18,551***	***7,330***	***0***	***25,881***	***Subtotal***	***88,551***	***0***	***0***	***0***	***0***	***88,551***	***195,399***

Table 5. The IPR Water Replenishment for Basin Sustainability (62.5 MGD or 70,000 AFY, Scenario 5) from Simulation Period FY2015-16 to FY2046-47.

Historical Spreading at SFSGs (unit: acre-feet)					Modeling with MWD Delivery at SFSGs (62.5 MGD or 70,000 AFY)							
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Simulation Period	(1) SFSGs Delivery	(2) Spillway Delivery	(3) Buena Vista SG Delivery	(4) Hanson Pit Delivery	(5) Peck Road SG Delivery	Total Delivery [(1) to (5)]	Projected Annual Production
2012/Q3	0	0	0	0	2044/Q3	17,500	0	0	0	0	17,500	
2012/Q4	0	4,305	0	4,305	2044/Q4	17,500	0	0	0	0	17,500	
2013/Q1	0	0	0	0	2045/Q1	17,500	0	0	0	0	17,500	
2013/Q2	0	0	0	0	2045/Q2	17,500	0	0	0	0	17,500	
Subtotal	***0***	***4,305***	***0***	***4,305***	***Subtotal***	***70,000***	***0***	***0***	***0***	***0***	***70,000***	***195,869***
2013/Q3	0	0	0	0	2045/Q3	17,500	0	0	0	0	17,500	
2013/Q4	0	9,440	0	9,440	2045/Q4	17,500	0	0	0	0	17,500	
2014/Q1	0	0	0	0	2046/Q1	17,500	0	0	0	0	17,500	
2014/Q2	0	0	0	0	2046/Q2	17,500	0	0	0	0	17,500	
Subtotal	***0***	***9,440***	***0***	***9,440***	***Subtotal***	***70,000***	***0***	***0***	***0***	***0***	***70,000***	***196,337***
2014/Q3	0	0	0	0	2046/Q3	17,500	0	0	0	0	17,500	
2014/Q4	0	0	0	0	2046/Q4	17,500	0	0	0	0	17,500	
2015/Q1	0	0	0	0	2047/Q1	17,500	0	0	0	0	17,500	
2015/Q2	0	0	0	0	2047/Q2	17,500	0	0	0	0	17,500	
Subtotal	***0***	***0***	***0***	***0***	***Subtotal***	***70,000***	***0***	***0***	***0***	***0***	***70,000***	***196,811***
GRAND TOTAL	***520,699***	***377,418***	***0***	***898,117***	**GRAND TOTAL**	***2,695,276***	***65,424***	***0***	***0***	***0***	***2,760,699***	***6,132,357***

Table 6. 3D Basin Model Simulated Maximum and Minimum Groundwater Elevations for Baseline Sustainability between FY2015-16 and FY2046-47 (Scenario 5 - Constant 62.5 MGD Replenishment).

Owner	Well ID	Recordation Number	Land Elev. (feet amsl)	Simulated Water Elevations (feet amsl)			
				Maximum	Date	Minimum	Date
LA County	Key Well (Well 3030F)	NA	389.00	301.50	2037/Q2	182.40	2015/Q3
City of Monrovia	Well 03	1900419	371.00	299.90	2037/Q2	175.20	2015/Q3
City of Monrovia	Well 05	1940104	374.00	302.40	2037/Q2	176.50	2015/Q3
Covina Irrigating Co.	Baldwin 01	1900885	401.00	302.80	2037/Q3	184.60	2015/Q3
Covina Irrigating Co.	Contract Well	1900881	496.00	320.50	2037/Q3	198.80	2015/Q3
Valley County Water District	Palm Well	8000039	364.00	295.10	2037/Q2	179.30	2015/Q3
Valley County Water District	Well SA1-1	8000185	465.00	315.10	2037/Q2	190.30	2015/Q3
Valley County Water District	Well SA1-2	8000186	448.00	311.80	2037/Q3	188.90	2015/Q3
Valley County Water District	Well SA1-3 (Lante Well)	8000060	457.00	314.90	2037/Q3	189.00	2015/Q3
Valley County Water District	Maine West	1900028	426.00	314.10	2037/Q2	185.60	2015/Q3
Valley County Water District	Morada	1900029	484.00	318.20	2037/Q3	194.50	2015/Q3
Valley County Water District	Nixon East	1900032	424.00	315.30	2037/Q2	185.50	2015/Q3
Valley County Water District	Arrow	1900034	456.00	315.40	2037/Q2	189.70	2015/Q3
California American Water Co.	Santa Fe	1900354	513.00	367.10	2037/Q2	216.60	2016/Q3
California American Water Co.	Buena Vista	1900355	451.00	343.60	2037/Q2	195.50	2015/Q3
California American Water Co.	Crown Haven	1903018	572.00	352.60	2037/Q2	207.80	2015/Q3
Conrock (CalMat) Co.	Reliance 1	1903088	550.00	339.40	2037/Q2	201.70	2015/Q3
Azusa Light & Water	Genesis 02	1902537	525.00	324.80	2037/Q3	199.60	2015/Q3
City of Arcadia	Longden 2	1901014	499.00	295.30	2037/Q2	174.70	2015/Q3
City of Arcadia	Peck 1	1902854	336.00	306.30	2037/Q1	169.60	2016/Q1
City of Glendora	Well 07G	1900831	533.00	323.30	2037/Q3	199.10	2015/Q3
City of Glendora	Well 04E	1901524	475.00	318.20	2037/Q3	196.80	2015/Q3
Golden State Water Co.	Graydon 02	1902461	403.00	299.80	2037/Q2	176.80	2015/Q3
City of Arcadia	Live Oak 1	8000127	340.00	295.50	2037/Q1	170.20	2016/Q1

Table 7. The IPR Water Replenishment for Augmented Basin Sustainability (77.5 MGD or 86,800 AFY, Scenarios 6, 7, and 8) from Simulation Period FY2015-16 to FY2046-47.

Historical Spreading at SFSGs (unit: acre-feet)					**Modeling with MWD Delivery at SFSGs (77.5 MGD or 86,800 AFY)**							
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Simulation Period	(1) SFSGs Delivery	(2) Spillway Delivery	(3) Buena Vista SG Delivery	(4) Hanson Pit Delivery	(5) Peck Road SG Delivery	Total Delivery [(1) to (5)]	Projected Annual Production
1983/Q3	10,369	0	0	10,369	2015/Q3	30,967	1,102	0	0	0	32,069	
1983/Q4	7,141	0	0	7,141	2015/Q4	28,841	0	0	0	0	28,841	
1984/Q1	9,982	0	0	9,982	2016/Q1	30,967	715	0	0	0	31,682	
1984/Q2	0	0	0	0	2016/Q2	21,700	0	0	0	0	21,700	
Subtotal	***27,492***	***0***	***0***	***27,492***	***Subtotal***	***112,475***	***1,817***	***0***	***0***	***0***	***114,292***	***193,187***
1984/Q3	0	0	0	0	2016/Q3	21,700	0	0	0	0	21,700	
1984/Q4	0	0	0	0	2016/Q4	21,700	0	0	0	0	21,700	
1985/Q1	8,468	0	0	8,468	2017/Q1	30,168	0	0	0	0	30,168	
1985/Q2	0	0	0	0	2017/Q2	21,700	0	0	0	0	21,700	
Subtotal	***8,468***	***0***	***0***	***8,468***	***Subtotal***	***95,268***	***0***	***0***	***0***	***0***	***95,268***	***191,058***
1985/Q3	0	2,153	0	2,153	2017/Q3	21,700	0	0	0	0	21,700	
1985/Q4	0	22,827	0	22,827	2017/Q4	21,700	0	0	0	0	21,700	
1986/Q1	11,604	8,428	0	20,031	2018/Q1	30,967	2,337	0	0	0	33,304	
1986/Q2	0	0	0	0	2018/Q2	21,700	0	0	0	0	21,700	
Subtotal	***11,604***	***33,408***	***0***	***45,011***	***Subtotal***	***96,067***	***2,337***	***0***	***0***	***0***	***98,404***	***189,109***
1986/Q3	0	0	0	0	2018/Q3	21,700	0	0	0	0	21,700	
1986/Q4	0	6,908	0	6,908	2018/Q4	21,700	0	0	0	0	21,700	
1987/Q1	0	13,630	0	13,630	2019/Q1	21,700	0	0	0	0	21,700	
1987/Q2	0	3,475	0	3,475	2019/Q2	21,700	0	0	0	0	21,700	
Subtotal	***0***	***24,013***	***0***	***24,013***	***Subtotal***	***86,800***	***0***	***0***	***0***	***0***	***86,800***	***187,342***
1987/Q3	0	0	0	0	2019/Q3	21,700	0	0	0	0	21,700	
1987/Q4	188	5,496	0	5,684	2019/Q4	21,888	0	0	0	0	21,888	
1988/Q1	19	13,320	0	13,339	2020/Q1	21,719	0	0	0	0	21,719	
1988/Q2	97	0	0	97	2020/Q2	21,797	0	0	0	0	21,797	
Subtotal	***304***	***18,816***	***0***	***19,120***	***Subtotal***	***87,104***	***0***	***0***	***0***	***0***	***87,104***	***189,993***
1988/Q3	0	0	0	0	2020/Q3	21,700	0	0	0	0	21,700	
1988/Q4	231	6,748	0	6,979	2020/Q4	21,931	0	0	0	0	21,931	
1989/Q1	0	18,114	0	18,114	2021/Q1	21,700	0	0	0	0	21,700	
1989/Q2	0	2,286	0	2,286	2021/Q2	21,700	0	0	0	0	21,700	

Table 7. The IPR Water Replenishment for Augmented Basin Sustainability (77.5 MGD or 86,800 AFY, Scenarios 6, 7, and 8) from Simulation Period FY2015-16 to FY2046-47.

Historical Spreading at SFSGs (unit: acre-feet)					**Modeling with MWD Delivery at SFSGs (77.5 MGD or 86,800 AFY)**							
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Simulation Period	(1) SFSGs Delivery	(2) Spillway Delivery	(3) Buena Vista SG Delivery	(4) Hanson Pit Delivery	(5) Peck Road SG Delivery	Total Delivery [(1) to (5)]	Projected Annual Production
Subtotal	***231***	***27,148***	***0***	***27,379***	***Subtotal***	***87,031***	***0***	***0***	***0***	***0***	***87,031***	***188,566***
1989/Q3	0	0	0	0	2021/Q3	21,700	0	0	0	0	21,700	
1989/Q4	0	0	0	0	2021/Q4	21,700	0	0	0	0	21,700	
1990/Q1	0	5,196	0	5,196	2022/Q1	21,700	0	0	0	0	21,700	
1990/Q2	0	5,271	0	5,271	2022/Q2	21,700	0	0	0	0	21,700	
Subtotal	***0***	***10,467***	***0***	***10,467***	***Subtotal***	***86,800***	***0***	***0***	***0***	***0***	***86,800***	***188,601***
1990/Q3	0	3,130	0	3,130	2022/Q3	21,700	0	0	0	0	21,700	
1990/Q4	0	2,640	0	2,640	2022/Q4	21,700	0	0	0	0	21,700	
1991/Q1	122	2,094	0	2,216	2023/Q1	21,822	0	0	0	0	21,822	
1991/Q2	0	3,070	0	3,070	2023/Q2	21,700	0	0	0	0	21,700	
Subtotal	***122***	***10,934***	***0***	***11,056***	***Subtotal***	***86,922***	***0***	***0***	***0***	***0***	***86,922***	***188,630***
1991/Q3	0	6,466	0	6,466	2023/Q3	21,700	0	0	0	0	21,700	
1991/Q4	0	0	0	0	2023/Q4	21,700	0	0	0	0	21,700	
1992/Q1	13,913	6,297	0	20,210	2024/Q1	35,613	0	0	0	0	35,613	
1992/Q2	24,020	0	0	24,020	2024/Q2	41,677	4,043	0	0	0	45,720	
Subtotal	***37,933***	***12,763***	***0***	***50,696***	***Subtotal***	***120,689***	***4,043***	***0***	***0***	***0***	***124,733***	***188,658***
1992/Q3	3,150	2,100	0	5,250	2024/Q3	24,850	0	0	0	0	24,850	
1992/Q4	0	7,363	0	7,363	2024/Q4	21,700	0	0	0	0	21,700	
1993/Q1	22,298	3,935	0	26,233	2025/Q1	39,555	4,442	0	0	0	43,998	
1993/Q2	31,510	0	0	31,510	2025/Q2	41,032	12,178	0	0	0	53,210	
Subtotal	***56,958***	***13,398***	***0***	***70,356***	***Subtotal***	***127,138***	***16,620***	***0***	***0***	***0***	***143,758***	***188,697***
1993/Q3	8,420	0	0	8,420	2025/Q3	30,120	0	0	0	0	30,120	
1993/Q4	7,110	0	0	7,110	2025/Q4	28,810	0	0	0	0	28,810	
1994/Q1	0	0	0	0	2026/Q1	21,700	0	0	0	0	21,700	
1994/Q2	0	13,720	0	13,720	2026/Q2	21,700	0	0	0	0	21,700	
Subtotal	***15,530***	***13,720***	***0***	***29,250***	***Subtotal***	***102,330***	***0***	***0***	***0***	***0***	***102,330***	***189,124***
1994/Q3	338	0	0	338	2026/Q3	22,038	0	0	0	0	22,038	
1994/Q4	0	0	0	0	2026/Q4	21,700	0	0	0	0	21,700	
1995/Q1	0	0	0	0	2027/Q1	21,700	0	0	0	0	21,700	

Table 7. The IPR Water Replenishment for Augmented Basin Sustainability (77.5 MGD or 86,800 AFY, Scenarios 6, 7, and 8) from Simulation Period FY2015-16 to FY2046-47.

Historical Spreading at SFSGs (unit: acre-feet)					Modeling with MWD Delivery at SFSGs (77.5 MGD or 86,800 AFY)							
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Simulation Period	(1) SFSGs Delivery	(2) Spillway Delivery	(3) Buena Vista SG Delivery	(4) Hanson Pit Delivery	(5) Peck Road SG Delivery	Total Delivery [(1) to (5)]	Projected Annual Production
1995/Q2	11,862	0	0	11,862	2027/Q2	33,562	0	0	0	0	33,562	
Subtotal	***12,200***	***0***	***0***	***12,200***	***Subtotal***	***99,000***	***0***	***0***	***0***	***0***	***99,000***	***189,548***
1995/Q3	19,085	0	0	19,085	2027/Q3	40,785	0	0	0	0	40,785	
1995/Q4	2,420	0	0	2,420	2027/Q4	24,120	0	0	0	0	24,120	
1996/Q1	9,223	0	0	9,223	2028/Q1	30,923	0	0	0	0	30,923	
1996/Q2	0	0	0	0	2028/Q2	21,700	0	0	0	0	21,700	
Subtotal	***30,728***	***0***	***0***	***30,728***	***Subtotal***	***117,528***	***0***	***0***	***0***	***0***	***117,528***	***189,974***
1996/Q3	0	7,760	0	7,760	2028/Q3	21,700	0	0	0	0	21,700	
1996/Q4	4,280	915	0	5,195	2028/Q4	25,980	0	0	0	0	25,980	
1997/Q1	8,688	0	0	8,688	2029/Q1	30,388	0	0	0	0	30,388	
1997/Q2	34,723	4,767	0	39,490	2029/Q2	47,566	8,857	0	0	0	56,423	
Subtotal	***47,691***	***13,442***	***0***	***61,133***	***Subtotal***	***125,634***	***8,857***	***0***	***0***	***0***	***134,491***	***190,402***
1997/Q3	385	12,475	0	12,860	2029/Q3	22,085	0	0	0	0	22,085	
1997/Q4	0	2,420	0	2,420	2029/Q4	21,700	0	0	0	0	21,700	
1998/Q1	5,013	4,210	0	9,223	2030/Q1	26,713	0	0	0	0	26,713	
1998/Q2	0	0	0	0	2030/Q2	21,700	0	0	0	0	21,700	
Subtotal	***5,398***	***19,105***	***0***	***24,503***	***Subtotal***	***92,198***	***0***	***0***	***0***	***0***	***92,198***	***190,826***
1998/Q3	7,760	0	0	7,760	2030/Q3	29,460	0	0	0	0	29,460	
1998/Q4	0	0	0	0	2030/Q4	21,700	0	0	0	0	21,700	
1999/Q1	0	0	0	0	2031/Q1	21,700	0	0	0	0	21,700	
1999/Q2	0	0	0	0	2031/Q2	21,700	0	0	0	0	21,700	
Subtotal	***7,760***	***0***	***0***	***7,760***	***Subtotal***	***94,560***	***0***	***0***	***0***	***0***	***94,560***	***191,073***
1999/Q3	0	0	0	0	2031/Q3	21,700	0	0	0	0	21,700	
1999/Q4	131	0	0	131	2031/Q4	21,831	0	0	0	0	21,831	
2000/Q1	0	554	0	554	2032/Q1	21,700	0	0	0	0	21,700	
2000/Q2	928	0	0	928	2032/Q2	22,628	0	0	0	0	22,628	
Subtotal	***1,059***	***554***	***0***	***1,613***	***Subtotal***	***87,859***	***0***	***0***	***0***	***0***	***87,859***	***191,320***
2000/Q3	9,162	0	0	9,162	2032/Q3	30,862	0	0	0	0	30,862	
2000/Q4	12,280	5,950	0	18,230	2032/Q4	33,980	0	0	0	0	33,980	

Table 7. The IPR Water Replenishment for Augmented Basin Sustainability (77.5 MGD or 86,800 AFY, Scenarios 6, 7, and 8) from Simulation Period FY2015-16 to FY2046-47.

Historical Spreading at SFSGs (unit: acre-feet)					**Modeling with MWD Delivery at SFSGs (77.5 MGD or 86,800 AFY)**							
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]	Projected Simulation Period	(1) SFSGs Delivery	(2) Spillway Delivery	(3) Buena Vista SG Delivery	(4) Hanson Pit Delivery	(5) Peck Road SG Delivery	Total Delivery [(1) to (5)]	Projected Annual Production
2001/Q1	0	576	0	576	2033/Q1	21,700	0	0	0	0	21,700	
2001/Q2	0	0	0	0	2033/Q2	21,700	0	0	0	0	21,700	
Subtotal	***21,442***	***6,526***	***0***	***27,968***	***Subtotal***	***108,242***	***0***	***0***	***0***	***0***	***108,242***	***191,570***
2001/Q3	0	0	0	0	2033/Q3	21,700	0	0	0	0	21,700	
2001/Q4	0	10,685	0	10,685	2033/Q4	21,700	0	0	0	0	21,700	
2002/Q1	0	0	0	0	2034/Q1	21,700	0	0	0	0	21,700	
2002/Q2	448	0	0	448	2034/Q2	22,148	0	0	0	0	22,148	
Subtotal	***448***	***10,685***	***0***	***11,133***	***Subtotal***	***87,248***	***0***	***0***	***0***	***0***	***87,248***	***191,821***
2002/Q3	0	0	0	0	2034/Q3	21,700	0	0	0	0	21,700	
2002/Q4	673	516	0	1,189	2034/Q4	22,373	0	0	0	0	22,373	
2003/Q1	1,170	514	0	1,684	2035/Q1	22,870	0	0	0	0	22,870	
2003/Q2	4,285	3,110	0	7,395	2035/Q2	25,985	0	0	0	0	25,985	
Subtotal	***6,128***	***4,140***	***0***	***10,268***	***Subtotal***	***92,928***	***0***	***0***	***0***	***0***	***92,928***	***192,073***
2003/Q3	5,971	15,149	0	21,120	2035/Q3	27,671	0	0	0	0	27,671	
2003/Q4	0	18,785	0	18,785	2035/Q4	21,700	0	0	0	0	21,700	
2004/Q1	8,002	12,345	0	20,347	2036/Q1	29,702	0	0	0	0	29,702	
2004/Q2	0	0	0	0	2036/Q2	21,700	0	0	0	0	21,700	
Subtotal	***13,974***	***46,278***	***0***	***60,252***	***Subtotal***	***100,774***	***0***	***0***	***0***	***0***	***100,774***	***191,676***
2004/Q3	0	0	0	0	2036/Q3	21,700	0	0	0	0	21,700	
2004/Q4	0	29	0	29	2036/Q4	21,700	0	0	0	0	21,700	
2005/Q1	38,690	0	0	38,690	2037/Q1	46,557	13,833	0	0	0	60,390	
2005/Q2	50,860	0	0	50,860	2037/Q2	44,993	27,567	0	0	0	72,560	
Subtotal	***89,550***	***29***	***0***	***89,579***	***Subtotal***	***134,950***	***41,400***	***0***	***0***	***0***	***176,350***	***192,130***
2005/Q3	18,903	6,837	0	25,740	2037/Q3	40,470	133	0	0	0	40,603	
2005/Q4	0	17,783	0	17,783	2037/Q4	21,700	0	0	0	0	21,700	
2006/Q1	0	19,140	0	19,140	2038/Q1	21,700	0	0	0	0	21,700	
2006/Q2	24,284	5,049	0	29,333	2038/Q2	40,581	5,403	0	0	0	45,984	
Subtotal	***43,187***	***48,809***	***0***	***91,996***	***Subtotal***	***124,451***	***5,537***	***0***	***0***	***0***	***129,987***	***192,585***
2006/Q3	3,373	0	0	3,373	2038/Q3	25,073	0	0	0	0	25,073	

Table 7. The IPR Water Replenishment for Augmented Basin Sustainability (77.5 MGD or 86,800 AFY, Scenarios 6, 7, and 8) from Simulation Period FY2015-16 to FY2046-47.

Historical Spreading at SFSGs (unit: acre-feet)				
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]
2006/Q4	1,981	0	0	1,981
2007/Q1	0	0	0	0
2007/Q2	0	0	0	0
Subtotal	***5,354***	***0***	***0***	***5,354***
2007/Q3	0	0	0	0
2007/Q4	0	0	0	0
2008/Q1	166	1,710	0	1,876
2008/Q2	7	32	0	39
Subtotal	***173***	***1,742***	***0***	***1,915***
2008/Q3	605	0	0	605
2008/Q4	0	0	0	0
2009/Q1	26	0	0	26
2009/Q2	0	0	0	0
Subtotal	***631***	***0***	***0***	***631***
2009/Q3	0	0	0	0
2009/Q4	0	0	0	0
2010/Q1	3,780	0	0	3,780
2010/Q2	5,447	16,933	0	22,380
Subtotal	***9,227***	***16,933***	***0***	***26,160***
2010/Q3	1,597	5,053	0	6,650
2010/Q4	7,050	9,900	0	16,950
2011/Q1	27,495	1,715	0	29,210
2011/Q2	12,417	6,763	0	19,180
Subtotal	***48,559***	***23,431***	***0***	***71,990***
2011/Q3	6,670	7,330	0	14,000
2011/Q4	11,690	0	0	11,690
2012/Q1	191	0	0	191
2012/Q2	0	0	0	0
Subtotal	***18,551***	***7,330***	***0***	***25,881***

Modeling with MWD Delivery at SFSGs (77.5 MGD or 86,800 AFY)							
Projected Simulation Period	(1) SFSGs Delivery	(2) Spillway Delivery	(3) Buena Vista SG Delivery	(4) Hanson Pit Delivery	(5) Peck Road SG Delivery	Total Delivery [(1) to (5)]	Projected Annual Production
2038/Q4	23,681	0	0	0	0	23,681	
2039/Q1	21,700	0	0	0	0	21,700	
2039/Q2	21,700	0	0	0	0	21,700	
Subtotal	***92,154***	***0***	***0***	***0***	***0***	***92,154***	***193,043***
2039/Q3	21,700	0	0	0	0	21,700	
2039/Q4	21,700	0	0	0	0	21,700	
2040/Q1	21,866	0	0	0	0	21,866	
2040/Q2	21,707	0	0	0	0	21,707	
Subtotal	***86,973***	***0***	***0***	***0***	***0***	***86,973***	***193,539***
2040/Q3	22,305	0	0	0	0	22,305	
2040/Q4	21,700	0	0	0	0	21,700	
2041/Q1	21,726	0	0	0	0	21,726	
2041/Q2	21,700	0	0	0	0	21,700	
Subtotal	***87,431***	***0***	***0***	***0***	***0***	***87,431***	***194,001***
2041/Q3	21,700	0	0	0	0	21,700	
2041/Q4	21,700	0	0	0	0	21,700	
2042/Q1	25,480	0	0	0	0	25,480	
2042/Q2	27,147	0	0	0	0	27,147	
Subtotal	***96,027***	***0***	***0***	***0***	***0***	***96,027***	***194,465***
2042/Q3	23,297	0	0	0	0	23,297	
2042/Q4	28,750	0	0	0	0	28,750	
2043/Q1	45,632	3,563	0	0	0	49,195	
2043/Q2	34,117	0	0	0	0	34,117	
Subtotal	***131,795***	***3,563***	***0***	***0***	***0***	***135,359***	***194,931***
2043/Q3	28,370	0	0	0	0	28,370	
2043/Q4	33,390	0	0	0	0	33,390	
2044/Q1	21,891	0	0	0	0	21,891	
2044/Q2	21,700	0	0	0	0	21,700	
Subtotal	***105,351***	***0***	***0***	***0***	***0***	***105,351***	***195,399***

Table 7. The IPR Water Replenishment for Augmented Basin Sustainability (77.5 MGD or 86,800 AFY, Scenarios 6, 7, and 8) from Simulation Period FY2015-16 to FY2046-47.

Historical Spreading at SFSGs (unit: acre-feet)				
Simulation Period	(1) Local Runoff SFSG	(2) Untreated Import SFSG	(3) Recycled Water	Spreading @ SFSG [(1)+(2)+(3)]
2012/Q3	0	0	0	0
2012/Q4	0	4,305	0	4,305
2013/Q1	0	0	0	0
2013/Q2	0	0	0	0
Subtotal	***0***	***4,305***	***0***	***4,305***
2013/Q3	0	0	0	0
2013/Q4	0	9,440	0	9,440
2014/Q1	0	0	0	0
2014/Q2	0	0	0	0
Subtotal	***0***	***9,440***	***0***	***9,440***
2014/Q3	0	0	0	0
2014/Q4	0	0	0	0
2015/Q1	0	0	0	0
2015/Q2	0	0	0	0
Subtotal	***0***	***0***	***0***	***0***
GRAND TOTAL	***520,699***	***377,418***	***0***	***898,117***

Modeling with MWD Delivery at SFSGs (77.5 MGD or 86,800 AFY)							
Projected Simulation Period	(1) SFSGs Delivery	(2) Spillway Delivery	(3) Buena Vista SG Delivery	(4) Hanson Pit Delivery	(5) Peck Road SG Delivery	Total Delivery [(1) to (5)]	Projected Annual Production
2044/Q3	21,700	0	0	0	0	21,700	
2044/Q4	21,700	0	0	0	0	21,700	
2045/Q1	21,700	0	0	0	0	21,700	
2045/Q2	21,700	0	0	0	0	21,700	
Subtotal	***86,800***	***0***	***0***	***0***	***0***	***86,800***	***195,869***
2045/Q3	21,700	0	0	0	0	21,700	
2045/Q4	21,700	0	0	0	0	21,700	
2046/Q1	21,700	0	0	0	0	21,700	
2046/Q2	21,700	0	0	0	0	21,700	
Subtotal	***86,800***	***0***	***0***	***0***	***0***	***86,800***	***196,337***
2046/Q3	21,700	0	0	0	0	21,700	
2046/Q4	21,700	0	0	0	0	21,700	
2047/Q1	21,700	0	0	0	0	21,700	
2047/Q2	21,700	0	0	0	0	21,700	
Subtotal	***86,800***	***0***	***0***	***0***	***0***	***86,800***	***196,811***
GRAND TOTAL	***3,214,125***	***84,174***	***0***	***0***	***0***	***3,298,299***	***6,132,357***

Table 8a. 3D Basin Model Simulated Maximum and Minimum Groundwater Elevations for Baseline Sustainability between FY2015-16 and FY2046-47 (Scenario 6 - Constant 77.5 MGD Replenishment without 15 MGD Delivery).

Owner	Well ID	Recordation Number	Land Elev. (feet amsl)	Simulated Water Elevations (feet amsl)			
				Maximum	Date	Minimum	Date
LA County	Key Well (Well 3030F)	NA	389.00	315.50	2037/Q2	183.10	2015/Q3
City of Monrovia	Well 03	1900419	371.00	314.60	2037/Q2	176.00	2015/Q3
City of Monrovia	Well 05	1940104	374.00	317.30	2037/Q2	177.40	2015/Q3
Covina Irrigating Co.	Baldwin 01	1900885	401.00	316.80	2037/Q3	185.20	2015/Q3
Covina Irrigating Co.	Contract Well	1900881	496.00	335.90	2037/Q3	199.30	2015/Q3
Valley County Water District	Palm Well	8000039	364.00	308.30	2037/Q2	179.80	2015/Q3
Valley County Water District	Well SA1-1	8000185	465.00	330.60	2037/Q2	191.20	2015/Q3
Valley County Water District	Well SA1-2	8000186	448.00	327.00	2037/Q3	189.80	2015/Q3
Valley County Water District	Well SA1-3 (Lante Well)	8000060	457.00	330.20	2037/Q3	190.00	2015/Q3
Valley County Water District	Maine West	1900028	426.00	329.10	2037/Q2	186.90	2015/Q3
Valley County Water District	Morada	1900029	484.00	333.40	2037/Q3	195.20	2015/Q3
Valley County Water District	Nixon East	1900032	424.00	330.40	2037/Q2	186.80	2015/Q3
Valley County Water District	Arrow	1900034	456.00	330.80	2037/Q2	190.70	2015/Q3
California American Water Co.	Santa Fe	1900354	513.00	384.30	2037/Q2	221.90	2016/Q3
California American Water Co.	Buena Vista	1900355	451.00	360.70	2037/Q2	198.50	2015/Q3
California American Water Co.	Crown Haven	1903018	572.00	369.20	2037/Q2	210.80	2015/Q3
Conrock (CalMat) Co.	Reliance 1	1903088	550.00	355.90	2037/Q2	203.50	2015/Q3
Azusa Light & Water	Genesis 02	1902537	525.00	340.60	2037/Q3	200.30	2015/Q3
City of Arcadia	Longden 2	1901014	499.00	309.60	2037/Q2	175.30	2015/Q3
City of Arcadia	Peck 1	1902854	336.00	319.10	2037/Q1	171.10	2016/Q1
City of Glendora	Well 07G	1900831	533.00	339.00	2037/Q3	199.70	2015/Q3
City of Glendora	Well 04E	1901524	475.00	333.40	2037/Q3	197.30	2015/Q3
Golden State Water Co.	Graydon 02	1902461	403.00	315.00	2037/Q2	177.60	2015/Q3
City of Arcadia	Live Oak 1	8000127	340.00	308.40	2037/Q1	171.50	2016/Q1

Table 8b. 3D Basin Model Simulated Maximum and Minimum Groundwater Elevations for Baseline Sustainability between FY2015-16 and FY2046-47 (Scenario 7 - Constant 77.5 MGD Replenishment with 15 MGD Delivery).

Owner	Well ID	Recordation Number	Land Elev. (feet amsl)	Simulated Water Elevations (feet amsl)			
				Maximum	Date	Minimum	Date
LA County	Key Well (Well 3030F)	NA	389.00	303.40	2037/Q2	182.70	2015/Q3
City of Monrovia	Well 03	1900419	371.00	300.40	2037/Q2	173.10	2015/Q3
City of Monrovia	Well 05	1940104	374.00	303.30	2037/Q2	175.00	2015/Q3
Covina Irrigating Co.	Baldwin 01	1900885	401.00	304.80	2037/Q3	184.90	2015/Q3
Covina Irrigating Co.	Contract Well	1900881	496.00	323.50	2037/Q3	199.30	2015/Q3
Valley County Water District	Palm Well	8000039	364.00	296.50	2037/Q2	179.30	2015/Q3
Valley County Water District	Well SA1-1	8000185	465.00	317.90	2037/Q2	191.10	2015/Q3
Valley County Water District	Well SA1-2	8000186	448.00	314.40	2037/Q3	189.60	2015/Q3
Valley County Water District	Well SA1-3 (Lante Well)	8000060	457.00	317.60	2037/Q3	189.80	2015/Q3
Valley County Water District	Maine West	1900028	426.00	316.70	2037/Q2	186.50	2015/Q3
Valley County Water District	Morada	1900029	484.00	321.10	2037/Q3	195.10	2015/Q3
Valley County Water District	Nixon East	1900032	424.00	318.00	2037/Q2	186.40	2015/Q3
Valley County Water District	Arrow	1900034	456.00	318.20	2037/Q2	190.50	2015/Q3
California American Water Co.	Santa Fe	1900354	513.00	372.10	2037/Q2	221.70	2016/Q3
California American Water Co.	Buena Vista	1900355	451.00	348.00	2037/Q2	198.00	2015/Q3
California American Water Co.	Crown Haven	1903018	572.00	356.80	2037/Q2	210.60	2015/Q3
Conrock (CalMat) Co.	Reliance 1	1903088	550.00	343.20	2037/Q2	203.40	2015/Q3
Azusa Light & Water	Genesis 02	1902537	525.00	328.20	2037/Q3	200.30	2015/Q3
City of Arcadia	Longden 2	1901014	499.00	295.60	2037/Q2	172.40	2015/Q3
City of Arcadia	Peck 1	1902854	336.00	306.40	2037/Q1	168.70	2016/Q1
City of Glendora	Well 07G	1900831	533.00	326.60	2037/Q3	199.70	2015/Q3
City of Glendora	Well 04E	1901524	475.00	321.10	2037/Q3	197.30	2015/Q3
Golden State Water Co.	Graydon 02	1902461	403.00	301.00	2037/Q2	176.30	2015/Q3
City of Arcadia	Live Oak 1	8000127	340.00	295.60	2037/Q1	169.30	2016/Q1

Table 9. Comparison of Simulated Rising Water in the Second Quarter of Year 2037.

Model Simulation Scenario	Simulated Key Well Elevation (2037/Q2) feet amsl	Historical Measurements						Rising Water (Model Simulated)	
		Rising Water (Mean)		Rising Water (Lower 95%)		Rising Water (Upper 95%)			
		cfs	AFY	cfs	AFY	cfs	AFY	cfs	AFY
Scenario 4 -Baseline Delivery (39MGD Replenishment)	272.0	50	35,939	21	15,493	78	56,397	45	32,866
Scenario 5 -Basin Sustainability (62.5 MGD Replenishment)	301.3	102	73,995	74	53,574	131	94,550	88	64,070
Scenario 6 -Augmented Basin Sustainability (77.5 MGD without 15 MGD Delivery)	315.3	132	95,383	103	74,352	160	115,473	116	84,068
Scenario 7 -Augmented Basin Sustainability (77.5 MGD with 15 MGD Delivery)	303.2	106	76,776	78	56,397	135	97,374	84	60,776