INTRODUCTION

The Alta Irrigation District (AID) Management Zone Archetype Analysis (completed May 2016) is one of several technical work efforts that have been completed by CV-SALTS to inform the larger Central Valley Salt and Nitrate Management Plan (SNMP) planning effort and future, local/regional analyses. The AID Archetype Analysis, which is included as a part of the SNMP, serves as an example and “proof of concept” to test, on a spatially refined basis, the application of selected policies, data analysis methods, and salt and nitrate management approaches that are being considered by CV-SALTS. The results will be used to inform the development of implementation elements of the Central Valley SNMP.

Amongst other work efforts, the AID Archetype Analysis included an analysis of several management scenarios using the AID Management Zone (MZ) model (Figure 1) to evaluate the effects on groundwater quality of managing salt and nitrate in the MZ area over both near-term and long-term time frames. A total of five scenarios (a baseline condition along with four management scenarios) were ultimately identified and modeled. The results of this work effort were presented to the CV-SALTS Executive Committee (EC) in March 2016. During that meeting, several EC members suggested that it may be beneficial to run an additional management scenario that builds off of the current AID management scenarios and incorporates additional implementation measures identified by the Nitrate Implementation Measures Study (NIMS) and/or Strategic Salt Accumulation Land and Transportation Study (SSALTS) (CDM Smith, 2016a and 2016b; respectively).

In response to the request by CV-SALTS, the Larry Walker Associates (LWA) Team (consisting of LWA and Luhdorff & Scalmanini Consulting Engineers (LSCE)) has prepared this Technical Memorandum summarizing the work for an Aggressive Restoration Alternative Modeling Scenario. The information
generated by the Aggressive Restoration Alternative Modeling Scenario is critical in order for CV-SALTS to:

- Identify the types of measures that are necessary to address SNMP management goal #3 (Implement Managed Aquifer Restoration Program);
- Identify the types of measures that may also address SNMP management goal #1 (Ensure a Safe Drinking Water Supply);
- Identify costs associated with the above scenario for the AID study area and include those within the Economic Analysis that is currently underway and due to be completed by October 3, 2016;
- Identify potential environmental impacts associated with the above scenario for the AID study area in the Substitute Environmental Documentation (SED) that is currently underway and due to be completed by October 3, 2016; and
- Provide information that will be useful to valley-wide projections of costs and environmental impacts.

This Technical Memorandum includes the rationale, methodology, and results for the model simulation, including several sensitivity alternative simulations, as well as a brief discussion of the implications and lessons learned after performing this analysis on the AID Management Zone (MZ) as it might be extrapolated elsewhere in the Central Valley.

**Rationale**

The Aggressive Restoration Alternative Modeling Scenario merges an AID Archetype MZ modeling scenario (Scenario #3 Irrigation Efficiency, Reduced N Loading, and Artificial Recharge Changes) with select NIMS controls (focusing on nitrate-related issues within the AID area), and on-farm winter recharge. The new scenario involves the inclusion of the following to the mass loading, flow, and transport models:

- Agricultural wells will be pumped and used for irrigation without treatment of the produced water prior to land application;
- Municipal wells will be pumped and the groundwater treated before being distributed and served, and will include new wells that will be pumped, groundwater treated, and served to disadvantaged communities;
- A certain number of extraction and/or injection wells that would pump and treat groundwater before returning it to the subsurface at identified locations for a pump/treat and inject system; and
- On-farm winter recharge utilizing excess Kings River water delivered and applied to an area in AID during November to March.

**Methodology**

A strawman approach was presented to the CV-SALTS Project Committee (PC) to discuss the goals and specifics of this work on August 16, 2016. During this conference call presentation, the LWA Team

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1 The pump, treat, and serve aspect of the Aggressive Restoration Alternative Scenario considered what had already been developed in the NIMS project Pipeline Scenario 2d (Figure 5-17 in the NIMS document). The pump, treat, and serve aspect does not address individual private wells. Figure 2 shows NIMS Figure 5-17 for reference. The Cutler/Orosi Regional Drinking Water Project is also incorporated in this scenario.
presented the recommended approach. In order to change the ambient nitrate concentration in groundwater in AID’s boundary, some of the most reasonably aggressive measures are employed. Removing nitrate mass is accomplished by pumping groundwater out of the aquifer system. That water can either be treated and served, treated and reinjected, and/or not treated and applied to agricultural lands. Another aggressive measure to reduce nitrate in the system is a form of artificial recharge called on-farm winter recharge, where excess Kings River water would be applied during winter months to a particular agricultural area where the potential for accepting recharge is high. These two concepts (pumping and recharge) are employed in the Aggressive Restoration Scenario. The surface mass loading and flow regime for the Aggressive Restoration Scenario are based on the previously developed AID MZ Model Scenario #3. This scenario involved potential future water and nitrate management improvements, including increased water use efficiency; increased the number of artificial recharge projects; and decreased nitrogen loading (via adjusted crop yields and uptake, POTW effluent concentrations at 10 mg/L as N, and land use practices post- Dairy General Order and post- Irrigated Lands Regulatory Program)\(^2\).

**Groundwater Pumping**

The three different pumping regimes include: 1) pump with no treatment and apply to agricultural land, 2) pump with treatment and serve to communities, and 3) pump, treat, and reinject. The pump, no treat, and apply to agricultural lands results in no change to the AID flow model previously developed for Scenario #3. This does not necessarily improve the ambient groundwater quality, but it does remove some nitrate mass from the subsurface (only to be applied on the surface where some of it can be utilized by crops). The second pumping regime, pump with treatment and serve to communities was not explicitly simulated aside from existing community wells. This regime considered two potential new well fields for supplemental water to communities, located in the southern area of AID where nitrate concentrations are above the Maximum Contaminant Level (MCL) of 10 mg/L nitrate as N. **Figure 2**, taken from the NIMS report (CDM Smith, 2016a), illustrates the location of the two well fields and treatment plants that would provide water to several communities in AID. **Table 1** below is extracted from Table 5-5 from the NIMS report, where it details the different communities and their water demand. The Cutler/Orosi Regional Drinking Water Project (Kapheim, 2016) is a new project that plans to serve surface water to several communities, including: Cutler, Orosi, East Orosi, Sultana, Monson, Yettem, and Seville (**Figure 3**). The Cutler/Orosi Regional Drinking Water Project is a currently planned project for the area, unlike the Pipeline Scenario 2d. For this reason, the water demands for those seven communities in the Regional Drinking Water Project were considered related to the development of the two potential well fields’ water demand developed in NIMS’ “AID Pipeline Scenario 2d”.

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\(^2\) Refer to the AID MZ Report Larry Walker Associates and Luhdorff & Scalmnini, Consulting Engineers, May 2016. CV-SALTS Management Zone Archetype Analysis: Alta Irrigation District for more details about the inputs and results of Scenario #3.
Table 1 NIMS “AID Pipeline Scenario 2d” Community Water Demands (CDM Smith, 2016a)

<table>
<thead>
<tr>
<th>Community</th>
<th>Area (mile²)</th>
<th>Population</th>
<th>EPA System Classification</th>
<th>Water Demand (AF)</th>
<th>Served By Cutler/Orosi Regional Drinking Water Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutler</td>
<td>0.807</td>
<td>5,000</td>
<td>Medium</td>
<td>1,013</td>
<td>X</td>
</tr>
<tr>
<td>Delft Colony</td>
<td>0.066</td>
<td>454</td>
<td>Very Small</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Dinuba</td>
<td>6.47</td>
<td>21,453</td>
<td>Large</td>
<td>4,720</td>
<td></td>
</tr>
<tr>
<td>East Orosi</td>
<td>0.248</td>
<td>495</td>
<td>Very Small</td>
<td>127</td>
<td>X</td>
</tr>
<tr>
<td>London</td>
<td>0.629</td>
<td>1,869</td>
<td>Small</td>
<td>411</td>
<td></td>
</tr>
<tr>
<td>Monson</td>
<td>0.492</td>
<td>188</td>
<td>Very Small</td>
<td>18</td>
<td>X</td>
</tr>
<tr>
<td>Orange Cove</td>
<td>1.912</td>
<td>9,078</td>
<td>Medium</td>
<td>1,997</td>
<td></td>
</tr>
<tr>
<td>Orosi</td>
<td>2.446</td>
<td>8,770</td>
<td>Medium</td>
<td>1,048</td>
<td>X</td>
</tr>
<tr>
<td>Reedley</td>
<td>5.156</td>
<td>24,194</td>
<td>Large</td>
<td>5,323</td>
<td></td>
</tr>
<tr>
<td>Seville</td>
<td>0.636</td>
<td>480</td>
<td>Very Small</td>
<td>66</td>
<td>X</td>
</tr>
<tr>
<td>Sultana</td>
<td>0.444</td>
<td>775</td>
<td>Small</td>
<td>177</td>
<td>X</td>
</tr>
<tr>
<td>Traver</td>
<td>0.843</td>
<td>713</td>
<td>Small</td>
<td>157</td>
<td></td>
</tr>
<tr>
<td>Yettem</td>
<td>0.153</td>
<td>211</td>
<td>Very Small</td>
<td>57</td>
<td>X</td>
</tr>
<tr>
<td><strong>TOTAL WATER DEMAND</strong></td>
<td></td>
<td></td>
<td></td>
<td>15,213</td>
<td></td>
</tr>
<tr>
<td><strong>Total Water Demand MINUS Regional Drinking Water Project Communities</strong></td>
<td></td>
<td></td>
<td></td>
<td>12,708</td>
<td></td>
</tr>
</tbody>
</table>

**Pump, Treat, and Reinject**

In order to achieve the greatest improvement to groundwater quality through a reduction in nitrate concentrations, there are several considerations to be made for a pump, treat, and reinject design. Considerations include: existing ambient groundwater quality; proximity to disadvantaged communities; land use; and mass loading. Within AID, a priority ranking for assigning particular densities of pump/treat/reinject well locations was developed for selecting two design (test) areas. Existing ambient groundwater quality, developed as part of the AID MZ effort, is presented in four different vertical zones based on well depth (Figure 4). A map of disadvantaged communities is shown in Figure 5, from the California Department of Water Resources (DWR). Figure 6 shows the nitrate mass loading associated with land use surface activities for Scenario #3. Four ranking categories divide AID into areas of lowest priority to highest priority, which in turn influence the density of potential pump/treat/reinject well sites. The priority ranking areas reconcile: 1) the spatial and vertical variability of ambient nitrate groundwater quality, and 2) proximity to disadvantaged communities. Figure 7 shows the division of AID into priority ranked areas, where Rank 1 indicates the lowest priority. This is where the best groundwater quality exists in the north (near the headwaters of the Kings River). Slightly worse groundwater quality exists along the western boundary of AID, and Reedley is the only community in that area, making this a Rank 2 priority, i.e., still a relatively low priority. In the vicinity of AID’s southern boundary, there is poor groundwater quality but very few communities (Traver is the only one in this area) that would benefit from this intervention.

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3 The mass loading associated with recharge is also considered, but it is highly variable throughout AID.
area); this makes this a higher priority area, Rank 3. The highest priority area, Rank 4, occurs in the central part of AID where nitrate concentrations are high and there are nine communities.

It is within the highest priority ranking area (Rank 4) that two areas were selected to design a scenario involving a pump, treat, and reinject system to reduce the nitrate concentrations in groundwater. The goal for the Aggressive Restoration Scenario with the pump, treat, and reinject approach is to observe decreases in nitrate in ambient groundwater within 10 to 20 years. This involves removing nitrate mass using extraction wells, treating that water to remove the nitrate, and then injecting the clean water back into the system. In order to be most efficient with the removal of nitrate mass, the extraction wells must target specific vertical zones to maximize the mass removal. Injection wells are placed upgradient of disadvantaged communities, and extraction wells are placed in and around disadvantaged communities at locations downgradient of injection wells. The density of extraction and injection wells is determined based on how much mass is needed to be removed to achieve target concentrations within a target time frame using wells that can pump at a certain appropriate rate (see Appendix A for the complete methodology of calculating the estimated well density).

The first design area for pump, treat, and reinject is in Dinuba (Figure 8). There are high nitrate concentrations in the Upper and Production Zones in the vicinity of Dinuba, so a 10.25 square-mile area was selected for demonstration of the extraction and injection well site density calculation for flow and transport modeling. A total of 26 extraction wells (10 located in the upper 300 feet of the groundwater model layers and 16 located in lower model layers to a depth of about 750 feet; pumping at 500 gpm) and 41 injection wells (16 located in the upper 300 feet pumping at 312.5 gpm and 25 injection wells constructed to deeper depths around 750 feet; pumping at 320 gpm) were estimated as part of the design to remove nitrate mass and reduce the nitrate concentrations in groundwater. Regional groundwater flows in the west-southwest direction, so injection wells are placed upgradient hydraulically (or on the eastern and northeastern side of the design area). Extraction wells are placed strategically where the nitrate mass (and concentration) is highest, i.e., on the west and southwest of the design area.

The second design area for a pump, treat, and reinject system is the Cutler/Orosi area (Figure 9). This location is selected because it is a different setting compared to Dinuba, but it is still in the highest ranking priority area. The nitrate concentrations in Cutler/Orosi are not as high as Dinuba, and the area is slightly smaller, at 7.8 square miles. A total of 4 extraction wells (3 wells located in the upper 300 feet and 1 well located in lower model layers to a depth of about 750 feet; pumping at 500 gpm) and 7 injection wells (5 wells located in the upper 300 feet pumping at 300 gpm and 2 wells located deeper to depths around 750 feet; pumping at 250 gpm) are designed to remove nitrate mass and reduce the nitrate concentrations in groundwater. Regional groundwater flows in the northwest direction, so injection wells are located upgradient hydraulically (on the southern side of the area), and extraction wells are placed where nitrate mass (and concentration) is highest, on the western side.

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4 The time frames discussed in this Technical Memorandum represent the time from when a project is actually built and operable. The time frames do not include the time needed for planning, design, environmental documentation and approval, permitting, and construction.

5 The input variables and calculated parameters are provided in Appendix A as an example for the Dinuba design area aquifer footprint of the Upper Zone using the methodology outlined in Appendix A.
On-Farm Winter Recharge

There are two existing artificial recharge facilities within AID (the Dinuba Pond and the Traver Pond). Previous work on the AID MZ model did not indicate that these two locations impacted groundwater quality measurably. In an attempt to be more aggressive and utilize another approach for introducing clean water to the groundwater system, on-farm winter recharge was selected. To locate the most appropriate location for applying excess surface water to the land, several factors are considered to develop a recharge index. Considerations include soil type, presence of deep ripping, subsurface material texture (0-50ft, 50-100ft, and 100-150ft), and the depth to water (RMC, 2014). Figure 10 shows a map of recharge indices (modified from RMC, 2014) and an area located north of Dinuba and east of Reedley that is selected with a high recharge potential index. The concept behind on-farm winter recharge is to utilize excess Kings River floodwaters and apply that water via existing conveyances onto farmland over a period between November and March. According to Table 8 from RMC Agricultural Recharge Merced, Madera, and Fresno Draft Report (2014), on average, there are 47,000 AF annually of Kings River floodwater available. The area of high potential for recharge selected in Figure 10 is about 12 square miles, or 7,600 acres. This translates to applying about 6.18 feet of water over five months for the selected area.

Flow and Transport Model Adjustments

Although this scope of work provided for modeling of one Aggressive Restoration Scenario, different scenarios, or Plans, were developed after the initial modeling results were produced and interpreted; the Plans are described below. The focus of this modeling effort was the disposition of nitrate mass and changes in nitrate concentrations in response to restoration strategies; nitrate transport was handled conservatively without consideration of potential degradation.

**Plan A**: Mass loading is based on Soil Water Assessment Tool (SWAT)-Scenario #3 surface loading. Injection and extraction are based on well density calculations as listed in Table 2 for the Dinuba and Cutler/Orosi areas. On-farm winter recharge is incorporated (47,000 AF annually over 7,600 acres).

**Plan B**: Mass loading is based on a reasonable lower bound to surface loading, to explore the sensitivity to mass loading from surface activities. Although the SWAT dataset developed for the AID MZ model has been acknowledged to be preliminary, it estimates nitrate and water flux through the root zone on a daily time step over a 35-year time interval and is informed by crop development, considering detailed climatic, soils, and management information. The AID MZ analysis explicitly short-circuited flux from root zones to the aquifer body, bypassing the vadose zone, in order to examine the long-term implications of contemporary surface management options for groundwater quality. Even with this accelerated or “collapsed” view, the influence of rather distinct surface loading scenarios on groundwater quality was muted and subject to significant time lag. Actual loading to groundwater is time-dependent and also depends on the contents of and processes in the portion of the vadose zone lying below the root zone.

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6 For the Aggressive Restoration Scenario, the full amount of the indicated available Kings River floodwater was utilized for the very large simulated recharge area in the northern AID area. Practically, this entire amount would not be available for use as part of any one recharge operation, nor would this average annual amount be likely to be available every year without other constraints. With the implementation of the Sustainable Groundwater Management Act, it is likely that area Groundwater Sustainability Agencies will coordinate to assess and optimize the best use of available stormwater for groundwater sustainability purposes.
An arbitrary 50% reduction of Scenario #3’s mass loading was selected for Plan B. Rationale for this include:

- The sub-root/vadose zone has the potential to mediate the influence of fluxes from root zones on underlying groundwater. Recent field testing in these strata and from overlying root zones show average nitrate concentrations over this greater depth interval lower than observed or modeled for root zones alone. Samples were collected at six field sites\(^7\) (two sites each representing three commodities: almonds, vineyards, and tomatoes) at one-meter depth increments in the Kings Subbasin (Bachand et al., in progress). The average nitrate concentration for all depths (up to 9 meters) and field sites was 55 mg/L as N, during one snapshot in time\(^8\).

- SWAT assumptions assume immediately foreseeable changes to irrigation systems and management practices, and the SWAT model is pending further refinement as grower-reported data begin to inform inputs. Therefore, root-zone results may shift in response to additional, actual management changes, and as the model is further refined for use in the Central Valley.

Injection and extraction is the same as Plan A. On-farm winter recharge is incorporated (47,000 AF annually over 7,600 acres).

**Plan C**: The pumping and injection rates (in both extraction and injection wells, respectively) are increased by a factor of 1.5 for each well (e.g. extraction wells pumping at 500 gpm in Plan B pump at 750 gpm in Plan C). The idea for increasing the pumping is to increase the hydraulic gradient to improve the cycling of water between the extraction and injection wells. Rather than increasing the number of extraction and injection wells, which might lead to short-circuiting of clean water, the amount of pumping was increased to improve circulation and mixing of groundwater between the injection and extraction well locations in each area. Mass loading and the on-farm winter recharge are the same as Plan B.

**Plan D**: The pumping and injection rates (in both extraction and injection wells, respectively) are doubled for each well (e.g., extraction wells pumping at 500 gpm in Plan B pump at 1,000 gpm in Plan C) to increase the hydraulic gradient and further improve the cycling of water between the extraction and injection wells\(^9\). Mass loading and on-farm winter recharge are the same as Plan B.

**Groundwater Pumping**

**Pump, No Treatment, and Apply** – No adjustments were made to the agricultural pumping that the AID MZ groundwater flow model had in Scenario #3.

**Pump, Treat, and Serve** - The total amount of water demand indicated from communities served by NIMS’ “AID Pipeline Scenario 2d” is 15,213 AF (NIMS Table 5-5). Seven communities comprise the total

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\(^7\) Three soil borings were drilled at each of the six field sites to depths of about 30 feet. The fields are actively farmed, and soil samples were collected to characterize nitrogen concentrations near the land surface and below the root zone.

\(^8\) Lower vadose-zone concentrations may exist due to lower rates of historical loading, or due to dilution by low-nitrate recharge sources. It is unknown how concentration profiles in this interval vary over time and space. In any case, this lower concentration will be recharging the underlying aquifer at these six locations before the more elevated root-zone concentrations arrive, if they ever do.

\(^9\) There is a limit to the number of extraction and injection wells that might be considered for any given area. If extraction and injection wells are spaced too closely, the intended restoration process that might occur along the flow path between the injection and extraction locations may be short-circuited by a nearby extraction well removing clean water too soon.
water demand, including Cutler, East Orosi, Monson, Orosi, Seville, Sultana, and Yettem. Clean drinking water would be provided via surface water from the Cutler/Orosi Regional Drinking Water Project (Kapheim, 2016)). The Cutler/Orosi Regional Drinking Water Project communities’ demand equates to 2,506 AF of surface water, leaving a total of 12,707 AF needed to be pumped from municipal wells. The amount of groundwater pumping in the groundwater flow model already equals 12,551 AFY within the urban footprints of major communities, including Reedley, Dinuba, Cutler, Orosi, and Orange Cove; this leaves approximately 2,662 AFY remaining to satisfy the other NIMS communities’ demands. Four virtual wells could be placed in the southern portion of AID (where NIMS “AID Pipeline Scenario 2d” outlines two potential well fields) and pump a total of 1,650 gpm. Based on the highest ambient nitrate concentrations present in the Production Zone in the two proposed well field areas in the southern portion of AID, the amount of nitrate mass removed would be extremely minor and of little consequence to AID as a whole (8 x 10^{-8} kg/yr, which represents 6 x 10^{-16}% of the total mass in AID). Because this would not make a measurable impact on AID, the flow and transport model was not adjusted to account for the NIMS or Cutler/Orosi Regional Drinking Water Projects.

**Pump, Treat, and Reinject** – Extraction and injection wells were added to the model at locations indicated in Figure 11. The pumping rates and numbers of wells are indicated in Table 2 and based on the well density calculations for each design area.

### Table 2 Extraction and Injection Well Design Summary

<table>
<thead>
<tr>
<th>Area</th>
<th>Depth Category</th>
<th>Extraction Wells</th>
<th>Injection Wells</th>
<th>Total # Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># Wells</td>
<td>Well Depth (ft)</td>
<td>Pumping Rate (gpm)(^{10})</td>
<td># Wells</td>
</tr>
<tr>
<td>Cutler/Orosi</td>
<td>Upper</td>
<td>3</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>1</td>
<td>752</td>
<td>500</td>
</tr>
<tr>
<td>Dinuba</td>
<td>Upper</td>
<td>10</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>16</td>
<td>752</td>
<td>500</td>
</tr>
<tr>
<td><strong>Total Wells</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**On-Farm Winter Recharge**

In order to adjust the flow and transport model to accommodate the on-farm winter recharge of 47,000 AF to the 190 cells in the area selected to receive additional surface water during winter months based on its appropriateness to receive excess recharge water, each cell was given 6.18 additional feet of

\(^{10}\) These extraction pumping rates represent values for extraction wells in Plans A and B. Pumping rates for Plan C is 1.5*Plan A; pumping rates for Plan D is 2*Plan A.

\(^{11}\) These injection pumping rates represent values for injection wells in Plans A and B. Pumping rates for Plan C is 1.5*Plan A; pumping rates for Plan D is 2*Plan A.
recharge over the year with a concentration of 0.31 mg/L nitrate as N. This additional volume and mass (concentration * volume) is added to the original recharge and surface mass loading from AID MZ Model Scenario #3 at those model cells.

**Model Results and Sensitivity Alternatives**

The model results are presented to allow for comparison between the different model runs. Scenario #3 is considered to be the “No Project” model run, where there are no restoration activities besides the potential future improvements in surface mass loading. Plan A is considered to be the “Project” model run and includes restoration activities of extraction/injection, and enhanced recharge. Plans B, C, and D are included as sensitivity alternatives. Due to the fact that the hydrogeology in AID is complex and dynamic, the results of the modeling are not always straightforward. The model results are provided below, including: 1) the extraction/injection focused area results, 2) the on-farm winter recharge focused area results, and 3) the larger area of the entire AID MZ and how these restoration activities changed the overall nitrate conditions in groundwater beneath AID over time.

**Pump, Treat, and Reinject Simulation Results**

Simulation results for the pump, treat, and reinject (extraction and injection) areas indicate improvement in groundwater quality over time, though not always to the target concentration goal in the time frame anticipated. For Dinuba, which had an extra 67 wells (26 extraction wells and 41 injection wells) added to its 10.25 square mile area, time series volume-weighted average nitrate concentration plots are provided for three different aquifer zones (Upper, Lower, and Production Zones) in Figure 12. Compared to Scenario #3’s volume-weighted simulated average nitrate concentration in the Dinuba area footprint, the extraction and injection wells made a substantial impact on resultant nitrate concentrations, producing a reduction in nitrate concentration of 18 mg/L as N in the Upper Zone, almost 4 mg/L as N in the Lower Zone, and almost 8 mg/L as N in the Production Zone over 100 years of simulated transport for Plan A. Plans B, C, and D showed improvements compared to Plan A. The Upper Zone did not achieve its target of 5 mg/L as N during the entire 100-year simulation. The lowest concentration attained in the Upper Zone occurred in Plan D with a value of 10.5 mg/L as N after 40 years. The Lower Zone reached its target of 5 mg/L as N with Plan C and Plan D after about 60 years and 34 years, respectively. Plans A through D reached 7.5 mg/L as N in the Lower Zone in about 37 years, 20 years, 12 years, and 9 years, respectively. The Production Zone did not achieve its target of 5 mg/L as N during the entire 100-year simulation. The Production Zone did, however, reach 7.5 mg/L as N in Plans B, C, and D before the end of the 100-year simulation (at about 95 years, 29 years, and 21 years, respectively). A summary of the simulation results is provided in Table 3. All of the aquifer zones show the area reaching an equilibrium condition over time, meaning that the amount of nitrate mass entering the area equals or almost equals the amount of mass leaving the area. In all cases, it takes decades for groundwater beneath the Dinuba area to reach a state of equilibrium.

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12 The average concentration of Kings River water is taken from measurements from CEDEN Station Kings River at Manning Avenue 551KRAMAV between 1991 and 2000.
13 Volume-weighted average concentrations were developed for *each grid cell* by taking an average of the mass and volume in each layer associated with the Upper Zone and computing a volume-weighted concentration. A similar volume-weighted average computation was applied for the Lower Zone and the Production Zone.
In the Cutler/Orosi design area, which had an extra 11 wells (4 extraction wells and 7 injection wells) added to its 7.8 square mile area, time-series volume-weighted average nitrate concentration plots are provided for three different aquifer zones (Upper, Lower, and Production Zones) in Figure 13. Compared to Scenario #3, the extraction and injection wells reduced the simulated nitrate concentration by about 0.3 mg/L as N, 4.3 mg/L as N, 4.7 mg/L as N, and 5.1 mg/L as N in the Upper Zone for Plans A, B, C, and D respectively. The Lower and Production Zones show a different pattern in the simulated nitrate concentration results. The increase in deeper pumping in the Lower Zone was enough to transmit the higher nitrate concentration water from the surface loading through the Upper Zone downward, ultimately worsening the quality in the Lower Zone slightly as seen in Plan A (by between about 0.2 to 0.5 mg/L as N). Plans B, C, and D, however, resulted in the extraction and injection system reaching the target of 5 mg/L as N in 23 years, 14 years, and 11 years, respectively, in the Lower Zone. The Production Zone was unable to achieve its target of 5 mg/L as N over the 100-year simulation period. The Production Zone showed initial decreases in nitrate concentrations in all four Plans during the first 5 years. Concentrations in the Production Zone continued to decrease for Plans B, C, and D, reaching 7.5 mg/L as N in 3 years, 2 years, and 2 years, respectively. A summary of the simulation results is provided in Table 4. All of the aquifer zones show signs of reaching or almost reaching equilibrium during the 100-year simulation period.

**Table 3 Summary of Dinuba Design Area Extraction/Injection Simulation Results**

<table>
<thead>
<tr>
<th>Aquifer Zone</th>
<th>Number of Years to Reach:</th>
<th>Nitrate Concentrations (mg/L as N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 mg/L as N</td>
<td>7.5 mg/L as N</td>
</tr>
<tr>
<td></td>
<td>Plan</td>
<td>B</td>
</tr>
<tr>
<td>Upper Zone</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lower Zone</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Production Zone</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Table 4 Summary of Cutler/Orosi Design Area Extraction/Injection Simulation Results**

<table>
<thead>
<tr>
<th>Aquifer Zone</th>
<th>Number of Years to Reach:</th>
<th>Nitrate Concentrations (mg/L as N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 mg/L as N</td>
<td>7.5 mg/L as N</td>
</tr>
<tr>
<td></td>
<td>Plan</td>
<td>B</td>
</tr>
<tr>
<td>Upper Zone</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lower Zone</td>
<td>-</td>
<td>23</td>
</tr>
<tr>
<td>Production Zone</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
On-Farm Recharge Simulation Results

The on-farm winter recharge was designed to apply excess Kings River surface water during a five-month period in the winter (November to March). The simulation of this increased winter time recharge essentially diluted the existing surface mass loading from Scenario #3 in the cells where excess water was applied. The increased recharge volume promoted vertical movement of water downward through the aquifer system in the vicinity of the on-farm recharge area. Figure 14 shows the time-series plots of simulated nitrate concentrations over the 100-year simulation period for the Upper, Lower, and Production Zones for Scenario #3, and Plans A through D. On-farm recharge improved conditions in the Upper Zone by reducing simulated nitrate concentrations by 12 mg/L as N in 20 years (Plan A) compared to Scenario #3 where no on-farm recharge occurred. Over 100 years, on-farm recharge activities reduced the simulated nitrate concentration by 18.5 mg/L as N (Plan A) in the Upper Zone compared to Scenario #3. One of the negative side effects of flushing an increased amount of water downward is that poor shallow water quality migrates downward deeper into the aquifer. As seen in the Lower Zone time-series plot (Figure 14), the presence of on-farm recharge increased the nitrate concentration for the Lower Zone compared to Scenario #3. The Production Zone, however, showed the same improvement pattern as the Upper Zone, with a reduction of about 3 mg/L as N in 20 years and 100 years (Plan A compared to Scenario #3). The proximity of the on-farm recharge area to the Dinuba pump, treat, and reinject design area influenced the flow regime of that area. The pumping stresses from the extraction and injection wells in the Dinuba design area increased the movement of water for Plans C and D, thereby affecting the movement of on-farm recharge clean water.

AID Simulation Results

The cumulative effect of the three restoration efforts (on-farm winter recharge, Dinuba pump/treat/reinject, and Cutler/Orosi pump/treat/reinject) on AID are evident in the simulated nitrate concentrations temporally and spatially. Figure 15 shows the time-series plots of simulated volume-weighted average nitrate concentrations for the Upper, Lower, and Production Zones for AID as a whole. In the Upper Zone, compared to Scenario #3, all of the restoration simulations (Plans A, B, C, and D) resulted in improving nitrate conditions: Plan A reduced the nitrate concentration by 1.2 mg/L as N in 20 years and 4.6 mg/L as N over 100 years; Plans B, C, and D reduced the nitrate concentration by about 8.6 mg/L as N in 20 years and 16.7 mg/L as N in 100 years. The Lower Zone showed improvements when the surface mass loading was halved (Plans B, C, and D). Otherwise, restoration efforts in Plan A only proved to flush poorer water quality water downward into the Lower Zone, slightly worsening conditions (Plan A shows higher simulated nitrate concentrations of 0.08 mg/L as N in the Lower Zone compared to Scenario #3 after 20 years and 0.12 mg/L as N after 100 years). Plans B through D improved conditions in the Lower Zone by about 0.4 mg/L as N after 20 years and 3 mg/L as N after 100 years compared to Scenario #3. The Production Zone showed similar trends to the Upper Zone, where all restoration simulations resulted in improvement of AID as a whole over time. Simulated volume-weighted average nitrate concentrations in the Production Zone improved by 0.3 mg/L as N for Plan A in 20 years and about 1.4 mg/L as N for Plan A in 100 years. Plans B through D improved the Production Zone’s nitrate concentration in AID by about 3 mg/L as N in 20 years and 6.7 mg/L as N in 100 years.

The localized effects of the restoration efforts can be seen spatially over time in Figures 16, 17, and 18 for the Upper Zone, Lower Zone, and Production Zone, respectively, for Scenario #3, Plan A, and Plan B for selected times (initial ambient conditions, after 5 years of simulated time, after 10, 20, 50, and 100 years of simulated time). The initial ambient conditions maps are provided for reference, but the comparisons of the different restoration efforts should be made with Scenario #3. Figure 16, the time-series maps of the Upper Zone, shows localized areas of improvement in the areas of restoration.
activities. The on-farm recharge area (the northern-most circular outline in AID) shows improvement of the Upper Zone in as early as 5 years in Plans A and B compared to Scenario #3. A plume of lower nitrate concentration water is seen extending out of the Dinuba pump, treat, and reinject area (the central-most circular outline in AID); this is especially visible after 20 years. The effects of the Cutler/Orosi pump, treat, and reinject area are less noticeable in the Upper Zone (the eastern-most circular outline in AID). The maps in Figure 16 illustrate the significant improvement of conditions in Plan B throughout AID, when the assumed mass loading is reduced by half, representing recharge concentrations resembling more of what has been measured in the field in the Kings Subbasin.

It is difficult to see the subtle differences in the spatial nitrate concentrations in the Lower Zone (Figure 17) over time. The recharge area shows the worsening conditions in the Lower Zone as a result of the increased recharge promoting the migration of poorer quality shallower water downward into the Lower Zone in Plans A and B compared to Scenario #3. Plumes of cleaner water are seen migrating from inside the Dinuba and Cutler/Orosi design areas, especially after 50 years of simulated time for Plans A and B. The reduction in mass loading from Plan A to Plan B makes a noticeable but small impact in the Lower Zone.

The improvements in the Production Zone due to the restoration efforts in Plans A and B are seen in Figure 18. When comparing the time-series maps to Scenario #3, the on-farm recharge clean water can be seen, and the plumes of cleaner water can also be seen extending out of the Dinuba and Cutler/Orosi design areas where pump, treat, and reinject activities helped remove nitrate from the subsurface and cycle clean water back into the system. Even with these restoration activities, there are parts of AID that remain above the MCL and show signs of worsening conditions over time.

Conclusions and Lessons Learned

The following is a list of conclusions and lessons learned from the work completed for the Aggressive Restoration Scenario:

- A targeted approach for restoration works better in smaller geographic settings where there is more control and knowledge about the transport of water and nitrate mass.
- Applying pump, treat, and reinject designs to large regional areas is not practicable because there are too many other complications such as non-point sources, local rural/urban/domestic pumping stresses, and lateral influxes that interfere with the movement and restoration of the water that is attempted with the pump, treat, and reinject system design.
- On-farm recharge is advantageous for flushing the root zone with clean water, but the effects of the increased recharge are not always discernible in the precise area of the recharge activity; recharge effects may be seen downgradient and may be affected by nearby pumping stresses.
- On-farm recharge aids in the vertical movement of clean water, but can also result in displacement of existing poor shallow water quality causing this water to move downward into lower parts of the aquifer system, sometimes including the Production Zone.
- On-farm recharge and any attempts at enhanced natural recharge or artificial recharge are greatly dependent on the ability of the aquifer materials to accept additional water. Factors such as soil and subsurface texture, the presence of deep ripping, and the depth to the water table, are all factors that determine the ability of a particular area to transmit excess water vertically downward into the aquifer. Locations for on-farm recharge or any increased recharge efforts must be considered and selected according to their recharge index and the overall
hydrogeologic setting. On-farm recharge efforts are not suitable in urban areas where open space to apply excess clean floodwaters is scarce. Urban areas with buildings, pavement, and roads, for example, do not provide a suitable area for on-farm recharge efforts.

- Pump, treat, and serve efforts are an excellent way to provide clean drinking water to communities, but this approach does not serve as a particularly beneficial tool for restoration. The amount of nitrate (or salt) mass removed from municipal pumping is minor compared to the amount of mass entering the system through surface mass loading and lateral fluxes on a regional scale. Most of the pump, treat, and serve water is consumed; therefore, little treated water returns to the aquifer system, offering little or no replenishment to the aquifer.

- Restoration is not likely feasible on the scale of the Central Valley. It appears to be unrealistic even on the scale of AID, as it would likely take on the order of thousands of new wells\(^1\) to pump, treat, and reinject clean water back into the system while intercepting surface mass loadings before they migrate down into the Production Zone. Localized efforts in areas that are of high priority (based on proximity to communities and existing ambient conditions) may be potentially ideal for restoration activities that may include on-farm recharge, other artificial recharge efforts, and pump/treat/reinject efforts. Even so, restoration activities may take decades to result in satisfactory declines in impaired groundwater quality, and eventually the areas may reach equilibrium where the mass entering equals the mass exiting. Therefore, targeted reductions in nitrate concentrations may still be difficult to achieve.

\(^{14}\) See Appendix B.
References


CDM Smith. 2016b. Strategic salt accumulation land and transportation study (SSALTS).


Appendix A Well Density Calculation

In order to achieve the target nitrate concentration, \( C_{\text{target}} \), in the aquifer that belongs to a particular footprint or map area, the following methodology is employed. The cell-based volume of water \( V_i \) (the results of the flow numerical model) with a background nitrate concentration \( C_i \), where \( i \) goes from 1 to the total number of cells “\( i \)” in the specific aquifer footprint. To start the well density calculations, the volume of water \( (V_1) \) that needs to be extracted from the aquifer footprint, treated, and reinjected back into the aquifer needs to be calculated to achieve the target concentration, \( C_{\text{target}} \). Once that volume, \( V_1 \) is known, the number of extraction wells can be estimated based on the typical well capacities of the local aquifer and assigned time frame of operation “\( t \)”.

To determine the volume \( V_1 \), it is assumed that the aquifer footprint has complete mixing within its known total water volume \( V = \sum_{i=1}^{I} V_i \) and has its associated volume-based nitrate mass, or resident mass, \( M = \sum_{i=1}^{I} V_i \cdot C_i \). These equations provide the volume-based average nitrate concentration, or average resident concentration, \( C \), which is equal to \( M/V \).

The volume, \( V \), can be divided into two water volumes: \( V_1 \) (extracted water volume with concentration \( C \)), then treated and reinjected with concentration \( C_{\text{inj}} \), and \( V_2 \) (the remaining water volume in the aquifer with concentration \( C \)). The nitrate mass balance equation for the system therefore becomes:

\[ C_{\text{target}} \cdot V = C \cdot V_2 + C_{\text{inj}} \cdot V_1 \tag{1} \]

By assuming that \( C_{\text{inj}} = 0 \), Equation (1) becomes

\[ C_{\text{target}} \cdot V = C \cdot V_2 \rightarrow \frac{C_{\text{target}}}{C} = \frac{V_2}{V} = P \tag{2} \]

Where “\( P \)” is the fraction or proportion of remaining water volume in the system \( (V_2) \), of the total system water in the system \( (V) \). Then the fraction of the extracted water volume \( (V_1) \) of “\( V \)” can be calculated as:

\[ 1 - P = \frac{V_1}{V} \tag{3} \]

By assigning the value for the target system concentration \( C_{\text{target}} \), equations (2) and (3) can be combined to estimate the extracted water volume \( (V_1) \) as follow,

\[ V_1 = V \left( 1 - \frac{C_{\text{target}}}{C} \right) \tag{4} \]

Equation (4) is used to determine the volume of water \( (V_1) \) that needs to be extracted from the aquifer footprint, treated, and reinjected back into the aquifer, given \( V \) and \( C \), and by assigning \( C_{\text{target}} \).

To estimate the number of extracted wells needed to pump “\( V_1 \)” out of the system, the time frame of operation “\( t \)” is set to represent how long it will take to extract “\( V_1 \)” from the system and then reinject it immediately to the system. The volumetric flow rate of extracted wells is written as:

\[ n \cdot Q_p = \frac{V_1}{t} \rightarrow n = \frac{V_1}{(t \cdot Q_p)} \tag{5} \]
Where,

\( n \) : is the unknown number of extraction wells needed to take out “\( V_1 \)”,

\( Q_p \): is the assigned production rate of each extraction well, based on local well capacities and properties of the local aquifer footprint’s porous media.

Equation (5) is used to determine how many extraction wells are needed, given \( V_1 \) from equation (4), and by assigning \( t \) and \( Q_p \).

In conclusion, extraction well density calculation is based on: known water volume “\( V \)”, known background nitrate concentration “\( C \)”, assigned target concentration “\( C_{\text{target}} \)”, assigned production rate “\( Q_p \)”, and assigned the time frame of operation “\( t \)”. This can be shown mathematically by combining equations 4 & 5 as follows,

\[
n = \frac{V \cdot \left(1 - \frac{C_{\text{target}}}{C}\right)}{(t \cdot Q_p)} \quad (6)
\]

Lastly, the number of injection wells (\( n_I \)) necessary to inject treated (clean) water with volume (\( V_1 \)) can be determined by assigning a multiplication factor (>1) of \( Q_p \) to represent the injection flow rate per injection well (\( Q_I \)) and then get the number of injection wells needed. The multiplication factor is multiplied to the integer number of extraction wells “\( n \)”, to get “\( n_I \)”, and then the individual injection well rate \( Q_I \) can be calculated as follows:

\[
Q_I = \frac{(n \cdot Q_p)}{(n_I)} \quad (7)
\]

An example of the input variables and calculated parameters for the Dinuba design area’s aquifer footprint for the Upper Zone are provided below:
<table>
<thead>
<tr>
<th>Variable or Parameter</th>
<th>Source</th>
<th>Units</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>M (resident nitrate mass extracted)</td>
<td>Post-processing of interpolated background nitrate</td>
<td>mg</td>
<td>5.03211E+12</td>
</tr>
<tr>
<td></td>
<td>concentration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V (Total water volume)</td>
<td>Post-processing of flow model result</td>
<td>L</td>
<td>2.52444E+11</td>
</tr>
<tr>
<td>C (average resident nitrate concentration)</td>
<td>Estimated</td>
<td>mg/l</td>
<td>19.93359503</td>
</tr>
<tr>
<td>C_t (Concentration target)</td>
<td>Assigned</td>
<td>mg/l</td>
<td>5</td>
</tr>
<tr>
<td>P</td>
<td>Equation 2</td>
<td></td>
<td>0.250832827</td>
</tr>
<tr>
<td>Q_e (Extraction Well rate)</td>
<td>Assigned</td>
<td>gpm</td>
<td>500</td>
</tr>
<tr>
<td>Q_d (Extraction Well rate)</td>
<td>L/year</td>
<td></td>
<td>994805748</td>
</tr>
<tr>
<td>t (time frame of operation)</td>
<td>Assigned</td>
<td>Year</td>
<td>20</td>
</tr>
<tr>
<td>n (number of extraction wells)</td>
<td>Equation 5</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Multiplication factor</td>
<td>Assigned</td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>n_i (number of injection wells)</td>
<td>Estimated</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Q_i (Injection Well rate)</td>
<td>Equation 7</td>
<td>gpm</td>
<td>312.5</td>
</tr>
</tbody>
</table>
Appendix B Extrapolation of Pump, Treat, and Reinject to the AID Boundary

This appendix introduces the concept of extrapolating the methodology used for estimating the well density (or calculating the number of extraction and injection wells) to achieve restoration for the entire AID boundary. The well density calculations can be applied to the entire AID area, using a target concentration of 5 mg/L as N over 20 years. In order to achieve this, the extraction wells would have to remove enough background mass and surface mass loading (accumulated in 20 years) to achieve 5 mg/L as N in 20 years by extracting and injecting clean water to replace the removed water. This method assumes complete mixing occurs and the entire AID footprint is treated like one big volume full of a particular nitrate mass (it does not take into consideration lateral fluxes into AID; hence, this can contribute to an incomplete accounting of more or less mass which can affect the number of wells estimated prior to evaluating the result of the well field design with a modeling tool). The table below summarizes the number of wells for each aquifer zone and their pumping rates and types. A total of 615 extraction wells and 985 injection wells would be needed, for a total of 1,600 new wells drilled and operated in the about 200 square-mile area of Alta Irrigation District.

<table>
<thead>
<tr>
<th>Proposed Well Variable</th>
<th>Upper Zone with Mass Loading for 20 Years</th>
<th>Lower Zone</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Extraction Wells</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well Flow (gpm)</td>
<td>500</td>
<td>500</td>
<td>615</td>
</tr>
<tr>
<td>Number of Wells</td>
<td>238</td>
<td>377</td>
<td>615</td>
</tr>
<tr>
<td></td>
<td><strong>Injection Wells</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well Flow (gpm)</td>
<td>313</td>
<td>312</td>
<td>985</td>
</tr>
<tr>
<td>Number of Wells</td>
<td>381</td>
<td>604</td>
<td>985</td>
</tr>
<tr>
<td><strong>Total Number of New Wells</strong></td>
<td>619</td>
<td>981</td>
<td>1,600</td>
</tr>
</tbody>
</table>
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Figure 1 Location Map, AID MZ Model Area

Legend
- Cutler/Orosi Design Area for Pump, Treat, & Reinject
- Dinuba Design Area for Pump, Treat, & Reinject
- On Farm Winter Recharge Area
- Alta Irrigation District Boundary
- AID MZ Active Model Area
- AID MZ Model Grid
- Counties of California

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Figure 2 NIMS Approach for “AID Pipeline Scenario 2d”

Adapted from NIMS Figure 5-17 Alta Irrigation District Pump, Treat, and Serve Scenario 2d (Land use from DWR http://www.water.ca.gov/landwateruse/lsrvymain.cfm)

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Figure 3 Cutler/Orosi Regional Drinking Water Project Service Area Map
Figure 4 Existing Ambient Groundwater Quality in AID

AID Model Layers 1-15

AID Model Layers 16-22

AID Model Layers 23-26

AID Model Layers 27-38

Legend
Nitrate Concentration
- <=5.0 mg/L as N
- 5-10 mg/L as N
- 10-15 mg/L as N
- 15-20 mg/L as N
- 20-25 mg/L as N
- 25-30 mg/L as N
- 30-40 mg/L as N
- 40-45 mg/L as N
- 45-50 mg/L as N
- >50 mg/L as N

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Figure 5 Disadvantaged Communities (DWR Mapping Tool)
Figure 6 Scenario #3 Recharge Nitrate Mass Loading
Figure 7 Priority Ranking Based on Existing Ambient Nitrate Concentrations and Disadvantaged Community Proximity

Best GWQ in the north
(headwaters of Kings River)

Worst GWQ in the South and Central AID

Rank 1 = lowest priority → lowest density of pump/treat/reinject well sites

Rank 4 = highest priority → highest density of pump/treat/reinject well sites
Figure 8 Dinuba Design Area for Pump, Treat, and Reinject Approach

Nitrate mass in Production Zone

- Green: <=5,000 kg
- Light Green: 5,000-10,000 kg
- Yellow: 10,000-15,000 kg
- Light Yellow: 15,000-20,000 kg
- Orange: 20,000-30,000 kg
- Dark Orange: 30,000-40,000 kg
- Red: 40,000-60,000 kg
- Red: >60,000 kg

Regional GW Flow Direction

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Figure 9 Cutler/Orosi Design Area for Pump, Treat, and Reinject Approach
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Figure 11 Pump, Treat, and Reinject Approach – Dinuba and Cutler/Orosi Areas

LEGEND
- Model Cell in Pump, Treat, and Reinject Design Area
- Model Cell with Extraction or Injection Well
- Alta Irrigation District Boundary
- Lower Zone Injection Well
- Lower Zone Extraction Well
- Upper Zone Injection Well
- Upper Zone Extraction Well

Flow Direction

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Figure 14 On-Farm Winter Recharge Area Time-Series Plots of Simulated Nitrate Concentration – Upper, Lower, and Production Zones

On-Farm Recharge Area, Upper Zone

On-Farm Recharge Area, Lower Zone

On-Farm Recharge Area, Production Zone
Figure 15 AID Time-Series Plots of Simulated Nitrate Concentration – Upper, Lower, and Production Zones

[Graphs showing simulated nitrate concentration over time for Upper, Lower, and Production Zones]
Figure 16 Time-Series Maps of Simulated Volume-Weighted Upper Zone Nitrate Concentrations in AID for Scenario #3, Plan A, and Plan B

<table>
<thead>
<tr>
<th>UPPER ZONE</th>
<th>Simulated Time (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Initial Ambient</td>
<td>Scenario #3 (No On-Farm Recharge or Extraction/Injection Rest. Activities)</td>
</tr>
<tr>
<td>Initial Ambient</td>
<td>Plan A (Scen #3 Mass Loading WITH On-Farm Rech &amp; Ext/Injection)</td>
</tr>
<tr>
<td>Initial Ambient</td>
<td>Plan B (Half of Scen #3 Mass Loading WITH On-Farm Rech &amp; Ext/Injection)</td>
</tr>
</tbody>
</table>

Legend:
- N/A
- < 2.5 mg/l as N
- > 2.5 - 5.0 mg/L as N
- > 5.0 - 7.5 mg/L as N
- > 7.5 - 10.0 mg/L as N
- > 10.0 - 25.0 mg/L as N
- > 25.0 - 50.0 mg/L as N
- > 50.0 mg/L as N

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### LOWER ZONE Simulated Time (Years)

<table>
<thead>
<tr>
<th>LOWER ZONE</th>
<th>Simulated Time (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Ambient</td>
<td>5</td>
</tr>
<tr>
<td>Scenario #3 (No On-Farm Recharge or Extraction/Injection Rest. Activities)</td>
<td><img src="image1" alt="Map" /></td>
</tr>
<tr>
<td>Initial Ambient</td>
<td>Plan A (Scen #3 Mass Loading WITH On-Farm Rech &amp; Ext/Injection)</td>
</tr>
<tr>
<td>Initial Ambient</td>
<td>Plan B (Half of Scen #3 Mass Loading WITH On-Farm Rech &amp; Ext/Injection)</td>
</tr>
</tbody>
</table>

#### Legend
- **Nitrate Concentration**
  - N/A
  - < 2.5 mg/L as N
  - > 2.5 - 5.0 mg/L as N
  - > 5.0 - 7.5 mg/L as N
  - > 7.5 - 10.0 mg/L as N
  - > 10.0 - 25.0 mg/L as N
  - > 25.0 - 50.0 mg/L as N
  - > 50.0 mg/L as N
- **Design Areas**
  - Dinuba and Cutler/Cros Design Area
  - On-Farm Winter Recharge Area

---

CV-SALTS Alta Irrigation District Management Zone:
Aggressive Restoration Alternative Modeling Scenario Results
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Figure 18 Time-Series Maps of Simulated Volume-Weighted Production Zone Nitrate Concentrations in AID for Scenario #3, Plan A, and Plan B

<table>
<thead>
<tr>
<th>PRODUCTION ZONE</th>
<th>Simulated Time (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Ambient</td>
<td>Scenario #3 (No On-Farm Recharge or Extraction/Injection Rest. Activities)</td>
</tr>
<tr>
<td>Initial Ambient</td>
<td>Plan A (Scen #3 Mass Loading WITH On-Farm Rech &amp; Ext/Injection)</td>
</tr>
<tr>
<td>Initial Ambient</td>
<td>Plan B (Half of Scen #3 Mass Loading WITH On-Farm Rech &amp; Ext/Injection)</td>
</tr>
</tbody>
</table>

Legend
Nitrate Concentration
- N/A
- < 2.5 mg/L as N
- 2.5 - 5.0 mg/L as N
- 5.0 - 7.5 mg/L as N
- 7.5 - 10.0 mg/L as N
- 10.0 - 25.0 mg/L as N
- > 25.0 - 50.0 mg/L as N
- > 50.0 mg/L as N

CV-SALTS Alta Irrigation District Management Zone:
Aggressive Restoration Alternative Modeling Scenario Results
LSCE and LWA
SEPTEMBER 2016