UNIVERSITY OF CALIFORNIA, MERCED UCM

BERKELEY • DAVIS • IRVINE • LOS ANGELES • MERCED • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

Department of Civil & Environmental Engineering
University of California, Merced

April 18, 2018

To: Glenn Meeks, Central Valley Regional Water Quality Control Board

From: Thomas C. Harmon, Professor of Civil & Environmental Engineering

Subject: Peer Review of Reports to Support a Proposed Basin Plan Amendment to Establish a Central Valley-wide Salinity and Nitrate Management Plan (SNMP)

I am pleased to submit my review of the above-mentioned reports on developing a Central Valley-wide salinity and nitrate management plan (SNMP). My emphasis is on the nitrate aspects of the report, but I touch on salinity aspects as well since the two issues are connected and many parts of the reports address them simultaneously. More specifically, I reviewed the following documents: (1) ICM Task 5 Report, (2) ICM Tasks 7 and 8 Report, (6) NIMS Report, and (7) Aggressive Restoration Study, using background documents as needed to better understand the modeling details (Faunt 2009; Herr and Chen 2012; and Neitsch et al. 2011).

Prior to providing my comments, I want to note that I recognize the magnitude of the effort that went into completing the work. The work is of high quality and most of my comments are meant to be constructive, pointing to areas where the methodology might be improved or where the scope of the investigation might include issues not addressed in these reports but nonetheless relevant to establishing an optimal SNMP.

Below are direct responses to the questions/statements you provided in your review request. More specific comments keyed to reports sections are summarized in an attached Excel file.

1. Annual salt accumulation must be addressed with an Out-of-Valley solution

1a. Data generated by the Watershed Analysis Risk Management Framework (WARMF) watershed modeling tool used in conjunction with the USGS Central Valley Hydrologic Model (CVHM) was appropriate to evaluate ambient groundwater quality and changes in groundwater quality within the Central Valley and resulted in assumptions regarding import and export of salt that were reasonable estimates for the Central Valley.

Response: Details about the integration of CVHM and WARMF modeling approach and the resulting outputs were challenging to grasp from the report content. Both models are uncertain, and the degree of uncertainty varies spatially in the Central Valley, and the integrated modeling product is likely more uncertain than either of the model simulations individually. The CVHM model is well-calibrated for such a complex model but, as the developers note, better at describing groundwater conditions in some areas of the Valley and worse in others. The WARMF model is well-calibrated, but focuses on key checkpoints in the system and is also not likely to be uniformly accurate throughout the Valley. In the best case, the combined results will be as accurate as the combined results from CVHM and WARMF but more there is some error associated with combining the model outputs. From a scientific standpoint, the combined modeling product was not rigorously calibrated in terms of a systematic adjustment of parameters to optimize agreement with observations. Nor was it validated in terms of testing the calibrated model against observations differing from those employed in calibration. My impression from the reports (as well as general knowledge about historical groundwater data) is that rigorous calibration is probably not possible given the variability and uncertainty in historical groundwater quality data. Lack of calibration renders validation impossible. I did find that there was a reasonable effort to compare simulated salinity (TDS) and nitrate with observations, and these produced reasonable outcomes for the TDS. Model comparisons with observed nitrate concentrations were poor in comparison, which is not surprising given that TDS is a conservative "solute" while nitrate, is a reactive solute and likely undergoing transformations to greater and lesser extents in different locations.

Given this perspective, I conclude that the WARMF-CVHM approach was appropriate for estimating the salt and nitrate balance in the Central Valley, and that the simulated data produced by this modeling approach provides an appropriate approximation to the Central Valley horizontal and vertical variability in groundwater quality.

Recommendations: The following recommendations may help to improve the Central Valley's groundwater and salt balance modeling approach, recognizing that appropriate time and resources would need to be made available to act upon them:

- It was suggested in the reports, and I agree, that it would be preferable to create the dedicated modeling tools necessary to avoid the need to integrating results from different models that were created for different regions and perhaps different spatial resolutions. The SWAT-CVHM-MT3DMS modeling approach is a good step in that direction.
- Defining the capacity and strength of the salinity and nitrate sources in the vadose zone is central to the modeling effort, but also challenging. In general, estimates of groundwater restoration times will be very sensitive to source zone characteristics. That issue is true for the ICM case, and adds significant (possibly large) uncertainty to the modeling scenarios. At this time, I do not have a good idea for how to efficiently characterize and model these vadose zone source at a meaningful scale for the modeling approach used, but I believe it is possible and important to identify some field tests and modeling approaches to do so.

1b. The management options identified to treat and dispose of the annual salt accumulation included a reasonable range of feasible treatment and disposal measures that can be implemented in the Central Valley.

Response: I did not review the documents describing the various alternatives.

1c. A brine line is the most reasonable alternative to remove excess salt accumulation in the Central Valley.

Response: Based on Task 5 and Tasks 7 & 8 Reports, I was able to understand the sustainability problem stemming from the Central Valley's historical salt balance. If the plan is to sustain the Central Valley land use and land management practices as they stand today, then I agree that a brine line is likely to be the most reasonable alternative.

Recommendation: If the SNMP is to serve California for the next 50-100 years, a more comprehensive study is more appropriate, one that employs a broader systems approach, extending to least to all of California (including coastal waters) but preferably expanding to a global perspective. There are several reasons why an expanded approach makes sense: (1) the Central Valley population will be increasing over the next several decades, and the resulting water demands and land use changes are likely to be substantial and important to consider; (2) Environmental costs of engineered solutions (such as a brine line) can be better considered using a systems approach, including costs that may need to be passed along to state agencies, agricultural producers, and consumers; and (3) a still broader perspective (international) considers markets for Central Valley products (and the water footprint they represent), including potential markets for salt-based products.

2. Nitrate contamination in some locations may not be reasonably treated to achieve drinking water quality. Geology and nitrate concentrations in some locations are conducive to restoration. Reduction of nitrate levels in groundwater is possible in certain geologic settings (sandy soil conditions and relatively shallow groundwater levels). However, even with significant restoration activities, it may take 40 to 70 years to achieve drinking water standards in groundwater, and in some cases, even longer.

Response: The Aggressive Restoration modeling scenarios demonstrated that aquifer restoration in the Central Valley is a long-term venture in most cases. I believe that the simulations clearly demonstrated this but, it is worth noting, large-scale aquifer restoration such as is addresses in these reports is always a long-term venture. Chemicals which have been given many decades to enter and disperse in the subsurface require many decades to extract. Given this general observation, the following points are intended to address the issue of groundwater nitrate restoration more directly.

- In some cases, it may be possible to restore and maintain drinking water quality in the aquifer. However, as noted above with respect to vadose zone source zones, restoration potential and duration is strongly connected to the continued irrigation and fertilization practices. This issue was evidenced by the steady-state nitrate concentrations that resulted in many of the aggressive restoration simulations. In these simulation, nitrate-contaminated groundwater is extracted and treated, but "replacement" nitrate leaches from the soil to the aquifer or moves from the upper to lower aquifer layers. The long-term result is steady nitrate concentrations in the aquifer. Ideally, modified fertilization practices would reduce the loading on groundwater and result in either acceptable steady-state or even decreasing nitrate levels.
- Some interesting outcomes of the aggressive restoration scenarios had to do with providing a reliable drinking water supply for DUCs and DACs in the Central Valley. While some cost estimates were provided, it was not clear if they were considered manageable or excessive. From this perspective, if the costs are manageable then perhaps some form of the pump, treat, and serve option is the best with respect to Goal 1

(safe drinking water). With this goal met, attention could focus on Goals 2 and 3. In connection to a broader systems approach, planning for population increases in regions where it is may reduce long-term costs by providing economy of scale in what are otherwise relatively small-scale treatment systems.

- Again in the context of drinking water treatment costs, it would be interesting and informative to know if there were alternative cost-sharing models that would make various alternatives more or less competitive. For example, could treatment costs be shared by agricultural producers, suppliers, and consumers (i.e., inclusion of environmental costs of food, water, energy).

The Big Picture

a. **Are there any additional scientific issues that should be part of the scientific portion of the water quality criteria derivation that are not described above? If so, comment with respect to the report's key findings.**
b. **Taken as a whole, are the scientific portions of the study reports based upon sound scientific knowledge, methods, and practices.**

The study is based on sound scientific knowledge, methods, and practices for the study area (i.e., the engineering control volume) as defined. The results indicate that groundwater restoration in the Central Valley is a challenging and long-term prospect, at best, and infeasible without substantial reductions in salt and nitrate loading or major investments (such as treatment facilities and brine lines). The study appears to be premised on the need to sustain the current land use and land management practices in the Central Valley. In short, the study's "big picture" question is whether we need to re-engineer the Central Valley's salt balance to maintain the region's current agricultural enterprise. Based on the resulting appraisal of the Central Valley's salt and nitrate balances, I agree that the answer is yes.

Given that an broader study would require a larger and more costly effort, a more sound scientific approach would address the greater system. Such a "bigger picture" perspective would enable California to consider if re-engineering the Central Valley's salt balance is sufficient and if it is desirable or whether it might lead to other major problems. This would require identifying an SNMP (a more complex socio-environmental problem) that is technically feasible as well as food-water-energy smart, economically beneficial, and socio-culturally acceptable. This is obviously a much more challenging problem that will require a broader, multiple objective approach focused on optimizing state natural resources and their services to a broad range of Californians. Tackling such a problem will require envisioning changes in agricultural technology, climate, population and demographics, land use, and more.

References employed in this review:

The ICM Final Report: Task #5 – Recommended Methodologies to Assess Water, Salt, and Nitrate Balances for the Central Valley Floor and Two Prototype Areas Report (ICM Task 5 Report).

The ICM Final Report: Task 7 and 8 - Salt and Nitrate Analysis for the Central Valley Floor and a Focused Analysis of Modesto and Kings Sub-regions Final Report (ICM Task 7 and 8 Report).

The Nitrate Implementation Measures Study (NIMS) Final Report (NIMS Report).

Alta Irrigation District Management Zone: Aggressive Restoration Alternative Modeling Scenario Results (Aggressive Restoration Study).

Faunt, C.C., ed., 2009, Groundwater Availability of the Central Valley Aquifer, California: U.S. Geological Survey, Professional Paper 1766 (CVHM Report).

Herr, J. and C.W. Chen. (2012). WARMF: Model Use, Calibration, and Validation. Transactions of the ASABE, 55(4): 1387-1396 (WARMF paper)

Neitsch, S.L., J.G. Arnold, J.R. Kiniry, J.R. Williams. 2011. Soil & Water Assessment Tool, Theoretical Documentation, Version 2009. Texas Water Resources Institute Technical Report No. 406, Texas A&M University System (SWAT Manual)

Report Specific Comments

Document	Section (page)	Comment
ICM Task #5 Recommended Methodologeis to Assess Water, Salt, and Nitrate Balances…	1 (1)	The goal of Task 5 is to describes the Initial Conceptual Model (ICM) methodologies for assessing water, salt, and nitrate balances throughout the Central Valley. The resulting ICM will support Phase 2 work which will provide "refined, interconnected spatial detail" in subsequent modeling and planning efforts. This phased approach is a reasonable, and the resulting ICM appears to be based on input from relevant stakeholders intimately familiar with the problem.
	1 (1)	The ICM is relatively detailed and quantitative for a conceptual approach, and the details are difficult to appreciate in a concentrated review period. What is apparent is that outputs from several complex, spatially distributed models are to be integrated in the resulting ICM. From a hydrologic and mass balance perspective, the approach is reasonable. However, the section would benefit from some assurances as to how the ICM approach is going to be validated (or "reality-checked"/tested in the event that rigorous validation is not possible) would help to solidify this section by setting a target in addition to the scope (such as in reference to section 4.3).
	1 (2)	"…on a 30,000 foot level" is a vague expression that is used repeatedly and likely has some specific contextual meaning to the report authors. Yet the ICM is a fairly detailed approach, so it would be good to define what is meant by this expression.
	1 (2)	The significance of the selected 20-year evaluation period is not clear to the reader at this point, and a brief explanation would improve this introductory material.
	2.2 (7)	Methods of detecting bias is an important part of the methodology and several relevant and potentially important sources of bias are described. Were issues encountered and addressed regarding method detection limits and historical changes in same? This issue is addressed in Tasks 7 & 8 (p 4-4) but should be included in the list of potential sources of bias.
	Table 1	The Data/Decision matrix is a good idea that supports objective sorting of the model outcomes.
	4 (19)	"…a net mass recharge to groundwater is determined." Recharge may not be the correct word choice. Recharge pertains to water flow/flux to groundwater, not nitrate or salts, which is more ofter referred to as mass loading.
	4.1.1 (20)	If I follow the method, then the vertical groundwater velocity is estimated using Darcy's Law, with the vertical hydraulic conductivity estimated from CVHM material properties. This is an important aspect of the water, salt, and nitrate balance calculations. I am not an expert on CVHM, butI recall that the material property distribution is texture-based, and a geostatistical realization based on many borehole logs (and possibly other hydrogeologic data). In this context, the realization may be optimized with respect to the overall groundwater dynamics in the Valley, and may be more/less consistent with local values in different regions of the Valley. Was this considered in the method development? For instance, it seems that the 20-year travel zone estimates could easily be off by a factor of 1.5 or 2 based on the difference between the geostatistical conductivity field and an estimate based solely on local values.
	4.1 (water balance)	With CVHM as the hydrologic driver, it would be valuable to incorporate its uncertainty into the ICM methodology. For instance, Figure C17 from Flaunt et al. (2009) suggests that there would be significant uncertainty in the lithology and hydrogeological properites (as would be expected with any such modeling effort). This may be beyond the scope of the ICM, but the subject may merit some discussion with regard to sources of error or uncertainty in this effort.
	4.1 (29)	As the report states, WARMF model domain assumes zero leakage from stream segments (except for some segments of the San Joaquin R), and it is assumed that CVHM stream leakage is correct. Given the connection between WARMF and CVHM in the ICM approach, it would be good to call out potential discrepancies like this with regard to their potential impact on the ensuing calculations
	4.1 (29)	"The quality of this recharge is likely similar to other stream recharge and would likely tend to be more concentratined…" Please explain or provide a reference for this statement.
	4.1 (29)	"For the IAZs where this is relevant, this effect will be noted as one fo the approximations in the current salt and nitrate balances." This sentence needs attention. An effect should not be described as an approximation--perhaps "assumption" or "source of uncertainty."
	4.2 (36)	As the report states, there is no accounting for vadose zone thickness and recharge simply applys the salt and nitrate loads directly to the shallow aquifer. The report also appropriately points out that this could be an issue where depth to groundwater is very large. I few more sentences would be good here to point out potential regions in the model where this might be the case.
	4.3.2 (44)	These paragraphs a largely redundant with earlier discussion of nitrogen reactive transport and could be compressed.

Document	Section (page)	Comment
ICM Tasks 7 and 8: Salt and Nitrate Analysis for the Central Valley Floor…	4.2 (4-4)	The large spike of log(C) for nitrate (Figure 4-3) points to bias by the detection limit assignment of 0.1 to many concentrations.
	4.2 (4-7)	For CVHM model regions that demonstrate upward pressure gradients, and is there well data supporting this (from prior work)? It would be good to point this out in support of CVHM, which is being accepted as the flow driver in the ICM effort.
	Figure 4-4, Table 4-1	The trend analysis outcomes reported in Table 4-1 would be more meaningful if the statistical criteria for the descriptors (R^2, p-value). For statistically significant trends, a comparison of slopes might provide additional information about whether rates of change a resimilar in different regions of the Valley.
	Figure 4-4, Table 4-1	Were observed groundwater quality data trends tested on subsets of the timeframe, such as during drier and wetter periods? This might also yield additional information about water quality and hydroclimatic conditions.
	4.2	Were the groundwater quality data tested for spatial correlation, or were the wells overly clustered to allow for this type of analysis?
	5 (sample calculation and Figures 5-5 and 5-6)	The mass apportioning mechanism is a key aspect of the CVHM-WARMF model connection. An example calculation is used to demonstrate that salt mass is conserved when apportioning mass from WARMF to CVHM. There is a substantial difference in the hydrology with CVHM producing much larger recharge rates compared to WARMF. Thus, the same salt mass results in a concentration (TDS) that is about 3 times lower in the mass re-apportioned model. If we believe WARMF salt mass estimates and take CVHM as a more complete hydrologic model, then the lower estimates would seem to be a more accurate depiction of reality. The report would be improved if there was some validation of this point using observed salt levels. However, I recognize that the groundwate quality data may be too uncertain to support this type of validation.
	5 (5-15) & 8.2	"The groundwater recharge flows used in the WARMF-CVHM linkage wer higher than the correct flows show in Figure 5-5…" The errors introduced by this issue are presented in section 8.2 (Table 8-3) for most of the IAZs. How were excess salt and nitrate masses estimated, and why not show all the IAZs? Were subsequent analyses corrected based on these error estimates?
	6.1 (6-1)	The beginning of section 6 states that "specific analyses were added to the originally planned work to bracket uncertainty…" but the scope of these analyses were difficult to identify in the remainder of the section. It would be good to clarify where uncertainty was being addressed, such as where ranges of values were tested or multipliers were employed.
	Figure 7-2, Table 7-1	The results here focus on the 20-year modeling period. Has there been analysis of the results with respect to inter-annual variation or seasonal? It may be good to identify key climatic conditions when the groundwater is more/less vulnerable to salts/nitrate.
	Figures 7-3, 4, 5	The "track the mass" figures are quite informative, and should provide good ICM-level support for more refined modeling efforts
	Figure 7-6	As with Figure 7-2, it would may be informative to examine temporal behavior of various mass in/outflow terms.
	Figure 7-7, 7-8	The shallow groundwater quality estimates are highly sensitive to the loading scenarios. These issue is also connected with differences between WARMF and CVHM recharge values, as well as with neglecting vadose zone effects on mass loading. Are the loading scenarios intended to address all of these uncertainties?
	7.4	The starting and final masses of TDS and nitrate would be interesting to compare with historical changes in observed values
	Figures 7-19, 20	These figures seem to be very important, but are difficult to read and interpret. The report does not provide much in the way of conclusions regarding these figures. Is the general conclusion that the groundwater quality data is too variable for meaningful comparison with the IAZ-level simulated values?
	Figures 7-24, 25 7.7	The prioritization outcomes eappear to be reasonable for the ICM and ambient data. The conclusions that the IAZ-scale analyses are inadequate for characterizing large scale and local scale salt and nitrate conditions, and for supporting detailed local salt and nitrate management activities is consistent with the results presented. However, the ICM effort does represent a useful, high level approximation of Central Valley conditions, and can be refined with modest model developments and regular groundwater monitoring efforts.
	Figures 9-15, 16	The agreement between simulated and observed concentrations for the refined Modesto area model was quite poor. Results in Appendix H are more promising, but point to the lack of water quality data for validating such models. Do subsequent work plans include regular groundwater quality monitoring (perhaps on a quarterly basis), or do budgets not allow for this?
	10.2	The development of post processing databases is a major advancement and laudable accomplishment in this Phase I effort.
	10.2	The IAZ approach adds value to the current salt and nitrate problem in the Central Valley by creating a relatively objective approach to identifying hotspots and assimilative capacity in the Valley groundwater.

Document	Section (page)	Comment
Final NIMS Report	Goal 1	The stated most immediate management goal appears to be achievable in the short-term through treatment of nitrate-impacted groundwater. groundwater. As subsequent analyses point out, pump-and-treat will not restore groundwater quality quickly, or ever if land application of nitrogen continues unabated. However, pump-and-treat can provide drinking water to local entities, thereby achieving Goal 1. Why not achieve Goal 1 first, then worry about groundwater remediation after the legacy and land application managment problems have been addressed?
	General observation	While the approach is systematic, it is relatively simplistic (probably due to timelines and budgets). More detailed approaches will be executed at the IAZ (more local) scale. This may be fine as long as a regional plan is in effect. How will a collection of local solutions be checked for their regional synergy (as opposed to interference)?
	Alternative scenarios	One alternative not mentioned in the report is providing drinking water from surface water sources. Was this considered or was it ruled out due to clear treatment cost differentials (e.g., filtration, chlorination)?
	5.1 (5-1)	"Nitrate is higher on the east side…principally from agricultural practices." Soil types and lithology also contribute to these circumstances. Given this, and given the long-term perspective of the CV-SALTS effort, is it worthwhile to consider some type of land use policies that might "rearrange" the Central Valley activities to maintain productivity in a more sustainable manner?
	5.1 (5-3)	Regarding the volume of contaminated groundwater to be hypothetically treated, it is stated that the remediation analyses do not account for legacy nitrate in the vadose zone or continued flux of nitrate from other sources (most importantly from irrigated agricultural fertilization practices). These would seem to be key nitrate sources and their absence suggests that the pumping time estimates for the different scenarios are not very meaningful. How do these results relate to the Aggressive Restoration model simulations (SWAT + CVHM + MT3D-MS), which appear to address loading through the vadose zone and fertilization practices?
	5.1 (5-3)	Given Goal 1 as a priority, is pumping time required to reduce groundwater nitrate concentrations a relevant critierion. Also, is it likely that pump-and-treat times will be longer than the life cycle of the treatment facilities? Given these issues, should the cost analyses be less concerned with remediation progress and focus more on capital, O&M, followed by capital replacement costs.
	5.2 (5-3)	Regarding DACs and DUCs, how have stakeholder preferences been incorporated into the analyses or conclusions? It would be good to include this in the discussion to support institutional memory.
	5.3 (5-4)	Given that irrigated agriculture is the largest contributor to groundwater nitrogen loading, it seems imperative to incorporate this nitrogen loading (along with mitigation goals, such as targeted NUEs) in any temporal estimates of groundwater remediation. Unfortuanately, of the four nitrate-limiting practies noted, only the last one (pump and fertilize) is discussed further.
	5.4 (5-5)	Recharge of high quality water (stormwater) is an interesting suggestion that does not receive much attention in the report. This would be consistent with a more systems level approach, whereby groundwater recharge is being maximized while groundwater pollutants are being diluted. This issue is also tied to potential for enhanced leaching of TDS and nitrate from the vadose zone, but presumably this loading would be reduced after a few flushes.
	5.5.1 (5-5)	Pump and fertilizer is an appealing concept. How much might this practice tend to reduce normal fertiler application? If it is not a substantial change, then the affect of this approach is likely to be minimal.
	5.5.1 (5-7)	The report recommends irrigation and nitrogen management planning specific to each grower and management unit. This sounds like a good approach, but it would be good to add a few examples of what such plans might look like.
	5.5.2.1 (5-9)	The salt brine approach is presented briefly. A brine line is a major undertaking with major environmental implications. Would such a recommendation point to the need for regional and coastal analyses as to the costs and benefits of transferring salt from on part of California to another (or to the ocean). Should there be discussion in this report on the topic?
	5.5.3	Very little is said about in situ treatment of nitrate as an alternative, other than to explain it. Are there "waste-to-substrate" approaches associated with food processing, etc. in the Central Valley that could be used as a carbon source?
	5.5.4.2	The remediation scenarios and costs of treatment seem overly simplistic, even given the limited scope of this project. For example, in comparing scenarios 1a and 1b, the simple mass balance approach points to half the timeframe when you double the pumping rate. This is extremely rough. Doubling the pumping rate will change the groundwater "capture zone" alter the balance between clean and contaminated water being pumped. It will also alter the groundwater veloctiy field and therefore the mixing of contaminated zones and clean zones. Therefore I would not put a lot of weight on the timeframes resulting from these calculations.
	Table 5-6	Do the costs here consider variable groundwater concentrations? Concentrations will affect treatment consumables and therefore O&M costs.

Document	Section (page)	Comment
Aggressive Restoration Alternative Modeling Scenario Results (2016)	Introduction (1)	A brief description of some aspects of the modeling approach would have been useful and I recommend adding them in reference to Figure 1 (or in the next relevant report). Specifically, it was difficult to connect CVHM, MT3D-MS, and SWAT until eventually I found more details in report appendices (but these appendices were not called out in the report).
	Methodology (5)	The goal of the Aggressive Restoration pump, treat, and reinject approach is to observe decreases in nitrate in ambient groundwater within 10 to 20 years. Is this goal feasible given continued nitrogen loading in the area, or was the notion here that aggressive pumping might overcome the continued loading?
	Methodology (7)	In Plan C, the potential issue of "short-circuiting of clean water" was raised in the context of increasing pumping rates as opposed to increasing the number of injection and extraction wells. For Plan C and other simulations, were flow fields generated by CVHM checked to see whether simulated decreasing nitrate concentrations were due to efficient nitrate extraction or dilution due to the capture of clean water?
	On-Farm Recharge Simulation Results (11)	Flushing of shallow groundwater chemicals into deeper layers during winter time recharge is interpreted as a negative side effect. If pump, treat, and serve is the technology of choice, then do the benefits of recharge outweight the cost of pushing contamination downward? Will they ultimately be pushed deeper in the absence of winter time recharge activity?
	AID Simulation Results (12)	There is a tendency to accept that the Productionn Zone should remain unchanged, and perhaps this is justified by the cost of production wells. Nevertheless, is it worthwhile to consider restoration of the upper zone and vadose zone as a early goal, and addressing the Production Zone after nitrogen source strength has been reduced? Or there may be other approaches--I guess what I'm suggesting is that this is a multi-objective problem, and there may be other more optimal approaches from a systems perspective.
	Conclusions and Lessons Learned	That a targeted aproach for restoration works better in smaller geographic settings seems subjective. It is important to the Central Valley and the state of California that the local targed approaches are not only locally beneficial but enhance the sustainability of water resources regionally.
	Conclusions and Lessons Learned	While I agree with the second bullet point, what is meant by "rural/urban/domestic pumping stresses," and where was this featured in the simulations?
	Conclusions and Lessons Learned	Similar to the previous comment, the third bullet points to where on-farm recharge effects might appear and how they might be affected by nearby pumping stress, yet the report did not seem to address these issues. I assume this was gleaned from the simulation output, but it would be more typical to point to those results if they are to be part of the main conclusions.
	Conclusions and Lessons Learned	I agree that pump, treat, and serve has good potential to provide clean, reliable drinking water to local communities. I do not see it's shortcomings in terms of aquifer restoration as surprising--pumping cannot restore the aquifer while active sources and loading remain. The approach alone depletes the aquifer (as noted), but it was not clear from the report how signfiicant this would be over time. And, could this depletion be balanced by on-farm recharge?
	Conclusions and Lessons Learned	Regarding the final bullet point, I found it difficult to judge whether restoration is feasible on the scale of the Central Valley. Aquifer restoration activities that require decades or even 50 years are the norm in most major subsurface restoration scenarios. Costly yes, but infeasible no. I do agree with the bullet if land management practices with respect to nitrogen loading remain unchanged.